TREND ANALYSIS OF CLIMATIC PARAMETERS IN BANGLADESH AND THEIR PROBABLE IMPACTS ON THE PRODUCTIVITY OF THE MAJOR CROPS

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CERTIFICATE

*This is to certify that thesis entitled, "**TREND ANALYSIS OF CLIMATIC PARAMETERS IN BANGLADESH AND THEIR PROBABLE IMPACTS ON THE PRODUCTIVITY OF THE MAJOR CROPS"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (MS) IN AGROFORESTRY AND ENVIRONMENTAL SCEINCE**, embodies the result of a piece of bona-fide research work carried out by **NAFIA JAHAN RASHMI**, Registration no. **08-2789** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated: December,2014
Place: Dhaka, Bangladesh

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DECLARATION

I do hereby declare that thesis entitled ***"Trend Analysis of Climatic Parameters in Bangladesh and Their Probable Impacts on the Productivity of the Major Crops"*** has been written and composed by myself with my own investigated research data.

I further declare that this thesis has not been submitted anywhere in any form for any academic degree.

December, 2014 Nafia Jahan Rashmi

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ABSTRACT

The study examines the trend of three main climatic parameters (e.g. maximum temperature, minimum temperature and rainfall) based on the analysis of historical climatic data recorded at 35 stations at seven divisions in Bangladesh for the period of 1983 to 2013. This study also assesses the relationship between the yield of three major crops e.g. rice (Aus, Aman, Boro), wheat and potato. Time series data for the 1997 to 2013 period was used at an aggregate level to assess the relationship between climatic parameters and crop yield using correlation analysis with the help of SPSS software. The findings of the study confirm that both yearly average maximum and minimum temperature for different months exhibited an overall increasing trend throughout the country except some decreasing trend during winter. Analysis of seasonal rainfall data revealed a negative correlation with time which indicates a decreasing trend of rainfall. In case of different cropping seasons such as rice growing seasons Aus, Aman, Boro and wheat and potato growing season Robi exhibited a strong increase in maximum and minimum temperature whereas rainfall found to have a decreasing trend. This study revealed that the climatic parameters have had significant effects on rice yield, but these effects vary among three rice crops. Maximum temperature had positive effects on all rice yields with statistically significant effect on Aus and Aman. Minimum temperature has a statistically significant negative effect on Aman rice and a significantly positive effect on Aus rice. Rainfall exhibited negative relation with rice yield but in case of Aman it had a statistically significant negative effect on yield. Climatic parameters had an adverse effect on wheat and potato yield, but these correlations were not statistically significant.

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LIST OF SYMBOLS AND ABBREVIATION

Symbols and Abbreviations	Full Word
%	Percent
et al.,	And others
J	Journal
No.	Number
cm	Centimeter
Agric.	Agriculture
°C	Degree centigrade
Etc.	Etcetera
DAE	Department of Agricultural Extension
mm	Millimeter
SPSS	Statistical Package for Social Sciences
BMD	Bangladesh Meteorological Department
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
CRI	Climate Risk Index
IUCN	International Union for Conservation of Nature
BRRI	Bangladesh Rice Research Institute
i.e.	That is
BBS	Bangladesh Bureau of Statistics
MS Excel	Microsoft Excel
°F	Degree Fahrenheit
kg	Kilogram
t	Ton
MmT	Million Metric Ton
GED	General Economic Division

Chapter 1

INTRODUCTION

Earth's climate history has experienced a number of changes due to its natural evolution as well as abrupt causes. The temperature, the rainfall, and the sea level rise are the indicators for the climate change. The global average air temperature in the twentieth century has increased by 0.6 °C and 1990 was the hottest decade in the last millennium (IPCC, 2001). The temperature in the twentieth century in all the continents and oceans had an obvious increasing trend. The standard deviation of the global average temperature was 0.24°C, the largest difference between two continuous years was 0.29°C (between 1976 and 1977), and the rate of the trend of temperature increase was 0.75°C, faster than any other century in the history from the eleventh century to the present. It is noticeable that in the last five decades, from 1956 to 2005, the temperature has increased by 0.64±0.13°C, twice faster than it did in the twentieth century (IPCC, 2001). So, it is clear that the trend of the temperature change has become more rapid in the recent years. There are 11 years in the period from 1995 to 2006 that are classified in the list of 12 years with the highest annual mean global surface air temperature in the history of temperature observation since 1850, of which 1998 and 2005 are the hottest.

Climate change in Bangladesh is an extremely crucial issue and according to National Geographic, Bangladesh ranks first as the nation most vulnerable to the impacts of climate change in the coming decades. Bangladesh is the nation most vulnerable to global climate change in the world, according to German Watch's Global Climate Risk Index (CRI) of 2011. This is based on the analysis of impacts of major climate events that occurred around the world in the twenty-year period since 1990. The reasons are complex and extremely intertwined. The country, which has no control of the water flow and volume, drains to the Bay of Bengal over 90% of the total run-off generated annually.

Coupled with the high level of widespread poverty and increasing population density, limited adaptive capacity and poorly funded, ineffective local governance have made the region one of the most adversely affected in the planet.

It is projected that, by 2020, from 500 to 750 million people will be affected by water stress caused by climate change around the world. Low-lying coastal regions, such as Bangladesh, are vulnerable to sea level rise and increased occurrence of intense, extreme weather conditions such as the cyclones from 2007–2009. In most countries like Bangladesh, yields from rain-fed agriculture could be reduced to 50% by 2020. For a country with increasing population and hunger, this will have an extremely adverse effect on food security. Although effects of climate change are highly variable, by 2030, South Asia could lose 10% of rice and maize yields while neighboring states like Pakistan could experience a 50% reduction in crop yield (Sunny and Sanwar, 2011).

Agriculture is the major sector of Bangladeshi economy, providing about 22% of total GNP. Perhaps more important is the fact that almost two-thirds (65%) of the labor force is employed in agriculture (Faruquee, 1998). Rice is by far the major crop in Bangladesh. In 1993-1995, average annual production was 18 MmT. In contrast, only 1.2 Mmt of wheat was produced annually in the same period (BBS, 1998). But IPCC-IV has stated that results of recent studies suggest that substantial decreases in cereal production potential in Asia could be likely by the end of this century as a consequence of climate change. However, regional differences in the response of wheat, maize and rice yields to projected climate change could likely be significant (Parry *et al.*,, 1999; Rosenzweig *et al.*,, 2001).

As a result of all this, Bangladesh would need to prepare for long-term adaptation, which could be as drastic as changed sowing dates due to seasonal variations, introducing different varieties and species, to practicing novel water supply and irrigation systems. In essence, we have to identify all present vulnerabilities and future opportunities, adjusting priorities, at times even changing commodity and trade policies in the agricultural sector while promoting training and education throughout the masses in all possible spheres. But this burning issue is scarcely analyzed in Bangladesh. There is a very few trend analysis about the change in the climatic parameters of Bangladesh. This work, however, aims to study the probable correlation between the climatic parameters and crop performances.

Objectives:

i. To observed the recent changes in the climatic parameters in Bangladesh; and

ii. To simulate a correlation between climatic parameters and crop production.

Chapter 2

REVIEW OF LITERATURE

This chapter provides a review of the pertinent literature on change in the climate parameter and crop agriculture. The reviews focus on the two main areas of this research: Recent trend of the climatic parameters and Impact of climate change on crop productivity.

2.1 Recent trend of the climatic parameters

The Third Assessment Report of IPCC (2001) stated that the global average surface temperature has increased over the 20th century by about 0.6℃. The global average surface temperature (the average of near-surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20th century, the increase has been 0.6 ± 0.2℃. Globally, it is very likely that the 1990s were the warmest decade and 1998 was the warmest year in the instrumental record, since 1861. On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2℃ per decade. This is about twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high-latitude regions. The increase in sea surface temperature over this period is about half that of the mean land surface air temperature. Temperatures have risen during the past four decades in the lowest 8 km of the atmosphere.

The fourth Assessment Report of IPCC (2007) has observed the following changes in the earth's climate. The 100-year linear trend (1906-2005) of global average surface temperature is 0.74 [0.56 to 0.92] ° C and is larger than the corresponding trend of 0.6[0.4 to 0.8] ° C (1901-2000). This observed warming is consistent with shrinking of Arctic sea ice and satellite data since 1978, it is already evident that annual average sea extent has shrunk by 2.7 [2.10 to 3.3] % per decade. Global average sea level has risen since 1961 at an average rate of 1.8 [1.33 to 2.30] mm/yr and since 1993 at 3.1 [2.4 to 3.8] mm/yr due to thermal expansion, melting glaciers and ice caps, and the polar ice sheets. The report also stated that from 1900 to 2005, precipitation has found to either increase or decrease in different part of the world and that globally, the area affected by drought might have increased since the 1970s. Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

IPCC (2013) reported that Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gasses have increased. Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia, and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe. In other continents, confidence in changes in heavy precipitation events is at most medium. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012. For the longest period when the calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming. Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterward. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951). For other latitudes, area-averaged long-term positive or negative trends have low confidence

IUCN, Bangladesh (2011) stated that the impact of global climate change on Bangladesh is becoming more visible day by day and is being analyzed and documented. Their observation indicated that the observed climatic data from 1971 to 2002 temperature has an increasing trend in the monsoon (June, July, and August). The average minimum and maximum temperature show an increasing trend annually 0.05° C and 0.03° C respectively. Average winter season (December, January, and February) maximum and minimum temperature show respectively a decreasing and increasing trend annually at 0.001° C and 0.016° C. It is also revealed that 1998 was the warmest year in the last 30 years.

There are studies that identified changes in rainfall characteristics. But these changes are not statistically significant and do not show any specific trend like that of temperature. Quadir and Iqbal (2008) studied rainfall data from 1951 to 2007 of nine coastal BMD stations and found that only five stations showed an increasing trend while four stations showed a negative trend for monsoon period rainfall. For winter and pre-monsoon period, there is an increasing trend of rainfall for all station except Bhola, which is an unusual phenomenon according to the authors. The author also reported higher pre-monsoon rainfall trend for the other parts of the country. On the other hand, GED (2009) reported that the “number of days without rainfall” in Bogra station (1972 to 2002) shows an increasing trend while the total annual rainfall is showing decreasing trend (not statistically significant). In another station in Rangpur (GED, 2009) both numbers of days without rainfall and annual total rainfall in Rangpur are increasing, which means more rain is occurring in short duration. All these may suggest an erratic behavior of rainfall.

Hasan and Rahman (2013), investigated on the temperature trend in Bangladesh. Maximum, minimum and mean monthly temperature data of last sixty–three years (1948-2010) collected from 35 stations of BMD located all over the Bangladesh have been used in this study. It has been found that monthly maximum temperature shows a positive trend of increase at a rate of 0.5°C per 100 years. The maximum increase occurred during November at a rate of 2.05°C per 100 years. However, monthly minimum temperature shows more statistically significant trend of increase at a rate of 1.40°C per 100 year. The maximum increase occurred during February at a rate of 2.73°C per 100 years. Monthly mean temperature shows a positive trend of increase at a rate of 0.8°C per 100 years. It is clear found that monthly minimum temperature has been increased significantly during the winter season (October to February) over the last sixty-three years. This study also reveals that temperature has been increasing predominantly over the last 21years (1990-2010) than last 63 years (1948-2010). The increase of monthly maximum temperature is 0.60° C, the monthly minimum temperature is 1.39°C and monthly mean temperature is 0.79°C per 100 years. The maximum increase of monthly maximum temperature has occurred in November at 2.05°C and monthly minimum temperature has occurred in February at 2.73°C in 100 years. The highest increase of monthly maximum temperature has occurred as 1.1 °C per 100 years at Dhaka and monthly minimum temperature has occurred as -0.2 °C per 100 years at Rajshahi. It has clearly found that maximum temperature has been increased dramatically over the last 21years period. Monthly maximum, minimum and mean temperature has shown a positive increase with a rate of 4.49 °C, 2.98 °C and 2.06 °C per 100 years respectively during the period of last 21 years (1990-2010).

Basak *et al.,* (2013); provide an assessment of climate change and variability based on analysis of historical data of temperature and rainfall recorded at 34 Meteorological stations located at seven regions in Bangladesh for the period of 1976 to 2008. Analysis of temperature data showed that at the majority of these stations, the yearly average maximum and minimum temperatures had increasing trends. Analysis of monthly average maximum temperature also showed an increasing trend for all months of the year except January and April; the increasing trend was particularly significant for the months of May to

September and February. Calculated average increase in temperature for these months was about 1℃ for the 33-years period from 1976 to 2008. Monthly average minimum temperatures also showed increasing trends for all months except January and November. The average increase in monthly average minimum temperature was about 0.7℃, while for January and November; the average decrease was about 0.06℃ during the same period. The magnitude of increase in monthly average maximum and minimum temperatures during the 33-yearsperiod from 1976 to 2008 is quite significant. Moreover, a significant increase of maximum temperature was observed at the Southeastern region for both yearly and monthly average data and Northern region for minimum temperature. Analysis of precipitation data during 1976-2008 showed an increasing trend of rainfall for the majority of stations during Monsoon and post-Monsoon seasons while decreasing trend of total rainfall during winter was found for a significant number of weather stations; pre-Monsoon period did not show any significant change in total rainfall. In general, these trends are consistent with the general climate change predictions.

Nishat and Mukharjee (2013), observed that Bangladesh is strongly affected by climate change. Increasing surface air temperature is most prominent in Bangladesh, where an increasing trend and temporal variation in the mean seasonal temperature is observed within the range of 0.4 -0.65℃ during the past 40 year period (1967-2007). Over the past few decades, a warmer winter is being experienced by the country with a prominent increase in the minimum temperature. Similar to this, more hot summer is also experienced during the pre-monsoon and monsoon seasonal months when a prominent rise in the maximum and minimum temperature is observed over the last few decades. A rise in the minimum temperature by 0.45℃ and 0.52℃ is observed during the winter (December, January, and February) and monsoon (June, July, August) season respectively. Maximum temperatures also observed to be increased during pre-monsoon (March, April, and May) and post-monsoon (June, July, August) the month by 0.87° C and 0.42℃ respectively. Rise in the minimum temperature during winter season (December, January, February) is observed in

25 out of 34 climate observatories of the Bangladesh meteorological Department (BMD), where it is prominent in Dhaka (0.05°C/year), Chudanga (0.05°C/year), Madaripur (0.06°C/year) and Sayedpur (0.08°C/year) stations. Rise in the maximum temperature during the hot summer of months June, July and August is observed in almost all the stations (except Rangpur), where it prominently observed in the range of 0.03°C-0.05°C/ year Sayedpur, Sitakunda, Sylhet and in Tangail station. In the case of rainfall in all seasons, there is an observed an overall increase in the mean seasonal rainfall, were found maximum during pre-monsoon and monsoon season by around 100mm increase in the mean seasonal rainfall. Although the winter season experiences the minimum rainfall, the historical trend is showing inclination in 27 out of 32 rainfall observatories of BMD. The increase in the pre-monsoon seasonal rainfall is also evident in 30 out of 32stations of BMD. Monsoon and post monsoon season rainfall also observed an increasing trend. The total number of the no rainy day in a year is decreasing.

Rakib (2013), reported an outline of temperature trends in Bangladesh. Bangladesh has warmed up during the last 18 years; annual temperature has increased by 0.4-0.6°C during the period 1981-2010. Annual average warming was mainly the result of monsoon and pre-monsoon warming. Averaged over all stations, the indices of temperature extremes indicate warming of both the cold tail and the warm tail of the distributions of daily minimum and maximum temperature in the monsoon and pre-monsoon season, which influences the most in overall temperature rise in Bangladesh in the past reference period 1981-2010. This increase has been found more in the eastern and south-western region than the other parts. The minimum temperature of the coastal and central areas of Bangladesh has also shown a significant increase. The analysis represents that the number of cold days has been reducing drastically in those regions. A minimum temperature of the coastal and central areas of Bangladesh has shown a significant increase. Also, the level of discomfort, in terms of Heat Index, has also shown an upward shift through time. The discomfort level has increased in the recent two decades markedly.

2.2 Impact of climate change on crop productivity

Several studies investigated the possible effects of climate change on world agricultural production (Rosenzweig and Parry (1994), Parry *et al.,* (1999), Rosenzweig and Parry (1994), assessed the likely impact of climate change on world food supply using a crop growth model. The main finding of the research is that global food production would be reduced slightly because of a two-fold increase in atmospheric CO^2 concentration. It was also found that climate change affects developed and developing countries differently. Countries in the lower latitude regions (i.e., developing countries) will bear the major brunt of the problems caused by climate change. Results from simulations of the effectiveness of adaptive options taken by farmers confirmed that these are rarely successful in alleviating the difference between developed and developing countries.

Parry *et al.,*, (1999); looked at the possible impacts of climate change on crop yields, world food supply and risk of hunger using the Hardly Centre Coupled Model (HadCM2) global climate change model scenarios. The consequences for crop yields are beneficial for countries in mid and high latitude regions (i.e., the developed world) while the effects are damaging for countries in low latitude areas (i.e., the developing world, excluding China). The availability of water supplies for irrigation and the costs of adaptation appeared to be important dimensions for further research.

The early studies on the impact of climate change on agriculture focused on developed countries, particularly the USA. One strand of research used the production function approach to forecasting the impact on crop yields through crop simulation models (Adams *et al.,*, (1989); Rosenzweig 1989; Adams *et al.,*, (1995); Kaiser *et al.,*, (1993)). Most of these studies estimate substantial harmful effects of climate change on agriculture in the USA. However, a recent study by Lobell *et al.,*, (2007); revealed that most Californian yields were only slightly affected by current climatic changes.

Other studies have employed a Ricardian model and used cross-sectional data to estimate the impact of climate change on agriculture (Mendelsohn *et al*.,, 1994; Reinsborough (2003), Weber and Hauer (2003), Schlenker *et al*.,, (2005); Lippert *et al*.,, (2009)). Mendelsohn *et al*.,, (1994); found that the USA's agriculture would potentially benefit from climate change. This study also forecasts a 1% increase in agricultural GDP under a CO2 doubling scenario. Similar results are found for Canadian agriculture by Weber and Hauer (2003). Reinsborough (2003), also showed that Canadian agriculture would be little affected by climate change in the next three decades. However, Schlenker *et al*.,, (2005); estimated negative impacts on agricultural receipts of approximately $5.3 billion annually for the USA. Finally, Lippert *et al.*, (2009); estimated some benefits arising from current climate change for German agriculture using district level data. However, their simulation results provided some indication of losses in the long-term when temperature and rainfall changes will become more severe. The consensus is that climate change is unlikely to affect developed countries' agriculture adversely over the remainder of this century.

Crop agriculture in developing countries is expected to be impacted greatly because of the sector's size, its climate sensitivity and the location of developing countries in the lower latitudes of the world (IPCC (2007); Mendelsohn (2009)). Recent studies have investigated the economic impact of climate change on agricultural production in developing countries (Lansigan *et al.*, (2000); Chang (2002); Gbetibouo and Hassan (2005); Kurukulasuriya and Ajwad (2007); Mariara and Karanja (2007); Haim *et al.*, (2008); Sanghi and Mendelsohn (2008); Deressa and Hassan (2009); Moula (2009); Wang *et al.*, (2009)). These studies used the Ricardian model, except for the studies by Lansigan *et al.*, (2000); Chang (2002) and Haim *et al.*, (2008); which used the production function approach.

Lansigan *et al.*, (2000); found that climate variability is most likely to affect Philippines rice production. Chang (2002) measured the likely effects of temperature and precipitation on 60 agricultural crops in Taiwan. This study revealed that climate change had important consequences for grain production and that farmers as a whole would suffer mildly from the rise in temperature, but an increase in rainfall could be devastating. Using a HadCM3 model, Haim *et al.,* (2008); predicted that Israeli wheat production would be severely affected from 2070 to 2100. However, irrigation and the application of nitrogen might reduce potential production losses.

Gbetibouo and Hassan (2005), employed district level data to assess the economic effects of climate change on a large variety of crops in South Africa. This study reveals that increasing temperature does not affect the net revenue of summer crops but is harmful to net revenue of winter crops. Nonetheless, irrigation has emerged as an effective adaptive option to arrest the negative effects of climate change. Employing district level data, Sanghi and Mendelsohn (2008), showed that climate change was likely to cause huge damage in Brazil and India by 2100.

Kurukulasuriya and Ajwad (2007), used farm level cross-sectional data to measure the impact of climate change on the profitability of smallholder farming in Sri Lanka. This study revealed that the arid zone of that country was expected to face the largest negative effects. However, wet areas are likely to benefit. Mariara and Karanja (2007) estimated the long-term impact of climate change on cereal production in Kenya. This study indicated that high summer temperatures lower net revenue while rising winter temperatures result in higher net crop revenue and this increases as rainfall increases. This study also mentions crop diversification, water conservation, irrigation and shading of crops as major adaptive methods. The main drawback of the study is that it did not address the long-term impact of climate change.

In Ethiopia, Deressa and Hassan (2009) determined that climate variables would affect crops significantly. Employing three climate scenario models, this study predicts that there will be a decline in net crop revenue in the years 2050 to 2100. However, adaptive measures will be able to reduce this revenue loss.

Another study by Molua (2009), assessed the impact of climate change on smallholder agriculture for Cameroon using nationwide field level data. In this study, crop revenue was found to be more sensitive to rainfall than temperature and that a higher temperature was detrimental to agricultural output. This study also identified some adaptive strategies, but it did not address the issue of farmers' adoption of these strategies.

Mendelsohn *et al.,* (2009); estimated the effects of climate on Mexican agriculture using farm-level survey data. They found farmland values were sensitive to climate change. More specifically, warmer temperatures were found to reduce land values. However, rain-fed farms will incur greater losses than irrigated farms.

Wang *et al.,* (2009) estimated the direct effects of rainfall and temperature on crop net revenue both for rain-fed and irrigated farms in China, and found that climate change was benign for irrigated farms but damaging for rain-fed farms. Furthermore, higher temperatures, on average, impact on crop revenue negatively while the average impact of higher rainfall is found to be positive. But the impacts are not unique across the regions of China.

