“Analysing Climatological Time Series of Temperature and Rainfall for Southern Districts of West Bengal over the period 1901-2011”

Thesis submitted for the Degree of Doctor of Philosophy
in Science (Geography)

by

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CERTIFICATE

*This is to certify that **Sri Dipak Bisai** M.Sc. in Geography and Environment Management completed his thesis entitled **"Analysing Climatological Time Series of Temperature and Rainfall for Southern Districts of West Bengal over the period 1901-2011"** under my guidance and is now submitting it for Ph.D (Science) examination in Geography 2016. This is an original piece of research work carried out by the candidate himself and findings for this research have not been used for any other thesis submitted in any university. It is further certified **Dipak Bisai** has followed the rules laid down by Vidyasagar University.*

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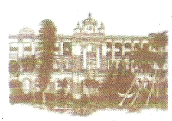

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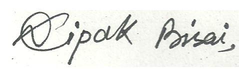
DECLARATION

This is declare that the thesis entitled "Analyzing Climatological Time Series of Temperature and Rainfall for Southern Districts of West Bengal over the period 1901-2011", submitted for the degree of Ph.D. in Geography of Vidyasager University is a record of my original work done under the supervision of Dr. Soumendu Chatterjee, Department of Geography, Presidency University. This is also to be stated that no part of the thesis submitted herewith has been submitted previously anywhere for any degree whatsoever either by me or anyone else.



(Dipak Bisai)

DEDICATION

I dedicate my Ph. D. work to my parents and my family. An especial tribute to my loving wife *Silpi Saha (Bisai)* and my sweet kid *Writabrata Bisai* whose inspiration all through the way has led my feet towards success.

I also dedicate this work to my guide Dr. Soumendu Chatterjee for his endless scientific supervision to meet my effort to a successful end.

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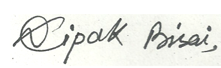

Dipak Bisai

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Summary:

Climatology is an integrative interdisciplinary science that deals with the relationship among Climatological parameters through temporal and spatial scale. This science is very complex because several variables within the Earth's atmosphere, such as temperature, rainfall, barometric pressure, humidity, wind velocity, clouds etc. are interacting with each other and maintains a nonlinear structure for a particular geographical area. The activeness and performance of these parameters has made often randomly ordered outlier due to uneven correlation of climatic parameters through frequency domain as well as time domain. Spatial inference of the climatic parameters is also an influencing character for climatological analysis. This study deals with the regional analysis of Climatological parameters like ambient atmospheric temperature and rainfall series. The authenticated and approved datasets are collected from India Meteorological Department (IMD, Alipur, Kolkata) and Indian Water Portal Department (www.**indiawaterportal**.org). The attribute of the implanted data series combines Mean Monthly Maximum ($TMin$) Temperature, Mean Monthly Minimum ($TMin$) Temperature and Average Monthly Rainfall series. Annual average and seasonal series is also considered for this analysis and these series has been confirmed from monthly average series. The considered temperature data being the SI unit of ℃ and rainfall data unit is millimeter respectively. Remarkably, the considered time series maintained consistency while used in this study and the nearest distance covers 5 km and the far distance of the data network has been covered 101 km from the farthest station. The temporal span has confirmed 111 years (1901-2011) and there is no such temporal gap over the considered time series.

The main objectives of this study are:

1. Quality Check and Change Point detection over the time series.
2. Variability analysis over the time series.
3. Potential Change Point detection over the time series.
4. Homogeneity construction of the time series.
5. Monotonic Trend detection.
6. Magnitude of Change and Pattern establishment.

The study area has been confirmed by 13 weather observatories location spread over the southern part of West Bengal. Primarily, the data quality control has been checked for proper analysis of the climatic system. Quality assurance or quality control is a system of routine technical activity, to measure and control the quality of the inventory while it is being developed. So, the quality control system has been designed with a particular process consisting continuous check to ensure the data integrity, correctness and sequential completeness. Data quality depends primarily on the location of a climatological station for data acquisition and its adjoining surroundings. Often encountered inconveniences in terms of data homogeneity due to changes in the immediate surroundings over temporal spell as well as changes of the observatory location and exchanges of the data observational techniques. Moreover, new techniques about the proper observation time, changes or replacements of the high performance instruments, different active observing practices, and formulae is used to calculate the mean of the series which can cause artificial discontinuities from the prior time. In primary step the data has been processed by correlation method. After that, some statistical method has been adopted for the assessment of homogeneity nature of the considered dataset. Both parametric and non-parametric statistical techniques has been selected for this analysis like Cumulative Deviation (CD), Standard Normal Homogeneity Test-I (SNHT-I), Pettitt Test, Buishand Range Test (BRT), Von-Neuman Ratio Test and CUSUM and Bootstrapping. To complete these inspections, different software has been used to find out the inhomogeneity, abruptness, variability, randomness, outlier etc. over the considered time series of $TMax$, $TMin$, $ATMax$, $ATMin$, $STMax$, $STMin$, monthly rainfall, annual rainfall and seasonal rainfall separately. The used software's are XLSTAT, Change Point Analyzer, AnClim , Regime Shift Detection, TREND, MAKESENS_1_0 and SPSS_20.1. Moreover the anthropogenic variability like data acquisition error, error made by the observer and data transmission error has been detected by these strong statistical methods. In accordance to these methods, the considered time series has always assumed as normal distribution and primarily a Null Hypothesis (H_o) has considered.

After that the Alternative Hypothesis (H_I) has been argued at α = 0.05 level of significance. If the value statistic has defend at chosen level of significance and if it is situated $\geq$ critical level as a function of, then the Null Hypothesis has rejected and Alternative Hypothesis has accepted. Always n is considered as the number of observations. Adjusted Partial Sums (APS) and Re-Scaled Adjusted Partial Sums (RAPS) have detected the variability and break point in the middle of the considered period. Single abruptness over the considered time series has been detected by Pettitt test. The ratio of mean square successive difference (year to year) has identified the randomness over the considered time series. One interesting statistical technique has implanted here like CUSUM and Bootstrapping. This method confirms the level of change at a particular point and bootstrapping has been confirmed by its associated interval limit over the considered period. Ultimately, inhomogeneity characters of the considered time series has established and their effect (Number of Null Hypothesis rejection) has been categorized by "$Useful$" , "$Doubtfull$" and "$Suspected$" group.

Homogenization of climatic parameters like temperature and rainfall series is a challenge to climate change researches, especially in cases where metadata are not always available. So, the reference series building was a difficult challenge in this concern. The quality check assessment has indicated that, there is no one considered series which has been considered as homogeneous. The result of the quality check has revealed uncertain frequency, outlier, abnormality, variability as well as significant change point over the considered period. Ultimately, Multiple Analysis of Series for Homogenization ($MASH$ v 2.03) has been used to conduct the homogenization process for considered time series. This process has been developed by the Hungarian Meteorological Service. This procedure has been performed by "DOS" based programme. This method is called relative homogeneity construction procedures that do not assume any reference series as homogeneous. The possible break points and change (Shift) on the time series can be detected and adjusted through mutual comparisons (with replacement or without replacement of sample shift value) of considered series within the same climatic area.

The candidate series has been chosen from the available considered series. In the mean time the remaining series has been considered as reference series. The climatic variability has analyzed from two types of main frequency domain such as temperature record as well as rainfall record. So, additive and multiplicative model has been used comparatively. According to the basic function of this method, additive model has considered for temperature series and on the other hand, multiplicative model has considered for rainfall series. According to "$base - 2\, numeral$" system, zero (0) amount of rainfall converted to 1 numeric value consideration where needed. Serial number of considered observatories with proper name, co-ordinates, nearest distance of the considered series has been implanted carefully into the MASH method to operate the process properly. Every series has been employed through CSV $(Comma\ Separated\ Values)$ format. The candidate series has been confirmed by manually inputs of series serial commend. The adjustment of every frequency has noticed a particular weighted reference series and displayed several difference series. The optimal weighted value is determined by minimizing the variance of the difference series, in order to increase the efficiency of the statistical test. After the relative homogenization process, several statistical tests has been conducted for significant climatic break point analysis (Sequential Mann-Kendall Test), trend analysis (Mann-Kendall Test), magnitude of Change analysis (Sen's Slope Estimator) and periodicity estimation (ACFs & PACFs). The major findings of this study are:

1. The increasing trend of the $TMax$ series from the middle of the considered series.
2. The positive increasing trend of the $TMax$ series from March to July for every observatory.
3. The ling upward outlier whisker from the median for South 24 Pargana observatory.
4. The cyclic pattern of $TMax$ and $TMin$ series by ACFs and PACFs.
5. Gentle positive trend for $ATMax$ time series after Mann-Kendall test.
6. The potential statistically significant change points in between two temporal span, according to Sequential Mann-Kendall test. These two spans are since 1954 to 1965 and 1982 to 1993.

7. The most uncommon seasonal noise signals and very low auto-correlation between adjacent and near adjacent observation.
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12. The negative trend of rainfall series over the time period.
13. The cyclic pattern of annual rainfall series with inference noise components.
14. The prediction of increasing temperature (ACFs & PACFs) for coming twenty years.
15. 0.003 ℃ is the decadal growth of $ATMax$.

Chapter-I (Introduction and Aspects of the Study)

1.0 Introduction:

Climate is a dynamic system influenced not only by the immense external environmental factors, such as solar radiation or the topographically diversified surface of the solid Earth, but also by the apparently insignificant phenomena. The dynamic system includes linearly unstable progresses and processes, such as baroclinic instability, extreme weather events etc. in the lower atmospheric subsection. Moreover, its dynamics are dissipative and transports energy from large spatial scales to small spatial scales by hydrodynamic process, while emaciated change or diffusion takes place at the smaller spatial scale. The thermodynamic change of climatic system over a small scale may drag effective influences at larger spatial scale. Transfer of internal energy of a dynamic climate system is generally nonlinear whereas every factor can influence its change. After all, the nonlinearities and the instabilities make the climate system unpredictable beyond certain characteristic period. These characteristic time scales are different for the subsystems, such as the ocean, mid-latitude troposphere, polar troposphere and tropical troposphere. Therefore, in a strict sense, we have an idea about deterministic view for our general climate system but we should use probabilistic ideas and statistics to describe the climate system. The global climate analysis does not refer the regional climatic pattern but regional analysis always refer the internal behave of the local scale climatic variability. Estimation of mean maximum and mean minimum temperature trend and magnitude, average rainfall trend and magnitude, humidity concentration differentiation etc. are the gravity factors in regional scale. In this circumstance, climate model building as second realization is more significant to the simulated climate that is identical to the first or general simulation of dynamic climate.

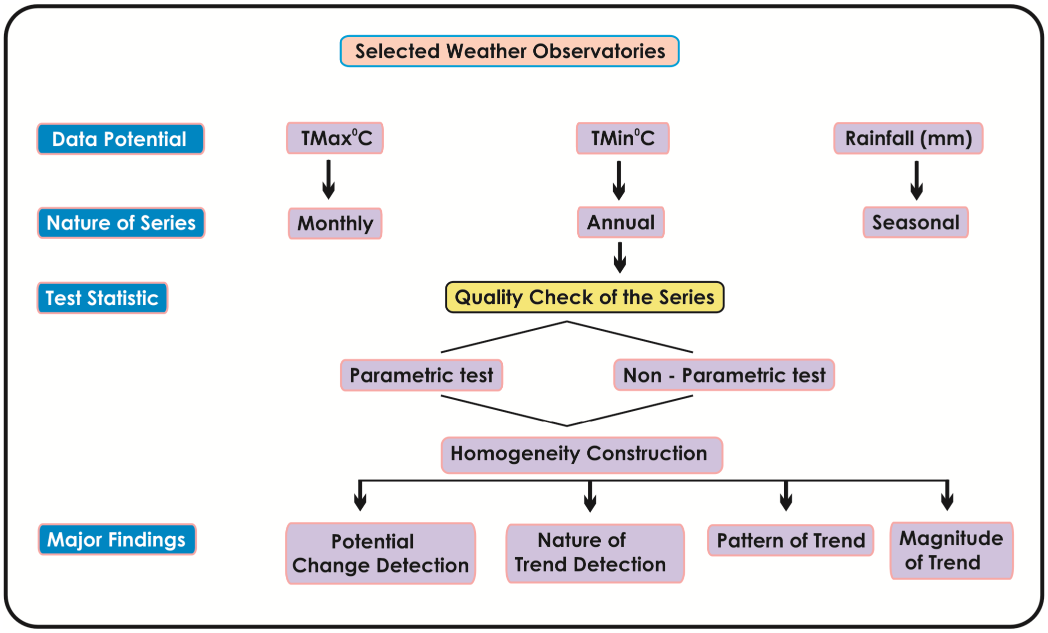
The Working Groups of the IPCC's Fifth Assessment Report (*AR5, 2015*) considers some important new evidences of climate change based on many independent scientific analyses from observations of the climate system over the world. Different paleo-climate archives, theoretical studies of climate processes and simulations have been used to estimate the climate models. This report has raised the common question against the prediction of climate change concerning future behavior. The degree of uncertainty is the usual behavior of the present climate structure in global scale as well as regional scale. While going through a variety of empirical climate studies it has been observed that a detailed analysis of changes in the trends of climate extremes has a vast application in the multivariable researches.

There seems to be a general agreement among the scientists that, the global surface air temperature has increased over the past hundred years by $0.3°C\ to\ 0.6°C$ on the basis of assumption of the enhanced Green House Effect or any other anthropogenic activities. The global mean surface air temperature is the most useful indicator of climate change and variability. Changes in the monthly mean maximum and monthly mean minimum temperature has revealed intensive result after statistical analysis. Because, increasing trends in the mean surface temperature can be changed by either the maximum or the minimum temperature. Relative change can be controlled by both of these temperature series. Sometimes, the series for mean maximum and mean minimum temperature exhibit with more sensitive differences and draw extreme variability of climate change. Diurnal temperature is also a very useful indicator for such changes. Every climatic portion does have some different components like seasonal component, cyclic component, trend component and irregular component. Eventually, their effects are most crucial and complex over the spatio-temporal extension. Over the last 50 years data evidence shows that the overall temperature has increased significantly. In this context, many researches have been conducted through scientific processes in different parts of the world. Their outcomes directly indicate that, the atmosphere and surface section of oceans have become warmer since the past half of the century.

1.1 Principal Objectives of this Thesis:

Various studies, discussing the topic of climatic changes, analysing present day or paleo-climatic and paleo-ecologic climate records linked with environmental, societal or economic systems, have already been carried out (*IPCC reports 1996, 1996a, 1996b, 1998, 2001 and 2007*).However, most of these studies using the Indian climatological datasets are based on the time series of a limited number of climatological stations, which are randomly selected over our country. These studies smacks of knowledge of regional importance of climatic change in a particular region. In this context we do not understand the influence of regional climatic change effect, which is very contrasting factor itself. Consequently, a better analysis of regional climate trend is essential to assess effect of climate change, natural hazards and the resulting potential risk for considered area. The objectives of this study is to reveal and quantify the decadal-scale variations and secular trends of mean maximum, mean minimum temperatures and mean monthly rainfall in yearly and four separate seasons during 1901 to 2011 for southern districts of West Bengal, India. Change point detection for the considered time series, nature of trends for all stations during the considered time period and magnitude of change have been analysed here. After all the secular trends in mean maximum, mean minimum and average monthly rainfall, The Southern part of West Bengal were analyzed and brought into relation between related active climatic phenomenon and their simulating forecasts. Some focus will be placed on variability and anomaly of mean maximum, mean minimum temperature and monthly rainfall characteristics and seasonal variation in them. These outcomes constitute an important basis for assessing the possible climatic influence for concurrent variability of climatic disruption, natural hazards entire ecosystem behaviour, hydrological changes, agricultural practices etc.

Figure-1 Organigram of Research Steps



To attain the objectives of this thesis, several working steps can be defined:

1. Quality Check and change point detection of the data series- Chapter-II
2. Variability Analysis of the time series- Chapter-III
3. Monotonic and Potential Change Point Detection- Chapter-IV.
4. Homogeneity Construction- Chapter-V
5. Magnitude of Change and Pattern establishment-Chapter-VI.

1.2 General Aspect and Global Scale Background with Literature Review:

Throughout the long geological time scale dates back 4.6 billion years, the Earth's climate has naturally changed numerously. Previously, some researchers has established that, the climate change during the Cenozoic Era was very significant which has been reconstructed by studying ocean sediments records (*Bradley, R.S., 1999*). To make the proxy data, the researchers have adopted different modeling techniques depending upon the evidences such as paleo corals, varved sediments, cave deposits, ice cores etc. Paleoclimatologists strive to produce age information from different sources to exclude age uncertainty and paleoclimatic interpretations must take in to account uncertainties in time control. On the other hand, radiometric dating, quality assessment of the secular variations in the radiocarbon clock over last millions years have specified the climatic variations. Besides these evidences, the chronological evolution of tree rings, lake planktons, insects and pollen etc. indicates dynamical change of climate over different geological time scale. The statistical models calibrated against such evidences and estimate the associated climate change in respective climatological parameters. Such types of paleo-climatological analysis highly depends on replication and cross-verification between paleo-climate records from independent sources in order to construct confidence in inferences on past climate variability and change.

According to the evidences of past record, the average temperature in late Mesozoic Era was $3°C\ to\ 5°C$ cooler than the present age due to changes in greenhouse gas forcing and ice sheet conditions. Evolution of life and human society greatly perform on the temperature change as well as climate change over the world. The average of the warmest times during the Middle Pliocene presents in a view of the equilibrium state of a global warmer world, in which atmospheric CO_2 concentrations (estimated to be between 360 to 400 ppm) were likely upper than pre-industrial average temperature values (*Raymo and Rau, 1992; Raymo et al., 1996*), and in which geologic evidence and isotopes agree that sea level was at least 15 to 25 m above than the present levels (*Dowsett and Cronin, 1990; Shackleton et al., 1995*), with correspondingly reduced ice sheets and lower continental aridity (*Guo et al., 2004*).

In the both analysis in terrestrial and marine paleo-climatic proxies values (*Thompson, 1991; Dowsett et al., 1996; Thompson and Fleming, 1996*) indicates that high latitudes were significantly warmer than the other regions, but the tropical sea surface temperatures and surface air temperatures were little different from the present average temperature. As a result, the substantial decrease of lower atmospheric temperature makes an argument against latitudinal temperature gradient in different time scale. Global Climate Model (*GCM*) simulations driven by reconstructed Sea Surface Temperature (SSTs) from the Paleo Research Interpretations and Synoptic Mapping Group (*Dowsett et al., 1996; Dowsett et al., 2005*) revealed winter surface air temperature warming of $10°C\ to\ 20°C$ at high northern latitudes with $5°C\ to\ 10°C$ increase over the northern north Atlantic ($60°N$), whereas there was no significant change of tropical surface air temperature (*Chandler et al., 1994; Sloan et al., 1996; Haywood et al., 2000, Jiang et al., 2005*) in the same considering time scale. The abruptness of the paleo-climate is a common feature which has been established by different dimensional analysis. *Alley et al., 1997; Alley and Agustsdottri, 2005* have made a referential analytical research work where they revealed that, an abrupt cooling of $2°C\ to\ 6°C$ was a common feature of Green Land ice core at 8.2 ka. A similar record was documented in Europe and North America where high resolution continental temperature proxy data were considered (*Von Grafenstein et al., 1998; Barber et al., 1999; Nesje et al., 2000; Rohling and Palike, 2005*). In the end of the first half of the Holocene (5ka to 4ka) were established by rapid changing events in climatological parameters at various latitudes, such as an abrupt increase in North Hemisphere sea ice cover (*Jennings et al., 2001*), a decreasing trend of atmospheric temperature in Greenland, reflecting a change in the hydrological cycle (*Masson-Delmotte et al.,2005b*), abrupt cooling events in European climate (*Seppa and Birks, 2001; Lauritzen, 2003*), widespread North American drought for centuries (*Booth et al., 2005*) and changes in South American climate (*Marchant and Hooghiemstra, 2004*).

Last 2000 years back, data record indicates more fluctuation and changing trend in global atmospheric temperature. *Mann et al., 1999* represents mean annual temperature which is based on a range of proxy type data series. This research is based on the data's extracted from tree rings, ice cores and documentary sources and number of instrumental records for both of temperature and precipitation from the 18th century onwards. In last 900 years data series exhibits multi-decadal fluctuations with amplitude up to $0.3°C$ superimposed in a negative trend of $0.15°C$, followed by a abrupt warming about $0.4°C$ matching the observed instrumental data during the first half of the 20^{th} century. Similar other two reconstructions one by *Jones et al., 1998* was based on a much smaller number of proxy data. On the other hand *Briffa et al., 2001* with the same number of proxy data which reveals continental fluctuation of temperature has been observed since AD 1400. These analysis is emphasizing on warm season rather than annual temperature with a geological focus on extra-tropical land areas. These literatures suggest a greater range of variability on centennial time scales prior to the 20^{th} Century which also indicates slightly cooler atmospheric condition during the 17^{th} Century in continental scale (*Mann et al., 1998, 1999*).

During the last few decades the issue of the influence of anthropogenic activities on natural systems on earth has caused a lot of important climatic variability as well as 'climate change' which is one of the central term used within this context. Many researchers are working on the behavior of climate characteristics in various parts of the world. These types of studies consists of wide range of observed climate indicators and shows the changes that are consistent with the globally warming world. Many international communities, non-government organizations and governments has taken a great interest to climate scientists leading to several studies on climate trend detection at global, hemispherical and regional scales (*IPCC 2007, Joeri et al., 2011; Spencer, R.W., 2008*.) The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20^{th} century, the increase of temperature has reached $\pm 0.6°C$ *to* $\pm 0.2°C$ (*IPCC, 2001*).

Temperature in the lower troposphere have been augmented by $0.13°C$ *to* $0.22°C$ per decade since 1979, according to the satellite temperature measurements (*Soon et al., 2000*). Generally, there is contradiction among the scientists that most of the observed increase in globally averaged temperatures since the mid- 20^{th} century is unequivocal and very likely due to the observed increase in anthropogenic greenhouse gas concentrations. The ten (10) warmest years of the 20^{th} century falls among the last 15 years of the century and 1998 is the warmest one. To some extent, other factors, such as variations in solar radiation (*Brohan et al., 2006*) and land use at regional scale, are also considered to be the causes of the observed global warming (*Jones, P.D. and Moberg, A., 2003; Soon et al., 2000*).Warming has been observed to have concentrated in the most recent decades, from 2001 to 2010.The concentration of the warming trend in the Northern Hemisphere has experienced prior to 2000. In particular, summer temperatures in the Northern Hemisphere during recent decades are the warmest in and around North European countries (*Faidas et al., 2004*). The average temperature near the surface of the Earth in 1999 was the 5^{th} highest so far recorded. The recorded temperature is $0.33°C$ more than the average temperature of the recorded period since 1961-1990 (*IPCC, 2001*).

In spite of, ongoing researches on climate change conducted by various International Agencies and Universities, the question, whether, rising global mean air temperature is caused either by increasing emissions of Green House Gases to the atmosphere or by the natural variability of climate has not yet been answered satisfactorily (*Faidas et al., 2004*). In terms of analysis of satellite temperature data a very slight warming trend since 1979 has been observed for the lower atmospheric temperature, but not to the extent shown by surface observations (*Faidas et al., 2004*).Major anomalies due to volcanic eruption and ocean current phenomena like El-Nino, are detected but overall the trend is near zero. The warming of lower atmospheric temperature has been recorded to be $0.04°C$ per decade through 23^{rd} year period, 1979-2001(*Spencer, R., 1990*). Climate diagnostics computation analysis with gridded data by HadCRUT4 (*Hadley Climate Research Unit*) suggested that the linear trends in temperature anomalies are approximately $0.07°C$ per decade from 1901 to 2010 and $0.17°C$ per decade from 1979 to 2010 globally (*Colin et al., 2012*).

Analysis of surface air temperature records around the Mediterranean basin indicates pattern similar to the global and hemispheric scale. Besides this general outcome, some extreme effect of temperature has drawn a cooling trend during the period since 1955-1975 and a strong warming trend has been observed during the 1980s and the first half of the 1990s (*Pierveitali et al., 1997*). However, the east-west Mediterranean difference in air and sea surface temperatures trend is distinct.

Most of the studies concerning air temperature around the Mediterranean area discern a positive trend in the western part for the period 1950-1990, and a negative trend has been observed around the eastern Mediterranean area for the same period (*Parker et al., 1994; Shasamanoglou H.S. and Makrogiannis T.J., 1992*), which reinforces the effect of Mediterranean oscillation between the western and eastern parts of this basin (*Kutiel H. and Maheras P., 1998*). In rare cases the regional analysis of climate variation does not match or follow the global climate variation but in most cases the analysis in regional scale are very significant for future trend analysis. It is established that, in middle latitude region, the local change in climatological variables are mainly controlled by the atmospheric circulation (*Parker et al., 1994; Hurrel J.W., 1995 and Hurrel J.W. and Van Loon H., 1997*).

Similar kinds of air temperature time series have been analyzed by the European Environment Agency and published a report in 2008. They have evaluated from the observed data for the years from 1950 to 2007, the warming trend of temperature (mostly in spring and summer) for the entire European continent (*EEA, 2008*). In Romanian, it has already been established that during 1901-2007 the annual mean temperature has increased by $0.5°C$, with a higher rate in the extra- Carpathians region (*Hobai R., 2009*). Considering the regional temperature trends: Moldavia (*Sararu L. and Tuinea P., 2000*),Northwestern Romania (*Hauer et al., 2003*) and Valcea country (*Vasenciuc et al., 2005*) have concluded differently according to the number of weather stations and the analyzed period. It is quite difficult to compare the results of such studies, in general, because most of them show increasing trends in the majority of the analyzed data series; however, they did not determine the statistical significance of those trends (*Croitoru et al., 2011*).

During the last few decades, lots of evaluation is undertaken using deterministic mathematical models that require daily temperature records of the extremes as input and its behavioural variability due to their adverse socio-economic impacts. However, studies of extreme temperature trends and intra-seasonal variability of daily temperatures over various regions of the globe are still fluctuating. Such similar studies have been carried out by different researches. Significant decrease in day temperature with extreme low temperature has been found in United States but there is no significant increase in the number of extreme warm temperature (*Karl et al., 1996*). The analysis using the daily temperature data of Australia for the period from 1961to 1995, the results have indicated an increase in the frequency of warm days and nights and decrease in cool days and nights (*Plummer et al., 1999*). Similar such briefly reviewed analysis on variability and trends in extreme climate events over Australia, China, Central Europe, New Zealand and United States has indicated that number of the frosty days decreased over these countries and days with warm maximum temperature increased remarkably over Australia and New Zealand (*Easterling et al., 2000*). The south-west monsoon region also undergoes the changing nature of climatological extremes. Analysis of the time series of daily temperature and rainfall for the period from 1961 to 1998 over South-east Asia and South Pacific have indicated an increase in annual number of hot days and warm nights significantly and a decrease in annual number of cool days and cool nights significantly (*Manton et al., 2001*).

In Indian context, it is very important to explain the seasonal variation of temperature and rainfall conditions due to climate change. The geographical area in and around the Indian Sub-continent is completely controlled by the monsoon type of climate. Now a days few number of climatic variability studies are conducted over Indian Sub-continent. Such literature studies suggests that, the frequency of occurrence of hot days and hot nights showed widespread increasing trend, while that of cold days and cold nights has shown widespread decreasing trend (*Kothawale et al., 2009*). The frequency of the occurrence of hot days is found to have significantly increased over East–Central (EC), West-Central (WC) and Indian Peninsula (IP), while that of cold days showed significantly decreasing trend over Western-Himalaya (WH) and West- Central (WC).

The three regions East-Central (EC), West- Central (WC) and North-West (NW) showed significant increasing trend in the frequency of hot nights (*Kothawale et al., 2009*). Regarding trends in temperature at regional scale, the mean maximum temperature time series of Indian sub climatic zones are showing a rising trend at most of the stations and few numbers of stations indicate decreasing trend, on the other hand, the mean minimum temperature have indicated a rising trend in winter season (*Sharad K. Jain and Vijoy K., 2002*). At most of the stations in the South, Central and Western Part of India a rising trend was found (*Sharad K. Jain and Vijoy K., 2002*). It is true that, the climatic analysis bounded entirely in regional scale are often supportable to the global scale.

In this context, the regional scale temperature and rainfall analysis is most important to detect fluctuations and changes over the time. In this regard several studies have emphasized the temporal and spatial changes in temperature and rainfall over several regions of India (*Dash et al., 2007; Dash S.K. and Hunt J.C.R., 2007*).The comprehensive analysis of extreme temperature events during Indian Monsoon period shows the increase (decrease) in the frequency and magnitude of extreme (Moderate) rain events over Central India (*Dash et al., 2007*). In the mountainous region of the Himalayas, a limited number of studies in Nepal, covering some parts of the Himalayas and Tibet have also revealed similar trend based on earlier publications and pre-monsoon temperature records in the Western Himalayas. It also signifies a decreasing trend during the second half of the twentieth century (*Pant G.B. and Borgaonkar H.P., 1984; Li C. and Tang M., 1986; Seko K. and Takahashi S., 1991*). Spatio-temporal variability ofrainfall is one of the most relevant characteristics or most critical factor determining the overall impact of Climate Change. Rainfall variability and extreme rain events has a significant environmental consequence that causes considerable damages in urban as well as rural areas. So the rainfall variability and trend analysis is one of the important tools for policy maker. Rainfall is much more difficult to predict than temperature but there are some predictive statements that the scientists could make regarding rainfall. The rainfall will increase accompanied with various intense events (*Md. A. R. and Begum M., 2013*).

In recent years, there is a great certain contradictions among the scientific community concerning the variability and trends of precipitation and their effects on the environment during the20th century (*Karl T., Knight R., 1998; Folland C. K., Karl T.R., 2001; Zhang et al., 2001*). As an example, in Europe, the precipitation trend appears to be positive in the northern part (*Folland et al., 1996; Schonwiese C., Rapp J., 1997*) and negative in the south. The majority of the Mediterranean region has a tendency toward decreasing winter precipitation during the last few decades, mostly starting in the 1970s and proceeding to an accumulation of dry years in the 1980s and 1990s (*Schonwises et al., 1994; Palutikof et al., 1996; Piervitali et al., 1997*). Recently, some literatures suggest that, the changes in daily temperature and precipitation extreme occur in central and South Asia and 70% of the stations have statistically significant increase in the percentage of warm nights/days and decrease in the percentage of cold nights/days (*Schonwises C., Rapp J., 1997*).

Some recent literature reveals that, rainfall time series analysis have indicated increasing trend in the number of short spell heavy rain elements and decreasing trends in the occurrence of long spell rain event in India (*Klein et al., 2006*).

Time series dataset modeling is an important technique to establish the status of the data series as well as to enhance the scientific method depending upon the statistical tools. Subsequently, it may fulfill the statistical scientific investigation and general approaches to data analysis in specific way. In order to be sufficiently accurate and realistic, a model must be able to capture mathematically the key characteristics of a system being studied. In the same time, a model must be designed in a meaningfully straightforward manner so that it can be easily understood, manipulated and interpreted. In different literatures, the researchers are using multivariate models building techniques, such as Global-mean temperature has also been modelled as a structural time series having non-stationary residuals but no deterministic trend component (*Gordon A.H., 1991; Woodward W.A. and Gray H.L., 1993*). If such models were indeed correct, then the fitting of a model comprising a trend and stationary residuals could result in the erroneous detection of a trend.

The analysis of climatological behave of earth is at the same time very easy and very difficult. Because it is composed by different important elements. They play an important role in different geographical regions. Temperature, rainfall, humidity, sunshine, cloud condition etc. are strongly significant in synoptic temporal as well as spatial scale. The space time continuity of climatilogical parameters can help greatly in an analysis, because analysis is essentially an interpolation in between places where observations are taken. Relating parameter makes a combined result to establish climatological identity of a particular region. Previously, some analyses, theories and classifications have indicated several types of climate spread over the world. However, a single calculated value that depends upon single or cluster of parameters of a particular region is less enough to get variability or trend for the whole climatilogical condition. Such as the average values of mean temperature or rainfall in regional scale do not suggest the global climate significantly, it may misguide the analysis of the results.

Recognizing climate trend at the global scale is different and makes no sense due to large scale spatio- temporal variability of climate. So it should be easy to indicate the climate change by conducting regional scale analysis. The analysis of temperature time series is most important to evaluate the climatic variability. It makes a possible interpolation between the time points as well as in spatial dimension. Whereas no such advantages exist for precipitation, which is intermittent and difficult to interpolate with the yearly time series. The present work incorporates main three types of parameter like mean surface air temperature, monthly rainfall. Daily temperature variation mainly differs from the mean value which signify regional anomaly of the temperature time series. Those types of study are crucial in order to obtain better estimates of the sensitivity of natural systems towards the climate in future.

So it is an important aspect of climate change study which involves the changing behavior of daily temperature in particular. The increase in the mean temperature in a time series are expected to be accompanied by increased frequencies of hot days and warm nights. As it has been demonstrated by *Katz and Brown, 1992*, that the extreme climatic events are more sensitive to climatic changes than their mean values.

This means that if global climate change is a real phenomenon, it should be detected and clearly revealed in the behavior of the regional variability of climate. Recently this type of studies draw attention of the scientific society and they have demonstrated the regional variability of climate (*Easterling et al., 2000; Meehl et al., 2000; Frich et al., 2002*), because living creatures and ecosystems, as well as the human society, are very sensitive to the severity, frequency and persistence of extreme temperature events. So, regional scale analysis of climatological variability will help to apprehend the local weather as well as local scale climatic effect in considered region.

1.3 Characteristics of Monsoon Type of Climate :

Monsoon Circulation in Indian sub-continent performs its role around every dimension and controls the entire climatic environment. Its extraordinary characters affects the geographical extension ranging from the tropical south to temperate and alpine Himalayan region in the north. The elevated regions receive sustained winter snow-fall in this continent. This climate is also strongly influenced by the Himalayas and the Thar Desert (*IMD, 2010*). The northern Himalayan range always act as a barrier to the frigid katabetic winds flowing from Central Asia and keeps the sub-continent area relatively warm in winter season. The north and north-western parts of the country experience severely hot in summer time. Alternatively, the mean temperature becomes very cold and obtain freezing level in winter season. Based on temperature effect in Indian-subcontinent, there are seven important zones distributed over this country. Monsoon type of climate is characterized by strong temperature variations in different seasons over India and its variation ranges from mean temperature of about $10°C$ in winter season to $32°C$ in Summer.

According to the categorization by India Meteorological Department (*IMD*), January and February covers winter season. However, in case of the north-western part of the country, the month of December can be included in this season. The season winter starts its journey in early December, from when the mean temperature starts lowering. The associated weather condition in winter season prevails with almost clear sky, low humidity, and light northernly cold wind.

The cold air mass entering from the north direction and has made an enormous influence over the north-western and central part of this country during winter. The mean air temperature varies from $22°C$ to $27°C$ during January. The mean daily minimum temperature ranges from $22°C$ in the extreme south through $10°C$ in the northern plains to 6 ℃ in Punjab (*IMD, 2010*). The rainfall during this season is generally observed over the western Himalayas region and extreme north-eastern part of the country. Coastal parts of Tamil Nadu and some parts of Kerala have experienced medium amount of rainfall due to the location of Western Ghats. Often, the eastern part of the country including West Bengal experiences Westerlies rain bearing system. From the beginning of March, the temperature start to increase all over the Indian continent. India Meteorological Department (*IMD*) have recognized the period from March to May as hot humid Summer or Pre-monsoon season. In this season, the central part of the country becomes very hot with daytime maximum temperature. The mean daily temperature ranges from $30°C$ to $35°C$. In this period the night-time mean minimum temperature remains not below $29°C$ in and around the Southern part of West Bengal. The range of daytime maximum and night time minimum temperature is found to be more than $15°C$ as recorded in most of the weather observatories. The daytime maximum temperature may exceed $45°C$ in western and south central part of the country. From the last week of May, the temperature becomes keen and often advection inversion of the temperature around surface level changes the condition which influences the low pressure depression. Mainly, the coastal area of Andhra Pradesh, Odissa and the southern part of West Bengal generally face several depression hits during this season.

The late Summer generally welcomes several local storms and violent thunderstorms associated with strong winds and gale lasts for short duration. The state of Bihar, Chhattisgarh, Odissa, West Bengal and some part of Assam faces this disturbance during Summer season. The effect of dusty local small scale depression is popularly known as "*Kal-baisakhi*" in eastern region of India and extremely hot and dry winds accompanied with dust is called "*Andhi*" over the plains of North West India. However, weather remains mild in coastal areas of the country owing to the influence of land and sea breezes in the late Summer.

The SW Monsoon is the dominative and the most influential season in Indian climate. This season extends from the month of June to September. However, the onset dates of Monsoon does not maintain regularity in its occurrences. The Indian sub continent receives more than 75 % of annual rainfall in this season. Generally, the onset of SW Monsoon starts its journey from the Kerala coast approximately on the first week of June and spreads over the whole country by the third week of July. Though, the onset frequency arrives about a week earlier over island in the Bay of Bengal. The SW Monsoon carries the heavy and widespread rainfall over India. It has been observed that, the SW Monsoon moves with two types of monsoonal current, one is called Arabian Sea branch and another is Bay of Bengal branch. However, the Bay of Bengal branch pours heavy rainfall on the Himalayan foothill and South Bengal plain area, which leads to flooding situation with very uncomfortable weather due to the association of high humidity and high temperature. Cyclonic condition with small scale low pressure is a common feature in this season, which is called "Monsoon Depression". The coastal part of Bay of Bengal regularly creates several such cyclonic depressions during monsoon season. In most cases the small scale depression helps to develop heavy rainfall and lasts continuously over two weeks. In first week of September SW Monsoon current become attenuated and generally pervades over the northern part of India. During the month of October the North-East monsoon or Post-monsoon starts with full strength. Then the wind follows inverse direction. The south central coastal part of Karnataka, part of Tamil Nadu and part of the Andhra Pradesh receives about 35% of rainfall in this season. The mean temperature over north-western parts of the country declines from the first week of October by 38 ℃ to 28^{o}C in middle of November. Fall of humidity level and almost clear sky is the common weather phenomenon in this season.

In West Bengal, the hot weather condition usually starts from the third week of March and continues till the date of the onset of Monsoon. Generally, the onset of Monsoon starts approximately from the second June in West Bengal region. The Summer season is one of the most important seasons in this area. The extremely harsh weather starts from the first week of May.

After 21st March, Summer solstice starts and the mean monthly temperature gradually increase day by day maintaining the long day duration. Consequently, the atmospheric pressure falls continuously. This atmospheric condition helps to develop low pressure in the adjoining areas of West Bengal. The extreme southern part of the West Bengal receives more solar radiation than the northern part of the West Bengal.

The adjacent areas like Bihar, Jharkhand and associated part of the Odissa becomes very hot due to the increase of daily mean maximum temperature. However, the south-eastern plateau fringe area of Chota Nagpur records maximum mean daily temperature in this Summer season. The extreme highest temperature varies from $40^{o}C$at Sagar Island along the coastal belt to $47.8^{o}C$ at Suri in the western plateau fringe in the Gangetic West Bengal and $45.0^{o}C$ at Malda to $40.0^{o}C$ at Jalpaiguri in the plains of North Bengal and $33.1^{o}C$ at Kalimpong to $26.7^{o}C$ at Darjeeling in the hills of the sub-Himalayan West Bengal. The southern part of West Bengal becomes uncomfortable as the Summer season progresses during March to May. Towards the western tract especially in the districts like Bankura, Purulia, Birbhum, West Medinipur and western part of Burdwan, the dry heat wave become dangerous when it is associated with hot dry wind. These types of harsh condition may occur at the noon or afternoon. During this time the relative humidity drops by 5% to 8% from the normal. According to India Meteorological Department (*IMD,Alipur*), the summer temperature rises above $39^{o}C$in the capital of West Bengal, Kolkata. One record shows that the maximum temperature rises at $39.6^{o}C$ at Kolkata (Reported on 21st April, 2008, *Ananda Bazar News paper*). At the end of May, the SW Monsoon pulls the mean temperature by creating low pressure depression and heavy rainfall during second week of June to September. In Post monsoon period the mean monthly temperature remains gentle and comfortable. On the other hand, the mean monthly temperature in Winter season (January to February) becomes lowest while the sun rests over the southern hemisphere and so the slant rays of the sun can reach the Indian sub-continent. The normally the mean minimum temperature ranges from $13^{o}C$ to $16^{o}C$. But the mean minimum temperature decreases and reaches$10^{o}C$to$14^{o}C$ often. The southern districts of West Bengal like Bankura, Birbhum, West Medinipur, Purulia and the part of Burdwan experiences the similar temperature. According to the India Meteorological Department (IMD), the mean minimum temperature decreases by $4^{o}C$ to $6^{o}C$ from its normal.

According to the record of the India Meteorological Department (IMD, Alipur), a place namely Panagarh located in the district of Burdwan records extremely low temperature during Winter season. The minimum temperature recorded to be about 8^oC. Monsoon is the principal rain bearing season in West Bengal as well as Indian sub-continent. Moreover, 73% to 80 % of rainfall is received in this season. The amount of rainfall of the season varies from 1000 mm in the southern part of West Bengal to over 4000 mm along the south facing slopes of eastern Himalanyan area. The northern districts of west Bengal receive more amount of rainfall in the Monsoon season. The central parts of the West Bengal receive slightly less than 1000 mm rainfall. The coastal belts of 24 Pargana, Purba Medinipur, Hooghly and Howrah districts receive moderate amount of rainfall during this season. The average number of rainy days of those districts ranges from 49 to 81 days. But the frequency fluctuates due to uncertainty of weather condition. The state experienced rainy day span of Monsoon of 102 days in 1972 and 137 days in 1999. The variation of rainfall depends on a number of complex factors. Some of them are perpetual while others vary from different temporal scale or one year to other. Relief and location of land and water are the most important regulatory factors for Monsoon rainfall. On the other hand, dates of onset, break of Monsoon, formation of low pressure depression and the movement of the axis of the Monsoon trough are the most responsible factors for variability of rainfall in southern part of West Bengal. Consequently, the distribution of annual rainfall amount and number of rainy days are maximum over the northern districts of West Bengal and minimum through the southern districts, and yearly mean temperature behave is vice-versa. Major weather anomalies of Monsoon have left indelible impact on the entire cultural scenario of the state. Too early onset or considerable delay for Monsoon makes a vigorous start and its unusually prolonged wet spell causes heavy water logging and flooding in and around the southern districts of West Bengal.

During Summer season, the lower atmospheric temperature rises and air pressure falls in the northern part of the country. Towards the last week of May, an elongated low pressure area develops in the region which extends from the Thar Desert in the northwest to Patna (Capital of Bihar state) and Chota Nagpur in the east and southeast part of the country. The pressure lines are lying near 1000 mb. From the beginning of the 3rd week of June, an upper air cyclonic circulation strengthens a low pressure area over the northwest Bay of Bengal and adjoining coastal part of Odissa and central West Bengal region. The several associated cyclonic circulation develops and extends up-to 7.6 km height above the sea level. Generally, in the morning time the pressure line generally lies over the coastal area of Odisha and West Bengal and it makes a northeast movement with the increase of daytime temperature. Daily weather bulletin suggests that, the pressure line make aloft behaviour due to increase of day time temperature. In most of the events, it has shown about 6-7 kilometre height from the sea level during 12 noon to 2 pm. The average pressure level in Monsoon period may exhibit near 940mb as its perpetual mode in this region. Any kind of sudden local depression reduces pressure level and draws a cyclonic phenomenon in the coastal part of the West Bengal. At the same time, some other regional low pressure areas develop over the Chhatisgarh and Kutch area by which Monsoon through vortex maintain its overall track balance over India. During the second and third weeks of July, the insolation amount continuously increases and all the pressure lines are pushed towards north direction. In the meantime, several local depressions develop over the coastal part of Odisha and Andhra Pradesh due to sufficient supply of moisture from the Bay of Bengal. However, the atmospheric pressure becomes very low again. Sometimes it may reach at 840mb over the adjacent parts of Lower Gangetic area. These types of weather phenomenon develop cloudy sky with reducing visible range often. Scattered shower should continue during this period. If there has been several low pressure zones developed around the northern part of India spread over Madha Pradesh, Gujrat and Kutch etc. The inter passage of each low pressure zones become squeezed. The forecast suggests dominative active Monsoon sheds heavy rainfall over Gangetic West Bengal and its adjacent area. The observed pressure and its coverage is shown in Table-1.

The withdrawal of Monsoon from the extreme north-west end of the country has occurred in September and from the peninsula by October and from the extreme south-eastern part by December. Due to retreat of the Monsoon, this season is also called the season of retreating Monsoon. Sometimes it is referred to as the Post monsoon season. As the Monsoon retreats the low pressure across the Indo Gangetic plains elongates and gradually shifts southward. By October it reaches the Bay of Bengal and moves further southward as the season advances. The axis of low pressure roughly runs in an east-west direction along 13°N latitude. The surface pressure in most parts of the country varies from 1,010 to 1,012 mb. Consequently the pressure gradient is low. Unlike the south-west Monsoon, the onset of the north-east Monsoon is not clearly defined. In fact, on many occasions, the meteorologists fail to draw a clear demarcation between the withdrawal of the Summer Monsoon and the onset of Winter Monsoon over peninsular India. However, the direction of winds over large parts of the country is influenced by the local pressure conditions.

Table- 1. Observed pressure distribution over West Bengal in Monsoon Season.
Sources: Short time Weather Bulletin Forecast, IMD, Alipur, Kolkata

Year	Date	Pressure (mb)	Observed Area
2007	19th July	930	West Bengal, North Bihar, Jharkhand
2009	20th July	992	North west of Bay of Bengal
2010	26th July	850	West Bengal, Odisha & Chhattisgarh
2011	22nd July	700	Low Pressure over Bihar
2012	20th July	730	North East part of Bay of Bengal, Over southern districts of West Bengal.

1.3.1 Special Weather Phenomenon in West Bengal :

Several kinds of climatic hazards are the common features over West Bengal throughout the year. Change of weather pattern in synoptic scale has drawn such important special weather phenomenon like Norwester, Cyclonic Storms, Monsoon Cyclone, Burst of Monsoon etc. These phenomena have brought about climatic hazards like flood, drought, heat-wave, cold-wave etc. over South Bengal area (Table - 2).

Table-2: Principal Special Weather Phenomenon.

Principal Special Weather Phenomenon

Sl.No	Name	Period	Frequency
1	Norwester	Monsoon Period	Meso-Scale
2	Cyclonic Storms		Meso-Scale
3	Monsoon Cyclone		Meso-Scale
4	Burst of Monsoon		Meso-Scale

Norwester:

During the hot weather or Summer period the eastern and north eastern states in India like West Bengal, Assam, Odisha, Bihar and Jharkhand experiences sudden appearance of violent squall thunderstorm known as "*Kal-baisakhi*". It is vigorous and meso-scale convective system of weather phenomena spread over few kilometers to several kilometers in diameter. According to Bengali Calendar, this event usually happen on the month of *'Baisakh'* (Approx. 15th April to 15th May), which causes several hazards (Bengali meaning-*Kal)* in this region. This storm usually damages major crops like paddy and vegetables cultivation. Sudden drop in temperature in the afternoon is the first sign of this event. The surface temperature and dew point temperature decreases due to occurrence of thunderstorms, whereas surface pressure increases. In the starting phase, a low bank of dark cloud in the north-west appears. Then the blowing of the cool wind lasts for 15 to 20 minutes. After that the strong dusty squall starts. Frequent thunder and lightning followed by rain band and sometimes accompanied with hail, driven by the strong wind, are the common features of this event. A sharp depletion of the absolute humidity takes place before the onset of thunderstorm. The average speed of the Norwester ranges from 80 to 120 km/h. A fall of temperature by $2^oC\ to\ 4^oC$ is usual in general cases, but the fall of temperature even up to 12^oC has been recorded. The amount of rainfall varies from place to place over West Bengal. The variation of temperature ratio refractivity indicates sudden change in this event. It lasts for few hours.

Cyclonic Storm:

Cyclonic storm is one of the most important and destructive weather phenomena usually occurring over the coastal part of West Bengal, Odisha and Andhra Pradesh. The frequency and intensity gradually increases over the sea surface area and on the land area its character is vice-versa. Henry Peddington first introduced the name in the middle of 19^{th} century. Its structure is like a coil, where the central part encapsulate minimum pressure and act as a generator. A vast violent whirl of wind is spiraling around a centre of low pressure and travel along the surface of the sea at an average rate of 300 to 500 kilometer per day. The surrounding wind speed on an average, is 120 to 200 kilometer per hour. The average life span of cyclonic storm in the Bay of Bengal is about 5 to 6 days.

Monsoon Cyclone:

The cyclonic disturbances during the Monsoon period are most common weather event over Bay of Bengal. In between the month of June and September, several cyclones hit over the Southern part of west Bengal. These Monsoon cyclones are usually formed in the North Bay of Bengal and follow west and north-westerly course along the Gangetic West Bengal and adjoining north Odisha coast. The sudden fall of barometric pressure creates small scale local depression over the coastal part of Bay of Bengal by which entire wind forms whirling structure. The average wind speed remains 60 to 80 kilometer per hour. After this event, the entire mean maximum temperature becomes comfortable and decreases below $23^{o}C$ and make a chilly feeling in the evening time. Most of these disturbances do not erupt into severe storms. It creates heavy rainfall for several days. Middle of the Monsoon period experiences about this special weather phenomenon like Monsoon cyclone.

Burst of monsoon:

Bursting of Monsoon is the common feature in and around the Bay of Bengal associated with heavier rainfall than the normal. It is not the isolated weather phenomenon but commonly associated with the low pressure depression. Generally, small scale depressions with high saturation condition results in cumulonimbus cloud for heavy rainfall to occur continuously for several days. Some latest studies have revealed that the burst of Monsoons are likely to occur more frequently during the second week of August. The normal duration of the Monsoon burst is about a week but occasionally it could be longer than a week. The heavy rainfall occurs over the sub- Himalayan regions and the southern slopes of the Himalayas lead to flooding over the lower catchment area of the Ganga River.

1.4. Importance of Regional Analysis :

Lower atmospheric temperature and rainfall variability are principal elements of weather system. The proper examination of their behavior is important for understanding of climate variability. These factors are highly variable spatially and temporally at different local, regional and global scales. For the purpose of the prediction of future climate conditions, degree of variability of those two weather elements must be examined and understood properly. Sometimes the global scale prediction of the climate is not recognized for every geographical extension, but regional scale analysis may draw meaningful and straight forward and realistic results. Therefore, recently, the focus on climate variability is based on the detection of trend in regional scale. The length of data record is also a significant factor for analyzing regional scale climate condition. The results of regional analysis revealed the patterns of uncertainty in seasonally averaged and daily atmospheric temperature and rainfall. Climate change and variability over the last century is a subject of great topical interest among the scientific community. Its impact could have a major problem on natural and social systems at local, regional and national scales. It seems that, future climate change is more difficult to understand or predict with great certainty at the regional scale due to spatial resolution limitations of current climate models and to the likely influence of unaccounted for factors such as regional land use change (*R. A. Pielke, 2005*).

The Third Assessment Report predicted that the area-averaged annual mean warming would be about 3°Cin the decade of 2050s and about 5°C in 2080s over the land regions of Asia as a result of future increase in atmospheric concentration of greenhouse gases (*Lal et al., 2001*). The continuous rise in surface air temperature was projected to be most pronounced over boreal Asia in all seasons (*Mahyoub H. Al Buhairi, 2010*). Many investigators have studied climatic changes in various regions of the world including: United States (*Balling Jr. R. C. and Brazel S. W. 1987; Comrie A. C. and Broyles, B. 2002; Folland et al.,1997; Easterling D. R. 1999 and Karl T. R. and Easterling D. R. 1999*); Philippines (*Jose, et al,. 1996*); Europe (*Arnell, N. W. 1999; Velichkov, et al., 2002*); Kenya (*Kipkorir, E. C. 2002*); Arab Region (*Al-Fahed, et al., 1997; Elagib N. A. and Abdu, A. S. 1997; Abahussain, A. A. et al., 2002; Mahmoud M. S. and Ahmed, Z. 2006; Mahmoud, M. S. 2006*); Taiwan (*Chang, C. C. 2002; Yu, et al., 2002*); Israel (*Cohen S. 2002*); and Italy (*Moonen A. C. 2002*). Thus, given the relevance of the climate change in the world, the present research aimed to ascertain the occurrence of climatic variability in Southern part of West Bengal, which is considered one of the most important geographical areas of Indian sub-continent. The existing discrepancy between global and regional air temperature courses is one of the most intriguing issues for climatologists to resolve future climate. Sometimes, it also means that the temperature and rainfall predictions produced by numerical climate models significantly differ from those actually observed. The magnitude and trend of these differences is very difficult to estimate because temperature projections, e.g. for the region always depends upon the General Circulation Model. *Curry et al. (1996*) give three reasons for the current deficiencies of climate models concerning the description of the regional climate (*Rinke et al., 1997a,b*), such as inadequacies in the parameterization of physical processes, coarse horizontal resolution and large-scale dynamics can arise from problems that are a consequence of the insufficient description of low-latitude processes. The present work puts emphasis on the temporal variations in surface air temperature and rainfall over the considered period of instrumental observations in the South Bengal, India and for which the network of stations is sufficient to conduct such investigations.

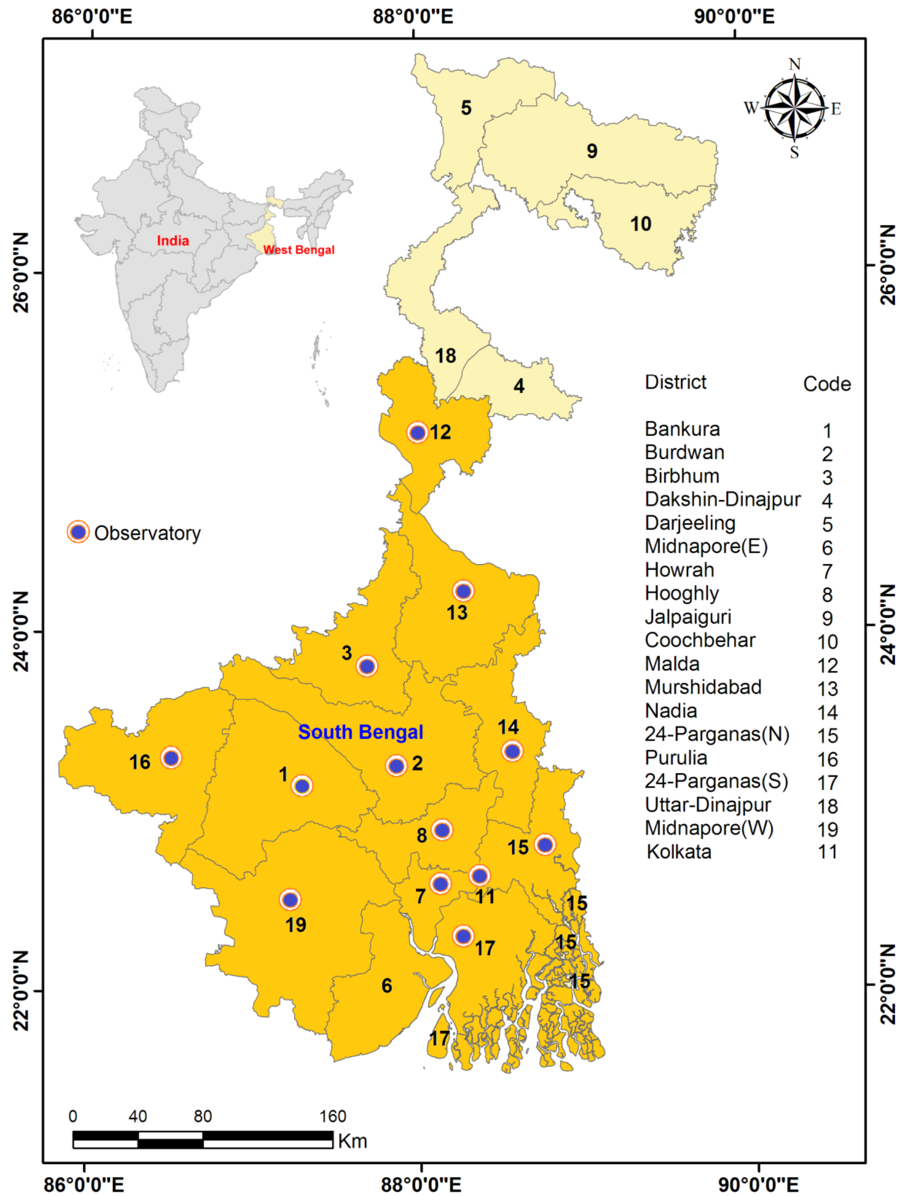
1.5 Geographical Situation of the Study Area:

West Bengal is an important state of Eastern India came up in 1st November, 1956 as a consequence of linguistic division of the country. In respect of nation's population it is the fourth most populous state having 91 million (2011 Census) inhabitants. Overall population density of this state is 1,029/km^2 (2011 Census). The area of the state is 88750 square kilometer. It is bounded by the countries of Bangladesh in the east, Nepal and Bhutan in the north and other Indian states like Odisha, Jharkhand, and Bihar in the west. The southern boundary is defined by the Bay of Bengal. The geographical extension of this area is $85^o50'East\ to\ 89^o50'East$ and $21^o38'North\ to\ 27^o10'North$. The capital of this state is Kolkata which was the capital of India in British Colonial period. Wide spread agricultural area in this region is potentially productive. Agriculture is completely regulated by the tropical Monsoon type of climate. The study area covers 13 districts of the southern part of this state. These districts are Malda, Murshidabad, Birbhum, Burdwan, Purulia, Bankura, Midnapore, Nadia, Hooghly, Howrah, North 24 Pargana and South 24 Pargana respectively (Figure-1). This area lies between $24^o41'49''North\ to 21^o38'North\ latitudes$ and $85^o50'East\ to\ 88^o56'43''East$ longitude

The considered area is associated with a distinct type of physiographic division. The Lower Gangetic Plain passes through the districts of Malda. Murshidabad, Nadia, Part of Burdwan, North 24 Pargana, South 24 Pargana and some part of Midnapore. The area is highly productive and important for agriculture. Huge amount of Paddy, Jute, Vegetables, Potato etc. are produced in this area. Western part of this area covering Bankura, Part of Burdwan, Purulia and western part of Midnapore is an extended part of plateau fringe of Chhotonagpur plateau. The most southern part of the West Bengal is surrounded by the coastal areas. Mainly, the southern part of Midnapore (now it is included in Purba Medinipur district) and South 24 Pargana are the coastal areas.

Though the area which has been considered for this study is influenced by tropical Monsoon type of climate but in regional scale it experiences different weather extremes and local phenomena in different seasons. Sometime the area faces several climatological hazards like heat wave, cold wave, uncertainty of rainfall, local depression etc. The area under study falls within the Lower Gangetic Plain, however, many drainage channels are found which are of secondary importance. Besides main river Hooghly, other rivers such as Damodar, Ajoy, Mayurakshi, Jalangi, Brambhani, Darakeswar, Shilabati, Rupnarayan, Kosai, Keleghai, Haldi and Subarnarekha are important. Maximum agricultural area has been encroached on by this river. Entire agro-based activities are completely regulated by this river. Capital of West Bengal, Kolkata is located on the bank of Hooghly (Bhagirathi). Other populated district towns of this area are English Bazar (Malda), Bahrampur (Murshidabad), Suri (Birbhum), Krishnanagar (Nadia), Burdwan town (Burdwan), Purulia town (Purulia), Arambag (Hooghly), Howrah town (Howrah), Bankura town (Bankura), Midnapore town (Midnapore), Barasat (North 24 Pargana) and Alipur (South 24 Pargana). Other important town in the South Bengal area are Kharagpur, Contai, Asansol, Durgapur, Tamluk also important economic sectors.

Figure-2: Geographical location of the study area.



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Chapter-II (Quality Check and Quality Assurance)

2.0 Data Potential:

Analytical result on climate change is complex, costly and needs long term data interpretation. It is essentially vital that such results are based on the best availability of its evidences. In every aspect it should be understood that the quality and provenance of that evidence must generate the fruitful result or simulation regarding the considered events. To explore the significant results, related data is the only substance in climatological purpose. Observations of weather parameters like temperature, rainfall, humidity etc. are required for long temporal scale. The vital importance of data mining has dragged quantitative and qualitative measurement by employing scientific techniques. The required information and dataset are not sufficient for community to conclude the result but they need the authentication exactness of the proposed information. Uncertain frequency or wrong information indicates wrong projection for future prediction. The main findings of this study are the analysis of the temporal scale of Climatological parameters and their correlation. The instrumental record of Southern Part of West Bengal temperature and rainfall are brief and geographically sparse. Year-to-year variability of air temperature and rainfall has been investigated using seasonal and annual means in the study.

2.1 General Description of the Data Network:

Monthly mean maximum, monthly mean minimum temperature and monthly rainfall time series from January 1901 to December 2011 were derived from the Indian Water Portal Department (www.indiawaterportal.org) and India Meteorological Department (IMD, Alipur, Kolkata). These three types of data contain 13 weather observatories spread over the southern part of West Bengal. The considered temperature data being the SI unit of ℃ and rainfall data unit is millimeter respectively. The stations names, the mean maximum air temperature ($TMax$), mean minimum air temperature ($TMin$), rainfall, coordinates, period covered and nearest station distance are shown in the Table-3. Remarkably, the considered time series maintained consistency while used in this study and the nearest distance covers 5 km and the far distance of the data network has been covered 101 km from the farthest station. Abbreviations of the datasets are following (Table-4).

Table-3: Considered Observatories, Coordinate, Period of Time Series and Nearest Distance of the station network.

SL No.	Observatories	Φ ºN	λ º E	Time Series (Year)	Nearest station	Distance (Km)
1	Bankura (Gobindanagar)	23 ° 14′24″	87 ° 04′09″	110	Purulia (Sahib Bandh)	75.5
2	Birbhum (Suri)	23 ° 54′34″	87 ° 31′47″	110	Murshidabad (Berhampur)	76.2
3	Burdwan (Rajbati)	23 ° 14′24″	87 ° 51′35″	110	Hooghly (Chuchura)	66.8
4	Hooghly (Chuchura)	22 ° 53′56″	88 ° 23′04″	110	North 24 Pargarna (Barasat)	18.9
5	Howrah (City Point)	22 ° 34′48″	88 ° 19′47″	110	Kolkata (Port trust point)	18.0
6	Kolkata (Port trust point)	22 ° 31′33″	88 ° 19′56″	110	South 24 Pargana (Alipur)	5.7
7	Malda (Ingrejbazar)	25 ° 00′34″	88 ° 08′26″	110	Murshidabad (Berhampur)	101.3
8	Midnapore (Abash)	22 ° 19′48″	87 ° 09′00″	110	Howrah (City Point)	97.4
9	Murshidabad (Berhampur)	24 ° 06′00″	88 ° 14′23″	110	Birbhum (Suri)	76.2
10	Nadia (Krishnanagar)	23 ° 24′36″	88 ° 30′36″	110	Burdwan (Rajbati)	69.4
11	North 24 Pargarna (Barasat)	22 ° 43′12″	88 ° 28′47″	110	Hooghly (Chuchura)	18.9
12	Purulia (Sahib Bandh)	23 ° 20′24″	86 ° 21′36″	110	Bankura (Gobindanagar)	75.5
13	South 24 Pargana (Alipur)	22 ° 31′33″	88 ° 19′56″	110	Kolkata (Port trust point)	5.7

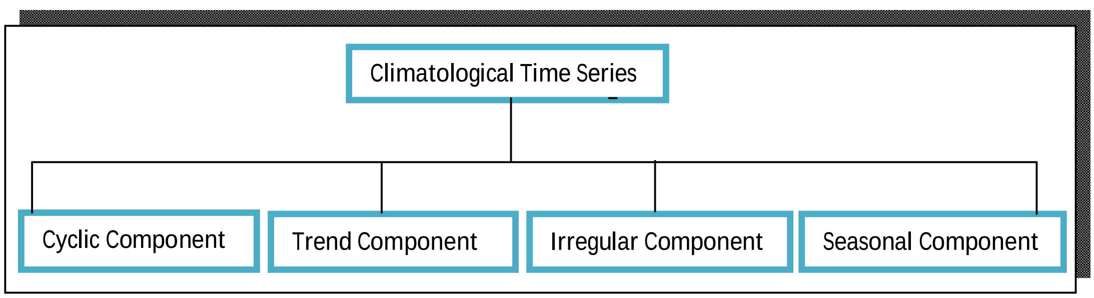
Table-4: Abbreviations of Considered Series.

Sl.No	Nature of Series	Abbreviation
1	Mean Monthly Maximum Temperature Series	*TMax*
2	Mean Annual Maximum Temperature Series	*ATMax*
3	Mean Seasonal Maximum Temperature Series	*STMax*
4	Mean Monthly Minimum Temperature Series	*TMin*
5	Mean Annual Minimum Temperature Series	*ATMin*
6	Mean Seasonal Minimum Temperature Series	*STMin*
7	Mean Monthly Rainfall Series	*MRain*
8	Mean Annual Rainfall Series	*ARain*
9	Mean Seasonal Rainfall	*SRain*

2.2 Quality Check and Homogeneity of the Dataset:

Quality assurance or quality control is a system of routine technical activities, to measures and control the quality of the inventory as it is being developed. So, the quality control system has been designed with a particular process consisting continuous checks to ensure the data integrity, correctness and sequential completeness. Extra acquisition of any error to be adjusted as a realistic one. Many researches have been adopted different quality control measurement and techniques for constructing the data as smooth and reliable. In respect to the climatological analysis for time series data, the quality check and its control is mandatory prior to proper analysis. In the present study the *TMax*, *TMin* and rainfall data sets were used as such maintaining the adjustment and applied. Because, it is earnestly necessary to avoid the unsatisfactory outlier stress in the dataset. Climatological time series dataset are generally combined with main four types of components.

Figure-3: Components of Climatological Time Series.



Cyclic component is a compulsory factor in Climatological time series data. This component ensures fixed temporal reorganization interval like daily fluctuation of temperature etc. The long term periodic fluctuation refers trend component. Another such component like seasonal fluctuation is more common in Climatological time series. Irregular component is the residual variation remaining after the trend cycle and seasonality have been extracted from original time series. This component appears as short term unsystematic fluctuations around the trend that do not follow any systematic or repeated pattern which could be captured by seasonal component. This variation occurs due to sudden change of parameters with residual variation. All these components were checked and controlled in this study for proper analysis (given in Chapter- III, IV & V)

Data quality depends primarily on the location of a climatological station for data acquisition and its adjoining surroundings. India Meteorological Department (IMD) has always performed some regulations to establish weather observatories in suitable place throughout the country. The considered study area of South Bengal encompasses plain land, coastal area and the part of plateau fringe zone. Generally, the long-term time series data of climatological observatories often contains brakes in the continuity of the time series, because of a variety of modifications that might occur time to time.

Often encountered inconveniences in terms of data homogeneity due to changes in the immediate surroundings over temporal spell as well as changes of the observatory location and exchanges of the data observational techniques. Moreover, new techniques about the proper observation time, changes or replacements of the high performance instruments, different active observing practices, and formulae used to calculate means on the data can cause artificial discontinuities from the prior time (*Jones et al., 1985; Karl and Williams, 1987; Gullett et al., 1990; Heino, 1994*). Whereas we have considered the time scale dataset since 1901, so it needs to check the dataset with prior adjustment method. In primary step the data has been processed by correlation method in Table-5, 6 & 7. However, considerable steps have been done to assess the quality of IMD data sets with significant conclusions to take into consideration for further studies. Whenever the tested temperature, rainfall value exceeds these initial level they are examined manually and if a correction is needed, then the data series are treated manually (*Gisler et al., 1997*). In these work few in-homogeneities have been found and the India Meteorological Department (IMD) database is considered to be reliable enough for a treatment as such. A homogeneous climatic time series is defined as one where variations are caused only by variations in weather and climate (*Conrad and Pollak, 1950*).

Table-5: Results of Correlation for Mean Monthly Maximum Temperature ($TMax$) Series.

	Mal	Mur	Bir	Bur	Pur	Ban	Mid	Nad	Hoo	How	Kol	N.24 Pgs	S. 24 Pgs
Mal	1	0.99	0.98	0.98	0.94	0.96	0.97	0.99	0.96	0.97	0.98	0.95	0.74
Mur	0.99	1.00	0.99	0.99	0.80	0.97	0.98	0.99	0.98	0.97	0.98	0.92	0.69
Bir	0.98	0.99	1.00	1.00	0.79	0.99	0.99	0.99	0.98	0.97	0.98	0.93	0.72
Bur	0.98	0.99	1.00	1.00	0.79	0.99	0.99	0.99	0.98	0.98	0.99	0.94	0.73
Pur	0.94	0.80	0.79	0.79	1.00	0.77	0.80	0.80	0.78	0.83	0.83	0.85	0.74
Ban	0.96	0.97	0.99	0.99	0.77	1.00	0.99	0.97	0.96	0.96	0.98	0.93	0.75
Mid	0.97	0.98	0.99	0.99	0.80	0.99	1.00	0.98	0.97	0.97	0.99	0.95	0.76
Nad	0.99	0.99	0.99	0.99	0.80	0.97	0.98	1.00	0.98	0.97	0.98	0.93	0.69
Hoo	0.96	0.98	0.98	0.98	0.78	0.96	0.97	0.98	1.00	0.97	0.97	0.91	0.67
How	0.97	0.97	0.97	0.98	0.83	0.96	0.97	0.97	0.97	1.00	0.98	0.93	0.73
Kol	0.98	0.98	0.98	0.99	0.83	0.98	0.99	0.98	0.97	0.98	1.00	0.97	0.78
N.24 Pgs	0.95	0.92	0.93	0.94	0.85	0.93	0.95	0.93	0.91	0.93	0.97	1.00	0.89
S. 24 Pgs	0.74	0.69	0.72	0.73	0.74	0.75	0.76	0.69	0.67	0.73	0.78	0.89	1.00

Table-6: Results of Correlation for Mean Monthly Minimum Temperature ($TMin$) Series.

	Mal	Mur	Bir	Bur	Pur	Ban	Mid	Nad	Hoo	How	Kol	N.24 Pgs	S. 24 Pgs
Mal	1	0.99	0.99	0.98	0.96	0.96	0.98	0.98	0.97	0.95	0.97	0.97	0.95
Mur	0.99	1.00	0.99	0.99	0.96	0.98	0.99	0.99	0.98	0.98	0.99	0.98	0.95
Bir	0.99	0.99	1.00	1.00	0.96	0.98	0.99	0.99	0.99	0.99	0.98	0.99	0.95
Bur	0.98	0.99	1.00	1.00	0.96	0.98	1.00	0.99	0.99	0.99	0.99	0.99	0.95
Pur	0.96	0.96	0.96	0.96	1.00	0.96	0.96	0.96	0.95	0.94	0.96	0.95	0.93
Ban	0.96	0.98	0.98	0.98	0.96	1.00	0.98	0.98	0.98	0.97	0.98	0.97	0.92
Mid	0.98	0.99	0.99	1.00	0.96	0.98	1.00	0.99	0.99	0.98	1.00	0.99	0.96
Nad	0.98	0.99	0.99	0.99	0.96	0.98	0.99	1.00	0.99	0.99	0.99	0.99	0.95
Hoo	0.97	0.98	0.99	0.99	0.95	0.98	0.99	0.99	1.00	0.99	0.99	0.99	0.94
How	0.95	0.98	0.99	0.99	0.94	0.97	0.98	0.99	0.99	1.00	0.99	0.99	0.92
Kol	0.97	0.99	0.98	0.99	0.96	0.98	1.00	0.99	0.99	0.99	1.00	1.00	0.96
N.24 Pgs	0.97	0.98	0.99	0.99	0.95	0.97	0.99	0.99	0.99	0.99	1.00	1.00	0.96
S. 24 Pgs	0.95	0.95	0.95	0.95	0.93	0.92	0.96	0.95	0.94	0.92	0.96	0.96	1.00

Table-7: Results of Correlation for Mean Monthly Rainfall Series.

