Trends in Climatic Variables and Their Combined Effects on Irrigation Water Demand in the Dry Season

by

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Farzana Nasrin

....

Farzana Nasrin

Dedicated to my

Beloved parents

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Abstract

Agriculture is a key economic sector in Bangladesh and one of the main users of fresh water resources. At present, climate change is thought to be putting extra stress on agricultural productivity and hence food security because climate change may lead to changes in irrigation water requirement. Most of the studies related to the effects of climate change on irrigation water requirement have been done based only on changes of temperature and/or rainfall. Other climatic variables, such as solar radiation, humidity and wind speed, which may also affect the irrigation water requirement, were not taken into consideration in those studies. To find out the impact of climate change on agricultural water requirement, the combined effects of all the variables need to be considered.

This study is based on secondary data and information. Data of four meteorological stations, namely Dhaka, Jessore, Bogra and Chandpur, on daily observations of air temperature, air humidity, wind speed, solar radiation and rainfall are used. The stations are selected such that one station is selected from each of the North-Central, South-West, North-West and South-East hydrological planning regions of Bangladesh. 10-day time scale for data analysis has been used as it closely resembles agricultural and water resources planning activities in Bangladesh. The Penman-Monteith method is used for reference crop evapotranspiration (ET_0) computation and both parametric and non-parametric methods are used for testing the statistical significance of trends in different hydro-climatic variables.

The results of the analysis reveal that maximum temperature has increasing trends of 0.2^{0}C, 0.2^{0}C and 0.1^{0}C per decade for Dhaka, Jessore and Chandpur, respectively, during the dry season (November-May). In contrast, Bogra has a decreasing trend of 0.2^{0}C per decade. Minimum temperature has increasing trends of 0.3^{0}C, 0.2^{0}C, 0.2^{0}C and 0.1^{0}C per decade at Dhaka, Jessore, Bogra and Chandpur, respectively. The relative humidity has increasing trends at four stations in all 10-day periods of the dry season. The average increasing trends are 0.9%, 2.5%, 3.0% and 1.4% per decade at Dhaka, Jessore, Bogra and Chandpur, respectively. The other important climatic variable is the sunshine hour which has decreasing trends in all 10-day periods at the four stations. The average decreasing trends at Dhaka, Jessore, Bogra and Chandpur

stations are 0.7, 0.5, 0.5 and 0.7 hours per decade, respectively. Wind speed has both decreasing and increasing trends depending on the stations. The average decreasing trends in wind speed at Dhaka and Chandpur are 15.8 and 40.8 km/day per decade, respectively. The average increasing trends in wind speed are 5.5 km/day and 1.1 km/day per decade at Jessore and Bogra, respectively. From the trend analysis of climatic variables at four stations, it is found that sunshine hour has decreasing trend and relative humidity, maximum temperature and minimum temperature have increasing trends.

The combined effect of the trends of above climatic variables on ET_0 and net irrigation requirement (NIR) of Boro rice, which is the staple crop in Bangladesh, are then evaluated. The ET_0 is found to have decreasing trends at all stations. The decreasing trends are 0.2, 0.2, 0.1 and 0.3 mm/day per decade (10 years) at Dhaka, Jessore, Bogra and Chandpur, respectively, during the dry season. The average decrease of ET_0 from 1961 to 2007 is found to be about 23%, 25%, 8% and 33% at Dhaka, Jessore, Bogra and Chandpur, respectively. The net irrigation requirements (NIR) for Boro rice were estimated from rice evapotranspiration and rainfall data. Decreasing trends in NIR of 0.1, 0.1, 0.1 and 0.4 mm/day per decade at Dhaka, Jessore, Bogra and Chandpur stations, respectively, are found. Seasonal mean NIR of 1991-2007 is found to be lower than that of 1961-1975.

It appears from this study that the combined effect of the climatic variables of the four stations is the decreasing trends of ET_0 and NIR. Besides, the rainfall has increasing trends at the four stations which also contribute to the decreasing trend in NIR. Though the temperatures have increasing trends which should increase ET_0 and NIR, the effects of other variables are more dominating than that of temperatures. The findings of this study convey a clear message to the policy and decision makers and water managers that the irrigation sector would not be adversely affected due to climate change. These findings are in contrary to the general belief and reported modeling results which state that due to climate change water requirement for irrigation would increase.

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Abbreviations and Acronyms

AAM	Amman Airport Meteorological
ASCE	American Society for Civil Engineers
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering and Technology
DJF	December January February
ET_c	Crop Water Requirement
ET_0	Reference Crop Evapotranspiration
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	Gross Domestic product
GISS	Goddard Institute for Space Studies
HADCM3	Hadley Centre Coupled Model, version 3
IWFM	Institute of Water and Flood Management
IPCC	Intergovernmental Panel on Climate Change
NAPA	National Adaptation Programme of Action
NIR	Net Irrigation Requirement
PET	Potential Evapotranspiration
SMRC	SAARC Meteorological Research Centre
SPSS	Statistical Package for the Social Sciences

Chapter I

INTRODUCTION

1.1 Background of the Study and Present State of the Problem

Agriculture is a key economic sector in Bangladesh and one of the main users of water resources. Food self-sufficiency is a prime importance to Bangladesh. The population of Bangladesh is still growing by two million every year and may increase by another 30 million over the next 20 years. The majority of population is still dependent on agriculture for income and livelihood. In a normal year, the country is still deficit in food grain production. Therefore, there is a clear need for Bangladesh to expand food grain production as the total population continues to increase. A major strategy to increase food grain production will be through the expansion of irrigation coverage. The increased population is a large stress on agriculture productivity. At the very basic level, the problem is that food production has failed to keep pace with population growth and its increasing food requirements. Also, the early effects of climate change have started to take their toll.

At present the climate change is also a great stress for agricultural productivity. Because, climate change is may lead to changes in irrigation water requirement. Despite technological advances and improved crop varieties and irrigation system, weather and climate are still key factors in agricultural productivity. But agriculture particularly irrigation water, is always vulnerable to unfavourable weather events and climate condition. During the period 1973-1987, about 2.18 million tons of rice were damaged due to drought (Climate Change Cell, 2007). In Bangladesh, rice is the staple food of about 135 million people. Rice sector contributes one-half of the agricultural gross domestic product (GDP) and one-sixth of the national income in Bangladesh (BRRI, 2007). Over 80% of the total irrigated area is under rice cultivation. Boro rice needs full irrigation due to scanty rainfall. During dry season (November-May), water loss due to evapotranspiration far exceeds the gains due to rainfall that may occur. So the scarcity of irrigation water requirement has got more importance in the Boro season.

Global average surface temperature has increased by about 0.6 ^{0}C during the 20th century (IPCC, 2001). The fourth assessment report of intergovernmental panel on climate change (IPCC, 2007) shows a median increase of 3.3 ^{0}C in annual mean temperature throughout the Asia by the end of the 21st century. Increasing global temperature is expected to increase the intensity of extreme weather events and to change the amount and pattern of precipitation. From a general circulation model estimated that in Bangladesh the winter precipitation would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase by 12% and 27% for the above projection years, respectively, compared to the base year of 1990 (NAPA, 2003).

SAARC Metrological Research Centre (SMRC, 2003) showed increasing trend of mean maximum and minimum temperature in some seasons and decreasing trend in some other seasons. Observed data indicates the maximum and minimum temperature of Bangladesh have increasing trends (Mondal and Wasimi, 2004). The annual mean maximum temperature has shown significantly increasing trend over the period of 1961-1990 (MoEF, 2005). Both positive and negative temperature and precipitation trends have been established during recent decades (IPCC, 2001) while changes in global evaporation rates are still under discussion (Peterson et al., 1995). This increased temperature leads to higher evaporation rates and enables atmosphere to transport higher amounts of water vapor from the ground. The erratic nature of rainfall and temperature causes water scarcity due to changes in evapotranspiration rates. Water scarcity in the agricultural sector of North-East China, has been attributed to declining precipitation rates, overuse of ground water, deteriorating irrigation structures and inappropriate water management (Thomas, 2007).

The anticipated climate changes have many considerable effects on cropping systems. Agricultural demand, particularly for irrigation water, is considerably more sensitive to climate change. A field level climate change may alter the need for and timing of irrigation (IPCC, 2001). According to the simulation results from HADCM3, net irrigation requirements per unit irrigated area would decrease in the Middle East and

South Africa because of increased precipitation whereas the requirements in India would increase. Global net irrigation requirement would increase, relative to situation without climate change, by 3.5-5% by 2025 and 6-8% by 2075 (IPCC, 2001).

The crop production in Bangladesh is constrained by scarcity of irrigation water during dry season. Changes in evapotranspiration rates and the irrigation water demand are closely related. Besides land-surface evapotranspiration enhances the air humidity increasing (decreasing) the minimum (maximum) air temperature (Sun and Wu, 2001). Most of the studies that have been done so far related to the effects of climate change on irrigation water demand based only on temperature and/or rainfall. Other climatic variables, such as solar radiation, humidity and wind speed have not been taken into considerations which also affect evapotranspiration rates. To find out the impact of climate change on agricultural water requirement, particularly in the dry season, the trends of all climatic variables and their combined effects on irrigation water requirement need to be considered.

1.2 Objectives with Specific Aims and Possible Outcome

The specific objectives of this study are as follows:

i. To analyze the trends in the observed climatic variables at different decades (10-day periods) of the dry season; and
ii. To generate agricultural water demand time series and to evaluate the combined effects of the climatic variables on irrigation requirement.

The study will reveal the long-term trends in the observed climatic variables. It will also reveal whether irrigation requirement is increasing or decreasing due to climate change. This information will be useful in climate modeling, planning and decision making in water resources and agricultural management.

1.3 Organization of the Chapters

The thesis contains six chapters. The organization of the chapters is as follows:

Chapter I: Chapter one provides the background of the study and present state of the problems. It also highlights the objectives of the study and organization of the chapters.

Chapter II: Chapter two provides an overview of trends in climatic variables such as temperature, rainfall, wind speed, sunshine hour and relative humidity. The chapter also reviews the literature of changes of evapotranspiration and the effect of change in variables on evapotranspiration and irrigation water demand.

Chapter III: This chapter discusses the methods in detail used in the study to analyze the trends and significance level of trends. The chapter also shows the logic behind the methodological considerations employed to estimate evapotranspiration and net irrigation requirement. It also describes data collection methods used for the study.

Chapter IV: This chapter describes results of the trend analysis of different climatic variables of four study stations.

Chapter V: This chapter describes trend analysis of net irrigation requirement of four stations.

Chapter VI: This chapter concludes the findings of the study and provides recommendations for further study.

Chapter II
LITERATURE REVIEW

2.1 Trends in Climatic Variables

2.1.1 Trends in Temperature

The latest prediction from the fourth assessment report of Intergovernmental Panel on Climate Change (IPCC, 2007) shows a median increase of 3.3 ^{0}C in annual mean temperature throughout the South Asia by the 21st century. The year 2007 ties for second warmest in the period of instrumental data, behind the record warmth of 2005, in the Goddard Institute for Space Studies (GISS) analysis. The 1996 prediction from General Circulation Models (GCMs) shows that global mean surface temperature may rise between 0.9 ^{0}C and 3.5 ^{0}C by 2100 from that of 1990 (IPCC, 1996). For the best estimate value of climate sensitivity and mid-range IPCC emission scenario (IS92a), the projected increase is about 2 ^{0}C. The projections (IPCC, 2001) with the full set of 35 emission scenarios from a number of climate models show a wider range of increase in global mean temperature (1.4-5.8 ^{0}C). The corresponding earlier prediction (IPCC, 1990) in temperature was an increase of about 2.5 ^{0}C with a range between 1.5 ^{0}C and 4.5 ^{0}C. Regional changes in climatic parameters are more important compared to global and continental changes due to understand the regional vulnerability.

In observed data, there is a general increasing trend in temperature over the Indian Sub-continent. The observed increase in mean annual temperature in India during the period 1901-1982 is about 0.4 ^{0}C (Divya and Mehotra, 1995). This warming is mainly manifest in the post-monsoon and winter season and the steady increase is in contrast to the post-1940 cooling observed for the northern hemisphere. A significant increase in the consumption of fossil fuel, deforestation and land use has been attributed for this warming. A similar increase (0.5 ^{0}C) in temperature over Bangladesh is reported in Ahmad et al. (1996).

SAARC Meteorological Research Centre (SMRC, 2003) has projected climatic element up to 2050 and 2100 using 5-year running average method. It is found that trend of overall annual mean temperature is likely to increase by 0.21 ^{0}C and 0.39 ^{0}C by 2050 and 2100, respectively (SMRC, 2003).

GCM was used to estimate monthly average rate of change in temperature and precipitation for 10 meteorological stations in Bangladesh. The results revealed that the average increase in temperature would be 1.3 ^{0}C and 2.6 ^{0}C for the years 2030 and 2070 from the base year of 1990, respectively (NAPA, 2003). It was found that there would be a seasonal variation in changed temperature: 1.4 ^{0}C change in the winter and 0.7 ^{0}C in the monsoon months in 2030. For 2070 the variation would be 2.1 ^{0}C and 1.7 ^{0}C for winter and monsoon, respectively.

In Warrick et al. (1996), estimates of possible changes in average temperature and rainfall over Bangladesh during different seasons are given. Both for winter (November-February) and summer (March-May), an increase in average temperature of 1.25-1.5 ^{0}C by the year 2030 and 1.5-2.0 ^{0}C by 2050 over the base year (1990) is reported. Comparing outputs from a GCM with long-term climatic patterns over Bangladesh, Ahmed and Alam (1999) depicted a similar increase in winter (December-February) temperature over Bangladesh (1.3 ^{0}C and 2.1 ^{0}C for 2030 and 2075, respectively, over the 1990 level, which is 19.9 ^{0}C).

The observed data of 1971 to 1998 show that the temperature is generally increasing in the monsoon season (June-August). Average monsoon maximum and minimum temperature shows an increasing trend annually at the rate of 0.05 ^{0}C and 0.03 ^{0}C, respectively. On the other hand average winter (December-February) maximum and minimum temperature shows decreasing and increasing trend annually at the rate of 0.001 ^{0}C and 0.016 ^{0}C, respectively (Alam, 2002). The study also reveals that the trend has regional variation.

Roy et al. (2008) have predicted using a climate model that 1.4 ^{0}C and 4.12 ^{0}C increase of temperature in December to February of winter and 0.87 ^{0}C and 3.16 ^{0}C increase of temperature in monsoon of June, July and August in projection year of 2030 and 2075, respectively, compared to the base year 1990 assuming a scenario.

Mondal and Wasimi (2004) analysed the temperature data of 1960 to 1999 at 10 locations of Ganges Delta Area of Bangladesh and found an increase in minimum temperature 0.98 ^{0}C and that in maximum temperature was found to be 1.63 ^{0}C during November to December for 2030 and the corresponding values are 1.35^{0}C and 2.25 ^{0}C for 2050. For later months (January-May), where it was assumed that the rate of increase in minimum temperature is twice that of maximum temperature, the increase in minimum temperature is 1.73 ^{0}C and that in maximum temperature is 0.87 ^{0}C for 2030 and the corresponding values are 2.4 ^{0}C and 1.2 ^{0}C for 2050.

So, the predicted and observed data analysis indicates that there is an increasing trend in mean annual and seasonal temperature regionally and globally. The immediate impact of temperature rise will be on crop evapotranspiration.

2.1.2 Trends in Sunshine Hour

Padmanabhan (1973) found that the low number of bright sunshine hours of September and November of 1942 constituted a striking abnormality in that year due to continuous cloudiness at the time of flowering and maturity of the crop of Bengal, which prior of India covered the state of West Bengal in India and Bangladesh and suffered from a calamities famine in 1943. So the changes in sunshine hour have a bad impact on agriculture.

Studies on variations and trends of solar radiation have been conducted for many areas in the world. Most studies have found that there was a decrease in global radiation from the 1960's to the 1990's (Omran, 2000).

Persson (1998) analyzed fifteen years 1983-1997 of Swedish network of 12 solar radiation stations, for which a homogeneous radiation database has been built up. A clear increasing trend in global radiation of 7.2%/decade within the BALTEX area of Sweden was found. This is mainly due to the decreasing cloudiness.

In Mexico City, solar radiation attenuation is estimated by comparing global radiation intensity observed at a station in the downtown area relative to that observed in a cleaner rural area. The city receives on clear days during the dry season (1995-1996) 21.6% less solar energy than the rural surroundings. Similar values of attenuation are observed during the rainy season (1996) when aerosol concentration is abated by wash-out effect (Jauregui, 1998). The solar radiation attenuation is occurring in Mexico city due to highly polluted atmosphere. Global radiation attenuation shows an inverse dependence on wind speed and temperature, and is directly related to air pollution concentration and relative humidity.

The relative sunshine decreases of 0.18%, 0.19%, 0.22% at Shanghai, Nanjing and Hangzhou stations located in Eastern China every year, respectively, from 1961 to 2000 were found (Zhang et al., 2003). Air pollution increases the cloud cover and causes the decrease of relative sunshine. Shenbin et al. (2006) found that the trends of sunshine hour in 1961-1998 in China showed significant decreasing trend while the temperature and precipitation trends showed significant increasing trends.

The largest global radiation reductions have been reported between the late 1950's and the 1980's for industrialized cities like Hong Kong and Bet Dagan, Israel, which are 1.8 and 0.91 W m^{-2} $year^{-1}$, respectively. The cause of the decrease is highly correlated with cloudiness (Cohen et al., 2006).

IWFM (2008) has analyzed the trends in measured sunshine duration at eight stations in Bangladesh for different seasons, including the 36 ten-day periods in a year. The data analyzed range from 1961 to 2007. The average sunshine duration has declined over the three periods: 1961-1975, 1976-90 and 1990-06. The amount of decrease, particularly in the dry season, is quite significant. The winter, dry season, summer and monsoon rates of decline are respectively 0.38, 0.31, 0.22 and 0.18 hours a day in every 10 years for entire Bangladesh. The highest decrease (0.5 hours a day per 10 years) is found to be in Dhaka and the lowest in Chandpur (0.1 hours a day per decade), an estuarine station.