Derbile and Kasei (2012) analyzed the susceptibility of millet and guinea corn productivity to heavy rainfall in north-eastern Ghana for the period 1987-2008. Comparing the Standard Precipitation Index (SPI) and yields of millet and guinea corn they showed that heavy rainfall caused lower crop productivity. This finding was also supported by farmers in in-depth interviews and focus group discussions. The weakness of this study is that it did not employ any econometric techniques to establish the cause and effect relationship between crop yield and rainfall.

Sarker *et al.,* (2012); confirmed in their findings that climate variables have had significant effects on rice yields in Bangladesh. In that study, they used time series data for the 1972 to 2009 period at an aggregate level to assess the relationship between climatic variables and rice yield. The overall findings reveal that three climate variables have substantial effects on the rice yield of three different crops. For the Aus model, average seasonal maximum temperature and total seasonal rainfall are statistically significant. Moreover, the average minimum temperature is found to adversely affect the Aus rice, although this effect is not significant. The overall Aus model is also found to be significant. For the Aman rice model, all three climate variables were statistically significant. However, the direction of the effects is not identical. Maximum temperatures and rainfall have positive effects on yields, whereas minimum temperatures affect yields negatively. Finally, both maximum and minimum temperatures have substantial effects on yields in the Boro rice model. However, the maximum temperature is found to be negatively related to Boro rice yields. One interesting finding is that rainfall is significant for the Aus and Aman rice; this result supports the fact that these varieties grow in rain-fed conditions: Aus partially andAman entirely. In terms of the F and R^2 values, the three models obtain statistical significance, and the results for overall goodness for fit are consistent with those of Lobell (2010). Therefore, two climate variables (namely, maximum and minimum temperatures) are foundto adversely affect Boro and Aman rice yields, respectively.

Amin *et al.,* (2015); revealed in their findings using national level time series data for the period of 1972 to 2010 that the effects of all the climate variables have had significant contributions tothe yield and cropping area of major food crops with distinct variation among them. Maximum temperature statistically significantly affected all the food crops' yield except Aus rice. Maximum temperature also insignificantly affected cropping area of all the crops. Minimum temperature insignificantly affected Aman rice but benefited other three crops 'yield and cropping area. Rainfall significantly benefitted cropping area of Aus rice, but significantly affected both yield and cropping area of Aman rice. Humidity statistically positively contributed to the yield of Aus and Aman rice but, statistically, negatively influenced the cropping area of Aus rice. Sunshine statistically significantly benefitted only Boro rice yield. Overall, maximum temperature adversely affected yield and cropping area of all the major food crops and rainfall severely affected Aman rice only. Cropping area of Aus rice was influenced greatly by the climatic variations compared to the yield of this crop. The most influential climatic variables for Aman rice production in Bangladesh were observed to be maximum temperature and rainfall. The findings confirmed that temperature (both maximum and minimum) and rainfall increases beyond their optimum requirement may be devastating to the yield and cropping area of Aman rice. In contrast, humidity positively influenced the yield and cropping area of Aman rice and this is justifiable because this crop grows in moist (humid) conditions during the monsoon months. The influence of maximum temperature was also observed to be detrimental for Boro rice and wheat. However, minimum temperature and sunshine exposed positive interrelation with Boro rice and wheat in respect of both yield and cropping area with statistically significant contribution to Boro rice yield only. Output further indicated that while humidity insignificantly favored the yield, it also insignificantly affected the cropping area of Boro rice. Similar to the effect of maximum temperature, the effect of excessive humidity was also shown to be undesirable for wheat cultivation, though this was not statistically significant. However, the empirical evidence established strong credibility that, overall, climate variability and change adversely impacted yield and cropping area of major food crops in Bangladesh.

Mamun *et al.*, (2015); assessed a relationship between the variables and the yield of three major rice crops (eg. Aus, Aman and Boro) and examined the trend of three main climatic variables series data for the 1972-2010 period. The results of used OLS illustrate that three climatic variables have significant effects on the yield of three different rice varieties. Increase in temperature and humidity and the irregularity and gradually decreases in rainfall are statistically significant. Temperature maintains a negative correlation with Boro and the rainfall with Aman and Boro. The climatic variables explain 23, 91 and 89% of variance in Aus, Aman and Boro respectively. The P value indicates significant linear relationship between climatic variables and yield.

Zakaria *et al.,* (2014); conducted a study for the effect of climate variables (rainfall, maximum temperature) on Aman rice production and mapping in Bangladesh. We used time series data for the last decade (2003-2012) for rainfall and maximum temperature from BMD (Bangladesh Meteorological Department) and BBS (Bangladesh Bureau of Statistics) respectively. From the combined trend of rainfall and maximum temperature intensity (determined by GIS mapping), geographically Bangladesh is divided into four regions such as; North-Eastern Region, South-Eastern Region, South-Western Region and North-Western Region, in this research. In North-Eastern regions Aman production is proportional to rainfall and maximum temperature does not prominent variables which indicate the rainfall effect the rice production prominently. In the South-Eastern region rainfall and maximum temperature both are in repetitive and show less effect on production which indicates other variables are prominent in this region. There may have salinity and soil condition effect on the Aman rice production of this region. In South-Western region the both variables are prominent in this region. We know that most the area of the region is situated under tidal effect which may be the cause of production decrease. In North-Western region Aman production increased though rainfall decreased so significantly also average maximum temperature was high in this region. It implies that maximum temperature is the dominant factor in this region which increases the Aman rice production significantly. So, effect of maximum temperature becoming the dominant variable continuously for Aman rice production in the last decade of Bangladesh.

From the above discussion, it is clear that there is no mentionable research on the trend analysis of climatic parameters in Bangladesh or the impact of climatic parameters on crop productivity. Therefore, the present study has the immense importance to overview the changing trend of climatic parameters in Bangladesh and probable correlation between climatic parameters and crop performances as well as it will enable the policy makers to take action plan for climate change issues.

Chapter 3

MATERIALS AND METHODS

3.1 Study sites

The information furnished in the study based on the different databases. The study conducted based on the secondary data on climatic parameters and crop production. Maximum temperature, minimum temperature, and rainfall are the three major climatic parameters selected for the study. Climatic data was collected from 35 meteorological stations present in Bangladesh for the time period of 1983 to 2013. The study was carried out dividing the all metrological station into 7 divisions. Among them, Dhaka, Faridpur, Madaripur, Mymensingh and Tangail stations were selected for Dhaka division; Chandpur, Comilla, Teknaf, Chittagong_ambagan, Chittagong_patenga, Cox's Bazar, Feni, Hatiya, Kutubdia, M.court, Rangamati, Sandwip, and Sitakunda were selected for Chittagong division; Barisal, Bhola, Khepupara and Patuakhali stations were selected for Barisal division; Chuadanga, Khulna, Mongla, Satkhira, and Jessore station were selected for Khulna division; Rajshahi, Bogra and Ishurdi stations were selected for Rajshahi division; Sylhet and Srimangal stations were selected for Sylhet division and Rangpur, Sayedpur and Dinajpur stations were selected for Rangpur division. Major crops selected for the study were rice (*Aus, Aman, and Boro*), wheat and potato. The selected time period for the cropping data was 1997 to 2013. Production, area and yield data of the selected crops of the selected time span were obtained.

3.2 Collection of climatic and agricultural data and data range

In this study, the selected time span for climatic parameters was 1983 to 2013. The required climatic data of all 35 metrological stations of the selected time span were procured from Bangladesh Metrological Department (BMD). Temperatures data included daily, monthly average and annual mean maximum and minimum temperatures for the period of January 1983 to December 2013. It also included the daily rainfall data of the same period. These data was entering and processing in the computer by using MS-Excel programs. Further calculations such as monthly or yearly average temperature or rainfall were done through this program. For Agricultural data, the selected time span was 1997-2013. National level yield data of major food crops (Aus rice, Aman rice, Boro rice, Wheat, and Potato) in the selected time span were collected from various version of 'Statistical Yearbook of Bangladesh' published by Bangladesh Bureau of statistics (BBS) and Department of Agricultural Extension (DAE). As yield data were found as fiscal year basis, such as 1990-1991, 1991-1992, 1992-1993 etc. So these data were converted to yearly data as 1990-1991 was considered as 1991. All the data converted into standard units (metric tons, mm, °C).

3.3 Maximum and minimum temperatures

The trend of maximum and minimum temperature assessed for the period of January 1983 to December 2013 by calculating the average monthly temperature. Monthly data collected from the each station computed to assess a division wise monthly average of the maximum and minimum temperature. These computed data were used to assess the changes in maximum and minimum temperatures. Then a trend analysis of monthly average maximum temperature and monthly average minimum temperature were conducted for each division. These trends were assessed for each 7 divisions. In each case, the linear trend was assessed for the selected period from the R^2 value of the fit. Nature (increasing or decreasing) and significance of trend were estimated from the correlation coefficient (r^2) value of the climatic parameters with time by using SPSS.

3.4 Seasonal variation

These year-wise monthly data were then transformed into seasonal data according to the growing period of the crops. Three major rice crops (namely, *Aus, Aman, and Boro*) constitute 100% of total rice production and grow in three different seasons. *Aus* is typically planted in March or April and harvested in June or July. *Aman* is generally sown in July or August and harvested in November or December. Finally, *Boro* is planted in December or January and harvested in May or June (Islam 1988, BBS, 2009). To some extent, this common rice crop calendar varies marginally in different places depending on soil texture and land elevation. These growing seasons are practically harmonized with three climatic seasons: the hot summer (March–May), monsoon season (July–October) and the winter season (December–February). Further, the geographical distribution of all three crops is constant over time. Climate has always played a vital role in rice production. According to BRRI (1991), *Aus* rice requires supplementary irrigation during the initial stage of its growing season; in contrast, *Aman* is almost completely rain-fed rice that grows in the months of monsoons, although it requires supplementary irrigation during planting and sometimes in the flowering stage depending on the availability of rainfall. In contrast, *Boro* rice grows in the dry winter and the hot summer; thus, it is completely irrigated (Mahmood, 1997). Only 5% of *Aman* rice and 8% of Aus rice are irrigated (Ahmed, 2001).

The growing seasons for rice according to Sarker *et al.,* (2012) listed below:

- *Aus* Growing Season (March-August): This season is characterized by high temperature and evaporation of pre-monsoon summer with occasional thunderstorms and the intensive rainfall of the early months of monsoon.
- *Aman* Growing Season (June-November): Production of this season is dominated by the regular intensive rainfall of monsoon, highly humid weather and cloudiness.
- *Boro* Growing Season (December-may): This season is depicted as the driest and sunniest period of the year consists of the months of winter and pre-monsoon summer.

The cropping season for wheat and potato were counted from October to March, as both have the growing period in *Robi* season.

3.5 Rainfall pattern

In this study, changes in rainfall pattern have been assessed by analyzing changes in total rainfall during four season i.e.

- Pre-Monsoon (March-May),
- Monsoon (June-September),
- Post-Monsoon (October-November) and
- Winter (December-February)

The analysis was made separately for each division with the data of each weather station likewise the calculation of temperature data. Division wise monthly average rainfall was computed for the trend analysis of the rainfall. For the facility of the further calculation, monthly average rainfall data are also transformed into seasonal data.

3.6 Investigation on the impact of climatic parameter on crop production

An investigation was taken to identify the probable linkage between the climate variability and change and trend of crop production, so the impact on production can be revealed. For this part of the analysis, the production data of major crops i.e. *Aus* rice, *Aman* rice, *Boro* rice, wheat and potato, the major crops of Bangladesh was used to recognize the trend of production of these crops in response to the highest maximum and lowest minimum and amount of seasonal rainfall for the period of 1997 to 2013. Then, an attempt was taken to investigate any possible correlation between the trend of climate change and trend of change in the crop production, to realize any types of probable impacts of climate change on crop production during the specified period.

3.7 Data analysis

After the collection of all the data, the information was processed and compiled by MS Excel 2007 and SPSS-20 software. Then further calculations were done through this software. The analysis of trends for temperature, rainfall, was carried out using the Statistical Package for Social Sciences (SPSS) software.

Correlation analyses were used to test the relationship among the variables which were also done through this software.

Chapter 4

RESULTS

4.1. Trend of annual maximum and minimum temperature

Bangladesh has a tropical monsoon-type climate, with a hot and rainy summer and a dry winter. Though the regional variations are minor, the results of the study were categorized into 7 divisional regions for the benefit of better understanding. It was found in the study that in the selected time period (1983-2013), surface air temperature throughout the Bangladesh experienced an increasing trend for almost every month. There is a prominent increase of summer temperature and decrease in the winter temperature. This situation indicates summer months became hotter and winter became cooler. The study showed that the month of July and September had the increasing trend for all the division. Among the divisions, Chittagong division experienced a significant increase of temperature. Almost every month showed an increasing trend for both maximum and minimum temperature. On the other hand, the northern part of the country experienced fluctuation of temperature. The Rajshahi and Rangpur division showed a significant decrease in January as well as an increase in the months from May to September. Description of temperature trend for each division listed below:

4.1.1 Trend of temperature in Dhaka division

Analysis showed that Dhaka division experienced a fluctuation in the temperature trend. Changing of maximum and minimum temperature trend of different months in Dhaka division was showed in Figure 1 and 2. The month of January observed a statistically significant decreasing trend of maximum temperature along with a decreasing minimum temperature trend which was not statistically significant. A continuous increase of maximum and minimum temperature found in the month of July, August, and September and these increasing trends were statistically significant. The correlation coefficient values for those months were 0.534 & 0.609; 0.417 & 0.392 and 0.573 & 0.411, respectively. For the month of May, there was an increasing trend observed which was statistically significant. Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 1. The overall analysis indicated that the monsoon had a significant increase of temperature along with decreasing temperature in winter.

Table 1. Correlation results for maximum and minimum temperature with time in Dhaka

Months	Climatic parameter	Correlation coefficient for time	R^2
January	Maximum Temperature	-0.447*	0.167
	Minimum Temperature	-0.124	0.021
February	Maximum Temperature	0.180	0.016
	Minimum Temperature	0.265	0.100
March	Maximum Temperature	-0.063	0.002
	Minimum Temperature	0.276	0.055
April	Maximum Temperature	-0.159	0.030
	Minimum Temperature	0.173	0.052
May	Maximum Temperature	0.319	0.098
	Minimum Temperature	0.411*	0.186
June	Maximum Temperature	0.293	0.109
	Minimum Temperature	0.227	0.046
July	Maximum Temperature	0.534**	0.391
	Minimum Temperature	0.609**	0.371
August	Maximum Temperature	0.417*	0.158
	Minimum Temperature	0.392*	.0183
September	Maximum Temperature	0.573*	0.261
	Minimum Temperature	0.411*	0.190
October	Maximum Temperature	0.192	0.033
	Minimum Temperature	0.205	0.022
November	Maximum Temperature	-0.008	0.00
	Minimum Temperature	-0.159	0.012
December	Maximum Temperature	-0.334	0.090
	Minimum Temperature	0.089	0.014

** and * Represetns 0.01% and 0.05% level of significance

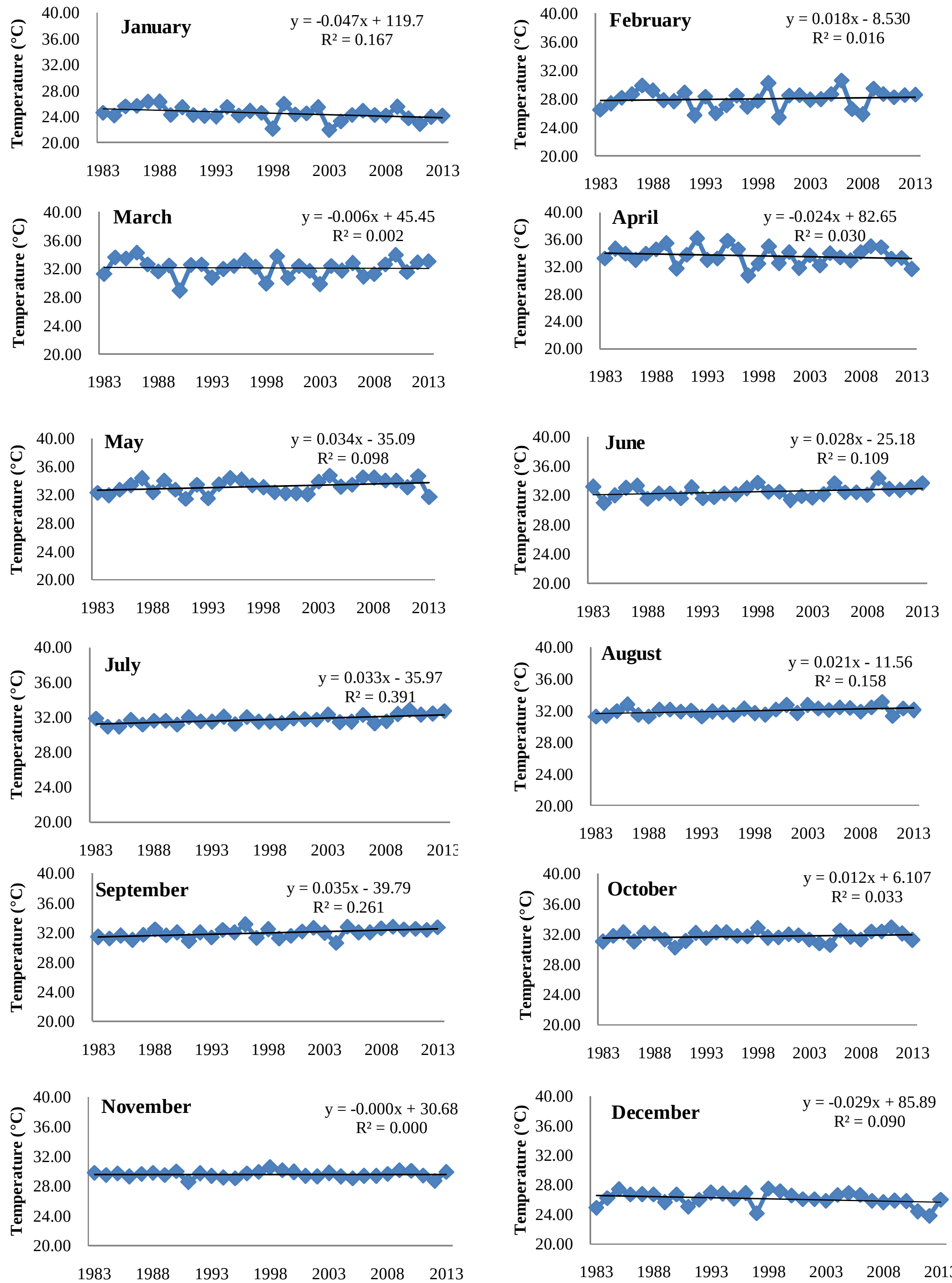

Figure 1. Trend of average maximum temperature (°C) of different months in Dhaka (1983-2013)

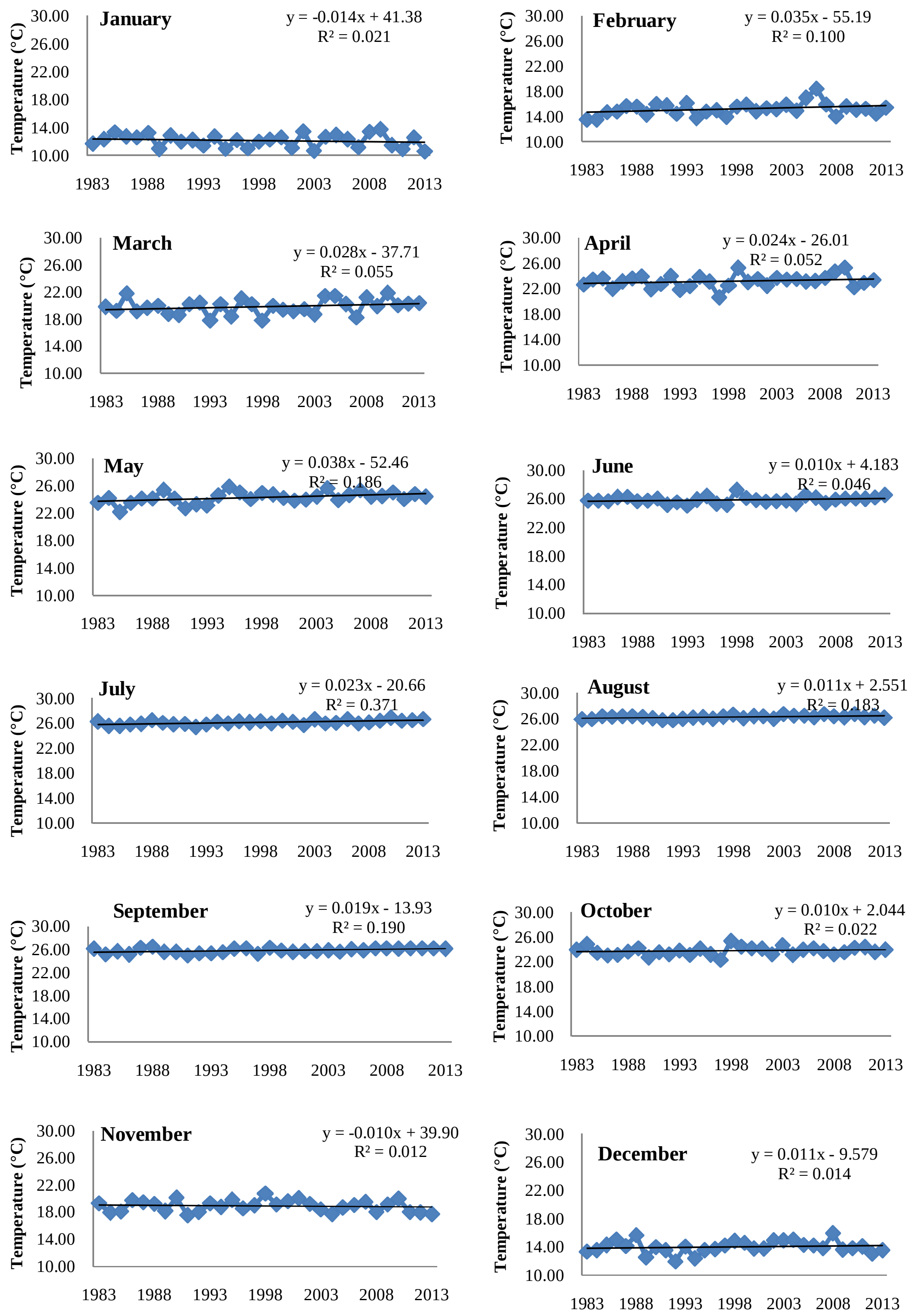

Figure 2. Trend of average minimum temperature (°C) of different months in Dhaka (1983-2013).