	Mal	Mur	Bir	Bur	Pur	Ban	Mid	Nad	Hoo	How	Kol	N.24 Pgs	S. 24 Pgs
Mal	1	0.97	0.96	0.93	0.89	0.90	0.86	0.92	0.87	0.85	0.86	0.85	0.82
Mur	0.97	1.00	0.99	0.97	0.92	0.94	0.91	0.97	0.93	0.91	0.91	0.91	0.87
Bir	0.96	0.99	1.00	0.98	0.93	0.96	0.93	0.96	0.94	0.92	0.93	0.92	0.89
Bur	0.93	0.97	0.98	1.00	0.95	0.98	0.97	0.98	0.98	0.97	0.97	0.96	0.93
Pur	0.89	0.92	0.93	0.95	1.00	0.97	0.93	0.93	0.93	0.92	0.91	0.91	0.88
Ban	0.90	0.94	0.96	0.98	0.97	1.00	0.98	0.96	0.97	0.96	0.96	0.95	0.92
Mid	0.86	0.91	0.93	0.97	0.93	0.98	1.00	0.95	0.98	0.99	0.98	0.97	0.96
Nad	0.92	0.97	0.96	0.98	0.93	0.96	0.95	1.00	0.97	0.96	0.96	0.97	0.92
Hoo	0.87	0.93	0.94	0.98	0.93	0.97	0.98	0.97	1.00	0.99	0.98	0.99	0.96
How	0.85	0.91	0.92	0.97	0.92	0.96	0.99	0.96	0.99	1.00	0.99	0.98	0.97
Kol	0.86	0.91	0.93	0.97	0.91	0.96	0.98	0.96	0.98	0.99	1.00	0.98	0.97
N.24 Pgs	0.85	0.91	0.92	0.96	0.91	0.95	0.97	0.97	0.99	0.98	0.98	1.00	0.96
S. 24 Pgs	0.82	0.87	0.89	0.93	0.88	0.92	0.96	0.92	0.96	0.97	0.97	0.96	1.00

2.3 Statistical Treatment for Homogeneity and Change point Detection:

Five homogeneity tests has used to test the homogeneity (quality check) of the mean monthly $TMax$, mean monthly $TMin$, annual average $TMax$ and $TMin$, mean seasonal $TMax$ and $TMin$ and rainfall series. Standard Normal Homogeneity Test (SNHT), Buishand Range (BRT) Test, Pettitt Test, Von Neumann Ratio (VNR) Test and CUSUM & Bootstrapping have selected for this purpose. Under null hypothesis, the annual values Y_i of the testing variables Y are independent and seems to identically distributed and the series are considered as homogeneous. However under alternative hypothesis, SNHT, BR Test and Pettitt Test and CUSUM & Bootstrapping assume the series consisted of break in the mean and considered as inhomogeneous. These four tests are capable to detect the year where break occurs with its considered significance level. On the other hand the VNR test is not able to give information on the year break but estimate the calculated value with such confidence level by which we can compare that with the critical value under alternative hypothesis. There are some differences between SNHT, BRT and Pettitt test. SNHT-1 is sensitive in detecting the breaks near the beginning or the end of the considered time series. BR test and Pettitt test are easier to identify the break in the middle of the considered time series.

Besides, the SNHT and BR test assumed Y_i is normally distributed, whereas Pettitt test does not require this assumption because it is a non-parametric rank test. Considered Y_i(i is the year from 1 to n) is the testing variable with Y is the mean and s is the standard deviation.

Standard Normal Homogeneity Test (SNHT-1) for single shift in the time series

The SNHT-I (Standard Normal Homogeneity Test) method was first developed for single shifts or breaks (*Alexandersson, 1986*). Later it was extended to linear trends of arbitrary length and to double break (*Alexandersson, 1994; Alexandersson and Moberg, 1997*). This test is commonly known as relative or monotonic change in nature.

A statistic $T(y)$ is used to compare the mean of the first y years with the last of $(n-y)$ years and can be written as below:

$$T_y = y\overline{z_1} + (n-y)\overline{z_2}, \qquad y = 1, 2, ..., n. \qquad ....(1.1)$$

Where

$$\overline{z_1} = \frac{1}{y}\sum_{i=1}^{n}\frac{(y_i - \overline{y})}{s} \qquad \text{and} \qquad \overline{z_2} = \frac{1}{n-1}\sum_{i=y+1}^{n}\frac{(y_i - \overline{y})}{s} \qquad ....(1.2)$$

The year y consisted of break if value of T is maximum. To reject null hypothesis, the test statistic is greater than the critical value, which depends on the sample size.

$$T_0 = \max_{1\le y\le n} T_y \qquad ....(1.3)$$

2.4 Result and Discussion:

Artificial effect of the trend is more significant for the identification of actual trend for a time series. Here, Standard Normal Homogeneity Test (SNHT-I) has adopted for detecting the artificial trend of arbitrary length along the linear line. This test has been revealed the new arbitrary nature of time series which is intended to primary assumption of the inhomogeneity time series. The considered time series for $TMax$, $TMin$ and rainfall record period is N number of observation. This distribution denotes the normal distribution with its parameters mean and standard deviation. For a particular time series the minimum fluctuation of mean or standard deviation may indicate any possible break over the period. The station network is sufficiently dense enough, in order to efficient homogeneity process. This statement is earnestly necessary because, far-way location of the considered observatories may drag more error by which the homogenization may not be complete properly. According to the relative homogeneity test of the considered time series of $TMax$, $TMin$and rainfall, the SNHT-I has employed separately for all monthly, annually and for seasonally series for all observatories. The alpha (α) level has selected at 0.05% level of significance. Primarily, the Null hypothesis (Ho) has considered as the series are homogeneous and the alternative hypothesis (HI) is considered as the series is a date at which there is a monotonic change in the series. At the same time of analysis, the "ρ" value has computed using 10000 Mente Carlo simulations. The interval confirms at 99% level. In maximum cases the computed "ρ" values are greater in the level of significance for mean monthly maximum and mean monthly minimum series. The results of this analysis are shown in Table-8 & 9. The To values are the test statistic for every series. The result of the considered time series is most important and maximum monthly series of the different observatories are indicating breaks by separating the mean level over the period considered. The test statistic values for observatories Midnaopore, Malda, Murshidabad, North 24 Pargana, South 24 Pargana and Purulia are indicating more potential results for their monthly mean maximum ($TMax$) and monthly mean minimum ($TMin$) series.

The computed values for Bankura (January, March, June, September), Birbhum (April, June, July, September and October), Howrah (February, July, August and September), Kolkata (April, May, June), Midnapore (April, May, June) has revealed the minute difference but greater from the critical level at 0.05% level of significance. The exert time of discontinuity of breaks are not same for the all such $TMax$ and $TMin$ series for all observatories.

Some of the time series for monthly mean maximum temperature ($TMax$) indicates their probability value less then < 0.0001 : for August, October, November and December (Bankura), August, November and December (Birbhum), November and December (Burdwan), September and December (Hooghly), April, November and December (Howrah), August and November (Kolkata), September and December (Malda), August, November and December (Midnapore), January, May, November and December (Murshidabad), January, May, July, September and November (Nadia), January, May, July, September, November and December (North 24 Pargana), February, May, August, October, November and December (Purulia) and all series for South 24 Pargana. The results of the test SNHT-I for $TMax$ series are meaningful to identify the quality of the considered time series. The $TMax$ of February, November and December have indicated significant break for all observatories (Table-8). Each and every $TMax$ series for four observatories namely Nadia, North 24 Pargana, South 24 Pargana and Purulia indicates significant breaks over the considered period. The SNHT-I result has revealed the possible significant breaks in two decadal gaps through the 111 years time period. In the first section, the possible significant break has occurred since 1942 to 1952 and in the second section, the possible significant break has occurred in the last decade of the considered time series.

Similar such results are identifying for the mean monthly minimum ($TMin$) temperature time series for these observatories. The annual average series ($ATMax$) has indicated inhomogeneous structure over the period. $ATMax$series reveals that monotonic significant change since 1939 to 1947 and last decade of the time series. So, quality control is required for $ATMax$ series. The result of annual average of temperature ($ATMax$) time series and seasonal time series for mean maximum temperature ($STMax$) is shown in Table-10a.

According to the Standard Normal Homogeneity Test (SNHT-I), the Winter, monsoon and post-monsoon has indicated inhomogeneity character. But the observatories Bankura, Malda, Kolkata Midnapore and Murshidabad do not have any significant monotonic breaks for Summer series at 0.05% level of significance. The results of annual mean minimum ($ATMin$) and seasonal mean minimum ($STMin$) series has indicated similar results. $STMin$ series for Birbhum, Burdwan, Kolkata, Midnapore, Murshidabad and Nadia do not show any significant monotonic break for Summer season (Table-11b).

Table-8: Test Statistic of SNHT-I for Monthly Mean Maximum ($TMax$) Temperature Series.

Ban	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
To	5.36	**18.6**	**12.40**	5.13	**13.04**	1.71	**16.31**	**33.25**	1.59	**31.26**	**34.46**	**29.69**
ρ-Value	0.3	0.004	0.011	0.34	0.007	0.95	0.002	<0.0001	0.22		— <0.0001 —	
Bir												
To	**15.82**	**11.92**	**9.52**	8.92	**15.89**	2.94	7.84	**25.69**	6.41	5.23	**35.26**	**28.99**
ρ-Value	0.002	0.01	0.04	0.06	0.001	0.77	0.11	<0.0001	0.23	0.29	<0.0001	<0.0001
Bur												
To	**11.1**	**13.31**	6.82	8.21	**18.18**	2.77	**20.78**	**24.67**	6.99	**9.85**	**36.40**	**26.71**
ρ-Value	0.04	0.006	0.16	0.08	0.001	0.80	0.001	0.00	0.17	0.03	<0.0001	<0.0001
Hoo												
To	**23.01**	**9.62**	**25.37**	**20.72**	**22.99**	**12.62**	**19.74**	**11.39**	**46.88**	**28.42**	**15.02**	**19.30**
ρ-Value	0.001	0.06	0.20	0.02	0.021	0.01	0.001	0.06	<0.0001	0.001	0.002	<0.0001
How												
To	**26.96**	**9.95**	**13.10**	**27.08**	**33.77**	7.08	4.95	7.68	8.51	**16.14**	**28.14**	**25.39**
ρ-Value	0.001	0.03	0.009	<0.0001		0.16	0.41	0.13	0.09	0.005	<0.0001	<0.0001
Kol												
To	4.63	**16.50**	4.89	1.88	5.04	2.88	6.19	**20.90**	**13.11**	**18.14**	**38.83**	**25.65**
ρ-Value	0.39	0.003	0.37	0.94	0.36	0.78	0.23	<0.0001	0.006	0.002	<0.0001	0.00
Mal												
To	**25.98**	**13.92**	4.87	**9.34**	8.22	4.39	**10.27**	**10.27**	**38.47**	**25.55**	**13.26**	**39.27**
ρ-Value	0.00	0.004	0.37	0.04	1.00	0.47	0.03	0.03	<0.0001	0.00	0.006	<0.0001
Mid												
To	5.57	**17.84**	8.54	4.18	6.53	3.56	**17.38**	**27.31**	**12.37**	**15.38**	**32.08**	**29.86**
ρ-Value	0.25	0.002	0.068	0.52	0.20	0.62	0.001	<0.0001	0.009	0.004	<0.0001	<0.0001
Mur												
To	**37.02**	**11.57**	7.71	**14.86**	**22.18**	**9.50**	**11.41**	**15.71**	**24.10**	**12.55**	**22.80**	**24.58**
ρ-Value	<0.0001	0.05	0.09	0.003	<0.001	0.03	0.02	0.01	0.001	0.009	<0.0001	
Nad												
To	**38.83**	**9.77**	**15.26**	**17.48**	**30.28**	**10.63**	**25.95**	**14.20**	**44.21**	**27.45**	**29.06**	**20.76**
ρ-Value	<0.0001	0.06	0.006	0.00	<0.0001	0.04	<0.0001	0.003	<0.0001	0.001	<0.0001	0.00
N. 24 Pgs												
To	**38.83**	**9.77**	**15.26**	**17.48**	**30.28**	**10.63**	**25.95**	**14.20**	**44.21**	**27.45**	**29.06**	**20.76**
ρ-Value	<0.0001	0.05	<0.0001	0.00	0.001	<0.0001	0.04	<0.0001	0.004	<0.0001	0.001	<0.0001
S. 24 Pgs												
To	**89.21**	**86.92**	**87.63**	**88.82**	**90.95**	**93.38**	**102.22**	**100.64**	**96.06**	**95.98**	**95.63**	**93.79**
ρ-Value	----------<0.0001----------											
Pur												
To	**39.25** .	**30.69**	**14.43**	**10.27**	**48.30**	**14.04**	6.19	**38.38**	**20.15**	**40.85**	**50.87**	**51.82**
ρ-Value	0.001	<0.0001	0.05		0.07	<0.0001	0.007	0.06	<0.0001	0.02	<0.0001	<0.0001
α =	0.05											

To= Bold values are significant at $\alpha = 0.05$ level of significance.

Table-9: Test Statistic of SNHT-I for Monthly Mean Minimum ($TMin$) Temperature Series.

Ban	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
To	**17.22**	**20.01**	8.67	**10.20**	**11.29**	**15.53**	**27.87**	**27.80**	**19.33**	**16.75**	**38.82**	**19.89**
ρ-Value	0.002	0.00	0.07	0.03	0.01	0.002	0.00	<0.0001	0.001	0.002	<0.0001	0.00
Bir												
To	7.29	**20.30**	5.94	1.63	8.51	**9.88**	**25.35**	**25.32**	**12.17**	**13.66**	**41.01**	**34.25**
ρ-Value	0.11	<0.0001	0.25	0.97	0.67	0.03	0.00	0.00	0.05	0.007	<0.0001	<0.0001
Bur												
To	4.00	**25.46**	5.47	2.53	**9.72**	8.12	**17.76**	**19.61**	**17.64**	**18.26**	**39.22**	**20.18**
ρ - Value	0.53	<0.0001	0.31	0.85	0.03	0.08	0.01	0.02	0.02	0.001	<0.0001	0.01
Hoo												
To	**17.31**	**14.26**	8.95	7.61	**10.11**	5.50	**18.13**	**10.58**	4.53	6.07	**26.42**	**19.30**
ρ - Value	0.001	0.003	0.73	0.11	0.33	0.29	0.00	0.02	0.44	0.18	<0.0001	0.00
How												
To	**30.22**	**28.71**	**17.51**	**23.17**	**43.67**	**37.24**	**64.89**	**60.58**	**69.91**	**27.07**	**17.55**	**22.89**
ρ - Value	0.00	-	-	-	-	<0.0001	-	-	-	-	0.002	0.00
Kol												
To	5.89	**20.43**	**11.63**	8.98	3.67	7.08	**21.03**	**30.81**	**15.80**	**12.52**	**19.14**	**19.66**
ρ - Value	0.24	<0.0001	0.03	0.05	0.60	0.13	0.001	<0.0001	0.002	0.01	0.01	<0.0001
Mal												
To	**33.79**	**56.40**	**51.93**	**22.70**	**12.34**	**18.29**	**51.23**	**62.79**	**52.09**	**51.39**	**56.01**	**56.86**
ρ - *Value*	-	-	<0.0001	-	0.007	0.00	<0.0001	-	-	-	-	-
Mid												
To	7.92	**29.82**	**17.04**	**10.21**	5.07	6.77	**32.61**	**41.62**	**49.86**	**27.17**	**36.36**	**50.64**
ρ - *Value*	0.08	<0.0001	0.001	0.02	0.33	0.15	<0.0001	-	-	-	-	-
Mur												
To	7.57	**27.10**	**17.95**	5.24	5.18	**10.78**	**19.52**	**16.45**	**22.71**	**23.96**	**42.16**	**43.70**
ρ - *Value*	0.01	<0.0001	0.00	0.31	0.33	0.02	0.00	0.005	0.01	0.001	<0.0001	0.00
Nad												
To	**21.50**	**15.68**	3.62	4.34	8.54	7.59	5.54	**22.34**	**15.89**	8.00	**33.73**	**22.31**
ρ - *Value*	0.001	0.03	0.58	0.48	0.08	0.12	0.002	<0.0001	0.02	0.10	<0.0001	0.001
N.24 Pgs												
To	**19.37**	**11.17**	6.83	**13.41**	4.18	**19.96**	**54.58**	**60.11**	**32.10**	**13.15**	**27.98**	**20.27**
ρ - *Value*	0.00	0.01	0.17	0.005	0.49	0.00	<0.0001	-	-	0.009	<0.0001	0.009
S.24 Pgs												
To	**16.44**	**50.99**	**49.79**	**56.15**	**56.67**	**80.09**	**76.27**	**95.82**	**98.66**	**87.95**	**55.00**	**41.54**
ρ - *Value*	0.03	<0.0001	-	-	-	-	-	-	-	-	-	0.001
Pur												
To	**43.68**	**42.96**	**30.79**	6.38	**14.32**	**9.37**	7.22	6.85	3.85	**30.36**	**47.32**	**40.39**
ρ - *Value*	0.001	0.001	0.001	0.19	0.02	0.05	0.21	0.24	0.51	0.02	0.00	0.002

To= Bold values are significant at $\alpha = 0.05$ level of significance.

The result of $TMax$ and $TMin$ both are almost identical for the considered time period. The months of August, November and December (Bankura), February, November and December (Birbhum), February and November (Burdwan), November (Hooghly), February to October (Howrah), February, August, December (Kolkata), January to April and July to December (Malda), February and July to December (Midnapore), February and November (Murshidabad), August and November (Nadia), July to September and November (North 24 Pargana), and February to November (South 24 Pargana) test statistic are exhibit with < 0.0001 level of probability. The results of break years of the mean annual maximum ($ATMax$) and mean annual minimum ($ATMin$) series and seasonal series are shown in Table-11 (a & b). Except Howrah observatory, all the other considered observatories reveal breaks for $ATMax$ series. Winter and post-monsoon has revealed consecutive breaks for all observatories. The seasonal ($STMax$) series for the Monsoon season except Howrah has indicated significant break points. The change points are 2002 (Bankura), 1971 (Birbhum), 2009 (Burdwan), 2002 (Hooghly), 1981 (Kolkata), 2001 (Malda), 2000 (Midnapore), 2002(Murshidabad), 2005 (North 24 Pargana), 2002 (Purulia) and 2002 (South 24 Pargana) respectively.

The Summer season is very fluctuating in nature while their annual mean maximum temperature series make several breaks over the considered period. The Summer series for 4 stations like Bankura, Kolkata, Malda and Midnapore exhibits no such break points over the period. Winter, Monsoon and Post monsoon are very inconsistent with some common year of break points for $STMax$ series. Moreover, the temporal span from 1942 to 1955 and last decade are the most important for some common mean level change or break points. Under the null hypothesis $ATMin$ series are very abrupt in nature. Here it is proved that the $STMin$ of winter and post monsoon seasons are inconsistent and they reveals break points for all considered observatories. The annual series for $ATMin$ has indicated break points since almost last two decades. Figure-4 presents the $ATMax$ series of January, where separated mean levels of these series are showing by red dotted line and green dotted line. These lines specifically indicate the relative inhomogeneity of the time series. The red line indicates the prior homogeneity of the specified series and the green dotted line indicates second relative homogeneity over the considered time series.

The $TMax$ series for January (Bankura, Kolkata, Howrah, Murshidabad and Midnapore) does not show mean level change over the considered period. So, it can be stated that these $TMax$ series are initially consistent with their temperature frequency domain. The second mean level for January $TMax$ of Birbhum, Burdwan, Hooghly, Malda, Murshidabad, Nadia and North 24 Pargana is higher than the prior mean level. Only the green dotted line for Purulia observatory indicates high level of mean than the prior red dotted line. Another graphical presentation is shown in Figure-5 for the result of individual temperature structure of $TMax$ series of June. These graphs are almost reverse from the January temperature. Here also indicates that the second mean level (Green dot line) is situated over than the level of mean of prior red dot line. Figure-6 & 7 are showing the annual presentation of mean maximum ($ATMax$) and mean minimum ($ATMin$) temperature series. From the given figure, it is obtained that the maximum series of annual mean maximum ($ATMax$) and annual mean minimum temperature ($ATMin$) series are inhomogeneous.

Table-10: (a) Test Statistic of SNHT-I for Annual and Seasonal Mean Maximum ($ATMax$ & $STMax$) Temperature

(b) Test Statistic of SNHT-I for Annual and Seasonal Mean Minimum ($ATMin$ & $STMin$) Temperature

	(a)					(b)				
Ban	**Annual**	**Winter**	**Summer**	**Monsoon**	**Post-monsoon**	**Annual**	**Winter**	**Summer**	**Monsoon**	**Post-monsoon**
To	**24.15**	**30.84**	6.60	**30.87**	**37.73**	**19.84**	**20.25**	**21.61**	**31.64**	**34.73**
ρ-Value	<0.0001	0.00	0.20	<0.0001	<0.0001	0.001	0.001	0.01	0.00	<0.001
Bir										
To	**10.73**	**17.91**	**13.00**	**15.91**	**16.10**	**26.69**	**27.08**	7.49	**27.49**	**36.96**
ρ-Value	0.04	0.00	0.01	0.003	0.03	0.00	<0.0001	0.013	0.001	<0.0001
Bur										
To	**14.52**	**18.83**	**11.28**	**26.79**	**30.20**	**28.19**	**23.58**	6.17	**25.54**	**37.85**
***ρ* - Value**	0.004	0.00	0.03	0.00	<0.0001	<0.0001	<0.0001	0.22	<0.0001	<0.0001
Hoo										
To	**42.95**	**23.22**	**27.73**	**39.06**	**23.58**	**14.53**	**14.48**	**10.35**	**9.96**	**23.29**
***ρ* - Value**	<0.0001	0.001	0.01	0.00	0.00	0.002	0.003	0.05	0.03	0.00
How										
To	**10.71**	**19.27**	**33.57**	**10.19**	**25.76**	**55.19**	**44.89**	**51.54**	**78.19**	**13.48**
***ρ* - Value**	0.06	0.00	<0.0001	0.08	<0.0001	<0.0001	0.001	<0.0001	<0.0001	0.007
Kol										
To	**26.84**	**24.22**	3.38	**20.67**	**35.56**	**33.79**	**23.10**	6.58	**35.13**	**22.27**
***ρ* - Value**	<0.0001	<0.0001	0.06	0.00	<0.0001	<0.0001	<0.0001	0.17	<0.0001	<0.0001
Mal										
To	**14.91**	**14.50**	7.69	**38.60**	**33.67**	**73.70**	**73.69**	**32.48**	**66.58**	**60.73**
ρ* - *Value	0.004	0.003	0.13	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mid										
To	**25.61**	**27.86**	2.79	**28.58**	**28.94**	**28.36**	8.48	8.40	**53.71**	**38.49**
ρ* - *Value	0.00	<0.0001	0.75	<0.0001	<0.0001	<0.0001	0.09	0.09	<0.0001	<0.0001
Mur										
To	**36.79**	**19.21**	**26.94**	**20.40**	**16.88**	**40.66**	**44.09**	8.64	**17.96**	**39.85**
ρ* - *Value	<0.0001	0.00	<0.0001	0.00	0.001	<0.0001	<0.0001	0.06	0.005	<0.0001
Nad										
To	**40.38**	**22.86**	**31.63**	**44.36**	**14.05**	**18.54**	**18.63**	5.41	**17.11**	**30.14**
ρ* - *Value	<0.0001	0.001	<0.0001	<0.0001	0.003	0.02	0.02	0.31	0.01	<0.0001
N.24 Pgs										
To	**41.38**	**22.86**	**31.63**	**44.36**	**14.05**	**35.77**	**13.67**	**16.05**	**64.04**	**27.81**
ρ* - *Value	<0.0001	0.001	<0.0001	<0.0001	0.006	<0.0001	0.007	0.001	<0.0001	<0.0001
S.24 Pgs										
To	**104.29**	**100.6**	**95.45**	**104.43**	**99.20**	**96.18**	**67.01**	**74.34**	**98.07**	**73.71**
ρ* - *Value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pur										
To	**36.13**	**51.97**	**33.81**	**35.10**	**54.29**	**39.52**	**49.89**	**14.81**	7.85	**38.39**
ρ* - *Value	<0.0001	<0.0001	0.002	0.02	<0.0001	0.001	0.001	0.008	0.16	0.19

To= Bold values are significant at $\alpha = 0.05$ level of significance.

Table-11: (a) Results of SNHT-I (Break Points) for Annual Mean Maximum & Seasonal Mean Maximum ($ATMax$ & $STMax$) Series.

(b) Results of SNHT-I (Break Points) Annual Mean Minimum & Seasonal Minimum ($ATMin$ & $STMin$) Series.

	(a) Mean Maximum Temperature Series					(b) Mean Minimum Temperature Series				
Stations	**Annual**	**Winter**	**Summer**	**Monsoon**	**Post-monsoon**	**Annual**	**Winter**	**Summer**	**Monsoon**	**Post-monsoon**
Ban	**2005**	**2005**	-	**2002**	**2005**	-	**1975**	-	-	**1974**
Bir	**1938**	**1940**	**2005**	**1971**	**1939**	**1975**	**1974**	-	**1987**	**1974**
Bur	**1946**	**1941**	**2002**	**2009**	**1956**	**1986**	**1975**	-	**1987**	**1974**
Hoo	**2002**	**2002**	**2002**	**2002**	**2002**	**1930**	**1930**	**2007**	**2005**	**1973**
How	-	**1945**	**2002**	-	**1955**	-	-	**2006**	**2006**	-
Kol	**1946**	**1944**	-	**1981**	**1975**	**1986**	**1984**	-	**1986**	**1975**
Mal	**1938**	**1940**	-	**2001**	**1978**	**2002**	**2003**	**2003**	**2002**	**2002**
Mid	**1946**	**1945**	-	**2000**	**1956**	**1995**	-	-	**2002**	**1996**
Mur	**2002**	**2001**	**2002**	**2002**	**1950**	**1997**	**1998**	-	**1986**	**1974**
Nad	**2006**	**2002**	**2005**	**2005**	**1950**	**1984**	**1978**	-	**1986**	**1973**
N.24 Pgs	**2006**	**2002**	**2005**	**2005**	**1950**	**1986**	**1929**	**1997**	**2002**	**1972**
Pur	**2007**	**2003**	**2002**	**2002**	**2002**	**2002**	**2002**	-	-	**1997**
S.24 Pgs	**2002**	**2002**	**2004**	**2002**	**2002**	**2004**	**2003**	**2004**	**2004**	**2004**

To= Bold values are significant at $\alpha = 0.05$ level of significance.

The amount of monotonic change has detected by the Standard Normal Homogeneity Test (SNHT-I). The Table-12 and Figure-8 are showing the tabulated values and graphical construction of the amount of change for the mean monthly maximum ($TMax$) time series. It is interesting that, the fluctuations of the amount of changes has occurred randomly on different $TMax$ series and for different observatories. The amount of change for two months of Bnakura observatory has indicated negative value while the mean level of the after section is higher than the prior mean level. These months are May and June respectively. The other $TMax$series indicates positive amount of change because the prior mean level is always higher than the after mean level value. The average amount of change for mean monthly maximum ($TMax$) temperature for Bankura observatory is $\pm$ 0.8 °C. For the $ATMax$ series, the amount of change exhibit as$\pm$ 0.8 °C. In case of the seasonal maximum temperature ($STMax$) series for Bankura observatory, the amount of changes are 1.6 °C, $-$0.9 °C , 0.7 °C and 1.5 °C for winter, summer, monsoon and post monsoon respectively. The amount of change for Birbhum is very interesting while, 5 mean monthly maximum temperature ($TMax$) series has revealed their negative amount of change that means the after section mean levels are greater than the prior mean level. These series are January, March, April, May and October. Their mean difference values are $-$1.3°C , $-$1.0 °C, $-$1.4°C, $-$2.0°C and $-$ 1.3°C respectively. The average amount of change for this observatory is $\pm$ 0.2 °C.

Annual average of the mean maximum ($ATMax$) temperature series of Birbhum shows the amount of change by 0.37 ℃. The seasonal ($STMax$) series for Birbhum observatory has revealed the change of mean level like 0.85 ℃ ($Winter$), −1.19 ℃ ($Summer$), 0.37 ℃ ($Monsoon$) and 0.62℃ (Post Monsoon) respectively. Over all result of the Burdwan $STMax$ series are almost identical to Bankura and Birbhum. But it is noticeable that the mean monthly maximum ($TMax$) series of January(−1.0 ℃), March(−0.92 ℃), April (−1.3 ℃) and May (−1.9 ℃) has indicated negative shift of mean level for later section over the considered time series for Burdwan observatory. On the other hand remaining 8 series for this observatory has indicated positive shift over the considered time series. The average shift of the amount of change of this observatory is ± 0.2 ℃. The annual and seasonal series has indicated mean level shift like 0.5 ℃ ($Annual$), 0.8 ℃ ($Winter$), −0.9 ℃ ($Summer$), 1.3℃ ($Monsoon$) and 0.3℃ (Post Monsoon) for their observatories respectively. For the case of the Hooghly observatory, only 3 mean monthly maximum ($TMax$) series has indicated positive shift of mean level such as February (1.4 ℃), November (0.7 ℃) and December (0.9 ℃) respectively. Random and abrupt shift of the mean level has been found for Howrah ($TMax$)series. Here it is also found that the numeric value of the mean level shift is maximum for January (−3.7 ℃) and the average shifts of the mean level for prior and after section is ± 0.3 ℃ for this observatory. However, the seasonal series of Summer is showing negative shift (−1.11 ℃) for these observatories. But all other seasonal series indicates positive shift of mean level after this analysis.

The ambient temperature of the Kolkata region mostly remains higher than the average as recorded by the IMD, Alipur. As supported by the data records and previous literatures, this may be due to heat island effects. Results of SNHT-I reveals ten mean monthly maximum temperature series shows positive change. The average amount of mean level shift is 0.8 ℃. Only summer season temperature series negative (0.8 ℃) shift and other 3 seasons like winter, monsoon and post monsoon have experienced positive change in mean level by 0.9 ℃, 0.3 ℃ and 0.4 ℃ respectively. The mean monthly maximum temperature ($TMax$) series for Malda has indicated both types of mean level change like positive and negative altogether. First four monthly $TMax$ series indicates negative change of mean level except February.

Average change amount has indicated least numeric value $(0.1\,℃)$ for this observatory. The annual average ($ATMax$) series for this observatory indicates minimum value by $(0.2\,℃)$. Seasonal series remains with positive change of mean level except summer for this observatory. The result of the amount of change for the Midnapore observatory has revealed comparatively positive and negative order while only two mean monthly maximum temperature series is showing negative amount of mean level change like January $(-0.6\,℃)$ and May $(-1.4\,℃)$ respectively. Average shift of the $TMax$s series is $0.6\,℃$ for this observatory. The Murshidabad observatory reveals reverse result than the other observatories. Here it is also noticeable that, $TMax$ series indicates their after mean levels are lower than the prior mean level except July and December. $ATMax$ series for Murshidabad indicates negative change of the mean level. In case of the seasonal configuration, post monsoon indicates positive change of mean level, and other seasonal record shows negative change.

Nadia is the adjacent one weather observatory of Murshidabad. Whereas, the result of this observatory is almost identical with Murshidabad. Average change of the mean level is $\pm\,1.4\,℃$ for this observatory. Except November and December, rest of all the $TMax$ series indicates negative change of the mean level in accordance to prior and after mean level section. The mean level change for South 24 Pargana has revealed the special character, whereas change amounts are maximum than the other series. The average change of the mean level meets the amazing level of $6.7\,℃$. $ATMax$ series also indicate $6.4\,℃$ as maximum change than the other observatories. In technical manner, this data series for this observatory is less important for direct trend detection. The results of the $TMin$ series for monthly, annual and seasonal is shown in Table-13 and Figure-9. The $TMin$ series of the Bankura observatory also unfolds the same result like $TMax$ series and has guided to be inhomogeneous before the analysis. Average change of the mean level of the Birbhum observatory is $-0.47\,℃$. For this observatory, the consecutive $TMin$ series indicates negative and positive change over the considered period randomly. The change of the mean level for $ATMin$ series is $0.4\,℃$. The fluctuation of the mean level of the Burdwan observatory is very inconsistent and irregular while, the average shift of the $TMin$ temperature series is showing $0.37\,℃$.

Malda, Midnapore, Murshidabad, Nadia, North 24 Pargana and South 24 Pargana are consistently indicating the positive change of mean level for the both $TMin$ and $ATMin$ series. Henceforth, the South 24 Pargana has indicated its average amount of mean level change by 3.75℃ .

Figure-4: Graphical presentation of Mean Monthly Maximum ($TMax$) Temperature for January of selected observatories.

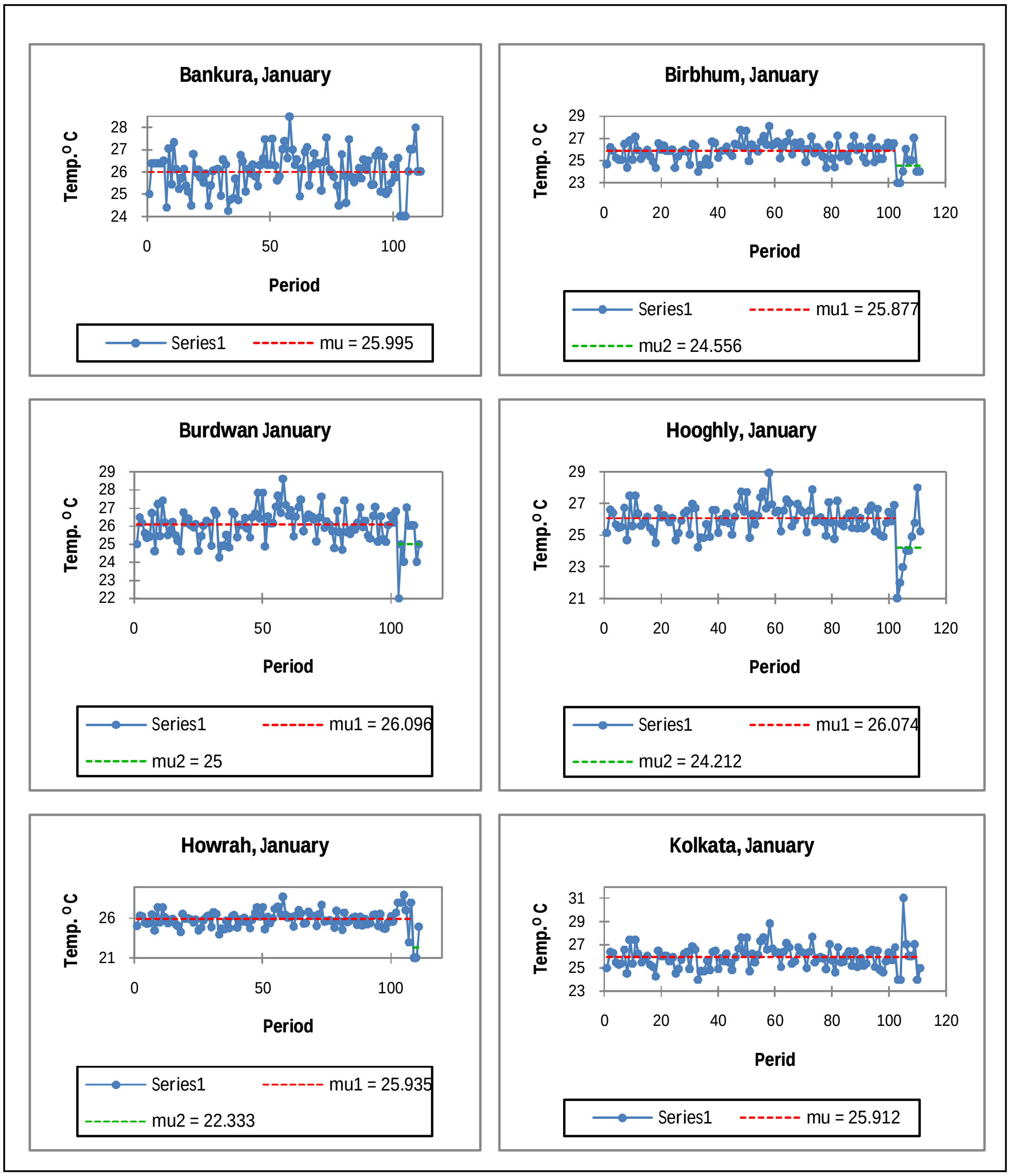
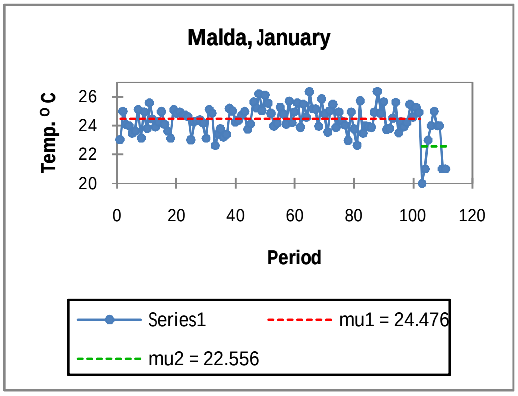
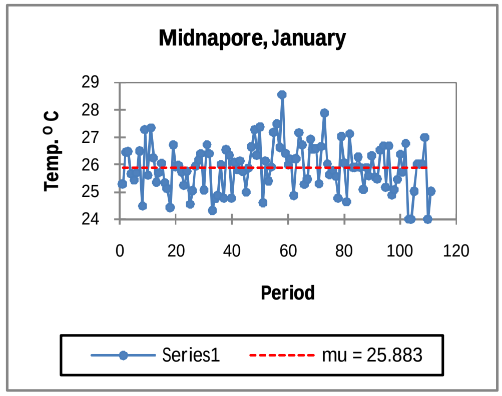
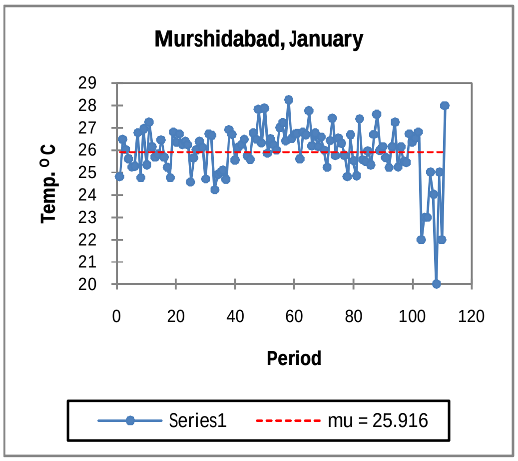
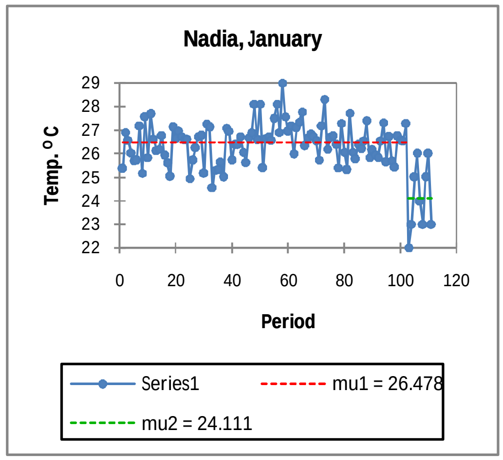


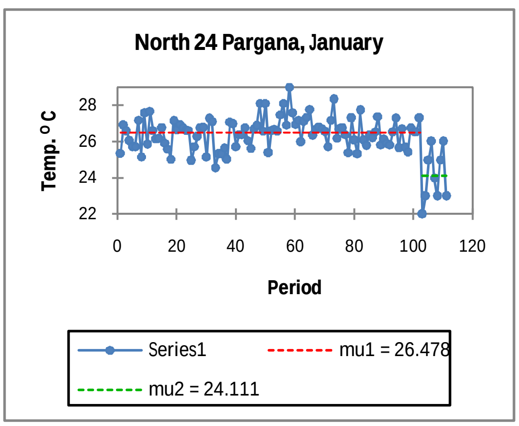
Figure Cont….


Malda, January
Temp. o C
Period
Series1
mu1 = 24.476
mu2 = 22.556


Midnapore, January
Temp. o C
Period
Series1
mu = 25.883


Murshidabad, January
Temp. o C
Period
Series1
mu = 25.916


Nadia, January
Temp. o C
Period
Series1
mu1 = 26.478
mu2 = 24.111


North 24 Pargana, January
Temp. o C
Period
Series1
mu1 = 26.478
mu2 = 24.111

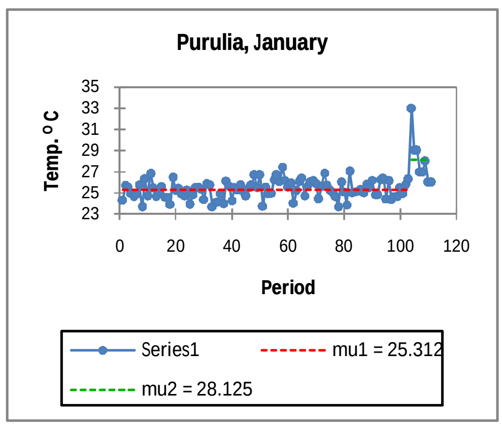

Purulia, January
Temp. o C
Period
Series1
mu1 = 25.312
mu2 = 28.125

Figure-5: Graphical presentation of Mean Monthly Maximum ($TMax$) Temperature Series for June of selected observatories.

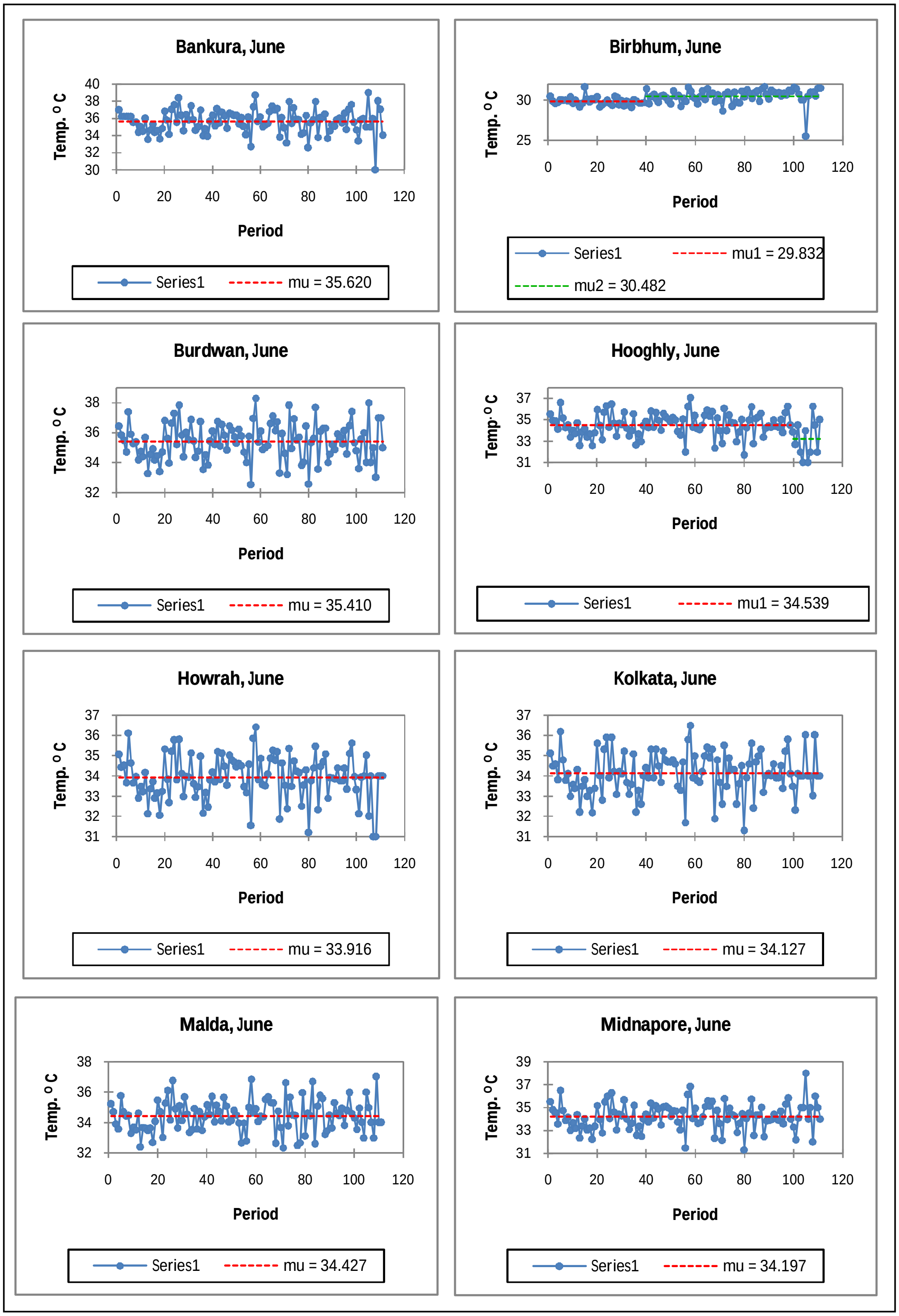


Figure Cont….

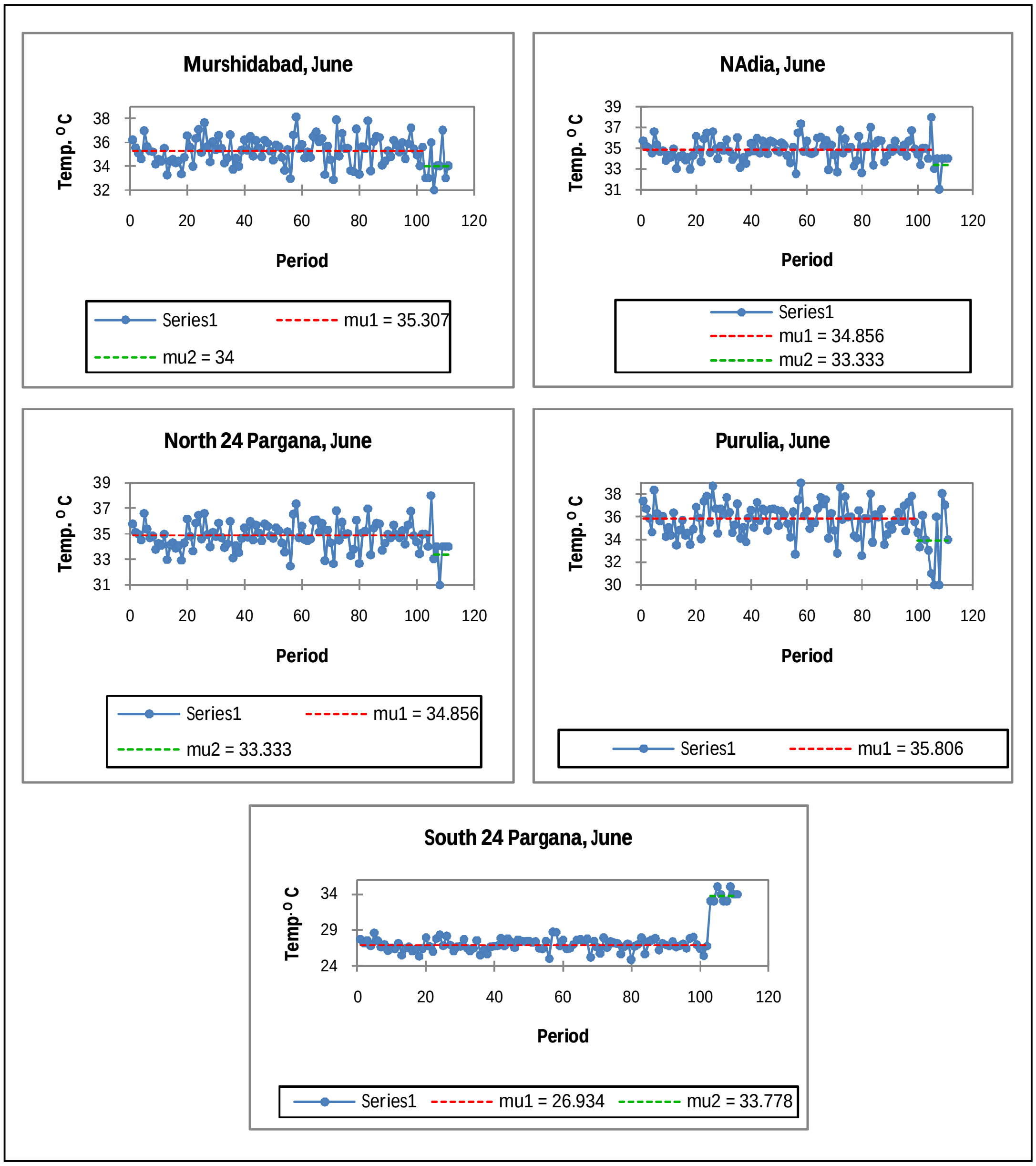

Murshidabad, June
Temp. °C
38
36
34
32
0
20
40
60
80
100
120
Period
Series1
mu1 = 35.307
mu2 = 34
NAdia, June
Temp. °C
39
37
35
33
31
Period
Series1
mu1 = 34.856
mu2 = 33.333
North 24 Pargana, June
Temp. °C
39
37
35
33
31
Period
Series1
mu1 = 34.856
mu2 = 33.333
Purulia, June
Temp. °C
38
36
34
32
30
Period
Series1
mu1 = 35.806
South 24 Pargana, June
Temp.°C
34
29
24
Period
Series1
mu1 = 26.934
mu2 = 33.778

Figure-6: Graphical presentation of Mean Annual Maximum ($ATMax$) Temperature Series for selected observatories.

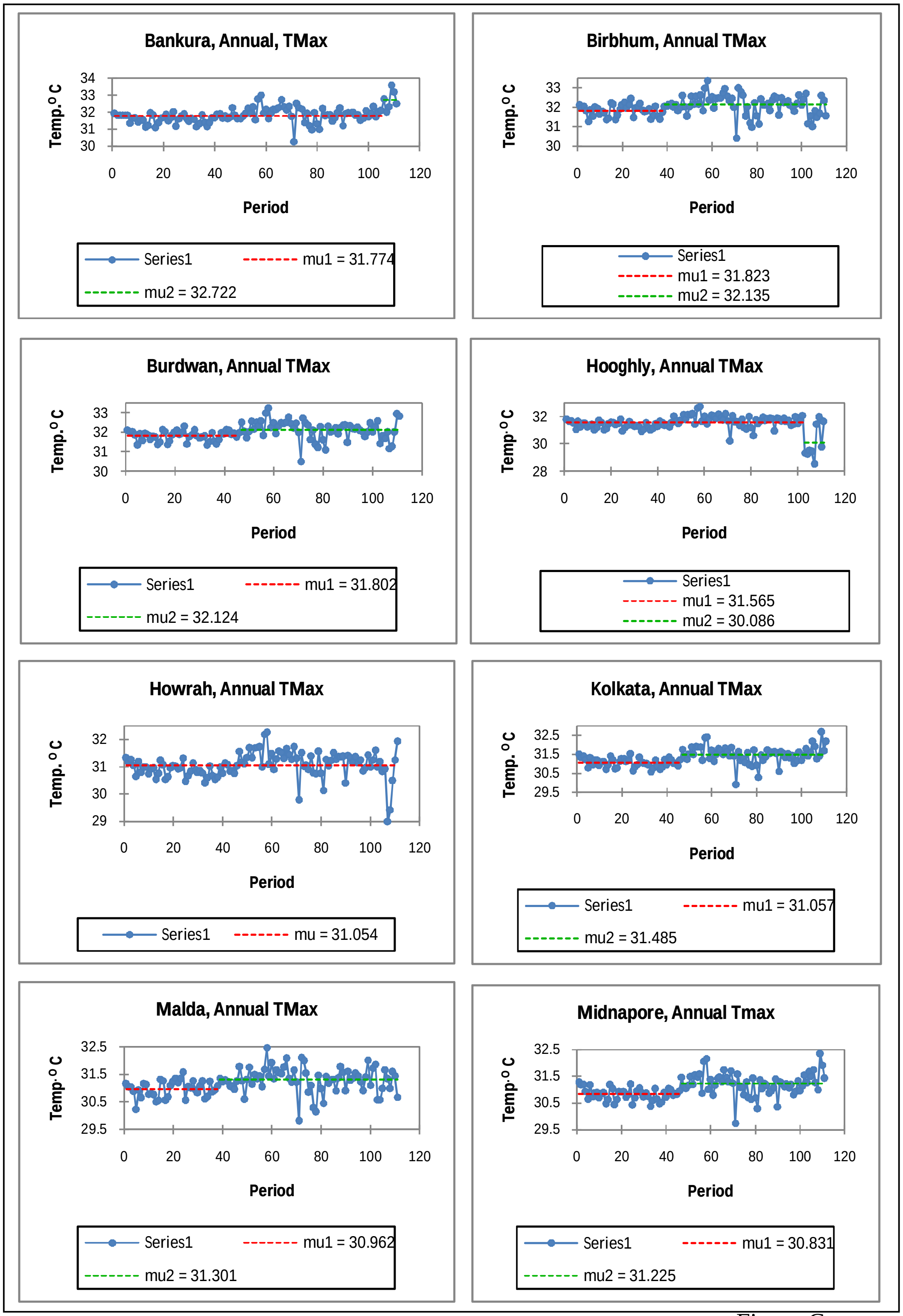


Figure Cont.…

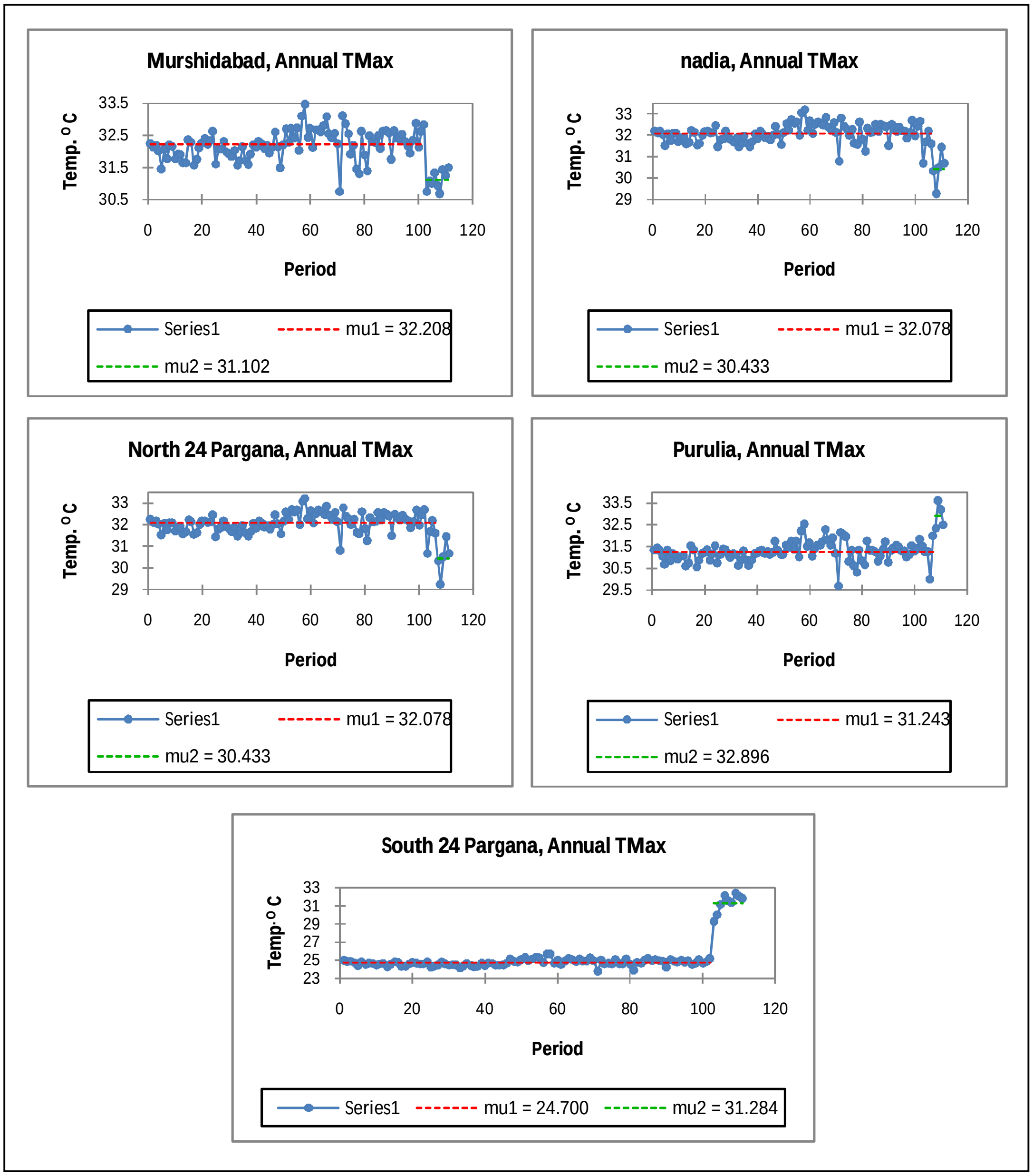

Murshidabad, Annual TMax
Temp. °C
33.5
32.5
31.5
30.5
0 20 40 60 80 100 120
Period
Series1
mu1 = 32.208
mu2 = 31.102
nadia, Annual TMax
Temp. °C
33
32
31
30
29
0 20 40 60 80 100 120
Period
Series1
mu1 = 32.078
mu2 = 30.433
North 24 Pargana, Annual TMax
Temp. °C
33
32
31
30
29
0 20 40 60 80 100 120
Period
Series1
mu1 = 32.078
mu2 = 30.433
Purulia, Annual TMax
Temp. °C
33.5
32.5
31.5
30.5
29.5
0 20 40 60 80 100 120
Period
Series1
mu1 = 31.243
mu2 = 32.896
South 24 Pargana, Annual TMax
Temp. °C
33
31
29
27
25
23
0 20 40 60 80 100 120
Period
Series1
mu1 = 24.700
mu2 = 31.284

Figure-7: Graphical presentation of Mean Annual Minimum ($ATMin$) Temperature Series for selected observatories.

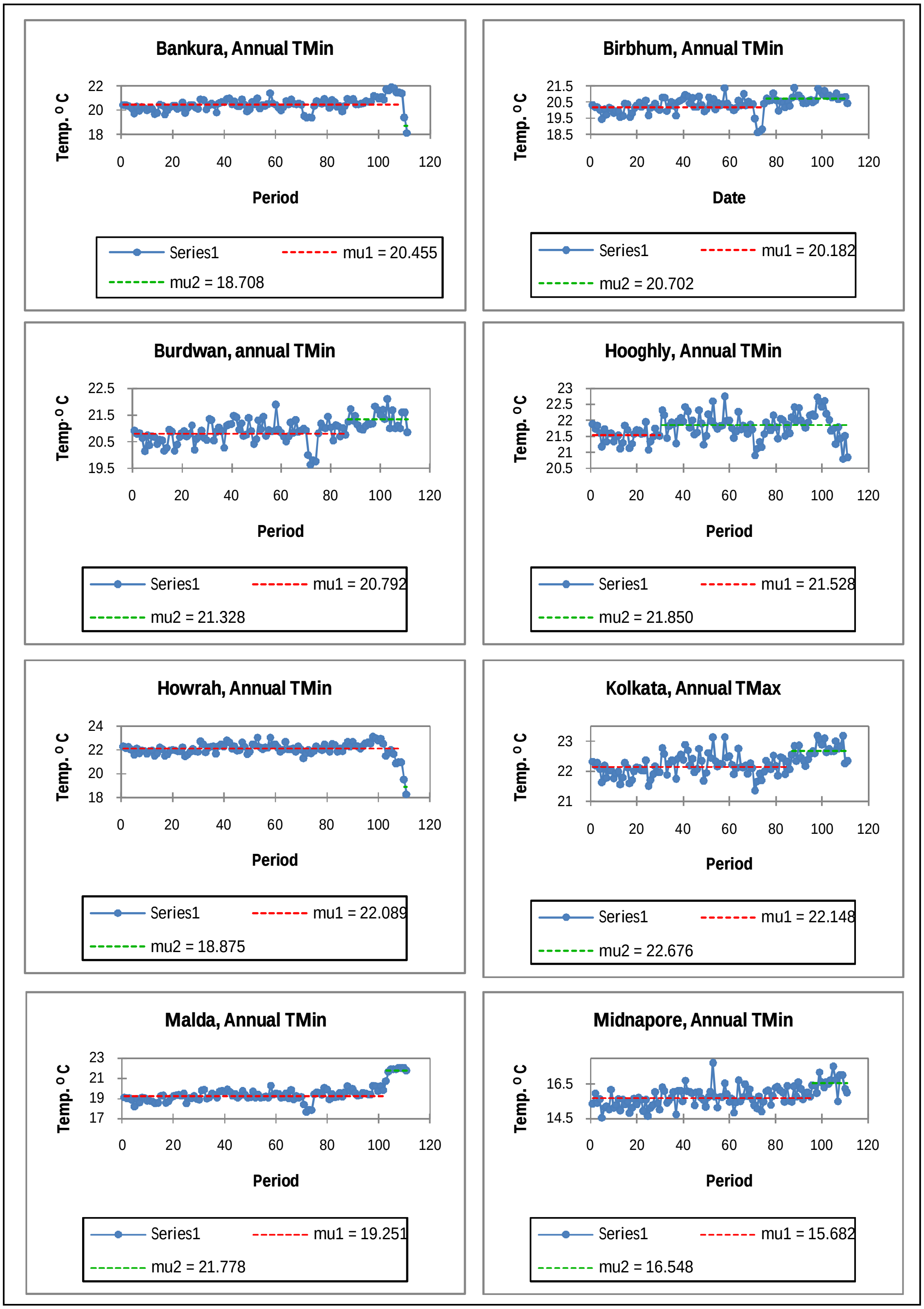


Figure Cont.…

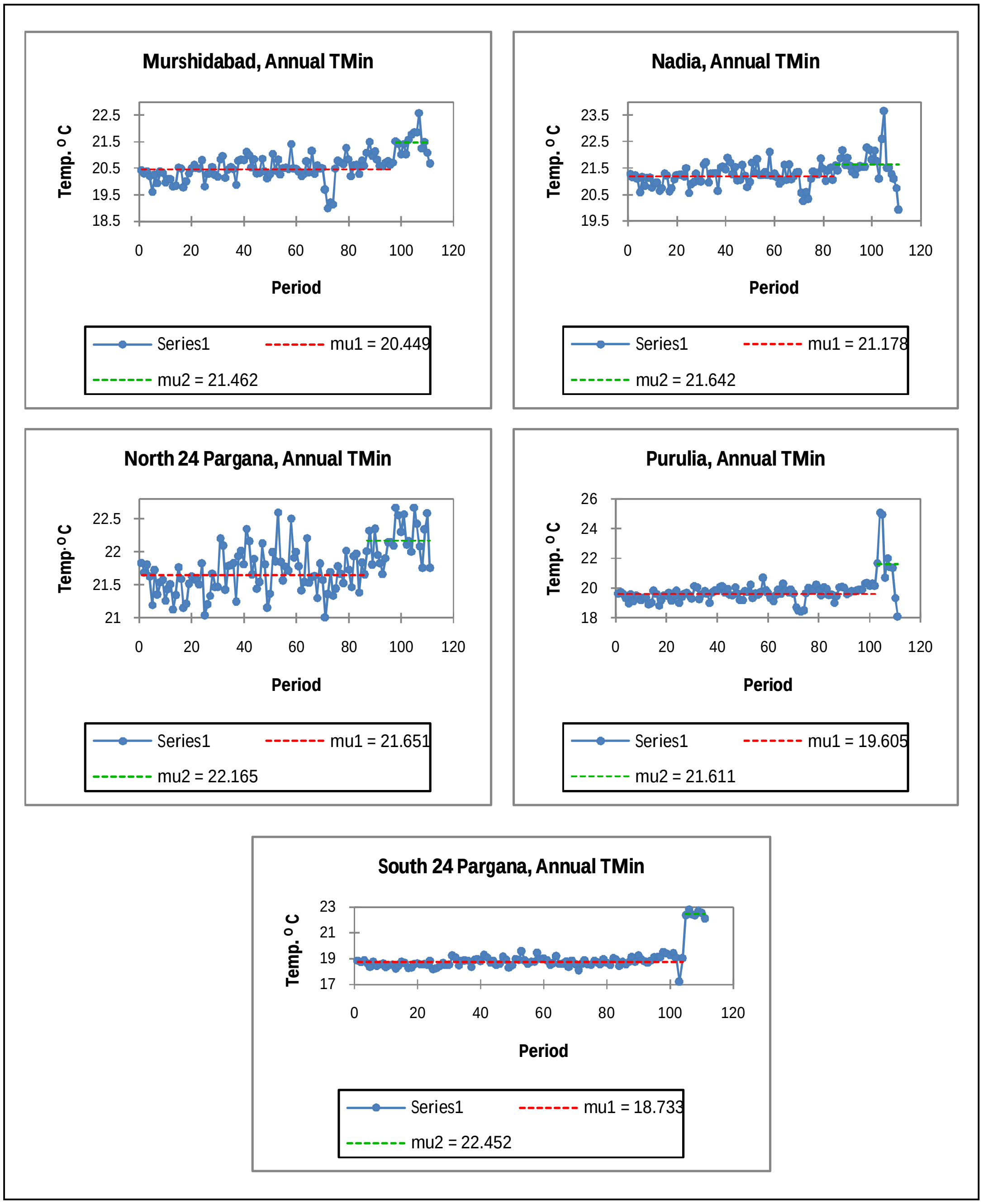

Murshidabad, Annual TMin
Temp. o C
22.5
21.5
20.5
19.5
18.5
0 20 40 60 80 100 120
Period
Series1
mu1 = 20.449
mu2 = 21.462
Nadia, Annual TMin
Temp. o C
23.5
22.5
21.5
20.5
19.5
0 20 40 60 80 100 120
Period
Series1
mu1 = 21.178
mu2 = 21.642
North 24 Pargana, Annual TMin
Temp. o C
22.5
22
21.5
21
0 20 40 60 80 100 120
Period
Series1
mu1 = 21.651
mu2 = 22.165
Purulia, Annual TMin
Temp. o C
26
24
22
20
18
0 20 40 60 80 100 120
Period
Series1
mu1 = 19.605
mu2 = 21.611
South 24 Pargana, Annual TMin
Temp. o C
23
21
19
17
0 20 40 60 80 100 120
Period
Series1
mu1 = 18.733
mu2 = 22.452

Table-12: Estimation of the Amount of Change by SNHT-I ($TMax\ series$)

Estimation of Amount of Mean Level Change ($TMax$ / $ATMax$ / $STMax$) by SNHT-I (^{o}C)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	AA	W	S	M	PM
Ban	0.8	2.0	2.3	1.7	-1.7	-1.0	0.7	1.1	0.4	1.4	0.5	0.8	0.8	1.6	-0.9	0.7	1.5
Bir	-1.3	1.3	-1	-1.4	-2	0.6	0.3	0.6	0.2	-1.3	0.8	0.9	0.3	0.8	-1.1	0.3	0.6
Bur	-1	1.4	-0.9	-1.3	-1.9	0.5	2	0.7	0.2	1.3	0.4	0.9	0.5	0.8	-0.9	1.3	0.3
Hoo	-1.7	1.4	-2.5	-2.6	-2.1	-1.3	-1.1	-0.9	-1.8	-1.8	0.7	0.9	-1.6	-1.4	-2.1	-1.3	-1.7
How	-3.7	1.4	-1.5	-2.4	-2.4	-1.2	-0.8	1.5	1.3	2.4	0.5	0.9	0.6	0.9	-1.8	1.1	0.3
Kol	1.0	1.4	1.4	-1	-1.2	0.3	0.5	0.4	1.5	0.4	4.4	0.6	0.6	0.9	-0.8	0.3	0.4
Mal	-1.9	1.2	-0.7	-1.4	-1.4	0.5	0.5	1.2	0.9	0.6	0.8	0.4	0.2	0.6	-0.9	0.6	0.8
Mid	-0.6	1.3	1.8	1.4	-1.4	0.8	0.6	0.7	0.4	0.8	0.5	0.8	0.5	0.8	-0.9	0.5	0.4
Mur	-2.5	-2.2	-0.9	-1.9	-2.6	-1.4	2.3	-2.4	-2.5	-1.2	0.7	0.8	-1.2	-1.3	-1.8	-0.6	0.4
Nad	-2.2	-2.2	-1.2	-2.1	-2.9	-1.6	-1.4	-1.1	-2	-1.7	0.4	1.1	-1.6	-1.4	-2.2	-1.4	0.5
N.24	-2.2	-2.2	-2	-2.1	-2.9	-1.6	-1.4	-1.1	-2	-1.7	0.4	1.1	-1.6	-1.4	-2.2	-1.4	0.5
Pur	2.7	2.8	4	-1.7	-4.1	-1.7	1.5	1.7	0.9	1.4	2.5	3	1.5	2.2	-2.6	1.4	2.1
S.24	6.6	7.2	6.8	7.2	7.4	6.7	6.4	6.3	5.9	6.4	7	6.8	6.4	6.6	7	6.2	6.7

AA= Annual Average, W= Winter. S=Summer, M=Monsoon, P=Post-Monsoon

Table-13: Estimation of the Amount of Change by SNHT-I ($TMin\ Series$)

Estimation of Amount of Mean Level Change ($TMin$ / $ATMin$ / $STMin$) by SNHT-I (^{o}C)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	AA	W	S	M	PM
Ban	-3.1	0.7	0.8	-4	-2.9	-3.3	-2.5	-3.2	-2.6	0.7	1.1	0.7	-2.3	-2.7	-2.5	-2.3	0.2
Bir	-2.0	1	0.9	-1.6	-1.5	1	0.6	0.7	-1	0.4	1.5	1.1	0.4	0.7	0.7	0.7	0.9
Bur	0.6	0.9	0.5	0.5	-1.5	0.1	0.6	0.8	0.6	0.6	1.3	-0.6	0.6	0.6	0.6	0.7	0.8
Hoo	-3	0.5	-3.6	-1.7	-1.2	-0.7	-1.3	0.6	0.5	1.4	1.1	0.8	0.3	0.4	-1.2	-0.7	0.7
How	-5	-4	-2.2	-2.5	-3.6	-2.8	-3	-2.4	-2.9	-2.7	1	-4.6	-3.2	-4.1	-3	-2.8	-2.5
Kol	-1.7	0.9	0.7	0.9	-1.1	0.6	0.6	0.6	0.5	0.5	1.1	0.8	0.6	0.6	0.4	0.6	0.7
Mal	2.1	3.1	3.4	1.9	1.4	1.3	1.6	2.2	1.9	2.1	3	2.8	2.1	2.8	1.5	1.9	2.6
Mid	-2	1.1	1	1	-1.2	0.9	0.7	0.7	1	0.9	0.9	0.8	0.7	0.5	0.8	0.9	1
Mur	0.8	1.2	1.3	0.7	-1.4	1	0.5	0.5	-3.3	1.4	2.9	0.6	1	0.7	0.7	0.9	0.9
Nad	-3.7	0.9	0.4	-2.3	-1.5	0.7	0.6	0.8	-1.7	0.3	1.4	1	0.5	0.7	-1.8	0.7	0.8
N.24	-1.6	0.5	0.5	1	1	1.1	1.3	1.2	0.7	0.5	1	-4.8	0.5	0.4	0.7	1	0.6
Pur	6	4.7	2.9	-3.2	-1.4	-2.5	-2.2	-2.2	-1.4	1.3	4.2	5.5	1.7	4.3	-3.2	-1.9	2.2
S.24	1.3	2.8	3.7	4.8	4.4	5.4	5.4	4.9	4.3	3.9	1.9	2.2	3.5	2	4.8	4.9	3.1

AA= Annual Average, W= Winter. S=Summer, M=Monsoon, PM=Post-monsoon

Figure-8: Graphical presentation of the Amount of Change of Mean level for $TMax$ Series.

