Effect of Progressive Irrigation Development on the Environment: A Case Study of North-Bangladesh

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BUET

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INSTITUTE OF WATER AND FLOOD MANAGEMENT
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Effect of Progressive Irrigation Development on the Environment: A Case Study of North-Bangladesh

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Dedicated to my

Beloved Parents, Sister and Wife

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Abstract

In Bangladesh, the groundwater irrigation development started in the 1960s and since then it has been increasing progressively especially in the Northern region. At present, irrigation covers almost all the agricultural land in the region during dry period that provides as a source for potential evapo-transpiration. In this study, an attempt has been made to analyze the impacts of progressive irrigation development on climatic parameters, land use, cropping pattern and soil fertility. This study is mostly based on secondary data and information. Data of greater Rangpur, greater Dinajpur and Patuakhali on daily maximum temperature, minimum temperature, relative humidity, evaporation and irrigated area were used. Rangpur and Dinajpur with extensive development in irrigation were considered as the study area and Patuakhali with very little irrigation was considered as the control area. Data on soil fertility and cropping pattern were also analyzed with relation to irrigated area. In case of soil fertility, the analysis was performed only within the study area.

The results of the analysis reveal that during the irrigation season (January-April), the maximum temperature is decreasing in Rangpur and Dinajpur at a rate of 0.5^0C and 0.46^0C per decade respectively. In Patuakhali, the maximum temperature is increasing at a rate of 0.237^0C per decade. The minimum temperature is increasing over the years in Rangpur and Dinajpur at a rate of 0.5^0C and 0.27^0C per decade but in case of Patuakhali, it does not show any definite trend. Although, the evaporation is supposed to have increased over time with the increase in irrigated area but it has been observed that the rate of evaporation is decreasing over time at a rate of 0.038 mm and 0.507 mm per decade in Rangpur and Dinajpur respectively. It has also been found that the relative humidity is increasing over the years at a rate of 0.137% and 1.275% per decade in Rangpur and Dinajpur respectively. The relative humidity of Patuakhali does not show any definite trend.

The study has also revealed that there is a positive relationship between irrigation development and cropping pattern changes. Mostly Boro rice is being cultivated with the development of irrigation. Cropping intensity in Rangpur, Dinajpur and in Patuakhali in the present decade is 227%, 212% and 200% respectively.

The carbon content in the 0-15 cm soil layer mostly increased in the study area. The study area experiences a sharp fall in the total nitrogen content which may be due to the changes in cropping systems. All the physiographic units showed a decline in the content of exchangeable potassium except for greater Dinajpur. Changes in the phosphorus availability in the study area are mixed.

From the FGDs, it has been observed that there is a perception that the maximum temperature is decreasing. The dryness of weather has also been reduced. Soil fertility has been reduced as the land is being cultivated continuously with the advent of irrigation.

The findings of the study suggest that the progressive development of irrigation in the last forty years has no adverse impact on the climatic parameters except that it has reduced the diurnal variation of temperature in the irrigated areas. As the irrigation is directly related with cropping pattern and hence with the soil fertility so the cropping pattern has to be chosen carefully to avoid any adverse impact on soil fertility.

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Chapter One
Introduction

1.1 Background

Endowed with water, fertile soil and favorable climate, Bangladesh has developed a predominantly agrarian economy over the centuries. Agriculture is the single most and the largest sector of Bangladesh's economy which accounts for about 35% of the GDP and about 70% of the labor force (BBS, 2006). Agricultural productivity holds the key to the country's overall economic growth and welfare to its people.

At present, agricultural land is declining at 1% rate each year due to rapid urbanization and homestead building as against constant growth of population at a rate of 1.292% (CIA, 2008). Agricultural practices that evolved in Bangladesh were in harmony with the nature's variation in climatic conditions. To fulfill the increased demand of food, it was necessary to produce more crops from the shrunken land resources by incorporating modern crop production technologies during dry season with the help of irrigation.

With the modernization of agriculture the necessity of irrigation has increased tremendously since the start of minor irrigation in early sixties. From 1969-70 to 1999-2000, area planted to rice increased by 0.17 million hectare only, but the total rice production increased more than two times from 11.82 million metric tons in 1969 to 23.07 million metric tons in 1999-2000 (BBS, 2005). Food grain production reached to 32.93 million tons during the year 2007-08 (DAE, 2008). This revolution in food production happened mainly due to introduction of irrigation in the early sixties, which created a favorable condition for the improved production practices, adoption of HYV crops and increased use of production inputs. Irrigation coverage has been increased from about 0.5 million ha in 1959-60 (BBS, 1960) to more than 4.88 million ha in 2007 (BADC, 2007). This development of irrigation in Bangladesh has passed through a series of phases from its traditional manually lifted devices to the modern mechanized minor irrigation and major canal irrigation.