4.1.2 Trend of temperature in Chittagong division

Chittagong division experienced a huge increase of temperature for all the months during the selected time period. Changing of maximum and minimum temperature trend of different months in Chittagong division was showed in Figure 3 and 4. There was a significant increase observed both for the cooler and hotter months. Maximum temperature showed an increasing trend for the winter months October, November, and February which were statistically significant. The correlation coefficient values for those months were 0.483, 0.529, and 0.512 respectively. Throughout the rainy season, the maximum temperature also showed the increasing trend and the correlation coefficient values for those months were very high i.e. June 0.490, July 0.642, August 0.452, and September 0.613 which were statistically significant. Summer was very hot for those time period as the maximum temperature exhibited an increased trend. For the months of April, May and June these trends had a significant increase with a correlation coefficient value of 0.494, 0.445, and 0.490, respectively. There found in the study an overall increase in the minimum temperature, but most of them were not statistically significant. The monsoon season exhibited a significant increase in the minimum temperature in the following months July, August, and September which had the correlation coefficient values of 0.579, 0.525, and 0.522. Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 2.

Table 2. Correlation results for maximum and minimum temperature with time in Chittagong

Months	Climatic parameter	Correlation co efficient for time	R^2
January	Maximum Temperature	0.158	0.030
	Minimum Temperature	0.013	0.006
February	Maximum Temperature	0.512**	0.238
	Minimum Temperature	0.064	0.011
March	Maximum Temperature	0.326	0.105
	Minimum Temperature	0.150	0.017
April	Maximum Temperature	0.494**	0.191
	Minimum Temperature	0.157	0.032
May	Maximum Temperature	0.445*	0.163
	Minimum Temperature	0.304	0.063
June	Maximum Temperature	0.490**	0.243
	Minimum Temperature	0.354	0.087
July	Maximum Temperature	0.642**	0.410
	Minimum Temperature	0.579**	0.392
August	Maximum Temperature	0.452*	0.218
	Minimum Temperature	0.525**	0.321
September	Maximum Temperature	0.613**	0.358
	Minimum Temperature	0.522**	0.283
October	Maximum Temperature	0.483**	0.187
	Minimum Temperature	0.321	0.112
November	Maximum Temperature	0.529**	0.226
	Minimum Temperature	0.037	0.001
December	Maximum Temperature	0.111	0.025
	Minimum Temperature	0.138	0.029

** and * Represetns 0.01% and 0.05% level of significance

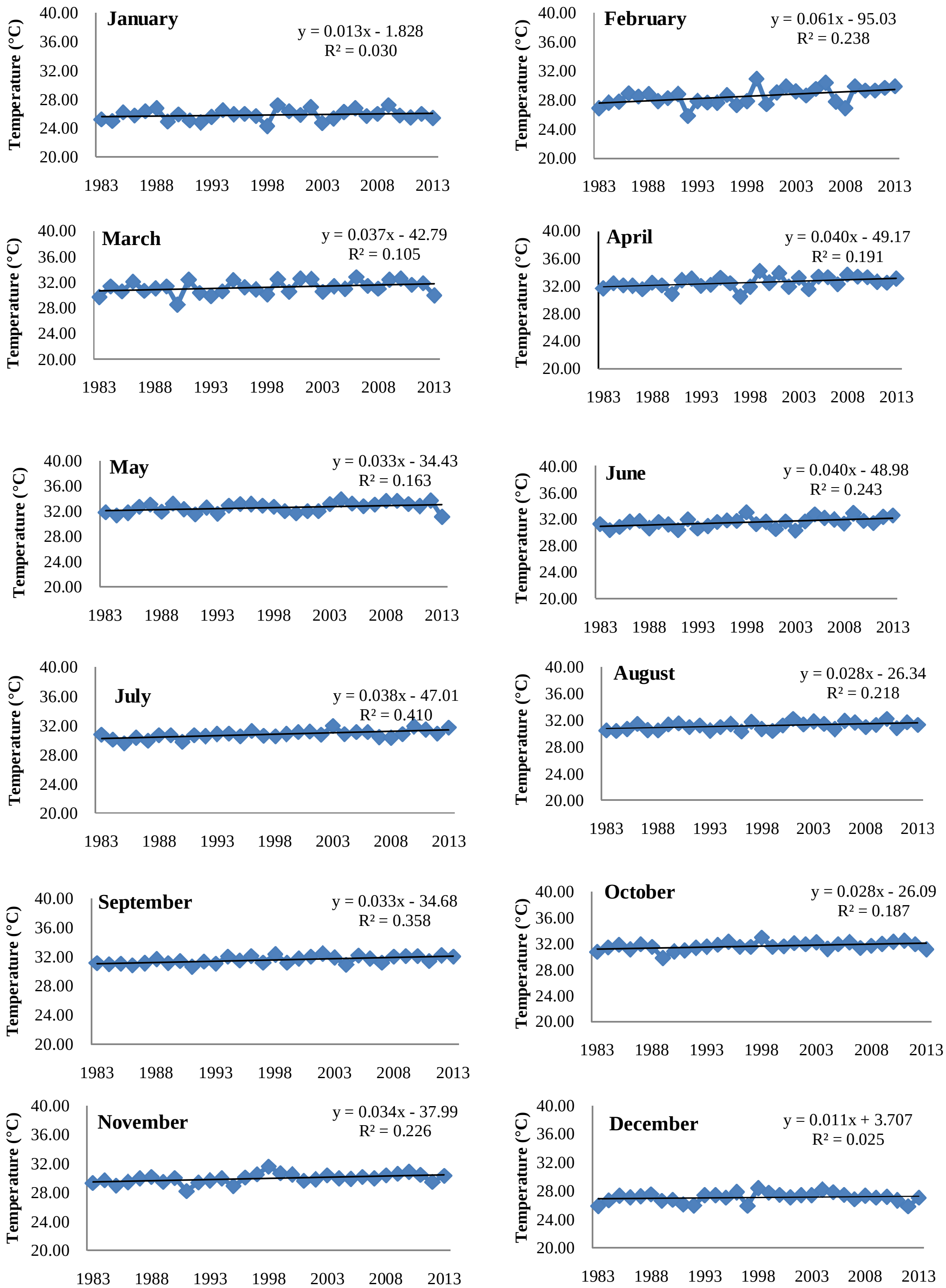

Figure 3. Trend of average maximum temperature (°C) of different months in Chittagong (1983-2013).

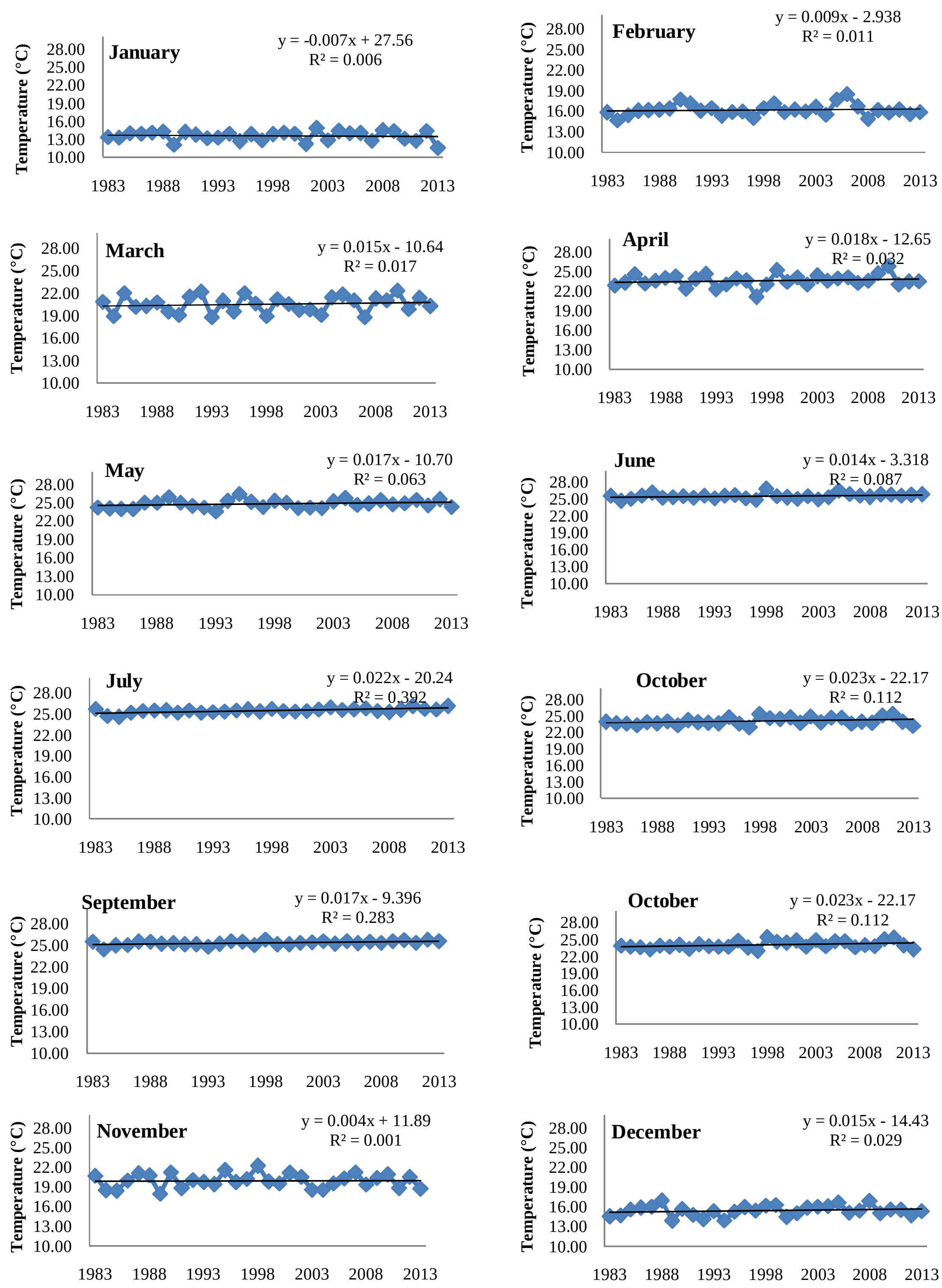

Figure 4. Trend of average minimum temperature (°C) of different months in Chittagong (1983-2013).

4.1.3 Trend of temperature in Khulna division

Khulna Division found a little significant change in the temperature trend. Changing of maximum and minimum temperature trend of different months in Khulna division was showed in Figure 5 and 6. The winter month's temperatures, both maximum and minimum had a negative correlation with time which indicates cooler winter. In them in November the maximum temperature observed to have a significant decrease in temperature and the correlation coefficient value was -0.416. Among the rainy season the month of July showed the increasing trend for both maximum and minimum temperature and the correlation coefficient values were 0.589 and 0.490, respectively. Minimum temperature exhibited a significant increase in the month of September which had correlation coefficient value of 0.487.

Table 3. Correlation results for maximum and minimum temperature with time in Khulna

Months	Climatic parameter	Correlation co efficient for time	R^2
January	Maximum Temperature	-0.346	0.126
	Minimum Temperature	-0.122	0.003
February	Maximum Temperature	0.077	0.018
	Minimum Temperature	0.118	0.035
March	Maximum Temperature	-0.029	0.000
	Minimum Temperature	0.054	0.000
April	Maximum Temperature	-0.125	0.006
	Minimum Temperature	0.205	0.044
May	Maximum Temperature	0.293	0.091
	Minimum Temperature	0.261	0.093
June	Maximum Temperature	0.315	0.129
	Minimum Temperature	0.348	0.151
July	Maximum Temperature	0.589**	0.334
	Minimum Temperature	0.490**	0.258
August	Maximum Temperature	0.338	0.099
	Minimum Temperature	0.346	0.144
September	Maximum Temperature	0.347	0.135
	Minimum Temperature	0.487**	0.232
October	Maximum Temperature	0.070	0.00
	Minimum Temperature	0.210	0.040
November	Maximum Temperature	-0.089	0.005
	Minimum Temperature	0.080	0.004
December	Maximum Temperature	-0.416*	0.163
	Minimum Temperature	0.207	0.061

** and * Represetns 0.01% and 0.05% level of significance

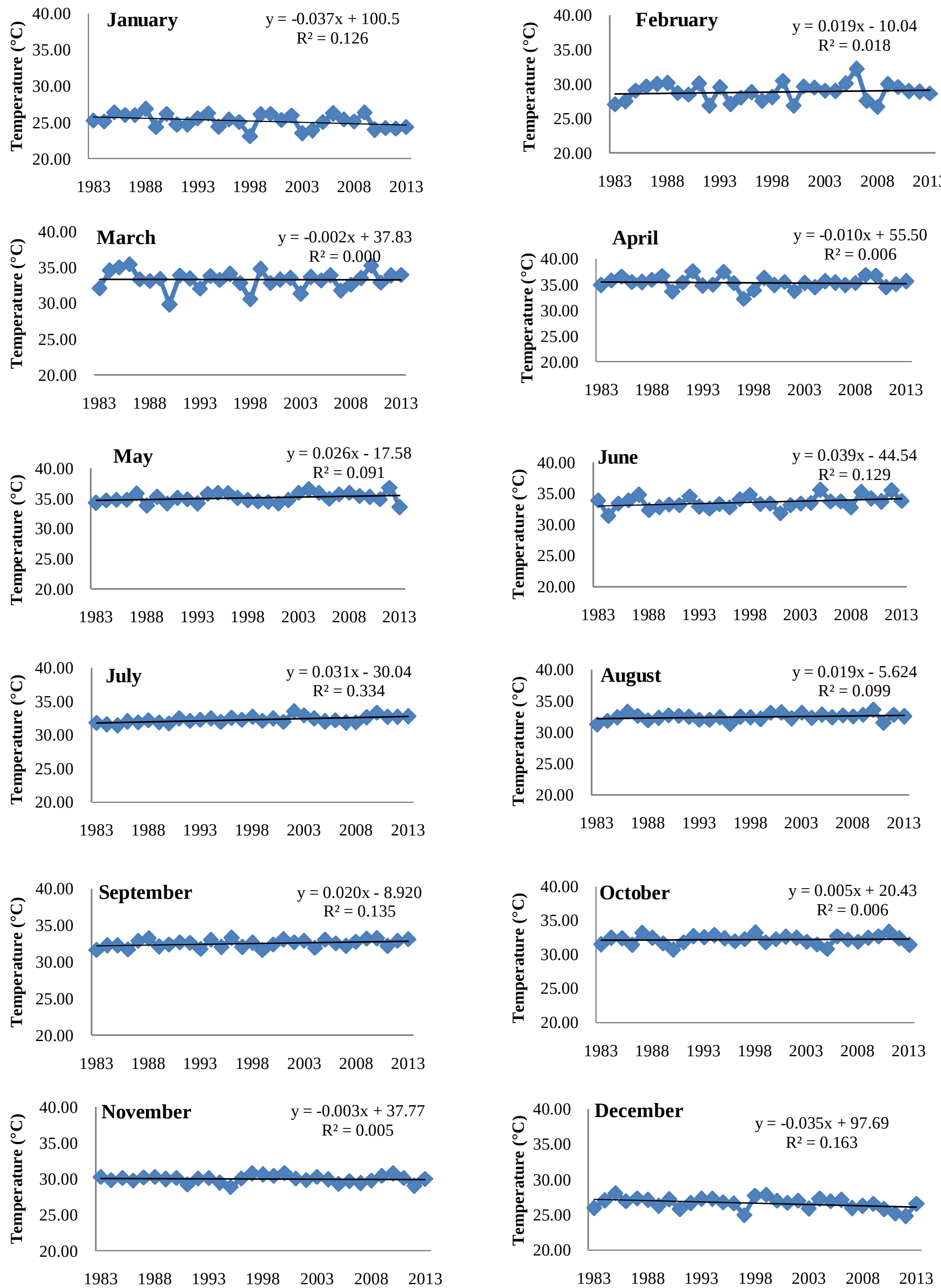

Figure 5. Trend of average maximum temperature (°C) of different months in Khulna (1983-2013).

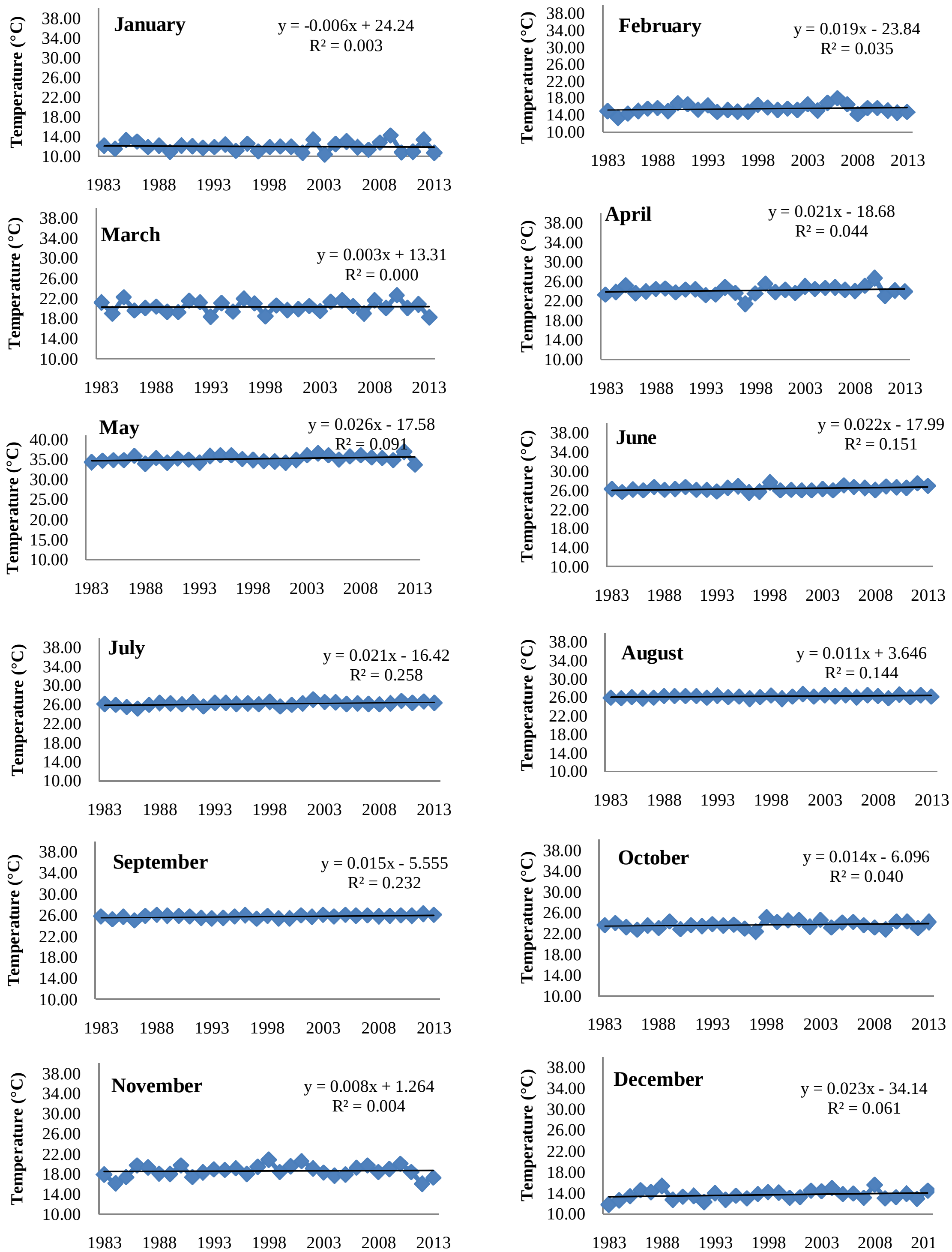

Figure 6. Trend of average minimum temperature (°C) of different months in Khulna (1983-2013).

4.1.4 Trend of temperature in Barisal Division

Barisal division observed to have a hot summer and rainy season whereas winter had a fraction less than the average temperature. Changing of maximum and minimum temperature trend of different months in Barisal division was showed in Figure 7 and 8. During winter, November, December, January and February the minimum temperature showed a negative correlation with time but these were not statistically significant and for the maximum temperature negative trend was found for the month of January and December but this trend also were not statistically significant. In the summer season, the study found an increasing trend for maximum temperature in the month of April, May and June having the correlation coefficient of 0.359, 0.469, and 0.397, respectively which were statistically significant. But during the rainy season July, August, and September exhibited increasing trend for both maximum and minimum temperature. The correlation coefficient values for maximum and minimum temperature for those months was 0.575 and 0.592; 0.478 and 0.574; 0.466 and 0.441, respectively**.** Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 4.