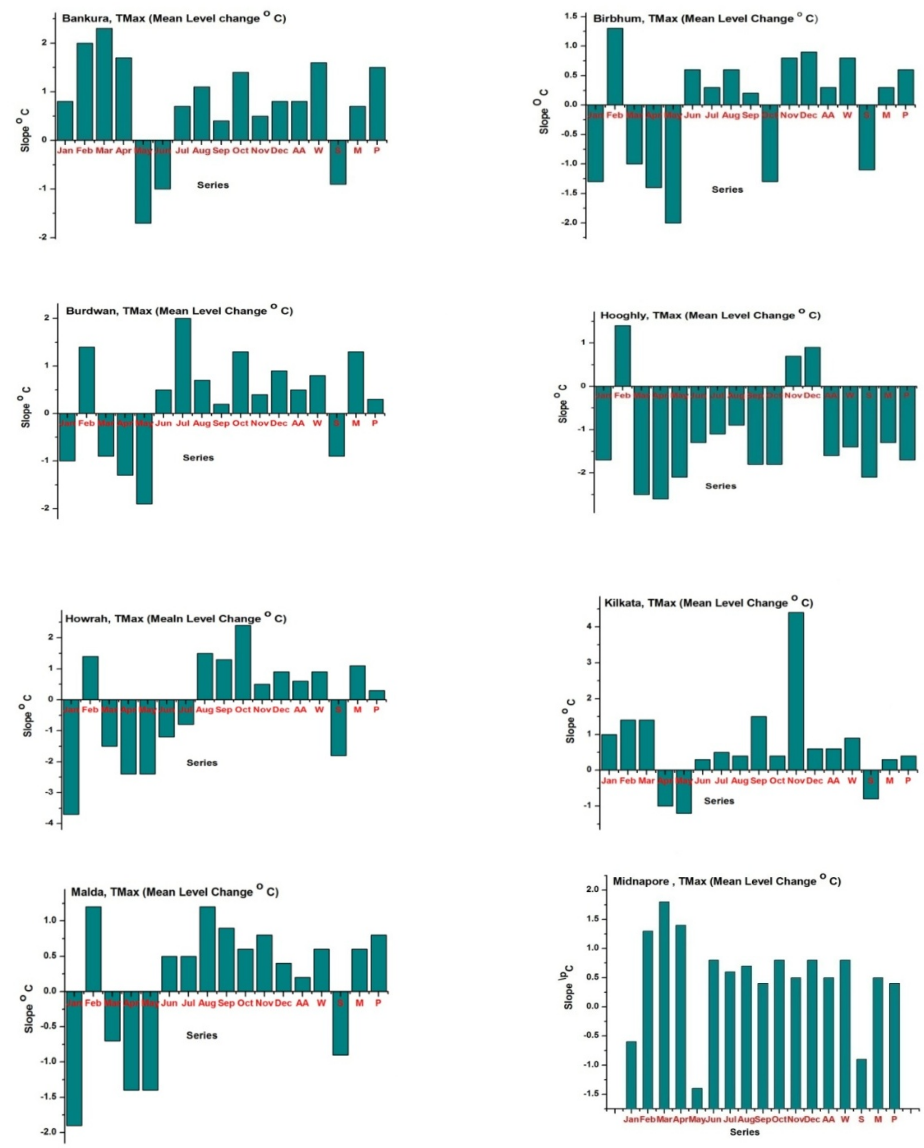
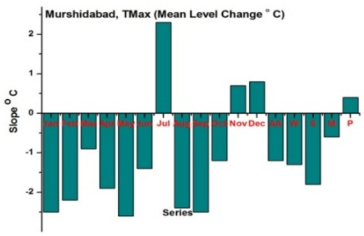
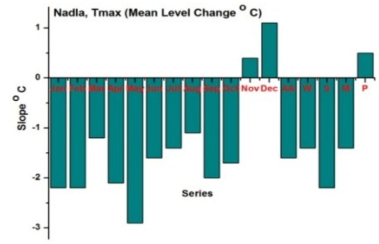
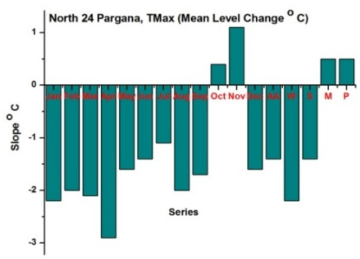
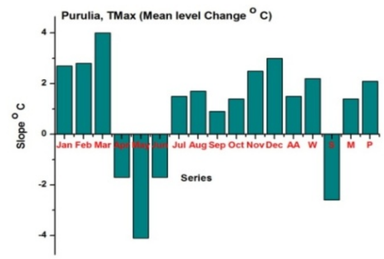


Figure Cont….


Murshidabad, TMax (Mean Level Change ° C)
Slope ° C
Series


Nadia, Tmax (Mean Level Change ° C)
Slope ° C
Series


North 24 Pargana, TMax (Mean Level Change ° C)
Slope ° C
Series


Purulia, TMax (Mean level Change ° C)
Slope ° C
Series

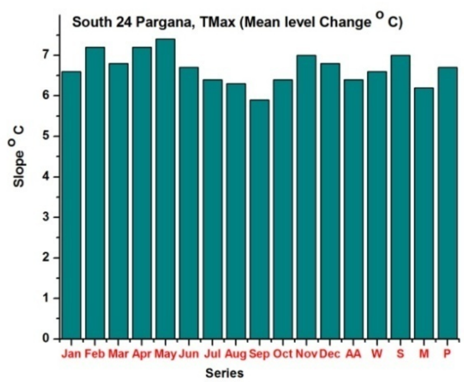

South 24 Pargana, TMax (Mean level Change ° C)
Slope ° C
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec AA W S M P
Series

Figure-9: Graphical presentation of the Amount of Change of Mean level for $TMin$ Series.

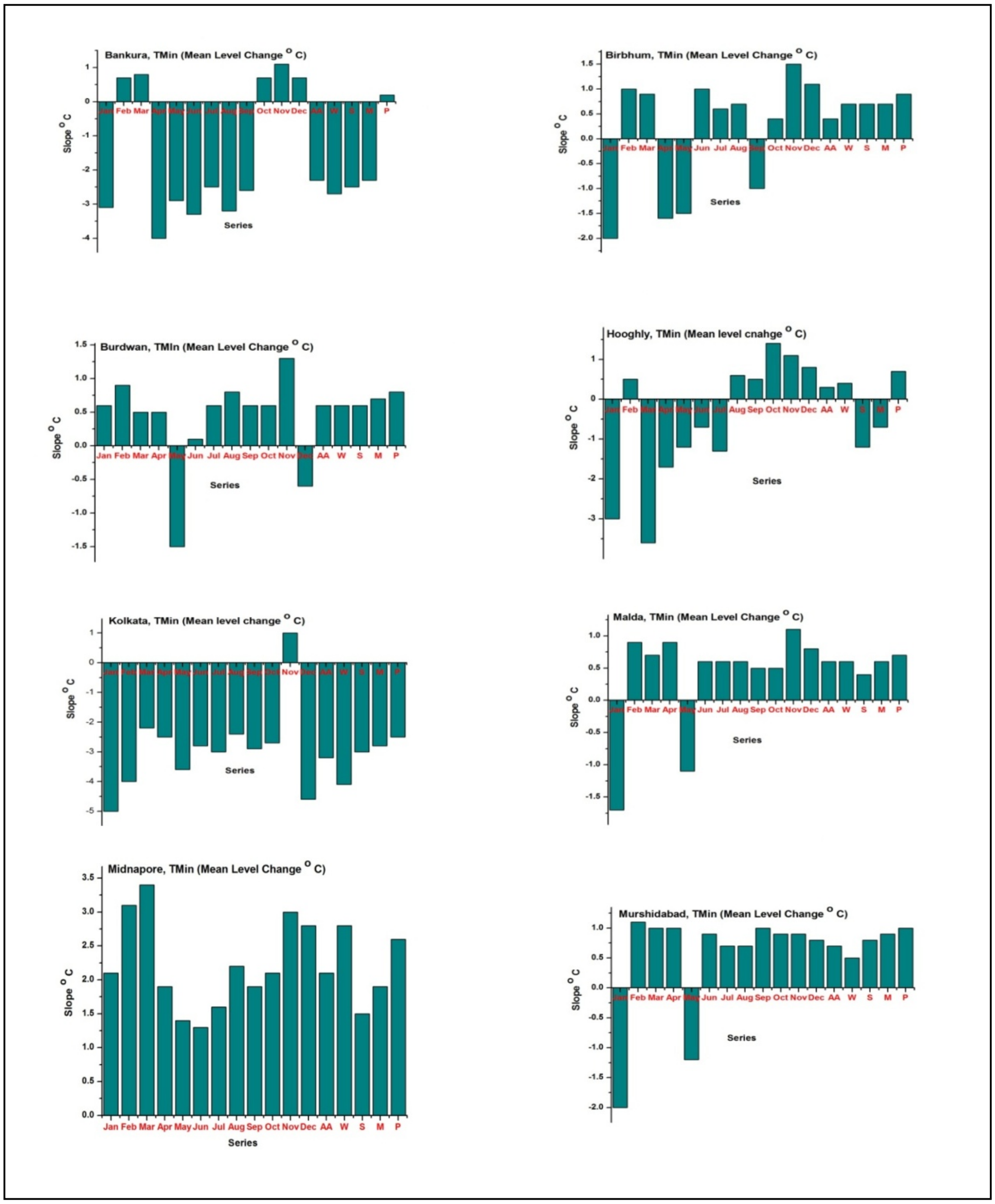
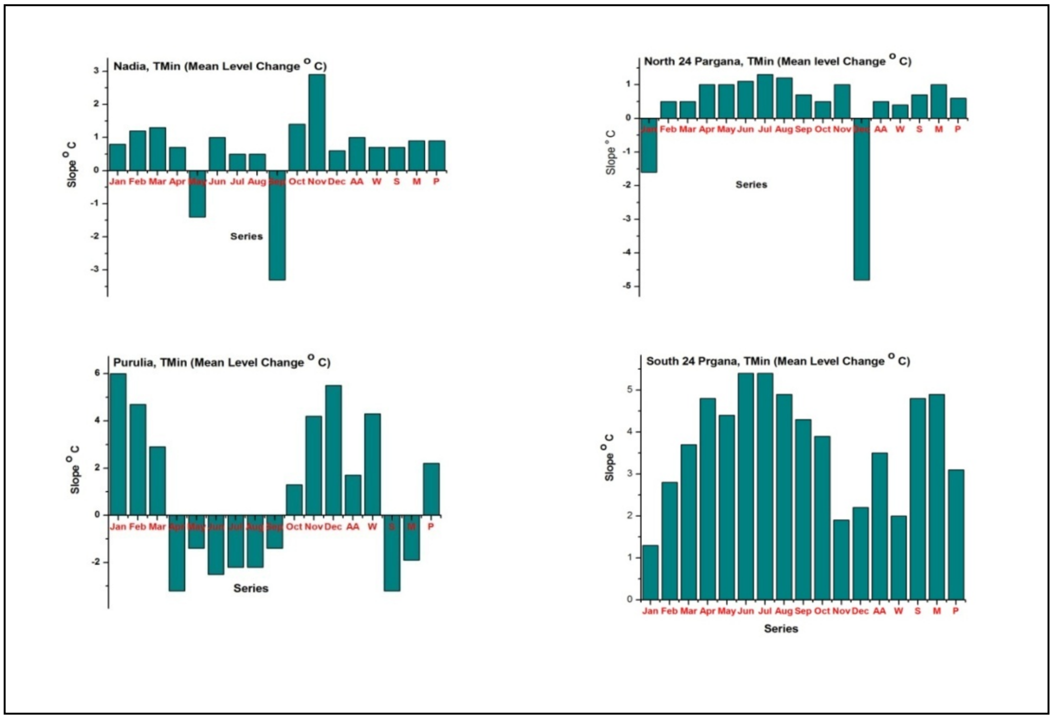


Figure Cont….


Nadia, TMin (Mean Level Change °C)
North 24 Pargana, TMin (Mean level Change °C)
Purulia, TMin (Mean Level Change °C)
South 24 Prgana, TMin (Mean Level Change °C)
Slope °C
Series
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec AA W S M P

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Chapter-III (Variability Analysis)

3.0. Variability Analysis and Residual Mass Curve Fitting :

Homogeneous time series are often required in climatological time series analysis. Because of the uncertainty about possible changes are often used in climatology and hydrology to get some insights into the homogeneity of a considered time series. In this work we use Cumulative Deviation Test (CDT) to detect the shift of mean at an unknown point. The cumulative deviation has the advantages that changes in the mean value of temperature or rainfall are easier to recognize (*Craddock, 1979*). The plotted graph of the Cumulative Deviation Test is called Residual Mass Curve (RMC). Thesis graphs are useful for the detection of shift of the mean offers opportunity to distinguish, real change from purely random fluctuations of time series. This test is based on Adjusted Partial Sums (APS) which is computed using the equations below-

$$S_0^* = 0 \qquad S_k^* = \sum_{i=1}^{k} (x_i - \bar{x}) \qquad k = 1, 2, \ldots\ldots, n. \qquad \ldots\ldots\ldots\ldots (3.1)$$

Where x_i are observed values of the climatic parameter, $\bar{x}$ is the sample mean and n is the number of records in the time series. When the series is homogeneous, then the value of S_k^* will rise and fall around zero. The year x has break when S_k^* has reached a maximum (negative shift) or minimum (positive shift) near the year. Furthermore, Re-scaled Adjusted Partial Sums (RAPS) has to be calculated. The symbol is used for the RAPS in this method is (S_k^{**}). These values are obtained by dividing S_k^*'s by the sample standard deviation (D_x) as:

$$S_k^{**} = \frac{S_k^*}{D_x} \qquad k = 1, 2, \ldots., n. \qquad \ldots\ldots\ldots\ldots\ldots (3.2)$$

The sample standard deviation (D_x) has been calculated by:

$$D_x = \frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x})^2 \qquad \ldots\ldots\ldots\ldots\ldots(3.3)$$

Where S_k^* is the k^{th} term of the RAPS, x_t is the observed time series at time t. $\bar{x}$ is the mean of x_t and D_x is the standard deviation of x_t and n is the number of observations. It is assumed that x_t follows a normal distribution of can be transformed into one (*Legates, 1991*) give the expected value and variance of S_k^* for the cases of independent and identically distributed x_t in addition to the case of a sudden jump and uniform monotonic linear trend as well as general trend. Sudden jumps in x_t appears as a broken linear trend in S_k^*, while a linear trend in the data shows a parabolic trend in S_k^*. For a monotonic positive trend, the values at the beginning of the record will be below the overall average and their adjusted partial sums will accumulate to a large negative value towards the middle of the time series records. The value towards the end of the time series will be above average and will balance S_k^* back to zero at the end of the time series record. This will results in the parabolic shape of the plot with negative ordinates when a positive linear trend exists in the data. For negative trends, the situation is reversed and the parabolic shape results with positive ordinates. In this the statistic Q is very sensitive and calculated as:

$$Q = \max\left|S_k^{**}\right| \qquad 0 \le k \le n \qquad \ldots\ldots\ldots\ldots\ldots(3.4)$$

The homogeneity of mean monthly maximum temperature $(TMax)$, mean monthly minimum temperature $(TMin)$, annual average of maximum temperature $(ATMax)$, annual average of minimum temperature $(ATMin)$, seasonal average of maximum temperature $(STMax)$, seasonal average of minimum temperature $(STMin)$ and annual average of rainfall of 13 observatories were tested separately.

The variation of mean monthly maximum temperature ($TMax$) have been estimated by the above stated method. The results of each time series for their homogeneity were analyzed for a significance level of 0.05 and the inhomogeneities were identified. Based on the cumulative deviation test, the high values of Q are an indication for non –homogeneity in the considered time series. Critical values of Q for some specified values of n are given by *Buishand* (1982), which are based on the synthetic sequences of Gaussian random numbers. Critical values for the test statistic can be found in Table: 14.

Table: 14: The 1% and 5% critical values for the $Q/\sqrt{n^2}$ statistic of the Cumulative Deviations test as a function of n (*Buishand 1982*)

	Number of records in the time series (n)						
n	10	20	30	40	50	100	110
1%	1.29	1.42	1.46	1.5	1.52	1.55	
5%	1.14	1.22	1.24	1.26	1.27	1.29	1.36

3.1 Rank-Wise Sensitive Shift Detection and Adjusted Partial Sums Estimation :

Another important homogeneity test is Adjusted Partial Sums Estimation. It takes account the position of each station wise change-point to reduce the effect of unequal sample sizes (*Kang and Yusof, 2012*). This method is popularly known as Buishand Range Test (BRT). *Wijngaad et al. (2003)* also employed this non-parametric method to estimate the unequal distribution of sample mean over European temperature time series. In order to evaluate the effect of homogeneity, stations with missing values are also selected by this method. This test is based on the ranks of the elements of a series. It is more sensitive to detect the significant breaks near the middle of a time series. The shifts in the mean value usually give rise to high values of the range. The critical value for this test is found in Table-15.

In this test, the adjusted partial sum is defined as:

$$S_0^* = 0 \qquad S_y^* = \sum_{i=1}^{y}(y_i - \bar{y}) \qquad y = 1,2,\ldots\ldots,n \ldots\ldots\ldots(3.5)$$

When the series is homogeneous, then the value of S_y^* will rise and fall around zero. The year y has break when S_y^* has reached a maximum (negative shift) or minimum (positive shift) near the year of observation. The significance of the test can be tested with the "Rescaled adjusted range" (R). The equation is as follows:

$$R = \frac{(\max\limits_{0\le y\le n} S_y^* - \min\limits_{0\le y\le n} S_y^*)}{s} \quad \text{..........................} \ (3.6)$$

Table: 15: The 1% and 5% critical values for the $R/\sqrt{n^2}$ statistic of the Buishand Range Test (BRT) as a function of n (*Buishand 1982*)

Number of records in the time series (n)

n	10	20	30	40	50	100	∞
1%	1.38	1.6	1.7	1.74	1.78	1.86	2.0
5%	1.28	1.43	1.5	1.53	1.55	1.62	1.75

3.2 Occurrence of Single Abrupt Change Detection :

Another homogeneity test we has been applied for the considered data series to determine the occurrence of single abrupt change. This test is commonly known as Pettitt Test. In 1979 it was introduced by the Pettitt (*Pettitt, A.N., 1979*). In this test the null hypothesis (H0): The Y variables follow one or more distributions that have the same location parameter (no change), against the alternative hypothesis (HI): a change point exists. This test is useful for evaluating the occurrence of single abrupt changes in climatic records (*Sneyers 1990; Tarhule and Woo 1998; Smadi and Zghoul 2006*). One of the reasons for using this test is that it is more sensitive to detect significant breaks in the middle also of the time series (*Wijngaard et al. 2003*). The statistics used for the Pettitt's test has been explained by *Kang and Yusof (2012)*; *Dhorde and Zarenistanak (2013)* and many others for detecting abrupt change in time series data. The critical value for this test follows in Table-16.

This test is based on the rank, r_i of the y_i and ignores the normality of the series:

$$X_y = 2\sum_{i=1}^{y} r_i - y(n+1) \qquad y = 1,2,\ldots\ldots..,n.$$

$$X_k = \max_{1\le y\le n}|X_y| \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.7)$$

Table: 16: The 1% and 5% critical values for the Pettitt Test statistic (*Prttitt, 1979*).

Number of records in the time series (n)

n	20	30	40	50	70	100	∞
1%	71	133	208	293	488	841	
5%	57	107	167	235	393	677	830

3.3 Detection of Randomness of Time Series :

The considered time series are sometimes assumed that it is not identical as normal distribution. So, non- location specific tests are earnestly needed to identify the randomness of the series. The ratio of the mean square of successive differences to the variance can easily identifying the randomness of the time series. In this work I have applied following method to reveal the randomness (*Von-Neumann J. 1941*). In this test, the ratio of mean of square successive (year to year) differences to the variance have been calculated. The test statistic is expressed as follows:

$$N = \frac{\sum_{i=1}^{n-1}(y_i - y_{i+1})^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.8)$$

According to this formula the sample or series is homogeneous, than the expected value $E(N) = 2$. When the sample has a break, then the value of N must be lower than 2, otherwise we can imply that the sample has rapid variation in the mean. The results of the test values have been compared with critical value Table-17.

Table-17. 1% and 5% critical value for n of the Von-Neumann Ratio Test.

	Number of records in the time series (n)					
n	10	20	30	50	100	110+
1%	0.72	1.03	1.19	1.36	1.54	5.56
5%	1.04	0.29	1.41	1.54	1.67	1.68

3.4 Result and Discussion :

The variability of mean monthly maximum temperature ($TMax$) mean monthly minimum temperature ($TMin$) and mean monthly rainfall have been estimated by the above stated cumulative deviation method. The data series of each station contains monthly, annual and seasonal average. The results of each time series for their homogeneity were analyzed at a significance level of α = 0.05 and the inhomogeneities were identified. Based on the cumulative deviation test, the high value of Q is an indication for non–homogeneity in the considered time series. Critical values of Q for some specified values of n are given by *Buishand (1982)*, which are based on the synthetic sequences of Gaussian random numbers. Critical values for the test statistic is shown in Table: 14. Every possible outcome of breaks has been compared at 95% confidence level. The cumulative deviation test statistic for the 6 month $TMax$ series has detected inhomogeneity for Bankura weather observatory. The mean monthly series ($TMax$) of February, May, August, October, November and December indicates high calculated values of Q as 1.85, 1.60, 2.026, 2.016, 2.925 and 2.618 respectively. All the above mentioned $TMax$ series rejects the null hypothesis at significance level of 0.05. The maximum deviation value have been detected for Post- monsoon and Winter months. All these results of cumulative deviation are shown in Table: 18. The month of January, March, April June, July and September has indicated break points, but the calculated values are not significant at considered significance level. The values of those months are 1.111, 0.735, 0.572, 0.513, 1.328 and 1.336, respectively. The significant breaks of this time series are found in 1946 (February), 1971 (May), 1972 (August), 1972 (October), 1957 (November) and 1952 (December).

The high temporal variability of mean maximum temperature ($TMax$) of November and December is most significant for all the considered observatories. The annual average temperature is another parameter for this analysis. Moreover, the significant breaks are identified either during 40s and 50s decades or in the last decade. Among them 8 mean annual maximum ($ATMax$) time series for the stations Bankura, Birbhum, Burdwan, Howrah, Kolkata, Malda, Midnapore and Purulia show significant break points between 1939 and 1952. The significant break points of those stations occurs in 1952, 1939, 1947, 1947, 1947, 1946, 1947 and 1947, respectively. On the other hand Hooghly, Murshidabad, Nadia, North 24 Pargana and South 24 Pargana are indicating significant break points in 2003. The calculated values $Q/\sqrt{n^2}$ for these observatories are 1.789, 1.656, 1.663, 1.663 and 2.788, respectively. Figure -10 shows the station wise graphical construction of the residual mass curves for annual average temperature time series.

Table: 18: Results of the Cumulative Deviation Test of Mean Monthly Maximum ($TMax$) Temperature Series.

Station & Break Years	Test $Q/\sqrt{n^2}$	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura		1.11	**1.85**	0.73	0.56	**1.60**	0.51	1.33	**2.03**	1.34	**2.02**	**2.93**	**2.62**
Year		1946	**1946**	2004	1953	**1971**	1968	1982	**1972**	1980	**1972**	**1957**	**1952**
Birbhum		1.08	**1.69**	**1.42**	1.22	**1.66**	0.65	1.24	**2.43**	1.15	0.65	**2.86**	**2.57**
Year		2003	**1946**	**1978**	1971	**1973**	1920	1982	**1972**	1980	1951	**1957**	**1940**
Burdwan		1.01	**1.79**	1.20	1.18	**1.71**	0.62	1.0	**2.25**	1.19	1.5	**3.01**	**2.49**
Year		1977	**1946**	1978	1971	**1971**	1920	1980	**1972**	1980	1957	**1957**	**1951**
Hooghly		**1.36**	**1.52**	**1.50**	1.28	**1.69**	1.10	1.28	0.92	**1.80**	**1.45**	**1.87**	**2.10**
Year		**1997**	**1946**	**1978**	1971	**1971**	2000	1997	2003	**2003**	**2003**	**1946**	**1941**
Howrah		0.89	**1.54**	1.21	**1.48**	**1.90**	0.80	0.54	1.12	0.67	**1.78**	**2.65**	**2.50**
Year		2007	**1946**	1978	**1971**	**1971**	1968	2005	1945	1948	**1975**	**1957**	**1951**
Kolkata		1.05	**1.99**	0.91	0.66	1.08	0.65	1.10	**1.96**	**1.51**	**1.78**	**3.10**	**2.48**
Year		1947	**1946**	1932	1971	1971	1940	1982	**1985**	**1951**	**1975**	**1957**	**1951**
Malda		**1.39**	**1.82**	1.01	1.19	**1.36**	0.79	1.06	**2.58**	**1.55**	**1.68**	**2.86**	**2.23**
Year		**2003**	**1946**	1978	1977	**1973**	1923	1982	**1972**	**1988**	**1972**	**1979**	**1943**
Midnapore		0.86	**2.07**	0.95	0.58	1.23	0.60	1.35	**1.99**	**1.46**	**1.73**	**2.83**	**2.63**
Year		1947	**1946**	1928	1999	1971	1923	1982	**1986**	**1951**	**1974**	**1957**	**1951**
Murshidabad		**1.66**	1.30	1.28	1.33	**1.75**	0.92	0.63	**1.72**	1.04	1.19	**2.30**	**2.39**
Year		**2003**	1946	1978	1971	**1973**	2000	1925	**1972**	2003	1951	**1957**	**1951**
Nadia		**1.70**	1.35	1.33	1.25	**1.64**	0.73	1.15	1.15	**1.46**	**1.43**	**2.69**	**2.26**
Year		**2003**	1946	1978	1977	**1973**	2006	2006	1951	**2006**	**2003**	**1957**	**1951**
N.24 Pgs		**1.70**	1.35	1.33	1.25	**1.62**	0.73	1.15	1.15	**1.46**	**1.43**	**2.69**	**2.26**
Year		**2003**	1946	1978	1977	**1973**	2006	2006	1951	**2006**	**2003**	**1957**	**1951**
Purulia		**1.70**	**2.02**	0.97	1.23	**2.21**	1.21	1.15	**2.01**	1.41	**2.30**	**2.78**	**2.50**
Year		**2002**	**1946**	1978	1976	**1976**	1977	2002	**1972**	1980	**1987**	**1962**	**1951**
S. 24 Pgs		**2.47**	**2.52**	**2.56**	**2.43**	**2.36**	**2.68**	**2.76**	**2.73**	**2.68**	**2.67**	**2.68**	**2.64**
Year		**2002**	**2001**	**2002**	**1999**	**2003**	**2003**	**2003**	**2003**	**2001**	**2003**	**2000**	**2002**

*Bold values of $Q/\sqrt{n^2}$ are significant at 0.05% significance level.

* Bold years are significant break year. $Q/\sqrt{n^2}$

Figure: 10. The plots of Residual Mass Curves of Mean Annual ($ATMax$) Maximum Temperature Series for 13 observatories.

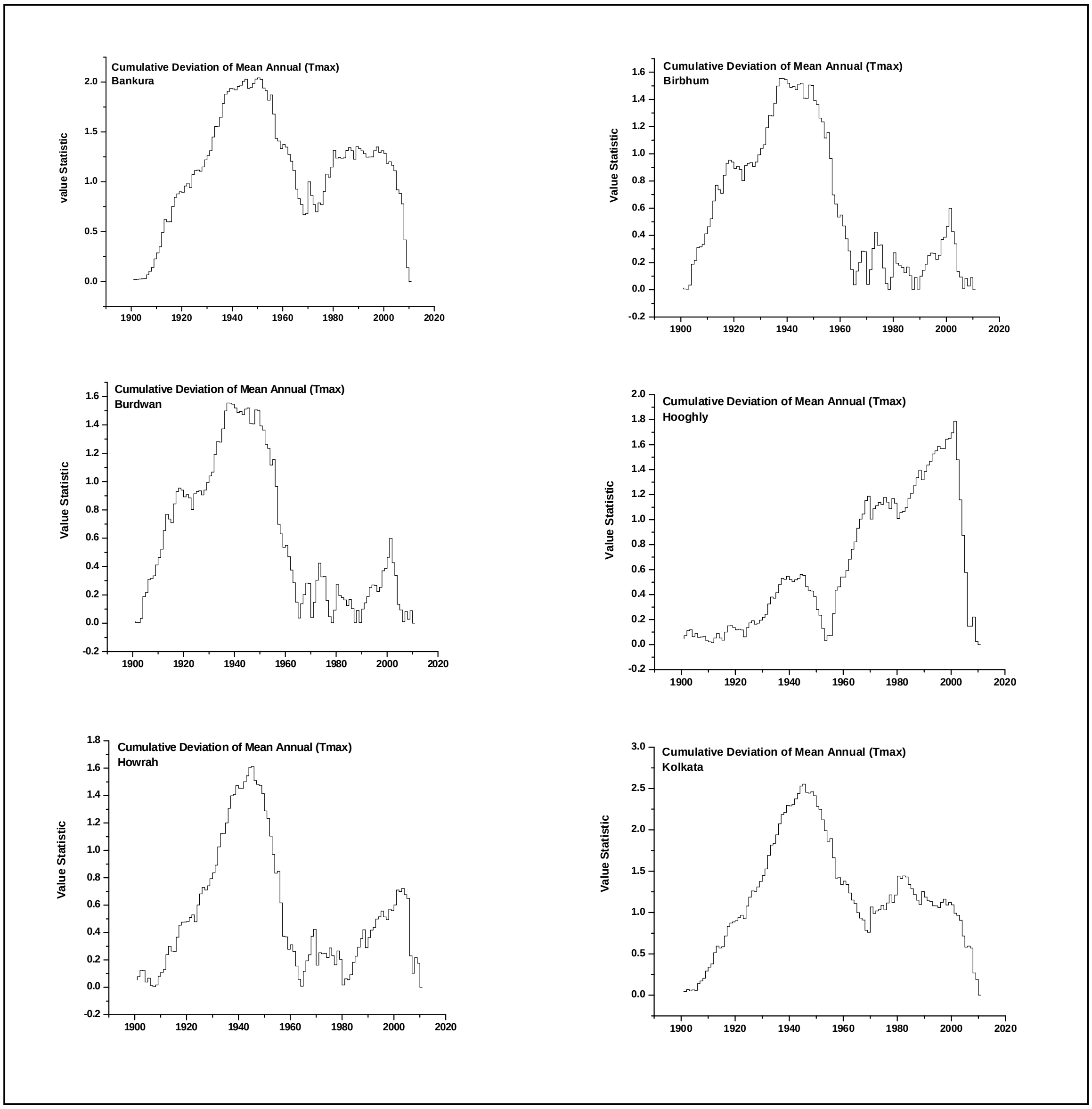
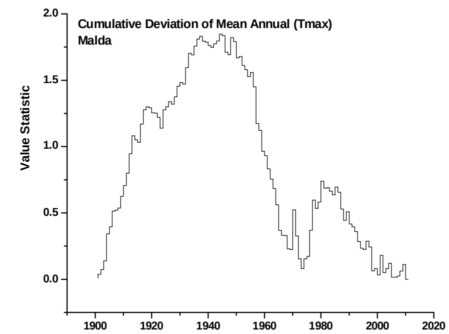
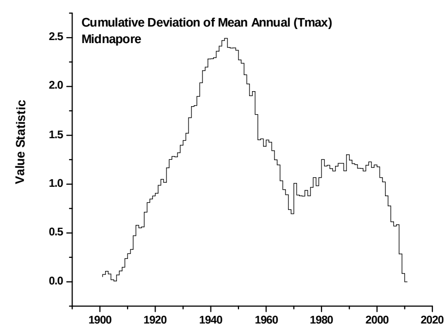
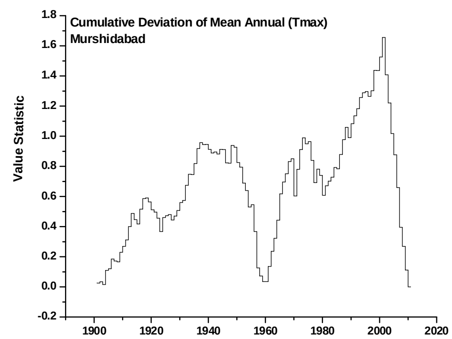
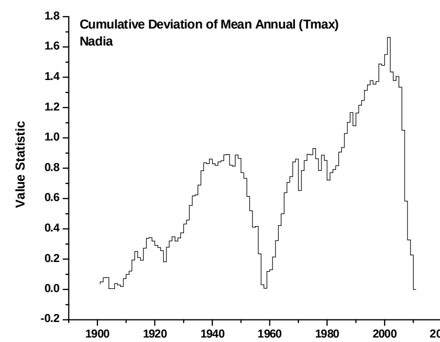


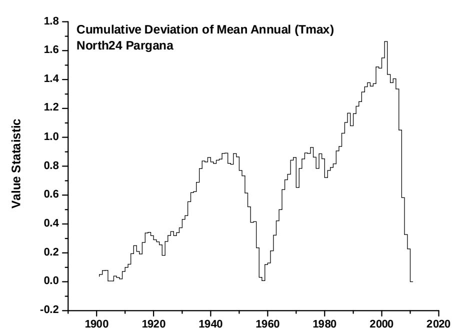
Figure Cont….

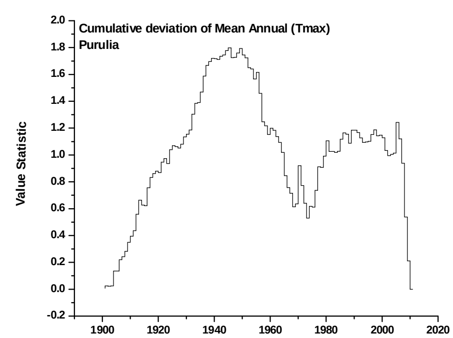

Cumulative Deviation of Mean Annual (Tmax)
Malda
Value Statistic


Cumulative Deviation of Mean Annual (Tmax)
Midnapore
Value Statistic


Cumulative Deviation of Mean Annual (Tmax)
Murshidabad
Value Statistic


Cumulative Deviation of Mean Annual (Tmax)
Nadia
Value Statistic


Cumulative Deviation of Mean Annual (Tmax)
North24 Pargana
Value Stataistic


Cumulative deviation of Mean Annual (Tmax)
Purulia
Value Statistic

In respect of the seasonal time series, the winter, monsoon and post-monsoon are indicating significant cumulative deviation values of potential break for the Bankura observatory (Table-19). The calculated values are 2.213, 1.870 and 2.771 respectively. In contrast to the other observatories there are some significant changes points for Bankura. The common significant year of change are found in 1941 to 1946 and 1971 to 1976 respectively. Winter and Post-Monsoon are more sensitive in this regard. On the other hand, the $TMin$ series has revealed almost similar results like $TMax$ series (Table-20). The month of February, May, September, October, November and December are indicating significant cumulative deviation values for the Bankura observatory. These are 2.10, 1.40, 1.42, 1.65, 2.92 and 2.08, respectively at 0.05% level of significance. The significant breaks for this observatory are 1975 (February), May (1969), September (1980), October (1975), November (1975) and December (1976). The time series for Birbhum also indicates inhomogeneity and the months of February, May, July, August, September, October, November and December indicate significant break points. Similar results have been found for the observatories like Burdwan, Hooghly, Murshidabad, Nadia and for Purulia. The concentration of the significant change points in Mean Annual Minimum Temperature time series is found during the period from ($ATMin$) 1971 to 1990 (Table-21). Cumulative Deviation tests for Bankura, Birbhum, Burdwan, Howrah, Kolkata, Malda, Midnapore, Nadia, North 24 Pargana and South 24 Pargana time series indicates significant change points at the 0.05% level of significance. Only for three observatories like Hooghly, Murshidabad and Purulia time series the test value remains below the critical limit. It is interesting that, the post-monsoon mean seasonal minimum ($STMin$) temperature time series indicates over all significant change at 0.05% level of significance.

Table: 19: Results of the Cumulative Deviation Test of Seasonal Maximum ($STMax$) Temperature Series.

Observatories	Test	Winter	Year	Summer	Year	Monsoon	Year	Post-Monsoon	Year
Bankura	Cumulative Deviation Test	2.21*	1946	1.22	1971	1.87*	1982	2.77*	1957
Birbhum		1.99*	1941	1.53*	1976	1.91*	1972	1.96*	1957
Burdwan		2.09*	1946	1.46*	1976	1.74*	1982	2.74*	1957
Hooghly		1.31	2003	1.59*	1971	1.70*	2003	1.32	2003
Howrah		2.15*	1946	1.79*	1971	0.95	1947	2.58*	1957
Kolkata		2.41*	1946	0.88	1971	2.01*	1982	2.85*	1957
Malda		1.83*	1946	1.29	1976	1.96*	1972	2.65*	1979
Midnapore		2.59*	1946	0.83	1971	2.01*	1982	2.69*	1957
Murshidabad		1.42*	1941	1.67*	1976	1.19	2003	2.04*	1951
Nadia		1.30	2003	1.47*	1976	1.50*	2006	1.86*	1951
North 24 Pargana		1.30	2003	1.47*	1976	1.50*	2006	1.86*	1951
Purulia		2.37*	1946	1.94*	1976	1.65*	2000	2.69*	1976
South 24 Pargana		2.75*	2002	2.60*	2003	2.78*	2003	2.71*	2003

*Values and corresponding years are Significant at 0.05% level of significance.

Table: 20: Results of the Cumulative Deviation Test of Mean Minimum ($TMin$) Temperature Series.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	$Q/\sqrt{n^2}$	0.91	**2.10**	1.08	0.72	**1.40**	0.92	1.12	**1.38**	**1.42**	**1.65**	**2.92**	**2.08**
Year		1938	**1975**	1983	1999	**1969**	1923	2010	**1988**	**1980**	**1975**	**1975**	**1976**
Birbhum	$Q/\sqrt{n^2}$	1.01	**2.18**	0.92	0.47	**1.42**	1.19	**2.35**	**2.16**	**1.51**	**1.74**	**3.01**	**2.69**
Year		1938	**1975**	1988	1984	**1969**	1922	**1976**	**1976**	**1980**	**1975**	**1975**	**1978**
Burdwan	$Q/\sqrt{n^2}$	0.94	**2.37**	1.01	0.52	**1.51**	1.09	**1.89**	**1.83**	**1.77**	**1.86**	**2.95**	**1.86**
Year		1938	**1975**	1983	1998	**1969**	1923	**1976**	**1977**	**1980**	**1974**	**1975**	**1978**
Hooghly	$Q/\sqrt{n^2}$	0.95	**1.73**	0.65	0.56	**1.54**	1.15	0.88	1.35	0.94	0.99	**2.43**	0.95
Year		2003	**1975**	1928	1967	**1969**	1966	2007	1987	1980	1930	**1974**	1931
Howrah	$Q/\sqrt{n^2}$	0.99	1.03	1.05	1.24	**1.84**	**1.60**	**1.67**	**1.61**	**1.72**	1.06	**2.01**	**1.59**
Year		2003	1946	2003	2003	**1971**	**1966**	**2007**	**2007**	**2007**	2007	**1972**	**1931**
Kolkata	$Q/\sqrt{n^2}$	0.82	**2.01**	**1.42**	0.99	0.93	1.05	**1.87**	**2.31**	**1.70**	**1.41**	**2.08**	**1.96**
Year		1938	**1980**	**1983**	1998	1969	1923	**1982**	**1987**	**1982**	**1974**	**1972**	**1931**
Malda	$Q/\sqrt{n^2}$	**1.99**	**2.83**	**2.02**	**1.42**	**1.14**	**1.43**	**2.24**	**2.35**	**2.18**	**2.57**	**3.22**	**3.15**
Year		**1979**	**1975**	**1985**	**1999**	**1994**	**1923**	**1993**	**1988**	**1987**	**1974**	**1975**	**1978**
Midnapore	$Q/\sqrt{n^2}$	0.95	**2.25**	**1.52**	1.05	1.09	1.03	**2.19**	**2.60**	**2.49**	**1.82**	**2.82**	**2.22**
Year		1938	**1963**	**1991**	1998	1969	1923	**1991**	**1988**	**1987**	**1988**	**1976**	**1939**
Murshidabad	$Q/\sqrt{n^2}$	1.25	**2.37**	**1.53**	0.82	1.10	1.23	**2.06**	**1.88**	**1.84**	1.05	**3.06**	**2.75**
Year		1979	**1975**	**1983**	1984	1969	1920	**1976**	**1977**	**1975**	1987	**1975**	**1978**
Nadia	$Q/\sqrt{n^2}$	0.64	**1.86**	0.85	0.62	1.10	1.05	**1.64**	**2.02**	0.77	1.34	**2.75**	**2.17**
Year		2006	**1975**	1938	1984	1971	1923	**1976**	**1977**	2007	1974	**1974**	**1978**
N.24 Pgs	$Q/\sqrt{n^2}$	1.20	**1.55**	1.15	1.21	0.75	1.30	**2.60**	**2.84**	**2.20**	**1.47**	**2.53**	**1.60**
Year		2003	**1963**	1976	1998	1994	1997	**1991**	**1987**	**1987**	**1971**	**1972**	**1931**
Purulia	$Q/\sqrt{n^2}$	**1.72**	**1.96**	**1.43**	0.69	**1.84**	1.15	0.66	0.63	0.56	**1.61**	**2.62**	**2.01**
Year		**2003**	**1989**	**2004**	1999	**1969**	1968	1976	1988	1980	**1988**	**1975**	**1978**
S. 24 Pgs	$Q/\sqrt{n^2}$	1.22	**2.09**	**1.71**	**1.82**	**1.83**	**2.17**	**2.12**	**2.39**	**2.55**	**2.48**	**2.98**	**2.41**
Year		1999	**1988**	**2005**	**2005**	**2005**	**2005**	**2005**	**2004**	**1998**	**1998**	**1976**	**1985**

Bold values and corresponding years are Significant at 0.05% level of significance.

Table-21: Results of Cumulative Deviation Test of Mean Annual Minimum ($ATMin$) Temperature Series for 13observatories.
Bold value statistic and corresponding years are significant at 0.05% level of significance.

SL No	Name of Observatory	$Q/\sqrt{n^2}$	At 95% significance level	Change Year
1	Bankura	**1.80**	Significant	1976
2	Birbhum	**2.42**	Significant	1975
3	Burdwan	**2.38**	Significant	1976
4	Hooghly	**1.69**	Significant	1931
5	Howrah	**1.71**	Significant	2003
6	Kolkata	**2.43**	Significant	1987
7	Malda	**2.84**	Significant	1987
8	Midnapore	**2.71**	Significant	1988
9	Murshidabad	**2.81**	Significant	1976
10	Nadia	**1.97**	Significant	1976
11	North 24 Pargana	**2.49**	Significant	1987
12	Purulia	**2.04**	Significant	1988
13	South 24 Pargana	**2.44**	Significant	1995

The rainfall series for these observatories are also tested separately to measure the variability. After the inspection of the rainfall series it is clear that, the mean monthly series for Birbhum (February, 1946), Burdwan (August, 1973), Murshidabad (February, 1946 & August, 1973 & December, 1973), Nadia (August, 1974), North 24 Pargana (December, 1973), Purulia (August, 1945) and South 24 Pargana (July, 1976) have significant change points at considered level of significance. The remaining mean monthly rainfall series are homogeneous at the accepted significance level. Over all, the significance of the mean monthly rainfall series are very low. But in regard to this test, annual series for rainfall is very interesting and show opposite behaves to that for the mean monthly maximum temperature series. The results of this test are shown in Table-22 & 23. In general the annual average rainfall series revealed inhomogeneity for all the observatories. It is also found from the Table-22 that the cumulative deviation tests for all stations detects inhomogeneity in the same year (1968). Only the Purulia observatory has indicated a significant change in 1967.

Table-22: Results of Cumulative Deviation Test of Mean Monthly Rainfall Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	$Q/\sqrt{n^2}$	0.74	1.18	0.67	0.61	1.22	0.86	0.61	1.33	1.06	0.80	0.42	1.29
Year		1972	1946	1953	1963	1973	1929	1968	1945	1936	1928	1910	1973
Birbhum	$Q/\sqrt{n^2}$	0.66	1.39	0.58	0.87	1.12	1.05	0.70	**1.56**	0.88	0.72	0.66	1.24
Year		1972	1946	1954	1963	1973	1929	1954	**1973**	1931	1936	1946	1973
Burdwan	$Q/\sqrt{n^2}$	0.63	1.21	0.63	0.68	1.20	0.95	0.52	**1.40**	0.98	0.80	0.65	1.38
Year		1972	1946	1921	1963	1973	1929	1995	**1973**	1931	1936	1946	1973
Hooghly	$Q/\sqrt{n^2}$	0.59	0.99	0.63	0.49	1.02	0.78	0.61	0.92	0.92	0.82	0.47	0.94
Year		1972	1940	1921	1920	1973	1923	1968	1945	1931	1929	1946	1973
Howrah	$Q/\sqrt{n^2}$	0.59	0.86	0.64	0.58	0.99	0.67	1.04	0.73	0.96	0.89	0.57	1.08
Year		1941	1940	1921	1969	1973	1923	1968	1945	1936	1929	1946	1973
Kolkata	$Q/\sqrt{n^2}$	0.49	0.88	0.69	0.72	1.23	0.64	1.15	0.66	1.09	0.96	0.86	0.82
Year		1941	1940	1921	1969	1973	1923	1976	1925	1936	1937	1986	1973
Malda	$Q/\sqrt{n^2}$	0.79	0.87	0.40	0.72	**1.42**	1.29	0.95	1.36	0.69	0.89	0.60	**1.53**
Year		1925	1946	1916	1963	**1973**	1957	1956	1973	1931	1956	1951	**1973**
Midnapore	$Q/\sqrt{n^2}$	0.43	0.81	0.52	0.44	0.95	0.59	0.97	0.82	0.99	0.83	0.46	1.22
Year		1919	1928	1921	1920	1973	1984	1968	1945	1936	1928	1946	1973
Murshidabad	$Q/\sqrt{n^2}$	0.68	**1.43**	0.57	0.82	1.08	0.96	0.86	**1.80**	1.06	0.75	0.82	**1.63**
Year		1921	**1946**	1921	1963	1973	1929	1993	**1973**	1931	1945	2008	**1973**
Nadia	$Q/\sqrt{n^2}$	0.46	1.06	0.61	0.54	0.86	0.82	0.83	**1.53**	1.28	0.85	0.49	1.23
Year		1972	1945	1921	1963	1973	1923	1996	**1974**	1969	1939	1946	1973
N.24 Pgs	$Q/\sqrt{n^2}$	0.55	0.78	0.53	0.52	0.80	0.73	0.93	0.72	1.05	0.83	1.29	**1.41**
Year		1941	1940	1921	1920	1973	1923	1968	2000	1936	1937	1986	**1973**
Purulia	$Q/\sqrt{n^2}$	0.72	1.30	0.82	0.47	0.95	0.90	0.65	**1.46**	0.93	0.80	0.47	1.38
Year		1919	1946	1953	1985	1971	1957	1920	**1945**	1936	1928	1910	1973
S. 24 Pgs	$Q/\sqrt{n^2}$	0.53	0.68	0.61	0.64	1.03	0.80	**1.56**	0.91	1.07	0.96	0.57	1.14
Year		1941	1940	1621	1969	1973	1984	**1976**	1965	1946	1937	1986	1973

Table-23: Result of Cumulative Deviation Test of Annual Rainfall Series for 13 observatories. * values are significant.

Result of Cumulative Deviation of Annual Rainfall Series

Sl No	Observatory	$Q/\sqrt{n^2}$	Change Year
1	**Bankura**	3.40*	1968
2	**Birbhum**	3.69*	1968
3	**Burdwan**	3.90*	1968
4	**Hooghly**	3.93*	1968
5	**Howrah**	4.00*	1968
6	**Kolkata**	4.04*	1968
7	**Malda**	3.72*	1968
8	**Midnapore**	3.98*	1968
9	**Murshidabad**	3.81*	1968
10	**Nadia**	4.03*	1968
11	**North 24 Pargana**	4.01*	1968
12	**Purulia**	3.87*	1967
13	**South 24 Pargana**	4.07*	1968

* **Values are significant at $\rho = 0.05$ level of significance**

Rank wise variability identification is one of the most important techniques for determination of homogeneity of time series. The results of this analysis are obtained followed equation- 3.1 and maximum (negative) and minimum (positive) shift near the possible breaks has been rescaled according to equation-3.3. The test statistic is compared with the value at 0.05% level of significance as a function of n (Table-15). Month-wise temporal time series of mean monthly maximum ($TMax$) temperature has been used for this test. The station Bankura indicates that, only six monthly series are statistically significant at chosen level of significance ($\alpha = 0.05$) (Table-24).

In the Indian context, Post-monsoon seasonal months are October, November and December are significant. The test statistic values for $TMax$ time series of these months are 2.12, 2.92 and 2.61, respectively. Besides these months, the other three series for the months such as February, May and August indicate significant change points. The test statistic values of these months are 1.85(1946), 1.94(1971) and 2.48(1972) respectively. The seven significant change points have been estimated for the station Birbhum at chosen significance level. The significant test statistic values and their corresponding years of change points in respective months are January 2.06(2003), February 2.00(1946), March 1.96(1978), May 1.84(1973), August 2.59(1972), November 2.86(1957) and December 2.57(1940) for the relevant $TMax$ series. The time series for Burdwan shows significant change points, and there test statistic values and corresponding years are January 1.97(1977), February 1.90(1946), March 1.79(1978), May 1.88(1971), August 2.45(1972), November 3.01(1957) and December 2.49(1951). The $TMax$ series for Hooghly indicates almost similar significant change points. This series estimates six significant changes in a 12 month section. Moreover, January, February, March, September, November and December are indicating statistically significant changes. The value of test statistic and corresponding years are 1.73(1997), 2.05(1946), 1.78(1978), 1.86(2003), 2.79(1946) and 2.22(1941). The station Howrah has confirmed five significant change points over the months of February, March, September, November and in December. The time series for Kolkata station similarly presents five significant changes over the month of February, August, October, November and December.

According to this method, the test statistic values of those months are 1.99(1946), 2.29(1985), 1.96(1975), 3.10(1957) and 2.48(1951), respectively. In terms of geographical situation of the considered observatories, Malda is the northern most station in the study area. Following this test, Malda indicates six significant change points altogether within the 12 month yearly span. The month of January, February, August, October, November and December here indicates significant change points at 0.05% level of significance. The significant change for Mindapore station indicates six significant changes over the months of February, July August, October, and November and December. The test statistic values and corresponding years are 2.07(1976), 1.85(1982), 2.37(1986), 1.96(1974), 2.83(1957) and 2.63(1951), respectively. On the other hand Murshidabad, Nadia and North 24 Pargana indicate similar significant changes. Consequently, 1971 and 1976 are similarly important for the Summer season in which most of the significant change points could be identified. In the same way, year 1972 and 1982 are most important for the Monsoon period. The mean monthly maximum temperature time series of February for all stations presents inhomogeneity. The test statistics are indicating significant breaks. It is to be noted that, the rank wise mean variability is more sensitive for those observatories. Rank wise successive mean difference and adjusted partial sums strongly indicate the variability of the monthly series for these stations.

Table-24: Results of Buishand Range Test (BRT) of Mean Monthly Maximum ($TMax$) Temperature Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	$R/\sqrt{n^2}$	1.63	**1.85**	1.43	1.11	**1.94**	1.01	1.67	**2.48**	1.67	**2.12**	**2.92**	**2.61**
Year		1946	**1946**	2004	1953	**1971**	1968	1982	**1972**	1980	**1972**	**1957**	**1952**
Birbhum	$R/\sqrt{n^2}$	**2.09**	**2.00**	**1.96**	1.33	**1.84**	1.01	1.67	**2.59**	1.28	1.27	**2.86**	**2.57**
Year		**2003**	**1946**	**1978**	1971	**1973**	1920	1982	**1972**	1980	1951	**1957**	**1940**
Burdwan	$R/\sqrt{n^2}$	**1.97**	**1.90**	**1.79**	1.32	**1.88**	0.94	1.52	**2.49**	1.50	1.65	**3.01**	**2.49**
Year		**1977**	**1946**	**1978**	1971	**1971**	1920	1980	**1972**	1980	1957	**1957**	**1951**
Hooghly	$R/\sqrt{n^2}$	**1.75**	**2.05**	**1.78**	1.34	1.74	1.40	1.28	1.56	**1.86**	1.72	**2.79**	**2.22**
Year		**1997**	**1946**	**1978**	1971	1971	2000	1997	2003	**2003**	2003	**1946**	**1941**
Howrah	$R/\sqrt{n^2}$	1.66	**1.94**	1.69	1.51	**1.94**	1.17	1.04	1.55	1.25	**1.94**	**2.65**	**2.50**
Year		2007	**1946**	1978	1971	**1971**	1968	2005	1945	1948	**1975**	**1957**	**1951**
Kolkata	$R/\sqrt{n^2}$	1.43	**1.99**	1.22	1.20	1.54	1.03	1.53	**2.29**	1.67	**1.96**	**3.10**	**2.48**
Year		1947	**1946**	1932	1971	1971	1940	1982	**1985**	1951	**1975**	**1957**	**1951**
Malda	$R/\sqrt{n^2}$	**2.03**	**1.92**	1.72	1.50	1.68	0.91	1.50	**2.63**	1.55	**1.76**	**2.86**	**2.49**
Year		**2003**	**1946**	1978	1977	1973	1923	1982	**1972**	1988	**1972**	**1979**	**1943**
Midnapore	$R/\sqrt{n^2}$	1.63	**2.07**	1.22	1.09	1.68	0.96	**1.85**	**2.37**	1.69	**1.96**	**2.83**	**2.63**
Year		1947	**1946**	1928	1999	1971	1923	**1982**	**1986**	1951	**1974**	**1957**	**1951**
Murshidabad	$R/\sqrt{n^2}$	**2.06**	**2.00**	**1.79**	1.45	0.86	1.44	0.98	**2.09**	1.04	**2.16**	**2.84**	**2.49**
Year		**2003**	**1946**	**1978**	1971	1973	2000	1925	**1972**	2003	**1951**	**1957**	**1951**
Nadia	$R/\sqrt{n^2}$	**2.06**	**2.00**	**1.75**	1.34	1.71	1.19	1.19	**2.00**	1.50	**2.00**	**2.94**	**2.69**
Year		**2003**	**1946**	**1978**	1977	1973	2006	2006	**1951**	2006	**2003**	**1957**	**1951**
N.24 Pgs	$R/\sqrt{n^2}$	**2.06**	**2.00**	**1.75**	1.34	1.71	1.19	1.19	**2.00**	1.50	**2.00**	**2.90**	**2.69**
Year		**2003**	**1946**	**1978**	1977	1973	2006	2006	**1951**	2006	**2003**	**1957**	**1951**
Purulia	$R/\sqrt{n^2}$	1.70	**2.02**	1.68	1.67	**2.21**	1.46	1.40	**2.13**	1.50	**2.35**	**2.78**	**2.50**
Year		2002	**1946**	1978	1976	**1976**	1977	2002	**1972**	1980	**1987**	**1962**	**1951**
S. 24 Pgs	$R/\sqrt{n^2}$	**2.47**	**2.52**	**2.56**	**2.45**	**2.36**	2.66	**2.76**	**2.73**	**2.67**	**2.67**	**2.68**	**2.64**
Year		**2002**	**2001**	**2002**	**1999**	**2003**	2003	**2003**	**2003**	**2001**	**2003**	**2000**	**2002**

The sensitive variability of mean annual maximum and seasonal maximum temperature has been estimated through the Buishand Range Test. The results are shown in Table-25 & 26. In case of the mean annual temperature, the test statistics are significant for all the considered time series. According to the internal properties of the Buishand Range Test, the significant change points are found to be concentrated during 1941 - 1950 and 2001- 2011 temporal blocks. Most of the significant changes are found in 1940s to 1950s. According to the Buishand Range Test, the seasonal series also involve significant break or change points. Shift in the mean of the considered time series are highly significant in Majority of cases. Most of the time series reveal significant changes or breaks when examined by this non-parametric test.

The time series for Hooghly (Summer), Howrah series (Monsoon), Kolkata (Summer), Midnapore (Summer), Nadia (Summer) and North 24 Pargana (Summer) show insignificant changes at 0.05% level. The values of test statistic for those series remains below the critical limit. Moreover, the winter series of those 13 stations indicates seven significant changes in the year of 1946. So it should be stated that, this remarkable year may be a static point for non-climatic change. On the other hand, 1971 and 1976 are similarly important for the Summer season. In the same way year 1972 and 1982 are most important for monsoon time series.

Table-25: Results of Buishand Range Test (BRT) of Mean Annual Maximum ($ATMax$) Temperature Series for 13 observatories.

Bold value statistic and corresponding years are significant at 0.05% level of significance.

SL No	Name of Observatory	$R/\sqrt{n^2}$	At 0.05% significance level	Change Year
1	Bankura	**2.07**	Significant	**1952**
2	Birbhum	**2.15**	Significant	**1939**
3	Burdwan	**2.05**	Significant	**1947**
4	Hooghly	**2.35**	Significant	**2003**
5	Howrah	**2.33**	Significant	**1947**
6	Kolkata	**2.62**	Significant	**1947**
7	Malda	**2.02**	Significant	**1946**
8	Midnapore	**2.60**	Significant	**1947**
9	Murshidabad	**2.61**	Significant	**2003**
10	Nadia	**2.55**	Significant	**2003**
11	North 24 Pargana	**2.55**	Significant	**2003**
12	Purulia	**1.82**	Significant	**1947**
13	South 24 Pargana	**2.78**	Significant	**2003**

Table-26: Results of Buishand Range Test (BRT) of Seasonal Maximum ($STMax$) Temperature Series for 13 observatories.
Bold value statistic and corresponding years are significant at 0.05% level of significance.

Station	Test (BRT)	Winter	Summer	Monsoon	Post-Monsoon
Bankura	$R/\sqrt{n^2}$	**2.24**	**1.87**	**2.19**	**2.79**
Break Year		**1946**	**1971**	**1982**	**1957**
Birbhum	$R/\sqrt{n^2}$	**2.63**	**1.93**	**2.15**	**2.05**
Break Year		**1941**	**1976**	**1972**	**1957**
Burdwan	$R/\sqrt{n^2}$	**2.09**	**1.88**	**2.04**	**2.77**
Break Year		**1946**	**1976**	**1982**	**1957**
Hooghly	$R/\sqrt{n^2}$	**2.56**	1.68	**1.77**	**2.56**
Break Year		**2003**	1971	**2003**	**2003**
Howrah	$R/\sqrt{n^2}$	**2.64**	**1.93**	1.43	**2.50**
Break Year		**1946**	**1971**	1947	**1957**
Kolkata	$R/\sqrt{n^2}$	**2.41**	1.48	**2.36**	**2.87**
Break Year		**1946**	1971	**1982**	**1957**
Malda	$R/\sqrt{n^2}$	**2.52**	**1.90**	**1.98**	**2.60**
Break Year		**1946**	**1976**	**1972**	**1979**
Midnapore	$R/\sqrt{n^2}$	**2.59**	1.44	**2.42**	**2.72**
Break Year		**1946**	1971	**1982**	**1957**
Murshidabad	$R/\sqrt{n^2}$	**2.61**	**1.97**	**1.93**	**2.86**
Break Year		**1941**	**1976**	**2003**	**1951**
Nadia	$R/\sqrt{n^2}$	**2.56**	1.71	**1.93**	**2.83**
Break Year		**2003**	1976	**2006**	**1851**
North 24 Pargana	$R/\sqrt{n^2}$	**2.56**	1.71	**1.93**	**2.83**
Break Year		**2003**	1976	**2006**	**1951**
Purulia	$R/\sqrt{n^2}$	**2.37**	**1.98**	**1.77**	**2.69**
Break Year		**1946**	**1976**	**2000**	**1976**
South 24 Pargana	$R/\sqrt{n^2}$	**2.75**	**2.61**	**2.78**	**2.71**
Break Year		**2002**	**2003**	**2003**	**2003**

The mean monthly minimum temperature **($TMin$)** series revealed the interesting results. The results of this calculation is shown in Table-27. The considered series for January is insignificant except for Kolkata, Malda and Purulia observatories.

The significant test statistic values and change points for the stations are 1.75 (1938, Kolkata), 1.99 (1979, Malda) and 1.90 (2003, Purulia). The mean monthly minimum time series of February for all stations presents inhomogeneity. Similarly, the month of November and December indicates significant breaks for all the stations. On the other hand the significant change points in mean monthly minimum ($TMin$) series for May, June, July, August, September and October occurred randomly over the period. Moreover, the time series for Burdwan and South 24 Pargana are very sensitive to their significant breaks.

Table-27: Results of Buishand Range Test (BRT) of Mean Monthly Minimum ($TMin$) Temperature Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	$R/\sqrt{n^2}$	1.46	**2.35**	1.21	1.03	**2.01**	1.69	1.12	**2.08**	**2.01**	**1.93**	**2.92**	**2.59**
Year		1938	**1975**	1983	1999	**1969**	1923	2010	**1988**	**1980**	**1975**	**1975**	**1976**
Birbhum	$R/\sqrt{n^2}$	1.45	**2.31**	0.98	0.72	**2.06**	**1.75**	**2.48**	**2.20**	1.53	**1.81**	**3.01**	**2.69**
Year		1938	**1975**	1938	1984	**1969**	**1923**	**1976**	**1976**	1980	**1975**	**1975**	**1978**
Burdwan	$R/\sqrt{n^2}$	1.39	**2.37**	1.09	0.75	**2.08**	**1.95**	**2.04**	**1.90**	**1.77**	**1.93**	**2.95**	**2.29**
Year		1938	**1975**	1983	1998	**1969**	**1923**	**1976**	**1977**	**1980**	**1974**	**1975**	**1978**
Hooghly	$R/\sqrt{n^2}$	1.49	**1.96**	1.06	0.94	**2.01**	**2.05**	1.44	**1.86**	1.36	1.33	**2.43**	**2.44**
Year		2003	**1975**	1928	1967	**1969**	**1966**	2007	**1987**	1980	1930	**1974**	**1931**
Howrah	$R/\sqrt{n^2}$	1.30	**1.90**	1.53	1.31	**2.06**	**2.06**	1.67	**1.83**	**1.84**	1.67	**2.35**	**2.23**
Year		2003	**1946**	2003	2003	**1971**	**1966**	2007	**2007**	**2007**	2007	**1972**	**1931**
Kolkata	$R/\sqrt{n^2}$	**1.75**	**2.01**	1.49	1.16	1.61	1.67	**2.02**	**2.48**	**1.80**	1.48	**2.47**	**2.28**
Year		**1938**	**1980**	1983	1998	1969	1923	**1982**	**1987**	**1982**	1974	**1972**	**1931**
Malda	$R/\sqrt{n^2}$	**1.99**	**2.83**	**2.03**	1.47	1.57	1.49	**2.24**	**2.35**	**2.18**	**2.60**	**3.22**	**3.15**
Year		**1979**	**1975**	**1985**	1999	1994	1923	**1993**	**1988**	**1987**	**1974**	**1975**	**1978**
Midnapore	$R/\sqrt{n^2}$	1.32	**2.25**	1.60	1.22	**1.85**	1.46	**2.35**	**2.80**	**2.54**	**1.92**	**2.82**	**2.22**
Year		1938	**1963**	1991	1998	**1969**	1923	**1991**	**1988**	**1987**	**1988**	**1976**	**1939**
Murshidabad	$R/\sqrt{n^2}$	1.57	**2.44**	1.56	0.96	**1.81**	**1.84**	**2.18**	**2.17**	**2.34**	1.50	**3.06**	**2.75**
Year		1979	**1975**	1983	1984	**1969**	**1920**	**1976**	**1977**	**1975**	1987	**1975**	**1978**
Nadia	$R/\sqrt{n^2}$	1.25	**2.18**	0.98	0.81	1.68	1.63	**1.91**	**2.29**	1.47	**1.78**	**2.82**	**2.45**
Year		2006	**1975**	1938	1984	1971	1923	**1976**	**1977**	2007	**1974**	**1974**	**1978**
N.24 Pgs	$R/\sqrt{n^2}$	1.52	**1.83**	1.22	1.34	1.46	1.63	**2.68**	**2.92**	**2.33**	1.56	**2.53**	**2.31**
Year		2003	**1963**	1976	1998	1994	1997	**1991**	**1987**	**1987**	1971	**1972**	**1931**
Purulia	$R/\sqrt{n^2}$	**1.90**	**2.04**	1.46	0.93	**2.19**	**1.84**	1.29	1.22	0.95	1.65	**2.62**	**2.19**
Year		**2003**	**1989**	2004	1999	**1969**	**1968**	1976	1988	1980	1988	**1975**	**1978**
S. 24 Pgs	$R/\sqrt{n^2}$	1.42	**2.09**	1.74	**1.87**	**1.83**	**2.28**	**2.12**	**2.39**	**2.55**	**2.48**	**2.98**	**2.41**
Year		1999	**1988**	2005	**2005**	**2005**	**2005**	**2005**	**2004**	**1998**	**1998**	**1976**	**1985**

The mean annual minimum temperature ($ATMin$) time series for all stations have shown interesting results in response to this test. The results are shown in Table-28. Most of the significant changes have occurred between 1971 and 1980 and 1981 and 1990. The mean annual minimum temperature ($ATMin$) time series indicate significant changes in 3 time bands 1930 - 1940, 1991 - 2000 and 2001 - 2011 respectively. Table-29 shows the test results for seasonal minimum temperature ($STMin$) time series.

The Winter and Post-monsoon time series are highly inhomogeneous for all stations. In case of the Monsoon season, the Purulia time series is not significant at 0.05% level of significance. On the other hand, Bankura, Kolkata, Malda, Midnapore and Nadia do not indicate any significant break over Summer season.

Table-28: Results of Buishand Range Test (BRT) of Mean Annual Minimum ($ATMin$) Temperature Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance.

SL No	Name of Observatory	$R/\sqrt{n^2}$	At 0.05% significance level	Change Year
1	Bankura	**2.40**	Significant	**1976**
2	Birbhum	**2.42**	Significant	**1975**
3	Burdwan	**2.40**	Significant	**1976**
4	Hooghly	**2.43**	Significant	**1931**
5	Howrah	**2.44**	Significant	**2003**
6	Kolkata	**2.44**	Significant	**1987**
7	Malda	**2.84**	Significant	**1987**
8	Midnapore	**2.72**	Significant	**1988**
9	Murshidabad	**2.81**	Significant	**1976**
10	Nadia	**2.39**	Significant	**1976**
11	North 24 Pargana	**2.51**	Significant	**1987**
12	Purulia	**2.26**	Significant	**1988**
13	South 24 Pargana	**2.44**	Significant	**1995**

Table-29: Results of Buishand Range Test (BRT) of Seasonal Minimum ($STMin$) Temperature Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance.

Station	Test (BRT)	Winter	Summer	Monsoon	Post-Monsoon
Bankura	$R/\sqrt{n^2}$	**2.48**	1.20	**2.17**	**4.39**
Break Year		**2007**	2010	**2006**	**1962**
Birbhum	$R/\sqrt{n^2}$	**2.51**	**2.05**	**2.40**	**2.87**
Break Year		**1975**	**1920**	**1976**	**1975**
Burdwan	$R/\sqrt{n^2}$	**2.41**	**2.12**	**2.18**	**2.90**
Break Year		**1976**	**1967**	**1977**	**1975**
Hooghly	$R/\sqrt{n^2}$	**2.32**	**2.11**	**1.93**	**2.32**
Break Year		**1938**	**1964**	**1982**	**1974**
Howrah	$R/\sqrt{n^2}$	**2.19**	**2.10**	**1.84**	**2.20**
Break Year		**1931**	**1967**	**2007**	**1969**
Kolkata	$R/\sqrt{n^2}$	**2.29**	1.59	**2.63**	**2.41**
Break Year		**1938**	1920	**1982**	**1973**
Malda	$R/\sqrt{n^2}$	**3.00**	1.69	**2.47**	**3.11**
Break Year		**1975**	1998	**1988**	**1975**
Midnapore	$R/\sqrt{n^2}$	**2.37**	1.64	**2.92**	**2.72**
Break Year		**1938**	1920	**1988**	**1973**
Murshidabad	$R/\sqrt{n^2}$	**2.98**	**1.76**	**2.22**	**2.97**
Breaks Year		**1976**	**1920**	**1976**	**1975**
Nadia	$R/\sqrt{n^2}$	**2.39**	1.55	**2.16**	**2.67**
Break Year		**1976**	1920	**1987**	**1974**
North 24 Pargana	$R/\sqrt{n^2}$	**2.25**	1.54	**2.99**	**2.52**
Break Year		**1938**	1995	**1987**	**1973**
Purulia	$R/\sqrt{n^2}$	**2.15**	**2.13**	1.25	**2.39**
Break Year		**1988**	**1971**	1976	**1975**
South 24 Pargana	$R/\sqrt{n^2}$	**2.59**	**2.12**	**2.40**	**2.75**
Break Year		**1985**	**2005**	**2005**	**1973**

In case of the Monsoon season, only the $STMin$ series for Purulia is not significant at 0.05% level of significance. The temporal records for all observatories are also examined by the same statistical test. Apparently it can be said that the monthly average rainfall series do have some inhomogeneity but, the test suggests that such inhomogeneities are negligible and the time series are reliable for trend detection. Rescaled adjusted partial sums has adjusted the sample standard deviation to find out even the minimum variability in the time series. In this concern, The month of August (Bankura), August (Birbhum), May (Malda), August (Murshidabad), August (Purulia) time series are indicating significant change point at considered level of significance. The significant test statistic value lies just above the critical limit. These inhomogeneous series does not signify any systematic pattern after the rescaled adjustment of mean level. Besides the above mentioned months, the remaining series are homogeneous which does not refer to any cyclic components therein. The relation factors or range of these series are quite similar. If we look upon the winter series of those observatories, only Bankura do not refer to any significant change point at the chosen level of significance. On the other hand rest of the observatories have indicated significant change points after this test. Moreover, the values of standard deviation and adjusted partial sums have indicated significant change points in between 1953 and 1957. The corresponding change years are 1953 (Birbhum), 1957 (Burdwan), 1956 (Hooghly), 1957 (Howrah), 1957 (Kolkata), 1953 (Malda), 1956 (Midnapore), 1953 (Murshidabad), 1956 (Nadia), 1957 (North 24 Pargana), 1953 (Purulia) and 1957 (South 24 Pargana). The results of test for annual average rainfall series is shown in Table-30. The annual average rainfall series indicate skewed distribution by which they indicate single significant change point over the period.