In Bangladesh the history of the development of irrigation system is not very old. Only few decades ago different types of irrigational means were developed to supply water for irrigation. The ground water irrigation was started in the 1960s. It is noted that big irrigation projects did not play positive role in the national irrigation sector. But minor irrigation program was very successful and covered more than 90% of the total irrigation. The main source of irrigation water is ground water covering about 80.60% of total irrigated area (BADC, 2007). Surface water irrigation has stagnated in recent years largely due to decrease in trans-boundary stream flows, shrinkage of wetlands and reduction of river recharge due to over extraction of ground water.

Irrigation is required mainly for Boro and wheat cultivation. Besides these some parts of the country grow other crops like paotato, oil seeds, pulses, vegetables, etc. Less quantity of irrigation water is needed for growing crops other than Boro & wheat. Boro is cultivated in about 90% of the total irrigated land (DAE, 2007).

After the introduction of ground water irrigation in 1960, it has been increasing progressively over the years specially in the northwest region. At present irrigation covers almost all the agricultural land in the region during dry period. Because of the dominance of the rice irrigation, where standing water is maintained in the fields, the evapotranspiration takes place at its potential rate. Water vapor is an important element in climate change because it exists in many forms and transformation from one form to another, exchanges a large amount of heat energy (IPCC, 2001). The exchange of moisture and energy between soil, vegetation and the overlying atmospheric boundary layer impacts the near surface atmospheric moisture and temperature (Liang, 2003). Before the introduction of groundwater irrigation most of agricultural land during dry season remained fallow and consequently the weather was too dry and climate was too hot. After the progressive development of irrigation it is assumed that a change in the weather and micro-climate system has taken place and it should also have impact on the other climatic parameters like relative humidity and precipitation (Liu and Yaohu, 2006). Simultaneously irrigation practice has changed the agricultural land use pattern with a manifold increase in cropped area. Moreover, irrigation has changed the cropping pattern with a shift from diversified cropping to mono cropping. Irrigation has resulted in continuous and yearlong cultivation with no time for the soil to re-invigorate. Such continuous cropping is expected to have negative effects on the soil fertility.

It has been estimated by National Water Management Plan (NWMP) that additional demand of 9.5 million tons of food grains will be created in 2025 compared to 2000. This increasing demand has to be met from our limited and shrinking land resources. In that case, the rate of increase of production should be 2 percent per annum to maintain food self sufficiency. In order to increase production, most of the irrigable areas will need to be brought under irrigation. As such, food security has been and will remain as a major concern for Bangladesh. But before any further large scale development of irrigation it has become necessary to study its negative impacts on both soil and on the environment.

In these contexts this study was taken up in order to assess the effects of progressive development of irrigation in the northwest region on the Environment. The term environment covers wide spectrum such as natural environment, physical environment, bio-physical environment, social environment etc. Here in this study, the term environment refers to climate, land use pattern and soil fertility. Thus the study assessed the effects of progressive irrigation development on climate, land use pattern and soil fertility.

1.2 Objective of the study

The specific objectives of the study are:

a) To find out the impact of progressive development of irrigation on climatic parameters like temperature, relative humidity and evaporation.
b) To find out the extent of impact of the present irrigation practice on agrarian land use pattern and cropping practice.
c) To correlate the irrigation development with soil fertility status (N, P, K & Organic Matter).

1.3 Limitation of the Study

While conducting the study, unavailability of data, non-matching of data periods, missing data etc. affected the progress of the analysis, interpretation of the results and the findings of the study. These limitations are given below:

a) Data of climatic parameters of the control area were of shorter duration than those of the study area.
b) Data of evaporation of study area and control area were not available for the same periods of records like other climatic parameters.

c) Irrigation data of control area did not have the same period of records like the data of study area.

d) Data of climatic parameters were collected from one meteorological station in each of the study and control areas (there was only one meteorological station in each of these areas). Considering the extent of the study and control areas, data from more meteorological stations would make the analysis more representative.

e) The control area is situated in coastal zone which is not ecologically similar to the study area. But no other similar districts were found where irrigation has not been developed over the years.

Chapter Two
Literature Review

2.1 Climate Change

2.1.1 Climate

"Climate" refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area. Classical climatology provides a classification and description of the various climate regimes found on Earth. The "weather", as we experience it, is the fluctuating state of the atmosphere around us, characterized by the temperature, wind, precipitation, clouds and other weather elements. The traditional knowledge of weather and climate focuses on those variables that affect daily life most directly: average, maximum and minimum temperature, wind near the surface of the earth, precipitation in its various forms, humidity, cloud type and amount, and solar radiation.