Table 4. Correlation results for maximum and minimum temperature with time of Barisal

Months	Climatic parameter	Correlation co efficient for time	R^2
January	Maximum Temperature	-0.070	0.008
	Minimum Temperature	-0.131	0.050
February	Maximum Temperature	0.394	0.120
	Minimum Temperature	-0.081	0.001
March	Maximum Temperature	0.244	0.066
	Minimum Temperature	0.020	0.000
April	Maximum Temperature	0.359*	0.102
	Minimum Temperature	0.126	0.035
May	Maximum Temperature	0.469**	0.209
	Minimum Temperature	0.295	0.077
June	Maximum Temperature	0.397*	0.159
	Minimum Temperature	0.292	0.117
July	Maximum Temperature	0.575**	0.379
	Minimum Temperature	0.592**	0.408
August	Maximum Temperature	0.478**	0.214
	Minimum Temperature	0.574**	0.284
September	Maximum Temperature	0.446*	0.174
	Minimum Temperature	0.441*	0.249
October	Maximum Temperature	0.258	0.088
	Minimum Temperature	0.228	0.060
November	Maximum Temperature	0.207	0.071
	Minimum Temperature	-0.007	0.00
December	Maximum Temperature	-0.080	0.010
	Minimum Temperature	-0.024	0.000

* * and * represents 0.01% and 0.05% level of significance

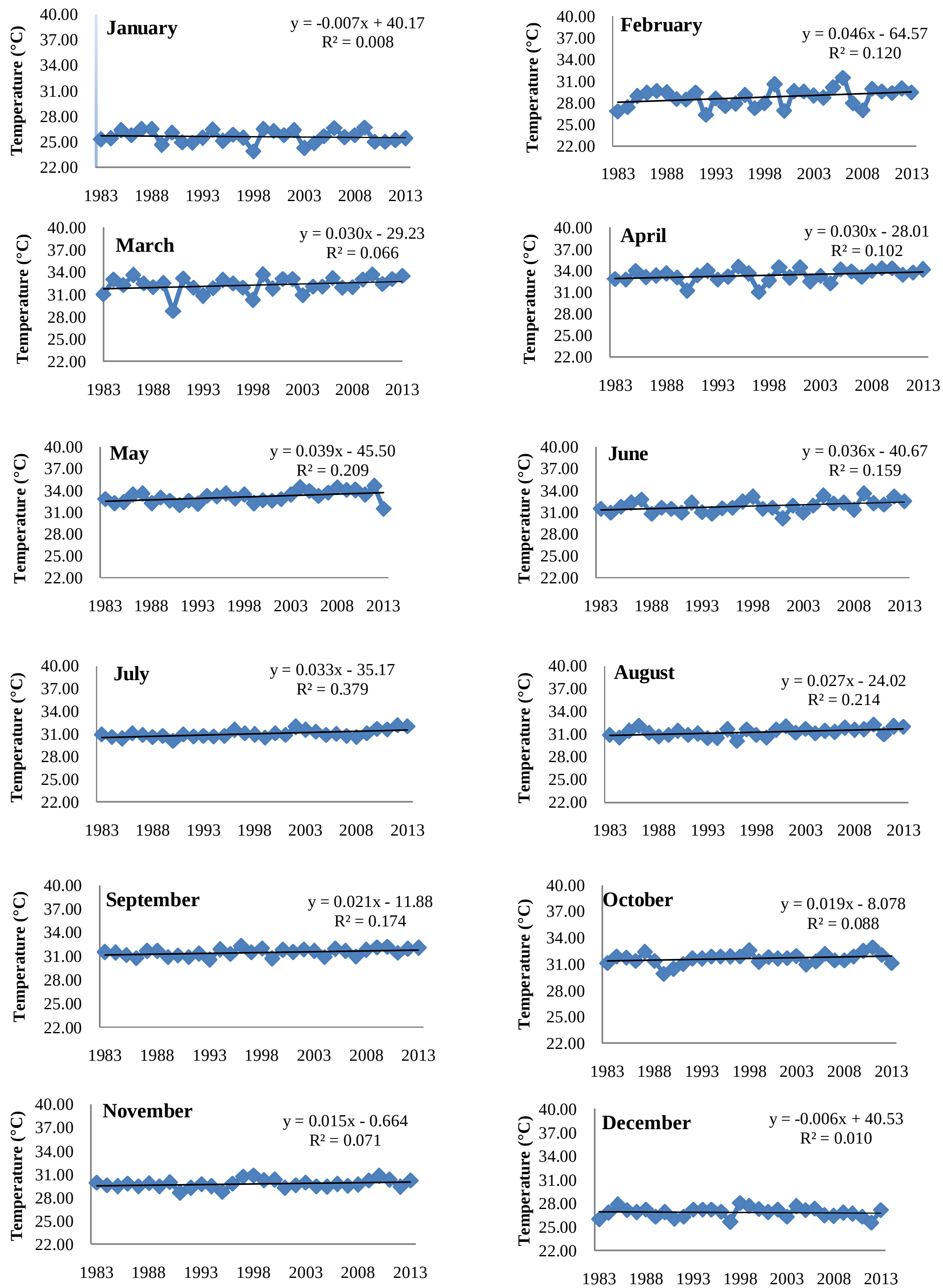

Figure 7. Trend of average maximum temperature (°C) of different month in Barisal (1983-2013).

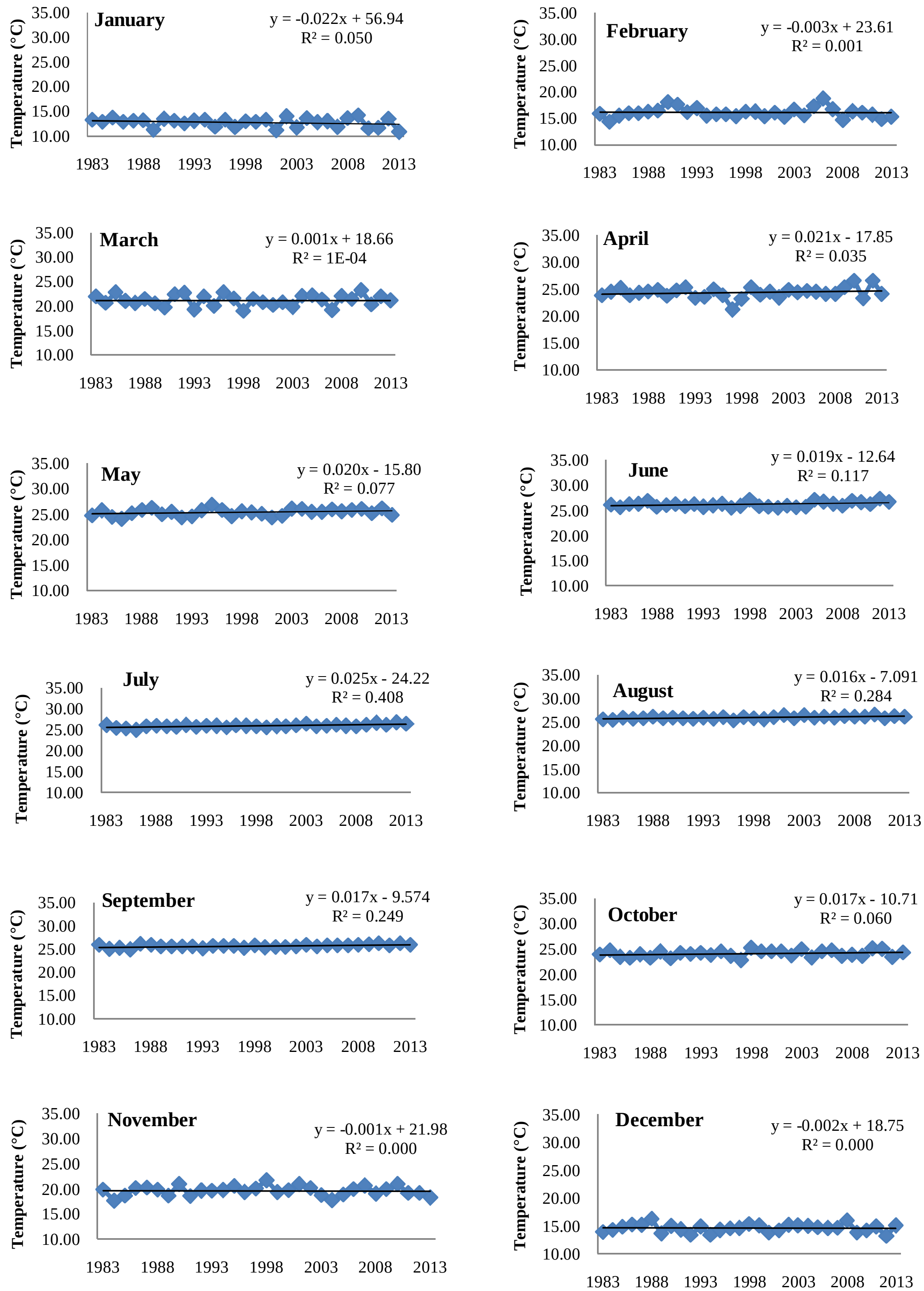

Figure 8. Trend of average minimum temperature (°C) of different month in Barisal (1983-2013).

4.1.5 Trend of temperature in Rajshahi Division

The temperature trend in this division found quite fluctuating where winter became cooler; and summer and the rainy season became hotter. Changing of maximum and minimum temperature trend of different months in Rajshahi division was showed in Figure 9 and 10. Maximum temperature of January, March, April, November and December exhibited a decreasing trend among them January and December had a statistically significant trend having the correlation coefficient value of -0.462 and -0.370. Minimum temperature found to have significant increasing trend during summer months. April, May and June showed a huge increasing trend having the correlation coefficient values of 0.459, 0.470 and 0.387, respectively which were statistically significant. July, August and September month exhibited increasing trend for both of maximum and minimum temperature and the correlation coefficient values were 0.640 and 0.694; 0433 and 0.623; 0.574 and 0.520, respectively. Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 5.

Table 5. Correlation results for maximum and minimum with time for Rajshahi

Months	Climatic parameter	Correlation co efficient for time	R^2
January	Maximum Temperature	-0.462**	0.224
	Minimum Temperature	-0.077	0.010
February	Maximum Temperature	0.185	0.026
	Minimum Temperature	0.323	0.124
March	Maximum Temperature	-0.011	0.00
	Minimum Temperature	0.423*	0.178
April	Maximum Temperature	-0.190	0.040
	Minimum Temperature	0.459**	0.201
May	Maximum Temperature	0.247	0.067
	Minimum Temperature	0.470**	0.217
June	Maximum Temperature	0.234	0.066
	Minimum Temperature	0.387*	0.140
July	Maximum Temperature	0.640**	0.443
	Minimum Temperature	0.694**	0.486
August	Maximum Temperature	0.433**	0.231
	Minimum Temperature	0.623**	0.391
September	Maximum Temperature	0.574**	0.313
	Minimum Temperature	0.520**	0.302
October	Maximum Temperature	0.205	0.048
	Minimum Temperature	0.137	0.028
November	Maximum Temperature	-0.139	0.055
	Minimum Temperature	0.112	0.011
December	Maximum Temperature	-0.370*	0.159
	Minimum Temperature	0.161	0.034

** and * Represetns 0.01% and 0.05% level of significance

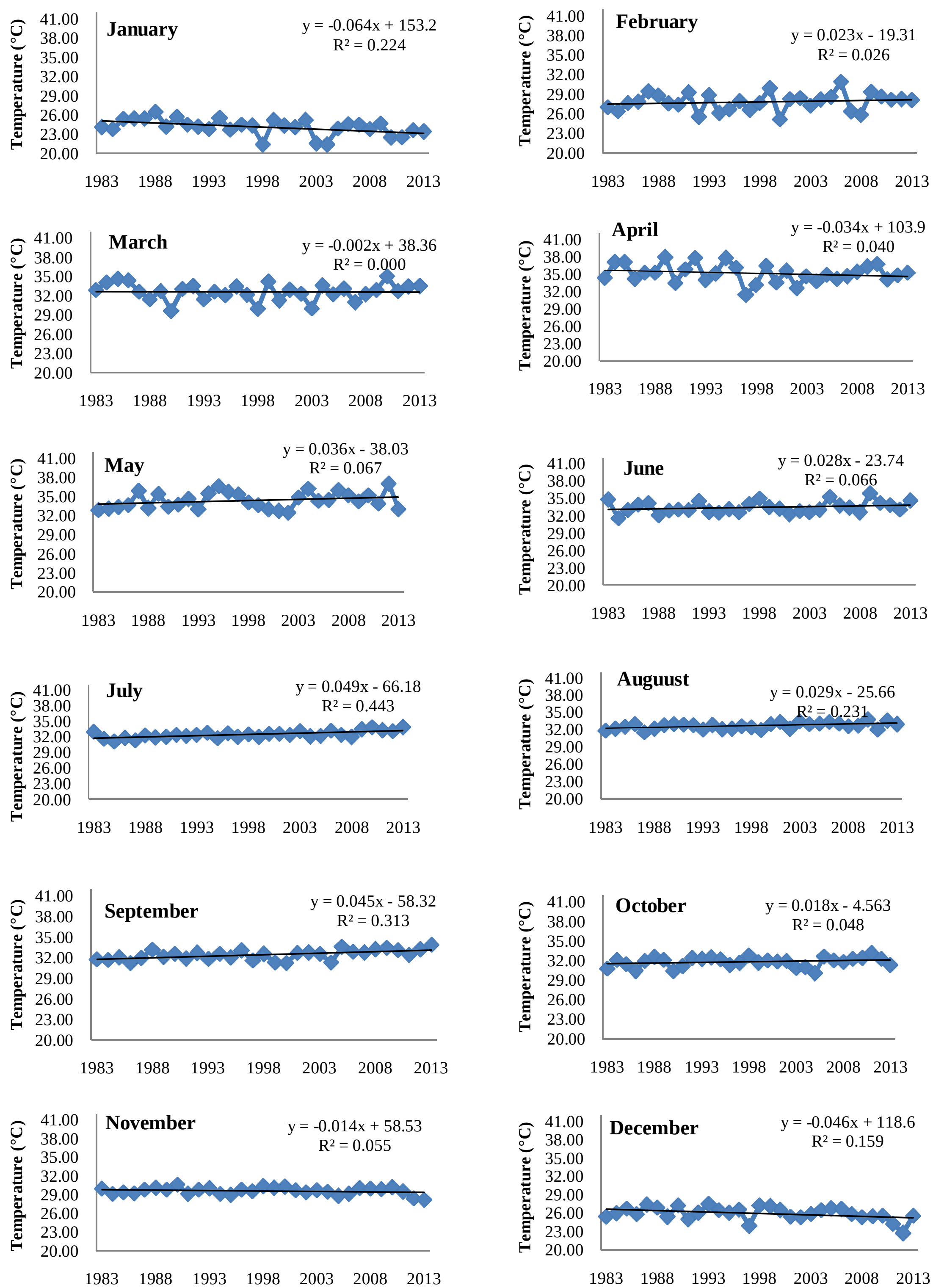

Figure 9. Trend of average maximum temperature (°C) of different months in Rajshahi (1983-2013).

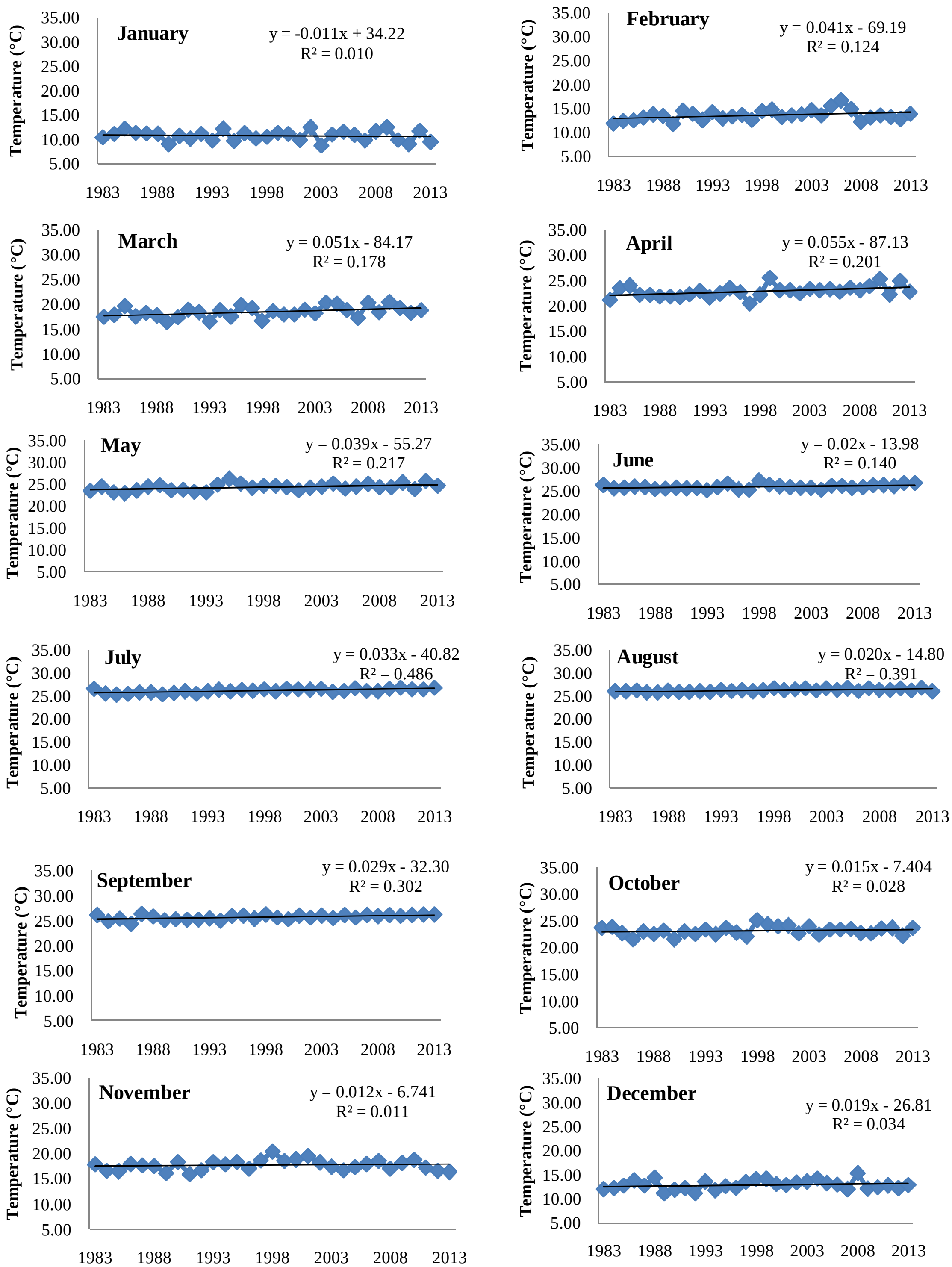

Figure 10. Trend of average minimum temperature (°C) of different month in Rajshahi (1983-2013).

4.1.6 Trend of temperature in Rangpur division

In Rangpur division, the minimum temperature observed to have a significant change. Changing of maximum and minimum temperature trend of different months in Rangpur division was showed in Figure 11 and 12. Minimum temperature showed a significant increase for all the season (Figure 12). In winter season February showed a significant increase in the minimum temperature and the correlation coefficient for this trend was 0.459. November exhibited increasing trend which was statistically significant. There observed an increasing trend for both maximum and minimum temperature during the rainy season. The correlation coefficient for maximum and minimum temperature for the month of July, August and September were 0.530 & 0.576; 0.333 & 0.501 and 0.783 & 0.643, respectively. During summer period March, April, and May observed to have increasing trend for minimum temperature. The correlation coefficient was 0.459, 0.441 and 0.451 which were statistically significant**.** Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 6.

Table 6. Correlation results for maximum and minimum temperature with time in Rangpur

Months	Climatic parameter	Correlation co efficient for time	R^2
January	Maximum Temperature	-0.375*	0.124
	Minimum Temperature	0.048	0.006
February	Maximum Temperature	0.218	0.039
	Minimum Temperature	0.459**	0.237
March	Maximum Temperature	-0.092	0.007
	Minimum Temperature	0.441*	0.203
April	Maximum Temperature	-0.302	0.106
	Minimum Temperature	0.440*	0.198
May	Maximum Temperature	0.304	0.100
	Minimum Temperature	0.451*	0.167
June	Maximum Temperature	0.118	0.04
	Minimum Temperature	0.064	0.012
July	Maximum Temperature	0.530**	0.304
	Minimum Temperature	0.576*	0.386
August	Maximum Temperature	0.333	0.14
	Minimum Temperature	0.501**	0.261
September	Maximum Temperature	0.783**	0.603
	Minimum Temperature	0.643**	0.453
October	Maximum Temperature	0.313	0.092
	Minimum Temperature	0.260	0.077
November	Maximum Temperature	0.366*	0.064
	Minimum Temperature	0.243	0.059
December	Maximum Temperature	-0.063	0.007
	Minimum Temperature	0.219	0.080

** and * represents 0.01% and 0.05% level of significance

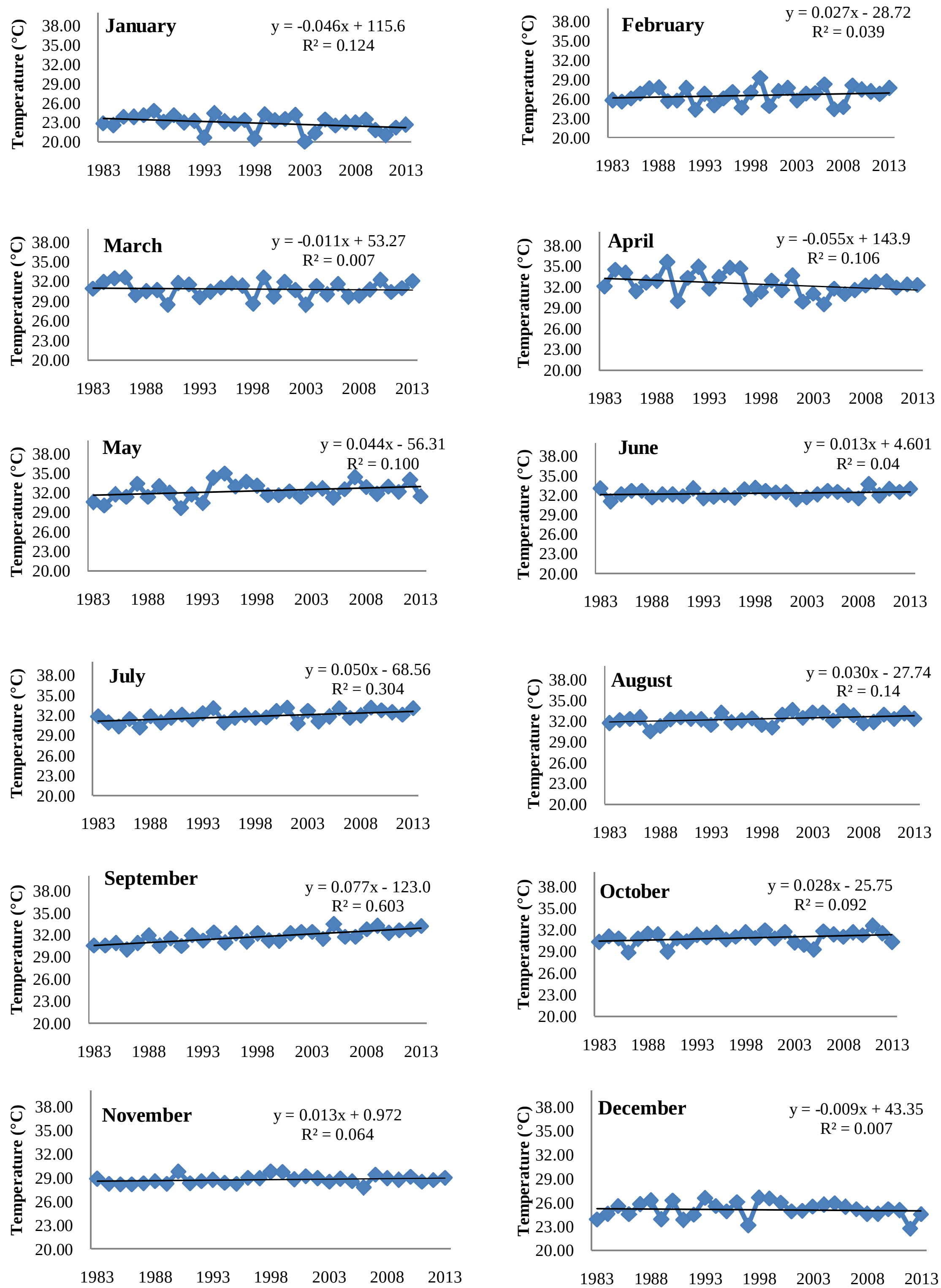

Figure 11. Trend of average maximum temperature (°C) of different month in Rangpur (1983-2013).