The curves are not symmetrical with respect to the Buishand test statistic values, so there is no dependency of variance of these distributions. The test statistic values are always > critical value when it is measured at α =0.05 level of significance. Overall conclusion of these results signify the inhomogeneous character of mean annual rainfall series for all considered observatories. Interestingly, all significant change occurred in a single year (1968) except Purulia.

Table-30: Results of Biushand Range Test (BRT) of Mean Annual Rainfall Series for 13 observatories. Bold value statistic and corresponding years are significant at 0.05% level of significance

SL No	Name of Observatory	$R/\sqrt{n^2}$	At 95% significance level	Change Year
1	Bankura	**3.40**	Significant	1968
2	Birbhum	**3.69**	Significant	1968
3	Burdwan	**3.90**	Significant	1968
4	Hooghly	**3.93**	Significant	1968
5	Howrah	**4.00**	Significant	1968
6	Kolkata	**4.04**	Significant	1968
7	Malda	**3.72**	Significant	1968
8	Midnapore	**3.98**	Significant	1968
9	Murshidabad	**3.81**	Significant	1968
10	Nadia	**4.03**	Significant	1968
11	North 24 Pargana	**4.01**	Significant	1968
12	Purulia	**3.87**	Significant	1967
13	South 24 Pargana	**4.07**	Significant	1968

Figure-11: Graphical presentation of the Annual Maximum Temperature ($ATMax$) Series after BRT (Buishand Range Test)

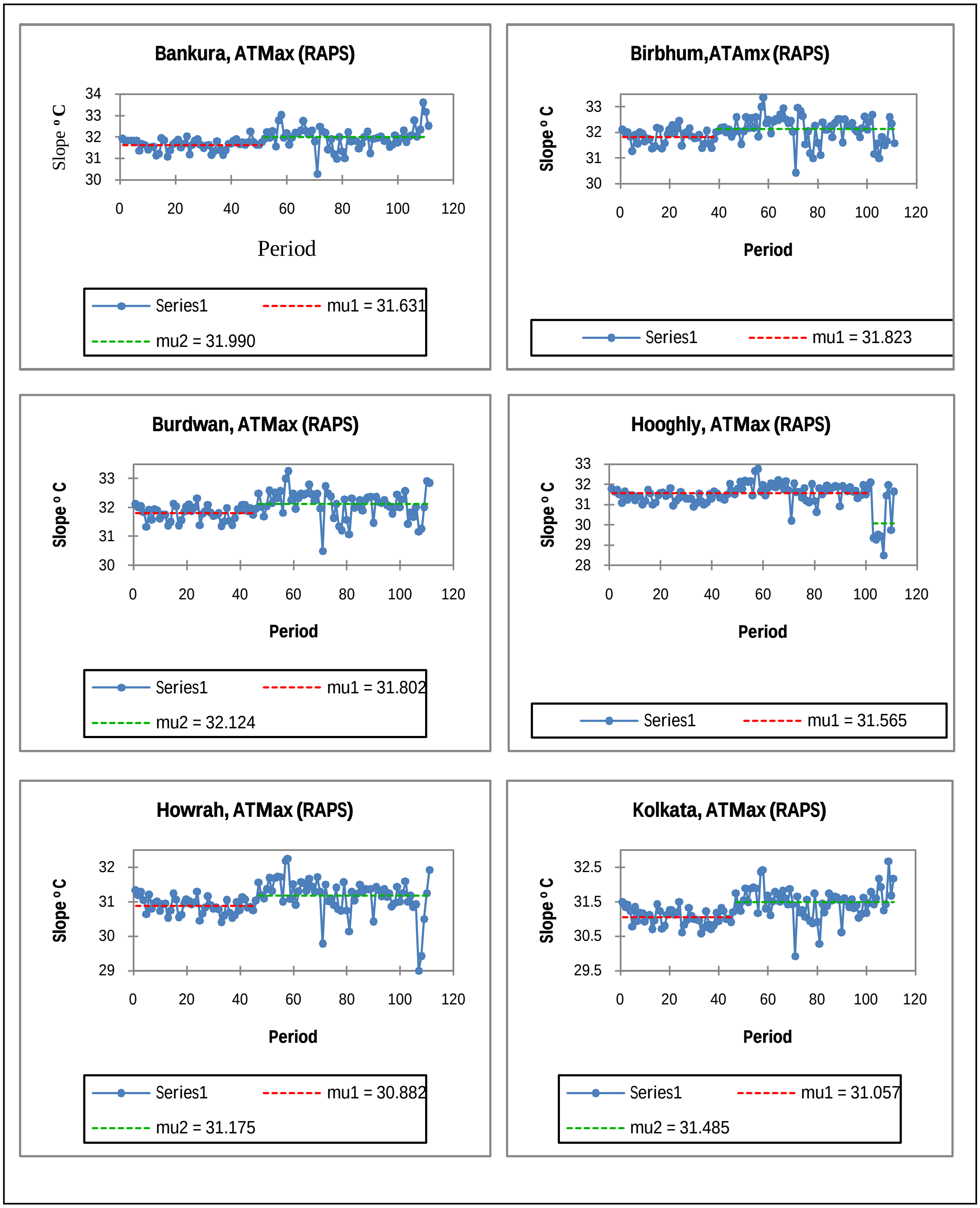


Figure Cont….

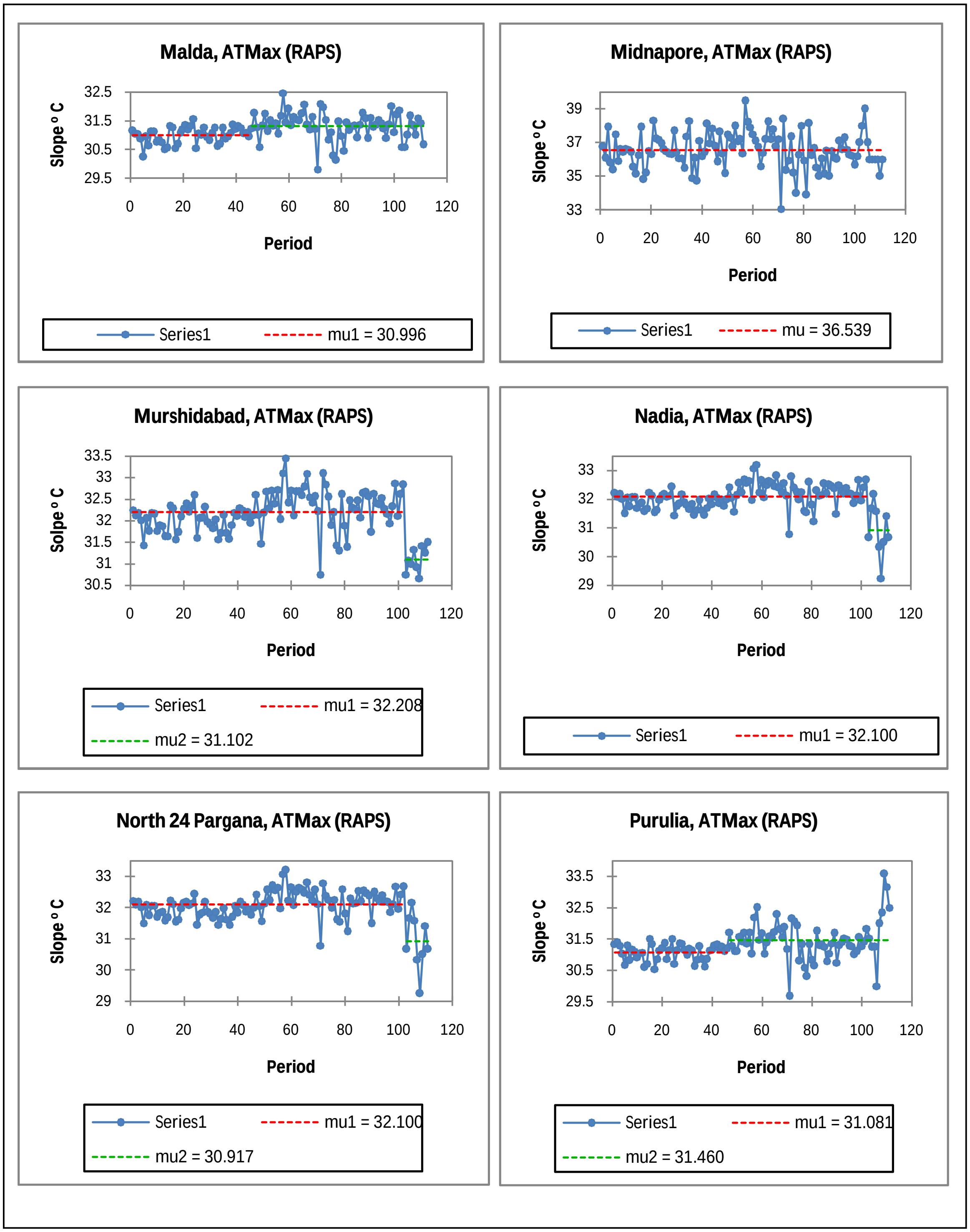

Malda, ATMax (RAPS)
Slope ° C
Period
Series1
mu1 = 30.996
Midnapore, ATMax (RAPS)
Slope ° C
Period
Series1
mu = 36.539
Murshidabad, ATMax (RAPS)
Solpe ° C
Period
Series1
mu1 = 32.208
mu2 = 31.102
Nadia, ATMax (RAPS)
Slope ° C
Period
Series1
mu1 = 32.100
North 24 Pargana, ATMax (RAPS)
Slope ° C
Period
Series1
mu1 = 32.100
mu2 = 30.917
Purulia, ATMax (RAPS)
Slope ° C
Period
Series1
mu1 = 31.081
mu2 = 31.460

Figure Cont….

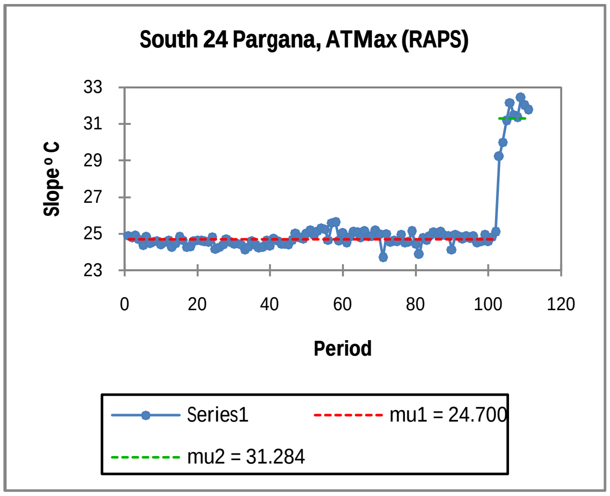


Figure-12: **Graphical presentation of the Annual Minimum Temperature ($ATMin$) Series after BRT (Buishand Range Test)**

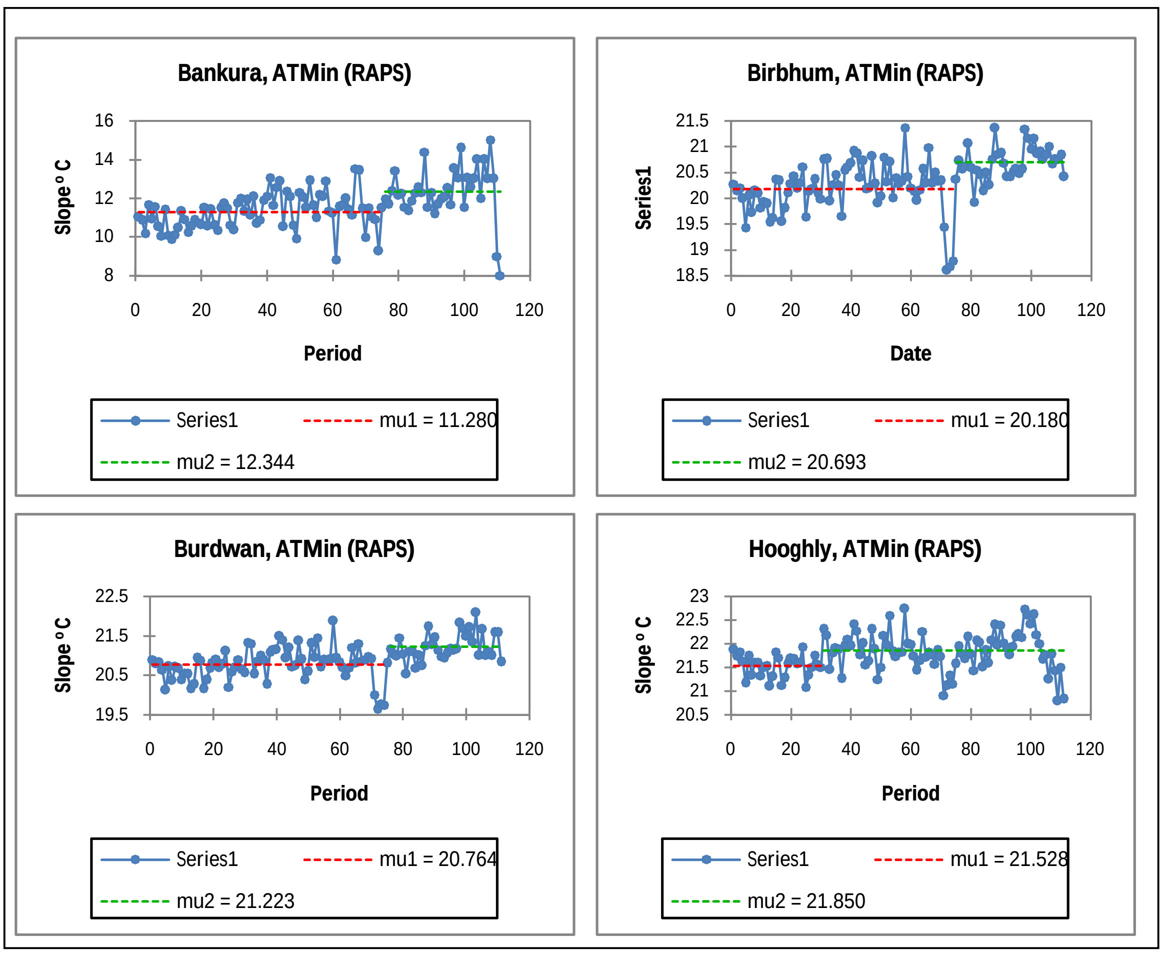


Figure Cont….

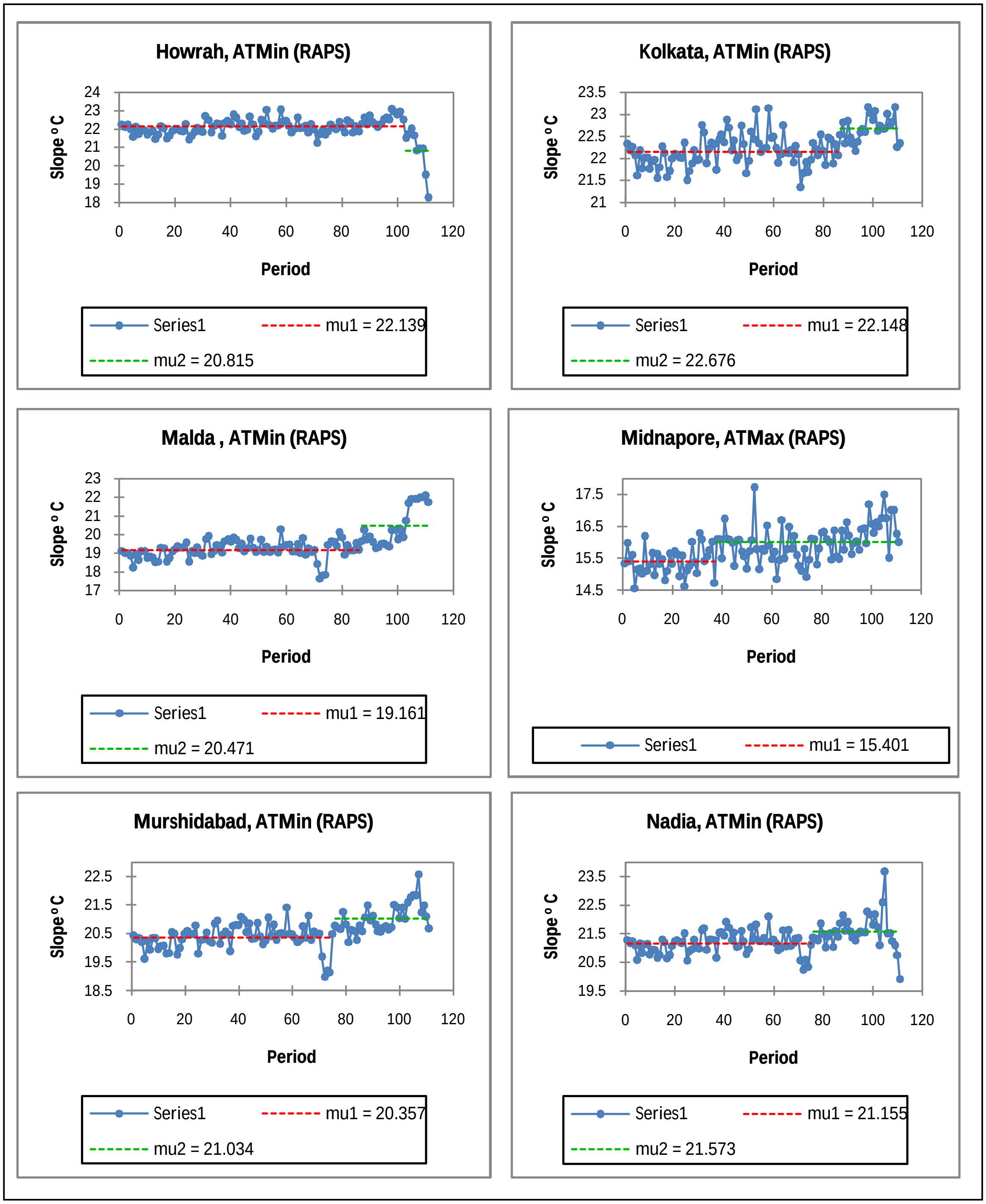
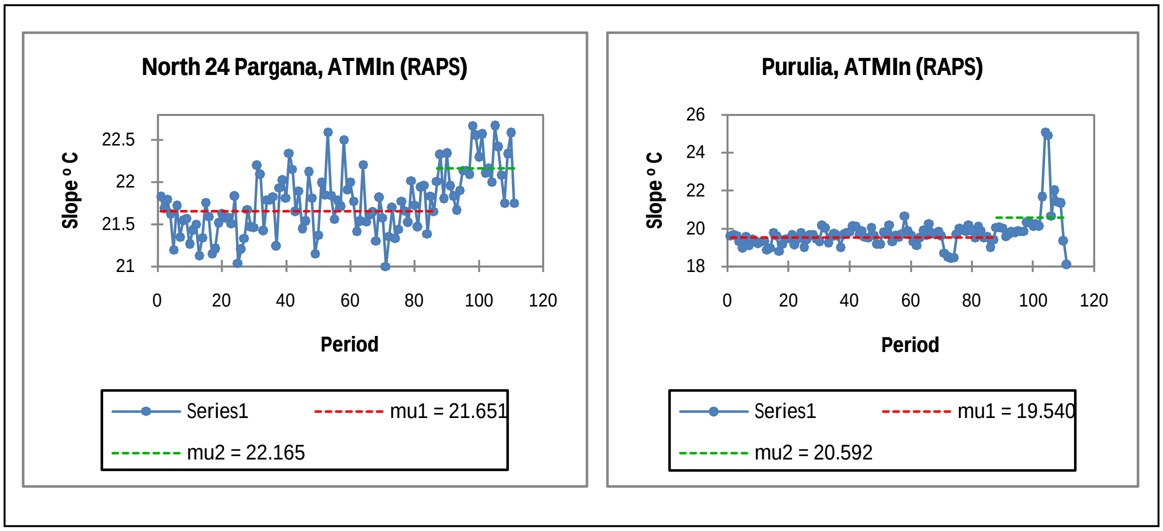

Howrah, ATMin (RAPS)
Slope ° C
Period
Series1
mu1 = 22.139
mu2 = 20.815
Kolkata, ATMin (RAPS)
Slope ° C
Period
Series1
mu1 = 22.148
mu2 = 22.676
Malda , ATMin (RAPS)
Slope ° C
Period
Series1
mu1 = 19.161
mu2 = 20.471
Midnapore, ATMax (RAPS)
Slope ° C
Period
Series1
mu1 = 15.401
Murshidabad, ATMin (RAPS)
Slope ° C
Period
Series1
mu1 = 20.357
mu2 = 21.034
Nadia, ATMin (RAPS)
Slope ° C
Period
Series1
mu1 = 21.155
mu2 = 21.573

Figure Cont….



Another homogeneity test applied to the considered data series to determine the occurrence of single abrupt change (Pettitt Test). The results of the Pettitt test for mean monthly maximum temperature is shown in Table-31. Whereas the mean monthly maximum time series ($TMax$) for November and December are indicating significant change at 0.05% level of significance for all the considered stations. The other mean monthly maximum temperature ($TMax$) time series for months like February, May and August have indicated some significant change except Murshidabad (February), Kolkata (May) and Malda (May). South 24 Pargana has revealed significant change for all $TMax$ series. The range of the probability values for all considered time series is ± 0.7649. This result suggests an alternative hypothesis to be applied for suitable modeling or trend analysis. $TMax$ series for Bankura is indicating 6 (Six) months with significant change points. These monthly series are February, May, August, October, November and December. Similarly, mean monthly maximum temperature time ($TMax$) series for Burdwan and Howrah also indicates 6 (Six) similar significant change points for the same months. Mean monthly maximum temperature time series for Kolkata station has indicated 6 (Six) significant change on the months of February, August, September, October, November and December.

The mean monthly maximum temperature time series for Nadia, North 24 Pargana and Purulia indicate 7 (Seven) such significant months like January, February, May, August, October, November and December. Interestingly, South 24 Pargana indicates significant change points for all the months. Most common months for all stations are February, May, August, October, November and December where inhomogeneity is present. This test has also revealed that, the average of successive mean differences of the time series for February is 0.96℃. Maximum mean shift value has occurred in the Bankura time series and its numerical value is 1.56 ℃ and the minimum shift has been seen for Hooghly mean monthly maximum temperature time series (0.7 ℃). The stations Birbhum, Burdwan, Howrah, Kolkata, Malda, Midnapore, Nadia, North 24 Pargana, Purulia and South 24 Pargana shift of mean value have been 0.81$°C$, 0.88 $°C$, 0.73 $°C$, 0.98 $°C$, 0.84 $°C$, 0.96 $°C$, 0.72 $°C$, 0.72 $°C$, 1.12 $°C$ and 1.6 $°C$ respectively. May is another important month, which 11 stations exhibits inhomogeneity but interestingly the mean for its second sub-section lies below the previous or the first mean level. This test reveals that the occurrence of significant change year for this month occur for the period since 1970 to 1980. The significant change points for August series for all the stations have occurred in a span of two decades. Some of the August $TMax$ series like for Bankura, Birbhun, Burdwan, Murshidabad, Purulia and South 24 Parnaga exhibit significant changes during 1970 - 1980. The other series for stations like Howrah, Kolkata, Midnapore, Nadia and North 24 Pargana are signifying important change points during 1940 - 1950. Moreover, it can be mentioned that, the change points are very sensitive within these decades.

Table-31: Results of Pettitt Test of Mean Monthly Maximum ($TMax$) Temperature Series for 13 observatories.
Bold and bold value statistic and corresponding years are significant at 0.05% level of significance.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	**Pettitt**	780	**1302**	474	510	**1048**	422	807	**1303**	726	**1261**	**2084**	**1991**
Birbhum		804	**1168**	**900**	**865**	**1114**	504	743	**1675**	696	**1145**	**2079**	**1918**
Burdwan		746	**1243**	752	846	**1156**	488	614	**1565**	654	**1175**	**2184**	**1817**
Hooghly		700	**1199**	751	726	**1030**	542	712	873	785	710	**1531**	**1603**
Howrah		755	**1307**	638	845	**1088**	463	501	**1118**	701	**1138**	**1891**	**1853**
Kolkata		732	**1570**	673	477	672	601	742	**1351**	**1031**	**1207**	**2125**	**1883**
Malda		692	**1207**	594	856	862	560	534	534	**1713**	**896**	**1205**	**1936**
Midnapore		587	**1618**	703	488	**888**	520	**930**	**1348**	**926**	**1164**	**1926**	**1843**
Murshidabad		739	823	800	944	**1165**	548	685	**1291**	433	**960**	**1712**	**1701**
Nadia		**918**	**988**	720	823	**1068**	502	660	**948**	604	**897**	**1910**	**1608**
N.24 Pgs		**918**	**988**	720	832	**1068**	502	660	**948**	604	**897**	**1910**	**1608**
Purulia		**1170**	**1559**	599	754	**1428**	650	586	**1244**	704	**1419**	**2051**	**1938**
S. 24 Pgs		**1106**	**1722**	**1002**	**1050**	**912**	**918**	**1186**	**1614**	**1252**	**1525**	**2173**	**2011**

Pettitt Test was applied to the mean annual maximum temperature time series for all considered stations separately. Its results are shown in Table-32. The graphical constructions of annual maximum temperature ($ATMax$) time series are given in Figure-13. In accordance to the investigation of homogeneity of the time series, this test suggests that, all mean annual maximum ($ATMax$) temperature contains inhomogeneity. The calculated k values for all observatories lie above the critical value. The result of the Pettitt test shows that the inhomogeneity is a general feature for all stations. The two tailed probability estimation of this test is always less than the level of significance, so the considered time series data sets are inconsistent in order. The chart of probability values and the corresponding confidence ranges are given in Table-33. The range of the probability value for all considered time series is ± 0.7649.

Table-32: Results of Pettitt Test of Mean Annual Maximum ($ATMax$) Temperature Series for 13 observatories. Bold and bold value statistic and corresponding years are significant at 0.05% level of significance.

SL No	Name of Observatory	Pettitt Test(k)	At 0.05% significance level
1	Bankura	**1698**	Significant
2	Birbhum	**1324**	Significant
3	Burdwan	**1540**	Significant
4	Hooghly	**1470**	Significant
5	Howrah	**1666**	Significant
6	Kolkata	**2038**	Significant
7	Malda	**1514**	Significant
8	Midnapore	**1946**	Significant
9	Murshidabad	**1072**	Significant
10	Nadia	**1350**	Significant
11	North 24 Pargana	**1350**	Significant
12	Purulia	**1490**	Significant
13	South 24 Pargana	**2100**	Significant

The probability distribution for the time series is very interesting and the range has a suitable numeric distribution. Among all considered observatories 10 annual series indicate their $\rho\ value$ below < 0.0001. Other three annual maximum series have $\rho\ values$ closed to zero (0). This distributions have confirmed the mean level change and has intensively distinguished the total length of temporal span over the considered period. Minute random frequencies of time domain have been adjusted with in the mean level of sub-sections for each series.

Table-33: Probability distribution result after Pettitt Test of Mean Annual Maximum ($ATMax$) Temperature Series for 13 observatories.

SL No	Name of Observatory	ρ value	Range
1	Bankura	**<0.0001**	0.000-0.0001
2	Birbhum	**0.000**	-0.000-0.001
3	Burdwan	**<0.0001**	0.000-0.0001
4	Hooghly	**<0.0001**	0.000-0.0001
5	Howrah	**<0.0001**	0.000-0.0001
6	Kolkata	**<0.0001**	0.000-0.0001
7	Malda	**<0.0001**	0.000-0.0001
8	Midnapore	**<0.0001**	0.000-0.0001
9	Murshidabad	**0.008**	0.006-0.010
10	Nadia	**<0.0001**	0.000-0.0001
11	North 24 Pargana	**0.000**	-0.000-0.001
12	Purulia	**<0.0001**	0.000-0.0001
13	South 24 Pargana	**<0.0001**	0.000-0.0001

Figure-13: Shift of mean level of Mean Annual Maximum ($ATMax$) Temperature Series of 13 observatories by Pettitt Test.

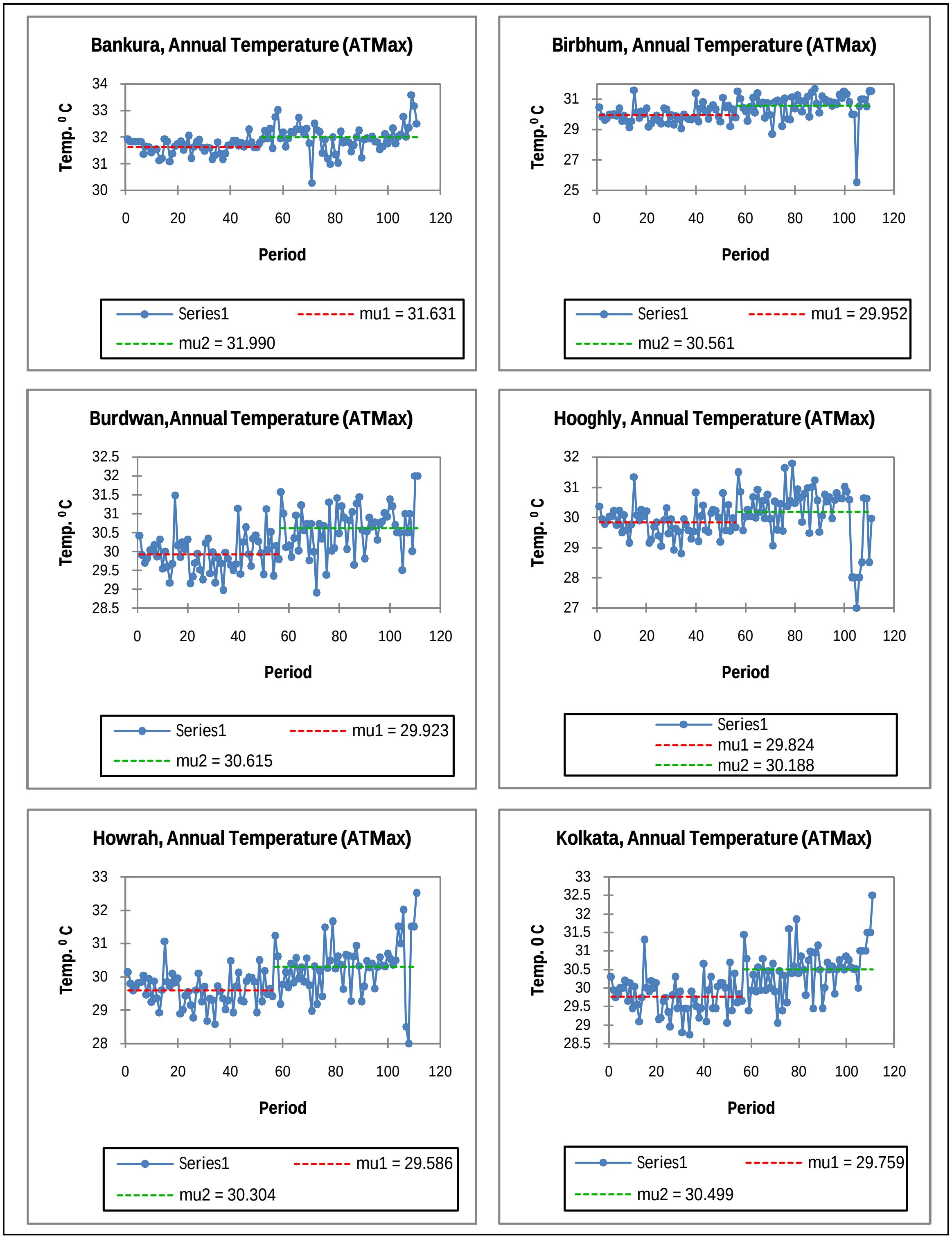


Figure Cont....

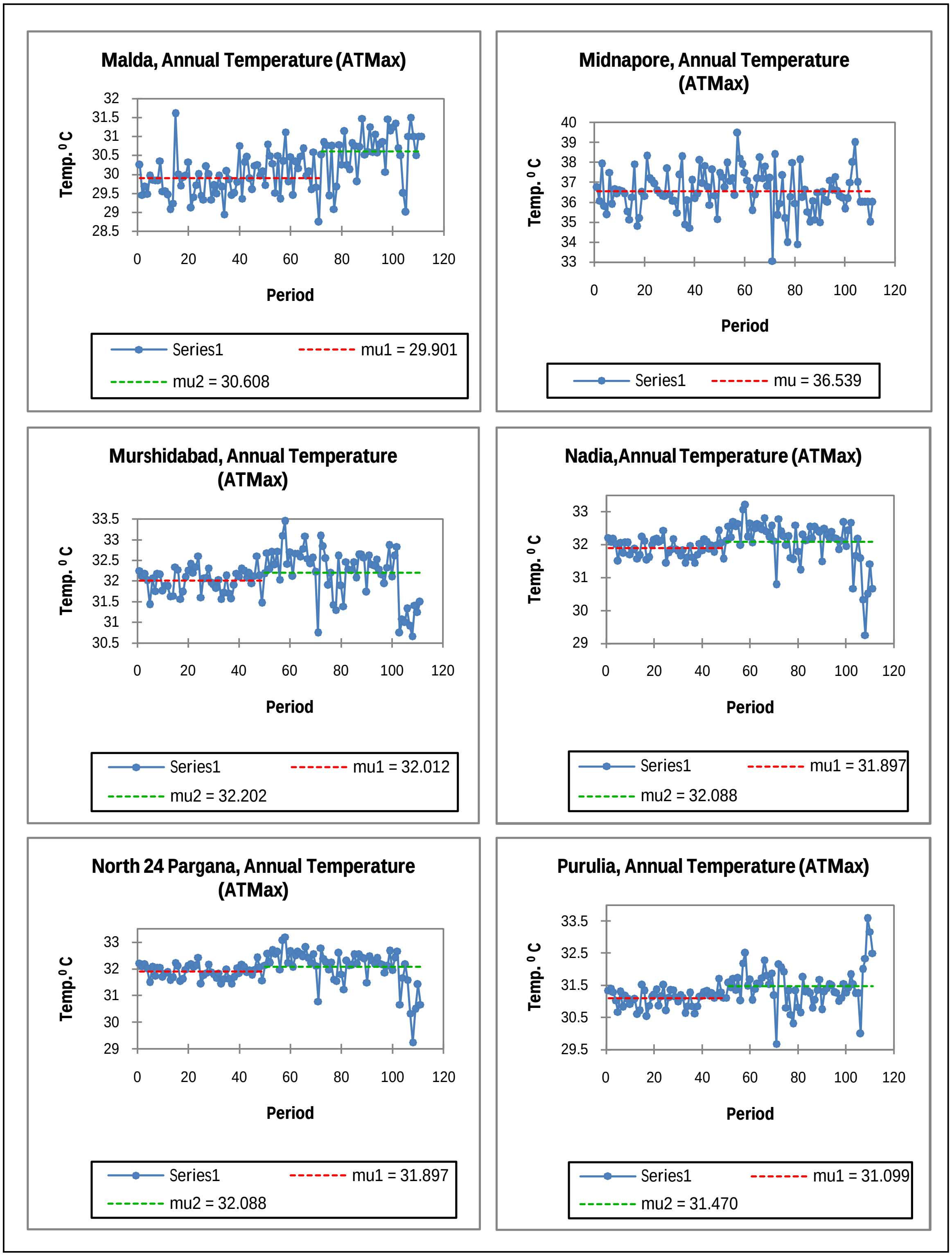

Malda, Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu1 = 29.901
mu2 = 30.608
Midnapore, Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu = 36.539
Murshidabad, Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu1 = 32.012
mu2 = 32.202
Nadia,Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu1 = 31.897
mu2 = 32.088
North 24 Pargana, Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu1 = 31.897
mu2 = 32.088
Purulia, Annual Temperature (ATMax)
Temp. °C
Period
Series1
mu1 = 31.099
mu2 = 31.470

Figure Cont...

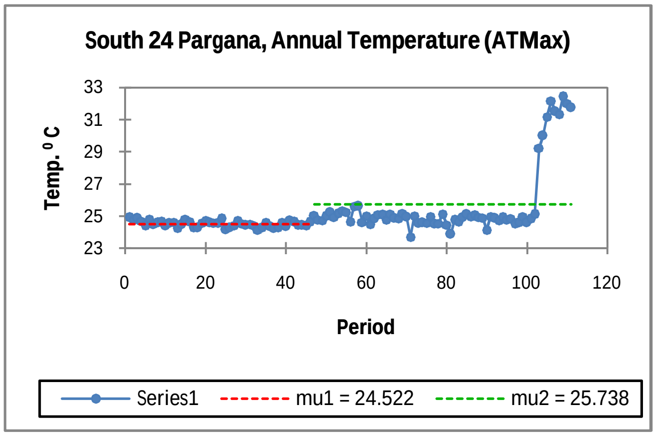


Table-34: Single Abrupt Change for Mean Seasonal Maximum ($STMax$) Temperature Series after Pettitt Test.

Station	Pettitt Test(k)	Winter	Summer	Monsoon	Post-Monsoon
Bankura	k	**1558**	**840**	**1175**	**1915**
Birbhum	k	**1367**	**1072**	125	824
Burdwan	k	**1468**	**981**	**1128**	**1938**
Hooghly	k	**1270**	804	679	**1325**
Howrah	k	**1582**	**956**	**1070**	**1814**
Kolkata	k	**1709**	546	**1400**	**1989**
Malda	k	**1306**	**943**	**1158**	**1823**
Midnapore	k	**1797**	542	**1382**	**1946**
Murshidabad	k	**1224**	**1084**	**898**	**1486**
Nadia	k	**1209**	**874**	624	**1501**
North 24 Pargana	k	**1209**	**874**	624	**1501**
Purulia	k	**1787**	**1289**	**986**	**1902**
South 24 Pargana	k	**1866**	**1054**	**1530**	**2082**

The seasonal maximum temperature ($STMax$) time series also indicates significant break points for each observatory. The results of "k $statistic$" are shown in Table-34. All the four seasons show significant change points at $\rho = 0.05$ level. The inspection of the $STMax$ series by the Pettitt test for winter season has revealed strongly significant change points for all observatories. The "k $statistic$" values for these results are above the critical level. The single abrupt change is common character for Winter The three observatories like Hooghly, Kolkata and Midnapore do not imply any change points at chosen level of significance for Summer or Pre-monsoon seasons. In case of the Monsoon season, the Birbhum, Hooghy, Nadia and North 24 Pargana, there in hardly any significant change points are not significant. All the Post monsoon series have revealed significant single abrupt change over the considered period except for Birbhum.

The Pettitt test is a robust statistical method that is intensively adjusted and specifies the randomness of the time series. In this work, its application is suitable where considered time series is the sufficiently accurate for temporal analysis. In Table 34, the bold values of the "k $statistic$" are significant at chosen level of significance. According to this test, the middle of the considered series involves the most of the single abrupt changes. Primarily, the data series for its application was raw in nature by which the abruptness is prominent.

Table-35 shows the single abrupt change in the mean monthly minimum temperature series for the period and the bold values are significant at chosen level of significance.

Table-35: Single Abrupt Change for Mean Monthly Minimum ($TMin$) Temperature Series after Pettitt Test.

Station & Break Year	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	**Pettitt (k)**	**7740**	**1398**	754	674	**884**	662	**1126**	**1136**	**1073**	**1102**	**1878**	**1736**
Birbhum		**867**	**1338**	650	240	**895**	810	**1683**	**1546**	**1150**	**1144**	**1970**	**1844**
Burdwan		746	**1536**	712	276	**916**	698	**1327**	**1172**	**1177**	**1236**	**1966**	**1646**
Hooghly		608	**1172**	536	348	**905**	807	540	**871**	649	696	**1563**	**1508**
Howrah		590	**928**	556	736	**1023**	**1033**	530	687	318	653	**1284**	**1441**
Kolkata		605	**1370**	**1068**	627	550	712	**1285**	**1450**	**1185**	**910**	**1709**	**1584**
Malda		**1216**	**1862**	**1114**	**866**	826	**990**	**1276**	**1291**	**1202**	**1577**	**2108**	**2072**
Midnapore		706	**1535**	**1098**	707	633	398	**1460**	**1602**	**1494**	**1120**	**1814**	**1702**
Murshidabad		822	**1467**	**1011**	567	660	**840**	**1411**	**1431**	**1008**	**1400**	**2128**	**1972**
Nadia		571	**1176**	545	406	726	735	**1157**	**1374**	658	817	**1818**	**1484**
N.24 Pgs		600	**1110**	**865**	800	602	770	**1577**	**1707**	**1351**	**891**	**1621**	**1392**
Purulia		**960**	**1493**	775	460	**1147**	784	674	721	**874**	**1171**	**1934**	**1746**
S. 24 Pgs		111	**1403**	**1012**	780	804	728	**1152**	**1501**	**1449**	**1225**	**1969**	**1626**

To identify the single abrupt change or change of mean value in the mean monthly minimum temperature time series, every series have been tested separately. The month of February, November and December do have single abrupt change points for all the observatories. The Table-35 also presents that, the time series for January (Bankura, Birbhum, Malda and Purulia), March (Kolkata, Malda, Midnapore, Murshidabad, North 24 Pargana and South 24 Pargana) have the significant change points over the considered time period. The mean monthly minimum time series for the month of April is very consistent except Malda observatory.

Monsoon months like July, August and September is indicating mean level change that has identified by this test. Table-36 is showing the single abrupt change of mean annual minimum temperature time series. According to this test, all the considered series indicates significant result at the chosen level of significance. $k\ statistic$ are strongly above the critical limit. Moreover, the Winter seasonal minimum temperature series for all the observatories has revealed the significant result except Midnapore (Table-37). The Summer seasonal minimum temperature time series are not consistently significant for all observatories. Moreover, the results of the Burdwan. Hooghly, Howrah, Malda, North 24 Pargana and Purulia are indicating significant single abrupt change over the considered period.

Table-36: Single Abrupt Change for Mean Annual Minimum ($ATMin$) Temperature Series after Pettitt Test.

SL No	Name of Observatory	Pettitt Test(k)	$\rho = 0.05$ significance level
1	Bankura	**1474**	Significant
2	Birbhum	**1742**	Significant
3	Burdwan	**1736**	Significant
4	Hooghly	**1308**	Significant
5	Howrah	**1114**	Significant
6	Kolkata	**1646**	Significant
7	Malda	**1938**	Significant
8	Midnapore	**1668**	Significant
9	Murshidabad	**1988**	Significant
10	Nadia	**1438**	Significant
11	North 24 Pargana	**1668**	Significant
12	Purulia	**1544**	Significant
13	South 24 Pargana	**1556**	Significant

Table-37: Single Abrupt Change for Mean Seasonal Minimum ($STMin$) Temperature Series after Pettitt Test.

Station	Pettitt Test(k)	Winter	Summer	Monsoon	Post-Monsoon
Bankura	k	**1678**	686	**1336**	**1732**
Birbhum	k	**1556**	708	**1788**	**1874**
Burdwan	k	**1612**	**834**	**1440**	**1902**
Hooghly	k	**1324**	**904**	729	**1434**
Howrah	k	**1216**	**1125**	677	**1123**
Kolkata	k	**1535**	673	**1658**	**1620**
Malda	k	**2142**	**978**	**1486**	**2042**
Midnapore	k	707	707	**1696**	**1845**
Murshidabad	k	**2034**	716	**1554**	**2052**
Nadia	k	**1482**	634	**1218**	**1685**
North 24 Pargana	k	**1220**	**948**	**1740**	**1676**
Purulia	k	**1858**	**970**	**1028**	**1692**
South 24 Pargana	k	**1668**	798	**1388**	**1918**

Bold values are significant at $\rho = 0.05$ level of significance.

Potential successive mean difference and their variability of the variance have been identified by the above stated method (equation-10) and the levels of significance are to be compared at 0.05% level of confidence. The critical value of this test is 1.68 at 0.05% level of confidence, where above numerals are significant. The results of the mean monthly maximum series are presented in Table- 38. The mean monthly maximum temperature time series of the Bankura observatory indicates four series for its randomness with their ratio of the mean square successive difference to the variance. The statistic values of these mean monthly maximum temperature time series are 1.96 (March), 1.89 (April), 2.11 (June) and 1.83(September) respectively. The mean monthly maximum temperature time series of Howrah and Murshidabad are also indicating four significant breaks. The Von Neumann Ratio for mean monthly maximum temperature time series of February (1.92), June (1.86), July (1.87) and October (1.70) are significant for Howrah weather observatory at 0.05% level of confidence. On the other hand the values for mean monthly maximum temperature time ($TMax$) series like March (1.81), April (1.80), May (1.68) and June (2.04) are significant for Murshidabad observatory. Each of Birbhum, Burdwan, Malda and Midnapore observatories are indicating 8 (eight) significant breaks. The mean monthly maximum temperature time series of station Kolkata also has 7(seven) significant break points. In reference to this test statistic, three weather observatories like Nadia, North 24 Pargana and Purulia exhibit 2 (two) significant breaks. Moreover, the mean monthly maximum temperature time series for South 24 Pargana is homogeneous in nature and propounded no such significant break.

Table-38: Results of Von-Neumann Ratio Test for Mean Monthly Maximum ($TMax$) Temperature Time Series. Bold values are significant at $\rho = 0.05$ level of significance.

Station	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	VNR	1.59	1.55	**1.96**	**1.89**	1.61	**2.11**	1.63	1.20	**1.83**	1.46	1.03	1.10
Birbhum		1.60	**1.68**	**1.93**	**1.89**	**1.77**	**2.16**	**1.85**	1.30	**1.78**	**1.89**	1.23	1.18
Burdwan		**1.77**	1.65	**1.88**	**1.90**	**1.74**	**2.14**	**1.83**	1.30	**1.82**	**1.94**	1.17	1.21
Hooghly		1.35	**1.72**	**1.71**	**1.78**	**1.70**	**1.81**	**1.75**	**1.68**	1.13	1.49	1.17	1.46
Howrah		1.60	**1.92**	1.49	1.47	1.34	**1.86**	**1.87**	1.38	1.65	**1.70**	1.28	1.38
Kolkata		**1.92**	1.61	**1.90**	**2.06**	**2.03**	**2.02**	**2.00**	1.49	1.67	**1.70**	1.07	1.37
Malda		1.33	**1.77**	**2.07**	**1.84**	**2.01**	**2.12**	**1.74**	**11.23**	1.09	1.66	**1.83**	1.13
Midnapore		**1.81**	1.62	**1.89**	**2.09**	**1.82**	**1.95**	**1.83**	1.48	1.75	**1.84**	1.27	1.41
Murshidabad		1.44	1.63	**1.81**	**1.80**	1.67	**2.04**	1.65	1.50	1.53	1.57	1.21	1.27
Nadia		1.33	1.65	1.67	**1.73**	1.56	**2.05**	1.55	1.46	1.17	1.54	1.26	1.45
N.24 Pgs		1.33	1.65	1.67	**1.73**	1.56	**2.05**	1.55	1.46	1.17	1.54	1.26	1.45
Purulia		1.24	1.34	1.62	1.26	0.94	**1.80**	1.67	1.14	1.78	1.50	0.94	0.84
S. 24 Pgs		0.49	0.47	0.36	0.43	0.45	0.37	0.18	0.16	0.26	0.17	0.31	0.45

Mean annual maximum ($ATMax$) temperature and seasonal mean maximum temperature ($STMax$) has been checked by this method to find out for its significant randomness. The results obtained from the Von-Neumann Ratio test for annual mean maximum temperature ($ATMax$) are closely similar for each considered time series. Moreover, it is very important and has revealed regional homogeneity condition. The calculated value of Von-Neumann Ratio for these series do not reach the critical value at 0.05% level of significance. So it can be stated that, there are no such significant randomness for considered time series under null hypothesis and the year to year mean square difference is almost identical. However, the calculated numerals of N distribution exhibit lower than expected (critical value) value. On the other hand the seasonal mean maximum temperature ($STMax$) time series indicates interesting result. The result of these time series is given in Table-39. The time series for Bankura, Birbhum, Burdwan, Kolkata, Malda and Midnapore are showing significant randomness in summer season. The other 7 seasonal time series are indicating randomness but they are insignificant at 0.05% level of significance. Besides the above mentioned result, the winter, monsoon and post-monsoon do not suggests significant randomness following this method.

Table-39: Result of Von-Neumann Ratio Test for mean annual maximum Temperature Series ($ATMax$) and
Mean Seasonal Maximum ($STMax$) Temperature Series. Bold values are significant at $\rho = 0.05\ level$.

Station	Test	Annual	Winter	Summer	Monsoon	Post-Monsoon
Bankura	VNR	1.176	1.151	**1.837**	1.218	1.113
Birbhum		1.411	1.304	**1.786**	1.297	1.586
Burdwan		1.361	1.410	**1.795**	1.342	1.476
Hooghly		1.038	1.163	1.628	1.161	1.232
Howrah		1.186	1.389	1.263	1.216	1.366
Kolkata		1.279	1.319	**2.044**	1.386	1.236
Malda		1.465	1.455	**1.845**	1.068	1.340
Midnapore		1.340	1.461	**1.915**	1.293	1.369
Murshidabad		1.088	1.266	1.567	0.654	1.282
Nadia		1.001	1.270	1.525	0.983	1.423
North 24 Pargana		1.002	1.280	1.535	0.983	1.423
Purulia		1.080	0.954	0.998	1.281	1.046
South 24 Pargana		0.095	0.179	0.261	0.102	0.190

The Von-Neumann Ratio test has been conducted to evaluate the randomness of mean monthly minimum temperature ($TMin$), mean annual minimum temperature ($ATMin$) and mean seasonal minimum temperature ($STMin$) series for 13 weather observatories in southern part of West Bengal.

The result of this test is shown in Table-40. The level of significance has been considered at 0.05% level. The results show that the mean square difference value for January, March and April are significant for Bankura weather observatory. The calculated values of those months are 1.68, 1.93 and 2.10, respectively. But there is no significant randomness for mean annual minimum and mean seasonal minimum temperature time series. For the station Birbhum, there are four significant random breaks over the mean monthly minimum temperature time series of January, March, April and June. The calculated values are 1.68, 1.98, 2.36, and 1.70 respectively. The mean monthly minimum temperature time series for Burdwan is also showing random significant breaks for the same months. The value of statistic are 1.90, 2.07, 2.40 and 1.76 respectively.

Table-40: Result of Von-Neumann Ratio Test (VNR) of Mean Monthly Minimum ($TMin$) Temperature Series.Bold values are significant at $\rho = 0.05\ level$.

Station	Test	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Bankura	VNR	**1.68**	1.35	**1.93**	**2.10**	1.38	**1.61**	1.05	0.90	**0.97**	1.38	1.08	1.05
Birbhum		1.68	**1.40**	**1.98**	**2.36**	**1.51**	**1.70**	**1.08**	0.99	**1.29**	**1.54**	1.06	1.08
Burdwan		**1.90**	1.31	**2.07**	**2.40**	**1.50**	**1.76**	**1.48**	1.41	**1.44**	**1.48**	1.08	1.23
Hooghly		1.82	**1.60**	**2.24**	**2.19**	**1.63**	**1.82**	**1.38**	**1.32**	1.84	1.51	1.39	0.21
Howrah		1.69	**1.41**	1.91	1.62	1.04	**1.30**	**0.75**	0.75	0.69	**1.27**	1.45	1.56
Kolkata		**2.07**	1.50	**2.03**	**2.03**	**1.73**	**1.85**	**1.48**	1.30	1.73	**1.55**	1.67	1.23
Malda		1.27	**0.76**	**1.15**	**1.84**	**1.57**	**1.33**	**0.73**	**0.69**	0.77	0.97	**0.63**	0.65
Midnapore		**2.03**	1.30	**1.29**	**2.04**	**1.69**	**1.78**	**1.19**	1.02	1.01	**1.30**	1.18	0.71
Murshidabad		1.62	1.20	**1.82**	**2.35**	1.52	**1.63**	1.25	1.14	1.23	1.42	1.03	0.89
Nadia		1.70	1.49	2.30	**2.39**	1.47	**1.62**	1.27	1.16	1.50	1.47	1.42	1.40
N.24 Pgs		1.87	1.63	2.26	**2.00**	1.70	**1.58**	0.83	0.77	1.40	1.49	1.39	122
Purulia		0.54	0.69	1.75	2.24	1.79	**1.78**	1.42	1.55	2.26	1.82	0.93	0.59
S. 24 Pgs		1.76	1.43	1.30	0.90	1.05	0.80	0.63	0.36	0.20	0.41	0.81	0.99

The mean annual minimum and mean seasonal minimum temperature time (Table-41) series have also been examined by the Von-Neumann Ratio test for the estimation of their randomness. The result shows that, there are no such significant change points for mean annual minimum temperature time series. Similarly, all the considered seasonal series does not indicate significant change at $\rho = 0.05$ level of significance. All the detected change points are lying below the critical limit. The prior change points are found to occur in between1952 and 1965 and also in a second span between 1982-1995.

Table-41: Result of Von Neumann Ratio Test (VNR) of Mean Annual Minimum ($ATMin$) Temperature and Seasonal ($ATMin$) Temperature Series. Bold values are significant at $\rho = 0.05\ level$.

Station	Test	Annual	Winter	Summer	Monsoon	Post-monsoon
Bankura	VNR	0.67	0.97	1.29	0.68	1.04
Birbhum		0.78	0.99	1.56	0.71	1.12
Burdwan		0.94	1.19	1.62	1.12	1.05
Hooghly		0.99	1.30	1.62	1.10	1.19
Howrah		0.50	1.09	0.88	0.44	1.28
Kolkata		0.93	1.37	1.57	1.04	1.41
Malda		0.30	0.39	1.22	0.40	0.63
Midnapore		1.27	1.54	1.54	0.65	1.06
Murshidabad		0.67	0.70	1.59	0.85	1.06
Nadia		0.98	1.28	1.62	0.96	1.33
North 24 Pargana		1.02	1.57	1.46	1.63	1.26
Purulia		0.61	0.38	1.70	1.47	1.18
South 24 Pargana		0.28	0.82	0.72	0.30	0.44

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Chapter-IV (Monotonic and Potential Change Point)

4.0 Potential Change Point Detection (CUSUM) and Bootstrapping:

The cumulative sum charts (CUSUM) and bootstrapping were performed as suggested by *Taylor (2000)*. Let, $x_1, x_2, \ldots\ldots. x_n$ represents n data points of a time series, and $\sum_0$, $\sum_1$, $\sum_2$, $\sum_3$, ………, $\sum_n$ are iteratively computed as follows:

(a) The average $\bar{x}$ of $x_1, x_2, \ldots\ldots. x_n$ is given by

$$\bar{x} = \frac{x_1+x_2+\cdots+x_n}{n} \qquad (4.1)$$

(b) Let, $\sum_0$ be equal to zero

(c) $\sum_i$ are computed recursively as follows

$$\textstyle\sum_i = \sum_{i-1} + (x_i - \bar{x}), \qquad i = 1, 2, \ldots..n \qquad (4.2)$$

Actually, the cumulative sums are not the cumulative sums of the values. Instead they are the cumulative sums of differences between the values and the average. These differences sum to zero so the cumulative sum always ends at zero, $\Sigma_{n=0}$.

The confidence level can be determined for the apparent change by performing a bootstrap analysis (*Taylor W. 2000; Davison A. C., Hinkley D. V., 1997*). Before performing the bootstrap analysis, an estimator of the magnitude of the change is required. One choice, which works well regardless of the distribution and despite multiple changes is, Δ_i which is defined as

$$\Delta_i = \max_{1\le i\le n} \Sigma_j - \min_{1\le i\le n} \Sigma_i \qquad (4.3)$$

Once the estimator of the magnitude of the change has been selected, the bootstrap analysis can be performed. A single bootstrap is performed by:

(a) Generating a bootstrap sample of n data points of time series, denoted as x_j(*j=1, 2, 3,…, n*), by randomly reordering the original n values. This is called sampling without replacement (SWOR).

(b) Based on the bootstrap sample, the bootstrap CUSUM is calculated following the same method and denoted as, Σ_j

(c) The maximum, minimum and difference of the bootstrap CUSUM are calculated and the difference between the maximum and minimum bootstrap CUSUM is defined as,

$$\Delta_j = \max_{1\le j\le n} \Sigma_j - \min_{1\le j\le n} \Sigma_j \qquad (4.4)$$

(d) Determine whether, $\Delta_j < \Delta_i$

The bootstrap analysis consists of performing a large number of bootstraps and counting the number of bootstraps for which bootstraps difference is Δ_j it is less than the original differenceΔ_i. Let N is the number of bootstrap samples performed and let K be the number of bootstraps for which $\Delta_j < \Delta_i$. Then the confidence level that a change occurred as a percentage is calculated as follows:

$$\text{Confidence Level (CL)} = \left\{\frac{K}{N}\right\}100 \qquad (4.5)$$

Bootstrapping results is a distribution free approach with only a single assumption, which is an independent error structure.

Once a change has been detected, an estimate of when the change occurred can be made. One such estimator is the CUSUM estimator. Let $i = m$, such that:

$$|\Sigma_m| = max\,|\Sigma_i| \qquad (4.6)$$

Then m is the point furthest from zero in the CUSUM chart. The point m estimates last point before the change occurred. The point $m+1$ estimate the first point after the change. The second estimator of when the change occurred is the mean square error (MSE) estimator. Let MSE (m) be defined as:

$$\text{MSE (m)} = \sum_{i=1}^{m}(x_i - \bar{x}_1)^2 + \sum_{i=m+1}^{n}(x_i - \bar{x}_2)^2 \qquad (4.7)$$

$$\text{Where, } \bar{x}_1 = \frac{\sum_{i=1}^{m} x_i}{m}, \text{ and } \bar{x}_2 = \frac{\sum_{i=m+1}^{n} x_i}{n-m}$$

In MSE error estimation, the data series is split into two segments, 1 to m, and m+1 to n, then it is estimated that how well the data in each segment fits their corresponding averages.

The value of m, for which MSE (m) is minimized, gives the best estimate of the last point before change, while the point m+1 denote the first point after change. In the same way, data of each segment can be passed through the above method to find level 2 change points that divides corresponding segments into sub-segments. Repetition of the procedure mentioned above helps us to find out significant change points at subsequent levels for each of which associated confidence limit and level can be determined by bootstrapping. In this manner multiple change points can be detected by incorporating additional change points each at successive passes that will continue to split the segments into two. Once the change points, along with associated confidence level, have been detected a backward elimination procedure is then used to eliminate those points that no longer qualify test of significance. To reduce the rate of false detection, when a point is eliminated, the surrounding change points are re-estimated along with their significance level. Thus the significant change points have been detected for the temperature time series considered for this study.

Variations and trends of annual mean maximum temperature ($ATMax$), annual mean minimum temperature ($ATMin$) and rainfall series were examined by following method. The cumulative sum charts (CUSUM) and bootstrapping were used for the detection of abrupt changes over the series. Section of the CUSUM chart with an ascending trend indicates a period when the values remaining above the overall average. Likewise, a section with a descending trend indicates a period of time where the values lie below the overall average. The confidence level can be determined by performing bootstrap analysis.

4.1 Result and Discussion:

Before the analysis of climatic trend and variability of the series, we have applied CUSUM and bootstrapping analysis for detecting change points. The application of bootstrapping is used to confirm the associated level of change with confidence interval. This method is a strong statistical technique for detecting potential change in the time series. Mean monthly maximum $(TMax)$, annual average of maximum temperature $(ATMax)$, seasonal maximum temperature $(STMax)$, mean monthly minimum temperature $(TMin)$, annual average of minimum temperature $(ATMin)$, seasonal minimum temperature $(STMin)$ and rainfall series are analyzed by this method. The mean monthly maximum temperature $(TMax)$ time series indicates that, the prior and after change confidence interval are not same for all months. Some of the months adjusted their sub-series order by different length. The differences of the mean values are also fluctuates in different adjusted length. The level-1 change does not meet the 100% confidence level for all such months. Moreover, the minimum series are presenting almost similar results. The results of annual average maximum temperature $(ATMax)$ is shown in Table-42. Each table contains different level of change with level identification. The consequent level number and their corresponding red band indicate the succession of change level for each observatory. The level -1 change for $ATMax$ of the Bankura observatory has occurred in 2007 while the confidence level is 97%. This change is identified since 2005 to 2009 temporal confidence interval. The change point for the prior and after mean level change are 31.76 ℃ and 32.72 ℃ respectively. There are three level of change (Level-2, 3, 5) in this time series, while only level-2 change meets the 100% confidence level. $TMax$ series for Birbhum observatory has indicated level-1 change in 1952, while its confidence interval is restricted in between 1949 to 1961 and this change meets the 100% confidence level. The mean level of prior and after change in 1952 is 31.87 ℃ and 32.43 ℃ respectively. This series has also detected other three changes in different level (Level-2, 3, 4.). The $ATMax$ series for Burdwan, Kolkata, Nadia and North 24 Pargana do not have any level -1 change.

Consequently, the $ATMax$ series for Hooghly, Howrah, Midnapore, Murshidabad, and Malda have met the 100% confidence level for level-1 change. Maximum segmentation (5) of the time series is found in Nadia and North 24 Pargana. The time series for Malda is very consistent and it has indicated single potential change point in 1940, while the confidence level meets 100% level of confidence. The mean temperature level for this series was 30.92 ℃ prior to the change and it becomes 31.30 ℃ after the change. According to the suggested literature, these types of result may confirm the actual shift of time series limit which has been treated by anthropogenic effect. For the annual average of minimum temperature ($ATMin$) results are quite different to the above statement (Figure-15 & Table-43). This result reveals that, only four observatories time series shows level-1 change. The $ATMin$ series for Hooghly has indicated level-1 change in 1932. Where confidence level meets 100% limit and confidence interval has been confirmed within long period of time (1925 to1960). The mean level for this change are 21.52 ℃ and 21.31 ℃ respectively. Another $ATMin$ series for North 24 Pargana also has indicated level-1 change in 1996, while confidence interval has specified since 1990 to 1999. The mean level change of prior and after change are 21.77 ℃ and 22.25 ℃ respectively. The $ATMin$ series for Kolkata and Malda also indicates level-1 change in 1988 and 2005 respectively. Graphical presentation of CUSUM for $ATMax$ is shown in Figure-14. The period of change has been indicated with shaded background which has been confirmed by the bootstrapping technique.

Table-42: Significant change with different level by CUSUM and Bootstrapping for $ATMax$ Series.

Bankura

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
42	(22, 51)	100%	31.591	31.844	2
58	(55, 67)	97%	31.844	32.273	5
71	(65, 100)	98%	32.273	31.766	3
107	(105, 109)	97%	31.766	32.722	1

Birbhum

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
52	(49, 61)	100%	31.877	32.43	1
76	(70, 78)	95%	32.43	31.53	2
83	(80, 85)	97%	31.53	32.236	3
104	(100, 109)	97%	32.236	31.694	4

Burdwan

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
52	(50, 54)	100%	31.823	32.446	3
71	(66, 94)	100%	32.446	31.984	2

Hooghly

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(46, 51)	100%	31.363	31.952	7
71	(63, 101)	98%	31.952	31.577	2
104	(103, 108)	100%	31.577	30.086	1

Table Cont.......

Howrah

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(46, 51)	100%	30.882	31.47	1
72	(68, 111)	100%	31.47	31.003	4

Kolkata

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(45, 61)	100%	31.057	31.453	4
110	(50, 111)	100%	31.453	32.167	4

Midnapore

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(46, 51)	100%	30.831	31.38	1
72	(62, 91)	99%	31.38	30.996	3
103	(97, 107)	97%	30.996	31.561	2

Murshidabad

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
52	(50, 55)	100%	32.016	32.63	2
71	(64, 102)	96%	32.63	32.256	5
104	(101, 104)	100%	32.256	31.102	1

Table Cont….

Nadia

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
21	(7, 21)	96%	31.898	32.19	6
26	(26, 40)	99%	32.19	31.849	5
52	(51, 54)	100%	31.849	32.532	2
71	(66, 93)	99%	32.532	32.082	3
108	(106, 109)	100%	32.082	30.433	4

Malda

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
40	(33, 70)	100%	30.962	31.301	1

North 24 Pargana

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
21	(7, 21)	95%	31.898	32.19	6
26	(26, 40)	99%	32.19	31.849	5
52	(51, 54)	100%	31.849	32.532	2
71	(67, 94)	98%	32.532	32.082	3
108	(106, 109)	100%	32.082	30.433	4

Purulia

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
52	(50, 56)	100%	31.099	31.656	2
71	(65, 106)	97%	31.656	31.227	5
109	(108, 109)	93%	31.227	32.896	1

Figure-14: CUSUM chart for $ATMax$ Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

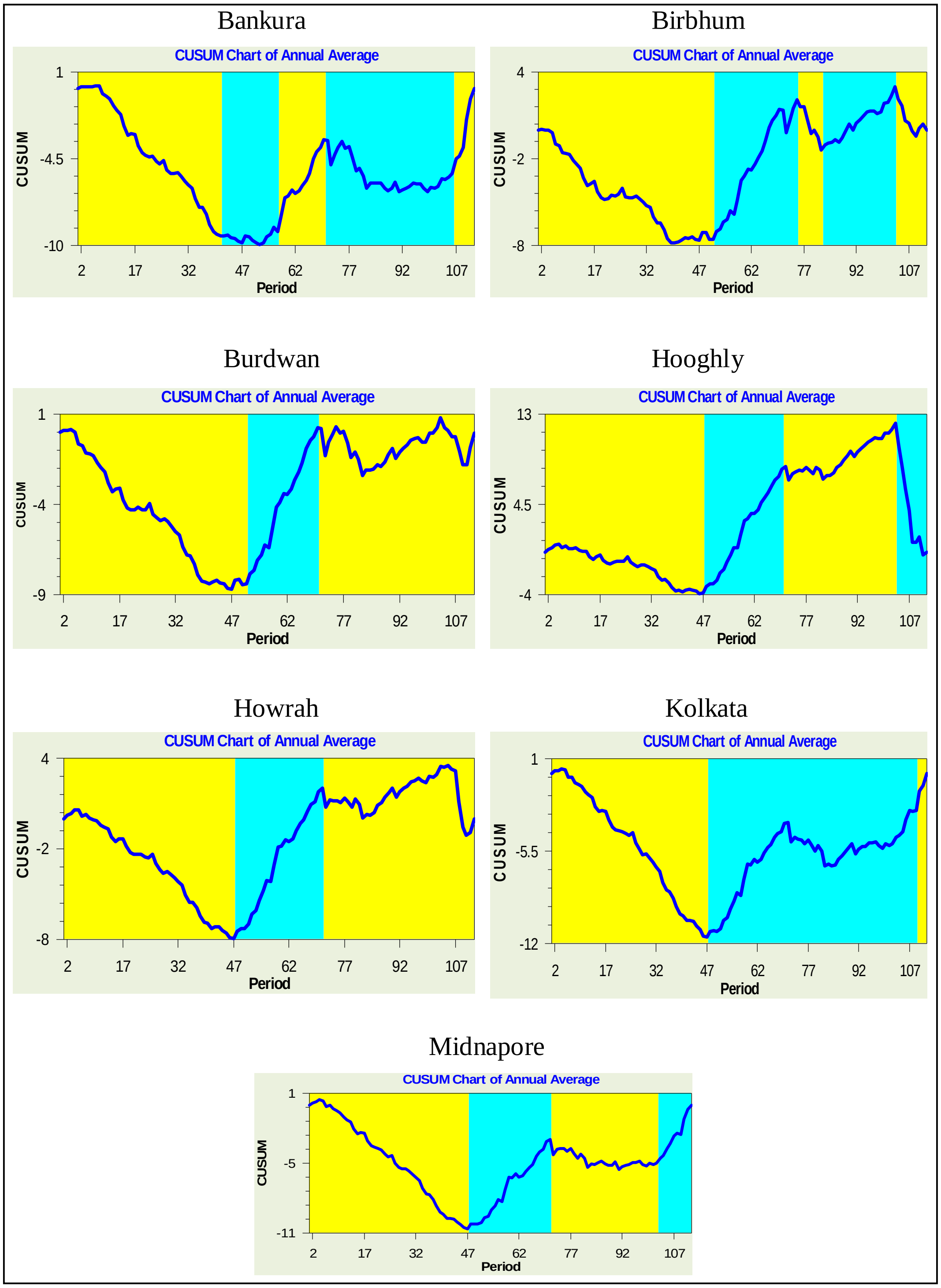
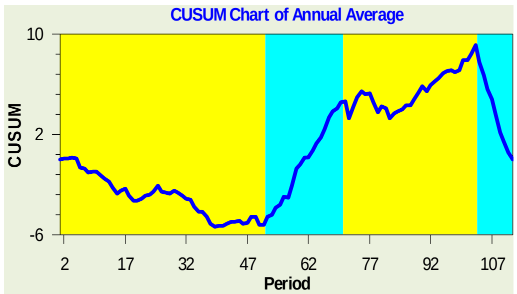
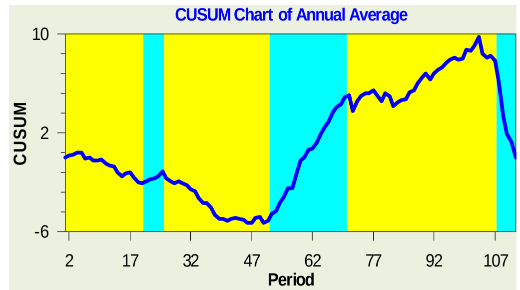


Figure Cont.....

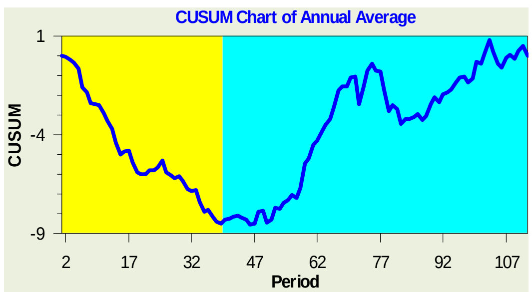
Murshidabad



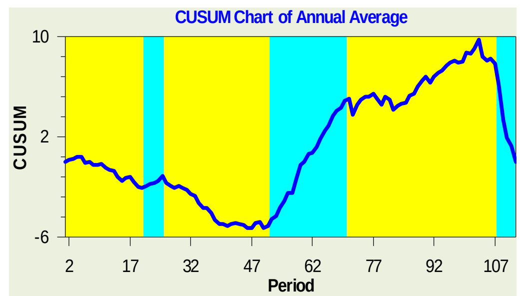
Nadia



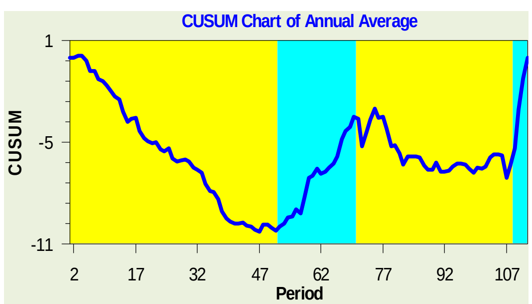
Malda



North 24 Pargana



Purulia



South 24 Pargana

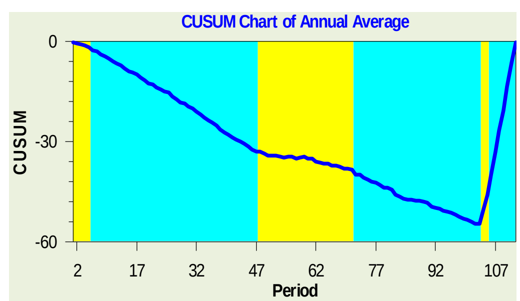


Table-43: Results of Significant change with different level by CUSUM and Bootstrapping analysis for $ATMin$ Series.