2.1.2 Climate System

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice (cryosphere), oceans and other bodies of water (hydrosphere) and living things (biosphere). Climate system is forced or influenced by various external forcing mechanisms, the most important of which is the sun. Also the direct effect of human activities on the climate system is considered an external force. (IPCC, 2007)

The atmosphere is the most unstable and rapidly changing part of the system. The earth's dry atmosphere is composed mainly of nitrogen (N_2, 78.1% volume mixing ratio), oxygen (O_2, 20.9% volume mixing ratio), and argon (Ar, 0.93% volume mixing ratio). These gases have only limited interaction with the incoming solar radiation and they do not interact with the infrared radiation emitted by the earth. However there are a number of trace gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3), which do absorb and emit infrared radiation. These so called greenhouse gases, with a total volume mixing ratio in dry air of less than 0.1% by volume, play an essential role in the earth's energy budget. Moreover the atmosphere contains water vapour (H_2O), which is also a natural greenhouse gas. Its volume mixing ratio is highly variable, but it is typically in the order of 1%. Because these greenhouse gases absorb the infrared radiation emitted by the earth and emit infrared radiation up- and downward, they tend to raise the temperature near the earth's surface. Water vapour, CO_2 and O_3 also absorb solar short-wave radiation.

Beside these gases, the atmosphere also contains solid and liquid particles (aerosols) and clouds, which interact with the incoming and outgoing radiation in a complex and spatially very variable manner. The most variable component of the atmosphere is water in its various phases such as vapour, cloud droplets, and ice crystals. Water vapour is the strongest greenhouse gas. For these reasons and because the transition between the various phases absorb and release much energy, water vapour is central to the climate and its variability and change. (IPCC, 2001)

Vegetation and soils at the land surface control how energy received from the sun is returned to the atmosphere. Some is returned as long-wave (infrared) radiation, heating the atmosphere as the land surface warms. Some serves to evaporate water, either in the soil or in the leaves of plants, bringing water back into the atmosphere. Because the evaporation of soil moisture requires energy, soil moisture has a strong influence on the surface temperature. The texture of the land surface (its roughness) influences the atmosphere dynamically as winds blow over the land's surface. Roughness is determined by both topography and vegetation. Wind also blows dust from the surface into the atmosphere, which interacts with the atmospheric radiation.

2.1.3 Human Influence on the Climate System

Human beings, like other living organisms, have always influenced their environment. It is only since the beginning of the industrial revolution (mid-18th century) that the impact of human activities has begun to extend to a much larger scale, continental or even global. Human activities, in particular those involving the combustion of fossil fuels for industrial or domestic usage, and biomass burning, produce greenhouse gases and aerosols which affect the composition of the atmosphere. The emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds has not only an impact on the radiative forcing, but has also led to the depletion of the stratospheric ozone layer. Land-use change, due to urbanization and human forestry and agricultural practices, affect the physical and biological properties of the Earth's surface. Such effects change the radiative forcing and have a potential impact on regional and global climate.

2.1.3.1 Anthropogenic perturbation of the atmospheric composition

For about a thousand years before the industrial revolution, the amount of greenhouse gases in the atmosphere remained relatively constant. Since then, the concentration of various greenhouse gases has increased. The amount of carbon dioxide, for example, has increased by more than 30% since pre-industrial times and is still increasing at an unprecedented rate of on average 0.4% per year, mainly due to the combustion of fossil fuels and deforestation. The concentration of other natural radiatively active atmospheric components, such as methane and nitrous oxide, is increasing as well due to agricultural, industrial and other activities. Chlorofluorocarbons and some other halogen compounds do not occur naturally in the atmosphere but have been introduced by human activities. Beside their depleting effect on the stratospheric ozone layer, they are strong greenhouse gases. Human industrial, energy related, and land-use activities also increase the amount of aerosol in the atmosphere, in the form of mineral dust, sulphates and nitrates and soot.

2.1.3.2 The enhanced greenhouse effect

The increased concentration of greenhouse gases in the atmosphere enhances the absorption and emission of infrared radiation. The atmosphere's opacity increases so that the altitude from which the Earth's radiation is effectively emitted into space becomes higher. Because the temperature is lower at higher altitudes, less energy is emitted, causing a positive radiative forcing. This effect is called the enhanced greenhouse effect. If the amount of carbon dioxide were doubled instantaneously, with everything else remaining the same, the temperature of the surface-troposphere system would increase by 1.2°C (with an accuracy of ±10%), in the absence of other changes.

2.1.3.3 The effect of aerosols

The direct effect of the aerosols is the scattering of part of the incoming solar radiation back into space. This causes a negative radiative forcing. Some aerosols, such as soot, absorb solar radiation directly leading to local heating of the atmosphere, or absorb and emit infrared radiation, adding to the enhanced greenhouse effect.

2.1.3.4 Land-use change

The term "land-use change" refers to a change in the use or management of land. Land-use change results in changing the physical and biological properties of the land surface and thus the climate system. Physical processes and feedbacks caused by land-use change, that may have an impact on the climate, include changes in albedo and surface roughness, and the exchange between land and atmosphere of water vapour and greenhouse gases (IPCC, 2001).