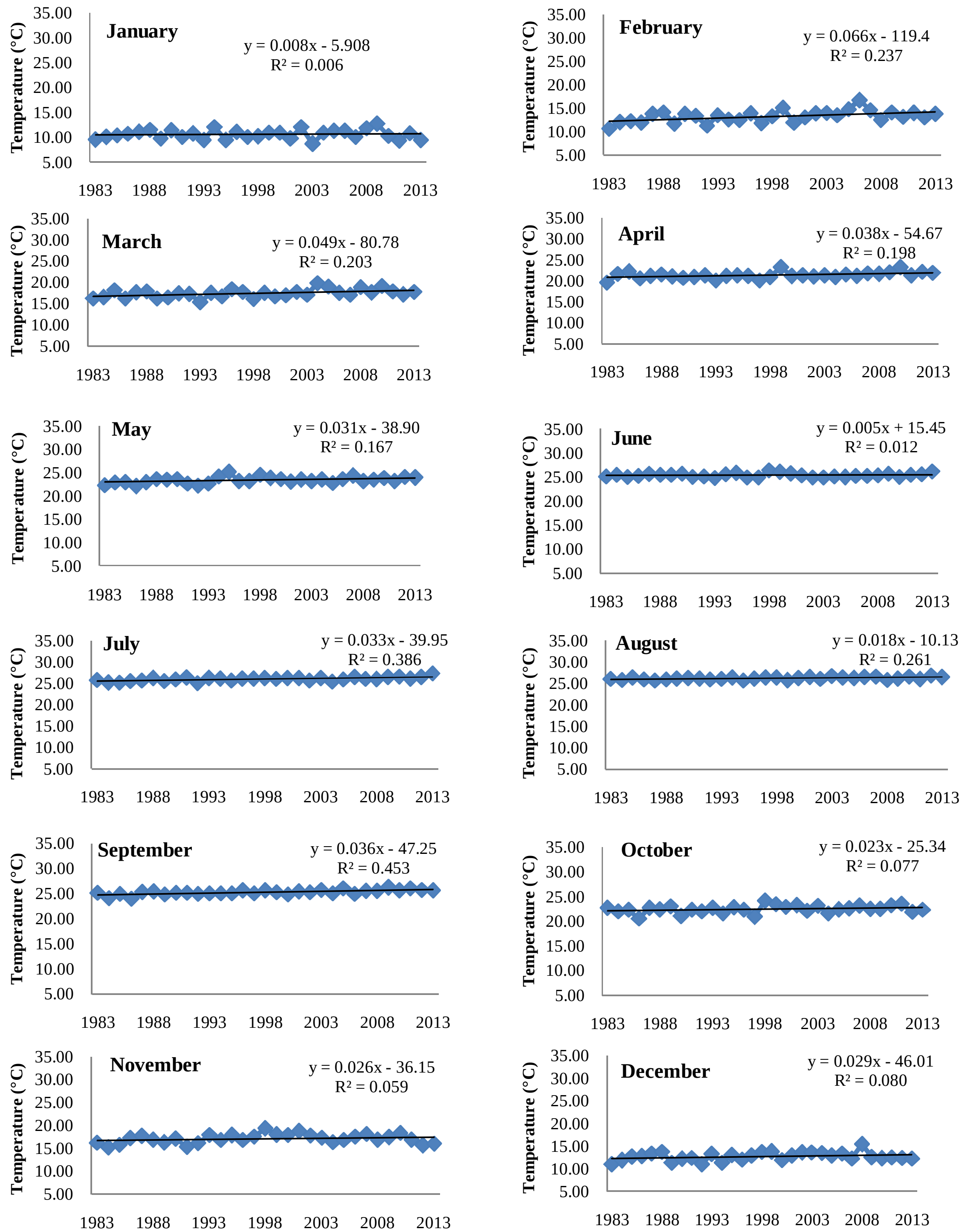

Figure 12. Trend of average minimum temperature (°C) of different month in Rangpur (1983-2013).

4.1.7 Trend of temperature in Sylhet division

Sylhet division observed to have a hot summer and rainy season along with a warm winter. Changing of maximum and minimum temperature trend of different months in Sylhet division was showed in Figure 13 and 14. Maximum temperature in the winter season showed an increasing temperature trend. Correlation coefficient values for the following winter months February, October and November were 0.464, 0.425, and 0.362, respectively which were statistically significant. This increasing trend indicated a warm winter. There were no significant increases or decreases observed during the hot summer months except for the March which had a statistically significant increase in maximum temperature having a correlation coefficient of 0.364. But during the rainy season July, August and September exhibited increasing trend for both maximum and minimum temperature. The correlation coefficient values for maximum and minimum temperature for those months were 0.491 and 0.780; 0.190 and 0.597; 0.578 and 0.725, respectively**.** Correlation coefficient and R^2 values of different months for the selected time period are listed in Table 7.

Table 7. Correlation results for maximum and minimum temperature with time in Sylhet

Months	Climatic parameter	Correlation coefficient for time	R^2
January	Maximum Temperature	0.028	0.00
	Minimum Temperature	-0.163	0.025
February	Maximum Temperature	0.464**	0.162
	Minimum Temperature	0.166	0.042
March	Maximum Temperature	0.364*	0.143
	Minimum Temperature	0.248	0.036
April	Maximum Temperature	0.134	0.016
	Minimum Temperature	0.231	0.056
May	Maximum Temperature	0.243	0.074
	Minimum Temperature	0.316	0.104
June	Maximum Temperature	0.155	0.053
	Minimum Temperature	0.088	0.027
July	Maximum Temperature	0.491**	0.225
	Minimum Temperature	0.780**	0.557
August	Maximum Temperature	0.190	0.076
	Minimum Temperature	0.597**	0.309
September	Maximum Temperature	0.578**	0.341
	Minimum Temperature	0.725**	0.422
October	Maximum Temperature	0.425*	0.217
	Minimum Temperature	0.253	0.063
November	Maximum Temperature	0.362*	0.151
	Minimum Temperature	-0.009	0.003
December	Maximum Temperature	0.261	0.066
	Minimum Temperature	0.235	0.087

** and * represents 0.01% and 0.05% level of significance

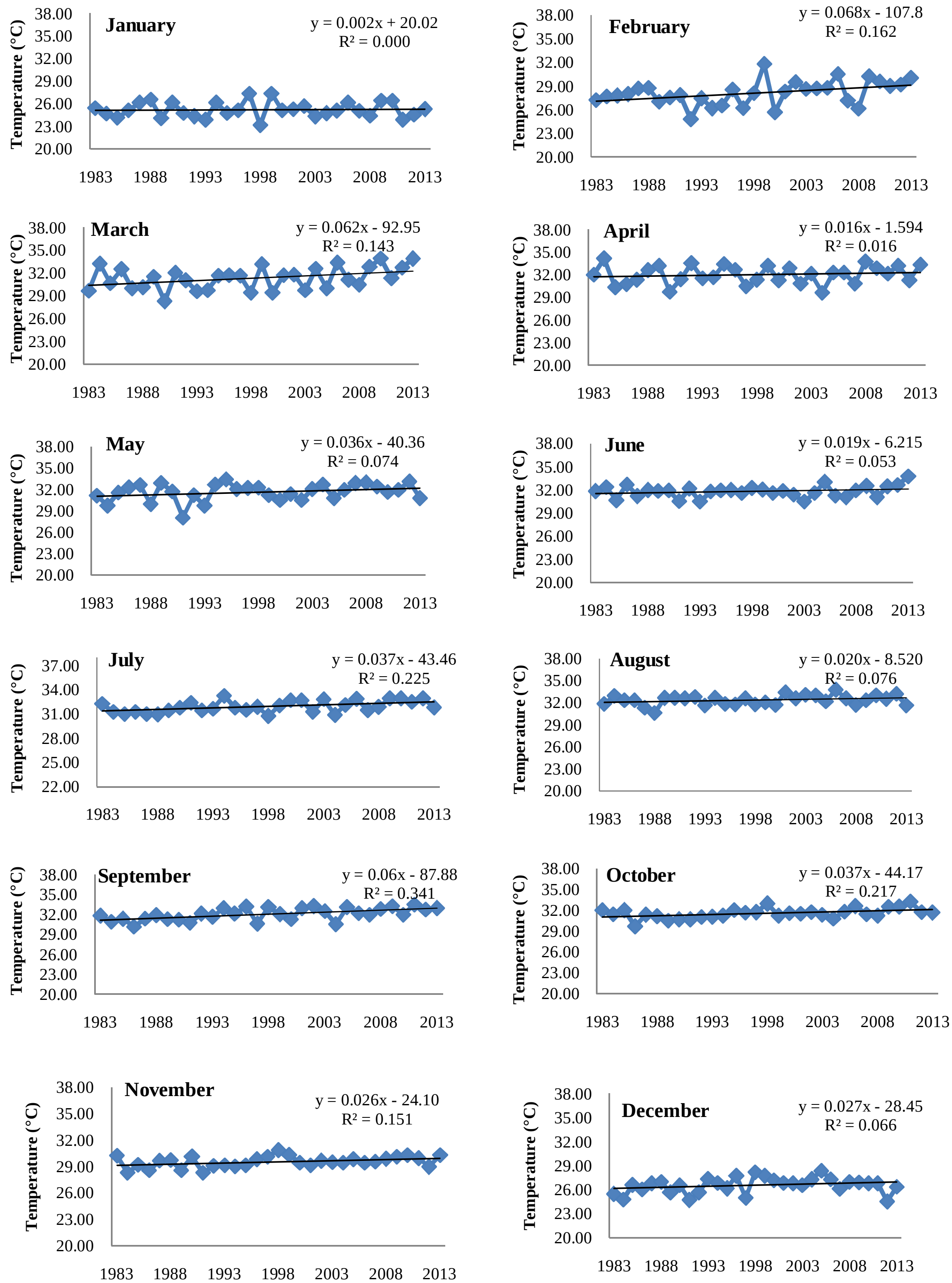

Figure 13. Trend of average maximum temperature (°C) of different month in Sylhet (1983-2013).

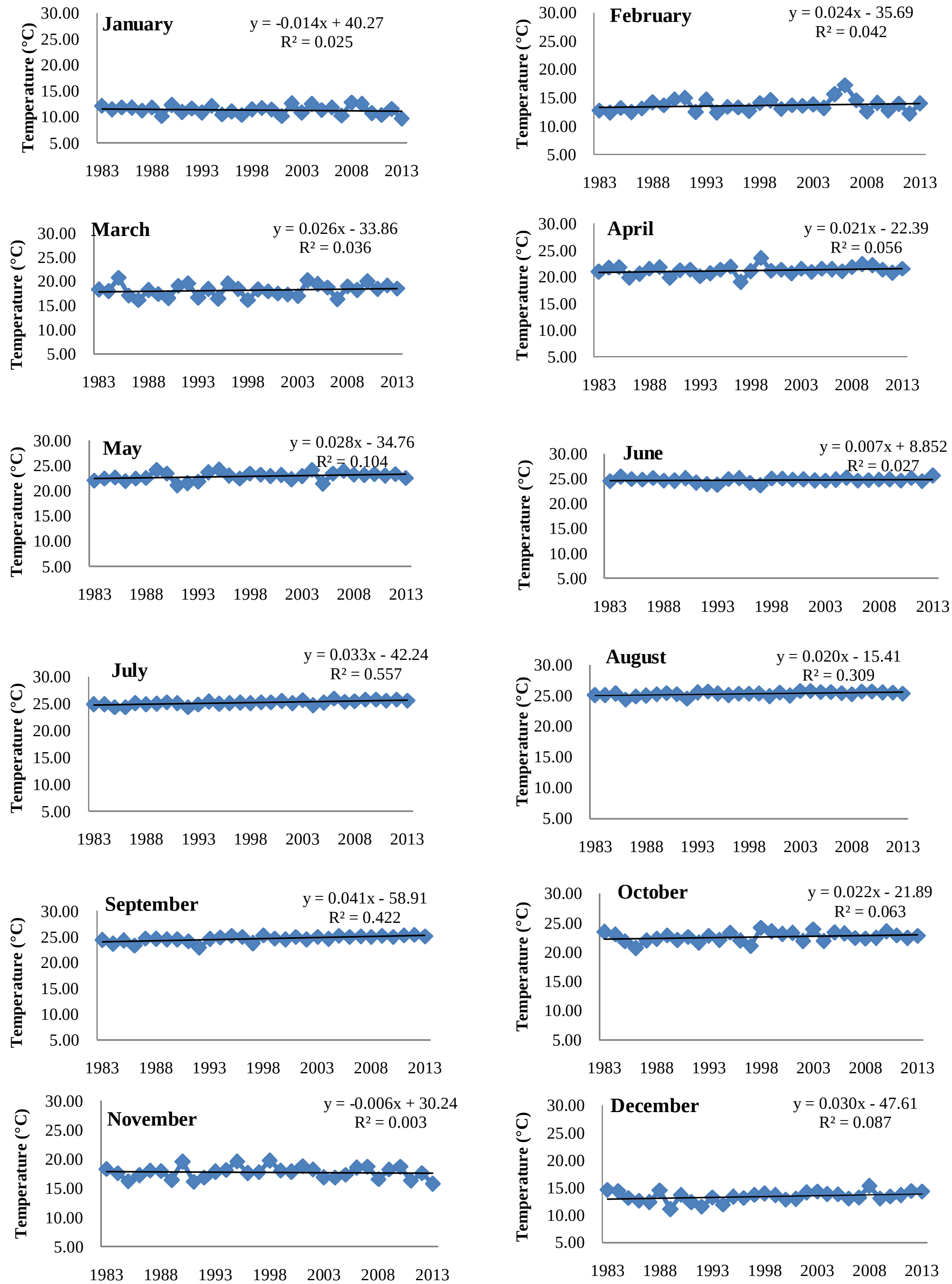

Figure 14. Trend of average minimum temperature (°C) of different month in Sylhet (1983-2013).

4.2 Seasonal rainfall trends

The changes in the seasonal rainfall patterns are important climatic phenomena for Bangladesh. In this study, the changes in rainfall pattern have been assessed by analyzing changes in total rainfall during four seasons namely *Monsoon*, *Pre-monsoon*, *Post-monsoon*, and *Winter*. Monsoon was very hot and humid, brings with heavy torrential rainfall whereas the winter was generally dry with a minimum rainfall. During monsoon season about four-fifths of the mean annual rainfall occurs. The pre-monsoon season was characterized by high temperature and thunderstorms accompanied with copious rainfall. Post-monsoon was a short living season characterized by the withdrawal of rainfall and gradual lowering of night temperature.

In the study, efforts were made to assess if there was any significant change in trends of rainfall. Throughout the country, there observed a decreasing trend in the seasonal rainfall. The trend of seasonal rainfall for the period of 1983-2013 was shown in Figure 15. The results of the linear trend model of changes in rainfall were displayed in Table 8.

Table 8. Correlation results for seasonal rainfall change with time

Climatic parameter	season	Correlation Coefficient	R^2
Rainfall	Monsoon	-0.103	0.017
	Pre-monsoon	-0.222	0.045
	Post-monsoon	-0.045	0.000
	Winter	-0.334	0.110

** and * Represetns 0.01% and 0.05% level of significance

During monsoon, the average total annual rainfall showed a decreasing trend which was not statistically significant (Fig. 15). The correlation coefficient value was -0.103 which represented poor statistical significance trend.

The pre-monsoon season also exhibited a decreasing trend with a correlation coefficient value of -0.222 which was not statistically significant. But the rainfall of post-monsoon season observed an insignificant change as the value of R^2 was 0. In the case of winter rainfall, there also found the decreasing trend of rainfall throughout the period. The correlation coefficient value was -0.334 which indicate a significant trend. In some years, it tends to zero. The trend analysis of seasonal rainfall for the period of 1983-2013 could reveal that from the last three decades the seasonal normal rainfall pattern has been altered.

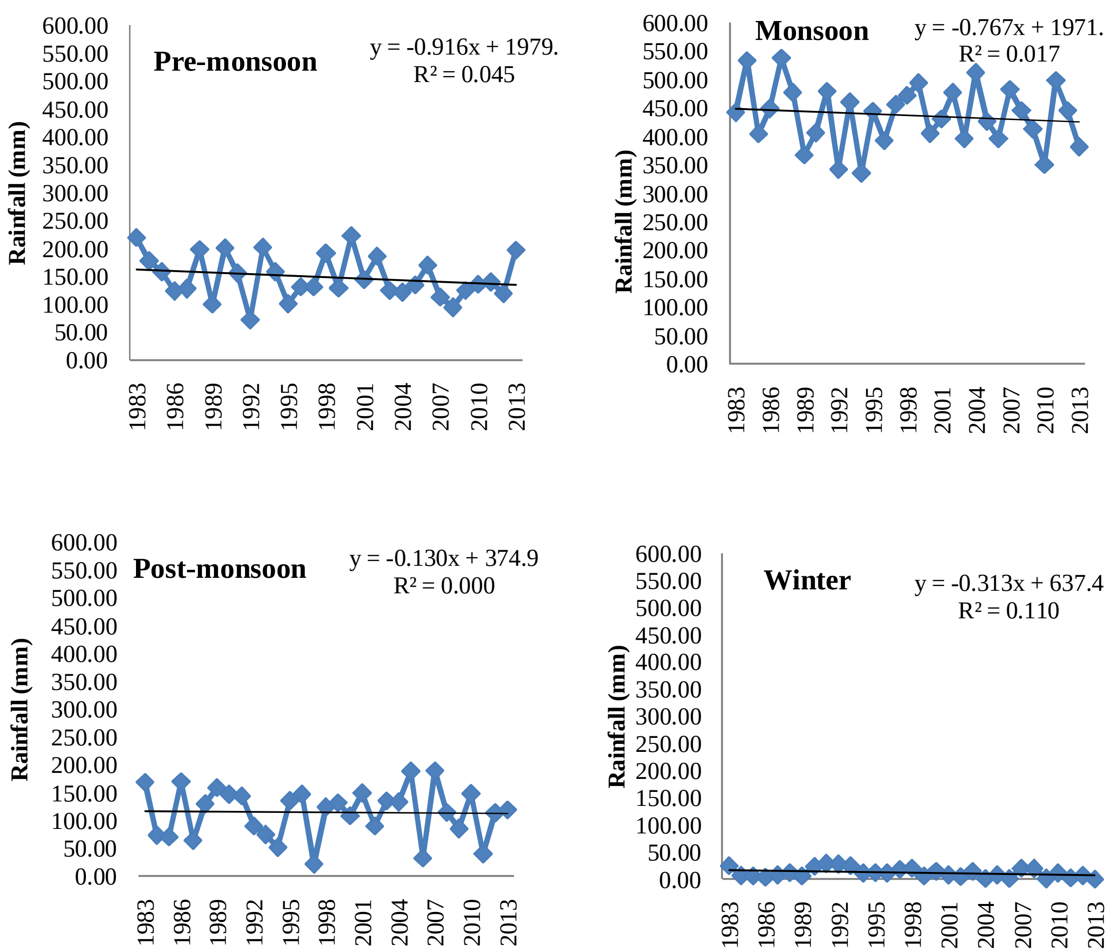

Figure 15. Trend of rainfall (mm) in different seasons (1983-2013).

4.3. Seasonal trend of climatic parameters

In this study, three rice-growing seasons namely Aus season, Aman season, Boro season and for wheat and potato Robi season were brought under consideration. To analyze the linear trend between time and climatic variables graphs were constructed with time as an explanatory variable to observe the spectacular impression about the variations and changes in the trends among the three climatic variables over the whole period (1983-2013). The value of correlation coefficient of time also calculated from the data set to evaluate the significance of the change in the trend. Among the climatic parameter maximum temperature fluctuated greatly but the overall trend was observed to increase for all the season. Small variations were noticed in the minimum temperature; however the trend was still appeared to increase. But the rainfall for all season showed a decreasing trend with fluctuations. The correlation results of climatic parameters with different growing season for time are showed in Table 9.