Hooghly

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
32	(25, 60)	100%	21.528	21.811	1
88	(34, 92)	98%	21.811	22.084	3
99	(96, 103)	94%	22.084	22.424	5
105	(105, 105)	100%	22.424	21.374	6

Kolkata

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
32	(28, 41)	100%	21.963	22.359	2
66	(44, 76)	91%	22.359	22.074	4
88	(83, 90)	93%	22.074	22.519	1
99	(94, 108)	100%	22.519	22.8	2

Malda

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
20	(17, 26)	100%	18.833	19.306	4
72	(72, 72)	100%	19.306	17.93	3
76	(76, 76)	99%	17.93	19.454	2
89	(81, 90)	97%	19.454	19.959	5
92	(91, 92)	98%	19.959	19.425	6
99	(99, 101)	98%	19.425	20.17	3
105	(105, 105)	98%	20.17	21.667	1
106	(106, 109)	99%	21.667	21.94	5

North 24 Pargana

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
32	(28, 50)	100%	21.482	21.77	2
96	(90, 99)	100%	21.77	22.253	1

Figure-15: CUSUM chart for $ATMin$ Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

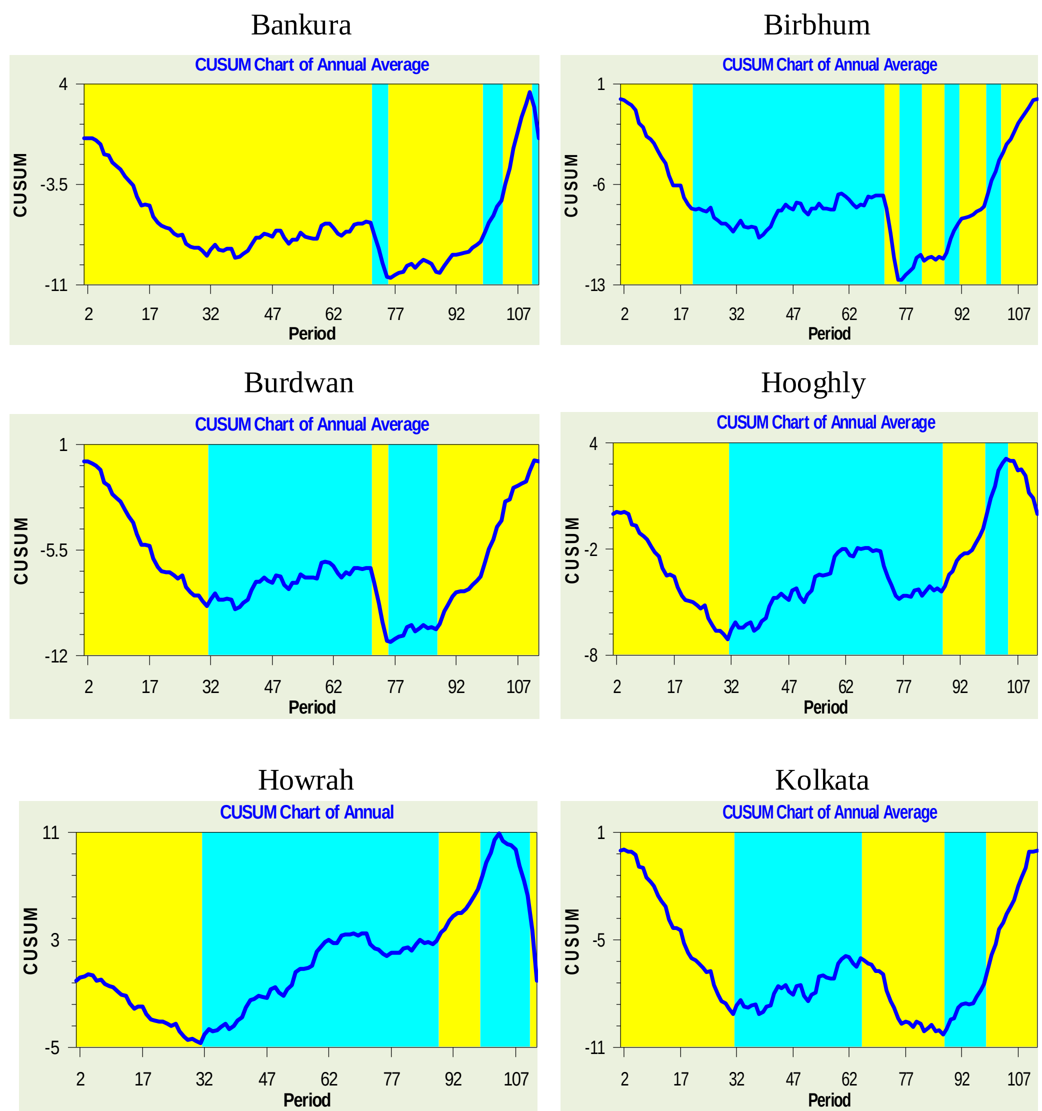
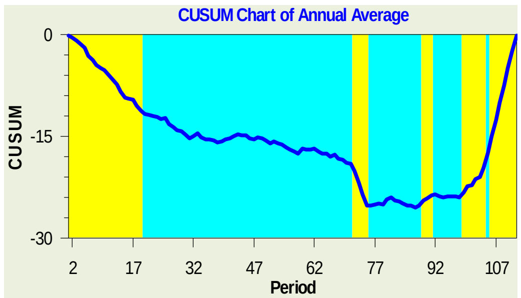
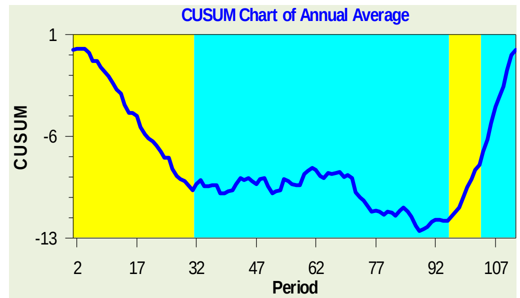


Figure Cont.....

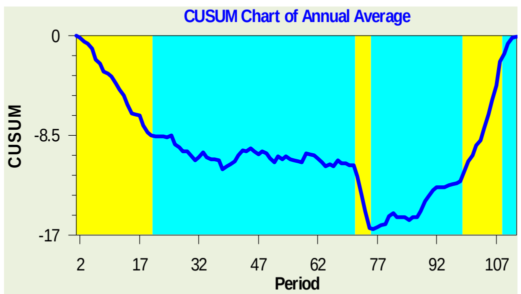
Malda



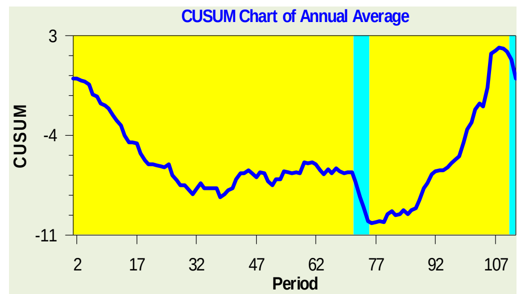
Midnapore



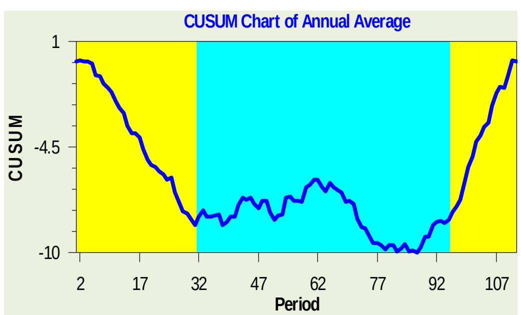
Murshidabad



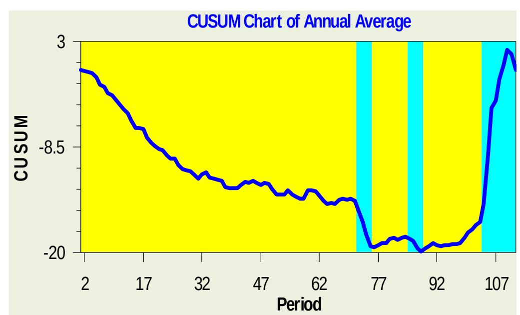
Nadia



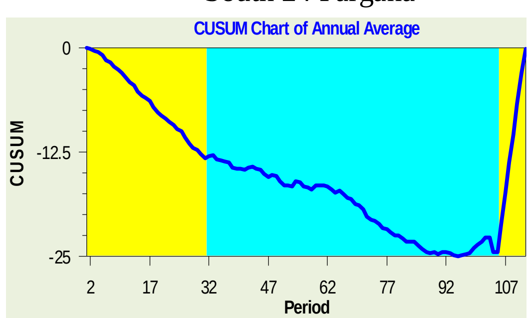
North 24 Pargana



Purulia



South 24 Pargana



This study also examines the seasonal temperature series for its potential change identification. It is also focused on the nature of the association of the data set for seasonal series. According to this analysis, the seasonal series are indicating maximum four sub-segments and minimum two segments for Winter season among the all observatories. In the given Table-44, first row indicates the yearly series. This table shows the Winter result for all the considered observatories. In case of the Bankura observatory, level -1 change has occurred in the temporal time in 2007 and the bootstrapping has confirmed its associated interval in between short temporal interval (2006-2009). Here, the confidence level has met the 98% level. The mean level difference for this inspection is 1.77 ℃ while the prior mean value is 28.56 ℃ and the after mean is 30.33 ℃. Here it is also presented that the after mean level is higher than the prior level of mean. This series also indicates other two sub-sections after the detection of potential change point. The second two sub-sets has met the 100% confidence level by this method for Bankura observatory. For the change point 1947, the after mean level is higher than the prior mean. On the other hand, for change point 1971, the after mean level is lower than the prior mean level. Observatory, Birbhum also reveals three potential change points where 1947 is the level-1 change. Here, the confidence interval has confirmed the temporal scale under five (5) years gap. The level-1 change has met 100% confidence level. The mean level has increased 1.09 ℃ in respect of change point detection. The change point at 1971 has also met the 100% confidence level by the bootstrapping association over the considered series. The primary or level-1 change is not confirm for the Burdwan observatory. This Winter series is quite different from the previous two observatories. The change point at 1971 is the common occurrence for this observatory, while the prior mean level is 29.72 ℃ and the after mean level is 28.81 ℃ respectively. The decrease of the mean value is 0.91 ℃. Other two changes has confirmed the level-3 and level-4 change respectively. It is remarkable that, the second mean level is higher than the prior mean level for these two changes. Winter seasonal temperature series for Hooghly is very interesting and its frequency domain is quite different than the other considered series.

The CUSUM analysis confirms the four levels of change which are significantly potential in character. The level-1 change has been observed at 2004 while the confidence interval has been adjusted within very short temporal span (2003-2005). The confidence level has confirmed 99% level of confidence. The change of mean level for the level-1 change is very interesting while the prior mean level value is 28.66 ℃ and the after mean value is 26.4 ℃ . The decrease of the mean level for the level-1 change is 2.26 ℃. The CUSUM analysis for this time series has adjusted the time series with 1000 bootstraps without the replacement of the particular data point and also adjusted the mean standard error for this series. Interestingly, this series has revealed two such level-2 changes depending upon their potential character. Those changes confirms in 1947 and in 2009. The confidence level of those changes are not same where the first level-2 Change meet the 100% confidence level and the after level-2 change confirms at 92% confidence level. Technically, these two changes are termed as level-2 change but their associated characters are different from each other. For the Howrah observatory, winter series has confirmed level-1 change in 1947. The confidence interval confirms the limit of just 5 years span (45-50). The mean level has been increased by 0.96 ℃. The considered time series presents the randomness positively. The $ATMax$ series fir this observatory is not smooth in respect to the variability of the frequency of $TMax$. So, the bootstrapping technique has typically adjusted the temporal span and indicates level-7 change point directly. For both cases like level-1 and level-7, the confidence level has been confirmed at 100% but the level-7 change has indicated the mean level for decreasing trend. The decrease of mean level is 0.62 ℃ while the prior mean value and after mean value are 28.93 ℃ and 28.25 ℃ respectively. The seasonal series for the Kolkata observatory is very important because it is considered as the Heat Island area. The winter series for this observatory consistently indicates the level-1, level-2 and level-3 changes. Level-1 change has occurred in 1947 and the confidence interval has been confirmed within 6 years (1945-1951) temporal gap. Bootstrap has confirmed the 100% confidence level. Increased mean level is 0.97 ℃ while the prior mean value and after mean values are 28.12 ℃ and 29.09 ℃ respectively.

The level-2 change has occurred in 1972. Level-3 change has occurred in 2006 while the confidence interval has been confirmed within 7 years (2003-2010) but the confidence limit does not meet the 100% confidence limit (91%). The mean level of the considered time series has been indicating increasing order in respect of prior and after sub-series configuration. Their numeric values of mean level are $28.40\,℃\ and\ 29.5\,℃$ respectively. The increased amount of mean level is $1.1\,℃$. According to real feeling of the local weather of the Midnapore observatory area, the winter temperature is always higher than the normal level that is recorded by the IMD in day time, but in night time it is quite adverse than the day time temperature. Normally the daily temperature diurnal range is very high in winter for Midnapore observatory. So, the winter temperature series for this observatory may differ from the nearest other observatories, but after the analysis of the $STMax\ (Winter)$series by the CUSUM and bootstrapping method, it reveals consistent two level of change those are significant and indicates the outlier composition of the series. The level-1 change has occurred in 1947 and the confidence interval has been confirmed within 6 years (1945-1951) temporal gap. The confidence limit positively meets the 100% level here. Prior mean value is $28.0\,℃$ and after mean value is $28.91\,℃$ respectively. Increased amount of mean value is $0.91\,℃$. Level-2 change has indicated the change year in 1972. This change also confirms the 100% confidence level but its temporal confidence interval is confirming long period of time gap (163-1990, 27 years). Instantly it's after mean level is lower than the prior mean level ($28.91\,℃\ to\ 28.42\,℃$). The Winter seasonal $STMax$ series of the Murshidabad observatory also indicates only three level of change such as level-1, level-3 and level-4 respectively excluding level-2 change. The level-1 change has occurred in 2004 with bootstrapping association for confidence level 99%. The sub-sectional mean level has followed decreasing order while the prior mean level is $28.96\,℃$ and the after mean level is $27.77\,℃$ respectively. Confidence interval has confirmed within 8 years (2001-2009) temporal gap. On the other hand, other two significant changes have occurred in 1947 and in 1971 accurately. The level-3 change and level-4 change has confirmed 100% confidence level where their mean level fluctuation is reverse with each other.

Moreover, the mean level for level-3 change is decreasing by $29.65\ ℃\ to\ 28.96\ ℃$ and for the level-4 change; the mean value is increasing like $28.63\ ℃\ to\ 29.65\ ℃$ respectively. The raw nature of the Winter temperature of the Nadia observatory is randomly ordered when it has employed for CUSUM and bootstrapping analysis through the Change Point Analyzer software. However, this $STMax$ series also indicates the three level of change where primary sub-section like level -1 change is prominent. It confirms in 2004 with the confidence level of 97%. The temporal confidence interval has confirmed with 8 years (2002-2010) temporal gap. The mean for this winter series has decreased by $1.32\ ℃$ while the prior mean level value and after mean level values are $29.15\ ℃\ and\ 27.83\ ℃$ respectively. For this series the bootstrapping has been performed typically and estimates the associated level of adjustment for conforming the level of any change. Here, the result shows that, this process actively indicates other two level of change like level-3 and level-6 respectively. Technically, the level-2, level-4 and level 5 are absent from this control chart. For the level-3 change, the associated mean value has been decreased by $0.84\ ℃\ \ (29.99\ ℃\ to\ 29.15\ ℃)$ and for the level-6 change, the mean values has increased by $1.1\ ℃\ \ (28.89\ ℃\ to\ 29.99\ ℃)$. But both the level has met 100% confidence limit. Remarkably, their associated confidence interval is different from each other.

Outlier influence in the winter temperature series for Malda observatory is very strong, because the level-1 change has not been identified here. So, it can be stated that, the primary data segmentation is completely a failure to identify the level-1 change. In this case, other three levels like level-2, level-3 and level-4 has been estimated by the CUSUM and bootstrapping method. After adjusting the Mean Standard Error (MSE), all changes completely meet 100% confidence level for this observatory. The level-2 change has occurred in 1975 with confidence interval 24 years $(1965 - 1989)$ while the mean level of this change point is decreased by $0.54\ ℃\ (28.19\ ℃\ to\ 27.65\ ℃)$. The level-3 change has occurred in 1947, while the mean level has been increased. For the last level of change like level-4 change has occurred in 2004 and its mean level has decreased by $0.60\ ℃$. North 24 Pargana is one of the important observatory that has been selected for this work.

The Winter $STMax$ series for this observatory has also been checked by the CUSUM and bootstrapping techniques. The result indicates that, only three level of change has been detected for this temperature series. The level-1 change has been identified in 2004 while its associated adjusted confidence interval is 9 years (2002-2011) temporal gap and the confidence limit is 97%. The mean level of the prior and after the segmentation is $29.15\ ℃\ and\ 27.83\ ℃$ respectively. Continuous decreasing trend nature is prominent from this result. On the other hand level-3 change has pointed out the change year in 1971 while its confidence level is 100%. Prior and after mean levels are $29.99\ ℃\ and\ 29.15\ ℃$ respectively. Here it is also presented that the decreasing trend order is the most common event for the mean level change. Another potential change point has been detected in 1953, which is considered as level-6 change. Remarkably, the confidence level is 100% and confidence interval is too short than the other two changes. The result of CUSUM and bootstrapping for the South 24 Pargana observatory is also shown in Table-44. The three level of change has been revealed by this technique, such as level-2, level-3 and level-4. The level-2 change has been confirmed in 1942 while confidence level is 93%. The association of the temporal gap has estimated for 15 years temporal gap $(1932\ to\ 1947)$ by the bootstrapping technique. The mean value of the prior segment is $27.51\ ℃$ and after segment mean level is $28.03\ ℃$ respectively. The increasing amount of the mean level temperature is $0.52\ ℃$. Level-3 change has confirmed in 2005 and the confidence level has met 100% level. Here also the mean level change indicates increasing trend value in accordance to the segmentation of the temperature time series. The prior mean level is $28.12\ ℃$ and the after mean value is $30.21\ ℃$. The amount of mean level change is $2.09\ ℃$. The level-4 change has been observed in 1953 over the considered $STMax$ series. Confidence level has been confirmed at 94 %. Here also a noticeable event is that the bootstrapping has taken long temporal span (51 years, 1953 to 2004) as its requirement for estimating the confidence interval and the mean level for the different subsection with increased amount of mean level.

The observatory Purulia does not reveal the level-1 change over the considered ($STMax$) temperature time series. This series has been indicated total three level of change like level-2, level-3 and level-4 respectively. The level-2 change has been confirmed its potential change year is 1942, 1953 for level-3 and 2005 for level-4 change over the considered time series. Henceforth, level-3 change has met with 100% confidence level and minimum interval temporal span has adjusted. Level-4 change, which has taken long temporal gap (51 years, 1953 to 2004) over the period. Graphical presentation of the CUSUM chart is shown in Figure-16 for winter temperature series.

Table-44: Significant change point with different level by CUSUM and Bootstrapping for $STMax$ Series (winter).

Bankura

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 50)	100%	28.36	29.295	3
71	(66, 77)	100%	29.295	28.566	3
107	(106, 109)	98%	28.566	30.333	1

Birbhum

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 50)	100%	28.432	29.522	1
71	(69, 74)	100%	29.522	28.391	2
85	(74, 112)	91%	28.391	28.766	3

Table Cont….

Burdwan

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
42	(32, 46)	95%	28.49	29.07	4
53	(50, 59)	95%	29.07	29.722	3
71	(68, 79)	100%	29.722	28.811	2

Hooghly

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 50)	100%	28.367	29.353	2
72	(65, 79)	100%	29.353	28.664	3
104	(103, 105)	99%	28.664	26.4	1
109	(108, 109)	92%	26.4	28.625	2

Howrah

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 50)	100%	27.979	28.933	1
72	(66, 82)	100%	28.933	28.253	7

Table Cont….

Kolkata

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 51)	100%	28.129	29.099	1
72	(66, 78)	100%	29.099	28.407	2
106	(103, 110)	91%	28.407	29.5	3

Midnapore

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 51)	100%	28.008	28.916	1
72	(63, 90)	100%	28.916	28.429	2

Murshidabad

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(45, 50)	100%	28.631	29.657	4
71	(66, 81)	100%	29.657	28.963	3
104	(101, 109)	99%	28.963	27.778	1

Table Cont….

Nadia

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
53	(51, 55)	100%	28.894	29.998	6
71	(68, 76)	100%	29.998	29.155	3
104	(102, 110)	97%	29.155	27.833	1

Malda

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
47	(44, 51)	100%	27.31	28.197	3
75	(65, 89)	100%	28.197	27.652	2
104	(86, 112)	100%	27.652	27.056	4

North 24 Pargana

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
53	(51, 55)	100%	28.894	29.998	6
71	(67, 77)	100%	29.998	29.155	3
104	(102, 111)	97%	29.155	27.833	1

Table Cont….

South 24 Pargana

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
42	(32, 47)	93%	27.518	28.037	2
53	(53, 104)	94%	28.037	28.127	4
105	(104, 107)	100%	28.127	30.219	3

Purulia

Table of Significant Changes for Winter

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
42	(32, 47)	93%	27.518	28.037	2
53	(53, 104)	94%	28.037	28.127	4
105	(104, 107)	100%	28.127	30.219	3

Figure-16: CUSUM chart for $Winter$ ($STMax$) Temperature Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

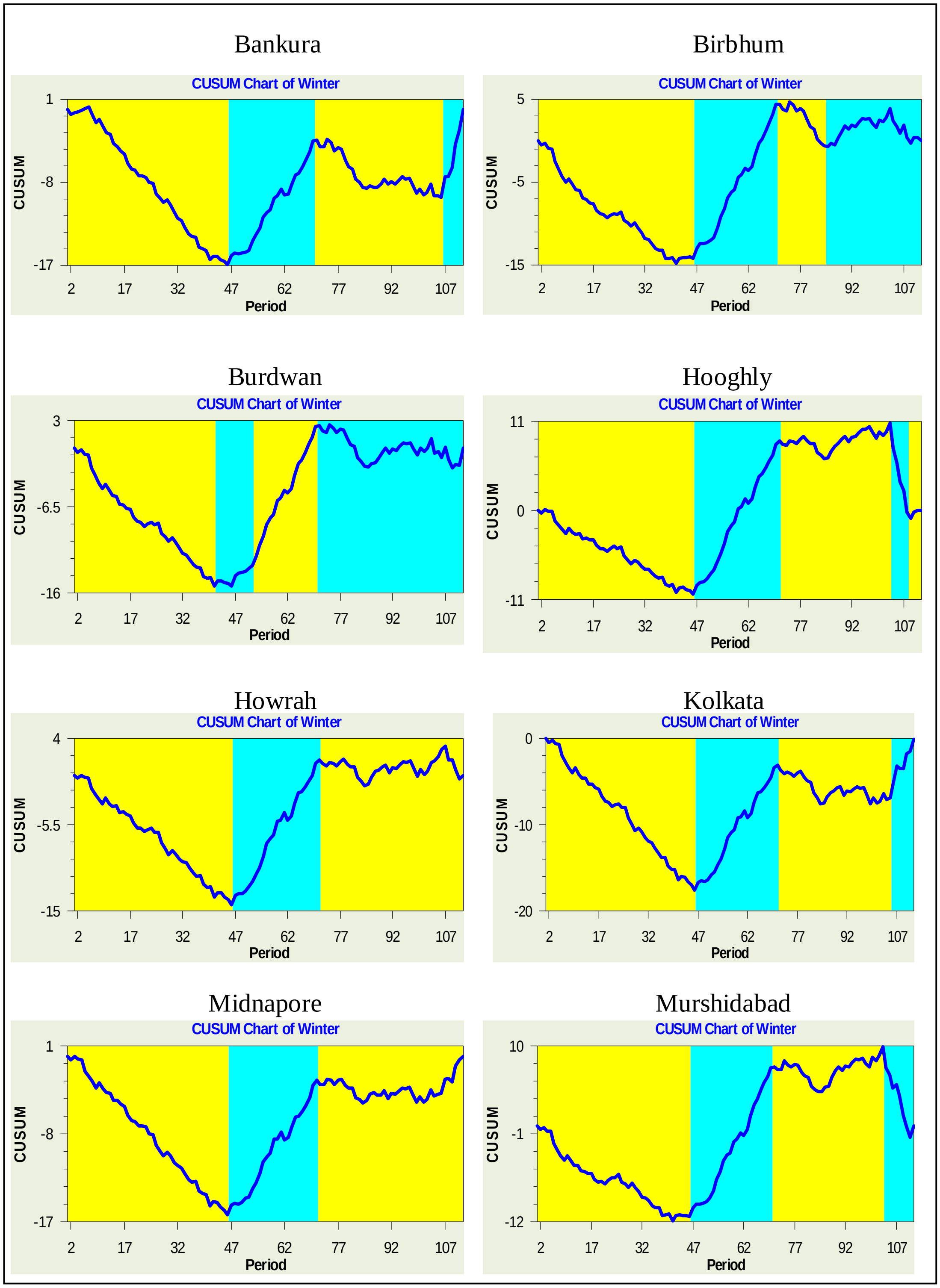
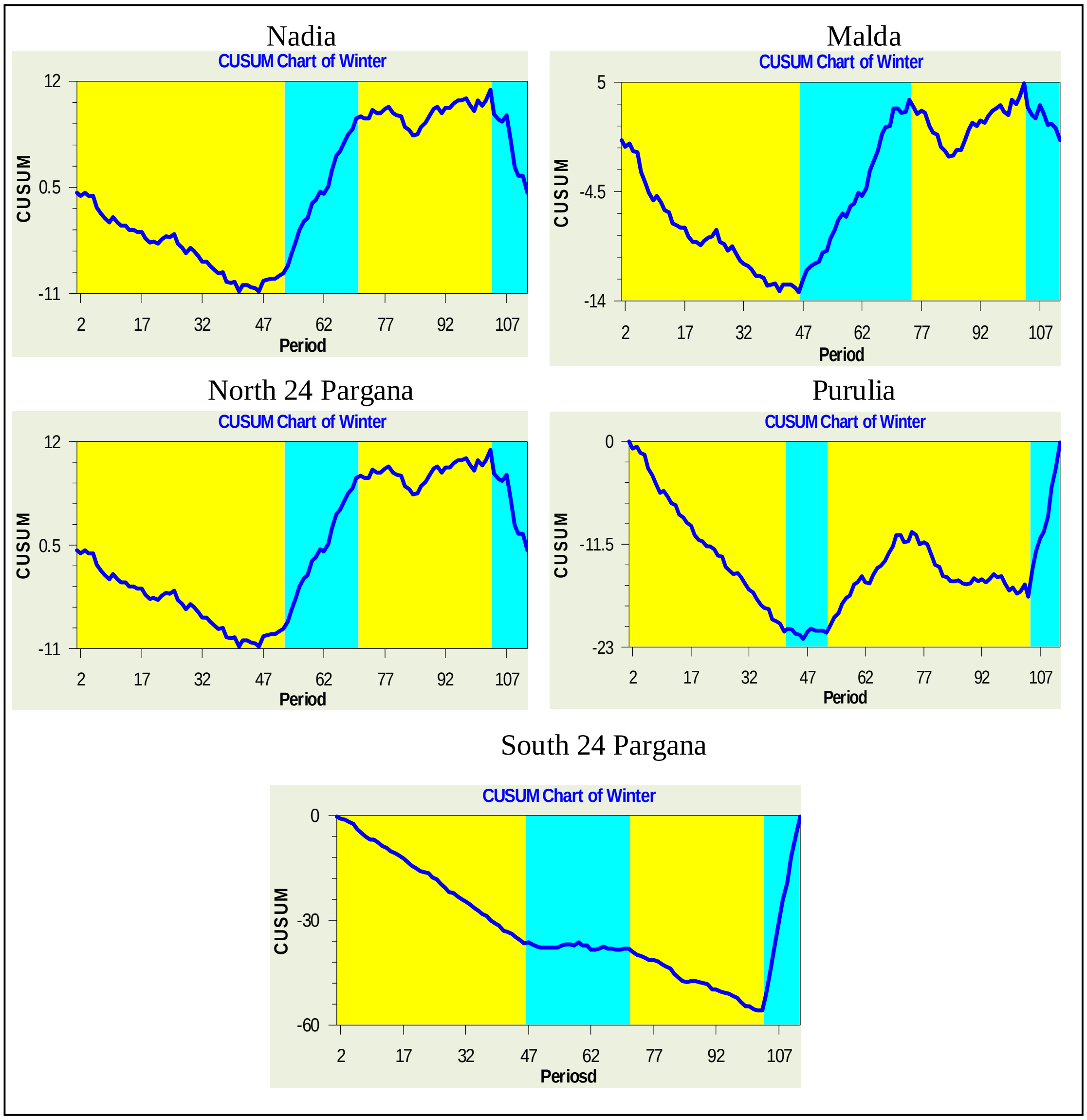


Figure Cont….


Nadia
CUSUM Chart of Winter
CUSUM
12
0.5
-11
2 17 32 47 62 77 92 107
Period
Malda
CUSUM Chart of Winter
CUSUM
5
-4.5
-14
2 17 32 47 62 77 92 107
Period
North 24 Pargana
CUSUM Chart of Winter
CUSUM
12
0.5
-11
2 17 32 47 62 77 92 107
Period
Purulia
CUSUM Chart of Winter
CUSUM
0
-11.5
-23
2 17 32 47 62 77 92 107
Period
South 24 Pargana
CUSUM Chart of Winter
CUSUM
0
-30
-60
2 17 32 47 62 77 92 107
Periosd

The significant potential hidden change point for Summer season has identified by this technique also. The result of the CUSUM and bootstrapping is shown in Table-45 & Figure-17. Bankura observatory has been indicating two respective changes such as level-1 and level-2 respectively. The mean level change is very significant for this observatory. Level-1 change has indicated decreasing trend and the level-2 change has been signifying the increasing trend over the period. The amount of those changes are $0.64\ ℃\ and - 0.69\ ℃$ respectively. For the Birbhum observatory, $STMax\ (Summer)$ series has detected two change points. Where one is primary or level-1 change and another is level-4 change. Level-1 change has detected in 2004 while its confidence level meets 100% and the bootstrapping has been confirming its interval on and from 1993 to 2009. The mean level for the level-1 change is $37.16\ ℃$ for the prior and $36.18\ ℃$ for after change. The amount of mean level change is $0.12\ ℃$. Level-4 change has detected with adjusting the long temporal interval such by 99 years (1904-2003). Here also present that the mean level of this change is decreasing to $0.45\ ℃$. The considered $STMax\ (Winter)$ series for the Burdwan is apparently consistent than the other summer series. However, no such prior change has identified fir this series. This series has revealed that level-4 change as a single change point. This level has been confirmed in 2004 and the confidence level is 99%. Detection of the change has detected between adjusted interval on and from 1979 to 2008 (29 years). The mean level for the prior change is $37.21\ ℃\ and\ 36.11\ ℃$ for after change. Outlier detection of the Summer for Hooghly observatory has invented three consecutive changes like level-1, level-2 and level-3 respectively. In this condition, primary or level-1 change has detected in 2004 while its confidence level is 97%. Dramatically, the shift of mean level is maximum by $1.94\ ℃$. The level-2 change has occurred in 1972. Its temporal gap is 42 years and confidence level is 96%. The sub-sequent mean level is continuously decreasing with amount to $0.73\ ℃$. Level-3 change coincides in 1948 at 98% confidence level. The mean level for this change has increased according to the prior and after change sequence. Another one summer series for Howrah observatory has indicated three sub-sequent changes in its considered temporal period. This inspection suggested that, level-2 change and two level-3 change is the common event.

The level-2 change has identified the significant change point in 1972 while its bootstrapping association has confirmed the adjusted temporal span since 1963 to 2001. Here the confidence level is 98%. The selected mean level has confirmed for the prior series by 35.57 °C and the after mean level is 34.84 °C. Level-3 change has happened in two times and indicated 1948 and 2004 are significant. In both the cases, confidence level is assign 100% level. The mean level change has settled at decreased trend order for 2004 change point and increased trend for 1948 change point selection. The change of mean level at 1948 is 0.61 °C. Observatory Kolkata has indicated two such changes like level-1 and level-2 respectively. Level-1 or primary change point was detected in 1972. The temporal span has encroached since 1962 to 2008. But the confidence level is 97% level. The mean level of the prior section is 35.76 °C and the after sections mean level is 35.08 °C consequently. The nature of mean level is negative and its amount is 0.68 °C. Level-2 change was settled in 1948. The confidence level is 98%. For this change the sectional mean level has been increased for the following decade. Mean level of the prior section is 35.15 °C and 35.76 °C for after section.

Significant change point for Summer seasonal series has also been calculated for the Midnapore observatory. This series does not signify any primary level of change. Only level-4 and level-5 change has been detected by the CUSUM and bootstrapping method. The level-4 change has indicated in 1948 is one of the significant event over the considered period. Its confidence interval since 1929 to 1962. But confidence level is 99%. Mean level change amount is 0.58 °C while the mean level for the prior section is 35.47 °C and the after mean level is 36.05 °C respectively. Henceforth, the level-5 change has indicated in 1972 is one of the significant change years. Interestingly, its confidence level is 100% and sectional mean level has decreased with the numeric amount by 0.65 °C. Summer seasonal series for the Murshidabad observatory is indicating single change point which considered as level-1 change. The confidence level is 100% and adjusted bootstrapping association confirms its interval since 2000 to 2006. The mean level of the considered series has separated at 2004 that is considered as potential change point over the series. Men level of the prior section is 37.04 °C and the after section mean level is 35.11 °C respectively.

Ultimately, the arrangement of the mean level has signified decreasing trend of Summer seasonal temperature series. Series for Nadia is indicating also single potential change point over the 111 years temporal period. This significant change has occurred in 2007, when its confidence level has been specified at 97% level. The given graph also presents that, the mean level has decreased according to following period. The shift amount of the mean level by $-2.36\ ℃\ (36.39\ ℃ - 34.05\ ℃)$. The summer temperature series has revealed single change point which is assigned as level-3 change for Malda observatory. It has occurred in 1977 while prior mean level is $35.95\ ℃\ and\ 35.42\ ℃$ for after change. The confidence level has been confirmed at 99% level. This change has taken long period of time since 1910 to 2002 temporal span. The North 24 Pargana has revealed level-1 change that has occurred in 2007. Temporal period has been confirmed by bootstrapping since 2005 to 2007. The shift of mean level are $36.39\ ℃\ and\ 34.05\ ℃$ respectively and the estimated confidence level is 97%. The observatory Purulia is the most western point of this study area. It is indicating three changes altogether. Among them, primary or level-1 change has occurred in 2004 and the other two change has signified level-2 change commonly. Their happening years are 1977 and 2008 respectively. The mean level change of the level-1 change is $5.44\ ℃$. The series has been considered at 100% confidence level. One of the level-2 change has occurred in 1977 and another is significant in 2008. The decreasing trend is prominent from 1977 and increasing trend from 2008 is prominent in sequence. According to the serial number of the observatory, South 24 Pargana is remaining with 13th observatory of the consideration. Here also present a significant change year that has occurred in 2006 over the temporal scale. But this change is level-4 change. Interestingly, bootstrapping adjustment has confirmed the potential change within a single year conformation (2006). But its confidence level has met 100% level. Change of mean level has further increased by $7.25\ ℃$. All these results for Summer temperature analysis are graphically constructed and shown in Figure-17.

Table-45: Significant change point with different level by CUSUM and Bootstrapping for $STMax$ Series (Summer).

Bankura

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
21	(15, 46)	90%	37.116	37.804	2
72	(51, 106)	95%	37.804	37.161	1

Birbhum

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
77	(4, 103)	92%	37.611	37.165	4
104	(93, 109)	100%	37.165	36.185	1

Bardwan

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
104	(79, 108)	99%	37.212	36.111	4

Table Cont….

Hooghly

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(30, 62)	98%	35.893	36.477	3
72	(61, 103)	96%	36.477	35.749	2
104	(102, 112)	97%	35.749	33.807	1

Howrah

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(33, 61)	100%	34.964	35.573	3
72	(63, 101)	98%	35.573	34.841	2
104	(101, 108)	100%	34.841	33.111	3

Kolkata

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(33, 60)	98%	35.156	35.762	2
72	(62, 108)	97%	35.762	35.085	1

Table Cont....

Midnapore

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
48	(29, 62)	99%	35.478	36.056	4
72	(63, 110)	100%	36.056	35.406	5

Murshidabad

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
104	(100, 106)	100%	37.045	35.111	1

Naida

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
107	(105, 107)	97%	36.399	34.056	1

Malda

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
77	(10, 102)	99%	35.956	35.429	3

Table Cont....

North 24 Pargana

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
107	(105, 107)	97%	36.399	34.056	1

Purulia

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
77	(20, 91)	99%	37.706	37.107	2
104	(104, 104)	100%	37.107	31.667	1
108	(108, 108)	96%	31.667	37	2

South 24 Pargana

Table of Significant Changes for Summer

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
106	(106, 106)	100%	27.228	34.476	4

Figure-17: CUSUM chart for *Summer* Temperature Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

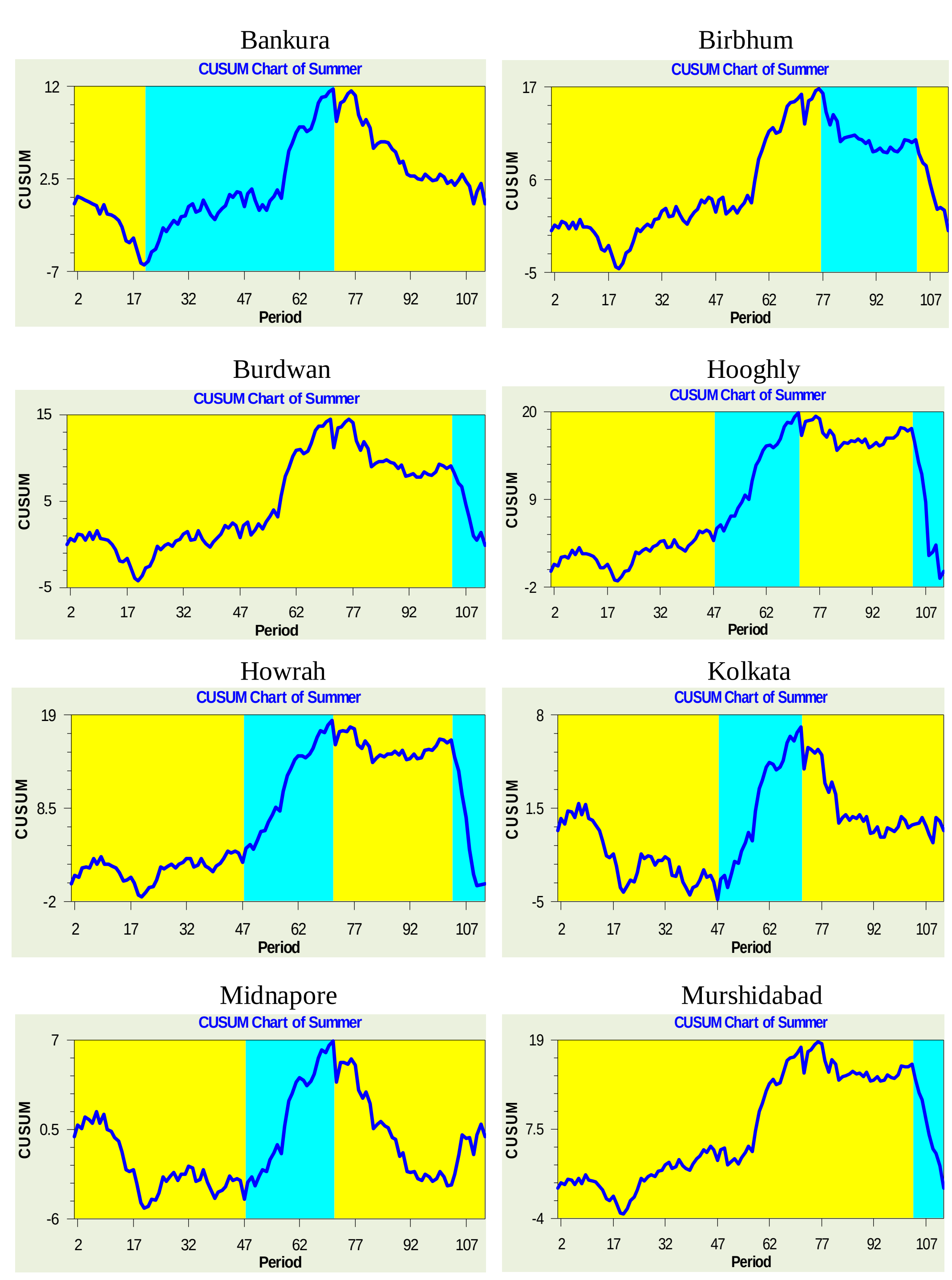
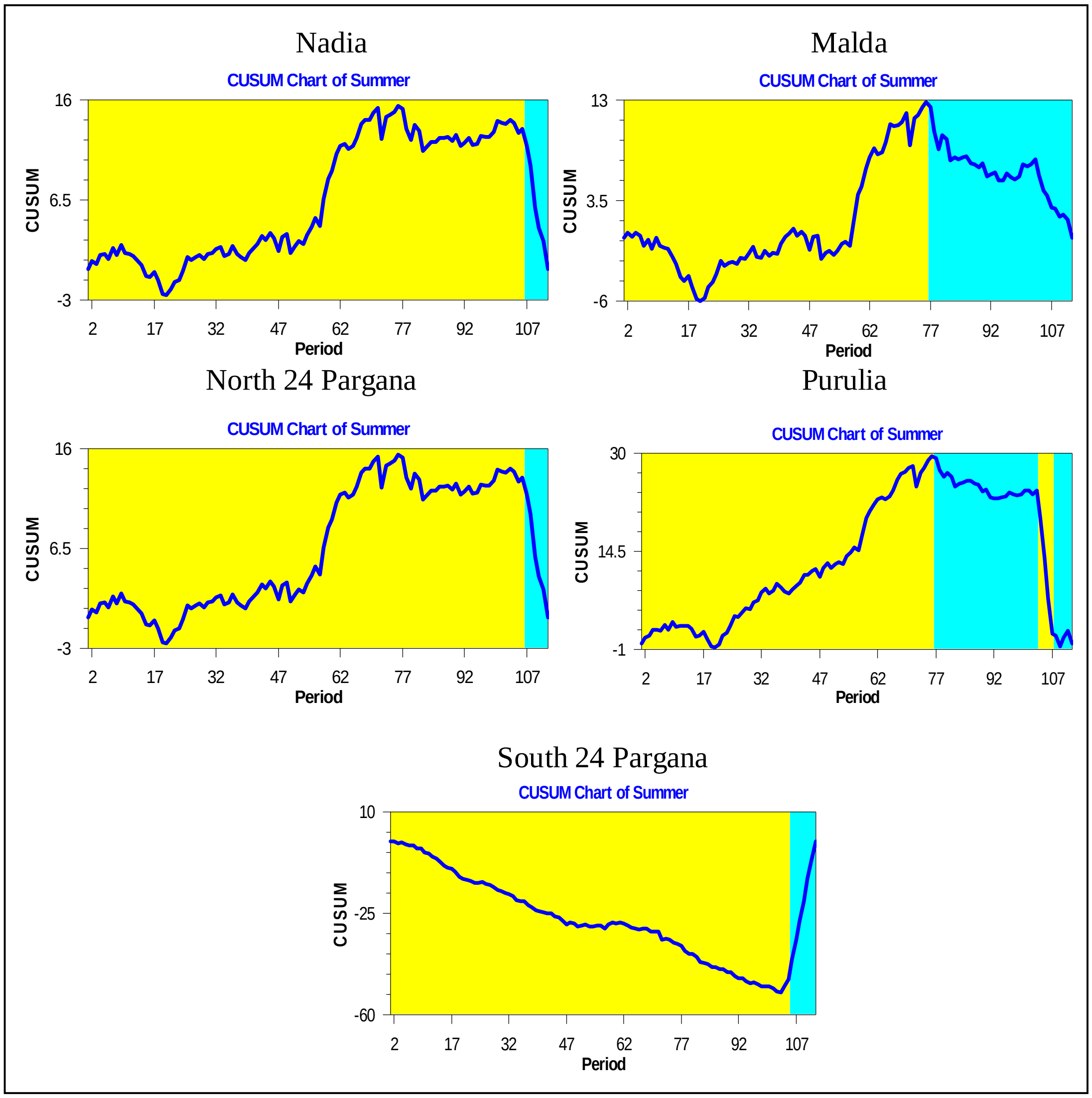


Figure Cont….


Nadia
CUSUM Chart of Summer
CUSUM
16
6.5
-3
2 17 32 47 62 77 92 107
Period
Malda
CUSUM Chart of Summer
CUSUM
13
3.5
-6
2 17 32 47 62 77 92 107
Period
North 24 Pargana
CUSUM Chart of Summer
CUSUM
16
6.5
-3
2 17 32 47 62 77 92 107
Period
Purulia
CUSUM Chart of Summer
CUSUM
30
14.5
-1
2 17 32 47 62 77 92 107
Period
South 24 Pargana
CUSUM Chart of Summer
CUSUM
10
-25
-60
2 17 32 47 62 77 92 107
Period

Monsoon is the important season over the Indian continent. Dominancy of this season is the key factor of this geographical area. Mainly, the monsoonal rainfall always plays an important role to control the entire yearly climatic effect over the Indian sub-continent and its adjacent area. The CUSUM and bootstrapping techniques has also applied on the time series for monsoon season. Table-46 is showing the results of CUSUM and bootstrapping for Monsoon temperature series of 13 considered observatories. All the considered time series has revealed different level of significant change whose illustration is given below.

The observatory Bankura has indicated three significant change including level-1, level-3 and level-5 respectively. Among them, the level-1 change has occurred in 2004 while the confidence interval has been adjusted since 1999 to 2008. The confidence level of the primary or level-1 change is 100% level. Prior and after mean value of the subsequent series are $31.71\,℃\ and\ 32.48\,℃$ respectively. These subsection mean level has indicated increasing of the mean temperature over the considered period. Second one change of this time series is level-3 change and it's also significant at chosen level of significance. 1908 is the another change point, while its confidence interval is typically adjusted within 42 years temporal span and it adjust at 92% level of confidence. The shift of mean level has indicated decreasing trend of the temperature series and the prior mean level is $31.91\,℃$ and after change mean level is $31.50\,℃$. To detect the level-5 change of this series, it has taken long period of time since 1943 to 2003. The mean level of this change has increased after the change detected. The observatory, Birbhum does not signify any level-1 change after processing of $STMax$ series through CUSUM and bootstrapping techniques. Ultimately, this series has detected five change points such as level-2, level-4, level-6, level-7 and level-10 respectively. The bootstrapping has taken long period of time for level-6 change which has occurred in 1973. All these subsequent change points does not meet the 100% level of confidence level except 1996. The shift of mean level for these changes are randomly indicating increasing and decreasing trend over this period. So it can be stated that the raw data set are randomly associated with outlier effect. The Burdwan Monsoon temperature series has detected two significant changes over the considered period.

The level-1 change for this series is indicating in 2011, there after associated bootstrapping has been adjusted within single year temporal span (2010 – 2011). The shift of the mean level is 0.33 ℃ while the prior mean level and after mean level are 32.33 ℃ *and* 32.66 ℃ respectively. It is signifying the increasing trend of *STMax* series. The shift of the mean level for the level-5 change is also indicating increasing trend of temperature while prior mean level is 32.07 ℃ and the after mean level is 32.33 ℃ . The considered series for the Hooghly observatory has revealed level-1 change in 2004 and also revealed other five successive change point after the CUSUM analysis. According to this analysis three change points has indicated increasing trend of mean level over the considered period.

On the other hand, left three change point has detected decreasing trend nature of the considered time series. The change point is 1933 has met the 100% level of confidence. The significant change points for this series are 1909 (level-5), 1933 (level-9), 1946 (level-6), 1983 (level-6) and 1926 (level-3) respectively. The time series for Howrah observatory does not indicate level-1 change over the period that means the series is not smooth and the frequency domain have some irregular fluctuation over the considered temporal scale. Altogether, seven subsequent change has detected while their mean level fluctuates randomly and only two changes has signified the data series at 100% confidence level. Critically examination of the series has revealed three times level-6 change over the time series. These potential change points are 1909, 1948 and in 2011. The Monsoonal series for the Kolkata observatory has indicated seven change points over the time period. Level -1 change has occurred in 1983 and the mean level of the prior and after change are 31.60 ℃ *and* 32.18 ℃ respectively. The amount of positive shift of mean level by 0.58 ℃ . Estimation of the change point for monsoon series of Midnapore observatory indicates four significant change points. Among them, level-1, level-6 and level-7 (two times) change has been detected. The level-1 change has pointed out the significant change year in 2004. Associated temporal span has confirmed its temporal scale since 1999 to 2004 to detect the level-1 change. The prior mean level is 31.17 ℃ and the after changes mean level is 31.81 ℃. All these detected change points has been confirmed with very short temporal span.

The Murshidabad observatory has revealed seven such change points leading with different level of changes. The primary or level-1 change has detected in 2005 and the specified mean level has indicated decreasing trend over the considered period. Sequence of the change point detection has established that the considered time series do have variability nature from beginning to end of the series. Temporal series for the Nadia observatory successively indicates three change in 2007, 1946 and in 1932. The level-1 change has occurred in 2007 while its confidence level has been considered at 99% level of confidence. The studies of Monsoon temperature series for Malda has detected only level-1 change over the considered period. It has detected change point in 2003 while prior mean level is 31.96 ℃ and the after mean level is 32.91 ℃ respectively. On the other hand, Monsoon series for Purulia has detected four important changes in 1920 (Level-6), 1972 (Level-7), 1973 (Level-2) and in 2004 (Level-3) respectively. In maximum cases the after mean level is higher than the prior mean level. The analysis of the time series for South 24 Pargana has revealed as some special address over the considered period. The application of the CUSUM and bootstrapping, this series for South 24 Pargana has indicated eight such change points with some common level of change year. The level-1 change has been detected in 2004 while the nature of specification of the sub series indicates increasing trend over the period. The graphical presentation of the CUSUM and bootstrapping result of Monsoon temperature series is given in Figure-18.

Table-46: Significant Change Point with different level by CUSUM and Bootstrapping for Monsoon $(STMax)$ Series

Bankura

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
8	(8, 50)	92%	31.91	31.507	3
73	(43, 103)	91%	31.507	31.711	5
104	(99, 108)	100%	31.711	32.481	1

Birbhum

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
30	(25, 50)	94%	32.263	31.996	2
73	(66, 93)	96%	31.996	32.42	6
96	(74, 97)	100%	32.42	32.067	7
102	(100, 104)	98%	32.067	32.542	10
108	(103, 109)	98%	32.542	32.933	4

Burdwan

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
83	(42, 97)	100%	32.078	32.335	5
111	(110, 111)	96%	32.335	33.667	1

Table Cont….

Hooghly

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
9	(7, 14)	97%	32.181	31.878	5
33	(30, 36)	100%	31.878	31.562	9
46	(45, 71)	99%	31.562	31.927	6
83	(53, 87)	98%	31.927	32.271	6
96	(89, 101)	92%	32.271	31.94	3
104	(104, 110)	97%	31.94	30.814	1

Kolkata

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
8	(7, 12)	96%	32.086	31.748	4
33	(28, 38)	100%	31.748	31.49	5
48	(47, 51)	100%	31.49	32.117	4
60	(54, 76)	94%	32.117	31.684	5
83	(71, 85)	99%	31.684	32.18	1
96	(92, 99)	96%	32.18	31.725	3
102	(102, 106)	91%	31.725	32.292	2

Table Cont....

Midanapore

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
9	(7, 16)	97%	31.387	31.076	7
30	(25, 32)	100%	31.076	30.776	6
46	(45, 59)	96%	30.776	31.179	7
104	(99, 104)	98%	31.179	31.815	1

Murshidabad

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
31	(29, 46)	100%	32.676	32.455	5
73	(71, 73)	96%	32.455	33.365	6
76	(76, 76)	98%	33.365	32.411	3
82	(82, 82)	94%	32.411	33.323	4
84	(83, 91)	99%	33.323	32.844	7
95	(87, 102)	96%	32.844	32.663	6
105	(105, 107)	99%	32.663	32.083	1

Nadia

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
32	(31, 33)	100%	32.546	32.125	5
46	(45, 56)	99%	32.125	32.594	4
107	(107, 107)	99%	32.594	31.278	1

Table Cont....

Malda

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
103	(100, 104)	100%	31.961	32.914	1

North24 Pargana

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
32	(31, 34)	100%	32.546	32.125	5
46	(45, 57)	99%	32.125	32.594	4
107	(107, 107)	99%	32.594	31.278	1

Purulia

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
20	(12, 40)	99%	31.081	30.795	6
72	(29, 72)	97%	30.795	29.88	7
73	(73, 102)	92%	29.88	31.031	2
104	(102, 112)	99%	31.031	32.407	3

Table Cont....

South 24 Pargana

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
9	(9, 13)	97%	25.734	25.484	4
22	(13, 26)	91%	25.484	25.345	3
33	(31, 43)	100%	25.345	25.185	4
48	(47, 50)	100%	25.185	25.837	6
60	(56, 68)	98%	25.837	25.366	3
83	(67, 88)	98%	25.366	25.685	4
104	(104, 104)	99%	25.685	30.667	1
107	(107, 107)	92%	30.667	32.5	3

Figure-18: CUSUM Chart for $Monsoon$ ($STMax$) Temperature Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

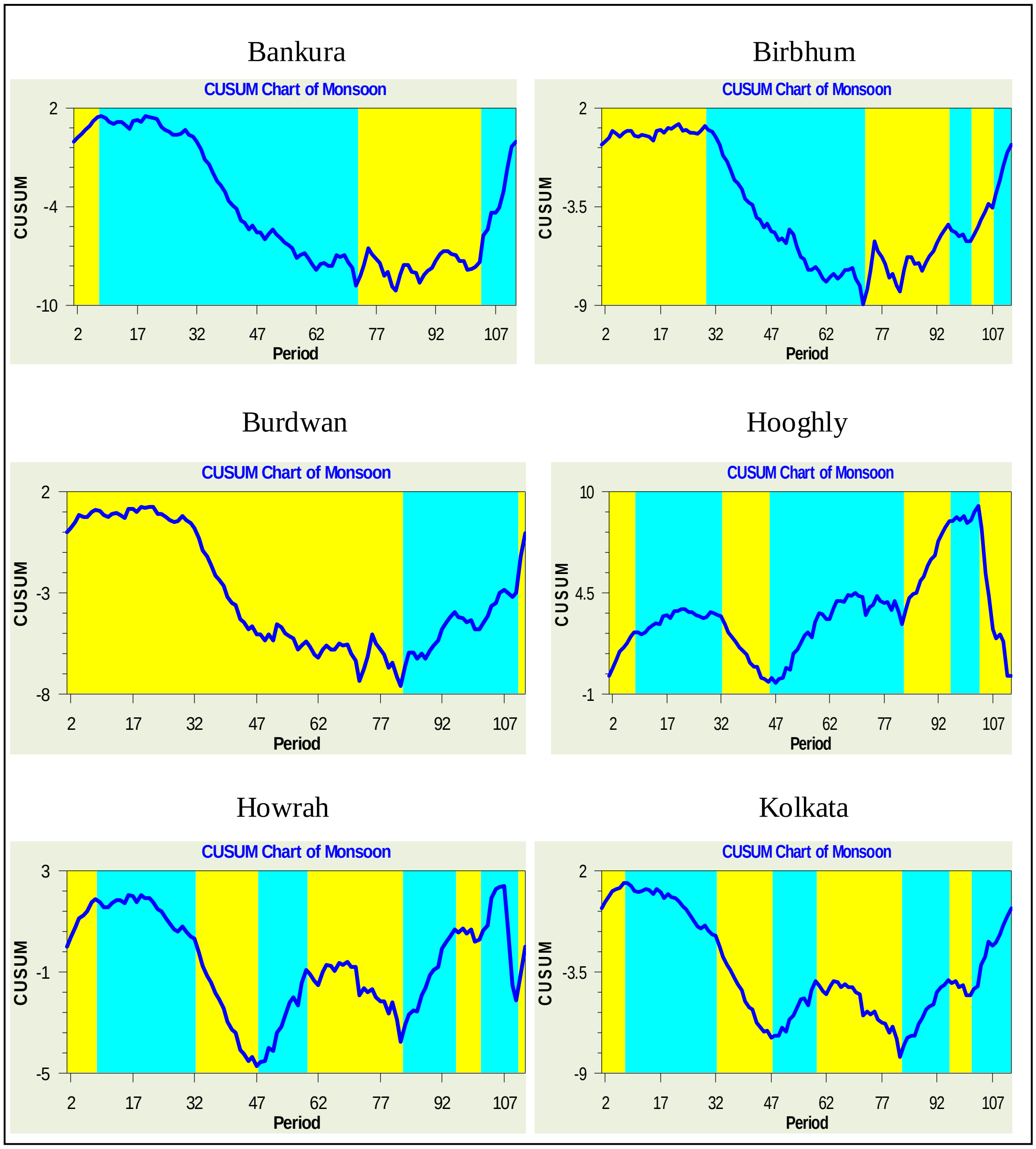
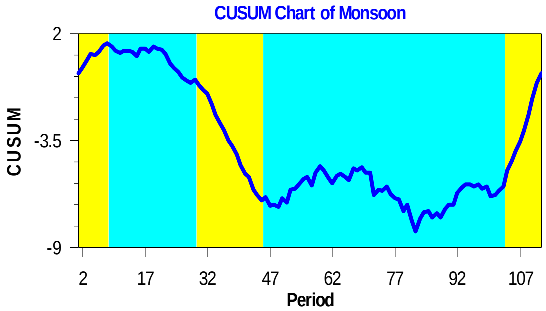
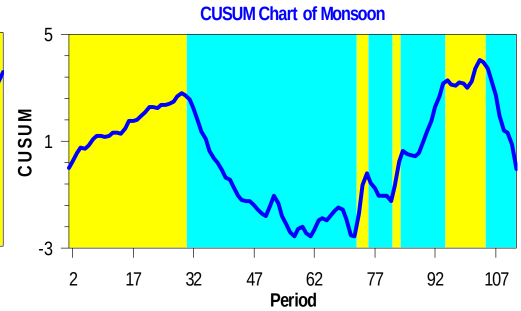


Figure Cont....

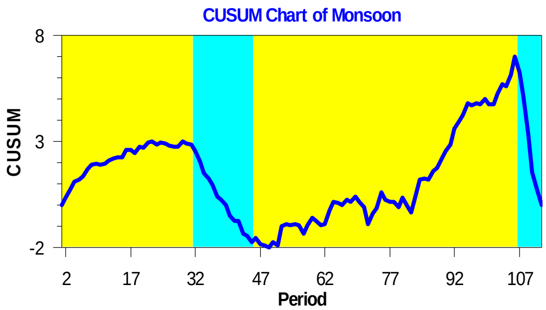
Midnapore



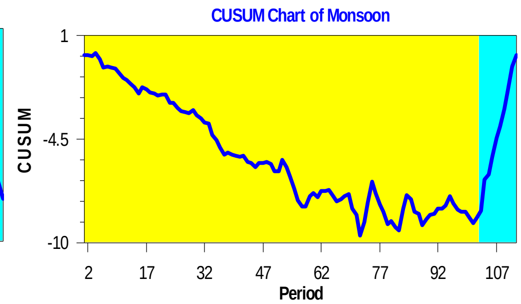
Murshidabad



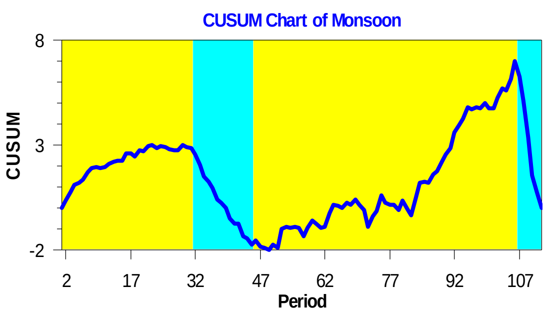
Nadia



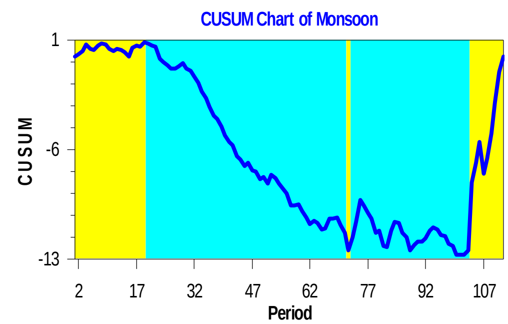
Malda



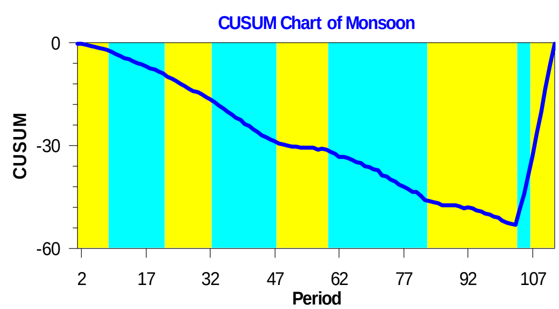
North 24 Pargana



Purulia



South 24 Pargana



Homogeneity test by the CUSUM and bootstrapping were applied for Post-monsoon series for all observatories separately in this study. The result of this analysis in tabulation format is given in Table-47. The observatory Bankura has indicated level-1 change in 2007 and its associated confidence interval has been confirmed since 2005 to 2007. The shift of mean value also indicates increasing trend of Post-monsoon temperature series. The prior mean value is $30.03\,℃$ and after mean value is $31.66\,℃$. Its confidence level has adjusted at 98% level of confidence. Other three changes are 1958 (Level-2), 1922 (Level-3) and 1941 (Level-4) respectively for this observatory. Amount of mean level change for level-1 change is $1.63\,℃$. Post-monsoon series for Birbhum observatory has been indicated level-1 change in 1941 and the confidence level has been confirmed at 100% level of confidence. The nature of the mean level change indicates decreasing trend of post-monsoon temperature series. According to this analysis, prior mean level and after mean level is $29.83\,℃\ and\ 30.48\,℃$ respectively. Post-monsoon series for Burdwan observatory reveals three level of changes like level-4 (2011), level-5 (1908) and level-5 (1952) respectively. This series does not signify any primary or level-1 change. Hooghly, Nadia, North 24 Pargana and South 24 Pargana have been revealed level-1 change in different year. These are 2004 (Hooghly), 1941 (Nadia), 1980 (Malda), 1941 (North 24 Pargana) and 2004 (South 24 Pargana) respectively. Remaining observatories like Howrah, Midnapore, Murshidabad, Purulia etc. does not indicate level-1 change over the considered period. These series exhibit with any other level of change while their mean level have randomly fluctuated. Level-1 change of Post-monsoon series for Nadia, Malda and North 24 Pargana has confirmed 100% confidence level. The graphical presentation of this result is shown in Figure-19.

Table-47: Significant Change Point with different level by CUSUM and Bootstrapping for Post-Monsoon ($STMax$) Series.

Bankura

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
22	(3, 30)	93%	29.559	29.128	3
41	(32, 56)	95%	29.128	29.554	4
58	(50, 84)	92%	29.554	30.035	2
107	(105, 107)	98%	30.035	31.667	1

Birbhum

Table of Significant Changes for Post-monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
41	(37, 71)	100%	29.832	30.482	1

Burdwan

Table of Significant Changes for Post monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
8	(8, 12)	99%	32.041	31.428	5
52	(47, 67)	100%	31.428	31.843	5
111	(109, 111)	96%	31.843	33.282	4

Table Cont....

Hooghly

Table of Significant Changes for Post-monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
22	(3, 29)	98%	29.999	29.522	5
41	(37, 54)	99%	29.522	30.1	4
77	(63, 87)	99%	30.1	30.62	3
104	(103, 108)	100%	30.62	28.805	1

Howrah

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
77	(71, 89)	100%	29.688	30.471	3

Kolkata

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
22	(3, 51)	98%	29.958	29.648	3
58	(46, 70)	100%	29.648	30.148	4
77	(63, 94)	97%	30.148	30.58	3
110	(107, 110)	93%	30.58	31.833	2

Table Cont….

Midnapore

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
58	(52, 68)	100%	29.188	29.858	2

Murshdabad

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
41	(36, 53)	98%	30.39	31.034	2
104	(97, 108)	100%	31.034	30.111	3

Nadia

Table of Significant Changes for Post Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
22	(3, 31)	96%	30.722	30.292	3
41	(37, 51)	99%	30.292	30.866	1
77	(65, 85)	100%	30.866	31.406	3
104	(103, 109)	100%	31.406	30.056	2

Malda

Table of Significant Changes for Post-Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
41	(18, 66)	97%	29.745	30.101	2
80	(69, 90)	100%	30.101	30.705	1

Table Cont….

North 24 Pargana

Table of Significant Changes for Post Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
22	(3, 30)	96%	30.722	30.292	3
41	(38, 54)	100%	30.292	30.866	1
77	(65, 85)	99%	30.866	31.406	3
104	(103, 108)	100%	31.406	30.056	2

Purulia

Table of Significant Changes for Post monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
58	(50, 70)	100%	28.71	29.354	3
104	(104, 107)	100%	29.354	31.556	4

South 24 Pargana

Table of Significant Changes for Post Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
16	(4, 21)	91%	24.03	24.361	4
22	(17, 39)	92%	24.361	23.87	3
58	(53, 64)	100%	23.87	24.473	4
104	(104, 104)	99%	24.473	29.5	1
107	(107, 107)	97%	29.5	32.083	2

Figure-19: CUSUM Chart for *Post Monsoon* Temperature Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

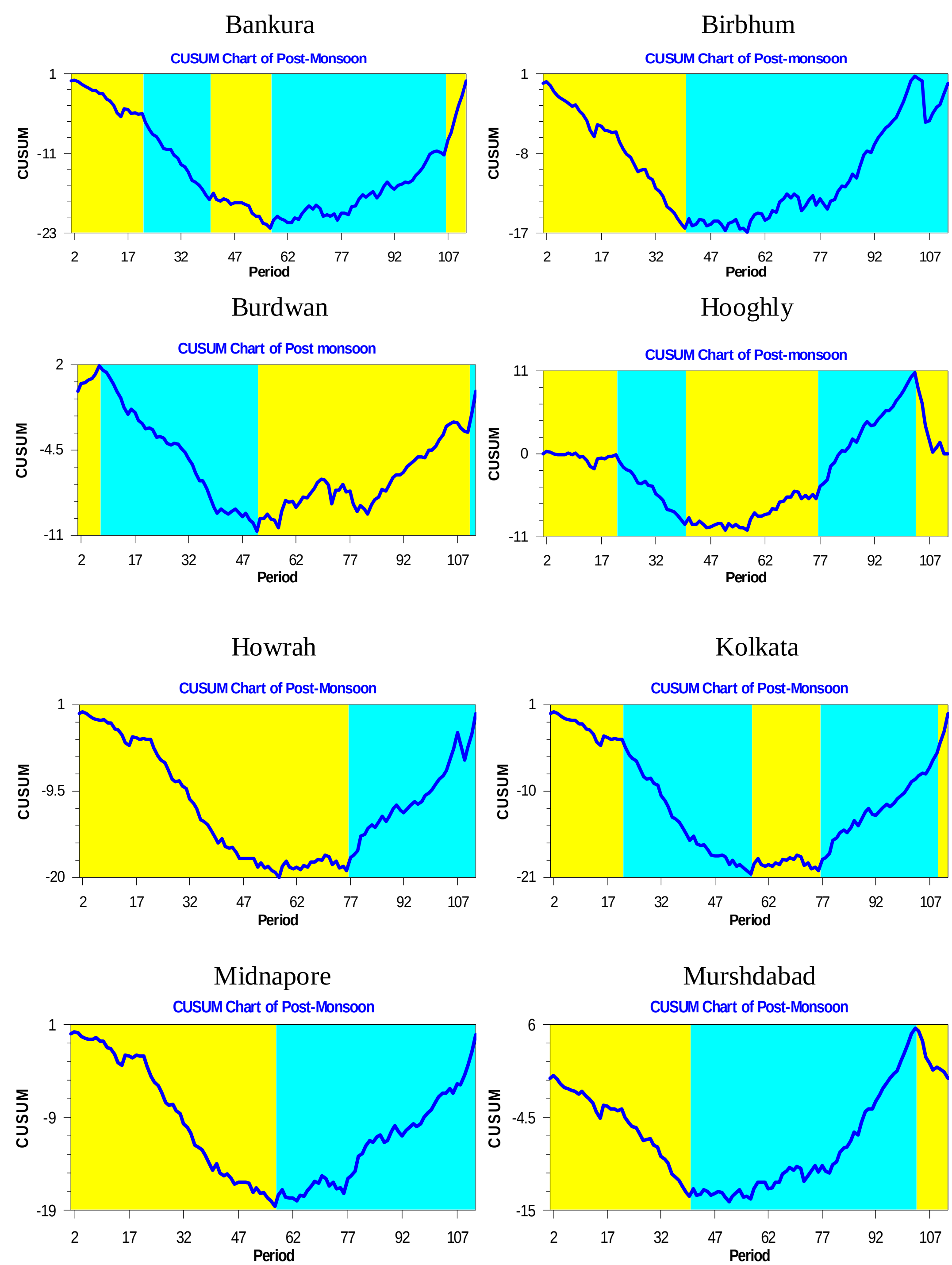
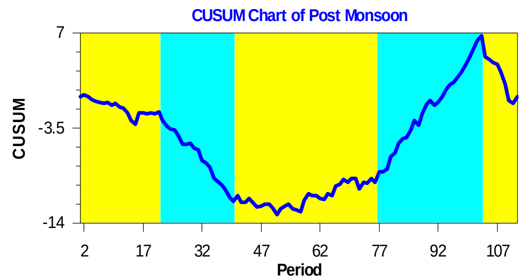
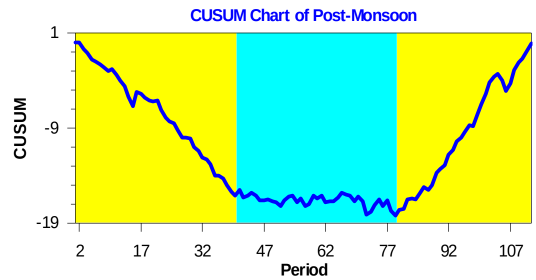


Figure Cont....