So, most of the studies have found that there are a decrease in sunshine hour which can seriously affect the evapotranspiration and the main causes of this decrease is cloudiness formed by air pollution.

2.1.3 Trends in Air Humidity

The relative humidity is an important factor affecting evapotranspiration. Relative humidity is important as it directly affects atmospheric visibility, strongly influencing the formation of clouds, fog and smog (Elliot and Angel, 1997) which also affects sunshine hour. The changes of relative humidity have been found by various studies.

Wijngaarden and Vincent (2004) found a substantial decrease in relative humidity throughout Canada during 1953-2003. The trend found by averaging the relative humidity for all 75 stations is 6% significant at the 5 % confidence level for winter and spring. These trend correlates with changes found in the dew point temperature and precipitation.

McCarthy and Toumi (2004) found that at subtropical latitudes variations in temperature contribute between 50% and 70% of the observed change in relative humidity. It was also shown that large relative humidity anomalies exist over the equatorial Indian, Atlantic, and far east Pacific Oceans during the summer season.

Ahmed et al. (2007) reported a significant increasing trend of annual relative humidity by a rate of 0.13 (%)/year from 1923 to 2005 at Amman Airport Meteorological (AAM) station of Jordan. These increasing trends are statistically significant in summer and autumn seasons. A major change point in the annual relative humidity occurred in 1979 at AAM station. The Authors estimated that the increase in relative humidity might be due to the increase of evaporation in the Mediterranean Sea which lies about 100 km from Jordan.

Singh et al. (2007) studied seasonal and annual trends of changes in rainfall, rainy days, heaviest rain and relative humidity over the last century for nine different river basins in northwest and central India. The majority of river basins have experienced an increasing trend in relative humidity both on seasonal and annual scales. An increase in annual mean relative humidity for six river basins has been found in the range of 1-18% of mean per 100 years, while a decrease for three river basins from 1-13% of mean per 100 years was observed, providing a net increase in the study area by 2.4% of mean per 100 years. It is understood that an increase in areal extent of vegetation cover as well as rainfall over the last century has increased the moisture in the atmosphere through enhanced evapotranspiration, which in turn has increased the relative humidity.

The above literatures show that in most of the cases, relative humidity is increasing. It is related with increase in temperature and evapotranspiration. The increasing relative humidity is also affecting sunshine hour forming more clouds, fogs, etc.

2.1.4 Trends in Wind Speed

Near-surface wind speed variability is investigated by Klink (2002) at seven stations in and surrounding Minnesota of USA, for recent climate records of 22–35 year in length. Analyses focus on mean annual wind speeds and on the 10th, 25th, 50th, 75th, and 90th percentiles of the annual distributions of mean daily wind speeds. Most of the seven stations showed a trend toward reduced mean annual wind speeds; though one station showed increasing speeds and one station had no overall trend. In general, wind speed trends were most pronounced at the 50th, 75th, and 90th percentiles of the annual distributions, regardless of the trend in the mean.

Fumika (2003) did an analysis on long-term changes in wind speed at AMeDAS (Automated Meteorological Data Acquisition System) stations of Japan using data for twenty years from March 1979 to February 1999. On the average over 482 stations, which were judged to be free from changes in site and/or anemometer height, daily maximum wind speed and daily mean wind speed showed a decrease of 0.41%/year and 0.26%/year, respectively. At some stations, wind speed was found to have decreased at a rate of 4-5% per year.

Tuller (2004) discussed trends in measured wind speed for four stations on the west coast of Canada. Periods of record vary with the station. They begin in the late 1940s or the 1950s and run through to the early to mid 1990s. The most prominent feature of the time series was a decline in mean annual and winter wind speeds at Cape St James, Victoria International Airport, and Vancouver International Airport during the middle portion of the record.

Wind speed also affects the evapotranspiration. In the Tiebatan Plateau, the wind speed has decreased in 85% of observations (Zhang et al., 2003). The analysis showed that decreasing trend in reference evapotranspiration of the Tiebatan Plateau was due to a decrease in wind speed and a decrease in net total radiation.

2.1.5 Trends in Rainfall

Rainfall affects evapotranspiration and irrigation requirement of the crop. Any change in the magnitude, distribution, or frequency of rainfall during the dry season due to global warming would result in water demand. To analyze the combined effect of climatic variables on net irrigation demand, the studies of the changes of rainfall should be reviewed.

Past studies show different changes in rainfall in Bangladesh. IPCC (1996) shows an increase in annual precipitation of about 2% over Bangladesh. An increasing trend in long-term precipitation (from observation of 1900 to 1994) of about 2% in mean annual precipitation is also projected in that report. However, even if this trend continues in future, it is still difficult to make any inference about the trend in dry season rainfall from an annual trend since there is a strong variability in rainfall over Bangladesh.

Existing published literature based on predictions from different GCMs provide varying scenarios not only in terms of magnitude but also in terms of direction of about possible intra-year changes in rainfall over Bangladesh due to global warming. Warrick et al. (1996) has reported 5-10% increase in both winter and summer rainfalls for the year 2030 and Brammer et al. (1996) has reported 8-15% increase in winter rainfall for 2050. In Ahmed and Alam (1999) a decrease in winter rainfall of 3% and 37% for 2030 and 2050, respectively, is reported. Karmakar and Shrestha (2000) predict that annual total rainfall over Bangladesh is likely to increase by 295.94 mm and 542.55 mm by 2050 and 2100, respectively. However, winter precipitation would decrease at negligible rate in 2030, while at 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12% and 27% for the two projection years, respectively (Rahman and Alam, 2003). It was also found that winter rainfall is likely to increase by 3.8% and 10.4 % by the year 2030 and 2075 (Roy et al., 2008).

Divya and Mehrotra (1995) reported that there is no long term trend in rainfall over India. Sing and Sontakke (2002) found a decreasing trend (statistically insignificant) in the summer monsoon (June-September) rainfall over the central and eastern Indo-Gangetic plain.

IWFM and CEGIS (2008) also reported that the precipitation would increase 1.56%, 13.19%, 10.49% and 2.51% in the North-West, North-East, North-Central and South-West hydrological regions of Bangladesh, respectively, during dry season for the two future periods 2025 with respect to the baseline period of 1979 to 1999 using the Regional Ciculation Model (RCM) PRECISA2.

Most of the studies show the increasing trends in rainfall mainly in summer. The results of winter rainfall are mixed which either decreasing or increasing. But most of the past results show decreasing trends. As the net irrigation requirement is the difference between crop evapotranspiration and effective rainfall, the changes of rainfall will affect water demand.

2.2 Changes in Evapotranspiration

The changes in climatic variables are likely to have a profound effect on evapotranspiration being the major component of hydrological cycle which will affect crop water requirement. The climatic variables (temperature, sunshine hour, relative humidity and wind speed) around the world are increasing or decreasing. Any change in magnitude of the variables has significant impacts on evapotranspiration.

The changes in evaporation, evapotranspiration and the correlation of climatic variables with them have been studied elsewhere in the world. Increases in cloud cover and thus decreases in net radiation have been identified as the most likely responsible for decreasing potential evapotranspiration in the United States and the former Soviet Union (Peterson et al., 1995). In India, Chattopadhyay and Hulme (1997) also found that increases in relative humidity and decreases in radiation are both correlated with the decreasing trend in potential evapotranspiration.

Milly and Dunne (2001) found that the annual average evaporation in the Mississipie River basin has increased by about 0.95 mm/each year during 1949-1997. Golubev et al. (2001) reported increases of actual evaporation in the warm seasons of several decades, mostly from large weighing type of lysimeters in six areas of Southern Russia and Ohio. In these cases, the ratio of rainfall to lake evaporation was low.

Yu et al. (2002) found that evapotranspiration from paddy fields for the two crop seasons in the Kao-Hsiung area of southern Taiwan has increased by 4.95% and 3.09% for one climate change scenario. The other scenarios show increases of 5.50% and 3.20%. The authors used for their study a sensitivity analysis of each meteorological variable using the Penman formula. Fourty eight years (1950-1997) data on temperature, relative humidity, sunshine hour, wind speed, and precipitation comprised the data base. Three meteriological variables, solar radiation, relative humidity, and temperature, were found to influence the evapotranspiration estimation.

Liu and Zeng (2004) reported a decrease in pan evaporation over the Yellow River basin in China between 1960 and 2000, mainly due to reductions in sunshine duration and solar irradiation, while Liu et al. (2004) associated their observed decrease in pan evaporation in eight different climatic regions in China to the changes in solar irradiance and water conditions.

Linacre (2004) used a simplified version of the Penman evaporation formula, which shows that the reduction of lake evaporation rates (E_0) is due chiefly to the general lessening of solar radiation at the surface. In consequence of the decline of E_0, a two-regime model of the evaporation from land surfaces shows that there has been a decrease in the rate of actual evaporation from land surfaces (Ea). Also, at places where rainfall exceeds decadal average pan evaporation rates (Ep), the rate of water loss from a US Class-A pan evaporimeter has decreased.

Goyal (2004) suggested an increase of 14.8% of total evapotranspiration (ET) demand with increase in temperature by 20%. ET is less sensitive (11%) to increase in net solar radiation, followed by wind speed (7%) in comparison to temperature. Increase in vapor pressure (20%) has a small negative effect on ET (-4.31%). A 10% increase in temperature and actual vapor pressure coupled with 10% decrease in net solar radiation could result even in marginal decrease of total ET (0.30%). Increase of 10% in temperature alone, with 10% decrease in net solar radiation, actual vapor pressure and wind velocity could also result in marginal decrease in total ET (0.36%). In the above study Penman–Monteith equation was used to estimate reference evapotranspiration, and sensitivity of ET of Rajasthan (India) has been studied in terms of change in temperature, solar radiation, wind speed and vapor pressure from the normal long-term meteorological parameters of 32 years (1971–2002). Changes in precipitation have not been considered in this study.

Shenbin et al. (2006) have been analyzed time series (1961-2000) of Penman-Monteith potential evapotranspiration (PET) for 101 stations on the Tibetan Plateau (TP). They have showed in their study that average PET trends (1961-2000) on the TP as a whole has decreased in all seasons. The average annual evapotranspiration rate has decreased by 13.1 mm/decade or 2.0% of the annual total. PET trends on the TP are mainly influenced by changes in wind speed and relative humidity.

Wang et al. (2006) have showed in their study that the annual and seasonal trends for both pan evaporation and reference evapotranspiration are decreasing in the whole Yangtze river basin for 1961-2000. The authors reported that the decreasing trends are associated with trends in net radiation and wind speed. The main factor associated with reducing pan evaporation and reference evapotranspiration is net radiation.

The above studies show that the changes of evapotranspiration of different regions are strongly correlated with increasing or decreasing climatic variables. Decreasing sunshine hour, cloudiness and increasing relative humidity, temperature and precipitation have significant impact on changes in evapotranspiration.

Thomas (2007) reported regionally and seasonally diverse trends in potential evapotranspiration in China. For China as a whole, seasonal and annual trends are decreasing. Decreasing sunshine duration appears as the major cause of reduced potential evapotranspiration south of 35^0 N, while in northern parts changes are most likely associated with maximum temperature (northeast China), relative humidity (central northern China) and wind speed (northwest China).

In Bangladesh, most of the studies were done to find the evaporation trends and the relation between climatic variables and evaporation. Ahmed and Alam (1999) show that the average evaporation in Bangladesh would remain almost unchanged in 2030 but would be slightly higher in 2075 with respect to the base year 1990. But in 2075, evaporation would be much higher in winter. There would be more precipitation during the monsoon period and less precipitation in winter. In the above study, the change in evaporation has been found only by considering the precipitation. IWFM (2008) using the BWDB data of 11 stations from 1964-65 to 1995-98 reported that evaporation rate has decreased in Bangladesh. The reduction in sunshine duration has been attributed to be the principal reason for such a decrease in evaporation. The decrease is higher in pre-monsoon summer months of March-May. The average decrease during this period is about 15% and this decrease is unambiguous. Mondal and Wasimi (2004) have estimated an increase in reference crop evapotranspiration (ET_0) of 3.0% by 2030 and about 4.1% by 2050 for the entire Ganges Delta Area within Bangladesh due to climate change. The authors used Penman-Monteith method for ET_0 computation, where the changes in maximum and minimum temperatures have been accounted for and other climatic factors, such as air humidity, wind speed and solar radiation were not taken into consideration. IWFM and CEGIS (2008) also reported that the potential evapotranspiration would increase 1.47%, 0.36%, 0.87% and 1.64% in the North-West, North-East, North-Central and South-West hydrological regions of Bangladesh, respectively, during dry season for the future period 2025 with respect to the baseline period of 1979 to 1999 using the Regional Ciculation Model (RCM) PRECISA2.

2.3 Changes in Irrigation Water Demand

To estimate irrigation water demand, reference crop evapotranspiration (ET_0) is to be estimated first. The evapotranspiration rate from a reference surface, not short of water, is called ET_0. The reference surface is a hypothetical grass reference crop with an assumed crop height of 12 mm and an albedo of 0.23. The factors affecting ET_0 are climatic parameters (temperature, relative humidity, sunshine hour and wind speed). ET_0 is a climatic parameter and can be computed from weather data (Allen et al., 1998). The FAO Penman-Monteith method is recommended as the sole standard method for determining ET_0 (Allen et al., 1998).

Crop water requirement (ET_C) is calculated by the product of reference crop evapotranspiration and K_C. Empirically-determined crop coefficients (K_C) is used to relate ET_0 to crop water requirement (ETc). For a given climate, crop and crop development stage, the crop water requirement (ET_C) of the period considered is:

$$ET_C = K_C * ET_0$$

The value of K_C varies with crop and development stages: initial, growing, mid-season, and late-season. In this study for boro rice irrigation in Bangladesh, where average relative humidity is greater than 70% and wind condition is moderate during the dry season, K_C values of 1.1, 1.25 and 1.0 are reasonable for the first and second months, mid-season and last four weeks, respectively (Doorenbos and Pruitt, 1977). The next step to estimate irrigation requirement is net irrigation requirement which is the difference between ET_C

and effective rainfall. The irrigation requirement can also be calculated from field irrigation requirement and gross irrigation requirement. But irrigation requirement from crop point of view, i.e. the net irrigation requirement, has been considered in this study.

Global climate change has serious impact not only on evapotranspiration but also on irrigation water in the future. Various studies have been undertaken in the past to evaluate the impact of climate change on water demand. The use of general circulation model and (GCM) projections has been the core of climate change impact assessment for agriculture and water resources in the past.

Alcamo et al. (2000) employed a raster-based model of Doll and Siebert (2001), with a spatial resolution of 0.5^0 by 0.5^0. The results show that irrigation requirements would increase in most irrigated areas in the north of the Mediterranean basin, which is mainly due to the decreased precipitation during the summer.

The IPCC (2001) reported that agricultural demand, particularly for irrigation water, is considerably more sensitive to climate change. Doll and Siebert (2001) applied a global irrigation water-use model with a spatial resolution of $0.5^0 x 0.5^0$ to assess the impact of climate change on net irrigation requirements per unit irrigated area. Using two types scenarios the authors found that net irrigation requirement per unit irrigated area generally would decrease across much of the Middle East and Northern Africa as a result of increased precipitation, whereas most irrigated areas in India would require more water. The extra irrigation requirements per unit area in most parts of China would be small with a greater increase in northern China. Two scenarios considered by Doll and Siebert (2001) show that global net irrigation requirements would increase, relative to the situation without climate change, by 3.5-5% by 2025 and 6-8% by 2075. In the above study, the precipitation and temperature were considered to assess the impact of climate change on irrigation water demand.

Doll (2002) reported that in Egypt, a decrease in net irrigation requirement of about 50% in the southern part is accompanied by an increase of more than 30% in the central part. The decrease in net irrigation requirements depends on the fact that the cropping patterns and growing seasons of an irrigated area are strongly influenced by temperature and precipitation conditions.

Doria et al. (2006) estimated the changes in future crop water requirements due to climate change in Southern Ontario of USA for 2020 and 2050 using CropWat. Results compared to the baseline climate which is based on 30 year-period (1971-2000) show a decrease in irrigation requirements of 27% compared to the current situation using models for 2020s. While in 2050s, there would be decreases of 2.71% (8mm), 21% (64mm) and 6% (59mm) for three different scenarios.

Rahman (2008) reported that the crop water requirement for T. Aman in command area of Teesta Barrage Project of Bangladesh would increase due to the climate change in the future projections (2025 and 2050) from that of the base line period 1990 which is depended on type of model and scenario.

To assess the impacts of temperature and precipitation on crop evapotranspiration and irrigation demand, Mondal et al. (2008) considered three scenarios of climate change which were-mild, moderate and severe changes scenarios-based on the first quartile, median and third quartile changes in predicted climate for South Asia in IPCC (2007). Average increase in demand was found to be about 6.6%, 7.7% and 8.5% under the mild, moderate and severe change scenarios, respectively. The lowest increase was found in the second 10-day period of April and the highest in the first 10-day period of December. So the authors found that due to temperature increase and rainfall increase or decrease will increase the demand of irrigation water. Other climatic factors were not included in the study.

Chapter III

METHODOLOGY AND DATA COLLECTION

3.1 Methodology

3.1.1 Trend Analysis

There are two methods of trend analysis- one is the parametric method and the other is the non-parametric method. Parametric method is the common and widely used method in hydrology and water resources. In the parametric method, a scatter plot of the dependent variable (Y) and the independent variable (X) is first made. A least-square linear regression line is then superimposed to the plot. This is can be done in Microsoft excels, SPSS, many other software packages. The fitted regression line has the equation of the following form:

$$\hat{Y} = \hat{a} + \hat{b}X$$

where $\hat{a}$ and $\hat{b}$ are the estimated intercept and slope of the line, respectively. The slope is actually the trend in the given variable. The unit of the slope depends on the unit of the Y and X variables. If the Y variable is sunshine duration in hours and X is the time in years, then the unit of trend is hours per year. In this study, analysis of trends of different climatic and hydrologic variables is done using this technique.