Table 9. Correlation results for different climatic parameters with time for different growing seasons

Season	Climatic parameter	Correlation coefficient	R^2
Aus	Maximum Temperature	0.565**	0.362
	Minimum Temperature	0.535**	0.315
	Rainfall	-0.242	0.054
Aman	Maximum Temperature	0.780**	0.780
	Minimum Temperature	0.472**	0.222
	Rainfall	-0.133	0.017
Boro	Maximum Temperature	0.219	0.058
	Minimum Temperature	0.339	0.119
	Rainfall	-0.231	0.075
Robi	Maximum Temperature	0.237	0.055
	Minimum Temperature	0.221	0.059
	Rainfall	-0.168	0.034

** and * represetns 0.01% and 0.05% level of significance

In Aus season, average annual maximum temperature had an increasing trend which had the correlation coefficient value of 0.565 and this trend was statistically significant at the 0.01 level of significance (Figure 16). The maximum temperature during this season was prominent. Minimum temperature data exhibited statistically significant increasing trend having correlation coefficient value of 0.535 (Figure 17). But the rainfall trend showed a negative correlation with the time that represent that the annual average rainfall had a decreasing trend (Figure 18). The correlation coefficient value for this trend was -0.242 which was not statistically significant.

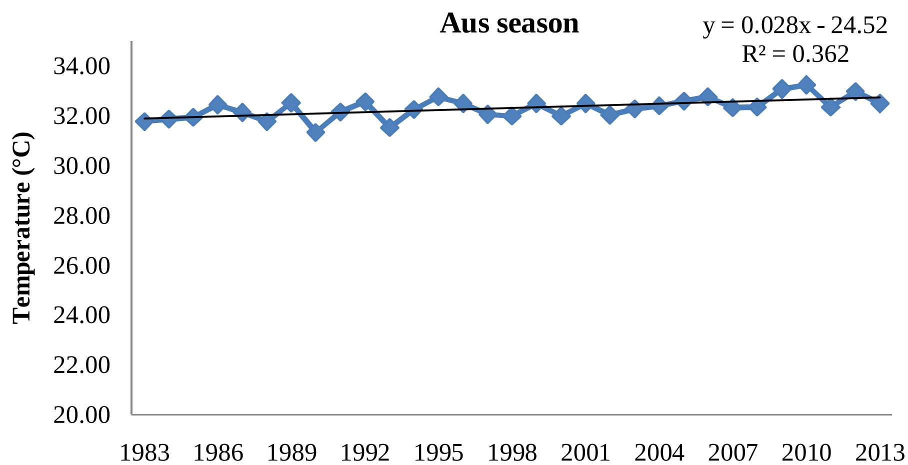

Figure 16. Trend of average maximum temperature (°C) of the *Aus* season (1983-2013).

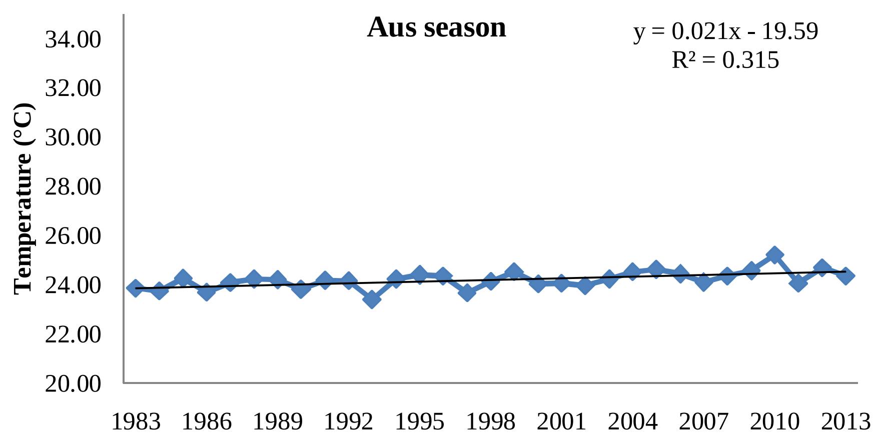

Figure 17. Trend of average minimum temperature (°C) of the *Aus* season (1983-2013).

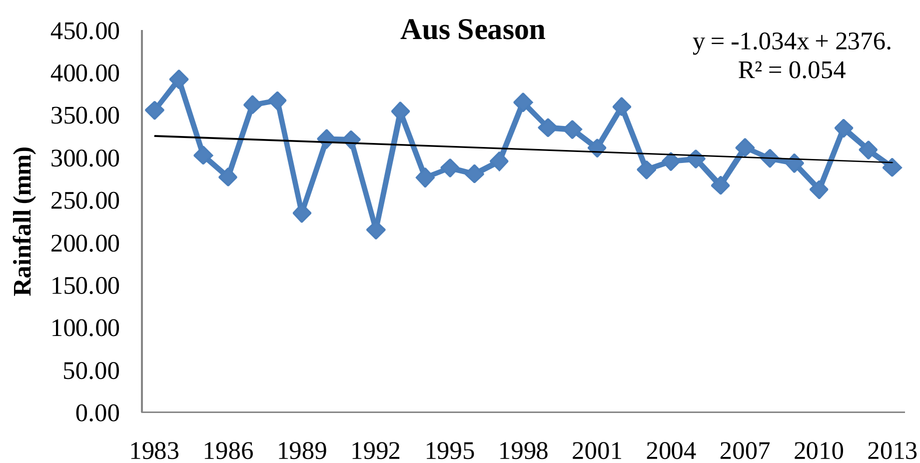

Figure 18. Trend of average rainfall (mm) of the *Aus* season (1983-2013).

During Aman season, maximum temperature data exhibited a more statistically significant increasing trend. The correlation coefficient value for this trend was 0.780 which was statistically significant (Figure 19). There also found an increasing trend of minimum temperature for the Aman season which had correlation coefficient value of 0.472 which was statistically significant (Figure 20). The study had an evident of negative correlation of rainfall with time which indicated the decreasing trend of rainfall (Figure 21), but the trend was not statistically significant which had correlation coefficient value of -0.133.

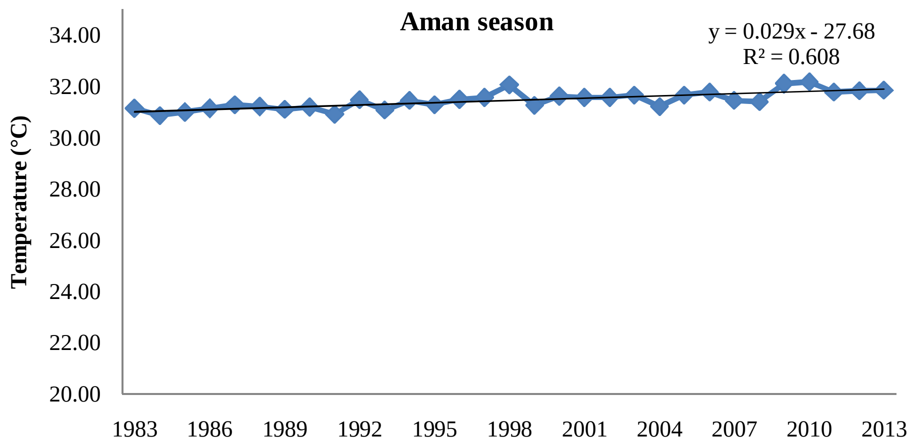

Figure 19. Trend of average maximum temperature (°C) of the *Aman* season (1983-2013).

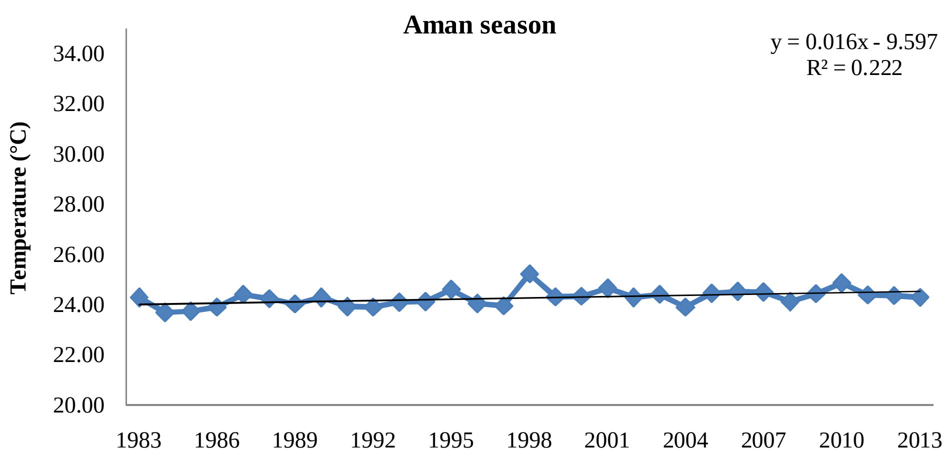

Figure 20. Trend of average minimum temperature (°C) of the *Aman* season (1983-2013).

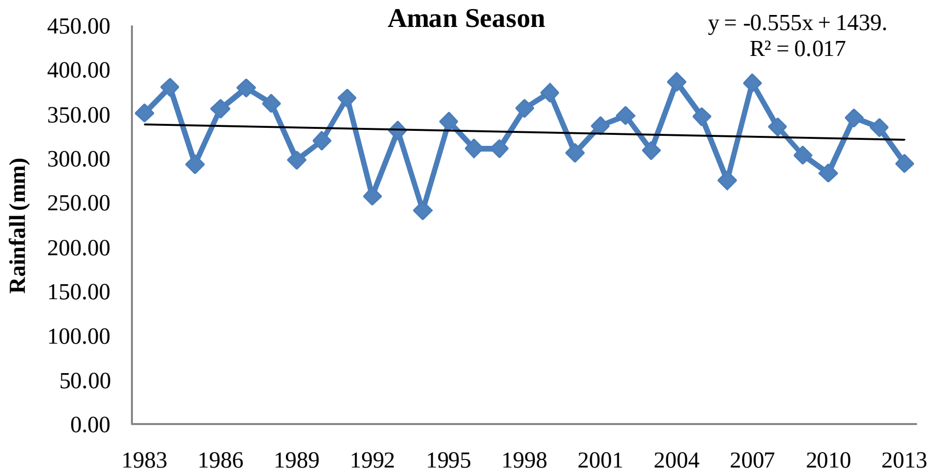

Figure 21. Trend of average rainfall (mm) of the *Aman* season (1983-2013).

In Boro season, there observed an increasing trend for both maximum and minimum temperature. But the trends were not statistically significant. The correlation coefficient values were respectively 0.219 and 0.339 (Figure 22 and Figure 23). But the rainfall showed a decreasing trend during this season having the correlation coefficient value of -0.231 which was not statistically significant (Figure 24).

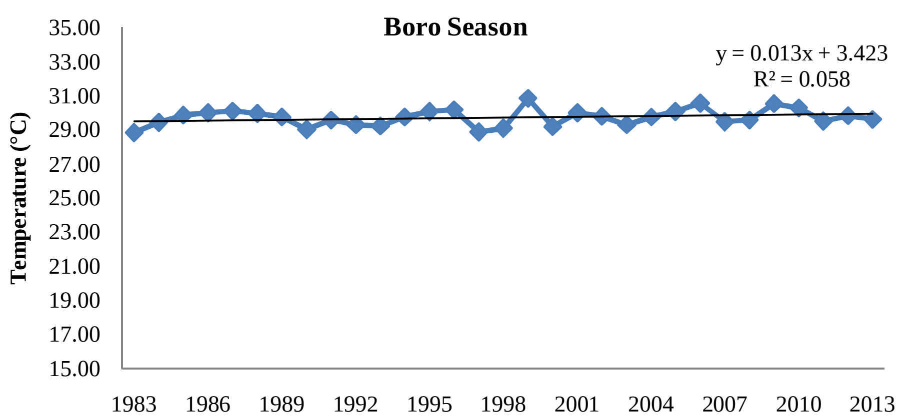

Figure 22. Trend of average maximum temperature (°C) of the *Boro* season (1983-2013).

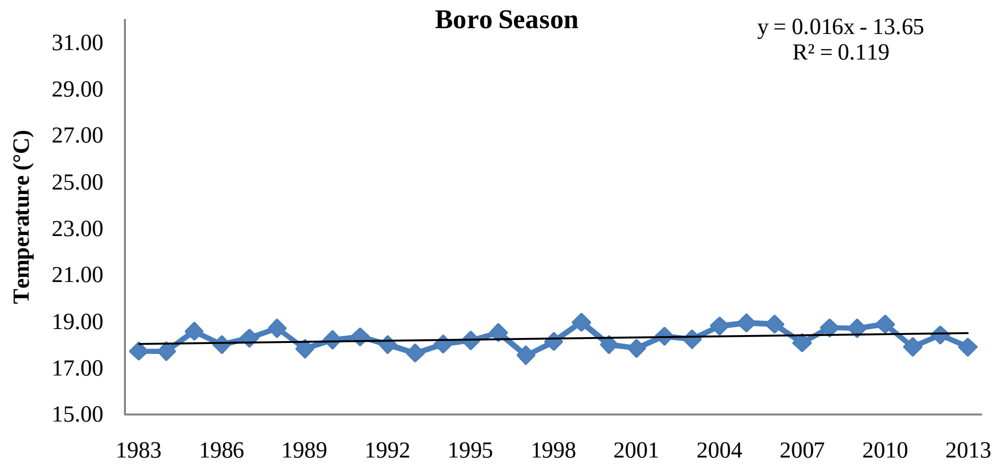

Figure 23. Trend of average minimum temperature (°C) of the *Boro* season (1983-2013).

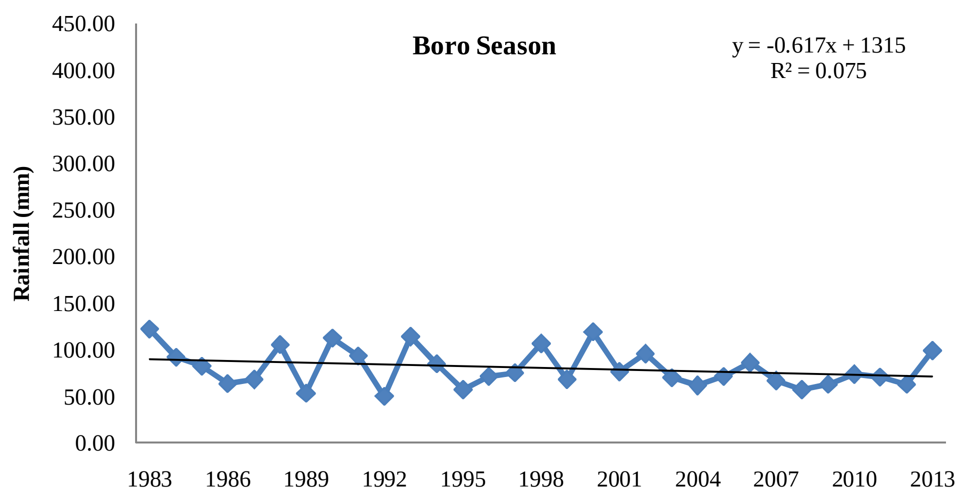

Figure 24. Trend of average rainfall (mm) of the *Boro* season (1983-2013).

Throughout the Robi season, there was also evident of statistically non-significant increasing trend in maximum and minimum temperature (Figure 25 and Figure 26). Correlation coefficient values for those parameters were 0.237 and 0.221, respectively. Likewise, the other season the annual seasonal rainfall exhibited a decreasing trend which was not statistically significant (Figure 27).

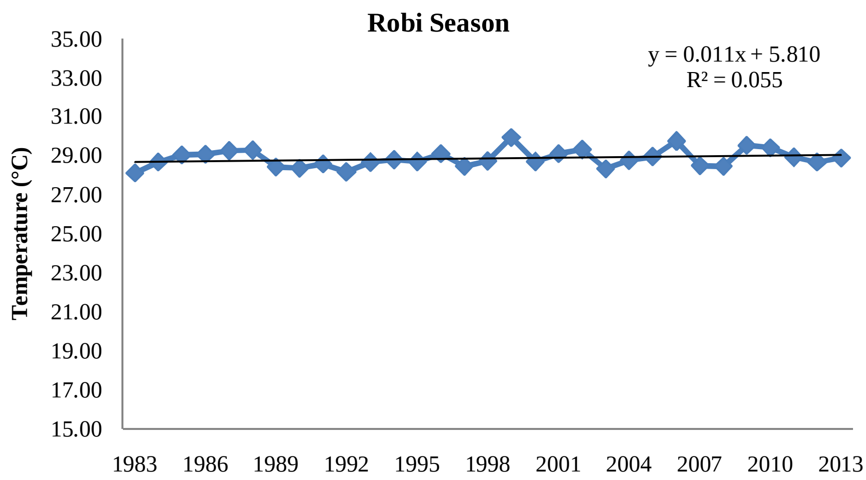

Figure 25. Trend of average maximum temperature (°C) of the *Robi* season (1983-2013).

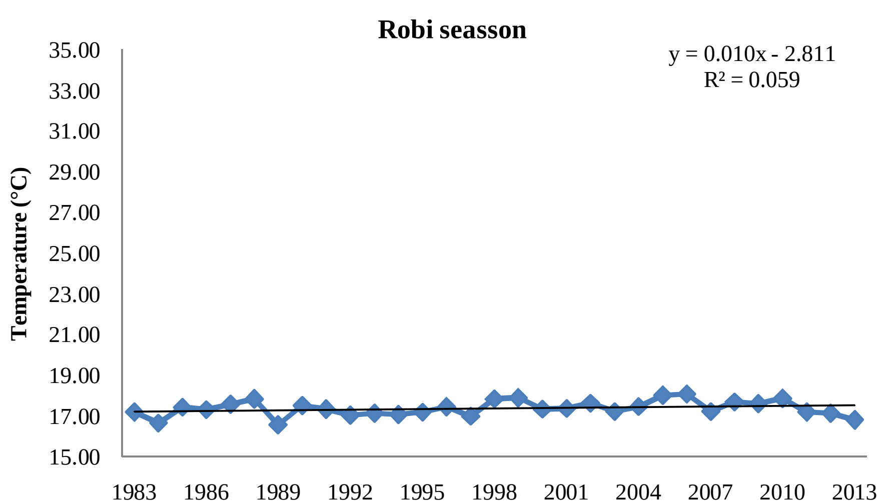

Figure 26. Trend of average minimum temperature (°C) of the *Robi* season (1983-2013).

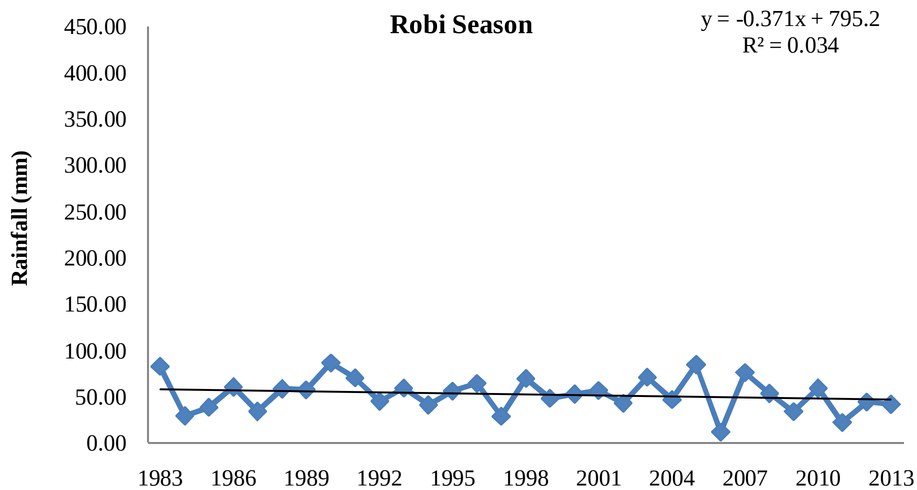

Figure 27. Trend of average rainfall (mm) of the *Robi* season (1983-2013).

4.4 Impact of climatic parameters on crop yield

This study examined the relationship between the yield of five major crops (Aus rice, Aman rice, Boro rice, Wheat and Potato) and three major climatic parameters (maximum temperature, minimum temperature and rainfall) for Bangladesh using the time series data for the time period 1997 to 2013. The significant impact of the climatic parameters on the crop yields were found in the study. The effects of the climatic parameters on crop yield examined through correlation analysis. The contributions of the climatic variables on the crop yield are presented in the Table 10.

Table 10. Correlation results for different climatic parameter with crop yield

Crop yield	Climatic parameter	Correlation coefficient	R^2
Aus Rice	Maximum Temperature	0.571*	0.941
	Minimum Temperature	0.499*	0.941
	Rainfall	-0.412	0.941
Aman Rice	Maximum Temperature	0.553*	0.815
	Minimum Temperature	-0.557	0.815
	Rainfall	-0.603*	0.815
Boro Rice	Maximum Temperature	0.319	0.743
	Minimum Temperature	0.093	0.743
	Rainfall	-0.115	0.743
Wheat	Maximum Temperature	-0.212	0.249
	Minimum Temperature	-0.431	0.249
	Rainfall	-0.042	0.249
Potato	Maximum Temperature	-0.037	0.773
	Minimum Temperature	-0.184	0.773
	Rainfall	-0.008	0.773

** and * represetns 0.01% and 0.05% level of significance

4.4.1 Correlation of Aus rice with climatic parameters

The results from the correlation analysis of climatic variables on Aus rice yields indicated that the climatic variables showed significant correlation with Aus rice yield. There observed a strong positive correlation between Aus rice yield and maximum temperature which had a correlation coefficient value of 0.571 and this correlation was significant at 0.05% level of significance (Figure 28). With minimum temperature, the yield of Aus rice also exhibited a strong positive correlation during the discussed period (Figure 29). The correlation coefficient value of this correlation was 0.499 which was significant at 0.05% level of significance. On the other hand, the yield of Aus rice with response to rainfall was found to show a negative correlation (Figure 30). In this case, the correlation coefficient value was -0.412 which was not statistically significant. Thus, this result implies that there is a highly significant contribution of climatic variables to the Aus rice yield. Although the rainfall does not appear to be statistically significant, it is negatively associated with the Aus rice yield.