2.1.4 Changes in climatic variables

2.1.4.1 Changes in Temperature

Global mean surface temperatures have risen by 0.74°C ± 0.18°C when estimated by a linear trend over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years (0.13°C ± 0.03°C vs. 0.07°C ± 0.02°C per decade). Global mean temperatures averaged over land and ocean surfaces, from three different estimates, each of which has been independently adjusted for various homogeneity issues, are consistent within uncertainty estimates over the period 1901 to 2005 and show similar rates of increase in recent decades. The trend is not linear, and the warming from the fi rst 50 years of instrumental record (1850–1899) to the last 5 years (2001–2005) is 0.76°C ± 0.19°C (IPCC, 2007).

Analysis of mean daily maximum and minimum land surface air temperatures continue to support a reduction in the diurnal temperature range in many parts of the world, with, globally, minimum temperatures increasing at nearly twice the rate of maximum temperatures between about 1950 and 1993 (Easterling et al., 1997). The rate of temperature increase during this time has been 0.1°C and 0.2°C/decade for the maximum and minimum, respectively. This is more than twice the rate of temperature increase over the oceans during this time. The rate of temperature increase for both maximum and minimum temperature over this period is greater than for the mean temperature over the entire 20th century, reflecting the strong warming in recent decades.

Since the Diurnal Temperature (DTR) is the maximum temperature minus the minimum temperature, the DTR can decrease when the trend in the maximum or minimum temperature is downward, upward, or unchanging. This contributes to less spatial coherence on the DTR map than on maps of mean temperature trend.

2.1.4.2 Changes in Water vapor

Changes in water vapour mixing ratio have been analysed for selected regions using in situ surface observations as well as lower-tropospheric measurements based on satellites and weather balloons. A pattern of overall surface and lower-tropospheric water vapour mixing ratio increases over the past few decades is emerging, although there are likely to be some time-dependent biases in these data and regional variations in trends. The more reliable data sets show that it is likely that total atmospheric water vapour has increased several per cent per decade over many regions of the Northern Hemisphere since the early 1970s. Changes over the Southern Hemisphere cannot yet be assessed (IPCC, 2001).

Satellite observations of upper-tropospheric humidity from 1980 to 1997 show statistically significant positive trends of 0.1%/year for the zone 10°N to 10°S. Other trends are not statistically significant, but include a 0.04%/year positive trend for the zone 60°N to 60°S but a negative trend of –0.1%/year over the region 30°S to 60°S.

Balloon observations of stratospheric water vapour above 18 km show an increase of about 1%/year for the period from 1981 to 2000. Shorter satellite records show a similar positive trend, suggesting that the change is global in character, but they also indicate a slowing of the positive trend after 1996.

2.1.5 Historical Changes of Temperature in the Past Millennium

New analyses indicate that the magnitude of Northern Hemisphere warming over the 20th century is likely to have been the largest of any century in the last 1,000 years. The 1990s are likely to have been the warmest decade of the millennium in the Northern Hemisphere and 1998 is likely to have been the warmest year. Because less data are available, less is known about annual averages prior to 1,000 years before the present and for conditions prevailing in most of the Southern Hemisphere prior to 1861 (IPCC, 2001).

Evidence does not support the existence of globally synchronous periods of cooling or warming associated with the 'Little Ice Age' and 'Medieval Warm Period'. However, reconstructed Northern Hemisphere temperatures do show a cooling during the 15th to 19th centuries and a relatively warm period during the 11th to 14th centuries, though the latter period is still cooler than the late 20th century. Analyses of borehole temperatures indicate a non-linear increase in global average ground surface temperature over land of 1.0 ± 0.3°C over the last 500 years, with most of the increase occurring since the late 19th century. There may be additional uncertainties due to the assumptions used in this technique, and decreasing resolution back in time limits confidence in the exact timing of the warming (IPCC, 2001).

2.1.6 Climate Change in Bangladesh Perspective

According to Ahmed and Alam (1999) the vulnerability to climate change for different sectors was assessed based on climate scenarios developed by General Circulation Models (GCMs) for two projection years of 2030 and 2075. The results revealed that the average increase in temperature would be 1.3°C and 2.6°C for the years 2030 and 2075 respectively.

Huq (2000) suggested after analyzing the climate change scenarios for Bangladesh that the temperature will increase by 0.7 °C and 1.1 °C and precipitation will increase by 11% and 28% in monsoon in the time horizon 2030 and 2050, respectively.

Karmakar and Shrestha (2000) studied the recent climatic changes in Bangladesh by using the surface climatological data on monthly and annual mean maximum temperature, minimum temperature and monthly and annual rainfall for the period 1961-90. The overall trend of annual mean maximum temperature for the period 1961-90 is of increasing order, which is statistically significant. The overall annual mean minimum temperature over Bangladesh for the period 1961-90 has a slight decreasing trend. The study also revealed that the annual mean temperature over Bangladesh has a slight increasing trend during the whole period 1961-90. The present changes in the climatic elements have been projected up to 2050 and 2100 years. The overall annual mean temperature over Bangladesh is likely to increase by 0.22°C and 0.41°C by 2050 and 2100 years respectively.