Trend analyses have been conducted using the nonparametric Mann-Kendall (MK) test (Helsel & Hirsch, 1992). This test has been widely used for hydrological data analysis (Lettenmaier et al., 1994). It is a rank-based procedure especially suitable for non-normally distributed data, censored data, and nonlinear trends. Its advantages are that it is distribution free, robust against outliers, and has a higher power than many other commonly used tests (Hess et al., 2001).

The equation of the non-parametric linear trend is the same as the parametric one. However, the techniques of parameter estimation are different and are described in conover

(1980). The slope of the line is estimated by comparing each data pair to all others in a pair wise fashion. For each pair, a slope is computed. The median of all possible pairwise slopes is taken as the non-parametric slope estimate. There are a number of methods for estimation of the intercept. One is the median of all possible intercepts computed by solving the kendall line using each slope and each data point (Dietz, 1989). The estimate of intercept produced by placing the line through the data medians is efficient in the presence of outliers and non-normal residuals. The method is robust, efficient and analogous to ordinary least square (OLS) method. Excel and SPSS have not incorporated the technique in the packages. So this method is not used in this study. However, the testing of the significance of the trends can be carried out using this technique in SPSS.

Both parametric and non-parametric methods (Maidment, 1992) have been used for testing the significance of trends of different climatic and hydrological variables. The most commonly used statistic in parametric method is Pearson's r and that in non-parametric method is Kendall's τ. Pearsnon's r is also called the linear correlation coefficient because r measures the linear association between two variables. If the data lie exactly along a straight line with positive slope, then $r = 1$. Pearson's r is not as resistant to outliers as was τ because it is computed using non-resistant measures-means and standard deviations. It also assumes that the data follow a bivariate normal distribution.

Tau (Kendall, 1938, 1975) measures the strength of the monotonic relationship between an independent variable X and a dependent variable Y. Tau is rank-based procedure and is therefore resistant to the effect of a small number of unusual values. Mann (1945) first suggested using the test for significance of Kendall's tau where the X variable is time (T) as test for trend. The Mann-Kendall test can be stated most generally as a test for whether Y values tend to increase or decrease with T (monotonic change). No assumption of normality is required. The Mann-Kendall test possesses the useful properties of other non-parametric tests that it is invariant to (monotonic) power transformations. It is applicable in many situations.

Tau is most easily computed by first ordering all data pairs by increasing X (T in the case of time series data). If a positive correlation exists, the Y's will increase more often than decrease as X increase. For a negative correlation, the Y's will decrease more often than increase. If no correlation exists, the Y's will increase and decrease about the same number of times.

A two-sided test for correlation will evaluate the following equivalent statements for the null hypothesis H_0, as compared to the alternate hypothesis H_1:

H_0: a) no correlation exists between X and Y $(\tau = 0)$, or

b) X and Y are independent, or

c) the distribution of Y does not depend on X, or

d) Prob (Y_i<Y_j for i<j)=1/2.

H_1: a) X and Y are correlated $(\tau \neq 0)$, or

b) X and Y are dependent, or

c) the distribution of Y (percentiles, etc.) depends on X, or

d) Prob (Y_i<Y_j for i<j) $\neq$ 1/2.

The test statistic S measures the monotonic dependence of Y on X. Kendall's S is calculated by substracting the number of discordant pairs (M), the number of (X,Y) pairs where Y decreases as X increases, from the number of concordant pairs (P), the number of (X,Y) pairs where Y increases with increasing X.

There are n(n-1)/2 possible comparisons to be made among the n data pairs. If all y values increased along with the X values

where P = "number of pluses", the number of times the Y's increase as the X's increase, or the number of Yi < Yj for all i < j,

M = "number of minuses," the number of times the Y's decrease as the X's increase, or the number of Yi > Yj for i < j .

for all i = 1,....(n-1) and j = (i+1),.....n.

There are S =n(n-1)/2 possible comparisons to be made among the n data pairs. If all Y values increase along with the X values, S =n(n-1)/2. In this situation, the correlation coefficient should equal +1. When all Y values decrease with increasing X, S = -n(n-1)/2 and τ should equal -1. Therefore dividing S by n(n-1)/2 will give a value always falling between -1 and +1. This then is the definition of τ, measuring the strength of the monotonic association between two variables:

$$\tau = \frac{S}{n(n-1)/2}$$

To test for significance of τ, S is compared to what would be expected when the null hypothesis is true. If it is further from 0 than expected, H_0 is rejected. For $n \le 10$ an exact test should be computed.

3.1.2 Estimation of Evapotranspiration

A large number of more or less empirical methods have been developed over the last 50 years by numerous scientists and specialists world wide, to estimate evapotranspiration from different climatic variables. Four such methods were presented to calculate the reference crop evapotranspiration (ET_0) are: the Blaney-Criddle, radiation, pan evaporation and modified Penman methods. These climatic methods to calculate ET_0 are all calibrated for ten-day or monthly calculations, not for daily or hourly calculations. The Blaney-Criddle method is for areas where available climatic data cover air temperature data only. The method is recommended for periods of one month or more. The radiation method was suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind speed or air humidity. The pan evaporation method gives acceptable estimates, depending on the location of the pan.

These methods are not very accurate for research. The results by these methods have been influenced by site or by bias in weather data collection. These methods do not behave the same way in different locations around the world. The modified Penman was frequently found to overestimate ET_0, even by up to 20% for low evaporative conditions.

The comparative studies may be summarized as follows:

The radiation method shows good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and tends to underestimate evapotranspiration.

Pan evaporation method clearly reflects the shortcomings of predicting crop evapotranspiration from open water evaporation. The method is susceptible to the microclimate conditions under which the pans are operating and the rigour of station maintenance. Their performance proves erratic.

The Penman method may require local calibration of the wind function to achieve satisfactory results. In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed. This method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors.

Smith (2000) gives an overview of the widely accepted practical procedures that have been developed by FAO and others to estimate crop water requirements and yield response to water stress. The methodologies of crop water requirements were first published as FAO Irrigation and Drainage Paper 24 in 1974 and revised in 1977 (Doorenbos and Pruit, 1977). A review and update of the methodologies are contained in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998). These methodologies use the Penman-Monteith equation that estimates daily reference crop evapotranspiration (mm/day) based on net radiation, soil heat flux, average air temperature, wind speed, vapor pressure deficit, and other humidity parameters. The Penman-Monteith method relies on a number of parameterizations to take into account environmental conditions. Values of crop surface resistance, albedo and crop height are set to 70 sm^{-1}, 0.23 and 0.12 m, respectively as recommended by Allen et al. (1998).

The Penman-Monteith method (Allen et al., 1998) is the method by which the reference crop evapotranspiration (ET_0) can be unambiguously determined and the method provides consistent ET_0 values in all regions and climates. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the American Society for Civil Engineers (ASCE) and European studies. The method is the most reliable way to estimate ET_0 under various climates (Jensen et al., 1990), as it reflects the changes in all meteorological factors affecting evaporation and plant transpiration. It is a method with strong likelihood of correctly predicting ET_0 in a wide range of locations and climates and has provisions for application in data-short situations. The use of older FAO or other reference ET methods is no longer encouraged. So the FAO Penman-Monteith method is recommended as sole standard method.

The FAO CROPWAT software incorporates these methodologies and procedures to simulate crop water use under various climate, crop, and soil conditions. This software has been used in this study.

3.1.3 Estimation of Net Irrigation Requirement

To estimate net irrigation requirement, crop water requirement is to be estimated first. ET_c is obtained by multiplying the reference crop evapotranspiration (ET_0) with an appropriate crop factor K_c. As mentioned earlier. ET_0 has been calculated by the Penman-Monteith method in this research. For determining K_c, the time and length of growing period of crops, which is commonly known as crop calendar, are required. For the Boro rice, the growing periods have been taken from January to May with transplanting during 21 December to 31 January and harvesting during 21 April to 31 May, following Mondal et al. (2008) [Figure 3.1]. Four stages of staggering of the Boro rice were assumed with each stage having equal proportion of land (25%). The net irrigation requirement (NIR) for

Boro rice is estimated from the difference of ET_c and effective rainfall by the following equation:

$$NIR = ET_c - R_e + S \text{ and } P$$

where,

NIR= net irrigation requirement,

ET_c= crop water requirement

R_e= effective rainfall

S and P = Seepage and Percolation

The seepage and percolation loss is not considered here. Because, irrigation requirement is considered here from crop point of view and seepage and percolation is loss part of irrigation water. R_e is the amount of rainfall not exceeding the ET_c. For example, if the ET_c in a particular 10-day period is 4 mm/day giving a total of 40 mm during the 10 days and the total rainfall is less than 40 mm, then the entire 40 mm is effective. However, if the rainfall is more than 40 mm, then the effective rainfall is 40 mm and the rest of the rainfall is ineffective. Rainfall is found to be very low in the dry season and fully effective in most of the 10-day periods. For example, the average rainfall was 0 mm in January, 2006 and the average ET_c was 3 mm/day. If the NIR appeared negative, it was replaced with zero.

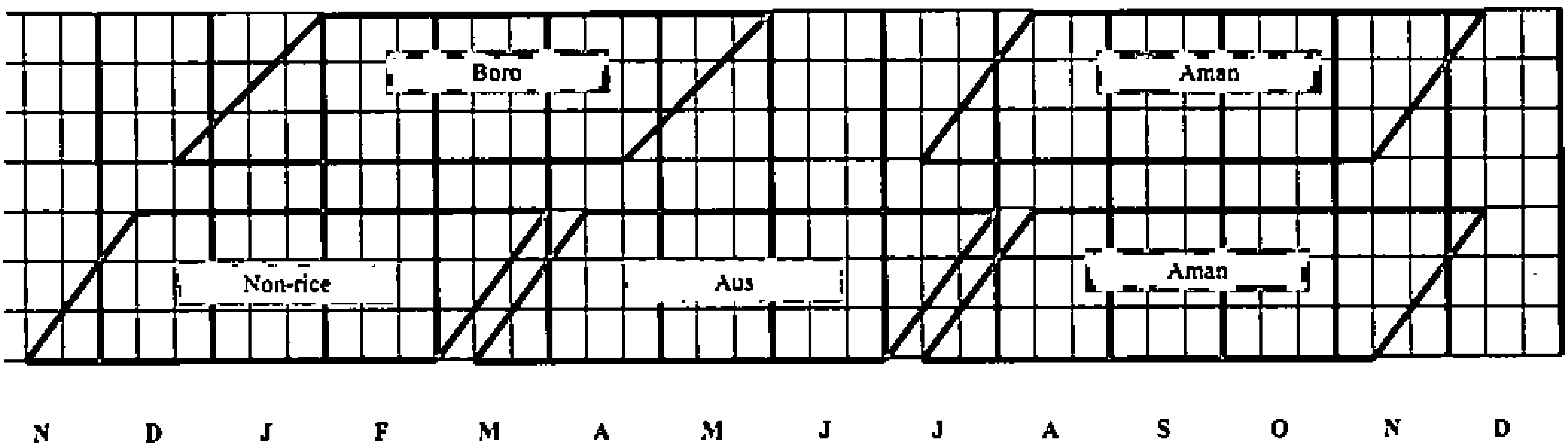

Figure 3.1: Crop calendar showing the growing season of Boro rice (Mondal et al., 2008)

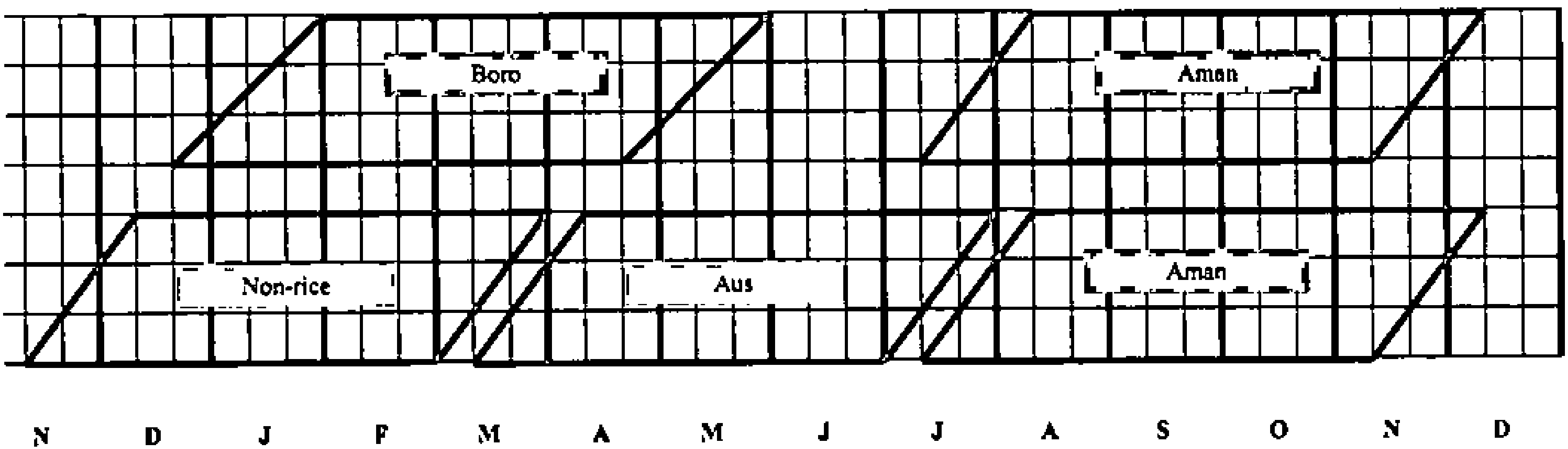

Figure 3.1: Crop calendar showing the growing season of Boro rice (Mondal et al., 2008)

3.2 Data Collection

This study is based on secondary data and information. Data of four meteorological stations, namely Dhaka, Jessore, Bogra and Chandpur, on daily observations of air temperatures, air humidity, solar radiation, wind speed and rainfall are used in this study. The stations are selected such that they can cover the North-Central, South-West, South-East and North-West hydrological regions, respectively. The locations of the stations are shown in Figure 3.2. The data from 1961-2001 were available with the Institute of Water and Flood management. The recent data since 2002 were collected from Bangladesh Meteorological Department (BMD). 10-day scale for the analysis has been used as it closely resembles the resources and agricultural planning activities in Bangladesh. The data of Chandpur station is not very reliable as there are many missing data and the long term data for this station was not available. From the daily values, the ten day average was obtained for each year, each month and each station.

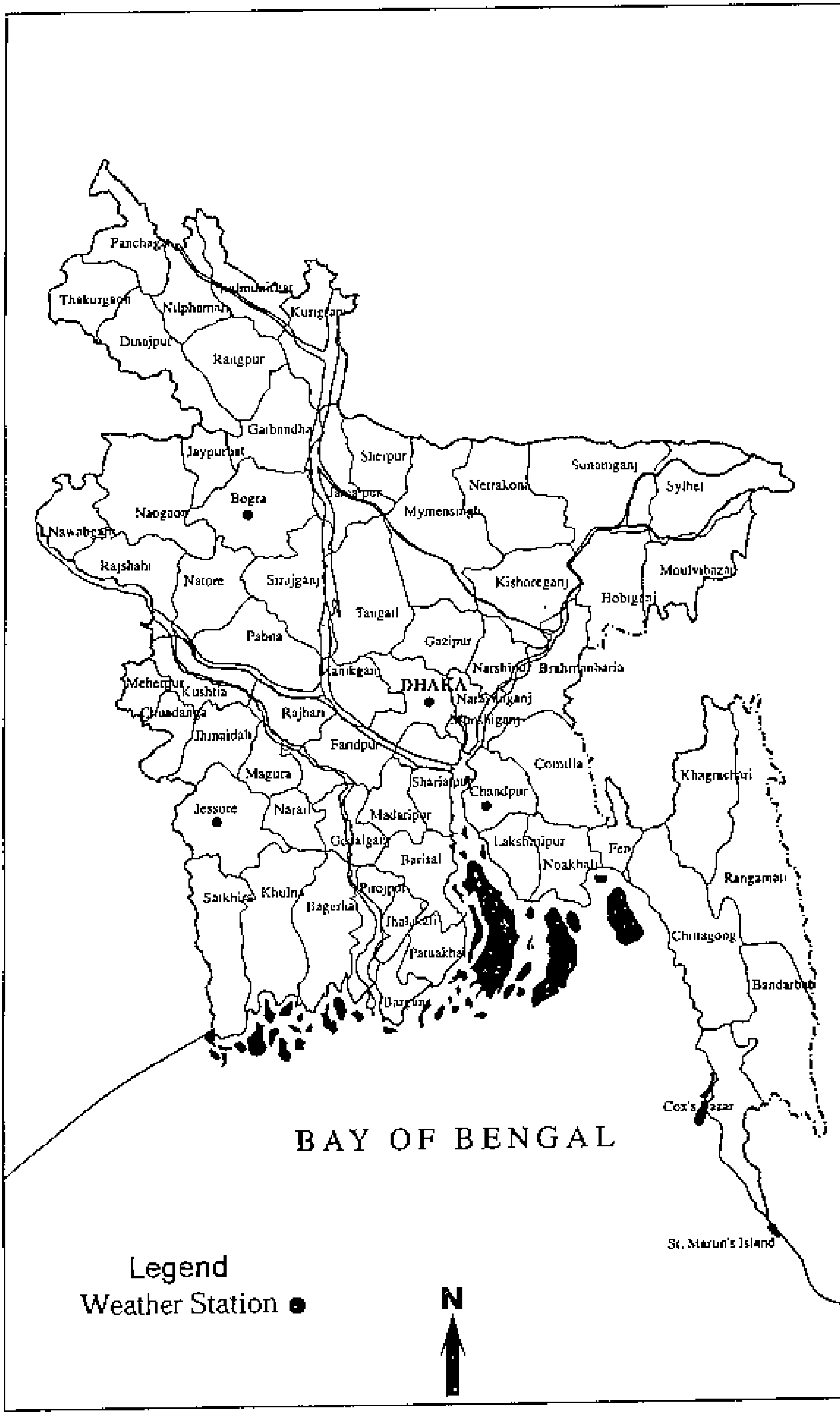

Figure- 3.2: Selected Station Locations of BMD

Chapter IV

DETERMINATION AND TESTING OF TRENDS IN CLIMATIC VARIABLES

4.1 Maximum Temperature

The trends in maximum temperature during different 10-day periods of the dry season (November-May) at four climatic stations (Dhaka, Jessore, Bogra and Chandpur) were estimated by the parametric method using the Statistical Package for Social Sciences (SPSS) software. They are given in Table 4.1. It is seen from the table that maximum temperature has increasing trends in most 10-day periods for the four stations. The average increasing trends of maximum temperature in the dry season from 1961 to 2007 for Dhaka, Jessore and Chandpur are 0.2^{0}C, 0.2^{0}C and 0.1^{0}C, respectively, per decade (10 years). Bogra has decreasing trend which is 0.2^{0}C per decade. Bogra is an irrigation intensive area which may be a possible reason for decreasing trend in maximum temperature.