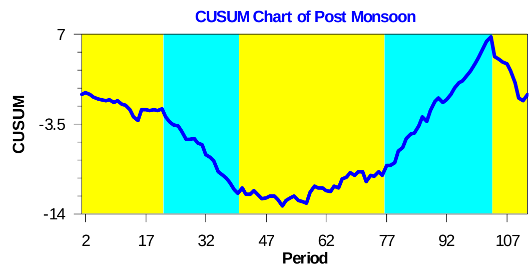
Nadia



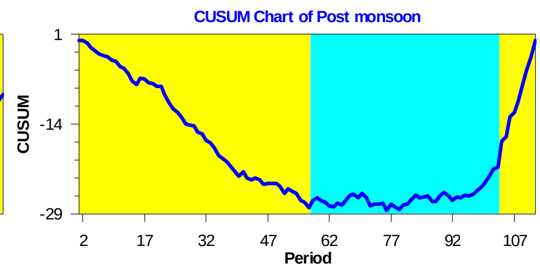
Malda



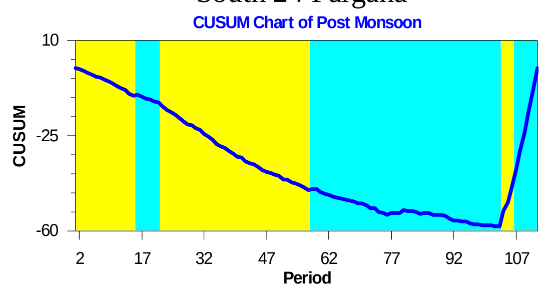
North 24 Pargana



Purulia



South 24 Pargana



Rainfall frequency is one of the important parameter by which Climatological trend will be established. In this study, we have considered the rainfall series separately like annual average and seasonally for estimating its variability or in-homogeneity. The results of the CUSUM and bootstrapping for this series are presents in Table-48. In respect of the mean monthly rainfall series of the considered observatories, there is some abnormality or in-homogeneity is the common character, which has found after the said statistical techniques applied. But it is more important to analyze the annual average rainfall series examination for the detection of proper forecasting of climatic nature. Moreover, some annual average rainfall series does not indicate any significant change. Some of the observatories are also indicating significant changes, those are illustrated here. The annual average rainfall series of the Hooghly observatory indicates level-1 change in 2001 while the confidence interval has been adjusted in between 1931 to 2006. The confidence level is meeting the 94% level of confidence. Sub-sectional mean value become low in respect of prior mean level. The prior mean value and after mean value are $128.73\,mm\ and\ 109.36\,mm$ respectively. The annual average rainfall series for the Howrah observatory has indicated a level-1 change in 1969. Its bootstrapping association has confirmed with the confidence interval since 1930 to 2006. The after changes mean level becomes higher than the prior mean level. The numeric values of these mean levels are $128.64\,mm\ and\ 140.35\,mm$ respectively. At the same time, the annual average rainfall series for Kolkata observatory has indicated its significant change point in 1969. This series also reveals the after change point mean level is higher than the prior mean level. The shift amount of the mean level by $16.75\,mm$. This change is also addressing level-1 change on the considered time series. The average rainfall series for the Malda observatory has indicated level-1 change over the considered time period, which has occurred in 1958 while its associated confidence interval has been confirmed since 1932 to 2009. The shift of mean level becomes low than the prior level of adjusted mean. On the other hand, North 24 Pargana indicates level-2 change over the considered period and the change point has been located in 1969. The mean level is successively higher for after change level. South 24 Pargana average rainfall series indicates a level-1 change in 1985. Here also the after change means level is higher than the prior mean level.

The result of the CUSUM and bootstrapping is very interesting for the annual average rainfall series which indicates 1969 as the common year of change for maximum observatories. The graphical presentation of this result is shown in Figure-20.

Table-48: Significant Change Point with different level by CUSUM and Bootstrapping for Annual Rainfall Series.

Hooghly

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
101	(31, 106)	94%	128.73	109.36	1

Howrah

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
69	(30, 106)	94%	128.64	140.35	1

Kolkata

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
69	(53, 94)	98%	127.26	144.01	1

Malda

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
58	(32, 109)	97%	119.97	112.01	1

Table Cont….

North 24 Pargana

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
69	(30, 107)	97%	128.78	139.78	2

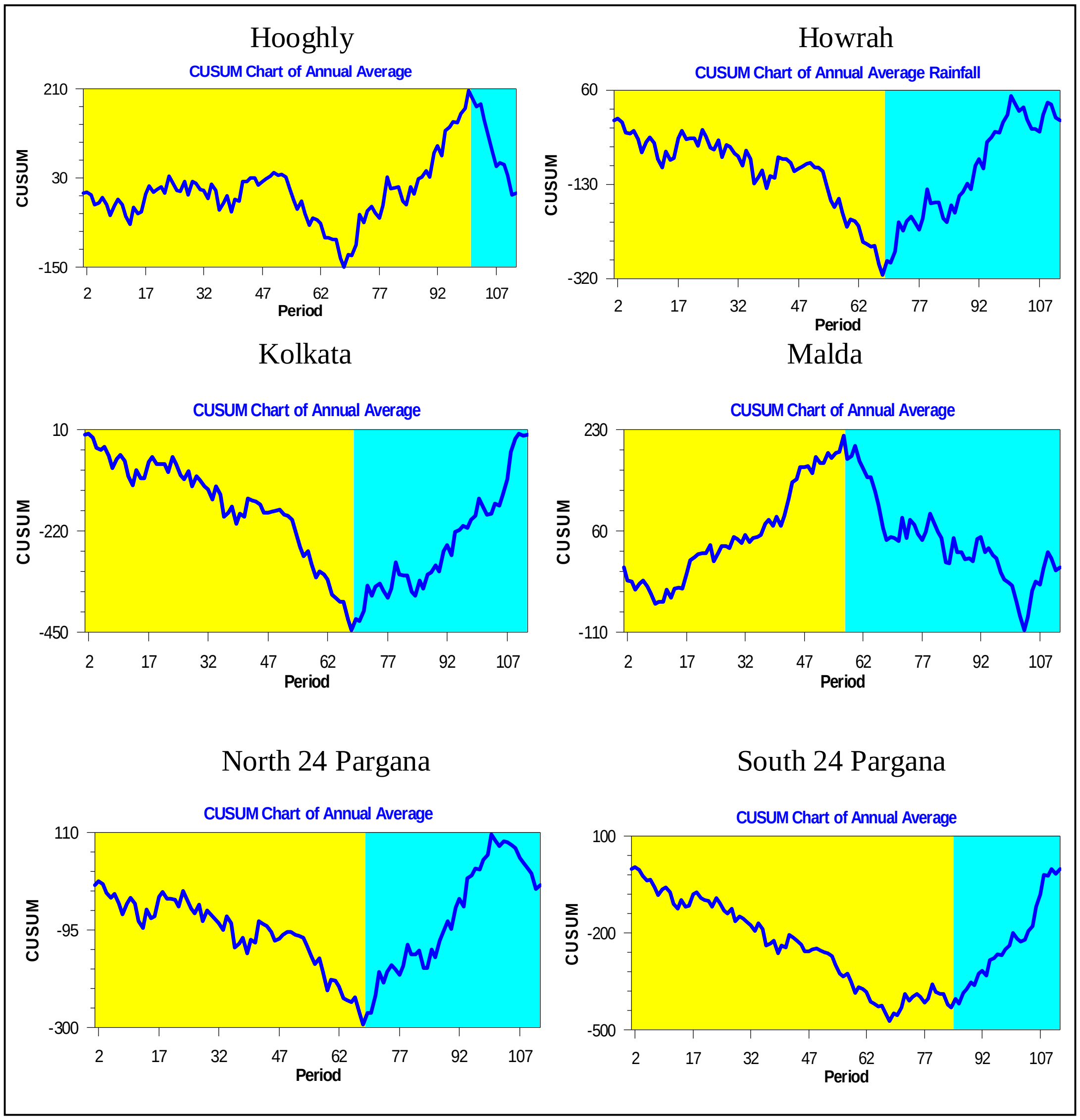
South 24 Pargana

Table of Significant Changes for Annual Average

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
85	(70, 99)	100%	113.95	134.44	1

Figure-20: CUSUM Chart for *Annual Rainfall* Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.



The quality check or homogeneity assessment has conducted for monsoon rainfall series. The results are very interesting where some of the series reveals different level of significant change. This result is shown in Table-49 & Figure-21. Thoroughly inspection has conducted for every series separately for this study. The observatory Birbhum indicates that, a level-3 change is significant after the CUSUM and bootstrapping analysis. This level-3 change has detected a change point in 1980. However, its confidence interval has been confirmed with long temporal span (1904-2007). The shift of mean level has indicated decreasing trend of monsoon rainfall series over the considered period while the prior mean level is $291.54\,mm$ and the after mean level is $266.5\,mm$ respectively. The confidence level has adjusted at 92% level of confidence. Hooghly observatory indicates a level-1 change point in 2001 while it's prior mean level and after mean level are $310.3\,mm\ and\ 249.07\,mm$ respectively. It also indicates a decreasing trend of Monsoon rainfall series. In-homogeneity assessment of the monsoon rainfall series for Howrah indicates a level-2 change in 1969 as significant change. The shift of mean level has indicated increasing trend of the monsoon rainfall series. The prior mean level is $305.18\,mm$ and after mean level is 333.27 mm respectively. Randomness of the rainfall frequency is the prominent character for this series, by which it indicates secondary or level-2 change over the considered temporal period. The bootstrapping technique has associated its confidence interval since 1918 to 2011. Observatories Malda, Midnapore and South 24 Pargana have indicated level -1 change in 1961, 2001 and in 1987. In accordance to the mean level shift, Malda and South 24 Pargana indicates increasing trend of the monsoon rainfall series and on the other hand Midnapore series indicates negative shift of mean level with decreasing trend of monsoon rainfall over the considered period. Other some Monsoon rainfall series like Murshidabad, North 24 Pargana and Purulia has revealed level-3 and level2 change, those are significant after this statistical application. For these three cases, the sectional mean level indicates continuous decreasing trend of Monsoon rainfall over the considered period. Bootstrapping techniques has typically adjusted their confidence interval over the long period of temporal span.

Table-49: Significant change point with different level by CUSUM and Bootstrapping for Monsoon Rainfall Series.

Birbhum

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
80	(4, 107)	92%	291.54	266.5	3

Hooghly

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
101	(62, 107)	92%	310.33	249.07	1

Howrah

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
69	(18, 112)	90%	305.18	333.27	2

Malda

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
61	(10, 93)	98%	305.59	278.37	1

Table Cont....

Midnapore

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
101	(24, 110)	96%	291.69	247.66	1

Murshidabad

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
101	(50, 110)	95%	291.69	247.66	3

Noth 24 Pargana

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
101	(6, 110)	97%	315.5	271.39	2

Purulia

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
93	(20, 112)	97%	292.03	260.34	2

South 24 Pargana

Table of Significant Changes for Monsoon

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Row	Confidence Interval	Conf. Level	From	To	Level
87	(73, 108)	99%	268.8	322.54	1

Figure-21: CUSUM Chart for *Monsoon Rainfall* Series of 13 observatories. Shaded meeting point is refers to significant potential change point in each figure.

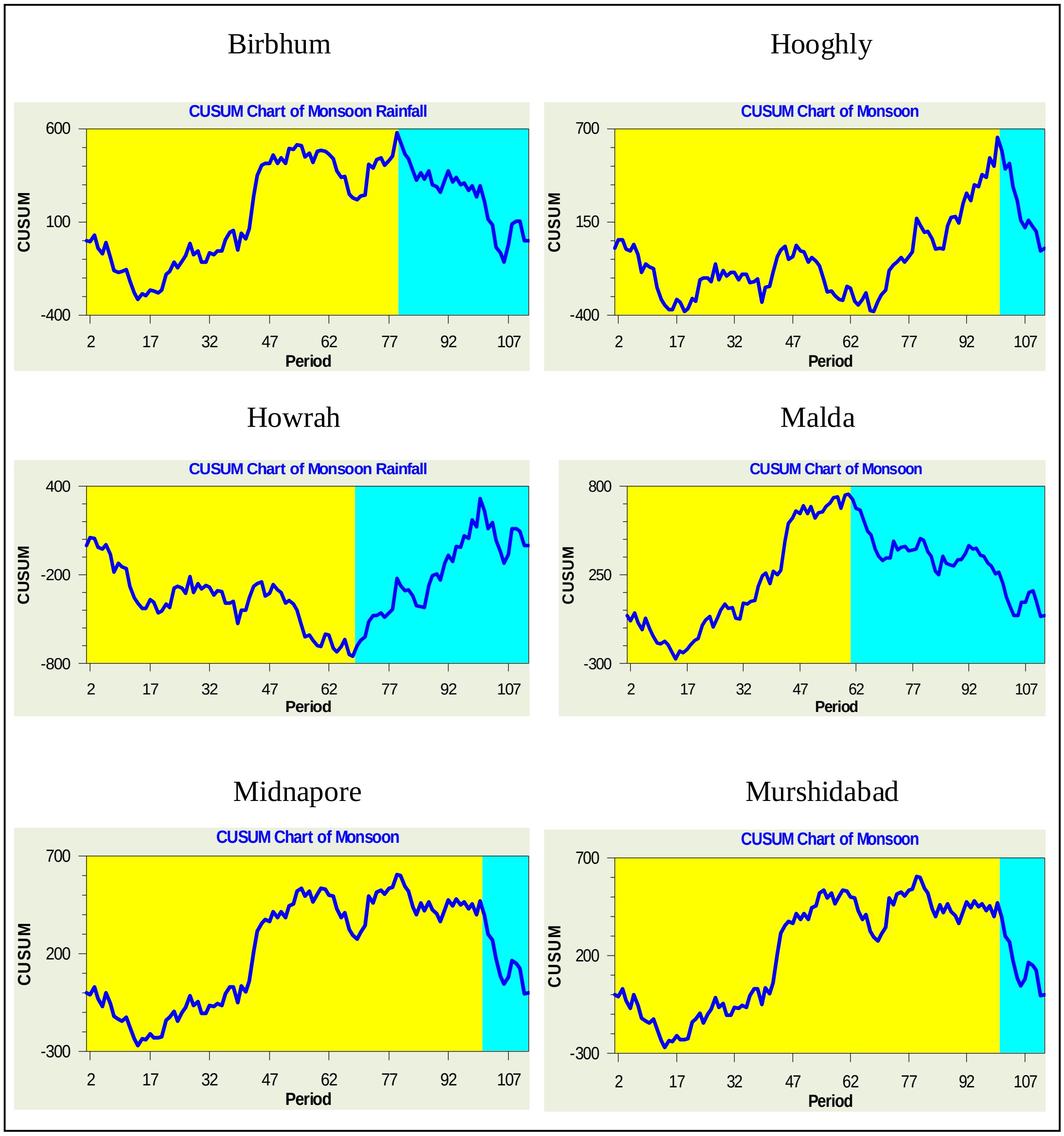
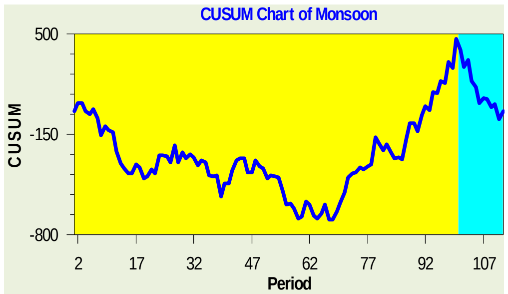
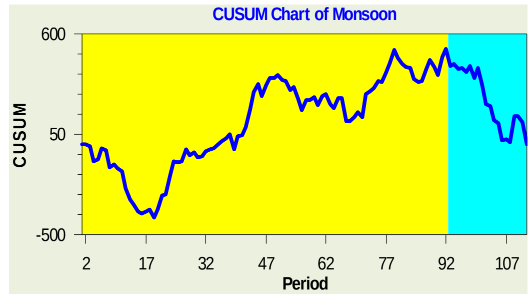


Figure Cont....

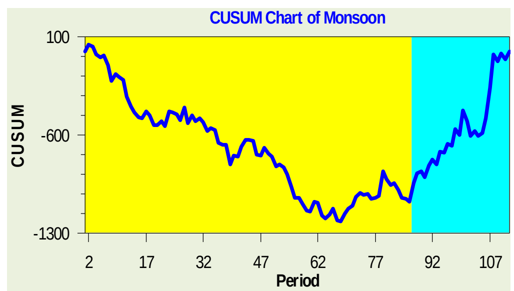
North 24 Pargana



Purulia



South 24 Pargana



4.2 Series Classification and its Qualitative Interpretation:

After the homogeneity assessment of the considered time series of mean monthly maximum $(TMax)$ temperature, mean monthly minimum $(TMin)$ temperature, annual average $(ATMax \,\&\, ATMin)$ temperature, seasonal average $(STMax \,\&\, STMin)$ temperature and monthly, rainfall, annual rainfall and seasonal rainfall were specified by their quality with usable manner. All considered series are thoroughly checked for quality control and the homogeneity by the authentic statistical methods to assess their inherent variability nature. All quality tests are absolute and the considered dataset are not at all compared with the neighboring station series. According to *Schonwiese and Rapp, (1997)*, a classification is made depending on the number of tests rejecting the null hypothesis. The quality check detects several types of errors like anomalous values, repetitive values of significant changes, several breaks for a particular series and consequent outlier with abrupt change, which has not follow the normal distribution. In many cases these considered data series did not pass the considered methods. So, the series were not primarily reliable for trend analysis. Many of the series were non-standardized in formats which were also difficult to inspect. According to *Wijngaard et al. (2003)*, the data series has been classified in three homogeneity classes such as: useful, doubtful and suspect depending on the number out of six statistical tests that reject the null-hypothesis with respective break in the series considered (shown in Table- 50).

a) Class A: Useful: The considered series that rejects one or none null hypothesis under the six tests at 5% significance level. This class reveals that the series is grouped as homogeneous in character and can be directly used for further analysis.

b) Class B: Doubtful: The considered series that reject two null hypothesis of the six tests at 5% significance level are attained this class. This class indicates the series have the inhomogeneous signal or outlier and should be critically inspected before further analysis.

c) Class C: Suspect: The considered series that reject three or all test null hypothesis at 5% significance level, then the series is classified into suspect group. This group of data series can be deleted or ignored before further analysis.

Table-50: Number of temperature and rainfall series (%) in different categories.

Period	Climatic Variable	Total Number of Series	Useful (Class-I)	Doubtful (Class-II)	Suspect (Class-III)
1901-2011	$TMax$	156	28 (17.94%)	21(13.46%)	107 (68.58%)
	$ATMax$	13	3 (23.07%)	1 (7.69%)	9 (69.23%)
	$STMax$	52	13 (25%)	7 (13.46%)	33 (63.46%)
	$TMin$	156	34 (21.79%)	15 (9.61%)	107(68.58%)
	$ATMin$	13	0	0	13 (100%)
	$STMin$	52	6 (11.53%)	2 (3.84%)	44 (84.61%)
	$MRain$	156	14 (8.97%)	6 (3.84%)	1 (0.64%)
	$ARain$	13	0	0	13 (100%)
	$SRain$	52	2(3.84%)	1 (1.92%)	49 94.23%)

4.3 Conclusion:

According to the above stated methodology like SNHT-I and CUSUM and Bootstrapping of the monthly temperature series for both $TMax$ & $TMin$ random change point has been observed over the considered period. Some of the monthly average rainfall series also indicates same character over the considered period. Moreover the annual rainfall series do have maximum abnormality over the considered period. Among the detected change point, some are significant at the chosen level of significance. The monthly average rainfall series of 13 observatories reveals the stationary frequency of rainfall amount. Some of the monthly average rainfall series do have some variability over the considered period. But it is noticeable that, the $TMax, TMin, ATMax, ATMin, STMax\ and\ STMin$ and some rainfall series are not indicating homogeneous construction. Depending upon the series classification stated above, the considered series is classified through the "Useful", "Doubtful" and "Suspected" categories. It can be inferred from the above stated category, maximum percentage of considered tine series are falling in doubtful (Class-II) and in suspect (Class-III) group.

Therefore, these series should not be used for further statistical analysis like trend analysis or forecasting of the climatic behavior. Following the Table-50, many of the series cannot be used directly for time series analysis and quality control is the prior step for homogenization of these series considered.

4.4 References:

Davison, A. C. and Hinkley, D. V., “Bootstrap Methods and Their Application,” Cambridge University Press, Cambridge, 1997.

Schoenwiese, C.D., Rapp, J., Climate Trend Atlas of Europe Based on Observations 1891-1990, 228 pp., Kluwer Acad. Publishers, Norwell, Massø, 1997

Taylor, W., “Change-Point Analysis: A Powerful Tool for Detecting Changes,” Taylor Enterprises, Libertyville, 2000. http://www.variation.com/cpa/tech/changepoint.

Wijngaard, J.B., Klein Tank, A.M.G., Konnen, G.P., 2003. Homogeneity of 20th century European daily temperature and precipitation series. International Journal of Climatology 23: 679 – 692.

Chapter-V (Homogeneity Construction and Trend Detection)

5.0 Homogeneity Construction by MASH Application :

Homogenization of climatic parameters like temperature and rainfall series remains a challenge to climate change researches, especially in cases where metadata are not always available. This research work has been undertaken by the raw data structure. In previous chapter, the climatic series has been checked thoroughly by different reliable statistical techniques. The result of these analyses has revealed uncertain frequency, outlier, abnormality, variability as well as significant change point over the considered period. It has also revealed that, every series of $TMax$, $TMin$, $ATMax$, $ATMin$, $STMax$, $STMin$ and rainfall series have indicated their inhomogeneity structure over the considered period. So, there are no such considered climatic series, which has been assumed as reference series. Ultimately, Multiple Analysis of Series for Homogenization ($MASH\ v$ 2.03) has been used to conduct the homogenization process for considered time series. This process has been developed by the Hungarian Meteorological Service (*Szentimrey, 1996; Szentimrey, 1999; Szentimrey, 2007*). This procedure has been performed by "DOS" based programme. This method is relative homogeneity construction procedures that do not assume any reference series as homogeneous. The possible break points and change (Shift) on the time series can be detected and adjusted through mutual comparisons (with replacement or without replacement of sample shift value) of considered series within the same climatic area. The candidate series has been chosen from the available considered series. In the mean time the remaining series has been considered as reference series. The climatic variability has analyzed from two types of main frequency domain such as temperature record as well as rainfall record. So, additive and multiplicative model has been used comparatively. According to the basic function of this method, additive model has considered for temperature series and on the other hand, multiplicative model has considered for rainfall series. According to "$base-2\ numeral$" system, zero (0) amount of rainfall converted to 1 numeric value consideration where needed.

Serial number of considered observatories with proper name, co-ordinates, nearest distance of the considered series have been implanted carefully into the MASH method to operate the process properly. Every series has been employed through CSV ($Comma\ Separated\ Values$) format. The candidate series has been confirmed by manually inputs of series serial commend. The adjustment of every frequency have noticed a particular weighted reference series and displayed several difference series. The optimal weighted value is determined by minimizing the variance of the difference series, in order to increase the efficiency of the statistical test. This analysis has been supported by the following statistical equations:

Consideration:

H0: an estimated breakpoint is false breakpoint.

H1: an estimated breakpoint is real breakpoint.

Conceptualization: A Climatological Time Series is Conceptualized to have 3 (Three) components

$$X_i(t) = C_i(t) + IH_j(t) + \in_i (t) \qquad (i = 1, 2, ...N) \quad (t = 1, 2, ...N) \qquad ....(5.1)$$

$$\in = Noise$$

C: Climate Change
IH: Inhomogeneity (Non-Climatic)

The model is additive (for temperature) and multiplicative (for rainfall) which transferred in to additive by Logarithmization.

Multiple comparisons of the examined series:

Candidate Series: $X_c(t) \quad c \in \{1, 2, ...N\}$ ....(5.2)

Inhomogeneity of the Candidate Series: $IH_c(t)$

Set of Reference Series: $R_c \subset \{1, 2, ...N\}$ .... (5.3)

$$\{(i \in R_c, if C_i(t) \approx C_i(t))\} \qquad ....(5.4)$$

Among these two apparently equal series it was difficult to consider a particular series as reference series to rectify the other series.

Optimal difference series

$$z_C^{(M)}(T) = X_c(t) - \sum_{i \in R_c^m} W_i . X_i(t) \qquad \text{..........(5.5)}$$

Where,

$$R_c^{(m)} \subseteq R_c (m = 1, ..., 2^{|R_c|} - 1)(\square : numarosity)$$

$$\sum W_i = 1, \quad W_i \geq 0$$

and Variance $(Z_c^{(m)} = \underset{w}{minmum})$

Hence, $$Z_c^{(m)}(t) = IH_c(t) - IH_{R_c^{(m)}} + \delta_c^{(m)}(t) \qquad \text{................(5.6)}$$

If,

$$and \quad IH_{R_c}(m)\ (t) = 0 \quad then \quad Z_c^{(m)}(t) \cong IH_c(t) \qquad \text{.........(5.7)}$$

If

i) Variance of the noise component to candidate series, and thereby variance of the difference series is approximately equal to zero and

ii) Inhomogeinity in optimal candidate series is approximately nil

Then we can conclude that, optimal difference series is Inhomogeous only due to inhomogeinity in the candidate series.

Optimal different series system has been calculated by the following steps

$$Z_c^{(m)}(t),\ m \in M^* \subset \{1, ..., 2^{|R_c|} - 1\},\ |M^*| \geq 2$$
$$Z_c^{(m)}(t): belongs \ \ to \ \ Subset \ \ R_c^{(m)}$$
$$\bigcap_{m \in M^*} R_c^{(m)} = \phi$$
$$Z(t) = IH(t) + \delta(t)$$

$$\text{.........(5.8)}$$

$$Z_c^{(m)}(t),\ m \in M^* \subset \{1, ..., 2^{|R_c|} - 1\},\ |M^*| \geq 2$$

$$i) \quad Z_c^{(m)}(t): belongs \ \ to \ \ Subset \ \ R_c^{(m)}$$

$$ii) \quad \bigcap_{m \in M^*} R_c^{(m)} = \phi$$

The difference series has also been synthesized.

Test statistics for difference Series (*Appendix- I)*

Critical Value (α) *is set by Monte Carlo Method at given significance Level* p.

After the MASH game application, following all tests has been analyzed through the *RH* software through R_ scripts configuration. These scripts will has shown in *Appendix-II.*

5.1 Slope Analysis :

Least square linear regression has been fitted by the following manner for detecting the slope of the considered time series.

$$Temperature = slope \times year + constant$$

$$\hat{y} = b_i x + b_o \qquad \text{..............................(5.9)}$$

Residual has been calculated by following formula:

$$e = y - \hat{y} \qquad \text{..........................(5.9.1)}$$

After that, month to month correlation of regression residual r_i was calculated by applying following formula:

$$r_i = \left\{ \sum_{t=1}^{n-1} (e_t)(e_{t+1}) / (n-k-1) \right\} / s^2 \qquad \text{...............(5.9.2)}$$

Where e is regression residual at t.

r is sample size, k is the number of parameter (here $k=1$), s^2 is residuals variance.

Here also calculated effective sample size ne using the above r value.

$$ne = n\left(\frac{1-r_1}{1+r_1}\right) \qquad \text{.........(5.9.3)}$$

Where $ne < n$. ne is used to compute standard error of slope to get new confidence interval (other than that was got doing regression analysis)

Calculation of standard error (SE)

$$SE\ of\ slope = Sb_i = \frac{\sqrt{\sum (y - \hat{y})^2 / ne - 2}}{\sqrt{(x_i - \bar{x})^2}} \qquad \text{……..(5.9.4)}$$

This analysis has combined with the confidence interval of the slope. Here, confidence level has confirmed at $\alpha = 0.05$ level of confidence.

The critical probability has been calculated depending upon the Degree of Freedom (df) value.

$$df = ne - 2 \qquad \text{………….(5.9.5)}$$

Finally, Marginal Error and Confidence Interval has confirmed by the following formula:

$$ME = Critical\,Value \times Standard\ Error$$

$$ConfidenceInterval = Sample\,Statistic \pm ME$$

5.2 Trend Detection by Mann-Kendall Test :

The Mann-Kendall test assure the trend in the data where the positive values indicate an increasing trend and the negative values indicate a decreasing trend over the considered time period. The strength of the trend is proportional to the magnitude of the Mann-Kendall test statistic whereas large magnitude indicates a strong trend. For the Mann-Kendall test the null hypothesis Ho : is that there is no trend in the tie series i.e. the observations yi are randomly ordered in time. This hypothesis has tested against the alternative hypothesis H_1: that there is an increasing or decreasing monotonic trend. The considered data values are evaluated as an ordered time series. Each data value has compared with all subsequent data values in the time series. If the data value of a later point of time is higher than a data value from an earlier time point, the statistic β is incremented by 1.

On the other hand, if the data value for a later time is lower than an earlier data value, β is decremented by 1. The net result of all such increments and decrements yields the final value of β.

Hence, β is calculated using the formula:

$$\beta = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(yj - yi) \qquad (5.9.6)$$

where y_i and y_j are the annual value in years i and j and $j > i$, respectively, and

$$sign(yj - yi) \begin{bmatrix} for(yj - yi) > 1 \\ for(yj - yi) = 0 \\ for(yj - yi) < 1 \end{bmatrix} \qquad (5.9.7)$$

A high positive value of the β statistic indicates an increasing trend, while a low negative value indicates a decreasing trend in the time series of the random variables.

The evaluation of the probability associated with β and the sample size n, is however necessary to determine the statistical significance of the trend. The variance of β is computed as:

$$VAR(\beta) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \qquad (5.9.8)$$

where q is the number of tied groups and t_p is the number of data values in the p th group.

For sample size of n >10, the sample distribution of β is known to follow a standard normal distribution z_c. The computed values of β and $VAR(\beta)$ are used to compute the z_c statistic as stated below (*Onoz, B.A.B., M., 2003*).

$$Zc = \begin{Bmatrix} \frac{\beta - 1}{\sqrt{VAR(\beta)}} \\ 0 \\ \frac{\beta + 1}{VAR(\beta)} \end{Bmatrix} \quad \begin{Bmatrix} if\,\beta > 0 \\ if\,\beta = 0 \\ if\,\beta < 0 \end{Bmatrix} \qquad (5.9.9)$$

All the statistical significance of the z_c values has been tested for at the 95% and 99% levels of significance. The critical values of z_c at 95% and 99% significance levels are $z_{c0.025=1.96}$ and $z_{c0.001=2.58}$ respectively.

Where the z_c value is negative, the trend is said to be decreased and the absolute value of z_c, computed using equation -36, is greater than the critical value. While the z_c value is positive and greater than the critical value, then the trend is said to be increased. When the absolute value of z_c is less than the critical value, the considered data series has shown no trends and the alternative hypothesis shows a rejected trend. The significance of a trend normally implies that the occurrence of the trend is not by a process of changing random sample, it has a definite cause. Moreover, the trend is significant at the 99% level of significance and then it may be highly significant (*Sen P. K. 1968*).

5.3 Climatic Change Point Detection by Sequential Mann-Kendall Test :

The Sequential version of Mann-Kendall test statistic (*Sneyres, et al.1990*) on time series x detects recognized event or change points in long time data series. The Sequential Mann-Kendall test is computed using ranked values, y_i of the original values in analysis x_j, x_j, $x_j \ldots x_n$. The magnitudes of y_i (i =2.......... n) are compared with y_j (j=1.....i -1). For each comparison, the cases where $y_i > y_j$ are counted and denoted by n_i . A statistic t_i can therefore be defined as (*Mohsin, et al. 2009*):

$$t_i = \sum_{1}^{i} n_i \qquad (5.2.0)$$

The distribution of test statistic t_i has a mean as

$$E(t_i) = \frac{i(i-1)}{4} \qquad (5.2.1)$$

and variance as

$$var\ (t_i) = \frac{i(i-1)(2i+5)}{72} \qquad (5.2.2)$$

The Sequential values of a reduced or standardized variable, called statistic $u\ (t_i)$ is calculated for each of the test statistic variable t_i as follows:

$$u(t_i) = \frac{t_i - E(t_i)}{\sqrt{var(t_i)}} \qquad (5.2.3)$$

While the forward sequential statistic, $u\ (t_i)$ is estimated using the original time series (x_1, x_2 , ...,. x_n), values of backward sequential statistic, $u'(t_i)$ are estimated in the same manner but starting from end of the series. In estimating $u'(t_i)$ the time series is resorted so that last value of the original time series comes first ($x_1, x_2, x_3, \ldots, x_n$.)

The sequential version of Mann-Kendall test statistic allows detecting of recognizing event or change point beginning of a developing trend. When $u\ (t_i)$ and $u'(t_i)$ curves are plotted. The intersection of the curves $u\ (t_i)$ and $u'(t_i)$ locates approximate potential trend turning point or change point over the time series. If in intersection of $u\ (t_i)$ and $u'(t_i)$ occur within ± 1.96 (5% level) of the standardized statistic, a detectable change at that point in the time series can be inferred. Moreover, if at least one value of the reduced variable in greater than a chosen level of significance of Gaussian distribution the null hypothesis (*Ho*: Sample under investigation shows in beginning of a new trend) is rejected.

5.4 Magnitude of Change Estimation (Sen's Slope Estimation) :

The magnitude of the trend of a time series is predicted by the help of Sen's slope estimator. In this study, linear trend is present in the data and hence the true magnitude of change has estimated by this method. Where, the slope (T_i) of all data pairs has been calculated using the formula as follows (*Douglas E.M et al.2000*).

$$T_i = \frac{x_j - x_i}{j - i} \qquad (5.2.4)$$

x_j and x_i presents as data values at time j and i $(j > i)$ respectively.

The median of the N values of T_i is considered as Sen's estimator of slope which is calculated by the formula:

$$Q_i = \begin{Bmatrix} T_{\frac{N+1}{2}} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) \end{Bmatrix} \quad \begin{bmatrix} N = odd \\ N = even \end{bmatrix} \qquad (5.2.5)$$

Sen's estimator is computed as $Q_{med} = T(N+1)/2$ if N appears odd and it has considered as

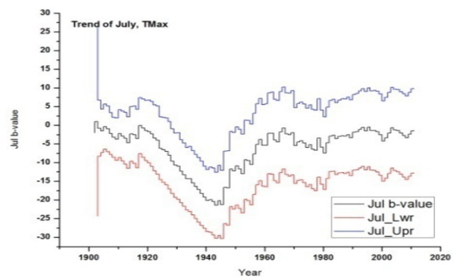
$Q_{med} = \left[T_{\frac{N}{2}} + T_{N+\frac{2}{2}}\right]/2$ if N is appears even. At the end, Q_{med} computed by a two sided test at 100 $(1-\alpha)$ % confidence interval and then a true slope can be obtained by this non-parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i indicates a downward or decreasing trend over the time series.

5.5 Result and Discussion :

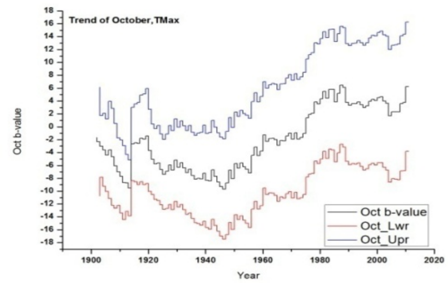
After the homogenization of all considered time series by MASH GAME application, all series have been intensively checked by the Cumulative Deviation (CD) test again and their results are given in *Appendix-III.* Ultimately the time series quality has controlled without any outlier component. In respect of regression analysis following the equation-27-32, "b" value or slope has been calculated for monthly, seasonally and annually constructed temperature and rainfall series. The confidence interval has estimated at α = 0.05 level of significance. In maximum cases the b values (slope) has indicated positive direction in respect of $Zero\ or\ equal\ level$. Some graphical presentation of "b"value or slope of the time series is given in Figure-22. Where, the middle line of those graphs has shown the actual slope of the considered series and the upper and lower line indicates confidence interval of the series considered. The months of January, February, March, May, June, August, September, November and December for Bankura, the months of February, March, May, June, July, September, and December for Birbhum, Burdwan, Nadia and Midnapore have indicated increasing trend over the considered period. Both the 24 Parganas are characterized by abnormal increasing trend. The mean monthly maximum ($TMax$) temperature series for different observatory indicates their increasing trend since 1945. This increasing trend has continuous and till 1975. After that the nature of mean monthly maximum temperature ($TMax$) time series has sustained a stable condition till 1980. It can be resolve that, this period is a climatic age over this area. After 1980, the mean maximum temperature ($TMax$) series have further increased till 2010. This scenario is the prominent character that reveals from this slope analysis for all observatories under study.

Figure-22: Significant increasing Slope tendency ($b\ value$) of some Monthly $TMax$ Series for different observatories.

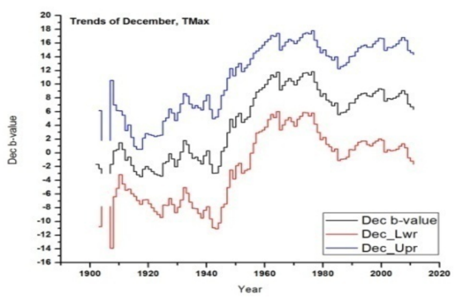
Bankura (July)



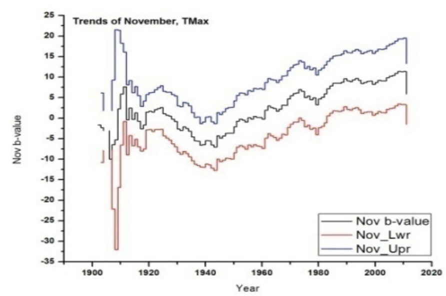
Bankura (October)



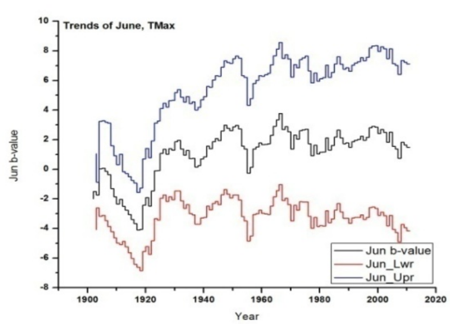
Birbhum (November)



Birbhum (December)



Burdwan (June)



Burdwan (October)

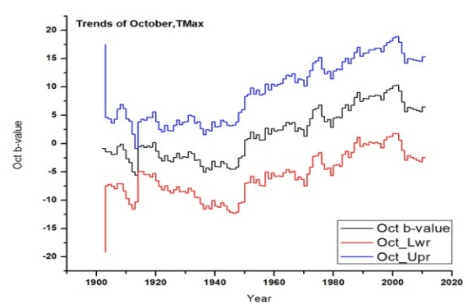
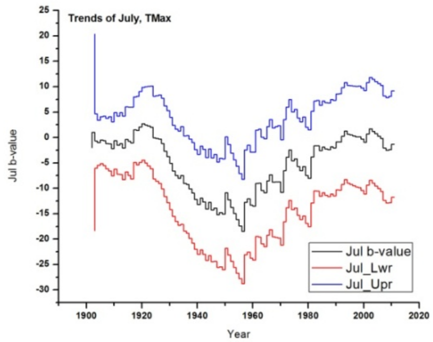
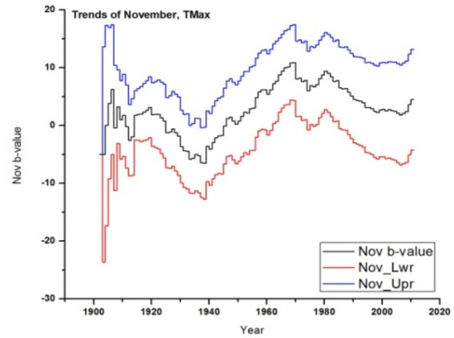


Figure Cont....

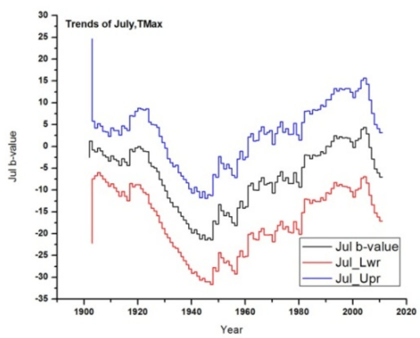
Hooghly (July)



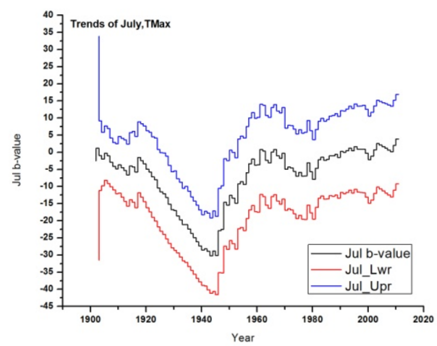
Howrah (November)



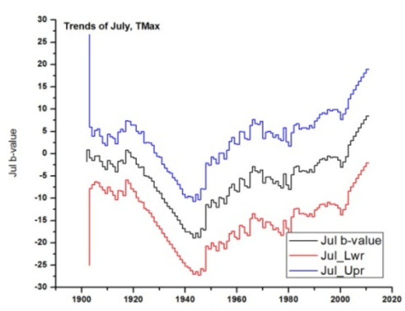
Kolkata (July)



Malda (July)



Midnapore (July)



Midnapore (October)

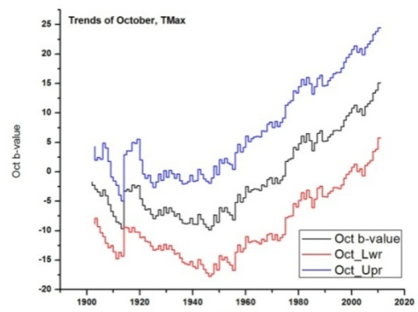
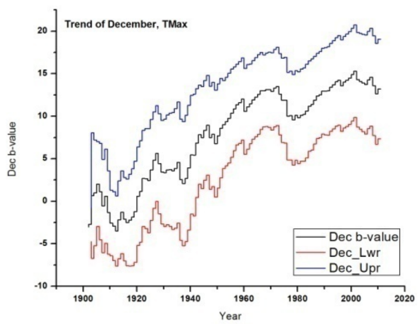
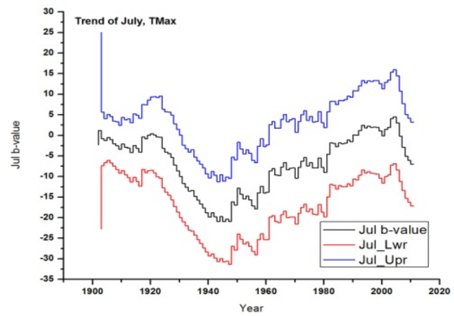


Figure Cont….

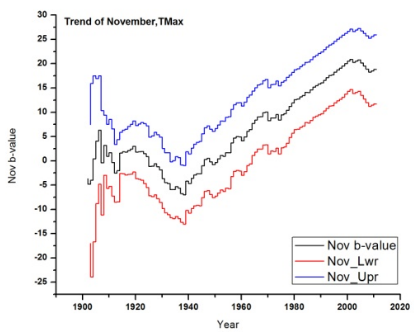
Murshidabad (December)



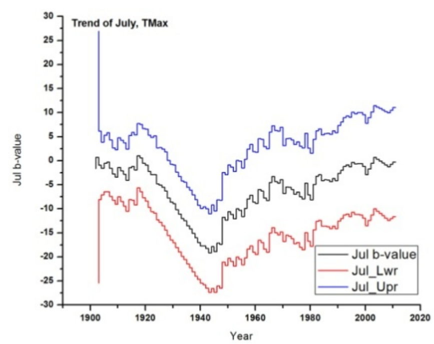
Nadia (July)



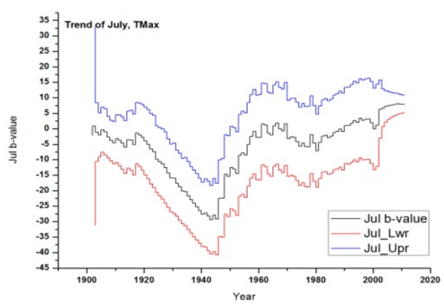
North 24 Pargana (November)



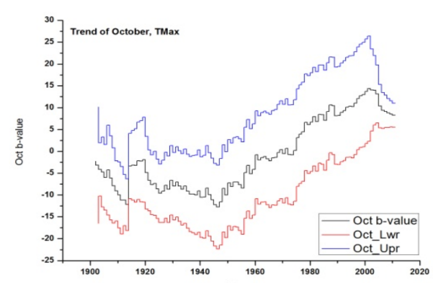
Purulia (July)



South 24 Pargana (July)



South 24 Pargana (October)

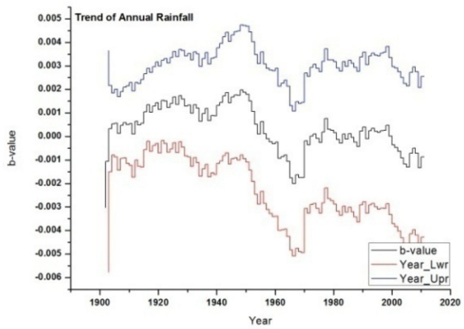


The mean annual temperature series for both $ATMax$ & $ATMin$ has revealed the increasing trend. Moreover, the seasonal series for each observatory are very rigid to maintain their increasing trend. Specially, the slope ($b\ value$) for winter and post-monsoon has indicated increasing trend over the considered time period. Moderately increasing nature has indicated for summer and monsoon seasons.

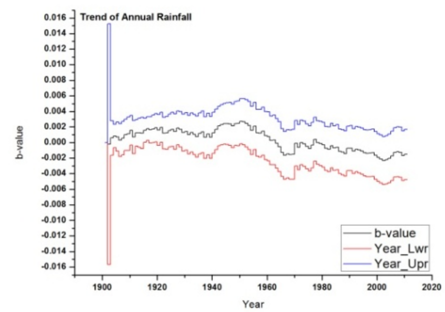
The annual rainfall series also examined for its slope identification over the considered period. The result of this analysis is shown in Figure-23. The considered series for Howrah, Kolkata, Midnapore, Nadia, North 24 Pargana and South 24 Pargana have indicated increasing trend since 1950. On the other hand, annual rainfall series for Bankura, Birbhum, Burdwan, Malda, Murshidabad and Purulia have indicated decreasing trend for rainfall series since 1950. The annual rainfall series for Hooghly observatory clearly indicates increasing trend on and from 1950 to 1980 and after that the trend has gradually decreased. Moreover, the minute observation among these results of slope indicates that, after 2010 the trend will be decreasing again. So it can be concluded that, the annual rainfall trend can be decreased for coming 20 years.

Figure-23: Significant increasing Slope tendency ($b\ value$) of Annual Rainfall Series of 13 observatories.

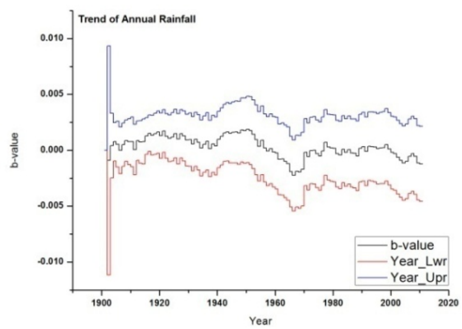
Bankura (Rainfall, Annual)



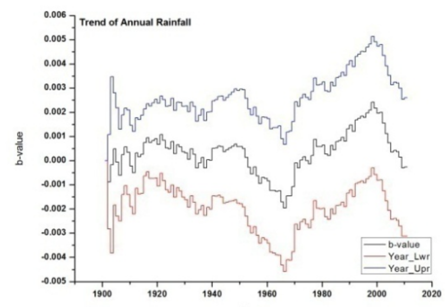
Birbhum (Rainfall, Annual)



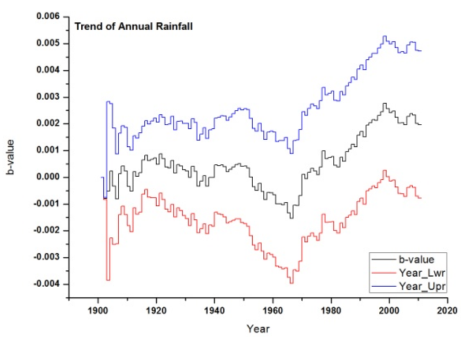
Burdwan (Rainfall,Annual)



Hooghly (Rainfall, Annual)



Howrah (Rainfall, Annual)



Kolkata (rainfall, Annual)

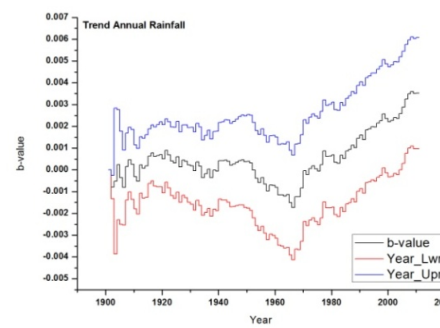
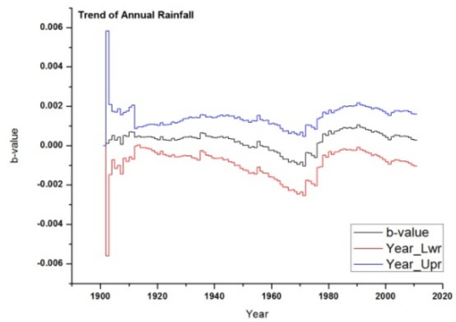
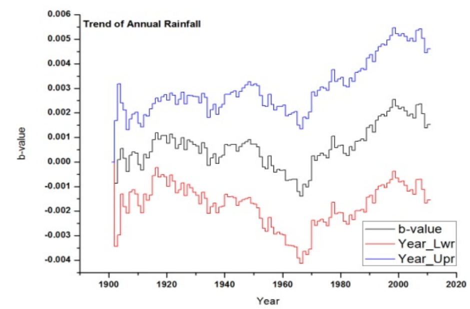


Figure Cont...

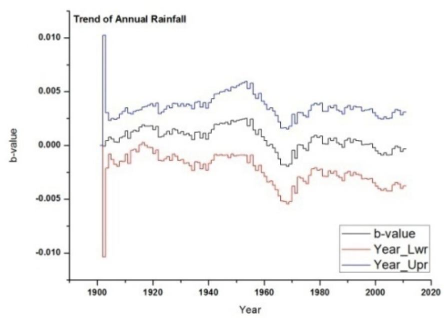
Malda (Rainfall, Annual)



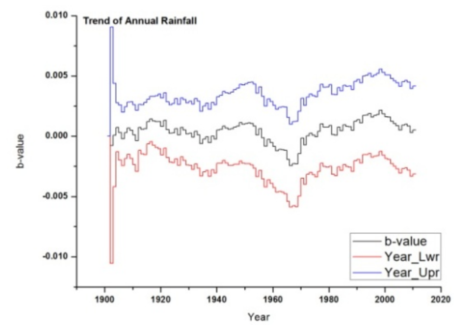
Midnapore (Rainfall, Annual)



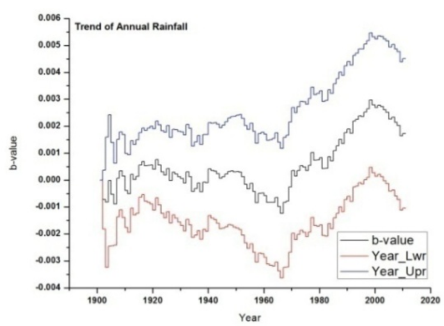
Murshidabad (Rainfall, Annual)



Nadia (Rainfall, Annual)



North 24 Pargana (Rainfall, Annual)



Purulia (Rainfall, Annual)

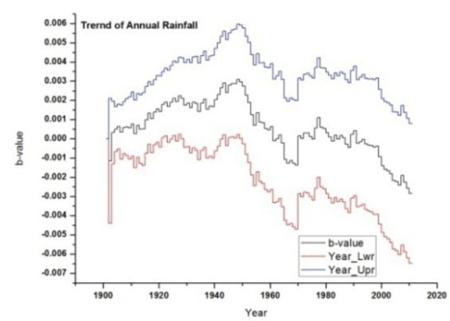
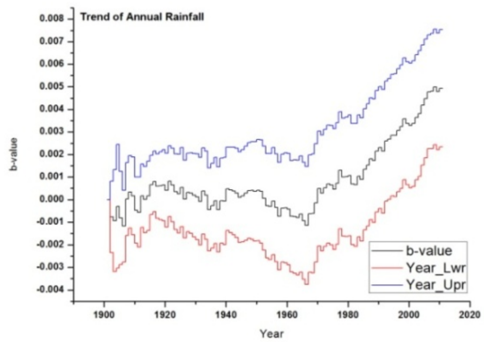


Figure cont….

South 24 Pargana (Rainfall, Annual)



Statistically assessment of the monotonic upward and downward trend of the $TMax$, $TMin$, $ATMax$,$ATMin$, $STMax$, $STMin$ and rainfall series has been detected by the Mann-Kendall test. In this test, null hypothesis (Ho) of no trend has checked with the alternative hypothesis (Hi) of increasing or decreasing trend over the considered period. The level of significance is a sensitive subjective matter for this test where result may check properly. The result of the Mann-Kendall test for mean monthly maximum ($TMax$) series is shown in Table-51. The increasing as well as decreasing trend has been detected for different mean monthly maximum ($TMax$) series. All these test statistic results value are statistically insignificant at chosen level of significance (at $\alpha = 0.05$). But their absolute calculated values have indicated the positive ($+ value$) and negative ($- value$) trend nature of the considered time series.

Mean monthly maximum ($TMax$) series for February, March, June, October, November and December has indicated positive insignificant trend for Bankura observatory. The remaining months for this observatory indicates negative insignificant trend over the considered time period. The detected positive trend of those months for Bankura observatory are 0.02(February), 0.01 (March), 0.02 (June), 0.07 (October), 0.08 (November) and 0.07 (December) respectively.

The $TMax$ series for the Birbhum observatory indicates positive trend for the months of March (0.09), April (0.01), May (0.02), June (0.02), October(0.05), November (0.13) and December 0.03 respectively. The mean monthly maximum ($TMax$) series for the Burdwan observatory indicates positive trend for the consecutive 10 months except April and July. Among the 12 months results, 7 months for the Hooghly observatory, mean monthly maximum ($TMax$) time series reveals positive trend, yet these are statistically insignificant at chosen level of significance. On the other hand, the Howrah observatory indicates positive trend for 4 months over the year. The observatory Kolkata also indicates positive trend for 7 months over the considered period. These months are February, March, June, September, October and November respectively. The result of the December $TMax$ series for Kolkata observatory critically refers no such trend ($value\ statistic\ is\ 0.00\ ℃$) after the homogenization of the mean monthly maximum series. Series for Malda observatory also indicates positive trend for 7 months. The result for the Midnapore observatory is very interesting and it reveals 9 months with positive trend. Among them, January and April remains neutral linear condition and they do not refer any positive or negative trend over the considered period. Trend for the mean monthly maximum ($TMax$) series for Murshidabad has revealed almost identical result after Howrah observatory. On the other hand, one adjacent observatory, Nadia has indicated its positive trend for 5 monthly series. According to the Mann-Kendall test, observatory North 24 Pargana has revealed 5 monthly series as positive trend like February, August, October, November and December respectively. Purulia is one of the western most observatory of the considered geographical study area. Normally, its temperature condition is always higher than the other adjacent observatory considered. The result of the Mann-Kendall test suggests that, 8 mean monthly maximum temperature ($TMax$) records as positive trend except January, April, July and August. Well populated district is South 24 Pargana, which is considered for this analysis and its result is almost rigid for every mean monthly maximum ($TMax$) series and has indicated upward trend over the period.

Table-51: Result of Mann-Kendall (Z_c) Test for Mean Monthly Maximum Temperature ($TMax$) Series.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N 24 Pga	Pur	S. 24 Pga
							Kendall-Z_c						
Jan	-0.03	-0.01	0.02	-0.01	-0.03	-0.07	0.02	0.00	-0.04	-0.08	-0.08	-0.06	0.18
Feb	0.02	-0.01	0.03	0.03	0.02	0.05	0.03	0.21	0.03	0.06	0.06	0.02	0.28
Mar	0.01	0.09	0.06	-0.03	-0.01	0.03	0.04	0.10	-0.04	-0.03	-0.03	0.01	0.22
Apr	-0.06	0.01	-0.10	-0.10	-0.08	-0.05	-0.04	0.00	-0.11	-0.09	-0.09	-0.07	0.18
May	-0.02	0.02	0.02	0.03	0.05	-0.04	0.01	-0.05	-0.13	-0.12	-0.12	0.04	0.17
Jun	0.02	0.02	0.03	-0.03	-0.02	0.01	0.06	0.05	-0.03	-0.02	-0.02	0.01	0.17
July	-0.03	-0.02	-0.07	-0.07	-0.07	-0.09	0.00	0.08	-0.10	-0.08	-0.08	-0.02	0.15
Aug	-0.09	-0.10	0.00	0.04	-0.14	-0.01	-0.05	0.21	0.11	0.06	0.06	-0.04	0.26
Sep	-0.06	-0.02	0.00	0.03	-0.02	0.01	-0.02	0.10	-0.06	-0.06	-0.06	0.00	0.16
Oct	0.07	0.05	0.10	0.06	-0.15	0.02	0.01	0.18	0.11	0.10	0.10	0.08	0.29
Nov	0.08	0.13	0.11	0.02	0.07	0.14	-0.12	0.34	0.31	0.32	0.32	0.07	0.44
Dec	0.07	0.03	0.17	0.04	0.04	0.00	-0.02	0.30	0.29	0.22	0.22	0.06	0.37

Table-52 provides the Mann-Kendall test statistic of the mean monthly minimum temperature ($TMin$) series. The $TMin$ series for the Bankura and Birbhum observatory indicates entirely positive trend for every months over 111 years temporal scale but all estimated test statistic remains statistically insignificant at chosen level of significance. Time mean monthly minimum ($TMin$) series for Burdwan observatory has noticed negative trend for the month of May and its test value is very immaterial or negligible (-0.01°C). Hooghly, Malda and Midnapore have indicated single month monotonic negative trend over the considered period. $TMin$ series for Howrah indicates negative trend results for 4 months, those are January, April, May and June respectively. Rest of the all mean monthly minimum temperature ($TMin$) series for this observatory have indicated positive trend over the considered period. In case of the North 24 Pargana, the mean monthly minimum temperature ($TMin$) series of January, July and August have indicated negative trend and other monthly series indicated positive trend over the considered period.

It is noticeable that, all these test statistic values are not significant at $\alpha = 0.05$ level of significance. Moreover the numeric values that is evaluated by the Mann-Kendall test are very small. According to the statistical properties of this test, the outcomes just guide the positive and negative nature of the considered time series. Moreover, the mean monthly minimum temperature ($TMin$) value becomes high in respect of temporal forwardness.

The distribution free Mann-Kendall test result of the average monthly rainfall series has shown in Table-53**.** It reveals the opposite result against $TMax$series. Maximum rainfall series has indicated negative trend result after the Mann-Kendall test. For the Bankura observatory, six monthly rainfall series have indicated negative trend over the considered period. January, February, March, June, July and August rainfall time series trends have shown like this result. For the Birbhum observatory, February, March, June, July and August have indicated negative trend over the considered period. The monthly average rainfall series of January (-0.03), February(-0.13), March(-0.04), June(-0.07), July $(-0.04)$and August (-0.14) have indicated negative trend for Burdwan observatory. On the other hand, observatory Hooghly has indicated five negative trend results for average monthly rainfall series over the considered temporal scale. Similar such result has indicated for Malda observatory. By this test statistic, the observatory Nadia has indicated negative trend for most of the monthly rainfall series. Moreover, the overall observation has dragged the common decision that the monsoon rainfall become less in amount, that why, the trend is signifying as negative. Comprehensive monthly average rainfall series has suggested these results in order to negative trend but the test values are not significant statistically.

Table-52: Result of Mann-Kendall (Z_c) Test for Mean Monthly Minimum Temperature Series.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N. 24 Pga	Pur	S. 24 Pga
	Kendall-Z_c												
Jan	0.08	0.10	0.07	0.02	-0.04	0.03	0.08	0.07	0.11	0.04	-0.04	-0.02	0.11
Feb	0.19	0.13	0.18	0.15	0.17	0.17	0.16	0.14	0.16	0.12	0.10	0.16	0.09
Mar	0.15	0.13	0.13	0.09	0.01	-0.01	0.09	0.15	-0.04	0.09	0.17	0.13	0.23
Apr	0.06	0.01	0.01	0.01	-0.09	0.09	0.12	0.08	0.08	0.05	0.14	0.02	0.16
May	0.07	0.00	-0.01	0.03	-0.03	0.04	0.13	0.03	0.01	-0.02	0.07	0.04	0.04
Jun	0.00	0.05	0.00	-0.07	-0.06	0.05	0.01	0.04	0.04	0.00	0.12	-0.07	-0.08
Jul	0.08	0.11	0.09	0.04	0.02	-0.01	-0.09	-0.10	0.10	-0.12	-0.12	0.01	0.16
Aug	0.03	0.07	0.15	0.13	0.10	0.06	0.23	0.06	0.10	0.13	-0.01	0.14	-0.02
Sep	0.10	0.06	0.11	0.05	0.09	0.07	0.23	0.11	0.17	0.03	0.06	0.13	0.04
Oct	0.09	0.09	0.26	0.11	0.07	0.06	0.08	0.08	-0.02	0.14	0.06	-0.02	0.10
Nov	0.03	0.09	0.13	0.14	0.19	0.09	0.28	0.03	0.14	0.11	0.08	-0.06	-0.05
Dec	0.15	0.14	0.20	0.04	0.27	0.18	0.26	0.11	-0.01	0.13	0.18	-0.08	0.15

Table-53: Result of Mann-Kendall (Z_c) Test for Monthly Rainfall Series.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N 24 Pga	Pur	S. 24 Pga
	Kendall-Z_c												
Jan	-0.01	0.01	-0.03	-0.02	0.04	0.00	0.09	-0.01	0.02	-0.02	0.00	0.02	-0.01
Feb	-0.15	-0.14	-0.13	-0.12	-0.07	-0.07	-0.14	-0.09	-0.15	-0.12	-0.08	-0.16	-0.04
Mar	-0.04	-0.04	-0.04	-0.03	-0.05	-0.08	-0.02	-0.03	-0.04	-0.03	0.01	-0.06	-0.04
Apr	0.04	0.08	0.03	0.00	0.03	0.06	0.05	0.01	0.04	-0.01	0.03	0.02	0.03
May	0.09	0.06	0.07	0.04	0.04	0.06	0.13	0.03	0.04	-0.01	0.01	0.10	0.04
Jun	-0.07	-0.08	-0.07	-0.04	0.00	0.03	-0.14	-0.02	-0.07	-0.06	-0.04	-0.13	0.07
Jul	-0.02	-0.10	-0.04	0.00	0.07	0.07	-0.09	0.06	-0.08	-0.03	0.08	-0.02	0.16
Aug	-0.13	-0.10	-0.14	-0.10	-0.05	0.01	-0.13	-0.03	-0.12	-0.09	-0.05	-0.11	0.06
Sep	0.07	0.03	0.05	0.06	0.09	0.14	0.04	0.08	0.08	0.13	0.10	0.03	0.12
Oct	0.07	0.11	0.10	0.07	0.10	0.13	0.14	0.07	0.11	0.12	0.08	0.06	0.11
Nov	0.07	0.08	0.10	0.05	0.09	0.12	0.09	0.08	0.06	0.07	0.14	0.07	0.06
Dec	0.03	0.02	0.07	0.01	0.05	0.01	0.00	0.03	0.03	0.03	0.17	0.04	0.02

Mann-Kendall test result (Z_c) for mean annual maximum ($ATMax$) and mean annual minimum ($ATMin$) temperature and Sen's Slope (Q_i) result is shown in Table-54. All the detected Z_c and Q_i values are indicating insignificant trend and these value statistic also negligible for explanation.

Annual $ATMax$ series for Bankura and Nadia have indicated the negative trend over the considered period. Moreover, the rest of the all observatories have indicated positive trend. The Z_c for $ATMin$ series have shown positive trend for all considered observatories. In comparative study with the Sen's Slope estimation and Mann-Kendall test, the result is almost similar in character. The result of Sen's Slope (Q_i) has also indicated positive trend for all such observatories except Murshidabad. This test has also revealed the magnitude of change, which are given below. The average magnitude of change is 0.003 per decade for mean annual maximum $(ATMax)$ series over the considered period.

Moreover, the results of Mann-Kendall and Sen's Slope estimator indicates negative trend for annual rainfall series. Remarkably, the amount of annual rainfall becomes less than the prior yearly rainfall frequency.

Table-54: Comparative result of Mann-Kendall Test and Sen's Slope Estimator for Annual $(ATMax$ & $ATMin)$ Temperature Series.

Z_c is significant at 0.05% level of significance. Sen's Slope: (-) = negative change and (+) = positive change.

Time Series	Mann-Kendall Trend Test				Sen's Slope (Q_i)	
	N	Z_c $ATMax$	Z_c $ATMin$	Significance level	$ATMax$	$ATMin$
Bankura	111	-0.001	0.229	NIL	0.000	0.004
Birbhum	111	0.021	0.188	NIL	0.001	0.005
Burdwan	111	0.026	0.113	NIL	0.002	0.003
Hooghly	111	0.024	0.120	NIL	0.006	0.003
Howrah	111	0.003	0.229	NIL	0.001	0.004
Kolkata	111	0.012	0.188	NIL	0.002	0.005
Nadia	111	-0.008	0.112	NIL	0.003	0.003
Malda	111	0.068	0.113	NIL	0.001	0.003
Midnapore	111	0.040	0.109	NIL	0.00	0.001
Murshidabad	111	0.027	0.120	NIL	-0.001	0.003
Nadia North 24 Pargana	111	0.028	0.188	NIL	0.0005	0.005
Purulia	111	0.015	0.107	NIL	0.0002	0.001
South 24 Pargana	111	0.009	0.226	NIL	0.00	0.005

Climatological time series analysis depends on the sequential observational study which is in ordered of time or space. This study has encompassed by only temporal period. To tress the actual climatological change point and beginning of the new trend over the period, $TMax$, $TMin$, $ATMax$, $ATMin$, $STMax$, $STMin$ and rainfall series were analyzed through Sequential version of Mann-Kendall test.

This method is most applicable in the both way like to recognize the significant true break identification and also indicates the newly developed decreasing or increasing trend over the considered period. In this study, the result of the Sequential version of Mann-Kendall test has proved again the general decision regarding climate definition. Actually, the construction of progressive and retrograde sequential line indicates the true change point when they meet each other at a particular point. According to the above stated equation in sequential version of Mann-Kendall test, the meeting point of $u(ti)$ and $u'(ti)$ has indicated change point over the considered period. In this concern many of the mean monthly maximum $(TMax)$ series has revealed the significant change in different year over the considered period. The remarkable significant change points are common in first decade (1901-1910), 5th decade (1940 1950), 7th decade (1960-1970) and in 9th decade (1980-1990) respectively for considered mean monthly maximum $(TMax)$ and mean monthly minimum $(TMin)$ series.

Mean annual maximum temperature $(ATMax)$ series has also been checked by this method which is shown in Figure-24 and Table-55. In respect of mean annual maximum temperature series $(ATMax)$, the station Bankura has indicated one significant change point in 1964 and its value statistic is 2.35 (significant at 0.05% level of significance). This series are also indicating other three change points but there value statistic are not significant at 0.05% level of significance. The result also provide that, the observatory Birbhum, Burdwan, Malda, Midnapore, Nadia and South 24 Pargana has shown common single potential change points in 1959, 1963, 1958,1958, 1963, 1958 and 1963 respectively. Some other such observatories have indicated double significant change points like Kolkata and North 24 Pargana. On the other hand, rest three observatories like Howrah, Hooghly and Murshidabad have indicated three potential significant change points each. These are 1964, 1981, 1993 (Hooghly), 1966, 1981, and 1992 (Howrah), 1965, 1981, 1988 (Murshidabad) respectively.

The mean annual minimum $(ATMin)$ temperature time series have revealed quite different result after this method. The observatories Birbhum, Burdwan, Hooghly, Kolkata, Malda, Midnapore, Murshidabad, North 24 Pargana and Purulia have indicated single significant change points in 1980, 1905, 2001, 1980, 2005, 2006, 2001, 1979 and 2006 respectively. The observatories Bankura and Howrah have indicated triple significant change points. Mysteriously, the station South 24 Pargana does not signify any significant change (Table-56 & Figure-25).

Figure: 24. Potential changes in Annual Average Maximum Temperature $(ATMax)$ Series as derived from Sequential Version of Mann-Kendall test statistic, $u(ti)$ forward sequential statistic drawn red in colour and $u'(ti)$ retrograde sequential statistic drawn black in colour.

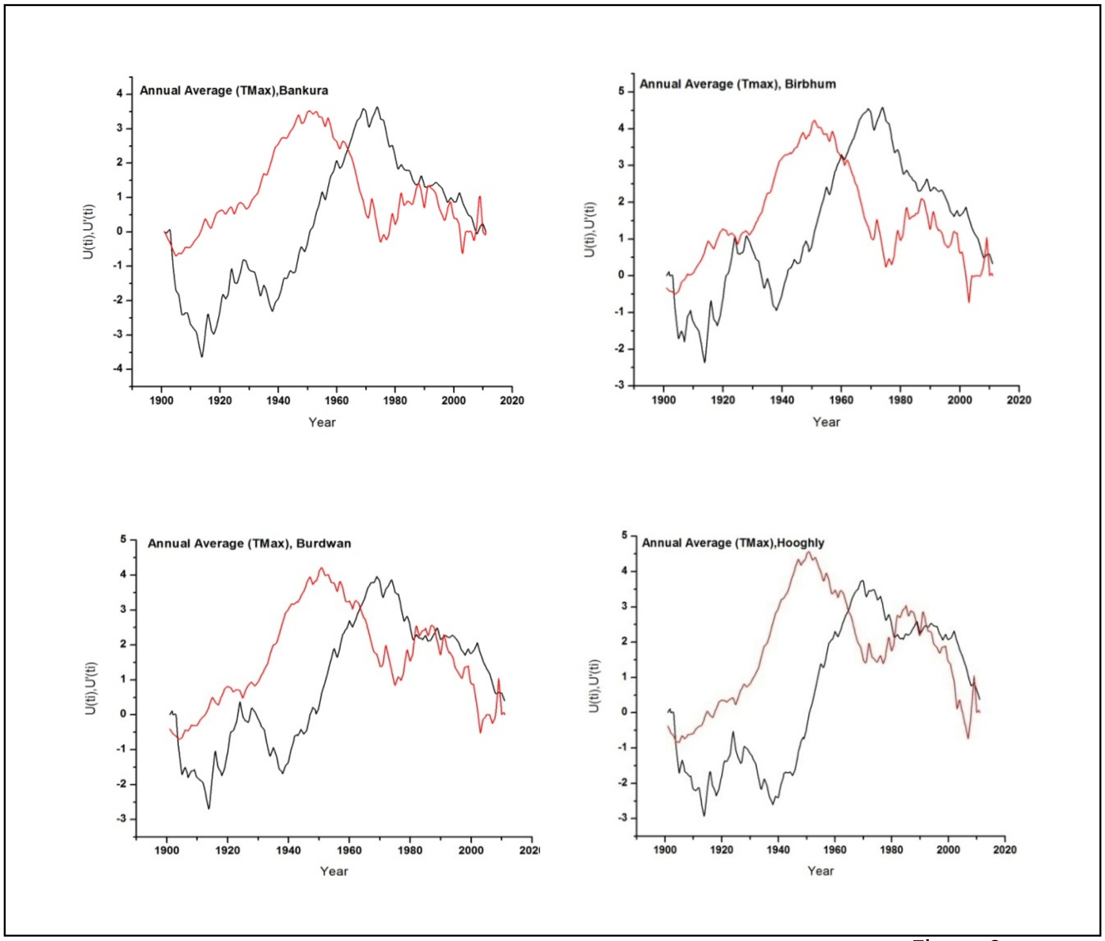


Figure Cont....