Miah (2003) examined thirty years (1971-2001) record of monthly average minimum temperature during the months of December and January in winter and monthly average maximum temperature during the months of April and May (Premonsoon) at Dinajpur, Rangpur, Rajshahi, Jessore, Ishurdi, Chuadanga and Srimangal stations by statistical method. He observed that the lowest minimum and highest maximum temperature trend has increased by 0.012°C/yr in winter except for Rajshahi where the temperature trend is downward. The temperature trend has increased by 0.013°C/yr in summer except for Chuadanga. The average temperature has increased by 0.0125 °C/yr within the period of 1971-2001 which is nearer to the global temperature increasing rate.

The study of Quadir (2008) using the data of 13 meteorological stations distributed over Bangladesh shows that the temperature is strongly increasing during life cycle of Aman rice (monsoon and post-monsoon seasons) along with the inter-annual fluctuations. The rainfall of August exhibits negative correlation (-0.48) and October positive correlation (0.51). The month of June has the positive correlation of 0.28. As Aman rice is rainfed, the variability of temperature and rainfall causes major impact on the yield of Aman rice.

According to Nishat (2008), the study of IPCC-III has shown that for Bangladesh the temperature would increase by 0.7 and 1.1^{0}C during the monsoon season for the year 2030 and 2050, respectively. Also the monsoon rainfall would increase by 11% and 28% compared to 1990 for the year 2030 and 2050, respectively.

According to IWFM (2008), annual and seasonal mean temperatures are found to have in general increasing trends in Bangladesh. The overall trend in mean annual temperature is found to be +0.10 and +0.21 ^{0}C per decade for data periods of 1948-2007 and 1980-2007, respectively. It thus appears that the warming has been more rapid in the recent decades. At seasonal time scales, the warming has strengthened in both summer and monsoon seasons and weakened in winter season over last three decades or so.

The study of Nasrin (2008) reveals that reference crop evapo-transpiration (ET_0) has decreasing trends at all stations. The decreasing trends are 0.2, 0.2, 0.1 and 0.3 mm/day per decade for Dhaka, Jessore, Bogra and Chandpur, respectively. The analysis has also found out 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. Bogra has decreasing trend of 0.2^{0}C per decade. Minimum temperature has increasing trends of 0.6^{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. The average increasing trends are 0.9%, 2.5%, 3.0% and 1.4% per decade at Dhaka, Jessore, Bogra and Chandpur, respectively.

Zaman S. (2009) has analyzed sunshine duration data at nine meteorological stations, which represent all hydrological regions of Bangladesh and spread more or less uniformly, to see the long-term changes and trends from 1961 to 2006. The analysis has shown that the sunshine duration experiences a decreasing trend at all selected stations. The overall annual decrease for the entire Bangladesh is found to be about 0.3 hours a day in every 10 years. For the years 1961 and 2006, ET_0 was calculated with their respective sunshine duration keeping other climatic parameters unchanged. It was found that the annual ET_0 has declined by 6.1% from 1961 to 2006 due to the decline in sunshine duration.

2.2 Development of Irrigation

2.2.1 Surface water irrigation development

Large scale water resources development in Bangladesh began in the early 1950s. At that time after several years of studies, a team of UN experts proposed the Ganges-Kobadak Project lying in the greater districts of Kushtia, Jessore and Khulna. Later on, BWDB completed a Master plan and initiated follow up studies and investigations of others. Three types of projects were envisaged: a) flood embankments with gravity drainage, b) flood embankments with tidal sluice drainage, and c) flood embankments with pump drainage. Irrigation within these flood protected areas was also envisaged but flood control was given a priority in the first stage. The principle that flood control and improved drainage creates opportunities for further development, including irrigation, became a basic tenet for water resources planning.

Although major emphasis fell on flood control projects, small scale surface and subsurface systems were experimented with throughout the 1950's and 60's. For example, two cusec low lift pumps, using surface water, were introduced through the Mechanized Cultivation and Power Pump Irrigation program (MCPPI) beginning in 1956. The program never reached full potential primarily because, EPADC was enable to establish an effective means of organizing farmers to share water from a single pump or to ensure the delivery of water at critical times for crop production (Thomas, 1972).

Shortcomings led to the replacement of the MCPPI scheme in 1968 by the Thana Irrigation Program (TIP). Unlike its predecessor, the TIP placed emphasis on organizing farmers to share and utilize before a pump was provided. The scheme proved exceptionally successful and by 1969-70, 18000 pumps irrigating 0.28 million hectares were in operation. Although constrained by the problems of water losses, poor maintenance and timely pump distribution, the major constraint facing this program was the availability of surface water (Hanratty, 1983).