Table 4.1: Trends in maximum temperature (^{0}C) per year during different 10-day periods at four climatic stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	0.07	0.06	0.07	0.01
	2	0.06	0.04	0.06	0.04
	3	0.04	0.02	0.05	0.03
Dec	1	0.04	0.02	0.02	0.02
	2	0.04	0.03	0.04	0.03
	3	0.04	0.03	0.03	0.03
Jan	1	-0.02	-0.02	-0.02	0.02
	2	-0.00	-0.03	-0.01	0.01
	3	0.00	-0.02	-0.01	-0.00
Feb	1	0.04	-0.01	-0.01	0.01
	2	0.00	-0.03	-0.05	0.01
	3	-0.05	-0.06	-0.09	-0.04

Table 4.1: (Continued)

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Mar	1	-0.01	-0.02	-0.05	0.03
	2	0.00	-0.00	-0.03	0.01
	3	-0.02	0.02	-0.06	-0.00
Apr	1	-0.00	0.00	-0.10	0.02
	2	0.03	0.10	-0.07	0.05
	3	-0.03	0.09	-0.10	-0.01
May	1	0.04	0.09	-0.05	0.03
	2	0.03	0.06	-0.01	-0.01
	3	0.01	0.05	0.00	-0.02
Average		0.02	0.02	-0.02	0.01

Both non-parametric and parametric correlations between maximum temperatures and time (years in this case) were estimated using the SPSS software. The correlations between 10-day maximum temperatures and time (years) for Dhaka station are given in Table 4.2. It is seen from the table that the maximum temperature at the Dhaka station has statistically significant increasing trends in the months of November and December at the 5% level of significance (significant level being less than or equal to 0.05). So, the probability of occurrence of rising trend in maximum temperature by chance is less than or equal to 5 % and there are at least 95% probability that such trends are due to some genuine reasons. There are statistically non-significant increasing trends in seven 10-day periods of January-May. But in the seven 10-day periods of January-April, maximum temperature has statistically non-significant decreasing trends. The third 10-day period of February has decreasing trend which is statistically significant at 5% level. It thus appears that though the overall trends are increasing, there are some variations among the different 10-day trends. The maximum temperature at Dhaka station has the most significantly increasing trend in the first 10-day of November.

Table 4.2: The correlation coefficient between 10-day maximum temperatures and time (years) and its significance level at Dhaka station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.449	0.000	0.564	0.000
	2	0.338	0.003	0.533	0.001
	3	0.248	0.031	0.438	0.007
Dec	1	0.327	0.005	0.401	0.014
	2	0.272	0.018	0.364	0.027
	3	0.277	0.016	0.357	0.030
Jan	1	0.087	0.443	-0.078	0.642
	2	-0.043	0.706	-0.024	0.885
	3	-0.078	0.489	0.010	0.951
Feb	1	0.127	0.263	0.231	0.162
	2	-0.036	0.753	0.033	0.844
	3	-0.228	0.044	-0.362	0.025
Mar	1	-0.088	0.436	-0.089	0.597
	2	-0.044	0.697	0.002	0.992
	3	-0.044	0.697	-0.083	0.618
Apr	1	0.009	0.940	-0.026	0.879
	2	0.143	0.209	0.162	0.332
	3	-0.201	0.076	-0.224	0.177
May	1	0.163	0.152	0.214	0.278
	2	0.127	0.263	0.181	0.278
	3	0.050	0.660	0.077	0.648

The correlations of 10-day maximum temperatures with years at Jessore station are shown in Table A_1 of Appendix A. The table shows that thirteen 10-day periods have increasing trends and the remaining eight 10-day periods have decreasing trends. Six 10-day periods have significantly increasing trends at 5% level. Two 10-day periods have increasing trends at 10% significance level (significant level being less than or equal to 0.10). Five 10-day periods have non-significantly decreasing trends. The second 10-day periods of January and February have decreasing trends at 10% significant level and the third 10-day of February has decreasing trend at 5% significant level. Overall the maximum temperatures have increasing trends. The maximum temperature at Jessore station has the most significantly increasing trend in the first 10-day of November.

The correlation statistics for maximum temperature at Bogra station are shown in Table A_2 of Appendix A. The correlations indicate increasing trends in ten 10-day periods and decreasing trends in eleven 10-day periods. Among the ten increasing 10-day periods, five 10-day periods have trends which are significant at 5% level. Among the eleven decreasing 10-day periods, five 10-day periods have significantly decreasing trends at 5% level and the second and the third 10-day periods of April have significantly decreasing trends at 10% level. So it is seen that the maximum temperatures at Bogra station have more decreasing than increasing trends. The most significant increasing trend occurs in the first 10-day of November at Bogra station.

The correlation coefficient of maximum temperature for Chandpur station is given in Table A_3 of Appendix A. Maximum temperatures of sixteen 10-day periods of Chandpur are increasing non-significantly. Maximum temperatures in the third 10-day of January and the third 10-day of February are significantly decreasing whereas that in the third 10-day of April, and the second and third 10 days of May are decreasing non-significantly. So the maximum temperature trends of Chandpur station are increasing non-significantly.

A scatter plot between maximum temperatures and years, with a superimposed linear trend line, is shown in Figure 4.1 as an example to have a visual idea of the trend.

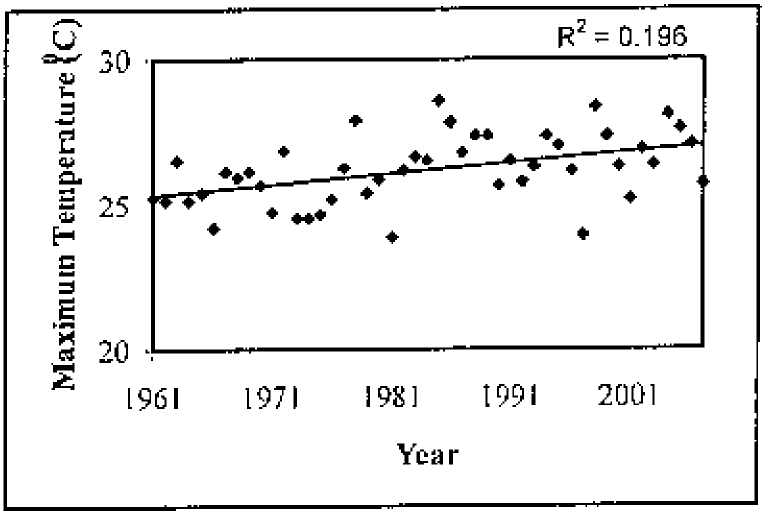

Figure 4.1: The maximum temperature in the second 10-day period of December at Dhaka station

4.2 Minimum Temperature

The estimated trends in minimum temperature at different 10-day periods for four stations are shown in Table 4.3. It is seen from the table that the minimum temperature has increasing trends in most 10-day periods. The average increasing trends in minimum temperature during the dry season are 0.3°C, 0.2°C, 0.2°C and 0.1°C per decade for Dhaka, Jessore, Bogra and Chandpur, respectively.

Table 4.3: Trends in minimum temperature (°C) per year during different 10-day periods at four climatic stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	0.06	0.04	0.07	0.00
	2	0.05	0.02	0.05	0.03
	3	0.04	0.00	0.03	0.01
Dec	1	0.04	0.02	0.02	-0.00
	2	0.04	-0.01	0.03	0.00
	3	0.06	0.03	0.03	0.02

Table 4.3: (Continued)

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Jan	1	0.05	0.00	-0.00	0.01
	2	0.06	0.02	0.00	0.01
	3	0.02	-0.01	0.01	-0.00
Feb	1	0.03	0.03	0.03	0.01
	2	0.07	0 04	0.04	0.01
	3	0.04	0.02	0.04	-0.01
Mar	1	0.01	-0.01	0 03	-0.02
	2	0.06	0.04	0.03	0.03
	3	0.05	0.04	0 03	0.03
Apr	1	0.01	0.02	0.02	-0.01
	2	0.02	0.02	-0.00	0.04
	3	-0.01	0.00	-0 01	-0.01
May	1	0.02	0.03	-0.00	0.00
	2	-0 00	0.00	0.01	-0.00
	3	-0 00	0.01	-0.01	-0.02
Average		0.03	0.02	0.02	0.01

The correlation statistics for 10-day minimum temperature at Dhaka station are shown in Table 4 4. It is found that all trends are increasing, the exception is for the third 10-day of April and the third 10-day of May. The increasing trends are statistically non-significant at nine of twenty one 10-day periods. The trends at the first 10-day of December is significant at 10% level and four 10-day periods during the months of December, February and March show significant trends at 5% level. It appears that the minimum temperatures have, in general, increasing trends. The most significant increasing 10-day periods are the first 10-day of November and the second 10-day of January.

Table 4.4: The correlation coefficient between 10-day minimum temperatures and time (years) and its significance level at Dhaka station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.38	0.001	0.52	0.001
	2	0.26	0.025	0.41	0.012
	3	0.19	0.094	0.26	0.125
Dec	1	0.21	0.067	0.33	0.051
	2	0.17	0.150	0.27	0.109
	3	0.31	0.007	0.47	0.004
Jan	1	0.17	0.135	0.34	0.037
	2	0.36	0.001	0.49	0.002
	3	0.17	0.145	0.15	0.386
Feb	1	0.13	0.252	0.24	0.156
	2	0.32	0.005	0.46	0.003
	3	0.15	0.191	0.23	0.164
Mar	1	0.02	0.870	0.06	0.737
	2	0.23	0.047	0.34	0.037
	3	0.23	0.047	0.31	0.060
Apr	1	0.05	0.651	0.07	0.658
	2	0.06	0.624	0.11	0.506
	3	-0.12	0.314	-0.12	0.470
May	1	0.12	0.303	0.19	0.257
	2	0.04	0.697	-0.01	0.977
	3	-0.03	0.792	-0.02	0.939

The correlation between minimum temperature and time (years) at Jessore station in Table B_1 of Appendix B shows that fifteen 10-day periods have non-significantly increasing trends. Only the third 10-day of December has increasing trend which is significant at 10% level. Six 10-day periods of January, March, April and May have non-significantly decreasing trends. Most 10-day periods have non-significantly increasing trends. The most significantly increasing trend is found in the third 10-day period of December.

The correlations of minimum temperatures at Bogra shown in Appendix B (Table B_2) are positive in sixteen 10 days and negative in five 10 days. But the positive correlations are non-significant in most of the time. Only six 10 days of November, December and March have significantly increasing trends. The decreasing trends of five 10 days of January, April and May are non-significant. So, the increasing trends are more significant than the decreasing trends. The most significant increasing 10-day is the first 10-day of November.

The correlations of minimum temperature and time (years) at Chandpur station is shown in Table B_3 of Appendix B. Sixteen 10-day periods of the dry season have non-significantly increasing trends. Only the third 10-day of December and the second 10-day of April have significantly increasing trends at 10% level. The third 10-day of January, the first 10-day of March, the first 10-day of April, and the third 10-day of May have non-significantly decreasing trends.

A scatter plot between minimum temperatures and years, with a linear line superimposed, is shown in Figure 4.2 as an example to get a visual idea of the trend.

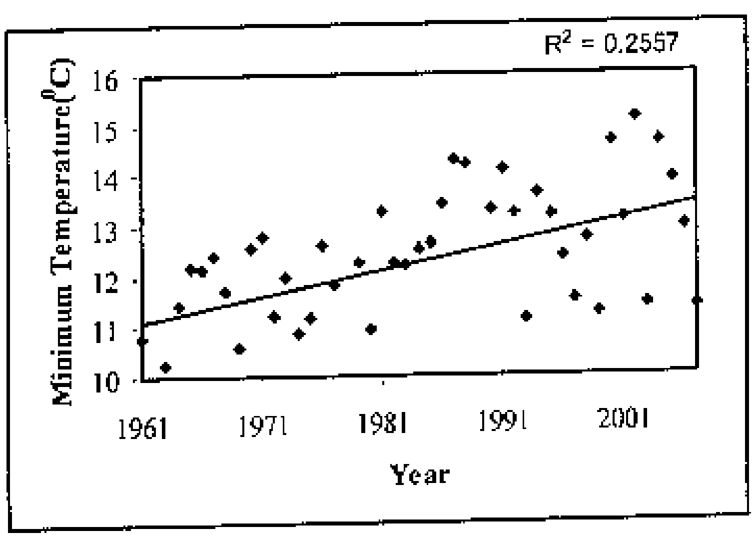

Figure 4.2: The minimum temperature in the second 10-day of January at Dhaka station

From the results of maximum and minimum temperatures, it is evident that it should have positive (increasing) impact on ET_0 trends. Increasing maximum temperature is significant at the first few 10-day periods of the dry season.

4.3 Relative Humidity

The estimated trends in relative humidity at different 10-day periods for four stations are shown in Table 4.5. It is seen from the table that the relative humidity has increasing trends in all 10-day periods for the four stations. The average increasing trends of relative humidity are 0.9%, 2.5%, 3.0% and 1.4% per decade at Dhaka, Jessore, Bogra and Chandpur, respectively.

Table 4.5: Trends in Relative Humidity (%) per year during different 10-day periods of four stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	-0.04	0.21	0.05	0.21
	2	0.03	0.20	0.12	0.03
	3	-0.04	0.24	0.14	0.17
Dec	1	0.02	0.27	0.12	0.23
	2	0.03	0.28	0.17	0.23
	3	0.07	0.30	0.14	0.23
Jan	1	0.12	0.32	0.25	0.34
	2	0.18	0.38	0.30	0.35
	3	0.09	0.30	0.24	0.17
Feb	1	0.07	0.28	0.29	0.26
	2	0.09	0.35	0.34	0.08
	3	0.35	0.53	0.61	0.29
Mar	1	0.05	0.07	0.40	-0.07
	2	0.16	0.25	0.45	0.15
	3	0.31	0.37	0.65	0.14

Table 4.5: (Continued)

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Apr	1	0.17	0.26	0.58	0.07
	2	-0.04	0.18	0.43	-0.15
	3	0.12	0.20	0.64	0.08
May	1	0.01	0.10	0.23	-0.01
	2	0.07	0.16	0.10	0.03
	3	0.00	0.06	0.08	0.00
Average		0.09	0.25	0.30	0.14

The correlation statistics for relative humidity at Dhaka station are shown in the Table 4.6. It is seen from the table that about all trends of seven months are statistically non-significantly increasing. The first and third 10 days of November, the second 10 days of April, and the first and second 10 days of May have decreasing trends. Three 10 days have significantly decreasing trends at 5% level. The relative humidity of Dhaka station shows an overall non-significantly increasing trend.

Table 4.6: The correlation coefficient between 10-day relative humidity and time (years) and its significance level at Dhaka station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.045	0.701	-0.088	0.614
	2	0.087	0.476	0.075	0.678
	3	-0.042	0.733	-0.097	0.591
Dec	1	0.005	0.965	0.049	0.784
	2	0.069	0.560	0.095	0.588
	3	0.124	0.293	0.193	0.265
Jan	1	0.243	0.047	0.396	0.023
	2	0.375	0.001	0.528	0.001
	3	0.191	0.113	0.261	0.136

Table 4.6: (Continued)

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Feb	1	0.071	0.540	0.107	0.534
	2	0.117	0.313	0.234	0.169
	3	0.296	0.014	0.397	0.020
Mar	1	0.005	0.966	0.014	0.939
	2	0.108	0.363	0.152	0.385
	3	0.148	0.219	0.343	0.047
Apr	1	0.165	0.164	0.226	0.193
	2	-0.052	0.660	-0.030	0.862
	3	0.277	0.055	0.317	0.064
May	1	-0.006	0.957	0.050	0.770
	2	-0.010	0.935	0.022	0.900
	3	0.062	0.595	0.047	0.786

The correlation statistics for relative humidity at Jessore station is shown in Table C_1 of Appendix C and it shows that fifteen 10-day periods of the dry season have increasing trends at 5% significant level. The first 10-day period of March and the three 10-day periods of May have non-significantly increasing trends. The first and third 10 days of April have significantly increasing trends at 10% level. The relative humidity at Jessore station has increasing trends in most 10-day periods.

The correlation statistics for relative humidity at Bogra station is shown in Table C_2 of Appendix C. In this station, the relative humidity at seventeen 10-day periods of the dry season has significantly increasing trends at 5% level. The first 10-day of November, the first 10-day of December, and the second and third 10 days of May show non-significantly increasing trends.