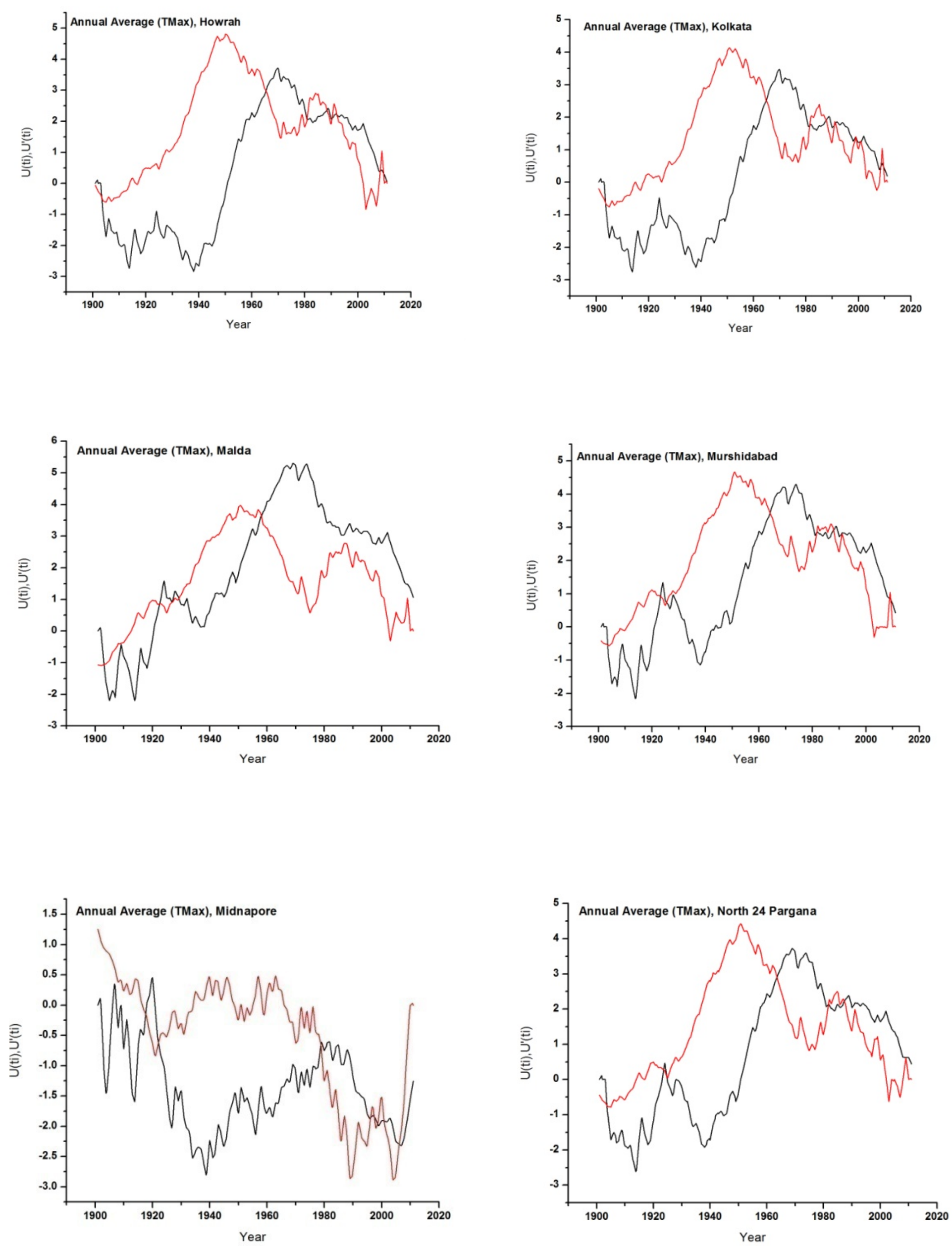

Annual Average (TMax), Howrah
Annual Average (TMax), Kolkata
Annual Average (TMax), Malda
Annual Average (TMax), Murshidabad
Annual Average (TMax), Midnapore
Annual Average (TMax), North 24 Pargana
U(ti),U'(ti)
Year

Figure Cont....

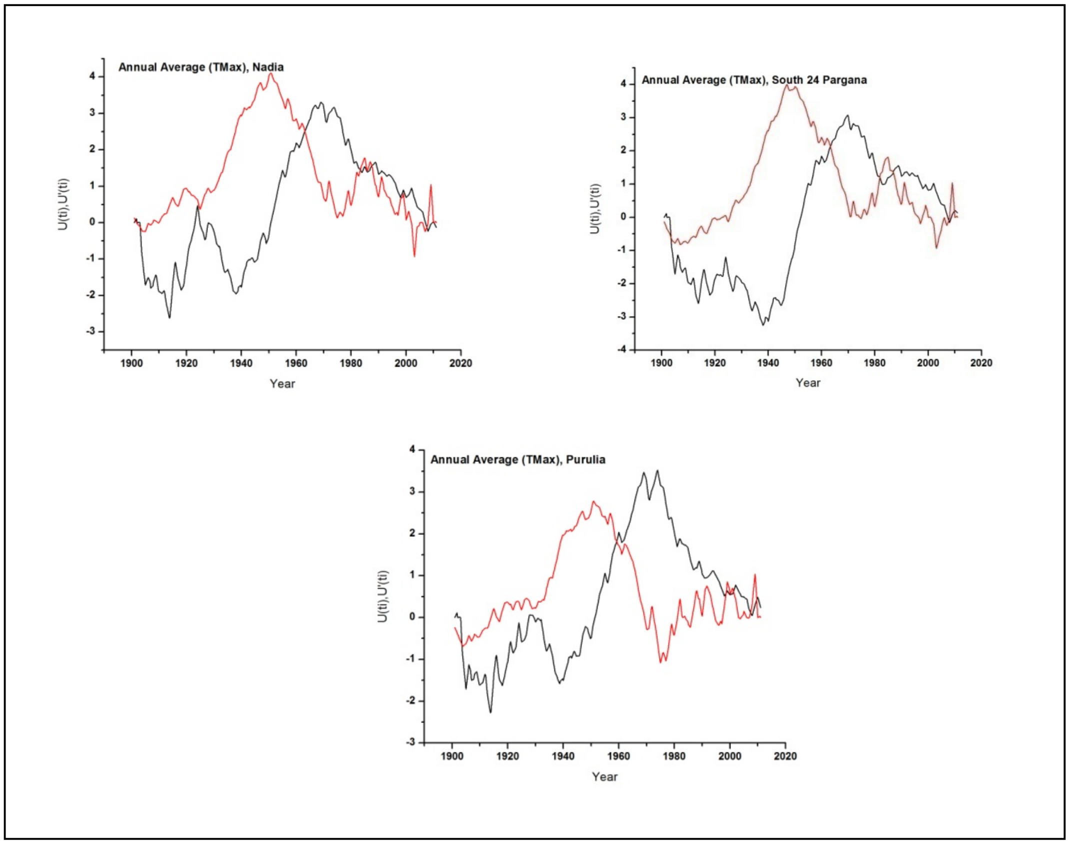

Annual Average (TMax), Nadia
U(ti),U'(ti)
Year
Annual Average (TMax), South 24 Pargana
U(ti),U'(ti)
Year
Annual Average (TMax), Purulia
U(ti),U'(ti)
Year

Table-55: Potential Change Points detected by Sequential Mann-Kendall Test for Mean Annual Maximum Temperature $(ATMax)$ Series for all observatories (values significant at $p < 0.05$).

Observatories	Detected Potential Change Points, $(ATMax)$ Annual Series.					Remark
	1st	2nd	3rd	4th	5th	
Bankura	-0.34	**2.35***	1.41	-0.24		
Year	1903	**1964**	1988	2007		
Birbhum	0.00	1.07	**3.34***	0.33		
Year	1903	1924	**1959**	2008		
Burdwan	-0.60	**3.20***	1.92	1.72	1.04	
Year	1903	**1963**	1981	1990	2009	
Hooghly	-0.65	**3.09***	**2.12***	**2.30***	0.00	
Year	1903	**1964**	**1981**	**1993**	2008	
Howrah	-0.56	**2.84***	**2.19***	1.92	**2.24***	
Year	1904	**1966**	**1981**	1990	**1992**	
Kolkata	-0.69	**2.79***	1.44	**2.01***	1.40	
Year	1904	**1964**	1981	**1987**	1999	
Malda	-1.06	0.84	1.14	**3.64***		
Year	1903	1922	1930	**1958**		
Midnapore	-1.26	**2.06***	1.04			
Year	1904	**1958**	2009			
Murshidabad	-0.50	0.95	**3.45***	**2.53***	**2.85***	
Year	1902	1922	**1965**	**1981**	**1988**	
Nadia	0.36	**2.56***	1.43	0.79		
Year	1925	**1963**	1986	1999		
North 24 Pargana	-0.77	0.31	**2.78***	1.70	**2.28***	
Year	1904	1922	**1964**	1981	**1987**	
Purulia	-0.53	1.84	0.27	0.54	1.04	
Year	1903	1959	1998	2000	2009	
South 24 Pargana	-0.69	**2.22***	0.73	1.41		
Year	1904	**1963**	1981	1986		

Statistic * denotes the significant point.

Table-56: Potential Change Points detected by Sequential Mann-Kendall Test for Mean Annual Minimum Temperature $(ATMin)$ Series for all observatories (values significant at $p < 0.05$).

Observatories	Detected Potential Change Points, $(ATMin)$ Annual Series.					Remark
	1st	2nd	3rd	4th	5th	
Bankura	**-2.80***	**-2.45***	**2.30***	-	-	
Year	**1912**	**1914**	**1998**	-	-	
Birbhum	-0.17	**2.32***	-	-	-	
Year	1937	**1980**	-	-	-	
Burdwan	**-2.01**	-1.33	-0.10	0.14	1.72	
Year	**1905**	1912	1922	1997	2006	
Hooghly	-1.44	-1.02	-0.91	0.23	**2.10***	
Year	1912	1914	1920	1933	**2001**	
Howrah	**-2.66**	**-2.23***	**2.30***	-	-	
Year	**1913**	**1915**	**1998**			
Kolkata	-0.17	**2.32***	-	-	-	
Year	1937	**1980**	-	-	-	
Malda	-1.80	-1.16	-0.10	0.14	**2.27***	
Year	1906	1912	1922	1997	**2005**	
Midnapore	-1.69	-1.52	-0.82	-0.77	**2.48***	
Year	1913	1923	1932	1986	**2006**	
Murshidabad	-1.44	-1.02	-0.87	0.23	**2.10***	
Year	1912	1914	1921	1933	**2001**	
Nadia	-0.44	-1.02	0.23	0.84	1.88	
Year	1912	1914	1933	1993	2003	
North 24 Pargana	0.11	**2.12***	-	-	-	
Year	1938	**1979**	-	-	-	
Purulia	-1.69	-1.52	-0.82	-0.77	**2.48***	
Year	1913	1923	1932	1986	**2006**	
South 24 pargana	-	-	-	-	-	
Year	-	-	-	-	-	

Statistic * marks denotes the significant point.

Figure: 25. Potential changes in Annual Average Minimum Temperature $(ATMin)$ Series as derived from Sequential Version of Mann-Kendall test statistic, $u(ti)$ forward sequential statistic drawn red in colour and $u'(ti)$ retrograde sequential statistic drawn black in colour.

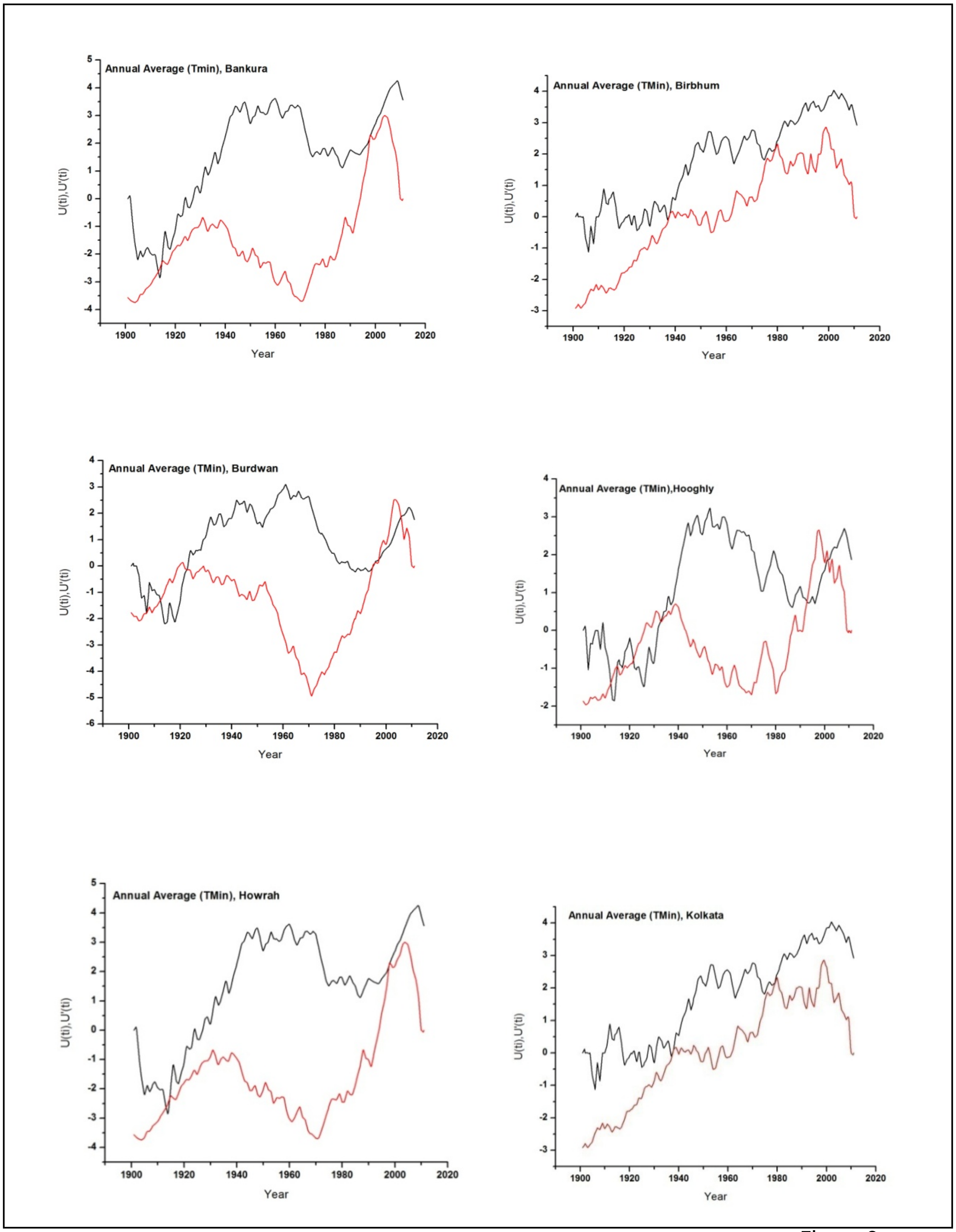
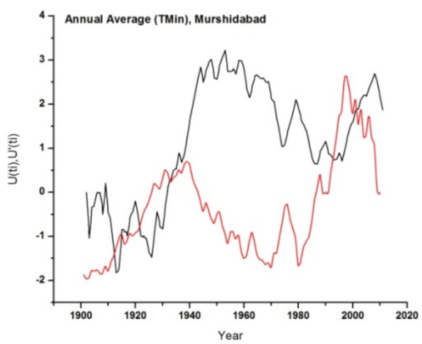
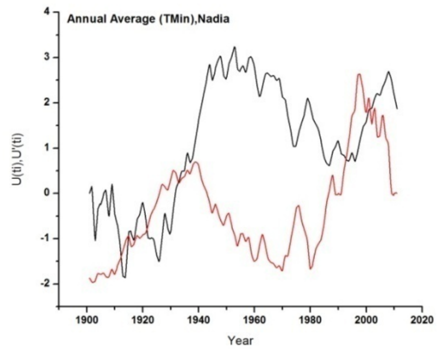
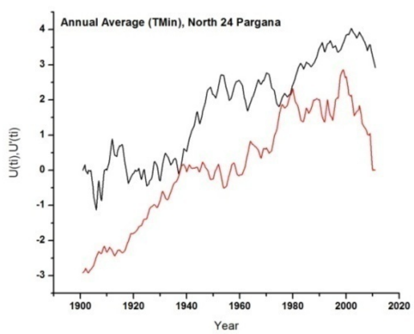
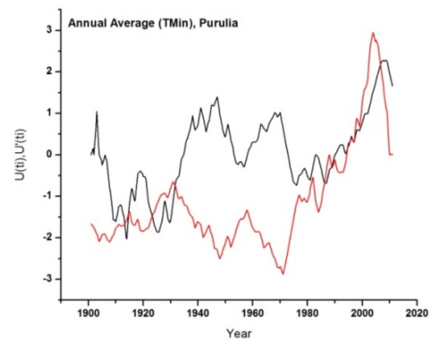


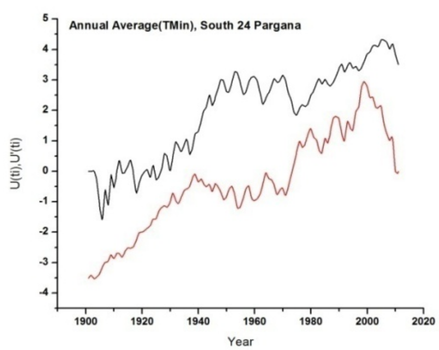
Figure Cont....


Annual Average (TMin), Murshidabad
U(ti),U'(ti)
Year


Annual Average (TMin),Nadia
U(ti),U'(ti)
Year


Annual Average (TMin), North 24 Pargana
U(ti),U'(ti)
Year


Annual Average (TMin), Purulia
U(ti),U'(ti)
Year


Annual Average(TMin), South 24 Pargana
U(ti),U'(ti)
Year

The potential trend turning point estimation by Sequential Mann-Kendall test for regional scale is more important to assess the near future climatic condition (*Chatterjee et al., 2014*). In this study, this method also applies for the detection of the statistically significant change point for considered seasonal series. The result of the winter season for mean maximum temperature ($STMax$) has shown in Table-57. This test has revealed some unfold significant change points over the considered period. Regionally selected 13 observatories $STMax\ (winter)$ series have employed here separately for proper investigation. The significant turning points are randomly associated with different observatories. Depending upon this test statistic, maximum eight change point has been detected for Burdwan winter series and minimum two change point for Hooghly observatory. Observatory Bnakura reveals four change points over the considered time series, but no one can meet the significance level (0.05% level of significance). These change years are 1913, 1925, 1982 and 1997. Observatory, Birbhum indicates four change points over the considered period where 1932 is statistically significant at chosen level of significance.

The result of the Burdwan observatory is very interesting where eight change points indicates altogether. Among them, 1964, 1973, 1982, 1989 and 1999 are the statistically significant. On the other hand, Hooghly indicates only two change points over the considered period where 1984 is the statistically significant one. For the Howrah observatory, 1907, 1970, 1981, 1996 and 2009 has detected change points but all these change does not statistically significant at chosen level of significance. Similarly, five change points have been detected for the Kolkata observatory, but these change points is also insignificant. The change point at 2006 is the significant one for Malda observatory. This series instantly reveals other three change points as insignificant statistically. Another five change points has been detected by the sequential Mann-Kendall test for Midnapore observatory, but their value statistic did not meet the significant level. The below stated table also presents that the 1985 and 1992 are significant change points for Winter series of Nadia observatory. Lastly, North 24 Pargana indicates two significant change points in 1989 and 1999 respectively after this statistical test. Summer season is one of the most important over the South Bengal area.

According to the previous temperature record by the India Meteorological Department (IMD), southern portion of the West Bengal becomes more suffocated due to increase of solar radiation in summer season. Sometimes it welcomes the heat wave condition over this region. The result of Sequential Mann-Kendall test of summer season is shown in Table-58. The result reveals that the significant some change points are present for the different observatories.

The result of the Bankura observatory, the Summer season has indicated six change points over the considered period. These change points are 1917, 1921, 1967, 1981, 2000 and 2004. Among them, two such change points are statistically significant. These change points are 1917 and 1921. For the Birbhum Summer temperature series, 1960 and 1994 are the significant change point. Except this change, another one change point detects by the Sequential Mann-Kendall test, which is 1907. After this test, 1960, 1989, 1996 and 2009 are the detected change or turning points for the Burdwan observatory. However, 1960 and 1989 are statistically significant at chosen level of significance. The observatory Hooghly indicates three change points while, 1961 and 1982 are statistically significant. The other insignificant change point for this observatory is 2000. The significant change point for Howrah observatory has revealed almost similar result like Hooghly observatory. Here also indicates three change points in 1959, 1984 and 1993 for Howrah observatory. Where, only, 1959 is the statistically significant.

The Kolkata observatory indicates four change points in 1961, 1982, 1987 and in 1999 while, 1961 and 1982 are the significant change at chosen level of significance. The observatory Malda has indicated five change points over the considered time period. These change points are 1907, 1961, 1982, 1986 and 1999. While four change points are significant except 1907. The Summer series (Mean minimum temperature) for Midnapore do not indicate any change point over the considered period. This type of result is rare after this analysis. Murshidabad observatory indicates three change points successively. These change points are 1961, 1982 and 1999 respectively. Among these change points 1961 and 1982 are significant respectively. Nadia observatory indicates two change points in 1959 and in 1992 respectively. From them, 1959 is the significant one by this test.

On the other hand, North 24 Pargana Summer series does not indicate any change over the considered time scale. The Purulia indicates one significant change point in 1959 and South 24 Pargana indicates three change points like 1907, 1955 and 2009 while 1955 is the statistically significant one. The Monsoon temperature (Mean maximum temperature) series has been employed by this statistical method to identify the potential change or turning point over the considered period. The result of this test has shown in Table-59. All the detected change points are not significant at chosen level of significance. The observatory Bankura indicates four change points but all these change points are not statistically significant. Location of these change points are 1906, 1915, 1964 and 1980 respectively.

Birbhum indicates five change points in 1963, 1980, 1987, and 2000 and in 2006 respectively. The observatory Burdwan indicates seven change points over the considered temporal span. All these value statistic lies under the significance level at $\alpha = 0.05$ level of significance. Change points in 1915 and 1932 has detected for the Hooghly observatory. Dramatically, Howrah does not have any change points over the considered period. Nadia and South 24 Pargana also indicates similar such result where, the progressive and retrograde sequential line does not meet at any point. In order to this statistical analysis, observatory Malda indicates three potential change points over the considered time period. These change points are 1920, 1958 and 1978. The value statistic of those change points are $-2.75, -2.10\ and - 2.22$ respectively. Here also present that, the observatory Kolkata indicates only change point at 2009 but it is not statistically significant at chosen level of significance. On the other hand, Midnapore observatory indicates three change points altogether. Among them, 1998 (-2.68) is statistically significant. Other two change point has detected in 1916 and in 1963 with their value statistic lower at the critical level. The Monsoon temperature series for Purulia observatory indicates a potential change point in 1928 and its value statistic is -2.62 . The rest of the observatories like Murshidabad and North 24 Pargana do not show any significant change point over the considered period.

Table-57: Potential Change Points detected by Sequential Mann-Kendall Test of Winter for Mean Seasonal Maximum Temperature ($STMax$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Winter for Seasonal Maximum ($STMax$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.37	-1.32	1.75	1.93	-	-	-	-	
Year	1913	1925	1982	1997	-	-	-	-	
Birbhum	**-2.03**	-0.87	0.05	0.01	-	-	-	-	
Year	**1932**	1959	1972	1980	-	-	-	-	
Burdwan	-1.04	-0.53	1.95	**2.47**	**3.08**	**2.95**	**3.05**	**3.36**	
Year	1913	1915	1953	**1964**	**1973**	**1982**	**1989**	**1999**	
Hooghly	-0.59	**2.75**	-	-	-	-	--	-	
Year	1912	**1984**	-	-	-	-	-	-	
Howrah	0.39	0.17	0.37	-0.31	-1.04	-	-	-	
Year	1907	1970	1981	1996	2009	-	-	-	
Kolkata	-1.24	-1.48	-1.54	0.70	1.19	--	-	-	
Year	1903	1913	1925	1971	1981	-	-	-	
Malda	-0.63	-0.76	-1.84	**-2.33**	-	-	-	-	
Year	1922	1978	1999	**2006**	-	-	-	-	
Midnapore	-1.25	-1.16	1.65	1.92	1.90	-	-	-	
Year	1913	1924	1980	1992	1999	-	-	-	
Murshidabad	0.45	-1.44	-1.72	-	-	-	-	-	
Year	1974	2002	2006	-	-	-	-	-	
Nadia	-1.37	-1.38	**2.73**	**2.86**	-	-	-	-	
Year	1914	1925	**1985**	**1992**	-	-	-	-	
N.24 Pga	-0.84	-0.51	-0.72	**1.98**	**2.58**	-	-	-	
Year	1913	1915	1924	**1989**	**1999**	-	-	-	
Purulia	-1.92	-1.22	-1.21	-0.77	-	-	-	-	
Year	1932	1948	1955	1957	-	-	-	-	
S.24 Pga	-0.60	-1.08	-1.27	-	-	-	-	-	
Year	1905	1912	1925	-	-	-	-	-	

Bold values and corresponding years are significant.

Table-58: Potential Change Points detected by Sequential Mann-Kendall Test for Summer for Mean Seasonal Maximum Temperature ($STMax$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Summer for Seasonal Maximum ($STMax$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	**-2.14**	**-2.65**	-1.04	-1.14	-1.25	-0.99			
Year	**1917**	**1921**	1967	1981	2000	2004			
Birbhum	-1.13	**2.82**	**2.44**						
Year	1907	**1960**	**1994**						
Burdwan	**3.22**	**2.08**	1.57	0.61					
Year	**1960**	**1989**	1996	2009					
Hooghly	**3.11**	**2.23**	1.02						
Year	**1961**	**1982**	2000						
Howrah	**2.39**	1.34	0.91						
Year	**1959**	1984	1993						
Kolkata	**2.67**	**2.03**	1.66	1.46					
Year	**1961**	**1982**	1987	1999					
Malda	-1.20	**2.87**	**2.48**	**2.61**	**2.25**				
Year	1907	**1961**	**1982**	**1986**	**1993**				
Midnapore									
Year									
Murshidabad	**3.06**	**1.96**	1.04						
Year	**1961**	**1982**	1999						
Nadia	**2.40**	1.23							
Year	**1959**	1992							
N.24 Pga									
Year									
Purulia	**2.22**								
Year	**1959**								
S.24 Pga	-1.10	**2.05**	1.04						
Year	1907	**1955**	2009						

Bold values and corresponding years are significant.

Table-59: Potential Change Points detected by Sequential Mann-Kendall Test for Monsoon for Mean Seasonal Maximum Temperature ($STMax$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Monsoon for Seasonal Maximum ($STMax$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	0.65	0.38	0.90	0.87	-	-	-	-	
Year	1906	1915	1964	1980	-	-	-	-	
Birbhum	-1.23	-1.91	-1.74	-1.32	-1.38	-	-	-	
Year	1963	1980	1987	2000	2006	-	-	-	
Burdwan	-0.91	-1.27	-1.67	-1.77	-1.85	-1.65	-1.78	-	
Year	1919	1926	1930	1967	1978	1986	1999	-	
Hooghly	-1.08	**-2.68**	-	-	-	-	-	-	
Year	1915	**1932**	-	-	-	-	-	-	
Howrah	-	-	-	-	-	-	-	-	
Year	-	-	-	-	-	-	-	-	
Kolkata	-0.96	-	-	-	-	-	-	-	
Year	2009	-	-	-	-	-	-	-	
Malda	-1.78	**-2.75**	**-2.10**	**-2.22**	-1.89	-1.04	-	-	
Year	1908	**1920**	**1958**	**1978**	1989	2000	-	-	
Midnapore	0.29	-0.63	**-2.08**	-	-	-	-	-	
Year	1916	1965	**1998**	-	-	-	-	-	
Murshidabad	-1.00	-1.71	0.51	-	-	-	-	-	
Year	1922	1932	2004	-	-	-	-	-	
Nadia	-	-	-	-	-	-	-	-	
Year	-	-	-	-	-	-	-	-	
N.24 Pga	-1.30	0.94	0.44	-	-	-	-	-	
Year	1908	1994	2002	-	-	-	-	-	
Purulia	-1.53	**-2.62**	-1.36	-1.30	-	-	-	-	
Year	1908	**1928**	1993	1995					
S.24 Pga	-	-	-	-	-	-	-	-	
Year	-	-	-	-	-	-	-	-	

Bold values and corresponding years are significant.

The investigation of potential change point of the Post-monsoon temperature time series has analyzed by the Sequential Mann-Kendall test. The result of this test has shown in Table-60. Several change points has been detected for different observatories. Bankura observatory indicates four change points over the considered time period but all these points do not significant at $\alpha = 0.05$ level of significance. Birbhum indicates three change points. Among them 1932 is the statistically significant. In case of the Burdwan observatory, eight change points has been detected where six change points are statistically significant. Their value statistic are 2.17 (1961), 2.45 (1963), 2.60 (1971), 2.95 (1982) and 3.36 (1998) respectively. According to this analysis, observatory Hooghly indicates two change point over the period considered. The change point at 1984 is the significant one and its test statistic value is 2.75.

Besides this change point, another one change point has been identified for this observatory which occurs in 1912 but its value statistic is lower than the critical level at chosen level of significance. The Post monsoon series for Howrah indicates four change points but these are not statistically significant. The Post-monsoon series for Kolkata observatory also indicates five change points but their intersection point values statistic are not significant. Similarly, the Post-monsoon series for Midnapore, Murshidabad, Purulia and South 24 Pargana does not indicate significant change points over the considered temporal scale. On the other hand, Malda, Nadia and North 24 Pargana indicate significant change points at chosen level of significance. The noticeable change points of those observatories are 2001 & 2006 (Malda), 1985 & 1992 (Nadia) and 1989 & 1999 (North 24 Pargana) respectively.

Table-60: Potential Change Points detected by Sequential Mann-Kendall Test for Post-Monsoon for Mean Seasonal Maximum Temperature ($STMax$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Post-Monsoon for Seasonal Maximum ($STMax$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.37	-1.40	1.75	1.93	-	-	-	-	
Year	1913	1925	1982	1997	-	-	-	-	
Birbhum	**-2.03**	-0.87	0.51	-	-	-	-	-	
Year	**1932**	1959	1979	-	-	-	-	-	
Burdwan	-1.04	-0.09	**2.17**	**2.45**	**2.60**	**2.74**	**2.95**	**3.36**	
Year	1913	1928	**1961**	**1963**	**1971**	**1974**	**1982**	**1998**	
Hooghly	-0.59	**2.75**	-	-	-	-	-	-	
Year	1912	**1984**	-	-	-	-	-	-	
Howrah	0.39	0.17	0.37	-1.04	-	-	-	-	
Year	1907	1970	1981	2009	-	-	-	-	
Kolkata	-1.24	-1.48	-1.39	0.69	1.20	-	-	-	
Year	1903	1913	1926	1969	1980	-	-	-	
Malda	-0.63	-0.76	-1.90	**-1.96**	**-2.33**	-	-	-	
Year	1922	1979	1996	**2001**	**2006**	-	-	-	
Midnapore	-1.37	-1.28	1.65	1.92	1.90	-	-	-	
Year	1912	1923	1980	1992	1999	-	-	-	
Murshidabad	0.45	-1.44	-1.72	-	-	-	-	-	
Year	1974	2002	2006	-	-	-	-	-	
Nadia	-1.37	-1.20	-0.88	**2.73**	**2.86**	-	-	-	
Year	1941	1926	1930	**1985**	**1992**	-	-	-	
N.24 Pga	-0.94	-0.59	**1.98**	**2.58**		-			
Year	1912	1924	**1989**	**1999**		-	-	-	
Purulia	-1.92	-1.22	-1.03	-	-	-	-	-	
Year	1932	1948	1956	-	-	-	-	-	
S.24 Pga	-1.08	-0.74	0.08	-	-	-	-	-	
Year	1912	1914	1976	-	-	-	-	-	

Bold values and corresponding years are significant.

After the homogenization process, the mean seasonal minimum temperature ($STMin$) time series become smooth and the application of Sequential Mann-Kendall test suggests minimum abnormality for these series. The progressive and retrograde line indicates several meeting points but in maximum cases their significant nature are less from the critical level. The result of this test for winter season is shown in Table-61. This table shows that, every winter series indicates change points but all these changes are not statistically significant.

Only three observatories like Midnapore, Purulia and South 24 Pargana indicates significant change point over the considered period. These change points are 2006 (Midnapore), 2006 (Purulia) and 1999 (South 24 Pargana) respectively. Including both significant and insignificant change points over the considered period, it should be suggested that, the temporal change of the climatic series happen during last two decades. Where their abnormality is very less but the turning fact is real for mean minimum winter season. This statement is previously proved by the Mann-Kendall test. Many researches have suggested that the change may negligible but fact is real or progressive over the long term analysis of time series. Summer series reveals quite different result from the Winter series. Table-62 presents the results of Sequential Mann-Kendall test for Summer season ($STMin$). Here also present that, the Summer temperature series for Kolkata, Murshidabad, Nadia, North 24 Pargana and South 24 Pargana indicates significant change over the considered period. These change points are 1985 & 1999 (Kolkata), 1984, 1991 & 2000 (Murshidabad), 2000 (Nadia), 1953 & 1958 (North 24 Pargana) and 2002 (South 24 Pargana) respectively. The Monsoon temperature ($STMin$) series also examined by this method and its result is shown in Table-63. From this result, six observatories indicates significant change points over the considered time period. These change points are 1981 (Birbhum), 1981 & 1989 (Kolkata), 1925 (Midnapore), 1981 (North 24 Pargana), 1926 (Purulia) and 1981, 1988 & 1998 (South 24 Pargana) respectively. Except these observatories, Burdwan, Hooghly, Howrah, Malda, Murshidabad and Nadia have revealed some change points but they are insignificant statistically. The results of post-monsoon minimum temperature ($STMin$) series is shown in Table-64. The remarkable observation of this analysis is that, the Post monsoon of mean minimum temperature ($STMin$) series indicates significant change points for seven observatories along with the increasing trend. The trend of the $u'(ti)$ values is always positive over the considered period. These change points are 2001 (Bankura), 1980 (Birbhum), 1999 (Hooghly), 2001(Howrah), 1980 (Kolkata), 1980 (North 24 Pargana) and 2003 (Purulia) respectively.

Table-61: Potential Change Points detected by Sequential Mann-Kendall Test for Winter of Mean Seasonal Minimum Temperature $(STMin)$ Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Winter for Seasonal Minimum $(STMin)$ Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.67	-0.88	1.49	1.90	-	-	-	-	
Year	1912	1918	1996	2002	-	-	-	-	
Birbhum	0.45	1.26	1.55	-	-	-	-	-	
Year	1938	1975	1983	-	-	-	-	-	
Burdwan	-0.98	0.35	0.31	0.28	-	-	-	-	
Year	1910	1923	1996	2000	-	-	-	-	
Hooghly	-1.42	-1.18	-	-	-	-	-	-	
Year	1913	1914	-	-	-	-	-	-	
Howrah	-1.67	-1.14	1.49	1.90	-	-	-	-	
Year	1912	1917	1996	2002	-	-	-	-	
Kolkata	0.45	0.75	1.69	1.84	-	-	-	-	
Year	1938	1974	1982	1987	-	-	-	-	
Malda	-1.22	0.35	0.31	0.28	-	-	-	-	
Year	1906	1923	1996	2000	-	-	-	-	
Midnapore	-1.32	-0.59	0.68	0.50	0.84	1.07	**2.33**	-	
Year	1910	1918	1932	1986	1990	1995	**2006**	-	
Murshidabad	-1.63	0.71	-	-	-	-	-	-	
Year	1912	1998	-	-	-	-	-	-	
Nadia	-1.63	-1.18	0.71	-	-	-	-	-	
Year	1912	1914	1998	-	-	-	-	-	
N.24 Pga	0.45	1.26	1.69	1.84	-	-	-	-	
Year	1938	1975	1982	1987	-	-	-	-	
Purulia	-1.32	-0.57	0.47	**2.33**	-	-	-	-	
Year	1910	1915	1933	**2006**	-	-	-	-	
S.24 Pga	1.56	1.91	**2.74**	-	-	-	-	-	
Year	1979	1985	**1999**	-	-	-	-	-	

Bold values and corresponding years are significant.

Table-62: Potential Change Points detected by Sequential Mann-Kendall Test for Summer of Mean Seasonal Minimum Temperature ($STMin$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Summer for Seasonal Minimum ($STMin$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.16	1.41	-0.10	1.50					
Year	1905	1934	1985	2006					
Birbhum	1.09	1.64	2.00						
Year	1975	1982	1985						
Burdwan	-1.04	0.60	0.83	0.92					
Year	1906	1923	1930	2002					
Hooghly	-0.82	1.65	1.08	1.74					
Year	1911	1939	1985	2004					
Howrah	-1.24	1.41	1.53	-0.10	1.50				
Year	1904	1934	1938	1985	2006				
Kolkata	0.37	0.79	1.34	1.80	**2.04**	**2.56**			
Year	1937	1939	1976	1981	**1985**	**1999**			
Malda	-1.04	0.60	1.01	0.07	1.11				
Year	1906	1924	1929	1993	2001				
Midnapore	-1.67	-0.81	0.46	0.90	1.80				
Year	1924	1932	1986	1990	1998				
Murshidabad	-0.95	1.80	1.87	**1.99**	**2.32**	**3.36**			
Year	1911	1939	1976	**1984**	**1991**	**2000**			
Nadia	-0.95	1.80	1.87	1.78	**3.36**				
Year	1911	1939	1976	1983	**2000**				
N.24 Pga	**2.66**	**2.58**	1.54	0.31					
Year	**1953**	**1958**	1981	2003					
Purulia	-1.59	-0.81	0.51	1.80					
Year	1924	1932	1991	1998					
S.24 Pga	-0.74	0.61	1.64	1.50	**2.06**				
Year	1905	1925	1924	1982	**2002**				

Bold values and corresponding years are significant.

Table-63: Potential Change Points detected by Sequential Mann-Kendall Test for Monsoon of Mean Seasonal Minimum Temperature $(STMin)$ Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Monsoon for Seasonal Minimum $(STMin)$ Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.03	1.57	1.70	1.04					
Year	1904	1935	1939	2009					
Birbhum	0.27	1.00	1.93	**2.55**					
Year	1931	1941	1974	**1981**					
Burdwan	-1.12	0.68	0.19						
Year	1905	1928	2006						
Hooghly	1.62	-1.71							
Year	1940	1992							
Howrah	-0.92	1.57	1.04						
Year	1905	1925	2009						
Kolkata	0.27	1.00	1.79	**2.55**	**2.90**				
Year	1931	1941	1973	**1981**	**1989**				
Malda	-1.12	0.68	-0.71	0.19					
Year	1905	1928	1998	2006					
Midnapore	**-1.96**	-0.64	0.29						
Year	**1925**	1975	1988						
Murshidabad	-0.98	-0.61	1.59	0.37	1.43				
Year	1902	1911	1939	1985	2002				
Nadia	-0.93	-0.61	1.53	0.37	1.43				
Year	1903	1911	1940	1985	2002				
N.24 Pga	0.44	1.00	1.93	**2.55**					
Year	1935	1941	1974	**1981**					
Purulia	**-1.96**	-0.64	0.29						
Year	**1925**	1975	1988						
S.24 Pga	0.10	0.90	1.41	**2.61**	**2.67**	**2.84**			
Year	1924	1931	1941	**1981**	**1988**	**1998**			

Bold values and corresponding years are significant.

Table-64: Potential Change Points detected by Sequential Mann-Kendall Test for Post-Monsoon for Mean Seasonal Minimum Temperature ($STMin$) Series for all observatories (values significant at $p < 0.05$).

Results of Sequential Mann-Kendall Test of Post-Monsoon for Seasonal Minimum ($STMin$) Temperature Series									
Observatory	1st	2nd	3rd	4th	5th	6th	7th	8th	
Bankura	-1.72	0.96	0.91	**2.80**					
Year	1907	1940	1979	**2001**					
Birbhum	0.18	0.45	0.93	**1.99**					
Year	1932	1936	1941	**1980**					
Burdwan	-0.98	0.75	0.97	0.27	1.01				
Year	1906	1932	1938	1991	2004				
Hooghly	-1.33	1.12	1.52	1.71	**2.33**				
Year	1912	1939	1985	1989	**1999**				
Howrah	-1.72	0.96	0.91	**2.80**					
Year	1907	1940	1978	**2001**					
Kolkata	0.18	0.45	0.93	**1.99**					
Year	1932	1936	1941	**1980**					
Malda	-0.98	0.97	0.27	1.09					
Year	1906	1931	1990	2000					
Midnapore	-0.98	0.72	0.27	1.09					
Year	1906	1932	1991	2000					
Murshidabad	0.86	-0.62	0.42						
Year	1940	1969	2003						
Nadia	0.86	-0.62	0.42						
Year	1940	1969	2003						
N.24 Pga	0.18	0.93	**1.99**						
Year	1932	1941	**1980**						
Purulia	-1.60	**2.55**							
Year	1907	**2003**							
S.24 Pga	0.33	0.83	1.89						
Year	1934	1940	1980						

Bold values and corresponding years are significant.

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Chapter-VI (Time Series Pattern and Major Findings)

6.0 Time Series Pattern Estimation:

Estimation of the time series pattern is another important aspect on climatic parameter analysis. Every climatic series has particular pattern itself. Actually, the linear dependency of the inter data points determines this character through the particular temporal period. The climatic time series pattern estimation is one of the basic goals in this analysis. Different literatures suggest that, the Autocorrelation Function (ACFs) and Partial Autocorrelation Function (PACFs) are the most appropriate techniques for this estimation. Known mean and variance of the considered time series helps to estimate the time domain signal over the considered period. This process helps to estimate the sinusoidal frequency and phase content of a short signal which changes or repeats its frequency over time. The basic fundamental of this technique has performed under Fourier Transform system. It is specified by two ways like ACFs (autocorrelation function) and PACFs (Partial autocorrelation function). Both autocorrelation and partial autocorrelation are computed for sequential lags in the series. In this study, these methods have been applied in association with RH test. Some mathematical logic has been confirmed step by step to get the result accordingly. The related R_script is given in appendix section. The first lag has an autocorrelation between Y_{t-1} and Y_t and so on. Hence ACFs and PACFs are the functions across all the lags. The equation of the autocorrelation is similar to bivariate r except that the overall mean $\bar{Y}$ is subtracted from each Y_t and from each Y_{t-k} and the denominator is the variance of the whole series.

$$r_k = \frac{\frac{1}{N-k}\sum_{t=1}^{N-k}(Y_t-\bar{Y})(Y_{t-k}-\bar{Y})}{\frac{1}{N-1}\sum_{t=1}^{N}(Y_t-\bar{Y})^2} \quad \text{……………..(6.1)}$$

Where N is the number of observations in the whole considered series, k is the lag. $\bar{Y}$ is the mean of the whole series and the denominator is the variance of the whole considered series.

The standard error and confidence limit has been adjusted here. This standard error of an autocorrelation is based on the squared autocorrelation from all previous lags. At lag-1, there are no previous autocorrelation, So, r_0^2 is set to Zero (0).

$$SE_{r_k} = \sqrt{\frac{1+2\sum_{i=0}^{k-1} r_i^2}{N}} \quad \text{……………(6.2)}$$

In this study we have also applied ACFs and PACFs to identify the periodic structure of the time series. Actually, this process has used over the time series to predict the current value in respect of previous value. Coefficient of the each and every pair of lag has signified the pattern of the time series and their association refers to the overall structure of the time series over the considered period. An algorithm has been applied for estimating the partial autocorrelation based on the sample correlations. These algorithms has been derived from exert theoretical relation between the partial autocorrelation function and the autocorrelation function. The approximate test for partial autocorrelation has confirmed at 5% level of significance and its comparable critical region has confirmed with $\pm 1.96/\sqrt{n}$, where n is the record of length. It reveals the conditional correlation between response variable and sample indicator variable.

The result of this estimation has been calculated with the help of homogenized data series. Graphical presentation of this study for annual $TMax$ series of all observatories is shown in figure 26. The result of ACFs in the given figure indicates signal of the correlated lags with vertical line and the blue dotted band extended both side of zero (0) level indicates the confidence limit of the calculation. The result of annual average maximum temperature for Bankura observatory indicates twenty five (25) years periodic fluctuations with noise signals over the considered time period. First 15 years temporal ACFs signal indicates positive fluctuation over the zero level and next 25 years signal indicates its reverse condition.

Fluctuations of ACFs signal for lower than zero level has indicated wide temporal gap for Bankura observatory. The noise signal at 1965 and in 1990 is more effective and indicates maximum positive fluctuation over the considered period. The observatory Birbbum indicates quite different result over the considered period. In this case the noise signal indicates 13 times over the considered period and left lag indicates negative noise signals over the considered period. Every lag fluctuation is situated beyond the confidence interval at 0.05% level of significance. Moreover, 76 years lag has been specified the three negative signal spans over the considered period. These signals has confirmed 28 years temporal period for negative fluctuation over the series. All these noise signals indicate statistically significant at chosen level of significance. From the beginning of the considered series, first three lags are positively correlated and after that, seven consecutive lags are negatively correlated. Middle of the considered time series confirms five lags positive correlation among them. Subsequently, after seven lags are negatively correlated with each other. The last section of the considered period is associated with negative correlation to their consecutive lags. But every residual ACFs signal cross over the confidence limit where they are considered as statistically significant. The results of the other considered mean annual maximum $(ATMax)$ temperature series indicates similar fluctuation over the considered period. According to the given figure, there is a cyclic pattern of the mean annual maximum $(ATMax)$ temperature series is a common character. But, amount of noise signals are not the same for all considered observatories. Howrah, Malda, Murshidabad and Purulia indicates randomly ordered noise signal within their negative correlated zone. Similarly, every observatory indicates specific temporal fluctuation of the mean annual maximum temperature $(ATMax)$ series over the considered period. Negatively arranged lag residuals are more prominent for all observatories for $ATMax$ series. The indication of the positive correlation residual signal highly confirms their climax point within every correlated zone. This character is common for all observatories. Increasing phase of the cyclic spam indicates steep gradient with short period of time, but the result of the negative signals are vice-verse.

Figure-26: **Autocorrelation plots ($TMax$) for Annual Average Maximum Temperature Time Series.**

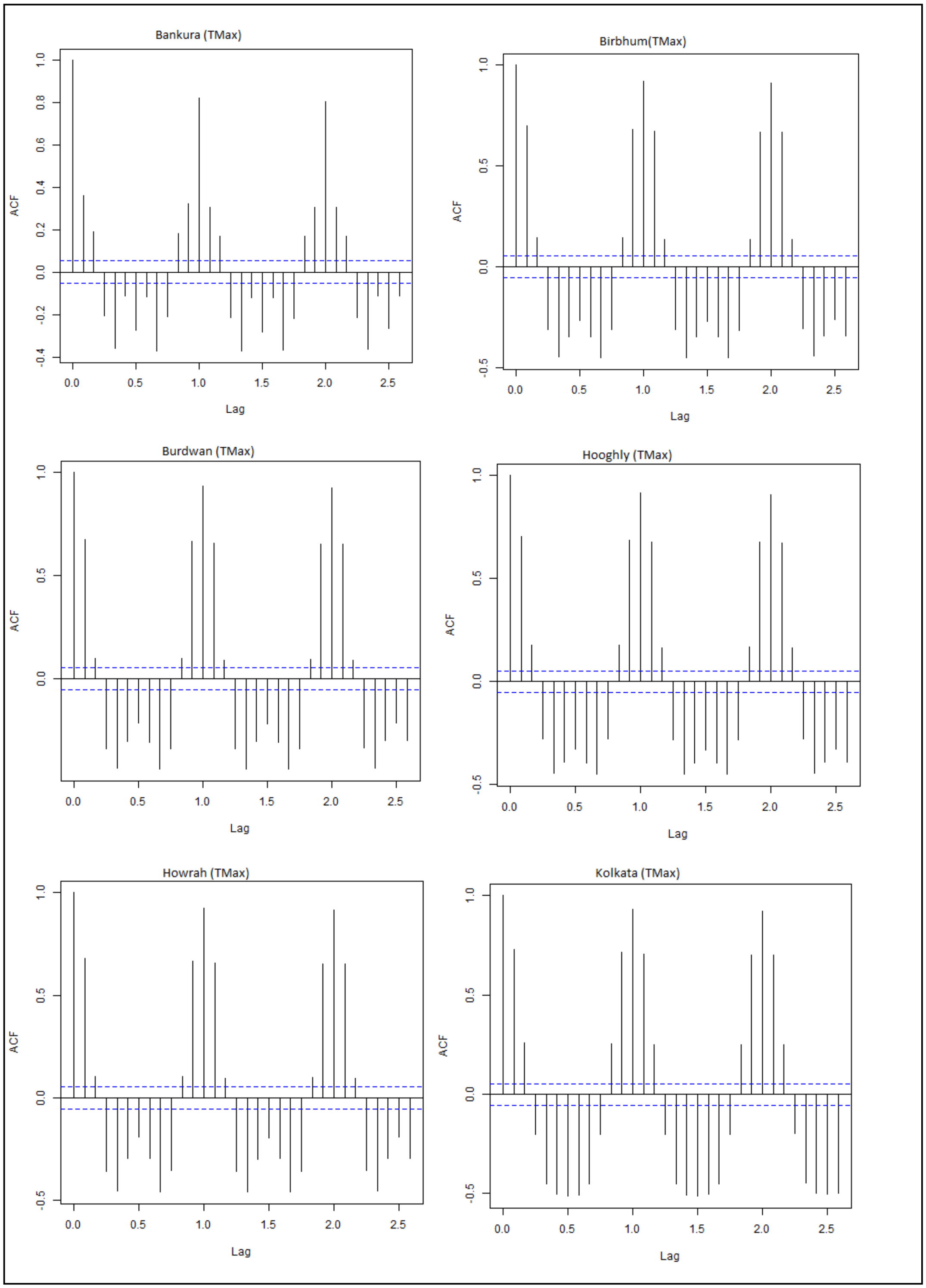
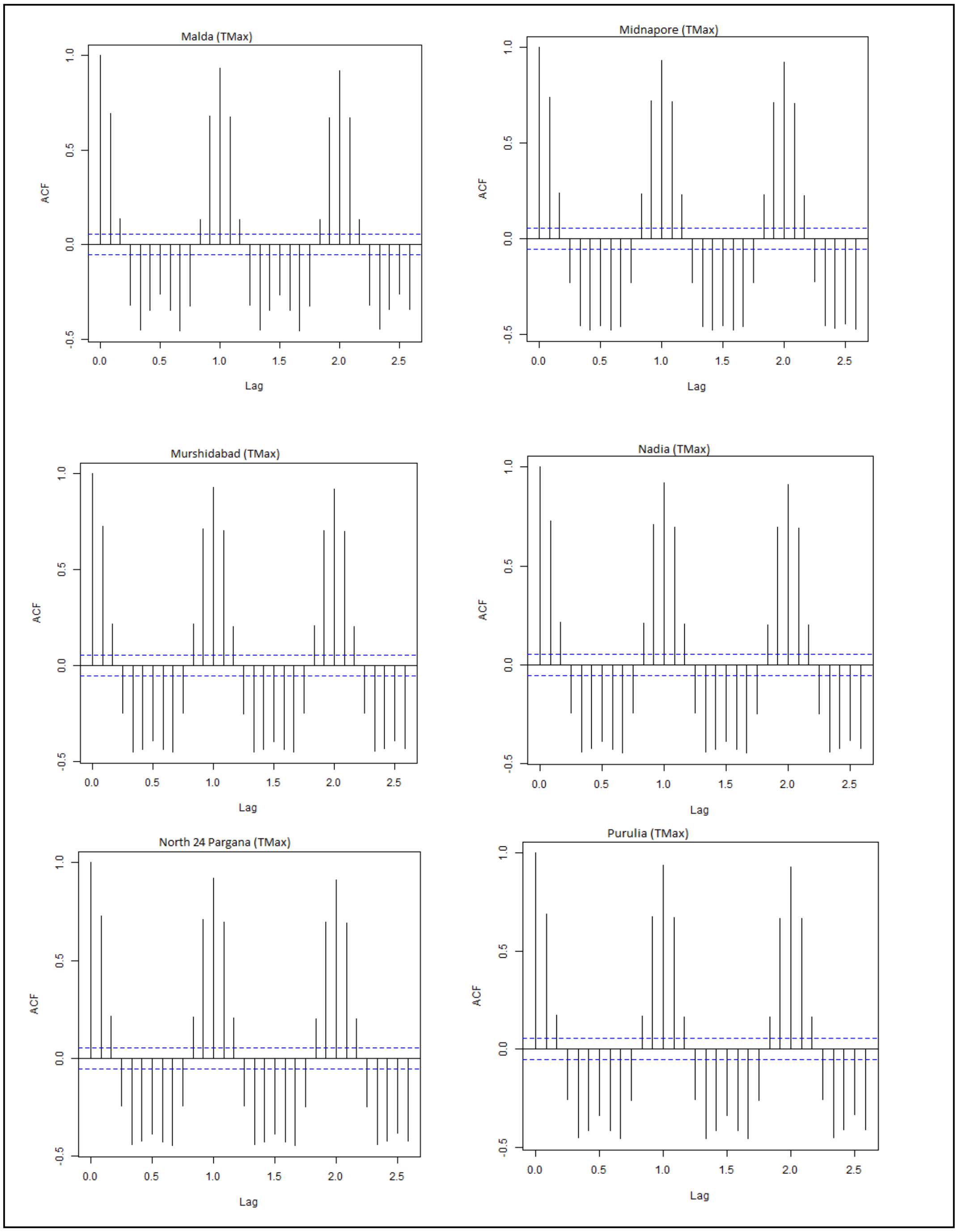


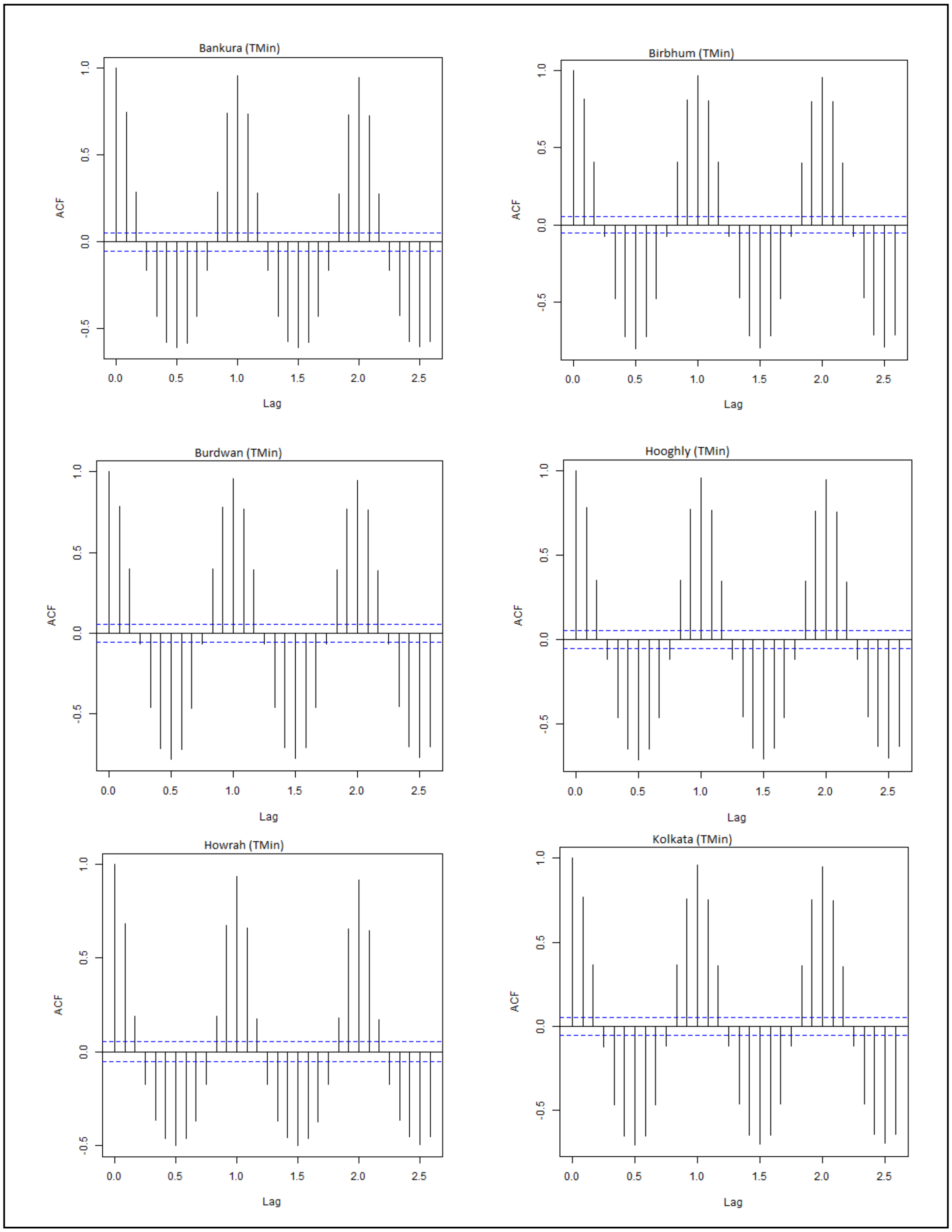
Figure Cont....

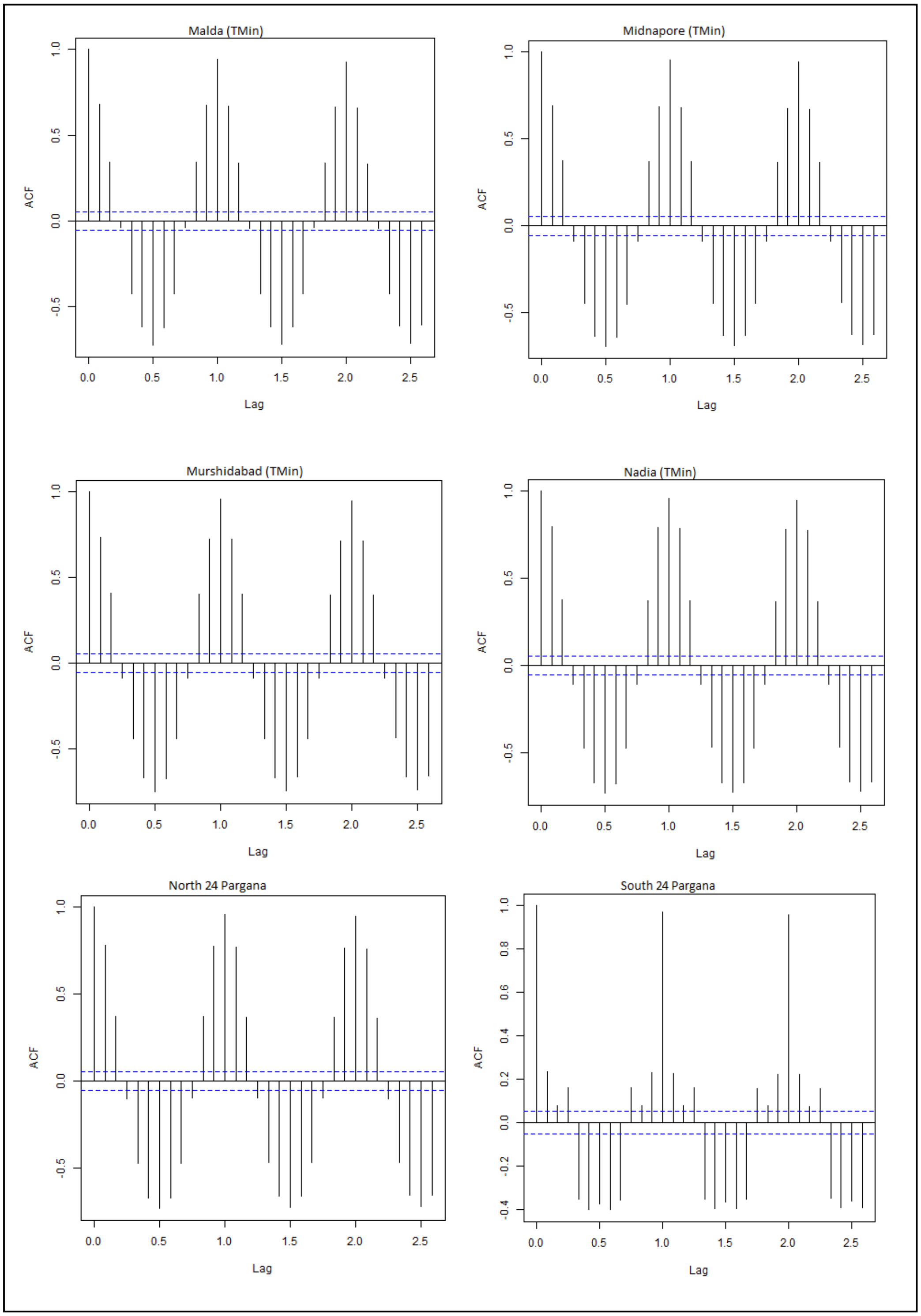

Malda (TMax)
Midnapore (TMax)
Murshidabad (TMax)
Nadia (TMax)
North 24 Pargana (TMax)
Purulia (TMax)
ACF
Lag
1.0
0.5
0.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5

The mean monthly minimum ($TMin$) series for all observatories result of trend and pattern results are almost identical with mean monthly maximum ($TMax$) series. Moreover, , since March to July and November to December series $TMin$ series indicates slow increasing trend and positive correlation (ACFs result) pattern approximately since 1940. Sometimes the mean monthly minimum ($TMin$) series has indicated their increasing trend pattern with two phase temporal segments.

The graphical presentation of the mean annual minimum ($ATMin$) temperature is shown in Figure-27. The plots of the ACFs are very interesting for mean annual minimum ($ATMin$) temperature time series. According to this graphical presentation, every observatory indicates several positive noise signal zone and negative noise signal zone successively. The temporal span of the both increasing and decreasing zone with residual signal has been confirmed within short period of time in respect of $ATMin$ series. The average cyclic period lasts for 25 years for both negative and positive autocorrelation. The observatories like Bankura, Howrah, Nadia and Midnapore indicates quite different results for negative autocorrelation period. The result of South 24 Pargana is different from other observatories. The positive autocorrelation residual noise signal has made sudden rising fluctuation over the considered period. This type of noise signal has occurred since 1954 to 1964 and in last decade of the considered period. The PACFs analysis for the mean annual maximum ($ATMax$) and mean annual minimum ($ATMin$) temperature suggests an additional result for all these considered observatories. This statement is that, the every forward PACFs has signified stationary character including cyclic character over the all observatories. The beginning of the considered period have some random residual fluctuation but middle to last decade indicate insignificant some residuals variation. This type of result always suggest for Auto-Regressive (AR) model for further analysis. Rainfall pattern of this region is very interesting and it reveals noise including cyclic pattern over the considered period. But their residual signals combined with stationary structure with minimum number of significant ACFs and PACFs frequency.

Figure-27. Autocorrelation plots ($TMin$) for Mean Annual Minimum Temperature Time Series.




Malda (TMin)
Midnapore (TMin)
Murshidabad (TMin)
Nadia (TMin)
North 24 Pargana
South 24 Pargana
ACF
Lag

6.1 Major Findings and Conclusion:

In this study, several globally scalable strong statistical methods are adopted for the analysis of the Climatological time series. The selected non-parametric test has randomly identified some significant change and variability nature of the considered time series. The variability and randomness are the common character for these raw data series. Henceforth, measurement of quality control is earnestly necessary for these data for climatic variability analysis and modeling. After the great deal with the analysis of time series by these reliable statistical methods, the following are the major findings for this study.

A. Before homogenization:

1. The considered time series ($TMax$, $ATMax$, $STMax$, $TMin$, $ATMin$, $STMin$ and $rainfall$ $series$) contains randomly distributed outlier in different years.
2. Maximum data series contains following components:
   • Trend component - It is a long term movement in a time series. It is the underlying direction (upward or downward) and rate of change in a time series, when allowance has been made for the other components.
   • Seasonal component - Seasonal fluctuations of known periodicity. It is the component of variation in a time series which is dependent on the time of the year.
   • Cyclic component - Cyclical variations of non-seasonal nature, whose periodicity is unknown.
   • Irregular component - Random or chaotic noisy residuals left over the time.
3. Level-1 change is the common factor for mean monthly maximum ($TMax$), annual average maximum ($ATMax$) and seasonal maximum ($STMax$) time series which has detected by the bootstrapping and CUSUM analysis.
4. The results of Cumulative Deviation (CD), Pettitt Test, Buishand Range Test (BRT), SNHT-I, CUSUM & bootstrapping and Von-Neumann Test statistic for every considered series indicates some significant change points and sub-segments for the considered time series in common year.
5. Moreover, 70 % of the considered series have detected several significant change points at chosen level of significance.

B. During Homogenization:

1. The inhomogeneous candidate series is synthesized as homogeneous with the help of difference series and optimal series building.
2. Average change of the mean level for different sub-inhomogeneity segments are 1.06 ℃ for both $TMax$ & $TMin$ series.
3. Outlier indication is the common factor for all such considered time series.

C. After Homogenization:

1. The increasing trend of the $TMax$ series from the middle of the considered series.
2. The positive increasing trend of the $TMax$ series from March to July for every observatory.
3. The ling upward outlier whisker from the median for South 24 Pargana observatory.
4. The cyclic pattern of $TMax$ and $TMin$ series by ACFs and PACFs.
5. Gentle positive trend for $ATMax$ time series after Mann-Kendall test.
6. The potential statistically significant change points in between two temporal span, according to Sequential Mann-Kendall test. These two spans are since 1954 to 1965 and 1982 to 1993.
7. The most uncommon seasonal noise signals and very low auto-correlation between adjacent and near adjacent observation.
8. The increasing winter temperature over every decade.
9. "Spike" and "Step Jump" character for annual average temperature time series.
10. The exception of "Phase Diffusion" structure for annual series.
11. Regular fluctuations of noise signal frequency domain after every twenty years (with high positive auto-correlation function) and after every twenty eight years (with high negative autocorrelation function).
12. The negative trend of rainfall series over the time period.
13. The cyclic pattern of annual rainfall series with inference noise components.
14. The prediction of increasing temperature (ACFs & PACFs) for coming twenty years.
15. 0.003 ℃ is the decadal growth of $ATMax$.

6.2 References: (Below listed papers are not sited but followed for time series pattern estimation)

Anderson, O., 1976, Time series analysis and forecasting: the Box-Jenkins approach: London, Butterworths, p. 182 pp.

Box, G.E.P., and Jenkins, G.M., 1976, Time series analysis: forecasting and control: San Francisco, Holden Day, p.575 pp.

Chatfield, C., 2004, The analysis of time series, an introduction, sixth edition: New York, Chapman & Hall/CRC.

Cook, E.R., 1985, A time series approach to tree-ring standardization, Ph. D. Diss.,Tucson, University of Arizona.

Ljung, L., 1995, System Identification Toolbox, for Use with MATLAB, User's Guide,The MathWorks, Inc., 24 Prime Park Way, Natick, Mass. 01760.

Monserud, R., 1986, Time series analyses of tree-ring chronologies, Forest Science 32, 349-372.

Salas, J.D., Delleur, J.W., Yevjevich, V.M., and Lane, W.L., 1980, Applied modeling of hydrologic time series: Littleton, Colorado, Water Resources Publications, p. 484 pp.

Wilks, D.S., 1995, Statistical methods in the atmospheric sciences: Academic Press, 467 p.

Appendix-I(1) (Difference Series, Malda, April, Serial no- 8)

CANDIDATE SERIES: 88888 (Index: 8)

NUMBER OF DIFFERENCE SERIES: 2

REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE SERIES

	44444	Variance	Deviation
88888	1.00000	0.41833	0.64678

	22222	Variance	Deviation
88888	1.00000	0.16659	0.40815

NO FORMER ESTIMATED BREAKS

EXAMINATION OF DIFFERENCE SERIES

1. DIFFERENCE SERIES

OUTLIERS (critical value: 8.20)

	Date	Stat.	Jump	Conf. Int.
1	2004	9.42	-2.00	[-3.07, -0.93]
2	2006	21.20	3.00	[1.93, 4.07]

BREAK POINTS (critical value: 21.76)

Test statistic before homogenization of diff. s.: 96.82

	Date	Conf. Int.	Stat.	Shift	Conf. Int.
			17.81	-	
1	2005	[2000,2008]	37.30	-1.29	[-2.02, -0.56]
			6.28	-	
2	2010	[2008,2010]	34.99	-2.99	[-4.73, -1.24]

Test statistic after homogenization of diff. s.: 17.81

2. DIFFERENCE SERIES

OUTLIERS (critical value: 8.20)

	Date	Stat.	Jump	Conf. Int.
1	1937	9.77	1.25	[0.59, 1.91]

```
 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  475.84

              Date    Conf. Int.    Stat.   Shift      Conf.
Int.
                                    21.73       -
         1    2004    [2004,2004]   99.71   -2.84    [ -3.82,
-1.85]
         2    2005    [2005,2005]   25.02    2.00    [  0.61,
3.39]
         3    2006    [2006,2006]   33.78   -1.80    [ -2.87,
-0.73]
                                     8.34       +

 Test statistic after homogenization of diff. s.:   21.73


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

(2) ***Difference Series, South 24 Pargana, April, Series no-13***

```
           CANDIDATE SERIES:  31313      (Index:  13)

 NUMBER OF DIFFERENCE SERIES: 2

 REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE
SERIES

             21212       Variance       Deviation
  31313   1.00000         0.57960       0.76132

             77777       Variance       Deviation
  31313   1.00000         0.55943       0.74795


 NO FORMER ESTIMATED BREAKS

 EXAMINATION OF DIFFERENCE SERIES

 1. DIFFERENCE SERIES

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.: 2269.87

              Date    Conf. Int.     Stat.   Shift      Conf.
Int.
                                      4.91       +
         1    2002    [2002,2002]  821.08     7.54    [  6.63,
8.45]
         2    2003    [2003,2003]   29.18    -2.00    [ -3.28,
-0.72]
         3    2004    [2004,2004]  357.50    -7.00    [ -8.28,
-5.72]
         4    2005    [2005,2005]   72.96    -2.33    [ -3.51,
-1.49]
                                      9.73       +

 Test statistic after homogenization of diff. s.:    9.73


 2. DIFFERENCE SERIES

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.: 1865.63

              Date    Conf. Int.     Stat.   Shift      Conf.
Int.
                                     13.46       +
         1    2002    [2002,2002]  622.15     6.82    [  5.88,
7.77]
         2    2003    [2003,2003]   26.98    -2.00    [ -3.33,
-0.67]
```

```
        3    2004    [2004,2004]  330.53   -7.00    [ -8.33,
-5.67]
        4    2005    [2005,2005]   36.43   -1.67    [ -2.83,
-0.77]
                                    8.99       +

 Test statistic after homogenization of diff. s.:   13.46


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

*(3) **Difference Series , Bankura, August, Serial no.1***

```
CANDIDATE SERIES:  11111      (Index:   1)

 NUMBER OF DIFFERENCE SERIES: 2

 REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE
SERIES

            99999      Variance       Deviation
  11111   1.00000       0.08916       0.29860

            10110      Variance       Deviation
  11111   1.00000       0.08374       0.28939


 NO FORMER ESTIMATED BREAKS

 EXAMINATION OF DIFFERENCE SERIES

 1. DIFFERENCE SERIES

 OUTLIERS ( critical value:   8.20 )

             Date     Stat.      Jump      Conf. Int.

        1    1981      9.93      0.56    [  0.27,   0.85]

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.: 1578.95

             Date    Conf. Int.     Stat.   Shift      Conf.
Int.
                                   15.27       -
        1    1970    [1970,1971]   27.77    0.51    [  0.19,
0.92]
                                    8.74       +
        2    1973    [1971,1973]   32.46    0.83    [  0.32,
1.33]
        3    1974    [1974,1974]  126.11   -1.47    [ -1.93,
-1.02]
                                    5.87       +
```

```
         4     1985     [1979,1986]    27.70     0.49     [  0.18,
0.85]
                                        0.20       +
         5     1987     [1987,1987]    35.49    -0.68     [ -1.08,
-0.29]
                                        1.29       +
         6     1990     [1988,1994]    27.68     0.41     [  0.16,
0.76]
                                        4.37       -
         7     2002     [2002,2002]   170.25    -1.06     [ -1.34,
-0.78]
                                        0.00       -
         8     2005     [2005,2005]   108.57     1.00     [  0.67,
1.33]
                                        0.00       -
         9     2009     [2009,2009]   455.99     3.00     [  2.51,
3.49]
        10     2010     [2010,2010]    31.67     1.00     [  0.38,
1.62]

 Test statistic after homogenization of diff. s.:   16.15


 2. DIFFERENCE SERIES

 OUTLIERS ( critical value:   8.20 )

               Date      Stat.      Jump      Conf. Int.

         1     2003      9.42       1.00    [  0.46,  1.54]

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  194.60

               Date     Conf. Int.     Stat.    Shift      Conf.
Int.
                                        9.10       +
         1     1984     [1982,1986]    30.95     0.30     [  0.30,
1.28]
                                       20.60       -
         2     2002     [1999,2002]    73.35    -0.88     [ -1.23,
-0.52]
                                        4.65       +
         3     2009     [2009,2009]   194.60     2.58     [  1.94,
3.22]
                                        9.42       +

 Test statistic after homogenization of diff. s.:   22.22


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

(4) Difference series, Birbhum, August, Serial no. 2

CANDIDATE SERIES: 22222   (Index: 2)

NUMBER OF DIFFERENCE SERIES: 2

REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE SERIES

	21212	Variance	Deviation
22222	1.00000	0.12524	0.35390

	33333	Variance	Deviation
22222	1.00000	0.08432	0.29038

NO FORMER ESTIMATED BREAKS

EXAMINATION OF DIFFERENCE SERIES

1. DIFFERENCE SERIES

OUTLIERS (critical value: 8.20)

	Date	Stat.	Jump	Conf. Int.
1	2008	9.42	1.00	[0.46, 1.54]

BREAK POINTS (critical value: 21.76)

Test statistic before homogenization of diff. s.: 147.45

	Date	Conf. Int.	Stat.	Shift	Conf. Int.
			17.24	-	
1	1970	[1970,1971]	64.96	0.97	[0.71, 1.77]
			5.64	+	
2	1973	[1971,1973]	24.87	1.33	[0.41, 2.25]
3	1974	[1974,1974]	118.67	-2.56	[-3.54, -1.83]
			8.97	+	
4	1985	[1981,1986]	34.36	1.00	[0.43, 1.66]
			0.54	+	
5	1987	[1987,1987]	34.95	-0.70	[-1.97, -0.51]
			21.54	+	
6	2004	[1999,2004]	55.37	0.77	[0.41, 1.13]
			4.07	-	

Test statistic after homogenization of diff. s.:   21.54

```
2. DIFFERENCE SERIES

OUTLIERS ( critical value:   8.20 )

             Date     Stat.      Jump      Conf. Int.