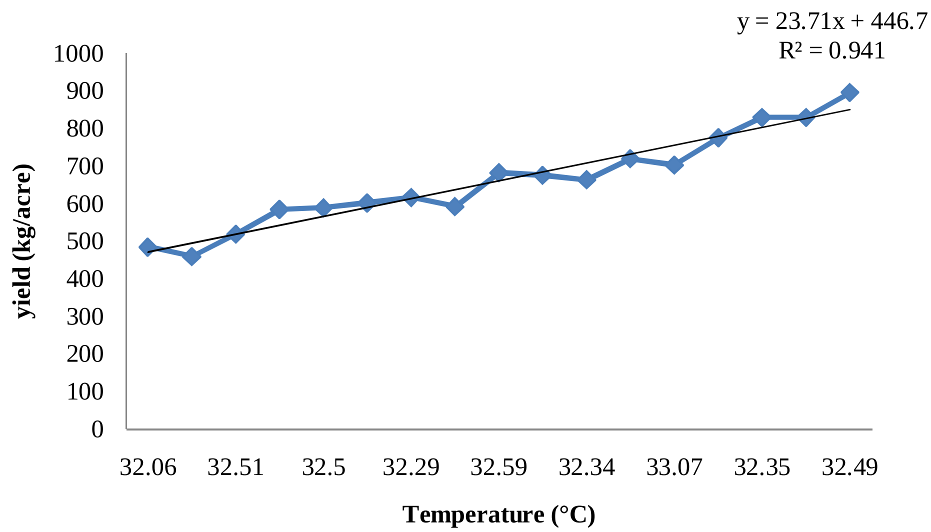

Figure 28. Annual variation of *Aus* yield with response to maximum temperature (°C) during (1997-2013).

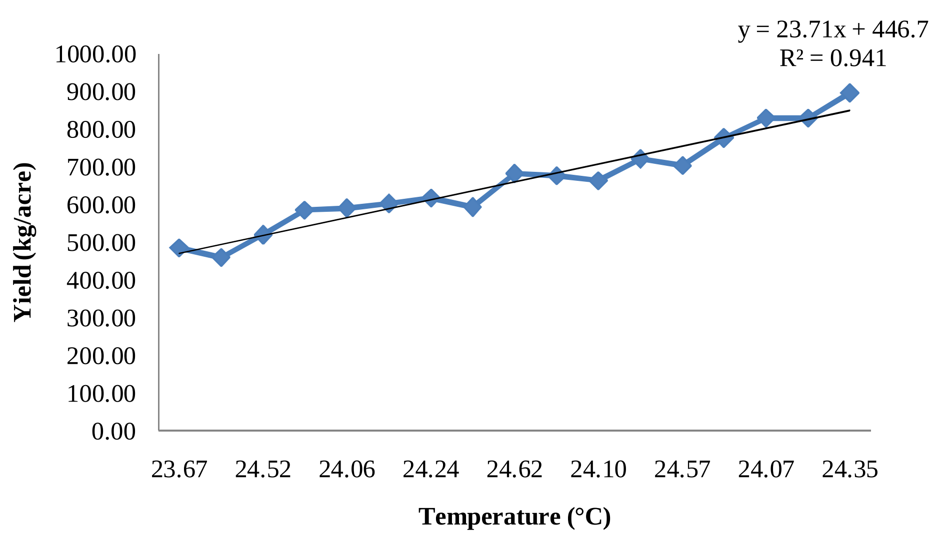

Figure 29. Annual variation of *Aus* yield with response to minimum temperature (°C) during (1997-2013).

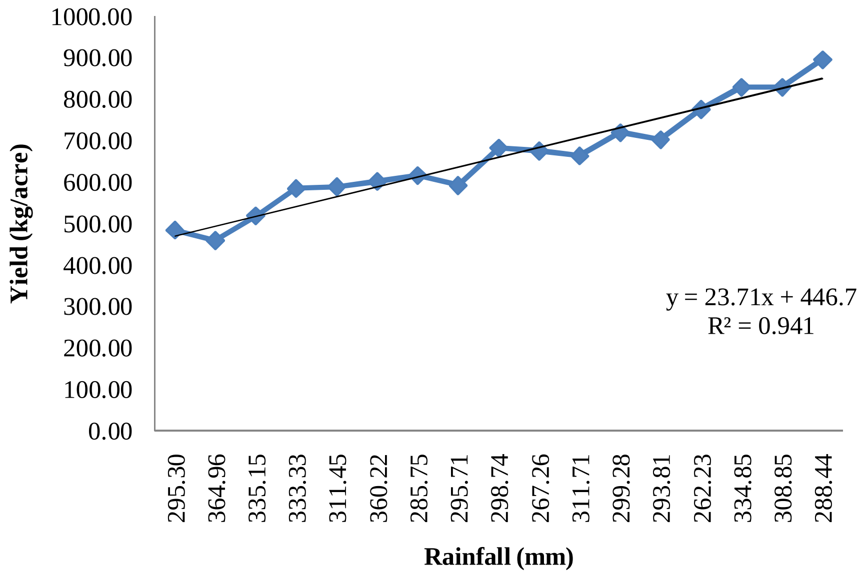

Figure 30. Annual variation of *Aus* yield with response to rainfall (mm) during (1997-2013).

4.4.2 Correlation of Aman rice with climatic parameters

The contributions of the climatic variables to the Aman rice were varied. The effects of maximum temperature exhibited a positive correlation while minimum temperature and rainfall exhibited a negative correlation. During the time period, 1997 to 2013, the relationship between Aman yields and maximum temperature showed a strong positive correlation (Figure 31). The correlation coefficient value of this relationship was 0.553 which was significant at the 0.05% level of significance. On the other hand, minimum temperature observed a negative correlation with Aman yield which had correlation coefficient value of -0.557 but this relationship was not statistically significant (Figure 32). There observed a strong negative correlation between Aman rice yield and rainfall which had a correlation coefficient value of -.603 and this correlation was significant at 0.05% level of significance (Figure 33). Among the three climatic variables, minimum temperature and rainfall had a negative effect on Aman yield which indicate an adverse effect on Aman rice production whereas maximum temperature had positive significant effects. All of these signify the crucial role for Aman rice production.

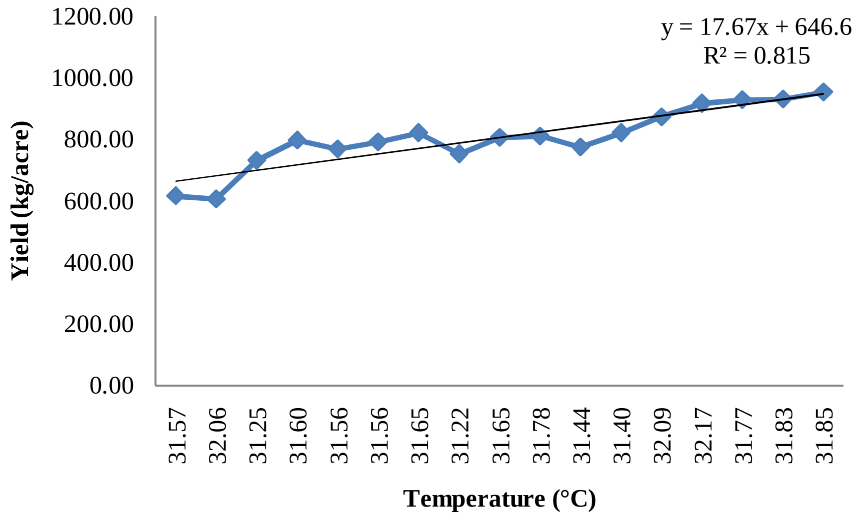

Figure 31. Annual variation of *Aman* yield with response to maximum temperature (°C) during (1997-2013).

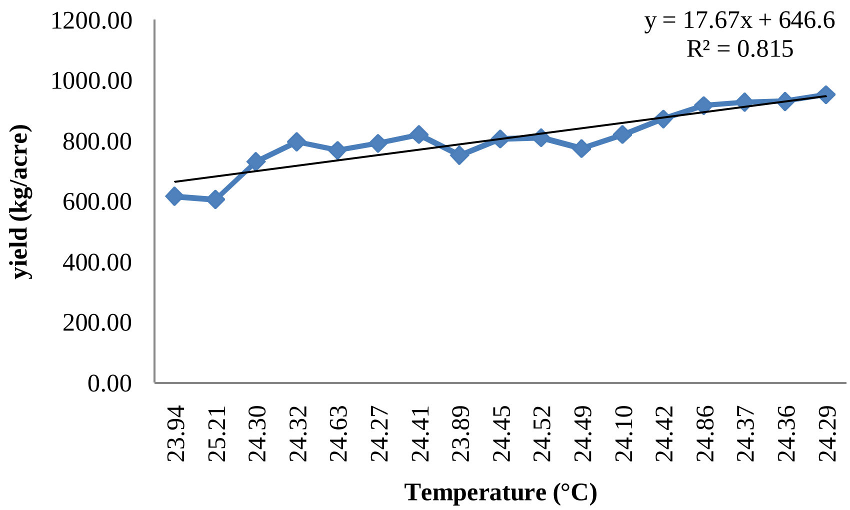

Figure 32. Annual variation of *Aman* yield with response to minimum temperature (°C) during (1997-2013).

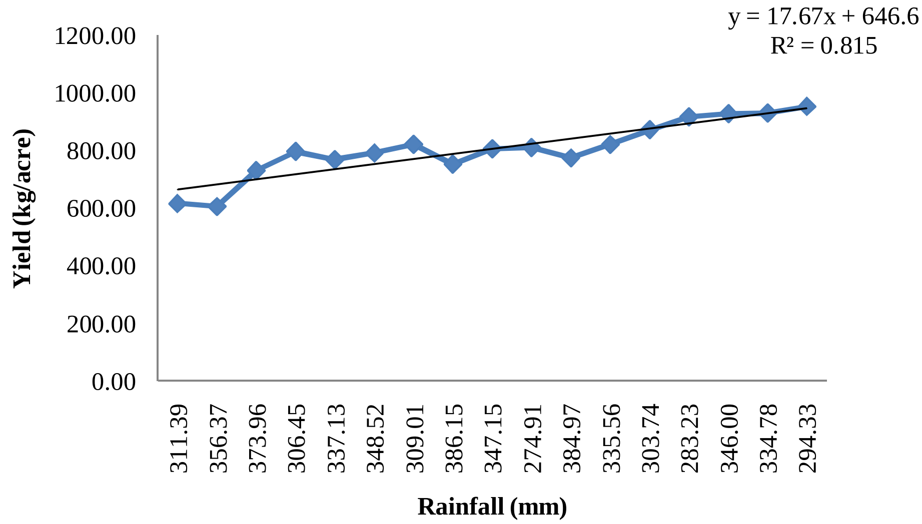

Figure 33. Annual variation of *Aman* yield with response to rainfall (mm) during (1997-2013).

4.4.3 Correlation of Boro rice with climatic parameters

The yield of Boro with response to maximum temperature during 1997-2013 exhibited a nearly strong positive correlation which had the correlation coefficient value of 0.319, but this relationship is not statistically significant (Figure 34). In case of minimum temperature, correlation coefficient value indicates non significant relation with Boro yield (Figure35). The yield of Boro rice showed a weak negative correlation with rainfall (Figure 36). The correlation coefficient value was -0.115 which was not statistically significant. Boro rice is grown using irrigation during dry season along with increasing scientific cultivation techniques. Though the result suggests that climatic variables have a little effect on Boro rice yield this effect is insignificant due to additive irrigation and latest technology.

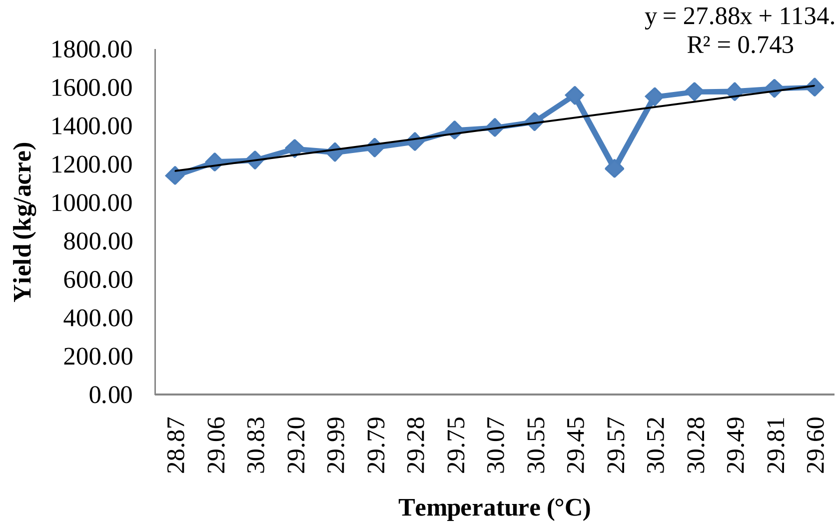

Figure 34. Annual variation of *Boro* yield with response to maximum temperature (°C) during (1997-2013).

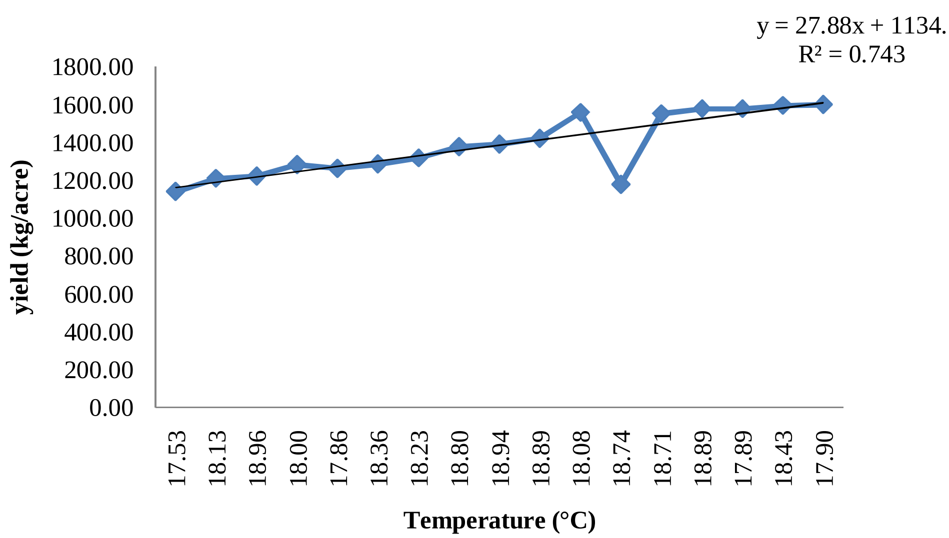

Figure 35. Annual variation of *Boro* yield with response to minimum temperature (°C) during (1997-2013).

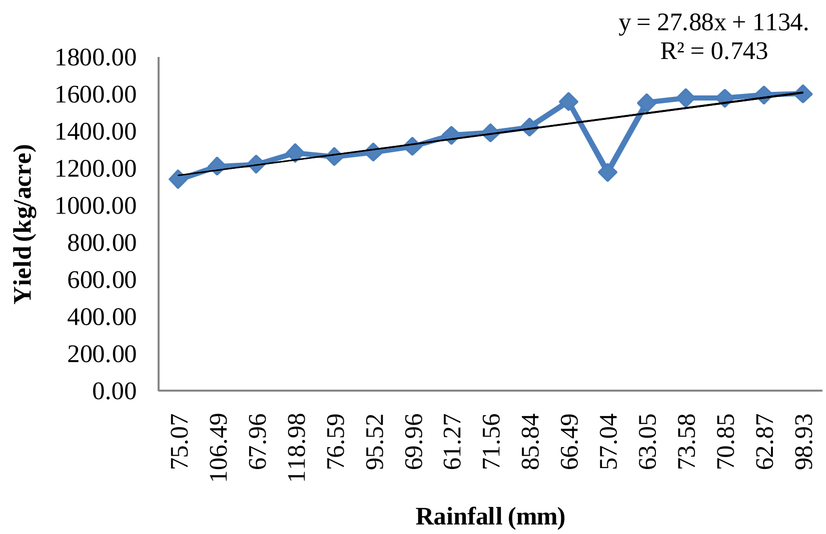

Figure 36. Annual variation of *Boro* yield with response to rainfall (mm) during (1997-2013).

4.4.4 Correlation of Wheat with climatic parameters

The contributions of the climatic variables to the wheat yield were not very significant. Though the effects of all the climatic parameters exhibited a negative correlation with yield but the relationship was not statistically significant. The yield of wheat showed a weak negative correlation with maximum temperature (Figure 37). The correlation coefficient value for this relationship was -0.212. But in case of minimum temperature the correlation coefficient value was -0.431 which was not statistically significant (Figure 38). There observed a negative correlation between wheat yield and rainfall which had a correlation coefficient value of -0.042 and this correlation was not statistically significant (Figure 39).

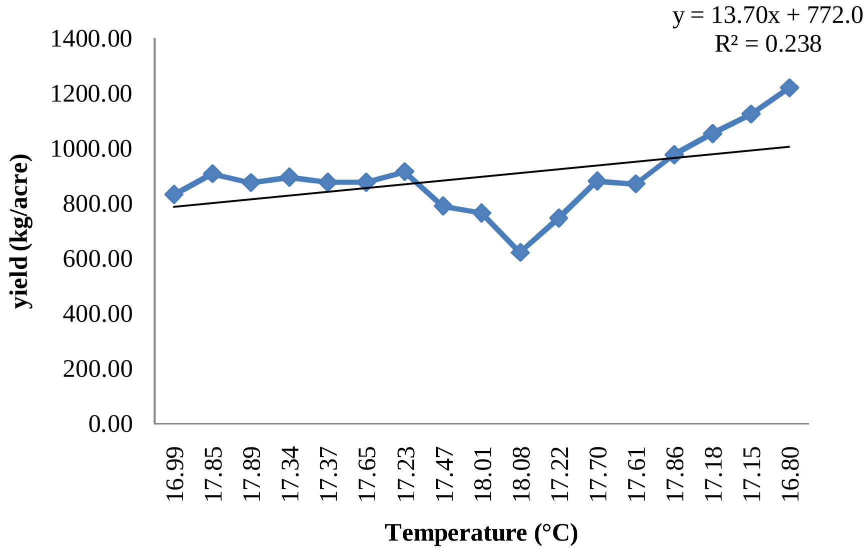

Figure 37. Annual variation of wheat yield with response to maximum temperature (°C) during (1997-2013).

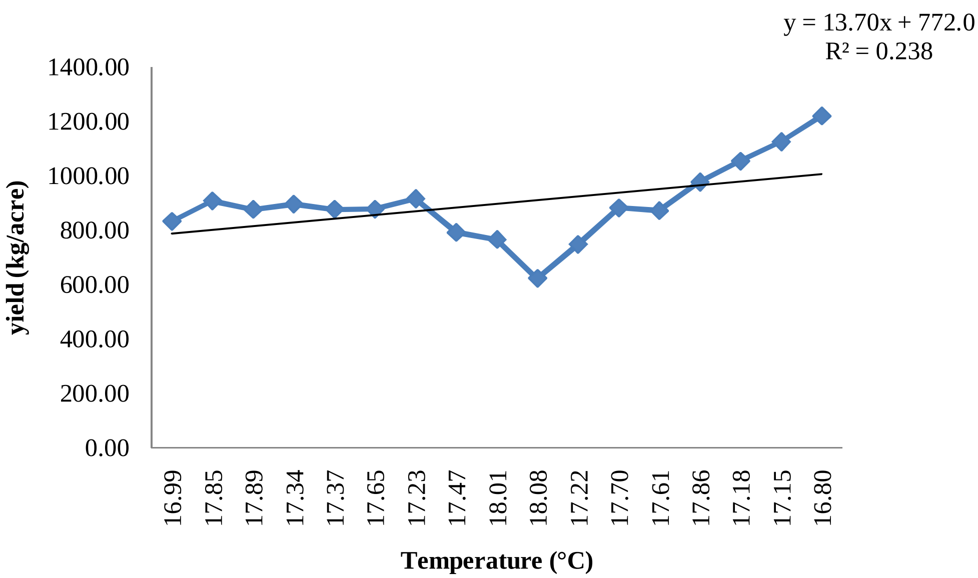

Figure 38. Annual variation of wheat yield with response to minimum temperature (°C) during (1997-2013).

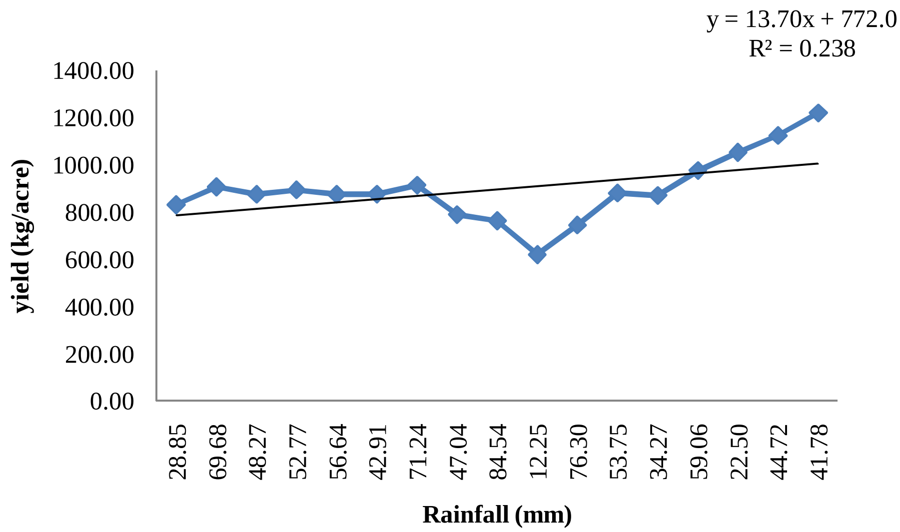

Figure 39. Annual variation of wheat yield with response to rainfall (mm) during (1997-2013).

4.4.5 Correlation of Potato with climatic parameters

The climatic parameter exhibited a negative correlation with potato yield but the relationship was not statistically significant. The yield of potato with response to maximum temperature during 1997-2013 exhibited a weak negative correlation which had the correlation coefficient value of -0.037 but this relationship is not statistically significant (Figure 40). In case of minimum temperature there observed a negative correlation with Potato yield but correlation coefficient value (-0.184) indicate there was no significant relation (Figure 41). There observed a weak negative correlation between potato yield and rainfall which had a correlation coefficient value of -0.008 and this correlation was not statistically significant (Figure 42).