Correlation statistics for relative humidity in Table C_3 of Appendix C at Chandpur station show that five 10-day periods of November, March, April and May have non-significantly decreasing trends. Only the second 10-day of April has decreasing trend at 10% level. The other eleven 10-day periods have significantly increasing trends at 5% level. The first 10-

day of February, the third 10-day of March and the second 10-day of April have increasing trends at 10% significant level.

It appears that the relative humidity of different 10-day periods at the four stations is increasing either significantly or non-significantly which should decrease ET_0 values.

A scatter plot between relative humidity and years, with a linear line superimposed, is shown in Figure 4.3 as an example to give a visual idea of the trend.

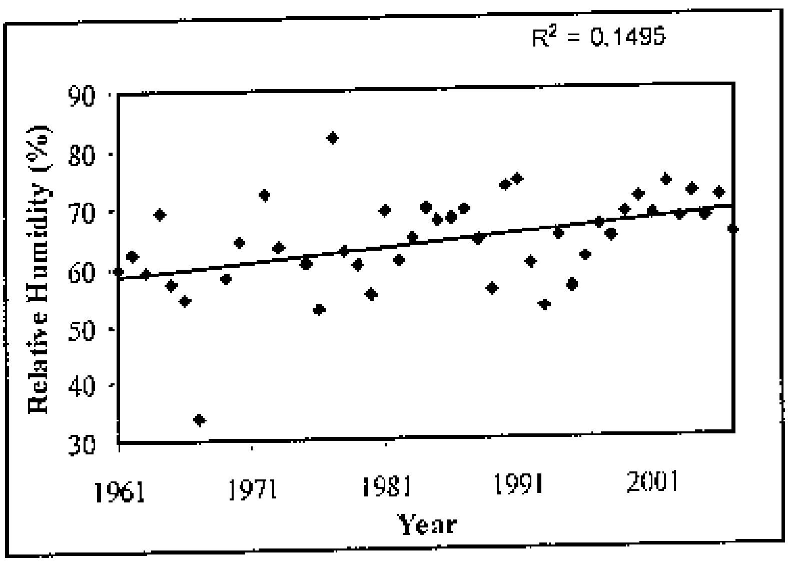

Figure 4.3: The relative humidity in the first 10-day of April at Dhaka station

4.4 Sunshine Hour

The estimated trends in sunshine hour at different 10-day periods for four stations are shown in Table 4.7. It is seen from the table that sunshine hour has decreasing trends during all 10-day periods at the four stations. The average decreasing trends in sunshine hour at Dhaka, Jessore, Bogra and Chandpur stations are 0.7, 0.5, 0.5 and 0.7 hours per decade, respectively.

Table 4.7: Trends in sunshine hour (hr) per year at different 10 days of four stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	-0.07	-0.08	-0.05	-0.09
	2	-0.43	-0.04	-0.05	-0.05
	3	-0.05	-0.05	-0.04	-0.07
Dec	1	-0.07	-0.06	-0.05	-0.08
	2	-0.06	-0.07	-0.04	-0.09
	3	-0.08	-0.06	-0.09	-0.12
Jan	1	-0.09	-0.09	-0.10	-0.11
	2	-0.08	-0.07	-0.08	-0.11
	3	-0.06	-0.05	-0.06	-0.11
Feb	1	-0.07	-0.06	-0.07	-0.08
	2	-0.06	-0.04	-0.06	-0.08
	3	-0.05	-0.05	-0.05	-0.08
Mar	1	-0.02	-0.01	-0.02	-0.04
	2	-0.03	-0.04	0.02	-0.06
	3	-0.05	-0.04	-0.04	-0.07
Apr	1	-0.02	-0.03	-0.03	-0.04
	2	-0.03	-0.01	-0.03	-0.04
	3	-0.05	-0.03	-0.05	-0.07
May	1	-0.05	-0.05	-0.03	-0.04
	2	-0.05	-0.03	-0.12	-0.07
	3	-0.06	-0.04	-0.06	-0.06
Average		-0.07	-0.05	-0.05	-0.07

The correlation statistics for sunshine hour at Dhaka station are given in Table 4.8. All 10-day periods have decreasing trends, which are statistically significant even at 5% significant level for 18 ten-day periods. Only the first and second 10 days of March and the first 10 days of April have statistically non-significant decreasing trends.

Table 4.8: The correlation coefficient between 10-day sunshine hour and time (years) and its significance level at Dhaka station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.403	0.000	-0.514	0.001
	2	-0.319	0.006	-0.457	0.004
	3	-0.474	0.000	-0.464	0.004
Dec	1	-0.465	0.000	-0.620	0.000
	2	-0.405	0.000	-0.571	0.000
	3	-0.521	0.000	-0.711	0.000
Jan	1	-0.490	0.000	-0.683	0.000
	2	-0.463	0.000	-0.691	0.000
	3	-0.295	0.009	-0.440	0.006
Feb	1	-0.330	0.004	-0.450	0.005
	2	-0.424	0.000	-0.611	0.000
	3	-0.307	0.007	-0.540	0.000
Mar	1	-0.077	0.497	-0.078	0.643
	2	-0.181	0.110	-0.298	0.069
	3	-0.381	0.001	-0.559	0.000
Apr	1	-0.175	0.122	-0.242	0.143
	2	-0.193	0.090	-0.260	0.115
	3	-0.500	0.000	-0.679	0.000
May	1	-0.305	0.007	-0.470	0.003
	2	-0.322	0.004	-0.483	0.002
	3	-0.259	0.022	-0.378	0.019

The Table D_1 of Appendix D shows the correlations of sunshine hour at Jessore station. It is seen from the table that nineteen 10-day periods of seven months have significantly decreasing trends. Among them, seventeen 10 days have significantly decreasing trends at 5% level. The second 10 days of May and the third 10 days of January have significantly decreasing trends at 10% level. Only the first and second 10 days of April have non-significantly decreasing trends.

The correlation statistics for sunshine hour at Bogra station are shown in Table D_2 of Appendix D. It is seen from the table that twenty 10-day periods have significantly decreasing trends. The sixteen 10-day periods have decreasing trends, which are significant at 5% level.

The correlation statistics for sunshine hour at Chandpur station shown in Table D_3 of Appendix D show significantly decreasing trends at 5% level in all 10-day periods.

A scatter plot between sunshine hour and years, with a linear line superimposed on the plot, is shown in Figure 4.4 as an example to get a visual idea of the trend.

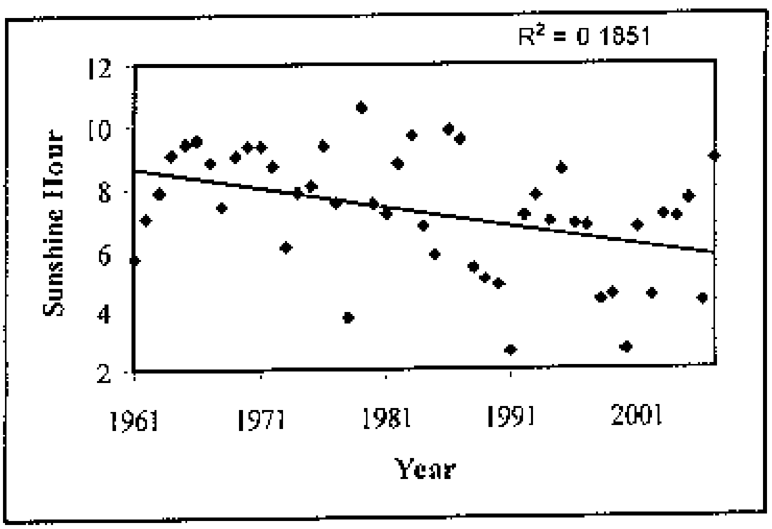

Figure 4.4: The sunshine hour in the third 10-day period of May at Dhaka station

4.5 Wind Speed

The estimated trends in wind speed at different 10-day periods for four stations are shown in Table 4.9. It is seen from the table that wind speed has both decreasing and increasing trends. The average decreasing trends at Dhaka and Chandpur stations are 15.8 km/day and 40.8 km/day per decade, respectively. The average increasing trends are 5.5 km/day and 1.1 km/day per decade at Jessore and Bogra stations, respectively.

Table 4.9: Trends in wind speed (km/day/year) during different 10-day periods at four stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	-0.92	0.19	0.09	-2.86
	2	-0.98	-0.48	-0.20	-3.15
	3	-0.86	0.13	0.10	-2.97
Dec	1	-1.06	-0.69	-0.04	-2.14
	2	-0.98	-0.45	0.05	-2.08
	3	-0.94	-0.60	-0.12	-1.78
Jan	1	-0.61	-0.25	0.13	-2.89
	2	-0.69	-0.32	0.40	-2.76
	3	-0.95	-0.46	0.10	-2.13
Feb	1	-1.49	-0.14	0.05	-2.32
	2	-0.77	0.21	0.17	-2.86
	3	-1.23	0.15	-0.40	-3.07
Mar	1	-2.31	-0.66	-0.32	-6.67
	2	-1.73	-0.33	-0.19	-6.99
	3	-0.91	1.76	0.31	-6.34
Apr	1	-3.77	0.57	0.56	-7.68
	2	-3.72	0.00	0.28	-8.22
	3	-2.22	3.77	0.87	-7.44
May	1	-2.04	3.44	0.51	-4.11
	2	-2.69	2.48	-0.30	-3.71
	3	-2.24	3.32	0.19	-3.48
Average		-1.58	0.55	0.11	-4.08

The correlation statistics for wind speed at Dhaka station are given in Table 4.10. About all 10-day periods have decreasing trends at 5% significant level. Only the second and third 10 days of March have statistically non-significant decreasing trends.

Table 4.10: The correlation coefficient between 10-day wind speed and time (years) and its significance level at Dhaka station

Month	10-day	Kendall's Tau_b	Significant level	Pearson's r	Significant level
Nov	1	-0 288	0.016	-0.395	0.017
	2	-0.288	0.061	-0.405	0.007
	3	-0.369	0.003	-0.445	0.007
Dec	1	-0.397	0.001	-0.545	0.001
	2	-0.353	0.004	-0.440	0.008
	3	-0 288	0 018	-0 343	0.043
Jan	1	-0.251	0.036	-0.287	0.090
	2	-0 266	0.026	-0.332	0.048
	3	-0.330	0.005	-0.504	0.002
Feb	1	-0.473	0.000	-0.545	0.001
	2	-0.334	0.005	-0.275	0.104
	3	-0.289	0.014	-0.424	0.010
Mar	1	-0.404	0.001	-0.516	0.001
	2	-0.188	0.115	-0.329	0.053
	3	-0.149	0.211	-0.203	0.242
Apr	1	-0.361	0.002	-0.549	0.001
	2	-0.381	0.001	-0.519	0.001
	3	-0.285	0.016	-0.332	0.051
May	1	-0.258	0.025	-0.281	0.092
	2	-0.238	0.042	-0.422	0.010
	3	-0.331	0.005	-0.465	0.005

The correlations of wind speed at Jessore station are shown in Table E_1 of Appendix E. The table shows that there are nine increasing trends and twelve decreasing trends. The month of May has significantly increasing trends at 10% significant level. Only the first and third 10 days of December have decreasing trends which are significant at 5% level. The wind speed decrease is prominent at the beginning of the dry season

The correlations of wind speed with time (years) in Table E_2 of Appendix E at Bogra have non-significantly decreasing trends in nine 10 days. The remaining twelve 10 days have non-significantly increasing trends.

The correlation statistics for wind speed for all 10 days at Chandpur station in Table E_3 of Appendix E show decreasing trends. Twelve 10 days of November, December, January, February and March show statistically non-significant decreasing trends. Besides, the first 10-day of February and the first 10-day of May have decreasing trends at 10% significant level. The wind speed of the third 10 days of February, the third 10 days of March, and six 10 days of April and May are decreasing significantly.

A scatter plot between wind speed and years, with linear line superimposed, is shown in Figure 4.5 as an example to get a visual idea of the trend in wind speed.

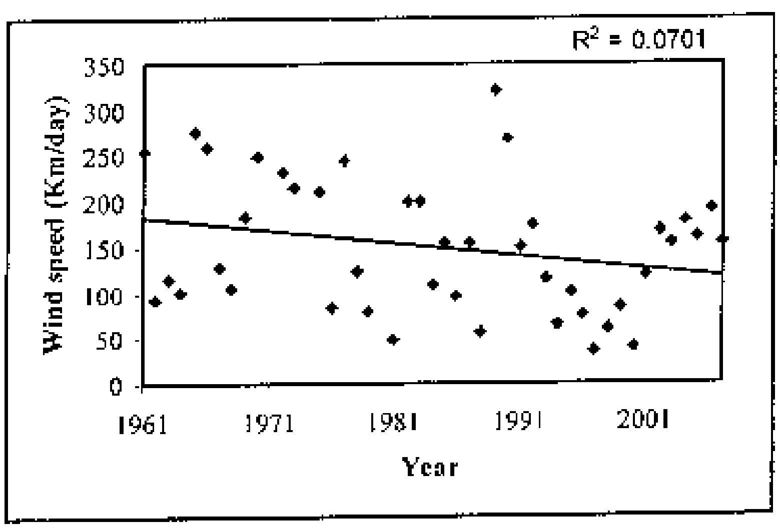

Figure 4.5: The wind speed in the third 10 days of April at Dhaka station

4.6 Reference Crop Evapotranspiration

Reference crop evapotranspiration (ET_0) depends on maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hour. Any increase in temperature, wind speed and sunshine hour will increase ET_0, whereas any increase in humidity will decrease the ET_0 From the trend analysis, it is seen that temperature and relative humidity have increasing trends and sunshine hour has decreasing trends. The wind speed has both increasing and decreasing trends. It is not clear what would be the combined effect of all these climatic variables on ET_0. Many literatures show increasing trends in the ET_0 values because of increase in temperatures due to global warming induced climatic change. The combined effect of all climatic variables was not studied in those literatures. So, it is necessary to analyze the trends of ET_0 values so that the combined effects of climatic variables on ET_0 are revealed.

The trends in reference crop evapotranspiration (ET_0) at four stations (Dhaka, Jessore, Bogra and Chandpur) were estimated by the parametric method using the Statistical Package for Social Sciences (SPSS) software. The estimated trends in ET_0 during different 10-day periods of the dry season (November-May) at the four different stations are given in Table 4.11. It is seen from the table that ET_0 has in general decreasing trends in different 10-day periods at the four stations. The overall decreasing trends for Dhaka, Jessore, Bogra and Chandpur stations are 0.2, 0.2, 0.1 and 0.3 mm/day, respectively, per decade (10 years) (the last row in the table).

Table 4.11: Trends in ET_0 values (mm/day per year) during different 10-day periods of the dry season

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	-0.01	-0.03	0.00	0.00
	2	-0.01	-0.02	0.00	-0.03
	3	-0.01	-0.01	-0.00	-0.01
Dec	1	-0.01	-0.02	0.00	-0.01
	2	-0.01	-0.01	-0.00	-0.03
	3	-0.01	-0.02	0.00	-0.02
Jan	1	-0.02	-0.02	-0.01	-0.03
	2	-0.01	-0.03	0.00	-0.01
	3	-0.01	-0.02	-0.00	-0.03

Table 4.11: (Continued)

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Feb	1	-0.01	-0.02	-0.00	-0.03
	2	-0.01	-0.02	-0.01	-0.03
	3	-0.02	-0.03	-0.02	-0.04
Mar	1	-0.03	-0.04	-0.01	-0.02
	2	-0.02	-0.05	0.00	0.00
	3	-0.03	-0.05	-0.01	-0.07
Apr	1	-0.04	-0.04	-0.02	-0.04
	2	-0.03	-0.03	-0.00	-0.02
	3	-0.04	0.00	-0.03	-0.07
May	1	-0.02	0.02	-0.01	-0.03
	2	-0.03	0.01	-0.01	-0.03
	3	-0.03	-0.03	-0.02	-0.06
Average		**-0.02**	**-0.02**	**-0.01**	**-0.03**

The changes in ET_0 values over a period of 47 years (1961-2007) at the four stations are shown in Table 4.12. These changes are estimated from the trend equations from which the ET_0 values of 1961 and 2007 are calculated. The percentage change in ET_0 for each 10-day period has been calculated by subtracting the value of 2007 from the value of 1961. The average decrease during the dry season from 1961 to 2007 is found to be about 23%, 25%, 8% and 33% at Dhaka, Jessore, Bogra and Chandpur, respectively. The decrease is maximum at Chandpur station and minimum at Bogra station. The data of Dhaka and Jessore are more reliable than Bogra and Chandpur because Bogra and Chandpur have many missing climatic data.

Table 4.12: Changes in ET_0 in (%) from 1961 to 2007 at different 10-day periods of four stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Nov	1	-16.99	-39.74	+6.54	-0.24
	2	-16.54	-26.72	+3.68	-36.77
	3	-18.61	-22.63	-2.98	-19.46

Table 4.12: (Continued)

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Dec	1	-26.23	-36.96	-0.37	-24.66
	2	-17.83	-26.45	-6.03	-42.05
	3	-23.20	-29.43	-9.77	-40.35
Jan	1	-28.11	-40.39	-17.64	-42.03
	2	-26.16	-40.25	+3.42	-27.50
	3	-17.80	-35.26	-1.86	-46.38
Feb	1	-20.48	-28.36	-5.02	-35.68
	2	-18.79	-28.24	-12.43	-42.05
	3	-26.82	-35 07	-23.14	-48.67
Mar	1	-26.92	-32.60	-12.73	-21.92
	2	-21 19	-38.02	+3.99	+1.27
	3	-25 14	-33.44	-12.48	-53.71
Apr	1	-28.24	-26 21	-12.64	-35.27
	2	-22.97	-18.45	-3.51	-21.12
	3	-29.80	+2.08	-26.53	-51.45
May	1	-17.19	+19.51	-11.07	-27.79
	2	-25.37	+10.67	-5.46	-22.00
	3	-21.32	-22 92	-16.32	-47.52
Average		-22.65	-25.19	-7.73	-32.64

Both non-parametric and parametric correlations between ET_0 values and time (years in this case) were estimated using the SPSS software. The correlations between 10-day ET_0 values and time (years) for Dhaka station are given in Table 4.13. It is seen from the table that the Dhaka station has statistically significant decreasing trends in ET_0 in all seven months of the dry season at a 10% level of significance (significant level being less than or equal to 0.10). In nineteen of the twenty-one 10-day periods, the trends are also significant at a 5% level of significance (significant level being less than or equal to 0.05). So, the ET_0 at Dhaka station is significantly decreasing. The first 10-day period of December and the first 10-day period of January have the most significantly decreasing trends.