        1    1974     12.44     -0.47    [ -0.69, -0.25]

        2    2003    180.38     -1.79    [ -2.01, -1.57]

        3    2010     56.30     -1.00    [ -1.22, -0.78]

BREAK POINTS ( critical value:  21.76 )

Test statistic before homogenization of diff. s.:  436.81

             Date     Conf. Int.     Stat.   Shift      Conf.
Int.
                                     16.13       -
        1    1971     [1970,1972]    74.22    0.45    [  0.32,
0.75]
                                      5.05       +
        2    1974     [1974,1974]    85.33   -0.50    [ -0.83,
-0.38]
                                     17.00       +
        3    2005     [2005,2005]   164.19   -1.20    [ -1.57,
-0.90]
        4    2006     [2006,2006]    56.30    1.00    [  0.54,
1.46]
        5    2007     [2007,2007]    75.06   -1.00    [ -1.40,
-0.60]
                                      0.00       -
        6    2009     [2009,2009]   138.65    1.11    [  0.78,
1.44]
                                      2.71       -

Test statistic after homogenization of diff. s.:   18.75


Result series (diff.s. with inhom.s.): MASHEX2.SER
Graphic result series: MASHDRAW.BAT
```

(5) Difference Series, Burdwan, August, Serial no-3

```
CANDIDATE SERIES:  33333      (Index:   3)

 NUMBER OF DIFFERENCE SERIES: 2

 REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE
SERIES

             1010      Variance       Deviation
  33333   1.00000       0.11420       0.33793

            21212      Variance       Deviation
  33333   1.00000       0.09692       0.31133


 NO FORMER ESTIMATED BREAKS

 EXAMINATION OF DIFFERENCE SERIES

 1. DIFFERENCE SERIES

 OUTLIERS ( critical value:   8.20 )

              Date     Stat.      Jump      Conf. Int.

         1    2003    105.79      1.98    [  1.66,   2.30]

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  544.16

              Date    Conf. Int.     Stat.   Shift      Conf.
Int.
                                     18.28       -
         1    1974    [1974,1979]    27.17    0.25     [  0.25,
1.26]
                                     13.30       -
         2    2005    [2005,2005]    57.38    0.98     [  0.58,
1.57]
         3    2006    [2006,2006]    26.98   -1.00     [ -1.67,
-0.33]
         4    2007    [2007,2007]    35.98    1.00     [  0.42,
1.58]
                                      0.00       -
         5    2009    [2009,2009]   485.70   -3.00     [ -3.47,
-2.53]
                                      0.00       -

 Test statistic after homogenization of diff. s.:   58.11


 2. DIFFERENCE SERIES

 OUTLIERS ( critical value:   8.20 )
```

```
              Date      Stat.       Jump      Conf. Int.

         1    2003      10.87       0.83    [  0.42,  1.24]

         2    2006      15.78      -1.00    [ -1.41, -0.59]

         3    2010      15.78       1.00    [  0.59,  1.41]

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  330.93

              Date     Conf. Int.     Stat.   Shift      Conf.
Int.
                                      12.99       -
         1    1970    [1970,1971]    95.00    0.86    [  0.68,
1.44]
                                      15.46       +
         2    1974    [1974,1974]   103.72   -1.02    [ -1.95,
-0.96]
                                       8.64       +
         3    1985    [1979,1986]    29.19    0.71    [  0.27,
1.22]
                                       0.19       +
         4    1987    [1987,1987]    30.79   -0.56    [ -1.46,
-0.34]
                                      17.20       +
         5    2004    [2004,2004]   247.55    1.42    [  1.11,
1.74]
                                      21.04       +
         6    2009    [2009,2009]    31.57   -0.54    [ -2.29,
-0.54]
                                       2.71       +

 Test statistic after homogenization of diff. s.:   26.28


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

(6) Difference Series, Malda, August, Series no-8.

```
CANDIDATE SERIES:  88888      (Index:   8)

 NUMBER OF DIFFERENCE SERIES: 2

 REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE
SERIES

            44444      Variance       Deviation
  88888   1.00000       0.63205       0.79502

            21212      Variance       Deviation
  88888   1.00000       0.17128       0.41386


 NO FORMER ESTIMATED BREAKS

 EXAMINATION OF DIFFERENCE SERIES

 1. DIFFERENCE SERIES

 OUTLIERS ( critical value:   8.20 )

             Date     Stat.      Jump      Conf. Int.

        1    2006     35.50      3.00    [  2.17,   3.83]

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  429.69

             Date    Conf. Int.     Stat.   Shift      Conf.
Int.
                                    16.05       -
        1    2003    [2003,2003]    52.62     2.55    [  1.36,
3.84]
        2    2004    [2004,2004]   289.14    -7.41    [ -8.92,
-5.90]
                                     2.71       -
        3    2006    [2006,2006]   157.68     4.08    [  2.96,
5.21]
                                     5.26       +
        4    2009    [2009,2009]    96.64    -3.17    [ -4.73,
-2.27]
                                     3.94       -

 Test statistic after homogenization of diff. s.:   16.05


 2. DIFFERENCE SERIES

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:   61.61
```

```
              Date     Conf. Int.     Stat.   Shift       Conf.
Int.
                                      16.70       -
         1    1970    [1969,1972]    58.19    1.31    [  0.77,
2.05]
                                      11.11       +
         2    1974    [1974,1974]    61.03   -1.27    [ -3.22,
-1.24]
                                      20.32       +
         3    2002    [2000,2003]    53.15   -0.81    [ -1.82,
-0.65]
                                       9.47       +

 Test statistic after homogenization of diff. s.:   20.32


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

(7) Difference Series, Midnapore, August, Serial no. 9

```
CANDIDATE SERIES:  99999      (Index:   9)

 NUMBER OF DIFFERENCE SERIES: 2

 REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE
SERIES

            31313   44444   21212      Variance
Deviation
  99999   0.12878 0.13144 0.73978       0.03428       0.18514

            55555       Variance       Deviation
  99999   1.00000        0.03364       0.18341


 NO FORMER ESTIMATED BREAKS

 EXAMINATION OF DIFFERENCE SERIES

 1. DIFFERENCE SERIES

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  189.37

              Date     Conf. Int.     Stat.   Shift       Conf.
Int.
                                      15.00       -
         1    1984    [1982,1984]    42.28    0.49    [  0.25,
0.83]
                                       1.76       -
         2    1987    [1985,1992]    32.06   -0.45    [ -0.77,
-0.19]
```

```
                                           5.66       +
         3    2004     [1996,2004]   24.21     0.42     [  0.20,
1.16]
                                           7.60       -
         4    2006     [2006,2006]   30.56     0.40     [  0.39,
1.71]
                                     15.20         +

 Test statistic after homogenization of diff. s.:   15.20


 2. DIFFERENCE SERIES

 BREAK POINTS ( critical value:  21.76 )

 Test statistic before homogenization of diff. s.:  754.97

              Date     Conf. Int.     Stat.   Shift      Conf.
Int.
                                           8.03       -
         1    1971     [1960,1973]   31.04    -0.39     [ -0.68,
-0.16]
                                           2.31       +
         2    1974     [1972,1977]   25.65     0.39     [  0.14,
0.76]
                                           9.62       -
         3    1984     [1981,1984]   31.45     0.44     [  0.20,
0.83]
                                           2.66       -
         4    1987     [1985,1994]   28.20    -0.40     [ -0.70,
-0.15]
                                           4.79       +
         5    2004     [2004,2004]   43.12    -0.84     [ -1.41,
-0.44]
         6    2005     [2005,2005]   43.50    -0.91     [ -1.55,
-0.48]
                                           4.19       +
         7    2008     [2007,2008]   62.93     0.91     [  0.51,
1.31]
                                           0.00       -
         8    2010     [2010,2010]   42.22    -1.00     [ -1.53,
-0.47]

 Test statistic after homogenization of diff. s.:    9.62


 Result series (diff.s. with inhom.s.): MASHEX2.SER
 Graphic result series: MASHDRAW.BAT
```

(8) Difference Series, Bankura, Monsoon, Serial no-3.

CANDIDATE SERIES: 33333 (Index: 3)

NUMBER OF DIFFERENCE SERIES: 2

REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE SERIES

	21212	Variance	Deviation
33333	1.00000	0.01923	0.13869

	55555	Variance	Deviation
33333	1.00000	0.01359	0.11658

NO FORMER ESTIMATED BREAKS

EXAMINATION OF DIFFERENCE SERIES

1. DIFFERENCE SERIES

OUTLIERS (critical value: 8.20)

	Date	Stat.	Jump	Conf. Int.
1	2006	8.43	-0.43	[-0.67, -0.19]

BREAK POINTS (critical value: 21.76)

Test statistic before homogenization of diff. s.: 96.13

	Date	Conf. Int.	Stat.	Shift	Conf. Int.
			14.62	+	
1	1964	[1961,1965]	33.83	-0.22	[-0.41, -0.11]
			11.21	+	
2	1971	[1970,1971]	85.85	0.67	[0.42, 0.92]
			1.48	-	
3	1974	[1974,1974]	96.13	-0.61	[-0.88, -0.42]
			18.29	-	
4	2003	[2003,2004]	78.97	0.42	[0.25, 0.58]
			6.42	+	
5	2009	[2009,2010]	22.85	-0.39	[-0.75, -0.12]
			0.02	-	

Test statistic after homogenization of diff. s.: 18.29

2. DIFFERENCE SERIES

```
OUTLIERS ( critical value:   8.20 )

            Date     Stat.      Jump      Conf. Int.

        1   1966     14.64      0.34     [  0.19,  0.49]

BREAK POINTS ( critical value:  21.76 )

Test statistic before homogenization of diff. s.:  209.94

            Date    Conf. Int.    Stat.   Shift      Conf.
Int.
                                   4.44       -
        1   1917    [1903,1926]   24.04   -0.08    [ -0.20,
-0.03]
                                  14.58       +
        2   1951    [1949,1953]   28.67    0.20    [  0.07,
0.33]
                                   3.08       +
        3   1954    [1953,1957]   23.28   -0.17    [ -0.45,
-0.07]
                                  18.11       -
        4   1971    [1971,1971]  114.89    0.42    [  0.31,
0.61]
                                   1.82       -
        5   1974    [1974,1974]  155.13   -0.45    [ -0.71,
-0.40]
                                  20.27       +
        6   2002    [2002,2002]  113.12   -0.65    [ -0.94,
-0.48]
        7   2003    [2003,2003]   42.61    0.58    [  0.27,
0.89]
        8   2004    [2004,2004]   27.98   -0.40    [ -0.78,
-0.16]
                                   2.14       +
        9   2006    [2006,2006]   98.19    0.57    [  0.37,
0.77]
                                   1.82       -
       10   2009    [2009,2009]   80.11   -0.51    [ -0.71,
-0.31]
                                   0.46       -

Test statistic after homogenization of diff. s.:   24.75


Result series (diff.s. with inhom.s.): MASHEX2.SER
Graphic result series: MASHDRAW.BAT
```

Cumulative deviation test for whole year, months and seasons.

(R_Script for Cumulative Deciation Test for Whole Year)

```
 x=read.csv(file="D:/TMaxdata/current.csv",header=FALSE)
jan=matrix(x[[2]])
n.jan=length(jan)
j.jan=mean(jan)
sd.jan=sd(jan)
k.jan=NULL
for(i in 1:n.jan){k.jan[i]=sum((jan[1:i])-j.jan)
{sk.jan=k.jan[1:i]/sd.jan
}}
sk.jan.abs=abs(sk.jan)
feb=matrix(x[[3]])
n.feb=length(feb)
j.feb=mean(feb)
sd.feb=sd(feb)
k.feb=NULL
for(i in 1:n.feb){k.feb[i]=sum((feb[1:i])-j.feb)
{sk.feb=k.feb[1:i]/sd.feb
}}
sk.feb.abs=abs(sk.feb)
mar=matrix(x[[4]])
n.mar=length(mar)
j.mar=mean(mar)
sd.mar=sd(mar)
k.mar=NULL
for(i in 1:n.mar){k.mar[i]=sum((mar[1:i])-j.mar)
{sk.mar=k.mar[1:i]/sd.mar
}}
sk.mar.abs=abs(sk.mar)
apr=matrix(x[[5]])
n.apr=length(apr)
j.apr=mean(apr)
sd.apr=sd(apr)
k.apr=NULL
for(i in 1:n.apr){k.apr[i]=sum((apr[1:i])-j.apr)
{sk.apr=k.apr[1:i]/sd.apr
}}
sk.apr.abs=abs(sk.apr)
may=matrix(x[[6]])
n.may=length(may)
j.may=mean(may)
sd.may=sd(may)
k.may=NULL
for(i in 1:n.may){k.may[i]=sum((may[1:i])-j.may)
{sk.may=k.may[1:i]/sd.may
}}
sk.may.abs=abs(sk.may)
jun=matrix(x[[7]])
n.jun=length(jun)
j.jun=mean(jun)
sd.jun=sd(jun)
k.jun=NULL
for(i in 1:n.jun){k.jun[i]=sum((jun[1:i])-j.jun)
```

```
{sk.jun=k.jun[1:i]/sd.jun
}}
sk.jun.abs=abs(sk.jun)
jul=matrix(x[[8]])
n.jul=length(jul)
j.jul=mean(jul)
sd.jul=sd(jul)
k.jul=NULL
for(i in 1:n.jul){k.jul[i]=sum((jul[1:i])-j.jul)
{sk.jul=k.jul[1:i]/sd.jul
}}
sk.jul.abs=abs(sk.jul)
aug=matrix(x[[9]])
n.aug=length(aug)
j.aug=mean(aug)
sd.aug=sd(aug)
k.aug=NULL
for(i in 1:n.aug){k.aug[i]=sum((aug[1:i])-j.aug)
{sk.aug=k.aug[1:i]/sd.aug
}}
sk.aug.abs=abs(sk.aug)
sep=matrix(x[[10]])
n.sep=length(sep)
j.sep=mean(sep)
sd.sep=sd(sep)
k.sep=NULL
for(i in 1:n.sep){k.sep[i]=sum((sep[1:i])-j.sep)
{sk.sep=k.sep[1:i]/sd.sep
}}
sk.sep.abs=abs(sk.sep)
oct=matrix(x[[11]])
n.oct=length(oct)
j.oct=mean(oct)
sd.oct=sd(oct)
k.oct=NULL
for(i in 1:n.oct){k.oct[i]=sum((oct[1:i])-j.oct)
{sk.oct=k.oct[1:i]/sd.oct
}}
sk.oct.abs=abs(sk.oct)
nov=matrix(x[[12]])
n.nov=length(nov)
j.nov=mean(nov)
sd.nov=sd(nov)
k.nov=NULL
for(i in 1:n.nov){k.nov[i]=sum((nov[1:i])-j.nov)
{sk.nov=k.nov[1:i]/sd.nov
}}
sk.nov.abs=abs(sk.nov)
dec=matrix(x[[13]])
n.dec=length(dec)
j.dec=mean(dec)
sd.dec=sd(dec)
k.dec=NULL
for(i in 1:n.dec){k.dec[i]=sum((dec[1:i])-j.dec)
{sk.dec=k.dec[1:i]/sd.dec
}}
sk.dec.abs=abs(sk.dec)
tot=matrix(x[[14]])
```

```
n.tot=length(tot)
j.tot=mean(tot)
sd.tot=sd(tot)
k.tot=NULL
for(i in 1:n.tot){k.tot[i]=sum((tot[1:i])-j.tot)
{sk.tot=k.tot[1:i]/sd.tot
}}
sk.tot.abs=abs(sk.tot)
win=matrix(x[[15]])
n.win=length(win)
j.win=mean(win)
sd.win=sd(win)
k.win=NULL
for(i in 1:n.win){k.win[i]=sum((win[1:i])-j.win)
{sk.win=k.win[1:i]/sd.win
}}
sk.win.abs=abs(sk.win)
sum=matrix(x[[16]])
n.sum=length(sum)
j.sum=mean(sum)
sd.sum=sd(sum)
k.sum=NULL
for(i in 1:n.sum){k.sum[i]=sum((sum[1:i])-j.sum)
{sk.sum=k.sum[1:i]/sd.sum
}}
sk.sum.abs=abs(sk.sum)
mon=matrix(x[[17]])
n.mon=length(mon)
j.mon=mean(mon)
sd.mon=sd(mon)
k.mon=NULL
for(i in 1:n.mon){k.mon[i]=sum((mon[1:i])-j.mon)
{sk.mon=k.mon[1:i]/sd.mon
}}
sk.mon.abs=abs(sk.mon)
pmon=matrix(x[[18]])
n.pmon=length(pmon)
j.pmon=mean(pmon)
sd.pmon=sd(pmon)
k.pmon=NULL
for(i in 1:n.pmon){k.pmon[i]=sum((pmon[1:i])-j.pmon)
{sk.pmon=k.pmon[1:i]/sd.pmon
}}
sk.pmon.abs=abs(sk.pmon)
print((max(sk.jan.abs)/sqrt(n.jan)))
print((max(sk.feb.abs)/sqrt(n.feb)))
print((max(sk.mar.abs)/sqrt(n.mar)))
print((max(sk.apr.abs)/sqrt(n.apr)))
print((max(sk.may.abs)/sqrt(n.may)))
print((max(sk.jun.abs)/sqrt(n.jun)))
print((max(sk.jul.abs)/sqrt(n.jul)))
print((max(sk.aug.abs)/sqrt(n.aug)))
print((max(sk.sep.abs)/sqrt(n.sep)))
print((max(sk.oct.abs)/sqrt(n.oct)))
print((max(sk.nov.abs)/sqrt(n.nov)))
print((max(sk.dec.abs)/sqrt(n.dec)))
print((max(sk.tot.abs)/sqrt(n.tot)))
print((max(sk.win.abs)/sqrt(n.win)))
```

```
print((max(sk.sum.abs)/sqrt(n.sum)))
print((max(sk.mon.abs)/sqrt(n.mon)))
print((max(sk.pmon.abs)/sqrt(n.pmon)))
Q.jan=max((sk.jan.abs)/sqrt(n.jan))
Q.feb=max((sk.feb.abs)/sqrt(n.feb))
Q.mar=max((sk.mar.abs)/sqrt(n.mar))
Q.apr=max((sk.apr.abs)/sqrt(n.apr))
Q.may=max((sk.may.abs)/sqrt(n.may))
Q.jun=max((sk.jun.abs)/sqrt(n.jun))
Q.jul=max((sk.jul.abs)/sqrt(n.jul))
Q.aug=max((sk.aug.abs)/sqrt(n.aug))
Q.sep=max((sk.sep.abs)/sqrt(n.sep))
Q.oct=max((sk.oct.abs)/sqrt(n.oct))
Q.nov=max((sk.nov.abs)/sqrt(n.nov))
Q.dec=max((sk.dec.abs)/sqrt(n.dec))
Q.tot=max((sk.tot.abs)/sqrt(n.tot))
Q.win=max((sk.win.abs)/sqrt(n.win))
Q.sum=max((sk.sum.abs)/sqrt(n.sum))
Q.mon=max((sk.mon.abs)/sqrt(n.mon))
Q.pmon=max((sk.pmon.abs)/sqrt(n.pmon))
result<-c(Q.jan, Q.feb, Q.mar, Q.apr, Q.may, Q.jun, Q.jul,
Q.aug, Q.sep, Q.oct, Q.nov, Q.dec, Q.tot,Q.win,Q.sum, Q.mon,
Q.pmon)
print(result)
output=matrix(result, ncol=1, byrow=TRUE,
dimnames=list(c("January","February","March","April","May","
June","July","August","September","October","Novmber","Decem
ber","Annual","Winter","Summer",  "Monsoon", "Post-
Monsoon"),c("Q Max")))
write.csv(output, file="D:/Result/CumDevTest.csv")
```

Mann-Kendall Trend.

```
require(Kendall, quietly = FALSE)
MKtau<-function(z) MannKendall(z)$tau
MKp<-function(x) MannKendall(x)$sl
x=read.csv(file="D:/TMaxdata/Current.csv",header=FALSE)
k=NULL
m=NULL
for (i in 2:18){k[i]=MKtau(x[[i]])
m[i]=MKp(x[[i]])
}
result=as.matrix(cbind(k,m))
result=na.omit(result)
dimnames(result)=NULL
rownames(result)=c("January", "February", "March", "April",
"May", "June", "July", "August", "September", "October",
"November", "December", "Yearly", "Winter", "Pre-Monsoon",
"Monsoon", "Post-Monsoon")
colnames(result)=c("Kendall-Z", "p-Value")
print(result)
write.csv(result, file="D:/Result/Mann_Kendall Trend.csv")
```

Moving Average.

```
tara<-function(x,y){
reg=lm(x~y)
coeff=as.numeric(reg$coeff[2])
confi=confint(reg,"y",level=0.95)
return(c(coeff,confi))
}
a=read.csv(file="D:/TMaxdata/Current.csv",header=FALSE)

x.jan=a[[1]]
y.jan=a[[2]]
n.jan=length(x.jan)
k.jan=NULL
m1.jan=NULL
for(i in 1:n.jan){k.jan=x.jan[1:i]
l.jan=y.jan[1:i]
m.jan=tara(k.jan,l.jan)
m1.jan=rbind(m1.jan,m.jan)
}

x.feb=a[[1]]
y.feb=a[[3]]
n.feb=length(x.feb)
k.feb=NULL
m1.feb=NULL
for(i in 1:n.feb){k.feb=x.feb[1:i]
l.feb=y.feb[1:i]
m.feb=tara(k.feb,l.feb)
m1.feb=rbind(m1.feb,m.feb)
}

x.mar=a[[1]]
y.mar=a[[4]]
n.mar=length(x.mar)
k.mar=NULL
m1.mar=NULL
for(i in 1:n.mar){k.mar=x.mar[1:i]
l.mar=y.mar[1:i]
m.mar=tara(k.mar,l.mar)
m1.mar=rbind(m1.mar,m.mar)
}

x.apr=a[[1]]
y.apr=a[[5]]
n.apr=length(x.apr)
k.apr=NULL
m1.apr=NULL
for(i in 1:n.apr){k.apr=x.apr[1:i]
l.apr=y.apr[1:i]
m.apr=tara(k.apr,l.apr)
m1.apr=rbind(m1.apr,m.apr)
}

x.may=a[[1]]
y.may=a[[6]]
n.may=length(x.may)
k.may=NULL
```

```
m1.may=NULL
for(i in 1:n.may){k.may=x.may[1:i]
l.may=y.may[1:i]
m.may=tara(k.may,l.may)
m1.may=rbind(m1.may,m.may)
}

x.jun=a[[1]]
y.jun=a[[7]]
n.jun=length(x.jun)
k.jun=NULL
m1.jun=NULL
for(i in 1:n.jun){k.jun=x.jun[1:i]
l.jun=y.jun[1:i]
m.jun=tara(k.jun,l.jun)
m1.jun=rbind(m1.jun,m.jun)
}

x.jul=a[[1]]
y.jul=a[[8]]
n.jul=length(x.jul)
k.jul=NULL
m1.jul=NULL
for(i in 1:n.jul){k.jul=x.jul[1:i]
l.jul=y.jul[1:i]
m.jul=tara(k.jul,l.jul)
m1.jul=rbind(m1.jul,m.jul)
}

x.aug=a[[1]]
y.aug=a[[9]]
n.aug=length(x.aug)
k.aug=NULL
m1.aug=NULL
for(i in 1:n.aug){k.aug=x.aug[1:i]
l.aug=y.aug[1:i]
m.aug=tara(k.aug,l.aug)
m1.aug=rbind(m1.aug,m.aug)
}

x.sep=a[[1]]
y.sep=a[[10]]
n.sep=length(x.sep)
k.sep=NULL
m1.sep=NULL
for(i in 1:n.sep){k.sep=x.sep[1:i]
l.sep=y.sep[1:i]
m.sep=tara(k.sep,l.sep)
m1.sep=rbind(m1.sep,m.sep)
}

x.oct=a[[1]]
y.oct=a[[11]]
n.oct=length(x.oct)
k.oct=NULL
m1.oct=NULL
for(i in 1:n.oct){k.oct=x.oct[1:i]
l.oct=y.oct[1:i]
```

```
m.oct=tara(k.oct,l.oct)
m1.oct=rbind(m1.oct,m.oct)
}

x.nov=a[[1]]
y.nov=a[[12]]
n.nov=length(x.nov)
k.nov=NULL
m1.nov=NULL
for(i in 1:n.nov){k.nov=x.nov[1:i]
l.nov=y.nov[1:i]
m.nov=tara(k.nov,l.nov)
m1.nov=rbind(m1.nov,m.nov)
}

x.dec=a[[1]]
y.dec=a[[13]]
n.dec=length(x.dec)
k.dec=NULL
m1.dec=NULL
for(i in 1:n.dec){k.dec=x.dec[1:i]
l.dec=y.dec[1:i]
m.dec=tara(k.dec,l.dec)
m1.dec=rbind(m1.dec,m.dec)
}

x.year=a[[1]]
y.year=a[[14]]
n.year=length(x.year)
k.year=NULL
m1.year=NULL
for(i in 1:n.year){k.year=x.year[1:i]
l.year=y.year[1:i]
m.year=tara(k.year,l.year)
m1.year=rbind(m1.year,m.year)
}

x.winter=a[[1]]
y.winter=a[[15]]
n.winter=length(x.winter)
k.winter=NULL
m1.winter=NULL
for(i in 1:n.winter){k.winter=x.winter[1:i]
l.winter=y.winter[1:i]
m.winter=tara(k.winter,l.winter)
m1.winter=rbind(m1.winter,m.winter)
}

x.sum=a[[1]]
y.sum=a[[16]]
n.sum=length(x.sum)
k.sum=NULL
m1.sum=NULL
for(i in 1:n.sum){k.sum=x.sum[1:i]
l.sum=y.sum[1:i]
m.sum=tara(k.sum,l.sum)
m1.sum=rbind(m1.sum,m.sum)
}
```

```
x.mon=a[[1]]
y.mon=a[[16]]
n.mon=length(x.mon)
k.mon=NULL
m1.mon=NULL
for(i in 1:n.mon){k.mon=x.mon[1:i]
l.mon=y.mon[1:i]
m.mon=tara(k.mon,l.mon)
m1.mon=rbind(m1.mon,m.mon)
}
x.pstmon=a[[1]]
y.pstmon=a[[17]]
n.pstmon=length(x.pstmon)
k.pstmon=NULL
m1.pstmon=NULL
for(i in 1:n.pstmon){k.pstmon=x.pstmon[1:i]
l.pstmon=y.pstmon[1:i]
m.pstmon=tara(k.pstmon,l.pstmon)
m1.pstmon=rbind(m1.pstmon,m.pstmon)
}
result=cbind(m1.jan, m1.feb, m1.mar, m1.apr, m1.may, m1.jun,
m1.jul, m1.aug, m1.sep, m1.oct, m1.nov, m1.dec, m1.year,
m1.winter, m1.sum, m1.mon, m1.pstmon)
rownames(result)=c(a[[1]])
colnames(result)=c("Jan b-value", "Jan_Lwr", "Jan_Upr", "Feb b-
value", "Feb_Lwr", "Feb_Upr", "Mar b-value", "Mar_Lwr",
"Mar_Upr", "Apr b-value", "Apr_Lwr", "Apr_Upr", "May b-value",
"May_Lwr", "May_Upr", "Jun b-value", "Jun_Lwr", "Jun_Upr", "Jul
b-value", "Jul_Lwr", "Jul_Upr", "Aug b-value", "Aug_Lwr",
"Aug_Upr", "Sep b-value", "Sep_Lwr", "Sep_Upr", "Oct b-value",
"Oct_Lwr", "Oct_Upr", "Nov b-value", "Nov_Lwr", "Nov_Upr", "Dec
b-value", "Dec_Lwr", "Dec_Upr", "Year b-value", "Year_Lwr",
"Year_Upr","Win b-Value", "Win_Lwr", "Win_Upr", "Sum b-Value",
"Sum_Lwr", "Sum_Upr", "Mon b-Value", "Mon_Lwr", "Mon_Upr",
"Postmon b-Value", "Postmon_Lwr", "Postmon_Upr")
write.csv(result, file="D:/Result/Regression.csv")
```

Plot Time Series.

```
#Graph of Original Series and ACF and PACF
require(Kendall)
require(boot)
x=read.csv(file="D:/TMaxdata/Current.csv", header=FALSE)
a=as.matrix(x[2:13])
rain=as.vector(t(a))
raints=ts(rain, start=c(1901,1), end=c(2011,12), frequency=12)
png(file="D:/Result/1Tol_Series.png")
plot(raints, col="Darkgrey")
lines(lowess(time(raints),raints),lwd=2, col="blue")
title("TMax 1901 - 2011")
dev.off()

a.jan=as.matrix(x[[2]])
rain.jan=as.vector(t(a.jan))
raints.jan=ts(rain.jan, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/2jan.png")
plot(raints.jan, col="Darkgrey")
lines(lowess(time(raints.jan),raints.jan),lwd=2, col="blue")
title("January 1901 - 2011")
dev.off()

a.feb=as.matrix(x[[3]])
rain.feb=as.vector(t(a.feb))
raints.feb=ts(rain.feb, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/3feb.png")
plot(raints.feb, col="Darkgrey")
lines(lowess(time(raints.feb),raints.feb),lwd=2, col="blue")
title("february 1901 - 2011")
dev.off()

a.mar=as.matrix(x[[4]])
rain.mar=as.vector(t(a.mar))
raints.mar=ts(rain.mar, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/4mar.png")
plot(raints.mar, col="Darkgrey")
lines(lowess(time(raints.mar),raints.mar),lwd=2, col="blue")
title("March 1901 - 2011")
dev.off()

a.apr=as.matrix(x[[5]])
rain.apr=as.vector(t(a.apr))
raints.apr=ts(rain.apr, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/5apr.png")
plot(raints.apr, col="Darkgrey")
lines(lowess(time(raints.apr),raints.apr),lwd=2, col="blue")
title("April 1901 - 2011")
dev.off()

a.may=as.matrix(x[[6]])
rain.may=as.vector(t(a.may))
raints.may=ts(rain.may, start=c(1901), end=c(2011), frequency=1)
png(file="D:/result/6may.png")
plot(raints.may, col="Darkgrey")
lines(lowess(time(raints.may),raints.may),lwd=2, col="blue")
title("May 1901 - 2011")
```

```
dev.off()

a.jun=as.matrix(x[[7]])
rain.jun=as.vector(t(a.jun))
raints.jun=ts(rain.jun, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/7jun.png")
plot(raints.jun, col="Darkgrey")
lines(lowess(time(raints.jun),raints.jun),lwd=2, col="blue")
title("June 1901 - 2011")
dev.off()

a.jul=as.matrix(x[[8]])
rain.jul=as.vector(t(a.jul))
raints.jul=ts(rain.jul, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/8jul.png")
plot(raints.jul, col="Darkgrey")
lines(lowess(time(raints.jul),raints.jul),lwd=2, col="blue")
title("July 1901 - 2011")
dev.off()

a.aug=as.matrix(x[[9]])
rain.aug=as.vector(t(a.aug))
raints.aug=ts(rain.aug, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/9aug.png")
plot(raints.aug, col="Darkgrey")
lines(lowess(time(raints.aug),raints.aug),lwd=2, col="blue")
title("August 1901 - 2011")
dev.off()

a.sep=as.matrix(x[[10]])
rain.sep=as.vector(t(a.sep))
raints.sep=ts(rain.sep, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/10sep.png")
plot(raints.sep, col="Darkgrey")
lines(lowess(time(raints.sep),raints.sep),lwd=2, col="blue")
title("September 1901 - 2011")
dev.off()

a.oct=as.matrix(x[[11]])
rain.oct=as.vector(t(a.oct))
raints.oct=ts(rain.oct, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/11oct.png")
plot(raints.oct, col="Darkgrey")
lines(lowess(time(raints.oct),raints.oct),lwd=2, col="blue")
title("October 1901 - 2011")
dev.off()

a.nov=as.matrix(x[[12]])
rain.nov=as.vector(t(a.nov))
raints.nov=ts(rain.nov, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/12nov.png")
plot(raints.nov, col="Darkgrey")
lines(lowess(time(raints.nov),raints.nov),lwd=2, col="blue")
title("November 1901 - 2011")
dev.off()

a.dec=as.matrix(x[[13]])
rain.dec=as.vector(t(a.dec))
```

```
raints.dec=ts(rain.dec, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/13dec.png")
plot(raints.dec, col="Darkgrey")
lines(lowess(time(raints.dec),raints.dec),lwd=2, col="blue")
title("December 1901 - 2011")
dev.off()

a.win=as.matrix(x[[15]])
rain.win=as.vector(t(a.win))
raints.win=ts(rain.win, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/14win.png")
plot(raints.win, col="Darkgrey")
lines(lowess(time(raints.win),raints.win),lwd=2, col="blue")
title("Winter 1901 - 2011")
dev.off()

a.sum=as.matrix(x[[16]])
rain.sum=as.vector(t(a.sum))
raints.sum=ts(rain.sum, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/15sum.png")
plot(raints.sum, col="Darkgrey")
lines(lowess(time(raints.sum),raints.sum),lwd=2, col="blue")
title("Summer 1901 - 2011")
dev.off()

a.mon=as.matrix(x[[17]])
rain.mon=as.vector(t(a.mon))
raints.mon=ts(rain.mon, start=c(1901), end=c(2011), frequency=1)
png(file="D:/Result/16mon.png")
plot(raints.mon, col="Darkgrey")
lines(lowess(time(raints.mon),raints.mon),lwd=2, col="blue")
title("Monsoon 1901 - 2011")
dev.off()

a.pstmon=as.matrix(x[[18]])
rain.pstmon=as.vector(t(a.pstmon))
raints.pstmon=ts(rain.pstmon, start=c(1901), end=c(2011),
frequency=1)
png(file="D:/Result/17pstmon.png")
plot(raints.pstmon, col="Darkgrey")
lines(lowess(time(raints.pstmon),raints.pstmon),lwd=2,
col="blue")
title("Post-pstmonsoon 1901 - 2011")
dev.off()

png(file="D:/Result/18acf.year.png")
acf(raints)
dev.off()
png(file="D:/Result/19pacf.year.png")
pacf(raints)
dev.off()

png(file="D:/Result/20acf.jan.png")
acf(raints.jan)
dev.off()
png(file="D:/Result/21pacf.jan.png")
pacf(raints.jan)
dev.off()
```

```
png(file="D:/Result/22acf.feb.png")
acf(raints.feb)
dev.off()
png(file="D:/Result/23pacf.feb.png")
pacf(raints.feb)
dev.off()

png(file="D:/Result/24acf.mar.png")
acf(raints.mar)
dev.off()
png(file="D:/Result/25pacf.mar.png")
pacf(raints.mar)
dev.off()

png(file="D:/Result/26acf.apr.png")
acf(raints.apr)
dev.off()
png(file="D:/Result/27pacf.apr.png")
pacf(raints.apr)
dev.off()

png(file="D:/Result/28acf.may.png")
acf(raints.may)
dev.off()
png(file="D:/Result/29pacf.may.png")
pacf(raints.may)
dev.off()

png(file="D:/Result/30acf.jun.png")
acf(raints.jun)
dev.off()
png(file="D:/Result/31pacf.jun.png")
pacf(raints.jun)
dev.off()

png(file="D:/Result/32acf.jul.png")
acf(raints.jul)
dev.off()
png(file="D:/Result/33pacf.jul.png")
pacf(raints.jul)
dev.off()

png(file="D:/Result/34acf.aug.png")
acf(raints.aug)
dev.off()
png(file="D:/Result/35pacf.aug.png")
pacf(raints.aug)
dev.off()

png(file="D:/Result/36acf.sep.png")
acf(raints.sep)
dev.off()
png(file="D:/Result/37pacf.sep.png")
pacf(raints.sep)
dev.off()

png(file="D:/Result/38acf.oct.png")
```

```
acf(raints.oct)
dev.off()
png(file="D:/Result/39pacf.oct.png")
pacf(raints.oct)
dev.off()

png(file="D:/Result/40acf.nov.png")
acf(raints.nov)
dev.off()
png(file="D:/Result/41pacf.nov.png")
pacf(raints.nov)
dev.off()

png(file="D:/Result/42acf.dec.png")
acf(raints.dec)
dev.off()
png(file="D:/Result/43pacf.dec.png")
pacf(raints.dec)
dev.off()

png(file="D:/Result/44acf.win.png")
acf(raints.win)
dev.off()
png(file="D:/Result/45pacf.win.png")
pacf(raints.win)
dev.off()

png(file="D:/Result/46acf.sum.png")
acf(raints.sum)
dev.off()
png(file="D:/Result/47pacf.sum.png")
pacf(raints.sum)
dev.off()

png(file="D:/Result/48acf.mon.png")
acf(raints.mon)
dev.off()
png(file="D:/Result/49pacf.mon.png")
pacf(raints.mon)
dev.off()

png(file="D:/Result/50acf.pstmon.png")
acf(raints.pstmon)
dev.off()
png(file="D:/Result/51pacf.pstmon.png")
pacf(raints.pstmon)
dev.off()

#Calculation of Original MK Values and Bootstrap confidence
interval 95%

MKtau<-function(z) MannKendall(z)$tau
boot.jan=tsboot(tseries = raints.jan, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.jan.conf=as.numeric(boot.ci(boot.jan, type="norm")$normal)
orig.tau.jan=as.numeric(boot.jan$t0)
result.jan=c(orig.tau.jan, boot.jan.conf)
```

```
boot.feb=tsboot(tseries = raints.feb, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.feb.conf=as.numeric(boot.ci(boot.feb, type="norm")$normal)
orig.tau.feb=as.numeric(boot.feb$t0)
result.feb=c(orig.tau.feb, boot.feb.conf)
boot.mar=tsboot(tseries = raints.mar, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.mar.conf=as.numeric(boot.ci(boot.mar, type="norm")$normal)
orig.tau.mar=as.numeric(boot.mar$t0)
result.mar=c(orig.tau.mar, boot.mar.conf)
boot.apr=tsboot(tseries = raints.apr, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.apr.conf=as.numeric(boot.ci(boot.apr, type="norm")$normal)
orig.tau.apr=as.numeric(boot.apr$t0)
result.apr=c(orig.tau.apr, boot.apr.conf)
boot.may=tsboot(tseries = raints.may, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.may.conf=as.numeric(boot.ci(boot.may, type="norm")$normal)
orig.tau.may=as.numeric(boot.may$t0)
result.may=c(orig.tau.may, boot.may.conf)
boot.jun=tsboot(tseries = raints.jun, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.jun.conf=as.numeric(boot.ci(boot.jun, type="norm")$normal)
orig.tau.jun=as.numeric(boot.jun$t0)
result.jun=c(orig.tau.jun, boot.jun.conf)
boot.jul=tsboot(tseries = raints.jul, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.jul.conf=as.numeric(boot.ci(boot.jul, type="norm")$normal)
orig.tau.jul=as.numeric(boot.jul$t0)
result.jul=c(orig.tau.jul, boot.jul.conf)
boot.aug=tsboot(tseries = raints.aug, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.aug.conf=as.numeric(boot.ci(boot.aug, type="norm")$normal)
orig.tau.aug=as.numeric(boot.aug$t0)
result.aug=c(orig.tau.aug, boot.aug.conf)
boot.sep=tsboot(tseries = raints.sep, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.sep.conf=as.numeric(boot.ci(boot.sep, type="norm")$normal)
orig.tau.sep=as.numeric(boot.sep$t0)
result.sep=c(orig.tau.sep, boot.sep.conf)
boot.oct=tsboot(tseries = raints.oct, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.oct.conf=as.numeric(boot.ci(boot.oct, type="norm")$normal)
orig.tau.oct=as.numeric(boot.oct$t0)
result.oct=c(orig.tau.oct, boot.oct.conf)
boot.nov=tsboot(tseries = raints.nov, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.nov.conf=as.numeric(boot.ci(boot.nov, type="norm")$normal)
orig.tau.nov=as.numeric(boot.nov$t0)
result.nov=c(orig.tau.nov, boot.nov.conf)
boot.dec=tsboot(tseries = raints.dec, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.dec.conf=as.numeric(boot.ci(boot.dec, type="norm")$normal)
orig.tau.dec=as.numeric(boot.dec$t0)
result.dec=c(orig.tau.dec, boot.dec.conf)
boot.win=tsboot(tseries = raints.win, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.win.conf=as.numeric(boot.ci(boot.win, type="norm")$normal)
```

```
orig.tau.win=as.numeric(boot.win$t0)
result.win=c(orig.tau.win, boot.win.conf)
boot.sum=tsboot(tseries = raints.sum, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.sum.conf=as.numeric(boot.ci(boot.sum, type="norm")$normal)
orig.tau.sum=as.numeric(boot.sum$t0)
result.sum=c(orig.tau.sum, boot.sum.conf)
boot.mon=tsboot(tseries = raints.mon, statistic = MKtau, R = 500,
l = 5, sim = "fixed")
boot.mon.conf=as.numeric(boot.ci(boot.mon, type="norm")$normal)
orig.tau.mon=as.numeric(boot.mon$t0)
result.mon=c(orig.tau.mon, boot.mon.conf)
boot.pstmon=tsboot(tseries = raints.pstmon, statistic = MKtau, R
= 500, l = 5, sim = "fixed")
boot.pstmon.conf=as.numeric(boot.ci(boot.pstmon,
type="norm")$normal)
orig.tau.pstmon=as.numeric(boot.pstmon$t0)
result.pstmon=c(orig.tau.pstmon, boot.pstmon.conf)

z<-matrix(raints, ncol=12, byrow=12)
zm<-apply(z, MARGIN=2, FUN=mean)
zs<-apply(z, MARGIN=2, FUN=sd)
z2<-sweep(z, MARGIN=2, STATS=zm) #subtract monthly means
z3<-sweep(z2, MARGIN=2, STATS=zs, FUN="/") #divide by monthly sd
zds<-c(t(z3))
attributes(zds)<-attributes(raints)
png(file="D:/Result/51deseasonalized.png")
plot(zds)
dev.off()
#do Mann-Kendall trend test
deseason.MK=MannKendall(zds)
#check robustness by applying block bootstrap
MKtau<-function(z) MannKendall(z)$tau
boot.deseason=tsboot(zds, MKtau, R=500, l=12, sim="fixed")
boot.deseason.conf=as.numeric(boot.ci(boot.deseason,
type="norm")$normal)
orig.tau.deseason=as.numeric(boot.deseason$t0)
result.deseason=c(orig.tau.deseason, boot.deseason.conf)
print(deseason.MK)

result=rbind(result.jan, result.feb, result.mar, result.apr,
result.may, result.jun, result.jul, result.aug, result.sep,
result.oct, result.nov, result.dec, result.win, result.sum,
result.mon, result.pstmon,result.deseason)
dimnames(result)=NULL
rownames(result)=c("January", "February", "March", "April",
"May", "June", "July", "August", "September", "October",
"November", "December", "Winter", "Pre-Monsoon", "Monsoon","Post-
Monsoon","Deseasonalized")
colnames(result)=c("MK-Tau","Confidence Level", "Lower Bound",
"Upper Bound")
print(result)
write.csv(result, "D:/Result/MK_Test_Result.csv")
```

Sen's Slope and Mann-Kendall Test.

```
require(wq)
require(Kendall)
x=read.csv(file="D:/TMaxdata/Current.csv", header=FALSE)
a=as.matrix(x[2:13])
b=as.vector(t(a))
pptn=ts(b, start=c(1901,1), end=c(2011,12), frequency=12)
jan=as.matrix(x[2])
jan.ts=ts(jan, start=c(1901), end=c(2011), frequency=1)
feb=as.matrix(x[3])
feb.ts=ts(feb, start=c(1901), end=c(2011), frequency=1)
mar=as.matrix(x[4])
mar.ts=ts(mar, start=c(1901), end=c(2011), frequency=1)
apr=as.matrix(x[5])
apr.ts=ts(apr, start=c(1901), end=c(2011), frequency=1)
may=as.matrix(x[6])
may.ts=ts(may, start=c(1901), end=c(2011), frequency=1)
jun=as.matrix(x[7])
jun.ts=ts(jun, start=c(1901), end=c(2011), frequency=1)
jul=as.matrix(x[8])
jul.ts=ts(jul, start=c(1901), end=c(2011), frequency=1)
aug=as.matrix(x[9])
aug.ts=ts(aug, start=c(1901), end=c(2011), frequency=1)
sep=as.matrix(x[10])
sep.ts=ts(sep, start=c(1901), end=c(2011), frequency=1)
oct=as.matrix(x[11])
oct.ts=ts(oct, start=c(1901), end=c(2011), frequency=1)
nov=as.matrix(x[12])
nov.ts=ts(nov, start=c(1901), end=c(2011), frequency=1)
dec=as.matrix(x[13])
dec.ts=ts(dec, start=c(1901), end=c(2011), frequency=1)
tot=as.matrix(x[14])
tot.ts=ts(tot, start=c(1901), end=c(2011), frequency=1)
win=as.matrix(x[15])
win.ts=ts(win, start=c(1901), end=c(2011), frequency=1)
sum=as.matrix(x[16])
sum.ts=ts(sum, start=c(1901), end=c(2011), frequency=1)
mon=as.matrix(x[17])
mon.ts=ts(mon, start=c(1901), end=c(2011), frequency=1)
pstmon=as.matrix(x[18])
pstmon.ts=ts(pstmon, start=c(1901), end=c(2011), frequency=1)
#Deseasonalization of monthly Time Series
require(boot)
z<-matrix(pptn, ncol=12, byrow=12)
zm<-apply(z, MARGIN=2, FUN=mean)
zs<-apply(z, MARGIN=2, FUN=sd)
z2<-sweep(z, MARGIN=2, STATS=zm) #subtract monthly means
z3<-sweep(z2, MARGIN=2, STATS=zs, FUN="/") #divide by monthly sd
zds<-c(t(z3))
attributes(zds)<-attributes(pptn)

sen.slope=function(ts){
 c(amount=mannKen(ts)$sen.slope, p.value=mannKen(ts)$p.value)
 }
sen.pptn=as.numeric(sen.slope(pptn))
sen.jan=as.numeric(sen.slope(jan.ts))
sen.feb=as.numeric(sen.slope(feb.ts))
```

```
sen.mar=as.numeric(sen.slope(mar.ts))
sen.apr=as.numeric(sen.slope(apr.ts))
sen.may=as.numeric(sen.slope(may.ts))
sen.jun=as.numeric(sen.slope(jun.ts))
sen.jul=as.numeric(sen.slope(jul.ts))
sen.aug=as.numeric(sen.slope(aug.ts))
sen.sep=as.numeric(sen.slope(sep.ts))
sen.oct=as.numeric(sen.slope(oct.ts))
sen.nov=as.numeric(sen.slope(nov.ts))
sen.dec=as.numeric(sen.slope(dec.ts))
sen.tot=as.numeric(sen.slope(tot.ts))
sen.win=as.numeric(sen.slope(win.ts))
sen.sum=as.numeric(sen.slope(sum.ts))
sen.mon=as.numeric(sen.slope(mon.ts))
sen.pstmon=as.numeric(sen.slope(pstmon.ts))
sen.zds=as.numeric(sen.slope(zds))
sen.out=rbind(sen.pptn,sen.jan,sen.feb,sen.mar,sen.apr,sen.may,se
n.jun,sen.jul,sen.aug,sen.sep,sen.oct,sen.nov,sen.dec,sen.tot,sen
.win,sen.sum,sen.mon,sen.pstmon,sen.zds)
dimnames(sen.out)<-NULL
rownames(sen.out)=c("Rain.orig_MonthlyTS",
"January","February","March","April","May","June","July","August"
,"September","October","November","December","YearlyTot","Winter"
,"Pre-Monsoon","Monsoon","Post-Monsoon","Deseasonilzed MothlyTS")
colnames(sen.out)=c("Sen Slope","p_value")
cv=function(amp){
c(cv.mon=phenoAmp(amp, mon.range = c(6, 10))$cv, cv.year=
phenoAmp(amp, mon.range = c(1, 12))$cv)
}
amp=cv(pptn)
phenoamp=matrix(amp, ncol=2, byrow=F)
dimnames(phenoamp)<-NULL
rownames(phenoamp)=c(x[[1]])
colnames(phenoamp)=c("Monsoon Rainfall CV","Yearly Rainfall CV")
fulcrum=phenoPhase(pptn, mon.range = c(1, 12))

png(file="D:/Result/Plotseason.png")
plotSeason(pptn, type = "by.era", num.era = 4, same.plot = TRUE,
ylab = NULL, num.col = 3)
dev.off()
Seasontrend=seasonTrend(pptn, 1901, 2011, type = "slope", method
= "mk")
write.csv(Seasontrend,file="D:/Result/Season_SenSlope.csv")
write.csv(fulcrum, file="D:/Result/Gravity_Centre.csv")
write.csv(phenoamp, file="D:/Result/Rainfall_Variation.csv")
write.csv(sen.out, file="D:/Result/SenSlope Result.csv")
```

Sequential Mann-Kendall Test.

```
require(pheno, quietly = FALSE)
x=read.csv(file="D:/TMaxdata/Current.csv",header=FALSE)
jan=x[[2]]
result.jan=seqMK(jan)
jan.prog=result.jan$prog
jan.retro=result.jan$retr

feb=x[[3]]
result.feb=seqMK(feb)
feb.prog=result.feb$prog
feb.retro=result.feb$retr

mar=x[[4]]
result.mar=seqMK(mar)
mar.prog=result.mar$prog
mar.retro=result.mar$retr

apr=x[[5]]
result.apr=seqMK(apr)
apr.prog=result.apr$prog
apr.retro=result.apr$retr

may=x[[6]]
result.may=seqMK(may)
may.prog=result.may$prog
may.retro=result.may$retr

jun=x[[7]]
result.jun=seqMK(jun)
jun.prog=result.jun$prog
jun.retro=result.jun$retr

jul=x[[8]]
result.jul=seqMK(jul)
jul.prog=result.jul$prog
jul.retro=result.jul$retr

aug=x[[9]]
result.aug=seqMK(aug)
aug.prog=result.aug$prog
aug.retro=result.aug$retr

sep=x[[10]]
result.sep=seqMK(sep)
sep.prog=result.sep$prog
sep.retro=result.sep$retr

oct=x[[11]]
result.oct=seqMK(oct)
oct.prog=result.oct$prog
oct.retro=result.oct$retr

nov=x[[12]]
result.nov=seqMK(nov)
nov.prog=result.nov$prog
nov.retro=result.nov$retr
```

```
dec=x[[13]]
result.dec=seqMK(dec)
dec.prog=result.dec$prog
dec.retro=result.dec$retr

tot=x[[14]]
result.tot=seqMK(tot)
tot.prog=result.tot$prog
tot.retro=result.tot$retr

win=x[[15]]
result.win=seqMK(win)
win.prog=result.win$prog
win.retro=result.win$retr

sum=x[[16]]
result.sum=seqMK(sum)
sum.prog=result.sum$prog
sum.retro=result.sum$retr

mon=x[[17]]
result.mon=seqMK(mon)
mon.prog=result.mon$prog
mon.retro=result.mon$retr

pstmon=x[[18]]
result.pstmon=seqMK(pstmon)
pstmon.prog=result.pstmon$prog
pstmon.retro=result.pstmon$retr

output<-
c(jan.prog,jan.retro,feb.prog,feb.retro,mar.prog,mar.retro,apr.pr
og,apr.retro,may.prog,may.retro,jun.prog,jun.retro,jul.prog,jul.r
etro,aug.prog,aug.retro,sep.prog,sep.retro,oct.prog,oct.retro,nov
.prog,nov.retro,dec.prog,dec.retro,tot.prog,tot.retro,win.prog,wi
n.retro,sum.prog,sum.retro,mon.prog,mon.retro,pstmon.prog,pstmon.
retro)
final=matrix(output, ncol=34,byrow=F)
rownames(final)=c(x[[1]])
colnames(final, do.NULL=T)
colnames(final)<-
c("January.Prog","January.Retro","February.Prog","February.Retro"
,"March.Prog","March.Retro","April.Prog","April.Retro","May.Prog"
,"May.Retro","June.Prog","June.Retro","July.Prog","July.Retro","A
ugust.Prog","August.Retro","September.Prog","September.Retro","Oc
tober.Prog","October.Retro","November.Prog","November.Retro","Dec
ember.Prog","December.Retro","Year.Prog","Year.Retro","Win.Prog",
"Win.Retro","Sum.Prog","Sum.Retro","Mon.Prog","Mon.Retro","PostMo
n.Prog","PostMon.Retro")
write.csv(final, file="D:/Result/SeqMann_Kendall_result.csv")
```

Von Neumann Test of Normality for Trend.

```
require(randtests, quietly = FALSE)
x=read.csv(file="D:/TMaxdata/Current.csv",header=FALSE)
jan=x[[2]]
result.jan=bartels.rank.test(jan, "left.sided", pvalue="normal")
statistic.jan=as.numeric(result.jan$statistic)
p.jan=result.jan$p.value
feb=x[[3]]
result.feb=bartels.rank.test(feb, "left.sided", pvalue="normal")
statistic.feb=as.numeric(result.feb$statistic)
p.feb=result.feb$p.value
mar=x[[4]]
result.mar=bartels.rank.test(mar, "left.sided", pvalue="normal")
statistic.mar=as.numeric(result.mar$statistic)
p.mar=result.mar$p.value
apr=x[[5]]
result.apr=bartels.rank.test(apr, "left.sided", pvalue="normal")
statistic.apr=as.numeric(result.apr$statistic)
p.apr=result.apr$p.value
may=x[[6]]
result.may=bartels.rank.test(may, "left.sided", pvalue="normal")
statistic.may=as.numeric(result.may$statistic)
p.may=result.may$p.value
jun=x[[7]]
result.jun=bartels.rank.test(jun, "left.sided", pvalue="normal")
statistic.jun=as.numeric(result.jun$statistic)
p.jun=result.jun$p.value
jul=x[[8]]
result.jul=bartels.rank.test(jul, "left.sided", pvalue="normal")
statistic.jul=as.numeric(result.jul$statistic)
p.jul=result.jul$p.value
aug=x[[9]]
result.aug=bartels.rank.test(aug, "left.sided", pvalue="normal")
statistic.aug=as.numeric(result.aug$statistic)
p.aug=result.aug$p.value
sep=x[[10]]
result.sep=bartels.rank.test(sep, "left.sided", pvalue="normal")
statistic.sep=as.numeric(result.sep$statistic)
p.sep=result.sep$p.value
oct=x[[11]]
result.oct=bartels.rank.test(oct, "left.sided", pvalue="normal")
statistic.oct=as.numeric(result.oct$statistic)
p.oct=result.oct$p.value
nov=x[[12]]
result.nov=bartels.rank.test(nov, "left.sided", pvalue="normal")
statistic.nov=as.numeric(result.nov$statistic)
p.nov=result.nov$p.value
dec=x[[13]]
result.dec=bartels.rank.test(dec, "left.sided", pvalue="normal")
statistic.dec=as.numeric(result.dec$statistic)
p.dec=result.dec$p.value
year=x[[14]]
result.year=bartels.rank.test(year, "left.sided",
pvalue="normal")
statistic.year=as.numeric(result.year$statistic)
p.year=result.year$p.value
```

```
output<-
c(statistic.jan,p.jan,statistic.feb,p.feb,statistic.mar,p.mar,sta
tistic.apr,p.apr,statistic.may,p.may,statistic.jun,p.jun,statisti
c.jul,p.jul,statistic.aug,p.aug,statistic.sep,p.sep,statistic.oct
,p.oct,statistic.nov,p.nov,statistic.dec,p.dec,statistic.year,p.y
ear)
final=matrix(output,
ncol=2,byrow=TRUE,dimnames=list(c("January","February","March","A
pril","May","June","July","August","September","October","Novmber
","December","Yearly"),c("NeumannStatistic","p-value")))
write.csv(final, file="D:/Result/Neumannresult.csv")
```

(A) Results of Cumulative Deviation for $TMax$ Series after MASH Game.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N 24 Pga	Pur	S 24 Pga
Jan	0.97	0.97	0.99	1.07	1.10	1.22	0.94	0.87	1.16	1.12	1.10	1.29	1.28
Feb	1.13	1.05	0.99	1.12	1.07	1.20	1.04	1.07	1.30	1.36	1.36	1.11	1.33
Mar	0.87	1.10	0.92	1.25	1.11	0.80	0.81	0.96	1.28	1.34	1.34	1.02	1.27
Apr	1.22	1.10	1.35	1.26	1.12	0.93	1.22	0.59	1.34	1.25	1.25	1.17	1.23
May	1.12	0.89	1.06	0.80	0.73	1.01	1.25	1.23	1.15	1.24	1.14	0.70	1.31
June	0.59	0.62	0.71	0.57	0.58	0.51	0.80	0.61	0.92	0.74	0.74	0.54	1.24
July	0.66	0.56	0.54	0.65	0.85	1.15	0.87	1.35	0.64	1.15	1.15	0.74	1.26
Aug	1.02	1.36	1.15	1.23	1.11	0.92	1.09	1.99	1.72	1.15	1.15	1.13	0.74
Sep	0.60	0.64	0.43	1.03	0.89	0.92	0.73	1.26	1.05	1.17	1.17	0.90	1.08
Oct	1.01	0.73	1.10	1.00	1.29	1.17	0.74	1.33	1.19	1.13	1.23	1.03	0.67
Nov	1.31	1.31	1.28	1.19	1.33	1.27	0.84	1.33	1.30	1.20	1.30	0.93	0.68
Dec	1.34	1.33	1.24	1.06	1.09	0.93	1.33	1.24	1.30	1.27	1.27	1.14	1.14
AA	1.24	1.30	1.08	1.17	1.28	1.15	1.18	1.13	1.16	1.29	1.06	1.02	1.20
Win	0.95	1.18	1.36	1.19	0.63	1.01	0.85	1.12	1.12	1.31	1.26	1.02	0.78
Sum	0.88	1.16	1.21	1.32	1.20	1.15	1.03	1.18	1.35	1.12	0.87	1.27	0.89
Mon	1.05	0.80	0.72	1.14	1.12	0.84	1.05	0.99	0.90	1.12	0.89	1.03	0.97
PM	0.95	1.18	1.36	1.19	0.63	1.01	0.85	1.12	1.12	1.31	1.26	1.02	0.78

(B) Results of Cumulative Deviation for $TMin$ Series after MASH Game.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N 24 Pga	Pur	S 24 Pga
Jan	0.91	1.01	0.94	0.95	1.00	0.83	0.97	0.95	1.26	0.64	1.20	1.12	1.22
Feb	1.34	1.09	1.29	1.26	1.03	1.33	1.25	1.32	1.01	0.88	1.07	1.28	0.93
Mar	1.09	0.92	1.01	0.66	1.05	1.03	1.02	1.35	1.26	0.86	1.15	1.01	1.27
Apr	0.73	0.48	0.53	0.57	1.25	1.00	1.07	1.06	0.83	0.62	1.22	0.70	1.08
May	0.82	1.27	1.25	0.98	1.35	0.93	1.15	1.10	1.10	1.10	0.76	0.96	1.24
June	0.92	1.19	1.10	1.16	1.14	1.06	0.98	1.04	1.24	1.06	1.31	1.15	1.28
July	1.62	1.29	1.14	0.88	1.26	1.10	1.35	1.20	1.31	1.21	1.32	0.67	1.08
Aug	0.72	1.01	1.16	1.36	1.07	0.87	1.34	1.24	1.25	1.35	1.21	0.64	1.32
Sep	0.81	0.86	1.08	0.95	1.25	1.18	1.33	1.27	1.05	0.78	0.91	0.56	1.22
Oct	0.94	1.05	1.21	0.99	1.06	0.90	0.95	0.87	0.50	1.34	0.85	1.14	0.95
Nov	0.82	0.96	1.05	1.30	1.26	1.19	0.47	1.06	1.25	1.18	1.23	1.13	1.18
Dec	1.05	1.21	1.16	1.11	1.36	1.28	1.20	1.14	1.25	1.26	1.32	1.24	1.22
AA	1.15	1.32	1.06	1.00	1.15	1.32	1.06	1.07	1.00	1.00	1.32	1.07	1.34
Win	1.27	1.29	1.17	1.20	1.27	1.29	1.17	1.18	1.20	1.20	1.29	1.18	1.36
Sum	1.13	1.31	1.13	1.09	1.13	1.38	1.13	1.33	1.27	1.27	1.02	1.33	1.09
Mon	1.23	1.37	1.06	1.52	1.23	1.37	1.06	0.72	0.87	0.87	1.37	0.72	1.26
PM	1.29	0.98	0.86	1.02	1.29	0.98	0.86	0.86	1.01	1.01	0.98	1.21	1.08

(C) Results of Cumulative Deviation for $Rainfall$ Series after MASH Game.

	Ban	Bir	Bur	Hoo	How	Kol	Mal	Mid	Mur	Nad	N 24 Pga	Pur	S 24 Pga
Jan	0.74	0.67	0.64	0.60	0.59	0.49	0.81	0.44	0.67	0.46	0.51	0.73	0.54
Feb	1.19	1.40	1.22	1.01	0.86	0.88	1.24	0.81	1.33	1.06	0.82	1.30	0.68
Mar	0.67	0.61	0.64	0.64	0.64	0.71	0.41	0.52	0.59	0.61	0.54	0.82	0.61
Apr	0.62	0.87	0.69	0.50	0.59	0.72	0.75	0.45	0.82	0.56	0.52	0.47	0.63
May	1.17	1.11	1.19	1.00	1.01	1.21	1.20	0.89	1.07	0.80	0.86	1.03	1.02
June	0.86	1.06	0.96	0.79	0.68	0.65	1.30	0.69	0.96	0.83	0.74	1.09	0.80
July	0.59	0.72	0.52	0.62	1.04	1.09	0.96	0.97	0.86	0.83	1.00	0.64	1.23
Aug	1.33	1.27	1.39	0.93	0.73	0.60	1.36	0.81	1.36	1.05	0.71	1.35	0.91
Sep	1.05	0.88	1.00	0.93	0.97	1.10	0.73	0.99	1.06	1.28	1.06	0.94	1.08
Oct	0.79	0.73	0.78	0.81	0.89	0.95	0.90	0.83	0.75	0.87	0.83	0.76	0.95
Nov	0.42	0.66	0.66	0.47	0.53	0.78	0.61	0.47	0.83	0.51	1.29	0.47	0.58
Dec	1.31	1.25	1.30	0.95	0.98	0.83	1.20	1.23	1.14	1.23	1.06	1.33	1.14
AA	0.60	0.88	0.62	0.94	1.31	1.21	0.93	0.99	0.49	0.74	1.22	1.06	1.20
Win	1.21	0.88	1.26	0.90	0.90	0.61	1.17	0.68	0.98	1.05	0.53	1.20	0.52
Sum	0.90	0.99	1.03	1.06	1.06	0.96	0.92	0.89	0.90	1.04	1.01	0.98	0.99
Mon	0.70	0.77	0.65	0.98	0.98	1.36	1.34	0.83	0.74	0.73	1.04	0.86	0.04
PM	0.70	0.77	0.65	0.98	0.98	1.36	1.34	0.83	0.74	0.73	1.04	0.86	1.22

Subject Index

A- **Andhi** is a strong, hot and dry summer afternoon wind from the west which blows over the western Indo-Gangetic Plain region of North India and Pakistan. It is especially strong in the months of May and June. Due to its very high temperatures (45 °C–50 °C or 115°F-120°F), exposure to it often leads to fatal heatstrokes.

Ajay River is a major river in Jharkhand and West Bengal. The word *"Ajay"* means "Not conquered".

B- **Brahmani** is a major seasonal river in the Odisha state of Eastern India.

Bihar is an East state in India.

BRT- Buishand Range Test.

C. **Chota Nagpur Plateau** is a plateau in eastern India, which covers much of Jharkhand state as well as adjacent parts of Odisha, West Bengal, Bihar and Chhattisgarh. The Indo-Gangetic plain lies to the north and east of the plateau, and the basin of the Mahanadi River lies to the south. The total area of the Chota Plateau is approximately 65,000 square kilometres (25,000 sq mi).

Chhattisgarh is a central state in India.

D. **Damodar River** is a river flowing across the Indian states of West Bengal and Jharkhand. Rich in mineral resources, the valley is home to large-scale mining and industrial activity. Earlier known as the **Sorrow of Bengal,** because of its ravaging floods in the plains of West Bengal, the Damodar and its tributaries have been somewhat tamed with the construction of several dams.

Darjeeling is a town and a municipality in the Indian state of West Bengal. It is located in the Mahabharat Range or Lesser Himalaya at an elevation of 6,700 ft (2,042.2 m).

Dwarakeswar River (also known as Dhalkisor) is a major river in the western part of the Indian state of West Bengal.

G. **Gangetic** - Low-lying plains region India & Bangladesh formed by Ganges River & its tributaries.

H. **Haldi River** is a tributary of Hooghly River flowing through Purba Medinipur district of the Indian state of West Bengal. The Keleghai joins the Kansai at Tangrakhali under Mahisadal police station in Tamluk subdivision.

Hooghly River is a distributary of the Ganga river in West Bengal, India.

J. **Jalangi River** is a branch of the Ganges river in Murshidabad and Nadia districts in the Indian state of West Bengal.

Jharkhand is a state in India.

K. **Kal Baisakhi**, or Nor'westers (a mass of thick black clouds or kal) a term used in West Bengal, are thundershowers known to arrive from the north or northwest direction, bringing good rain with squally winds during early summers.

Kalimpong is a hill station in the Indian state of West Bengal. It is located at an average elevation of 1,250 metres (4,101 ft).

Kanyakumari a town in Kanyakumari district in Tamil Nadu state, India. Formerly known as "Cape Comorin".

Karnataka is a state in India.

Keleghai River originates at Baminigram, near Dudhkundi, under Sankrail police station, in Jhargram subdivision of Paschim Medinipur district in the Indian state of West Bengal.

Kerala is a state in India.

Kosai River is a small river located near Kharagpur in the Indian state of West Bengal.

Kutch district (also spelled as **Kachchh**) is a district of Gujarat state in western India. Covering an area of 45,652 km, it is the largest district of India.

M. **Monsoon depression** is one of the most important synoptic scale disturbances on the quasi-stationary planetary scale **monsoon** trough over the Indian region during the summer **monsoon** season (June to September).

Mayurakshi River (also called **Mor River**) is a major river in West Bengal, India, with a long history of devastating flood.

P. **Panagarh** is the easternmost suburb of Durgapur, located in Kanksa police station of Durgapur subdivision in Bardhaman Districtof West Bengal.

Patna is the capital and largest city of the state of Bihar in India. Patna is the second largest city ineastern India after Kolkata.

Punjab is a state in North India.

R. **Rupnarayan** is a river in India. It begins as the Dhaleswari (Dhalkisor) in the Chhota Nagpur plateau foothills northeast of the town of Purulia. It then follows a tortuous southeasterly course past the town of Bankura, where it is known as the Dwarakeswar river. Near the town of Ghatal it is joined by the Shilabati river, where it takes the name Rupnarayan. Finally, it joins the Hoogli River. It is famous for the Hilsa fish that live in it and are used in Bengali cuisine. It is also notable for the West Bengal Power Development Corporation Limited (WBPDCL) thermal power plant built along its bank at Kolaghat in West Bengal.

S. **Sagar Island** is an island in the Ganges delta, lying on the continental shelf of Bay of Bengal about 100 km (54 nautical miles) south of Kolkata. This Island under South 24 Parganas District in India State West Bengal.

Silabati River (also known as **Silai**) originates in the terrain of the Chhota Nagpur Plateau in the Purulia district of the state of West Bengal in eastern India.

Suri is the capital of Birbhum district in the Indian state of West Bengal, India**.**

Subarnarekha River (also called Swarnarekha River) flows through the Indian states of Jharkhand, West Bengal and Odisha.

SW-South Western.

SNHT-1- Standard Normal Homogeneity Test-1.

T. **That Desert** is the Great Indian Desert. It is the 7th largest desert in the world. 85% area covers by India and 15% area covers by Pakisthan.

Tamil Nadu is a state southern state in India.

V. **VNR**- Von-Neumann Ratio test.

W. **West Bengal** is a state in Eastern India.

Considered Observatories List.

SL No.	Name of Observatories	Short form
1	Bankura	Ban
2	Birbhum	Bir
3	Burdwan	Bur
4	Hooghly	Hoo
5	Howrah	How
6	Kolkata	Kol
7	Malda	Mal
8	Midnapore	Mid
9	Murshidabad	Mur
10	Nadia	Nad
11	North 24 Pargana	N 24 pgs
12	Purulia	Pur
13	South 24 Pargana	S 24 Pgs

Seasons List

SL No.	Name of Seasons	Short form
1	Winter	W
2	Summer	S
3	Monsoon	M
4	Post-Monsoon	PM

LIST OF RESEARCH PAPERS IN PEER REVIEWED REFERRED JOURNALS

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