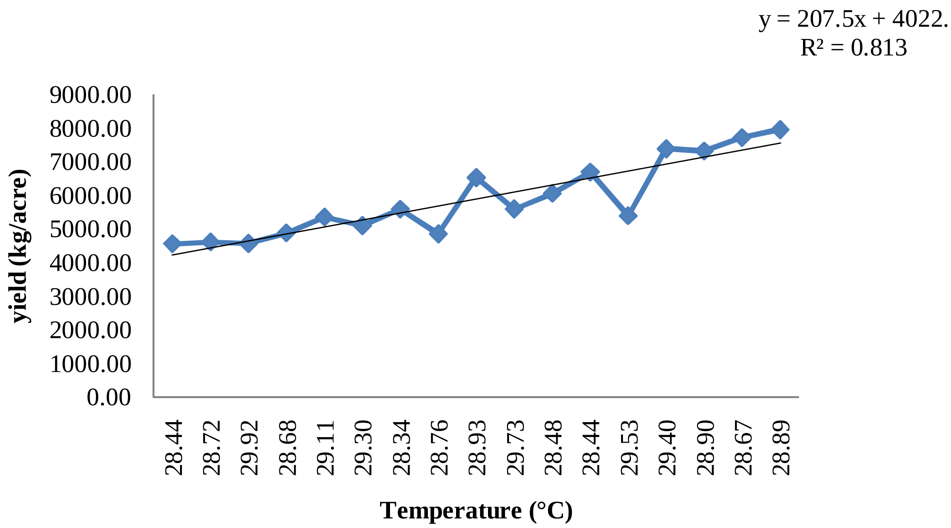

Figure 40. Annual variation of potato yield with response to maximum temperature (°C) during (1997-2013).

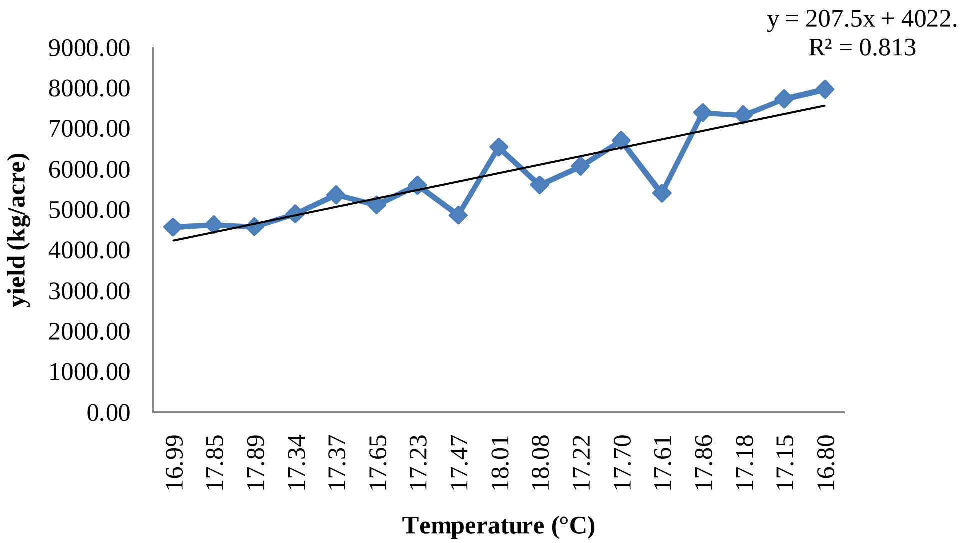

Figure 41. Annual variation of potato yield with response to minimum temperature (°C) during (1997-2013).

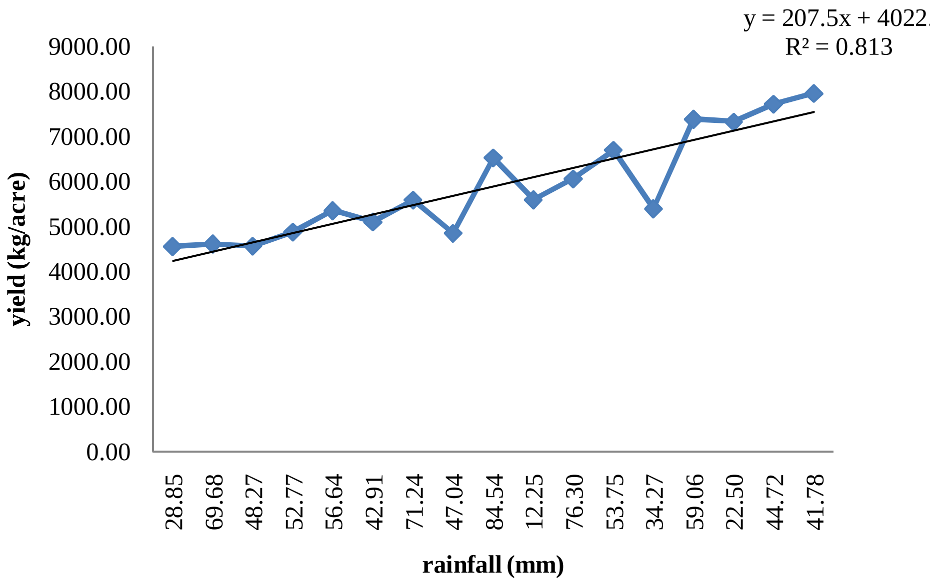

Figure 42. Annual variation of potato yield with response to rainfall (mm) during (1997-2013).

CHAPTER 5

DISCUSSION

The impacts of climate change are becoming prominent over last few decades. Though the climate is changing from its very inception but the trend of temperature change has become more rapid in the recent years. Although climate change is a global phenomenon its consequences will not evenly distribute. The developing country will be the first and hardest hit. In this study revealed that Bangladesh experienced a prominent change in the climatic parameters. The study was conducted dividing the country into 7 divisions considering the time period 1983 to 2013 where we tried to find the changing trend of the monthly average of the climatic parameters namely maximum temperature, minimum temperature and rainfall. During this time period Bangladesh experienced a hot monsoon (June to October), maximum temperature and minimum temperature showed a significant increasing trend during this season. Though the rise of the temperature was not prominent but throughout the country hot summer was experienced. Analysis of the data showed that monthly average minimum and the maximum temperature during winter had a decreasing trend especially in Dhaka, Barisal and Khulna division whereas Chittagong and Sylhet experienced a warmer winter. In the case of Rajshahi and Rangpur division, there observed a rise in the trend of minimum temperature but the maximum temperature had a decreasing trend. IUCN, Bangladesh (2011) stated that the observed climatic data from 1971 to 2002 temperature has an increasing trend in the monsoon (June, July and August). The average minimum and maximum temperature show an increasing trend annually. Average winter season (December, January and February) maximum and minimum temperature shows respectively a decreasing and increasing trend annually. Nishat and Mukharjee (2013), observed that over the past few decades (1967-2007), a warmer winter is being experienced by the country with a prominent increase in the minimum temperature. Similar to this, more hot summer is also experienced during the pre-monsoon and monsoon seasonal months when a prominent rise in the maximum and minimum temperature is observed over the last few decades. Rise in the minimum temperature during winter season (December, January, February) is observed in 25 out of 34 climate observatories of the Bangladesh meteorological Department (BMD), where it is prominent in Dhaka (0.05°C/year), Chuadanga (0.05°C/year), Madaripur (0.06°C/year) and Sayedpur (0.08°C/year) stations. Rise in the maximum temperature during the hot summer of months June, July and August is observed in almost all the stations (except Rangpur), where it prominently observed in the range of 0.03°C-0.05°C/ year Sayedpur, Sitakunda, Sylhet and in Tangail sation.

In the case of rainfall, this study showed a decreasing trend of rainfall during 1983 to 2013 for all the four seasons. The changes in the seasonal rainfall patterns are important climatic phenomena for Bangladesh. In this study, the changes in rainfall pattern have been assessed by analyzing changes in total rainfall during four seasons namely Monsoon, Pre-monsoon, Post-monsoon, and winter. Though the changes were not statistically significant the winter season had a prominent decrease in rainfall considering other seasons. Monsoon experienced a higher temperature with less rainfall which indicates a drastic weather. Similar to this winter season also experienced more hot and less rainfall. But Basak *et al* (2013); assessed in their study analyzing the precipitation data during 1976-2008 showed increasing trend of rainfall for majority of stations during Monsoon and post-Monsoon seasons, while decreasing trend of total rainfall during winter was found for significant number of weather stations; pre-Monsoon period did not show any significant change in total rainfall. In general, these trends are consistent with the general climate change predictions. Nishat and Mukharjee (2013), revealed that rainfall in all seasons there was observed an overall increase in the mean seasonal rainfall, where found maximum during pre-monsoon and monsoon season by around 100mm increase in the mean seasonal rainfall. Although the winter season experiences the minimum rainfall, the historical trend is showing inclination in 27 out of 32 rainfall observatories of BMD. The increase in the pre-monsoon seasonal rainfall is also evident in 30 out of 32 stations of BMD. Monsoon and post monsoon season rainfall also observed an increasing trend. The total number of the non-rainy day in a year is decreasing.

In this study, three rice-growing seasons namely Aus season, Aman season, Boro season and for wheat and potato Robi season were brought under consideration. Among the climatic parameter maximum temperature fluctuated greatly but the overall trend was observed to increase for all the season. Small variations were noticed in the minimum temperature; however the trend was still appeared to increase. But the rainfall for all season showed a decreasing trend with fluctuations. Aus season exhibited prominent increase in temperature both for maximum and minimum temperature. About 0.19℃ average increase of maximum temperature in Aus season observed and about 0.15℃ for minimum temperature. But there was decrease trend observed in case of rainfall. In addition the study also revealed that during aman season a prominent increase observed for both minimum and maximum temperature and the increases were about 0.40℃ and 0.03℃ respectively. Rainfall showed a decreasing trend during this season. Similar to this Boro season also showed increasing trend for maximum and minimum temperature but the increasing trends were not prominent as well as the rainfall exhibited a decreasing trend with time. In the present study we found that throughout the Robi season, there was also evident of statistically non-significant increasing trend in maximum and minimum temperature Likewise, the other season the annual seasonal rainfall exhibited a decreasing trend which was not statistically significant. From the study we can concluded that the overall climatic condition is changing during different rice growing seasons. But for the better yield performance temperature plays a crucial role.

Rice, the main staple food in Bangladesh, occupies nearly 80% of the total net cropped area of the country. Rice required 20 - 36°C average day temperature with night temperature 20 -23°C are ideal for its growth. The crop can tolerate 19°C to 40°C the optimum temperature required for germination is at least 10°C; for flowering is 22-23°C and for grain formation is 20-21°C. A mean air temperature of around 22°C is required for the entire growth. Very high temperatures along with high wind speed cause sun burning and scald diseases. Low temperature reduces formation of spikelets, germination, seedling development, tillering and shoot height. Rice has very high water requirement. Optimum well distributed rainfall during its almost 4 months growing period is 1120 to 1500 mm. Standing water from end of tillering to grain ripening is useful. The crop is highly sensitive to water deficiency at flowering and heading stages (source: IMD). A mean air temperature of around 22°C is required for the entire growth Extreme temperatures are destructive to plant growth and, hence, define the environment under which the life cycle of the rice plant can be completed. The critically low and high temperatures, normally below 20°C and above 30°C, vary from one growth stage to another. These critical temperatures differ according to variety, duration of critical temperature, diurnal changes, and physiological status of the plant. Subjecting the rice plant to temperatures below 20°C at about the reduction division stage of the pollen mother cells usually induces a high percentage of spikelet sterility (Satake, 1969). Low temperature-induced sterility is normally attributed to low night temperatures. High day temperatures, however, appear to alleviate the effects of low night temperatures. When the plant was subjected to a constant night temperature of 14°C for 9 days at the reduction division stage of pollen mother cells, a day temperature of 14°C induced 41% sterility. The percentage sterility was, however, decreased to 12% when the day temperature was raised to 26°C (Yoshida, 1981). According to BRRI (1991), *Aus* rice requires supplementary irrigation during the initial stage of its growing season; in contrast, *Aman* is almost completely rain-fed rice that grows in the months of monsoons, although it requires supplementary irrigation during planting and sometimes in the flowering stage depending on the availability of rainfall. In contrast, *Boro* rice grows in the dry winter and the hot summer; thus, it is completely irrigated (Mahmood, 1997). Only 5% of *Aman* rice and 8% of Aus rice are irrigated (Ahmed, 2001).

But in the study we found that in some months during the selected time period temperature exited the critical temperature for rice growth. For example in Rajshahi division in the month of April maximum temperature was above 37°C in several years. If temperatures continue to increase like last few decades that could exit the tolerable limits of the different crops.

From the study we found that there is a highly significant contribution of climatic variables to the Aus rice yield. The results from the correlation analysis of climatic variables on Aus rice yields indicated that the climatic variables showed significant correlation with Aus rice yield. There observed a strong positive correlation between Aus rice yield and maximum temperature and minimum temperature. Although the rainfall does not appear to be statistically significant, it is negatively associated with the Aus rice yield. Amin *et al.,* (2015) revealed in their findings that maximum temperature displayed positive effect on yield and negative for cropping area, but the effect was statistically not significant for both the cases. Contrastingly, while rainfall very insignificantly affected the yield, it showed statistically significant and positive influence on the cropping area. Minimum temperature and sunshine expressed positive influence on the yield and cropping area of Aus rice, although the effects were not significant. The adjusted R^2 value implied that 10% of the yield variation and 94% of the variation in cropping area of Aus rice is influenced by the climatic variability and change. Sarker *et al.,* (2012); confirmed in their findings that for the Aus model (1972 to 2009 periods), average seasonal maximum temperature and total seasonal rainfall are statistically significant. Moreover, the average minimum temperature is found to adversely affect the Aus rice, although this effect is not significant. The overall Aus model is also found to be significant.

This study revealed that the contributions of the climatic variables to the Aman rice were very significant. Though the effects maximum temperature exhibited a positive correlation, minimum temperature and rainfall exhibited a negative correlation. Among the three climatic variables, minimum temperature and rainfall had a negative effect on Aman yield which indicate an adverse effect on Aman rice production whereas Maximum temperature had positive significant effects. All of these signify the crucial role for Aman rice production. Amin *et al.,* (2015) stated that 1°C increase in maximum temperature at vegetative, reproductive and ripening causes a decrease in Aman rice production by 2.94, 53.06 and 17.28 tons respectively. This past study also stated that a 1 mm increasein rainfall at vegetative, reproductive and ripening stages decrease Aman rice production by 0.036, 0.230 and 0.292 ton respectively. Sarker *et al.,* (2012); confirmed in their findings that climate variables have had significant effects on Aman rice yields in Bangladesh. For the Aman rice model (1972 to 2009 periods), all three climate variables were statistically significant. The direction of the effects is not identical. Maximum temperatures and rainfall have positive effects on yields, whereas minimum temperatures affect yields negatively.

The present study showed that the yield of Boro with response to maximum temperature during 1997-2013 exhibited a nearly strong positive correlation. In the case of minimum temperature there was no significant relation with Boro yield. The yield of Boro rice showed a weak negative correlation with Rainfall. Amin *et al.,* (2015); stated that temperature climbing above the requirement seriously affected Boro rice yield in Bangladesh. The stated in their study that while the contribution of maximum, minimum temperature and sunshine displayed statistically significant correlation with the yield of Boro rice at the 10% level of statistical significance. In contrast, none of the climatic variables showed statistically significant contribution to the cropping area of Boro rice. While maximum temperature and humidity insignificantly affected the cropping area of this crop, the other three variables (minimum temperature, rainfall and sunshine) positively influenced the same. Mamun *et al.,* (2015) assessed a relationship between the variables and the yield of three major rice crops (eg. *Aus, Aman* and *Boro*) and examined the trend of three main climatic variables series data for the 1972-2010 period. The results of used OLS illustrate that three climatic variables have significant effects on the yield of three different rice varieties.

Wheat is a crop of cool environment. However, it requires different temperatures at different stages of plant growth and development. Temperature requirement may slightly differ from one variety to another at the time of germination, however, the general minimum temperature is required from 3.5-5.5°C and optimum 20-25°C and the maximum temperature is 35°C. On temperature below or above to optimum, germination of seed decreases slowly. If the temperature is more than 30°C at the time of maturity it leads to force maturity and yield loss. Optimum rainfall requirement is 50-87.5 cm during the growing season and the total water requirement is 45-55 cm for different varieties and seasonal conditions (agropedia). The findings of the present study showed that the contributions of the climatic variables to the Wheat yield were not very significant. Though the effects of all the climatic parameter exhibited a negative correlation with yield but the relationship was not statistically significant. The yield of Wheat showed a weak negative correlation with maximum temperature as well as with minimum temperature. Wheat is basically a temperate climate plant, grown in the summer season in temperate region and winter or *rabi* season in the sub - tropics. A mean daily temperature of 15 to 20°C is the optimum for its growth and development .The best adaptation of the crop is in areas with moderate temperature and sub- humid to semi-arid conditions. Environmental conditions cause wide fluctuations in emergence, growth, grain development, ripening and nutritional quality of the crop. On temperature below or above to optimum, germination of seed decreases slowly. If the temperature is more than 30°C at the time of maturity it leads to force maturity and yield loss**.** Higher temperatures of about 30 - 35°C ^{0}c have in general detrimental effect to the crop performance. The crop can withstand intense cold condition. The optimal range of temperature for the germination of winter wheat and for its vegetative growth is 15 to 20°C. Minimum, optimum and maximum cardinal temperatures for germination of wheat crop are 3 to 4.5°C, around 25^0c and 30- 32°C ^{0}c, respectively. high temperature during rapid growth and tillering periods results in poor tillering, low number of effective tillers, poor growth rate, short shoot height, low lai, short ears with lower number of spikelets, lower fertilization, lower grain weight and lower quality. Optimum rainfall requirement is 50-87.5 cm during the growing season and the total water requirement is 45-55 cm for different varieties and seasonal conditions. daily cu varies from 0.17 to 0.87 cm from emergence to grain filling, the high range being 0.62cm for the period from boot to dough stages (IMD). Amin *et al.*, (2015); stated that maximum temperature and humidity showed adverse effects on the yield and cropping area of wheat, although the influence was statistically significant only for maximum temperature and only for the yield. Experimental evidence further showed that minimum temperature, rainfall and sunshine positively influenced the crop (in terms of yield and cropping area), though the relation was not statistically significant. More surprisingly, the direction of climatic influence for all the climatic variables was observed to be similar to the yield and cropping area of this crop.

The potato is a plant mainly of typical temperate climate. The crop grows best in cool but frost-free seasons and does not perform well in heat. It is characterized by specific temperature requirements. The limits and optimal values for the growth of the above-ground part of the potato plant and for the tubers are different. Root growth occurs when soil temperatures are between 10 to 35°C, best, most active root development is at soil temperatures of between 15 and 20°C. Leaf (haulm) growth occurs at temperatures of between 7 to 30˚C, but optimal growth is at around 20 to 25°C. Optimum temperatures for stolon growth are similar. The optimum soil temperature for tuber initiation is 15 to 20°C ˚C. From experiments conducted in growth chambers it is known that haulm growth is fastest in the temperature range of 20°C - 25°C whereas the optimal range for tuberization and tuber growth is 15°C - 20°C. At a temperature higher than optimal a reduction or complete inhibition of tuberization and the intensified development of aboveground part of plants take place. The negative impact of high temperatures on tuber yield is the result of the consumption of assimilates by intensively growing shoots (Rykaczewska, 2013). In this study we found that the temperature during winter is decreasing in different part of the country. The climatic parameter exhibited a negative correlation with potato yield but the relationship was not statistically significant. The yield of Potato with response to maximum temperature during 1997-2013 exhibited a weak negative correlation.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1. Summary

The objective of the study was to estimate the recent changes in the climatic parameter in Bangladesh as well as to examine the relationship between crop yields and climatic parameters using aggregate-level time series data. Historical climatic data recorded at 35 stations at seven divisions in Bangladesh for the period of 1983 to 2013 have been analyzed. It was found in the study that in recent years, surface air temperature throughout the Bangladesh experienced an increasing trend for almost every month. There is a prominent increase observed in the summer temperature and decrease in the winter temperature. This situation indicates summer months became hotter and winter became cooler. The study showed that the month of July and September had the increasing trend for all the division. Among the divisions, Chittagong division experienced a significant increase of temperature. Almost every month showed an increasing trend for both maximum and minimum temperature. On the other hand, the northern part of the country experienced fluctuation of temperature. The Rajshahi and Rangpur division showed a significant decrease in January as well as an increase in the months from May to September. The trend analysis of seasonal rainfall for the period of 1983-2013 revealed a negative correlation with time which indicates a decreasing trend of rainfall from this we could reveal that from the last three decades the seasonal normal rainfall pattern has been altered. In the case of different cropping seasons such as Aus, Aman, Boro and Robi maximum and minimum temperature exhibited a strong increase whereas rainfall found to have a decreasing trend. The overall findings reveal that three climatic parameters have substantial effect on crop yield in Bangladesh. The yield of Aus rice found to have a statistically positive correlation with maximum and minimum temperature whereas a non significant negative correlation with rainfall. In case of Aman rice yield maximum temperature showed a significant positive effect but minimum temperature rainfall had a significant negative effect. Although the effects are not significant maximum and minimum temperature showed a positive correlation with Boro yield but rainfall showed a negative correlation. But in case of wheat and potato yield climatic parameters found to have adverse effect on their yield. Although the correlation are not statistically significant the correlation exhibited negative result.

6.2. Conclusion

The temperature and rainfall patterns are of great importance for an agro-based economy like Bangladesh. Over the past few decades, these patterns are changing and a very high temperature has been predicted, especially for the years 2050 and 2070 due to climate change. These changes will threaten the significant achievements which Bangladesh has made over the last 20 years in the agricultural sector. In view of these changes, it is necessary to regularly and systematically compile, monitor and analyze the relevant climatic parameters for assessing the impacts of climate change. But the aggregate-level data are unable to produce any regional variations of climate change and effects on crop yield (Lobell et al.,, 2007). To summarize national level data might not depict true scenario for different agro-ecological zones of the country about climate change impacts on crop yield. Therefore, region-specific research should be conducted to highlight the regional difference and to guide intensive measures on the perspective of climate change and cultivation of major crops of Bangladesh.

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APPENDICES

Appendix I. Thirty five ground base measuring stations of Bangladesh Meteorological Department