Table 4.13: The correlation coefficient between 10-day $\bar{ET}_0$ values and time (years) and its significant level for Dhaka station

Month	10-day Period	Kendall's Tau_b	Significant Level	Pearson's r	Significant Level
Nov	1	-0.36	0.002	-0.51	0.002
	2	-0.37	0.003	-0.46	0.007
	3	-0.30	0.010	-0.47	0 004
Dec	1	-0 49	0.000	-0.60	0.000
	2	-0.31	0.011	-0.49	0.003
	3	-0.36	0.003	-0.61	0.000
Jan	1	-0.48	0.000	-0 65	0.000
	2	-0.38	0.001	-0 56	0.003
	3	-0.33	0.009	-0.48	0.007
Feb	1	-0.29	0.019	-0.41	0.017
	2	-0.29	0.017	-0.40	0 021
	3	-0.40	0.001	-0.57	0 001
Mar	1	-0.32	0.008	-0.49	0.003
	2	-0.20	0.086	-0.36	0.033
	3	-0.30	0 011	-0.44	0.008
Apr	1	-0.30	0.010	-0.47	0.003
	2	-0.28	0.016	-0.39	0.016
	3	-0.40	0.001	-0.53	0.001
May	1	-0.20	0 100	-0.28	0.110
	2	-0.28	0 022	-0.41	0.016
	3	-0.27	0.030	-0.37	0.033

The correlation coefficients between 10-day ET_0 values and years at Jessore station are given in Table F_1 of Appendix F. It is seen from that table, according to the non-parametric correlation, ET_0 values from the first 10-day of November to the first 10-day of April are decreasing significantly at 5% level of significance. The second and the third 10-day periods of April and the third 10-day period of May show non-significant decreasing trends. The ET_0 is increasing non-significantly in the first and the second 10-day periods of May. The overall trend during the dry season is decreasing. The first 10-day of December and the second 10-day of January have the most significantly decreasing trends.

Correlations of 10-day ET_0 values with years at Bogra station are given in Table F_2 of Appendix F. The table shows that the ET_0 values at Bogra station have decreasing trends in eighteen 10-day periods, out of 21 ten-day periods, of the dry season. However, only five 10-day periods show significantly decreasing trends at 10% significant level.

The correlations of ET_0 with years at Chandpur station, shown in Table F_3 of Appendix F, also indicate decreasing trends. All 10-day periods, except the second 10-day period of March, have decreasing trends in ET_0 values. The nine 10-day periods also have significantly decreasing trends at 5% level. The second 10-day of November has decreasing trend at 10% significant level. The second 10-day of December, the second 10-day of February, and the third 10-day of May show the most significantly decreasing trends.

Although Chandpur station shows the highest negative trends in ET_0 values, most of the 10-day decreases are statistically non-significant. On the other hand, though the trends in Dhaka and Jessore stations are not as much as in Chandpur station, both Dhaka and Jessore show statistically significant decreasing trends in most 10-day periods. Bogra station shows statistically non-significant decreasing trends in most 10-day periods.

A scatter plot between ET_0 values and years, superimposed with linear line, is shown in Figure 4.6 as an example to get a visual impression of the trend.

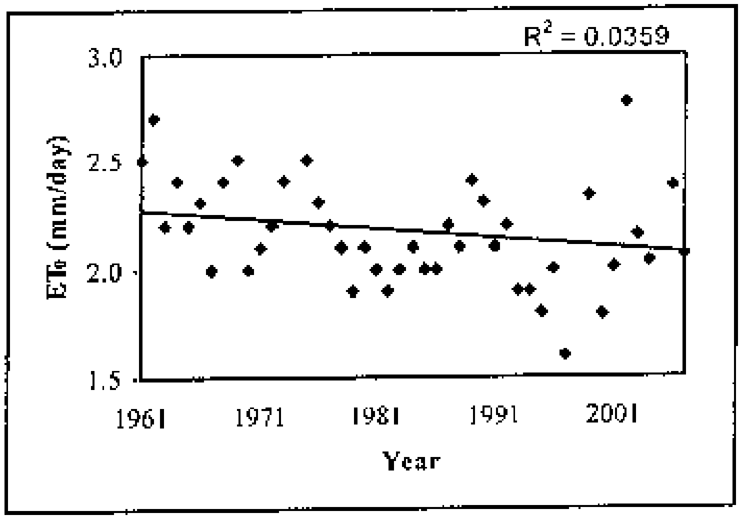

Figure 4.6: The ET_0 values in the first 10-day of January at Dhaka station

4.7 Sensitivity Analysis

The sensitivity of ET_0 has been studied in terms of change in temperature, relative humidity, wind speed and sunshine hour. The average value of the climatic variables (temperature, relative humidity, sunshine hour and wind speed) and ET_0 of the first 10-day period of April at Dhaka station has been used to analyze the sensitivity. Scatter plots between the changes in values of individual climatic variables and ET_0 have been made and the slope of a linear line superimposed on each plot is then estimated. The estimated slopes are used for evaluating the sensitivity of ET_0 to each climatic variable.

The changes in ET_0 values due to changes in values in different climatic variables are shown in the Figures 4.7-4.11. It is seen from the figures that ET_0 is most sensitive to temperature among the climatic variables. It is more sensitive to maximum temperature than minimum temperature. With each percentage increase in maximum temperature keeping other variables fixed, ET_0 increases by 0.8% (Figure 4.7). Then ET_0 is sensitive to relative humidity, solar radiation and wind speed in a decreasing order. ET_0 is least sensitive to minimum temperature for 0.1% increase in ET_0 due to 1% increase in minimum temperature (Figure 4.8).

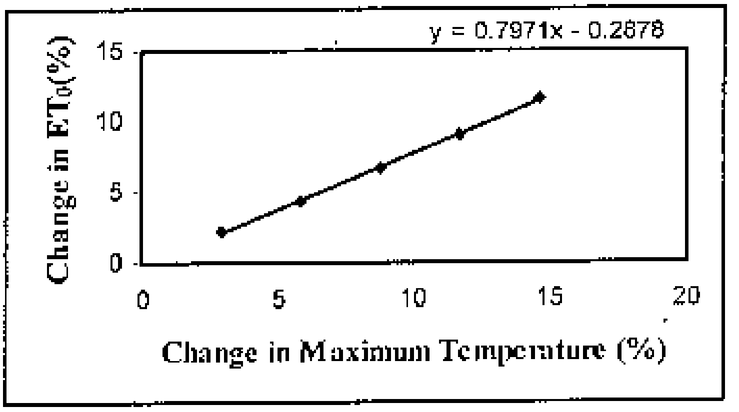

Figure 4.7: Sensitivity of ET_0 to maximum temperature

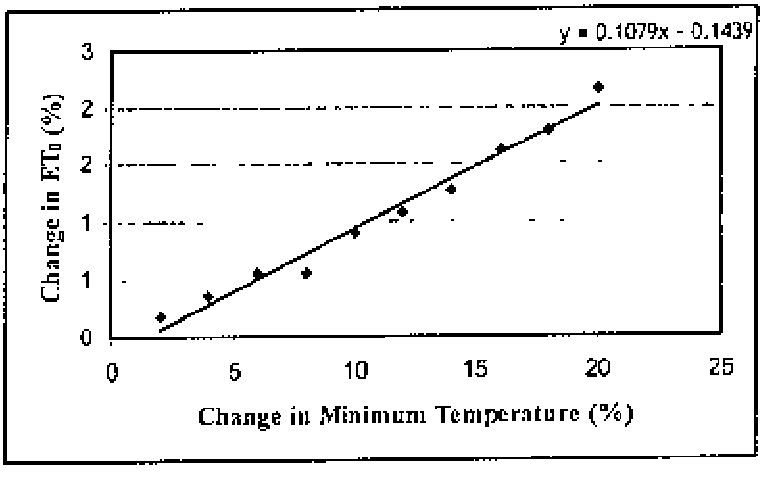

Figure 4.8: Sensitivity of ET_0 to minimum temperature

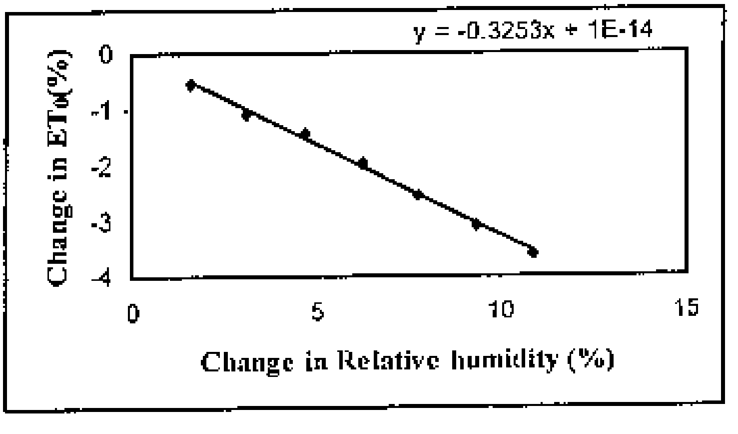

Figure 4.9: Sensitivity of ET_0 to relative humidity

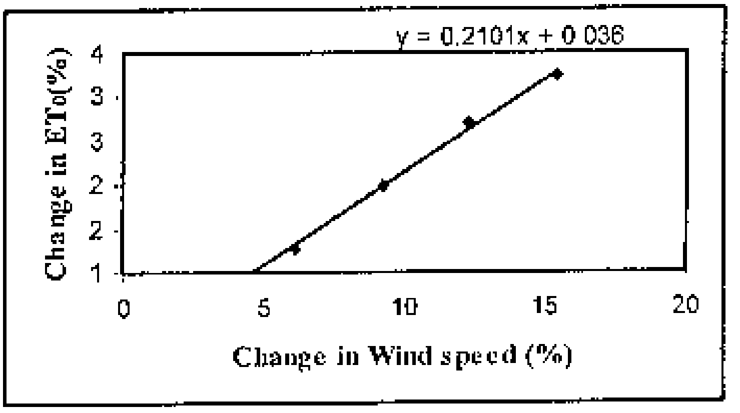

Figure 4.10: Sensitivity of ET_0 to wind speed

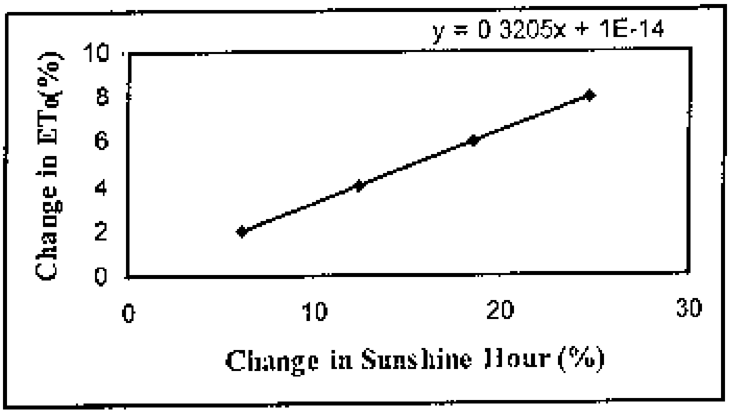

Figure 4.11: Sensitivity of ET_0 to sunshine hour

The joint effects of the variables on ET_0 have been also analysed and are shown in the Figures 4.12 and 4.13. From the Figure 4.12, it is seen that if both maximum and minimum temperatures are increased (decreased) by 1%, then the ET_0 will increase (decrease) by 0.8%. The Figure 4.13 shows that with 1% increase (decrease) of relative humidity and 1% decrease (increase) of sunshine hour, the ET_0 will decrease (increase) by 0.6%. The sensitivity of temperature is more than that of any other variables. But, from the values of slopes of Figures 4.12 and 4.13, it is clear that if the changes in relative humidity and sunshine hour become more than that of temperatures over a same period of time, then the decrease in ET_0 due to relative humidity and sunshine hour will be more than the increase in ET_0 due to temperature. This fact is the principal reason of decreasing ET_0 at the four stations.

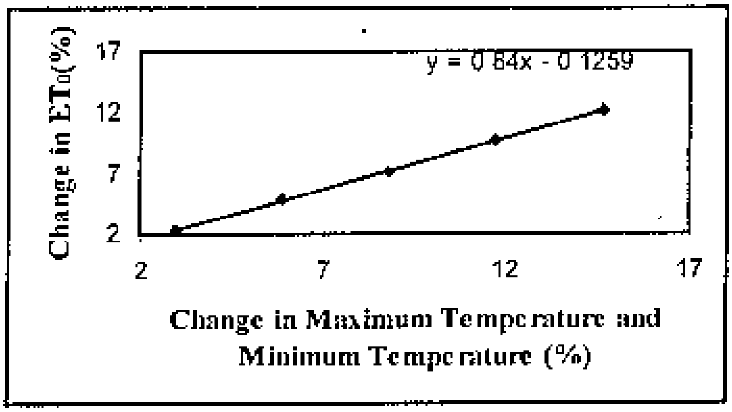

Figure 4.12: Sensitivity of ET_0 to maximum and minimum temperatures

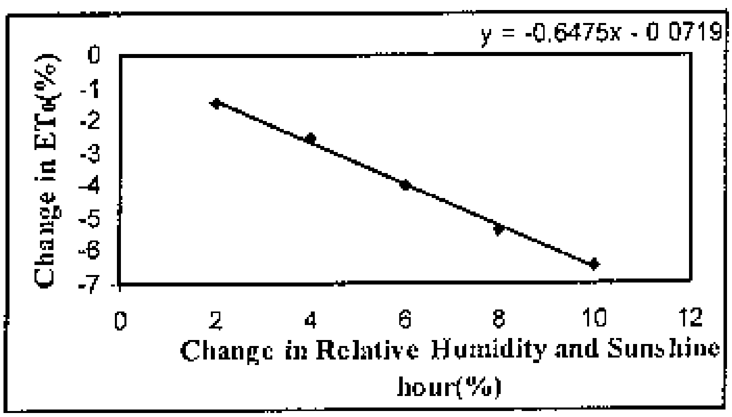

Figure 4.13: Sensitivity of ET_0 to relative humidity and sunshine hour

4.8 Rainfall

The available rainfall data of four stations has been divided into two seasons: winter and summer season. The winter season has been considered from November to February and summer season from March to May. Trends in seasonal rainfalls are then estimated from the data and are reported in Table 4.14. It is seen from the table that the rainfall has increasing trends in both seasons at all stations. The increasing trends of winter rainfall from 1961 to 2007 at Dhaka, Jessore, Bogra and Chandpur are 13.24, 9.99, 3.49 and 23.38

mm per decade, respectively. The increasing trends of summer rainfall are 27.90, 19.86, 31.51 and 15.43 mm per decade, respectively. It thus appears that, in both winter and summer seasons, rainfall is increasing. It is to be noted that, it is not useful to analyze rainfall trends at monthly or 10-day time scales during the dry season, in particular during the winter season, as there are frequent zero rainfall during this time of the year. The findings based on such data may be misleading.

Table 4.14: Trends in seasonal rainfall (mm/decade) at four stations from 1961 to 2007

Season	Dhaka	Jessore	Bogra	Chandpur
Winter	13.24	9.99	3.49	23.38
Summer	27.90	19.86	31.51	15.43

4.9 Major Findings on Changes in Climatic Variables

From the above result of the trend analysis of the climatic variables at the four stations, it appears that sunshine hour has decreasing trend and relative humidity has increasing trend. These trends result in a decreasing trend in reference crop evapotranspiration. Although the temperature is increasing, the impacts of these parameters are the main reasons of decreasing trends in ET_0 values. By the sensitivity analysis, it is found that the ET_0 is more sensitive to temperature than any other variables. However, as the changes in temperatures are relatively lower than the changes in sunshine duration and humidity, the net effect is the decrease in ET_0.

Chapter V

NET IRRIGATION WATER REQUIREMENT

5.1 Trends in Net Irrigation Requirement

The net irrigation requirement (NIR) has been calculated from the difference between crop water requirement (ET_C) values and effective rainfall (R_e) for four stations during the years of 1961-2007 for different 10-day periods. Then the trends of NIR for different 10-day periods at four stations in the dry season have been estimated with the SPSS software. The results are reported in Table 5.1. It is seen from the table that the NIR has decreasing trends in Boro season (January-May) at four stations. There are negative trends at ten 10-day periods and positive trends at five 10-day periods in Dhaka station. In Jessore station, there are ten negative trends and five positive trends. In Bogra station, thirteen 10 days have negative trends and two 10 days have positive trends. Chandpur station has fourteen 10-day periods with negative trends and one 10-day period with positive trend. Chandpur and Bogra have decreasing trends in most of the 10-day periods. The average decreasing trends during the Boro season are found to be about -0.01, -0.01, -0.01 and -0.04 mm/day per annum at Dhaka, Jessore, Bogra and Chandpur stations, respectively. It is to be noted that the result of Chandpur station is not very reliable as there are many missing climatic data and the long-term data at this station are also not available.