At present surface water irrigation is carried out by gravitational flow through a number of large scale irrigation projects implemented mainly by BWDB. In 2006-07, about 137,064 hectares were irrigated by such large projects.

2.2.2 Groundwater Irrigation Development

While experiments with minor surface irrigation were underway, early pilot programs to tap underground water were also commencing. In 1961, the German Government in cooperation with Water Development Board installed 380 four-cusec electrically powered wells in the Northwest part of Bangladesh, now called as North Bangladesh Tube-well (DTW) Project, Thakurgaon. Coverage per well was limited because of high seepage losses and provisions to train farmers in the techniques of irrigated agriculture were not developed. Subsequently, Extension Wing of the then Directorate of Land & Water Use (now Department of Water Management) under the then EPWAPDA (now BWDB) was extablished for training of farmers and improvement of sandy soil and establishment of irrigated agronomy. Later on, another 836 DTWs were commissioned in the project area. In 2003, the project has been handed over to Barendra Multipurpose Development Authority (BMDA). (Hashem, 2005)

In Bangladesh, pending major surface water development, the expansion of minor irrigation (small-scale irrigation) has formed a vital component of the Government's strategy in agriculture. Irrigation through major canals (large scale-irrigation) covered only about 4% of the total irrigated area in 2007, the remainder being classified under minor irrigation consisting of low lift pumps (LLP's: power operated centrifugal pumps drawing water from rivers, creeks and ponds), shallow tubewells (STW's: with a motorised suction mode pumping unit), deep tubewells (DTW's: with power operated force mode pumping unit), manually operated shallow tubewells for irrigation (MOSTI's: extracting water from a shallow tubewell) and traditional systems (BADC, 2007). At the end of the dry season, the water level can fall beyond the suction limit of the centrifugal pump. In these situations, it is possible to draw water by placing the STW in a pit. Lowering of a STW in a pit is called a deep-set shallow tubewell (DSSTW) or a very deep-set shallow tube-well (VDSSTW). When the static water levels fall further (over 10.7 m), submersible or vertical turbine pumps (FMTW's : force mode tubewells) are needed.

Between 1950 and 1979, public tubewells, regulations of private installations and public monopolies in the supply of pumps, motors and other equipment were a constraint to the development of irrigation. Since 1972, emphasis has been placed on minor irrigation through low lift pumps and mainly by tubewells (Shallow tubewells (STWs), Deep tubewells (DTWs) and Force mode tubewells (FMTWs)).

From 1979 to 1984, there was a liberalised expansion of minor irrigation with STWs in the private sector. In 1981-82, about 0.20 million ha of land was under irrigation with 43,000 operating STW's. The rate of installation of STW's development was 10,000 per year from 1981-82 to 1984-85, but numbers were reduced from 73,000 in 1984-85 to 47,000 in 1988-89. Several reasons are cited for this decline: private sector STW sales were limited by Government; some agricultural subsidies were removed; there was official concern over reported declines in groundwater levels where STWs operated; the concept of DSSTW had not been introduced by that time.

In 1991, the National Minor Irrigation Development Project (NMIDP) was established in response to the needs of farmers and the requirement of increased private sector investment in minor irrigation technologies. The project activity mainly concentrates on VDSSTWs and FMTWs technology, whereas irrigation by STW (shallow tubewell) is mainly controlled by the private sector. In 1995, 583 VDSSTWs and 135 FMTWs were in operation by farmers due to the promotional action of the project. There has been a general reduction of the area irrigated by DTW due to problems with management and finance, but this has been more than compensated by the rise in STW (including DSSTW). There has been an increase in salinity intrusion in the south-western part of the country which is related to the reduction of freshwater entering the area through the Ganges distributaries, especially the Gorai. There is some evidence for increased soil salinisation in the extreme South West (Satkhira area), which may be due to increased groundwater abstraction.

Currently, out of 8,640,727 ha net cultivable area about 4,882,879 ha area irrigated by different equipments in 2007 which is 56.51% of total cultivable area (BADC, 2007). Irrigation through groundwater (shallow tube-wells and deep tube-wells) covers 80.30% of the total area.

2.3 Soil Fertility

2.3.1 Soil:

Soil is the naturally occurring, unconsolidated or loose covering on the Earth's surface. Soil is made up of broken rock particles that have been altered by chemical and environmental conditions, affected by processes such as weathering and erosion. Soil is different from its parent rock(s) source(s), altered by interactions between the lithosphere, hydrosphere, atmosphere, and the biosphere. It is a mixture of mineral and organic constituents that are in solid, gaseous and aqueous states. Soil particles pack loosely, forming a soil structure filled with pore spaces. These pores contain soil solution (liquid) and air (gas).

Soil is used in agriculture, where it serves as the primary nutrient base for the plants. The types of soil used in agriculture (among other things, such as the purported level of moisture in the soil) vary with respect to the species of plants that are cultivated.