Table 5.1: Annual trends (mm/day) in 10-day NIR during Boro season for different stations

Month	10-day	Dhaka	Jessore	Bogra	Chandpur
Jan	1	-0.00	0.01	-0.00	0.00
	2	-0.01	-0.02	0.00	-0.01
	3	0.00	-0.04	-0.00	-0.02
Feb	1	-0.01	-0.03	-0.00	-0.02
	2	-0.02	-0.04	-0.01	-0.05
	3	-0.02	-0.03	-0.03	-0.04
Mar	1	-0.03	0.03	-0.02	-0.09
	2	-0.02	0.04	0.01	-0.01
	3	-0.05	-0.03	-0.01	-0.10
Apr	1	-0.06	0.05	-0.02	-0.10
	2	0.01	0.02	-0.00	-0.04
	3	0.04	-0.07	-0.04	-0.08
May	1	-0.01	-0.03	-0.03	-0.03
	2	0.01	-0.02	-0.01	-0.04
	3	-0.00	-0.01	-0.00	-0.00
Average Trend		**-0.01**	**-0.01**	**-0.01**	**-0.04**

5.2 Changes in Mean NIR of Boro Season over Three Time Periods

The NIR data have been divided into three time spans: 1961-1975, 1976-1990 and 1991-2007. Then the mean NIR for each 10-day period of three time periods has been calculated and is shown in Table 5.2 for Dhaka and Jessore stations and in Table 5.3 for Bogra and Chandpur stations. It is seen from these two tables that the mean NIR of 1976-1990 and 1991-2007 are lower than that of 1961-1975 at all stations. The two tables also show that the NIR values have decreased over the three time periods for Bogra and Chandpur stations. However, for Dhaka and Jessore stations, the mean NIR values during 1976-1990are higher than that of 1991-2007.

Table 5.2: Mean net irrigation requirement (mm/10-day) for different 10-day periods during three time periods at Dhaka and Jessore stations

Month	Decade	Dhaka			Jessore		
		1961-1975	1976-1990	1991-2007	1961-1975	1976-1990	1991-2007
Jan	1	6.0	5.5	4.6	3.5	3.8	5.4
	2	12.7	11.1	10.7	15.1	11.3	10.2
	3	18.7	18.37	17.7	28.7	17.5	15.6
Feb	1	28.8	23.1	20.0	34.0	23.9	23.2
	2	33.2	26.0	28.8	37.0	33.4	23.4
	3	24.2	20.6	19.6	30.6	30.8	20.8
Mar	1	45.3	29.5	38.7	38.1	35.3	47.1
	2	48.4	38.1	43.8	49.3	46.0	60.7
	3	49.3	36.3	31.4	52.1	18.6	31.0
Apr	1	58.2	39.3	39.9	43.9	51.7	53.2
	2	9.9	8.7	14.6	46.3	42.5	61.1
	3	61.5	53.9	50.4	70.3	62.2	54.5
May	1	10.1	6.7	8.6	26.4	21.2	15.2
	2	7.3	3.8	3.1	29.9	17.3	40.6
	3	2.5	2.8	1.8	5.9	4.7	0.0
Seasonal Total (mm)		416	324	334	511	420	462
Decrease (mm)		-	92	82	-	91	49
Decrease (%)		-	22	20	-	17	9

Table 5.3: Mean net irrigation requirement (mm/10-day) for different 10-day periods during three time periods at Bogra and Chandpur stations

Month	Decade	Bogra 1961-1975	Bogra 1976-1990	Bogra 1991-2007	Chandpur 1961-1975	Chandpur 1976-1990	Chandpur 1991-2007
Jan	1	5.5	5.9	5.2	6.4	4.9	6.1
	2	10.6	11.4	10.9	12.6	10.7	10.6
	3	17.8	20.8	16.3	26.4	14.7	17.9
Feb	1	27.0	31.1	22.8	32.3	21.3	23.9
	2	33.6	33.1	32.1	28.2	20.6	13.7
	3	26.1	25.8	21.3	26.2	20.2	19.7
Mar	1	43.9	44.1	39.4	57.3	32.1	36.8
	2	41.8	45.0	46.7	40.5	41.5	44.7
	3	50.1	57.1	48.3	56.9	36.7	23.5
Apr	1	55.6	55.0	55.2	47.5	26.9	21.2
	2	54.4	52.2	52.5	38.6	27.9	27.8
	3	62.6	53.3	51.4	66.4	45.5	44.8
May	1	22.3	12.6	12.4	17.4	8.1	6.4
	2	8.6	4.6	7.4	17.0	0.0	6.9
	3	1.9	4.7	2.8	8.6	4.7	3.4
Seasonal Total (mm)		462	457	425	482	316	307
Decrease (mm)		-	5	37	-	166	175
Decrease (%)			1	8		34	36

The mean NIR during the Boro season has decreased by 82 mm at Dhaka station from the period of 1961-1975 to the period of 1991-2007 which is calculated from the difference between the mean NIR of 1961-1975 and the mean NIR of 1991-2007. This decrease is about 20%. By the same way, the mean NIR has been calculated for other stations. The decrease in NIR for Jessore and Bogra stations are 49 mm and 37 mm which are about 10% and 36%, respectively. The mean NIR of Chandpur station has decreased by about 175 mm which is about 36%. The decrease is the highest at Chandpur, followed by Dhaka, Jessore and Bogra. Although the decrease is the highest at Chandpur station, the result of Chandpur is not very reliable as mentioned in the preceding chapter.

5.3 Trend in Boro Season NIR

The seasonal total NIR has been calculated at Dhaka, Jessore and Bogra stations from 1961 to 2007 and at Chandpur station from 1966 to 2002. The trends of total seasonal NIR are then estimated. Figures 5.1 and 5.2 show the trends in Boro season NIRs at Dhaka and Jessore, respectively. It is seen from the figures that the total seasonal NIRs at these two stations have decreasing trends from 1961 to 2007. In fact, the decreasing trends are found to be -0.62, -0.18, -1.33 and -4.10 mm/season per annum for Dhaka, Jessore, Bogra and Chandpur, respectively.

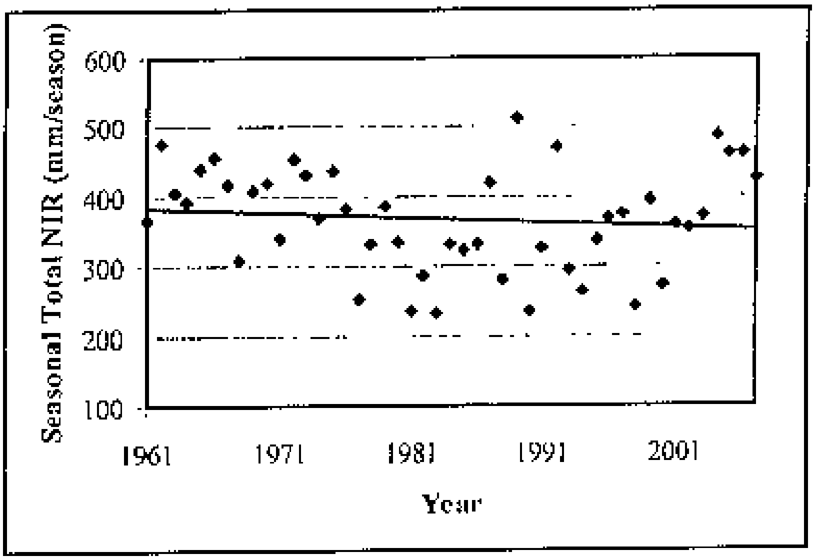

Figure 5.1: Total Seasonal NIR at Dhaka Station from 1961-2007

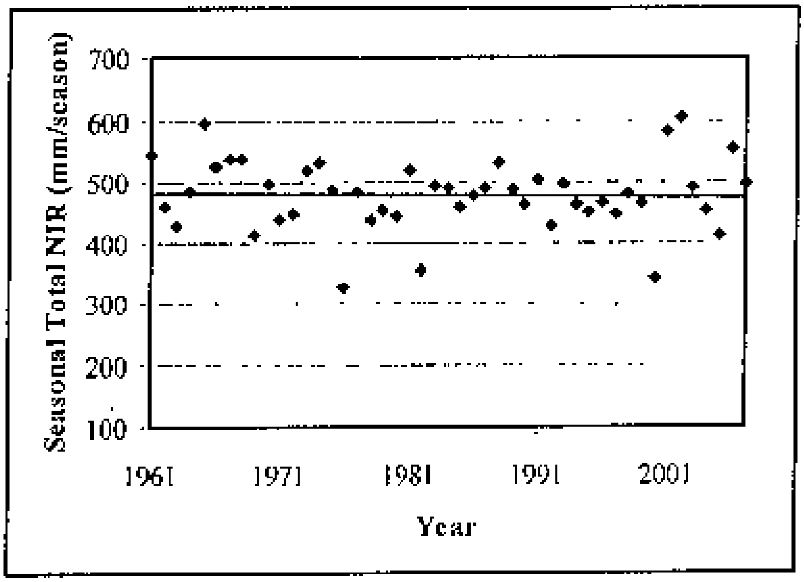

Figure 5.2: Total Seasonal NIR at Jessore Station from 1961-2007

5.4 Major Findings on NIR

From the above results of the trends, mean and seasonal total of net irrigation requirement at four climatic stations, it is found that the NIRs have decreased and the decreases are higher at Chandpur and Dhaka stations. However, the result of Chandpur is not very reliable due to the reasons mentioned in the earlier chapter. The data of Dhaka station is very reliable. From the Chapter IV, it is also found that there are decreasing trends in ET_0 at four stations. Since the temperature is increasing due to climate change, the ET_0 and NIRs are expected to increase. However, instead of increases, ET_0 and NIR are found to be decreasing. This is mainly due to changes in other climatic variables, such as decrease in sunshine duration and increase in air humidity, as well as increase in rainfalls. Doll and Siebert (2001) also found that net irrigation requirement per unit irrigated area generally would decrease across much of the Middle East and Northern Africa as a result of increased precipitation.

Chapter VI

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The effect of climate change on water resources is an important aspect of this decade. Since the irrigation water requirement is a major water requirement in Bangladesh, the present study investigates the combined effect of climatic variability on crop evapotranspiration and net irrigation water requirement for the Boro rice cultivated during the dry season. In most past studies, the effect of all climatic variables on evapotranspiration and irrigation water requirement was not considered and the effect of only one (temperature) or two (temperature and rainfall) variables was taken into account. The study investigates the long-term trends in climatic variables and their combined effect on reference crop evapotranspiration and irrigation requirement from 1961 to 2007 at four climatic stations. The findings show that the combined effect of the changes in climatic variables is quite different from what is generally thought and reported in many literatures. Not only the magnitude but also the direction of the changes in evapotranspiration and irrigation requirement is different. The specific conclusions drawn from this study are summarized below:

1. Maximum temperature has increasing trends in most 10-day periods at four stations. The average increasing trends for Dhaka, Jessore and Chandpur are 0.2^0C, 0.2^0C and 0.1^0C, respectively, per decade. The Bogra station has decreasing trend which is 0.2^0C per decade. Minimum temperature has also increasing trends in most 10-day periods. The average increasing trends are 0.3^0C, 0.2^0C, 0.2^0C and 0.1^0C for Dhaka, Jessore, Bogra and Chandpur, respectively, per decade.

2. The relative humidity has increasing trends in all 10-day periods at the four stations. The average increasing trends are 0.9%, 2.5%, 3.0% and 1.4% for Dhaka, Jessore, Bogra and Chandpur, respectively, per decade.

3. The other important climatic variable is the sunshine hour which has decreasing trends in all 10-day periods at the four stations. The average decreasing trends in Dhaka, Jessore, Bogra and Chanpur stations are 0.7, 0.5, 0.5 and 0.7 hour, respectively, per decade.

4. Wind speed has both decreasing and increasing trends. The average decreasing trends in Dhaka and Chandpur are 15.8 km/day and 40.8 km/day, respectively, per decade. The average increasing trends are 5.5 km/day and 1.1 km/day in Jessore and Bogra, respectively, per decade.

5. The evapotranspiration depends on climatic variables, such as maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hour. So the combined effects of the trends of these variables on ET_0 are evaluated. The estimated trends in ET_0 at different 10-day periods for the four different stations show an overall decreasing trend. The average decreasing trends at Dhaka, Jessore, Bogra and Chandpur are 0.2, 0.2, 0.1 and 0.3 mm/day per decade (10 years), respectively. The decrease is maximum at Chandpur station and minimum at Bogra station. The average decreases from 1961 to 2007 are found to be about 2.3%, 2.5%, 0.8% and 3.3% at Dhaka, Jessore, Bogra and Chandpur per decade, respectively.

6. The trend in rainfall during the winter season from 1961 to 2007 at Dhaka, Jessore, Bogra and Chandpur are 13.24, 9.99, 3.49 and 23.38 mm per decade, respectively. The summer trends are 27.90, 19.86, 31.51 and 15.43 mm per decade, respectively. So, the rainfall has increasing trends in the dry season at four stations.

7. The mean net irrigation requirements have decreased by 20%, 9%, 8% and 36% at Dhaka, Jessore, Bogra and Chandpur stations, respectively, during 1991-2007 compared with 1961-1975. The trends of the Boro season NIR are also decreasing at -0.62, -0.18, -1.33 and -4.1 mm per annum for Dhaka, Jessore, Bogra and Chandpur, respectively.

8. The above results show that though the temperature is increasing due to global warming induced climate change and it has a positive effect on ET_0 and NIR, the changes in other climatic variables (such as relative humidity, sunshine hour, wind speed and rainfall) are more dominant than the changes in temperature which result in a decrease in ET_0 and NIR. The findings of this study refute the findings of many past studies, particularly those based on modeling studies and not considering full set of climatic variables, which indicate increase in ET_0 and NIR due to climate change.

6.2 Recommendations

Based on the findings of the study and the experience gained during the study, the following recommendations are made:

1. The findings of the study suggest that both ET_0 and NIR are decreasing due to increasing humidity and rainfall and decreasing sunshine duration. The effect of these variables is more prominent than that of temperature. If one considers only the effect of one or two variables, s/he may come up with an increasing trend in ET_0 and NIR which may be misleading. So the combined effect of all the climatic variables needs to be considered to get a realistic picture.
2. The effect of CO_2 concentration in the atmosphere on reference crop evapotranspiration and net irrigation requirement was not taken into consideration in this study. Future study should consider this.
3. Climatic variables at four stations were investigated for trends in this study. Future studies should analyze data at other stations to make a general inference.
4. The study can be done also for monsoon season so that the trends of the ET_0 and NIR can be observed throughout the year.
5. The effect of decreasing ET_0 and NIR on the Boro rice production can be studied.

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APPENDIX A

Correlation Coefficient between 10-Day Maximum Temperatures and Time (Years)

Table A_1: The correlation coefficient between 10-day maximum temperatures and time (years) and its significance level at Jessore station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.458	0.000	0.603	0.000
	2	0.256	0.039	0.335	0.061
	3	0.194	0.097	0.291	0.086
Dec	1	0.196	0.103	0.281	0.107
	2	0.245	0.033	0.313	0.060
	3	0.192	0.123	0.239	0.189
Jan	1	-0.078	0.541	-0 195	0.292
	2	-0.207	0.081	-0.306	0.074
	3	-0.102	0.403	-0.149	0.407
Feb	1	-0.035	0.765	-0.078	0.654
	2	-0.205	0.079	-0.222	0.193
	3	-0.270	0.019	-0.414	0.011
Mar	1	-0.082	0.487	-0.141	0.419
	2	0.012	0.922	-0.035	0.850
	3	0.098	0.503	0.117	0.586
Apr	1	-0.030	0.844	0.005	0.983
	2	0.143	0.365	0.289	0.204
	3	0.285	0.057	0.455	0.029
May	1	0.379	0.006	0 506	0.007
	2	0.290	0.047	0.356	0.088
	3	0.123	0.378	0.354	0.076

Table A_2: The correlation coefficient between 10-day maximum temperatures and time (years) and its significance level at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.535	0.000	0.670	0.000
	2	0.379	0.001	0.605	0.000
	3	0.400	0.001	0.578	0.000
Dec	1	0.150	0.213	0.235	0.180
	2	0.278	0.016	0.404	0.013
	3	0.251	0.037	0.272	0.119
Jan	1	-0.038	0.757	-0.162	0.366
	2	-0.080	0.481	-0.095	0.568
	3	0.014	0.902	0.088	0.608
Feb	1	0.040	0.733	0.071	0.687
	2	-0.263	0.022	-0.334	0.043
	3	-0.417	0.000	-0.600	0.000
Mar	1	-0.278	0.016	-0.309	0.063
	2	-0.174	0.129	-0.267	0.110
	3	-0.274	0.021	-0.323	0.058
Apr	1	-0.371	0.002	-0.482	0.004
	2	-0.223	0.084	-0.303	0.104
	3	-0.227	0.055	-0.425	0.011
May	1	-0.045	0.701	-0.180	0.302
	2	0.030	0.801	-0.068	0.702
	3	0.030	0.794	0.027	0.876

Table A_3: The correlation coefficient between 10-day maximum temperatures and time (years) and significance levels at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.193	0.182	0.185	0.375
	2	0.269	0.048	0.410	0.030
	3	0.149	0.253	0.256	0.172
Dec	1	0.000	1.00	0.224	0.282
	2	0.213	0.110	0.300	0.113
	3	0.137	0.292	0.246	0.190
Jan	1	0.101	0.483	0.178	0.394
	2	0.016	0.905	0.092	0.640
	3	-0.016	0.440	-0.022	0.914
Feb	1	0.127	0.396	0.108	0.616
	2	0.027	0.836	0.052	0.789
	3	-0.215	0.092	-0.305	0.065
Mar	1	0.194	0.161	0.254	0.201
	2	0.080	0.548	0.097	0.615
	3	0.025	0.851	-0.004	0.984
Apr	1	0.128	0.365	0.203	0.319
	2	0.242	0.079	0.305	0.122
	3	-0.112	0.415	-0.801	0.687
May	1	0.226	0.103	0.387	0.046
	2	-0.025	0.860	-0.091	0.659
	3	-0.178	0.185	-0.151	0.445

APPENDIX B

Correlation Coefficient between 10-Day Minimum Temperatures and Time (Years)

Table B_1: The correlation coefficient between 10-day minimum temperatures and time (years) and its significance level at Jessore station.