2.3.2 Soil fertility:

Soil fertility is the characteristic of soil that supports abundant plant life. In particular the term is used to describe agricultural and garden soil.

Fertile soil has the following properties:

- It is rich in nutrients necessary for basic plant nutrition, including nitrogen, phosphorus and potassium.
- It contains sufficient minerals (trace elements) for plant nutrition, including boron, chlorine, cobalt, copper, iron, manganese, magnesium, molybdenum, sulfur, and zinc.
- It contains soil organic matter that improves soil structure and soil moisture retention.
- Soil pH is in the range 6.0 to 6.8.
- Good soil structure, creating well drained soil.
- A range of microorganisms that support plant growth.
- It often contains large amounts of topsoil.

Soil Fertility is the capability or ability of soils to supply elements essential for plant growth without a toxic concentration of any element. It is the inherent capacity of a soil to supply 14 of the 17 essential nutrient elements to the growing crop. It is the quality of soil that enables it to provide compounds or elements in adequate amounts and in proper balance for the growth of specified plants when other growth factors like light, moisture, temperature and the physical conditions of the soils are favourable. So, fertility is the potential nutrient status of a soil to produce crops. As plants have evolved in different climates and on different soils, they have different needs for the essential nutrients and different tolerance to the toxic elements. As such, a soil can be fertile for one plant and at the same time be unfertile for another plant. On the other hand soil productivity is a measure of the soils ability to produce a particular crop or sequence of crops under a specified management system.

2.3.3 Effect of Irrigation on Soil Fertility

The effect of long term irrigation and intensive cultivation on three soil series was investigated by Rahman et al (1995). These soils were from a calcareous belt in the G-K irrigation project area in Bangladesh, which had experienced declining crop yields. In order to evaluate the effect of irrigation and intensive cultivation on soil properties, three soil series from irrigated and non irrigated located in the same catena were studied. Soil properties such as organic carbon, electrical conductivity. CEC, potassium absorption ratio, exchangeable sodium percentage and ionic strength did not show any distinct changes between the investigated areas. The major changes identified between irrigated and non-irrigated soils were pH, void ratio, maximum water holding capacity, water soluble Na, ferrous iron, sodium absorption ratio, available nitrogen and free carbonate content.

Long term irrigation has considerable impact on soil chemical properties. Irrigating Lima and Kendaia silt loam soils with an average of 10.7 cm of water each year for 13 years caused no change in soil pH, organic matter. or available P, Ca, and Mg. Irrigation significantly reduced available K from an average of 109 kg/ha in non-irrigated plots to an average of 97 kg/ha in irrigated plots (Vittum et. al, 1968).

The growth and yield of rice crop were significantly reduced at different consecutive stages of growth due to irrigation with saline water. Panicle initiation and heading stages (P+H) and the maximum tillering and panicle initiation stages (M+P) were more susceptible to saline water irrigation for the production of yield components. But the growth of rice was more affected due to application of saline water at the early and maximum tillering stages (E+M) and could not recover appreciably at maturity through irrigated with fresh water afterwards. Continuous saline water drastically reduced all the growth and yield parameters. Effect of irrigation with saline water at heading and ripening stages of rice crop was found to be less pronounced irrespective of concentration (Mohiuddin et. al, 2007).

The impact of irrigation on soil fertility is due to three main issues: nitrate leaching, denitrification and soil aggregate dispersion. Of course the first one is more important in sandy soils, while the others are more harmful in clayey soils. One of the main ways for nitrogen losses from agro-ecosystems is nitrate leaching driven by rainwater or irrigation water percolation through the soil profile. Irrigation systems with a low efficiency (furrow, border, and wild flooding) enhance percolation and anaerobic conditions. Anaerobic conditions enhance the de-nitrification process (Fagnano, 2008).

Davidson et al., (1992) showed that denitrification can occur only a few minutes after watering. Shimojoki and Jaakkola (2000) found that irrigation doubled the N loss due to denitrification compared with a non-irrigated situation with fertilized barley. This process leads to a reduction of chemical fertility and of nitrogen availability for the crops, but also increases the environmental impact of cropping system, since N_2O is one of the most powerful greenhouse gases.

Irrigation systems with high rain intensity (i.e. high pressure rain-guns sprinkler) can be very harmful for soil structure at the top layer. The intensity of damage depends on the soil texture (maximum in clayey soils) and on the level of soil coverage (maximum on bare soil or in the first crop stages). In poorly draining clayey soils, the soil moisture surplus in the top layer enhances clay dispersion thus reducing soil aggregate stability (Pagliai et al., 2004).

The nutrient status of soil showed that organic matter, total N, exchangeable K and available P & S slightly increased due to cropping over the fallow. The highest increase but more or less similar was observed after dhaincha, deshi jute and tosha jute and the lowest in case of T Aus rice. The pH slightly decreased in all the treatment from initial stage (Khan et al, 2007).