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.194	0.119	0.248	0.170
	2	0.153	0.182	0.134	0.431
	3	0.035	0.764	0.004	0.979
Dec	1	0.128	0.286	0.078	0.661
	2	0.091	0.443	-0.029	0.868
	3	0.218	0.075	0.287	0.105
Jan	1	-0.021	0.859	0.017	0.921
	2	0.085	0.496	0.134	0.463
	3	-0.048	0.689	-0.070	0.692
Feb	1	0.176	0.136	0.220	0.205
	2	0.158	0.198	0.264	0.138
	3	0.120	0.291	0.134	0.423
Mar	1	-0.067	0.567	-0.073	0.674
	2	0.181	0.120	0.245	0.150
	3	0.156	0.182	0.239	0.160
Apr	1	-0.041	0.902	0.076	0.660
	2	0.053	0.653	0.083	0.629
	3	-0.050	0.660	0.023	0.889
May	1	0.024	0.834	0.120	0.479
	2	-0.066	0.553	0.021	0.898
	3	0.047	0.678	0.093	0.578

Table B_2: The correlation coefficient between 10-day minimum temperatures and time (years) and its significance level at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.460	0.000	0.660	0.000
	2	0.256	0.020	0 401	0.010
	3	0.222	0.050	0.264	0.110
Dec	1	0.116	0.314	0.234	0.163
	2	0.261	0.021	0.345	0.034
	3	0.236	0.044	0.410	0.013
Jan	1	-0.033	0.775	-0.051	0.766
	2	0.026	0.816	0.008	0.963
	3	0.013	0.907	0.018	0.913
Feb	1	0.149	0.183	0.251	0.124
	2	0.169	0.131	0.284	0.080
	3	0.170	0.127	0.296	0.068
Mar	1	0.189	0.094	0.283	0.085
	2	0.157	0.160	0.266	0.102
	3	0.231	0.044	0.345	0.037
Apr	1	0.065	0.552	0.128	0.431
	2	-0.008	0.948	-0.008	0.961
	3	-0.138	0.229	-0.062	0.715
May	1	-0.031	0.782	-0.013	0.937
	2	0..128	0.280	0.123	0.480
	3	-0.051	0.656	-0.114	0.500

Table B_3: The correlation coefficient between 10-day minimum temperatures and time (years) and its significance levels at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.160	0.317	0.035	0.879
	2	0.241	0.101	0.256	0.228
	3	0.059	0.675	0.040	0.844
Dec	1	0.050	0.760	-0.014	0.952
	2	0.112	0.440	0.022	0.910
	3	0.238	0.083	0.193	0.334
Jan	1	0.226	0.143	0.212	0.332
	2	0.236	0.127	0.077	0.734
	3	-0.026	0.862	-0.029	0.894
Feb	1	0.076	0.645	0.096	0.679
	2	0.067	0.640	0.057	0.785
	3	0.020	0.884	-0.055	0.785
Mar	1	-0.177	0.244	-0.270	0.212
	2	0.179	0.215	0.178	0.395
	3	0.189	0.224	0.197	0.378
Apr	1	-0.064	0.672	-0.203	0.352
	2	0.271	0.072	0.277	0.200
	3	-0.057	0.691	-0.092	0.663
May	1	0.218	0.173	0.041	0.859
	2	0.082	0.607	-0.003	0.989
	3	-0.020	0.895	-0.212	0.331

APPENDIX C

Correlation Coefficient between 10-Day Relative Humidity and Time (Years)

Table C_1: The correlation coefficient between 10-day relative humidity and time (years) and its significance level at Jessore station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.302	0.008	0.439	0.006
	2	0.255	0.024	0.416	0.009
	3	0.399	0.000	0 504	0.001
Dec	1	0.378	0.001	0.555	0.000
	2	0.382	0.001	0 561	0.000
	3	0.443	0.000	0 600	0.000
Jan	1	0.417	0.000	0.563	0.000
	2	0.599	0.000	0.739	0.000
	3	0.362	0.002	0.533	0.001
Feb	1	0.326	0.004	0.431	0.007
	2	0.423	0.000	0.637	0.000
	3	0.386	0.001	0 594	0.000
Mar	1	0.068	0.546	0.098	0.559
	2	0.257	0.024	0.356	0.028
	3	0.298	0.009	0.418	0.009
Apr	1	0.216	0.056	0.325	0.046
	2	0.243	0.032	0.265	0.108
	3	0.185	0.108	0.307	0.065
May	1	0.087	0.443	0.169	0.311
	2	0.180	0.113	0.267	0.105
	3	0.100	0.379	0.115	0.490

Table C_2: The correlation coefficient between 10-day relative humidity and time (years) and its significance level at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.080	0.475	0.045	0.784
	2	0.221	0.051	0.341	0.036
	3	0.228	0.058	0.324	0.061
Dec	1	0.179	0.120	0.291	0.081
	2	0.324	0.005	0.496	0.002
	3	0.245	0.036	0.380	0.022
Jan	1	0.406	0.000	0 574	0.000
	2	0.497	0.000	0.684	0.000
	3	0.283	0.012	0.459	0.004
Feb	1	0.376	0.001	0.483	0.002
	2	0.47	0.000	0.630	0.000
	3	0.568	0.000	0.713	0.000
Mar	1	0.350	0.002	0.448	0.005
	2	0.339	0.003	0.506	0.001
	3	0.445	0.000	0.626	0.000
Apr	1	0.441	0.000	0.586	0.000
	2	0.350	0.002	0.474	0.003
	3	0.458	0.000	00.656	0.000
May	1	0.238	0.041	0.345	0.039
	2	0.098	0.395	0.161	0.341
	3	0.092	0.425	0.126	0.459

Table C_3. The correlation coefficient between 10-day relative humidity and time (years) and its significance level at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.217	0.129	0.473	0.017
	2	-0.042	0.752	0.108	0.584
	3	0.291	0.033	0.353	0.071
Dec	1	0.216	0.123	0.508	0.008
	2	0.305	0.026	0.619	0.001
	3	0.257	0.055	0.598	0.001
Jan	1	0.365	0.006	0.627	0.000
	2	0.474	0.001	0.701	0.000
	3	0.150	0.293	0.309	0.133
Feb.	1	0.240	0.080	0.392	0.043
	2	0.055	0.691	0.153	0.455
	3	0.274	0.045	0.412	0.033
Mar	1	-0.087	0.514	-0.096	0.627
	2	0.117	0.392	0 227	0.255
	3	0.225	0.100	0.272	0.170
Apr	1	-0.017	0.900	0 184	0.358
	2	-0.234	0.075	-0.309	0.103
	3	0.154	0.282	0.233	0.263
May	1	-0.154	0.282	-0.011	0.957
	2	-0.062	0.659	0.063	0.758
	3	0.007	0.963	0.002	0.991

APPENDIX D

Correlation Coefficient between 10-Day Sunshine Hour and Time (Years)

Table D_1: The correlation coefficient between 10-day sunshine hour and time (years) and its significance level at Jessore station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.434	0.001	-0.497	0.005
	2	-0.374	0.004	-0.459	0.011
	3	-0.45	0.000	-0.552	0.002
Dec	1	-0.414	0.001	-0.537	0.002
	2	-0.348	0.007	-0.522	0.003
	3	-0.303	0.020	-0.454	0.012
Jan	1	-0.523	0.000	-0.686	0.000
	2	-0.504	0.000	-0.692	0.000
	3	-0.232	0.074	-0.356	0.054
Feb	1	-0.295	0.023	-0.476	0.008
	2	-0.269	0.035	-0.403	0.025
	3	-0.489	0.000	-0.695	0.000
Mar	1	0.053	0.681	0.012	0.952
	2	-0.285	0.028	-0.432	0.017
	3	-0.394	0.003	-0.514	0.004
Apr	1	-0.120	0.349	-0.274	0.134
	2	0.033	0.802	0.027	0.888
	3	-0.378	0.004	-0.545	0.002
May	1	-0.283	0.029	-0.452	0.012
	2	-0.242	0.061	-0.393	0.032
	3	-0.249	0.056	-0.360	0.051

Table D_2: The correlation coefficient between 10-day sunshine hour and time (years) and its significance levels at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.253	0.022	-0.406	0.009
	2	-0.292	0.008	-0.453	0.003
	3	-0.367	0.001	-0.479	0.003
Dec	1	-0.282	0.011	-0.488	0.002
	2	-0.259	0.020	-0.390	0.014
	3	-0.314	0.005	-0.479	0.002
Jan	1	-0.514	0.000	-0.682	0.000
	2	-0.433	0.000	-0.647	0.000
	3	-0.330	0.004	-0.473	0.003
Feb	1	-0.394	0.001	-0.494	0.002
	2	-0.291	0.013	-0.481	0.003
	3	-0.428	0.000	-0.626	0.000
Mar	1	-0.140	0.204	-0.232	0.150
	2	0.027	0.809	0.006	0.972
	3	-0.263	0.018	-0.382	0.017
Apr	1	-0.028	0.799	-0.070	0.672
	2	-0.130	0.245	-0.117	0.479
	3	-0.406	0.000	-0.578	0.000
May	1	-0.221	0.051	-0.350	0.031
	2	-0.215	0.054	-0.287	0.077
	3	-0.233	0.039	-0.575	0.020

Table D_3: The correlation coefficient between 10-day sunshine hour and time (years) and its significance level at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.408	0.002	-0.525	0.003
	2	-0.385	0.005	-0.525	0.005
	3	-0.419	0.002	-0.587	0.001
Dec	1	-0.423	0.002	-0.703	0.000
	2	-0.508	0.000	-0.673	0.000
	3	-0.372	0.005	-0.663	0.000
Jan	1	-0.408	0.002	-0.627	0.000
	2	-0.514	0.000	-0.753	0.000
	3	-0.513	0.000	-0.794	0.000
Feb	1	-0.398	0.003	-0.699	0.000
	2	-0.531	0.000	-0.724	0.000
	3	-0.572	0.000	-0.763	0.000
Mar	1	-0.336	0.006	-0.525	0.002
	2	-0.459	0.000	-0.648	0.000
	3	-0.510	0.000	-0.724	0.000
Apr	1	-0.366	0.003	-0.580	0.000
	2	-0.271	0.033	-0.385	0.033
	3	-0.604	0.000	-0.773	0.000
May	1	-0.374	0.005	-0.496	0.006
	2	-0.405	0.002	-0.607	0.000
	3	-0.441	0.001	-0.620	0.000

APPENDIX E

Correlation Coefficient between 10-Day Wind Speed and Time (Years)

Table E[1]: The correlation coefficient between 10-day wind speed and time (years) and its significance levels at Jessore station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.055	0.632	0.058	0.730
	2	-0.146	0.207	-0.193	0.246
	3	-0.048	0.678	0.042	0.800
Dec	1	-0.239	0.037	-0.276	0.094
	2	-0.111	0.337	-0.190	0.254
	3	-0.257	0.028	-0.297	0.074
Jan	1	-0.135	0.241	-0.104	0.535
	2	-0.163	0.155	-0.152	0.363
	3	-0.168	0.149	-0.178	0.292
Feb	1	-0.055	0.632	-0.060	0.720
	2	0.019	0.865	0.064	0.699
	3	0.007	0.950	0.039	0.818
Mar	1	-0.137	0.227	-0.128	0.444
	2	-0.073	0.521	-0.052	0.756
	3	0.121	0.285	0.262	0.112
Apr	1	0.040	0.725	0.061	0.718
	2	-0.007	0.950	0.000	1.0
	3	0.176	0.122	0.309	0.059
May	1	0.198	0.081	0.290	0.077
	2	0.190	0.094	0.234	0.158
	3	0.203	0.077	0.305	0.067

Table E_2: The correlation coefficient between 10-day wind speed and time (years) and its significance level at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.025	0.820	0.059	0.710
	2	-0.104	0.339	-0.137	0.385
	3	-0.017	0.875	0.071	0.658
Dec	1	-0.079	0.467	-0.019	0.906
	2	0.046	0.677	0 030	0.851
	3	-0.133	0.230	-0.080	0.622
Jan	1	0.005	0.963	0.061	0.963
	2	0.140	0.193	0.236	0.193
	3	0.023	0.828	0.067	0.828
Feb	1	-0.020	0.857	0.028	0.857
	2	0.040	0.711	0.077	0.711
	3	-0.153	0.163	-0.197	0.163
Mar	1	-0.117	0.281	-0.151	0.281
	2	-0.058	0.588	-0.081	0.588
	3	0.040	0.711	0.111	0.711
Apr	1	0.131	0.229	0.200	0.229
	2	0.038	.727	0.086	0.727
	3	0.185	.093	0.255	0.093
May	1	0.092	.401	0.128	0.429
	2	-0.046	.675	-0.076	0.640
	3	0.062	.576	0.062	0.704

Table E_3: The correlation coefficient between 10-day wind speed and time (years) and its significance level at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.102	0.447	-0.512	0.004
	2	-0.154	0.245	-0.542	0.002
	3	-0.162	0.203	-0.491	0.004
Dec	1	-0.160	0.240	-0.470	0.009
	2	-0.118	0.374	-0.419	0.019
	3	-0.456	0.677	-0.424	0.020
Jan	1	-0.129	0.320	-0.475	0.010
	2	-0.191	0.147	-0.526	0.003
	3	-0.026	0.849	-0.412	0.026
Feb	1	-0.215	0.097	-0.467	0.008
	2	-0.189	0.142	-0.465	0.008
	3	-0.307	0.017	-0.557	0.001
Mar	1	-0.450	0.000	-0.530	0.002
	2	-0.147	0.267	-0.353	0.060
	3	-0.256	0.048	-0.524	0.003
Apr	1	-0.522	0.000	-0.726	0.000
	2	-0.402	0.002	-0.647	0.000
	3	-0.347	0.007	-0.495	0.005
May	1	-0.239	0.075	-0.483	0.009
	2	-0.251	0.058	-0.509	0.005
	3	-0.210	0.118	-0.499	0.007

APPENDIX F

Correlation Coefficient between 10-Day ET_0 values and Time (Years)

Table F1: The correlation coefficient between 10-day ET_0 values and time (years) and its significance level at Jessore station

Month	10-day	Kendall's Tau_b	Significance	Pearson's *r*	Significance
Nov	1	-0.489	0.001	-0.637	0.001
	2	-0.353	0.019	-0.532	0.009
	3	-0.411	0.001	-0.490	0.006
Dec	1	-0.544	0.000	-0.601	0.001
	2	-0.469	0.001	-0.633	0.000
	3	-0.410	0.002	-0.646	0.000
Jan	1	-0.529	0.001	-0.722	0.000
	2	-0.705	0.000	-0.832	0.000
	3	-0.487	0.001	-0.659	0.000
Feb	1	-0.447	0.002	-0.589	0 002
	2	-0.361	0.009	-0.463	0.015
	3	-0.448	0.001	-0.531	0.004
Mar	1	-0.381	0.008	-0.500	0.011
	2	-0 428	0.003	-0.597	0.002
	3	-0.324	0.040	-0.445	0.043
Apr	1	-0.339	0.038	-0.312	0.180
	2	-0.205	0.221	-0.168	0.492
	3	-0.059	0.726	0.016	0.348
May	1	0.100	0.517	0.193	0.388
	2	0.038	0.809	0.108	0.642
	3	-0.254	0.119	-0.295	0.206

Table F_2: The correlation coefficient between 10-day ET_0 values and time (years) and its significance level at Bogra station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	0.109	0.365	0.271	0.335
	2	-0.057	0.629	0.087	0.619
	3	-0.053	0.708	-0.107	0.603
Dec	1	0.068	0.627	0.171	0.405
	2	-0.007	0.957	-0.282	0.139
	3	-0.097	0.464	0.109	0.365
Jan	1	-0.269	0.055	-4.33	0.027
	2	-0.014	0.910	0.079	0.668
	3	-0.034	0.808	-0.058	0.778
Feb	1	-0 097	0.454	-0.130	0.492
	2	-0.198	0.125	-0.318	0.087
	3	-0.406	0.001	-0.518	0.002
Mar	1	-0.252	0.052	-0.331	0.074
	2	0.074	0.568	0.098	0.606
	3	-0.228	0.077	-0.294	0.114
Apr	1	-0.192	0.130	-0.275	0.134
	2	-0.123	0.370	-0 065	0.749
	3	-0.258	0.041	-0.438	0.014
May	1	-0.119	0.339	-.163	0 372
	2	-0.016	0.901	-.097	0.611
	3	-0.172	0.181	-.251	0.180

Table F_3: The correlation coefficient between 10-day ET_0 values and time (years) and its significance level at Chandpur station

Month	10-day	Kendall's Tau_b	Significance	Pearson's r	Significance
Nov	1	-0.139	0.366	-0.417	0.054
	2	-0.248	0.091	-0..419	0.042
	3	-0.106	0.529	-0.406	0.084
Dec	1	-0.140	0.380	-0.534	0.013
	2	-0.457	0.001	-0.728	0.000
	3	-0.220	0.101	-0.568	0.002
Jan	1	-0.392	0.011	-0.661	0.001
	2	-0.138	0.398	-0.425	0.062
	3	-0.249	0.127	-0.628	0.003
Feb	1	-0.077	0.692	-0.616	0.015
	2	-0.457	0.001	-0.728	0.000
	3	-0.376	0.005	-0.697	0.000
Mar	1	-0.213	0.135	-0.667	0.000
	2	0.079	0.483	0.024	0.883
	3	-0.164	0.343	-0.656	0.003
Apr	1	-0.448	0.002	-0.672	0.000
	2	-0.223	0.120	-0.364	0.067
	3	-0.417	0.003	-0.743	0.000
May	1	-0.358	0.012	-0.578	0.002
	2	-0.426	0.040	-0.620	0.018
	3	-0.600	0.001	-0.780	0.000