A study conducted on selected irrigation schemes in East Wollega Zone of Oromia National Regional State, Ethiopia to investigate the likely changes of soil chemical parameters due to irrigation in the irrigated farms in comparison to the adjoining non irrigated farms. The study indicated that soil pH (H_2O), and exchangeable bases were higher in irrigated farmlands than the non-irrigated farmlands. On the other hands, soil organic matter (SOM), total nitrogen, and exchangeable acidity were lower in irrigated farmlands. Relatively, the lower organic matter and total nitrogen contents in irrigated farmlands attributed to the optimum soil moisture content through out the year that created favorable environmental condition for SOM decomposition (Getaneh et al., 2007).

2.4 Effect of Irrigation Development on Cropping Pattern and Intensity

Cropping patterns for land in the northern districts were governed by low soil moisture during the winter months. Major crops were aus and transplanted aman. Small amounts of jute, sugarcane, oilseeds and other winter crops were grown. Before introduction of irrigation cropping intensity of that area was about 95% reflecting the single crop economy of the area. With irrigation, yields and production increased and double or triple cropping became possible on most of the lands. Cropping intensity with irrigation was expected to 228 percent (IECO, 1964).

The Flood Action Plan (FAP-12) has shown that the traditional cropping pattern of the project area of Silimpur-Karatia Regulator Cum Bridges project, comprises of Dhainnya, Porabari and Silimpur union of Tangail, consists of Aus followed by B. Aman. Jute and Sugarcane are popular here, especially in the more elevated, sandy areas. The winter crops are mustard and wheat. Boro HYV can not be cultivated in elevated areas because of the high water cost involved in a sandy environment. The cropping pattern within the project area consists of Boro HYV under irrigation in the deeply flooded land, sometimes followed by B. Aman. In the medium low-land, it is possible to have T. Aman after HYV boro and in the medium to high land, jute or aus, rabi crops or sugarcane are found. These changes are a direct consequence of the embankment (Hunting Technical Services ltd, 1991).

From the Flood Action Plan (FAP-12), it has been found that the current cropping practice in the Konajpara Embankment Project area, Haluaghat upazilla in Mymensingh, has evolved in response to a number of changes in the crop environment. The hydrological regime has altered, making it safe for Aus, Jute and Aman cultivation. At the same time, and quite independently, irrigation has expanded rapidly, leading to a rapid expansion in the area under HYV Boro. Therefore, despite greater protection afforded to Aus, its acreage has declined as Boro cultivation expanded under irrigation. Current copping intensity is around 200 percent. The increase in cropping intensity would appear to be largely related to acreage expansion in Boro, and cannot be attributed to the project (Hunting Technical Services ltd, 1991).

From the Flood Action Plan (FAP-2), it has been found that the main shifts in cropped areas as a result of flood control relate to paddy crops, but there are also some adjustments in areas of rabi crops. The principle shifts are increased HYV Boro and declining B. Aus (and sometimes Rabi crops), increased T. aman and declining B. Aman, Increased T. Aman and declining B. Aus and increased HYV T. Aman and declining local T. Aman. Cropping intensities barely increase and may even decrease with project. Incremental HYV T. Aman cultivation for example, generally replaces another paddy crop (local T. Aman, B. Aus or B. Aman) and, if the cropping pattern HYV Boro-HYV T. Aman replaces rabi-B. Aus-local T. Aman, cropping intensities decline (Matt Macdonald Intl, 1992).

Over the last quarter of a century of post-Bangladesh years, cropping patterns tilted towards high yielding variety (HYV) of crops both in Kharif and Rabi season. Crop diversification has been taking place in the Rabi season. Growths of HYV aus and wheat areas have been diminishing since the decade of the eighties. Local varieties of rices have been declining and got negative cropping pattern changes including jute, barley, mustard and chilli throughout the whole period of 1971/71-1993/94. It was observed that real output price change and cropping pattern changes had little relationship. Improved technology of production (seed-fertilizer-Irrigation technology) had rather influenced cropping pattern changes (Alam and Abedin, 1996).

The Early Implementation Projects (EIP) have been successful in raising agricultural production. The increase in agricultural production has been about 35 percent on average. There were no significant changes in the cropping patterns of the project area. Field research data recorded a 10 percent increase due to double cropping. Cropping intensity increased from 115 to 125 percent in 1998, but is still lower than the district average which is 147 percent (Datta, 1999).

It is observed that cropping pattern and cropping intensity have been changed remarkably in the irrigated area of Teesta Barrage Project. Farmers have started to grow HYV Aman rice and at least two crops are grown in the irrigated area. The irrigation coverage in the Kharif-II season of 2002 was 61,044 ha in the Teesta Barrage Project area (IWM, 2003).

Recently completed Command Area Development Project (CADP) of Bangladesh Water Development Board (BWDB) covering 24,854 ha under irrigation, noted that cropping intensity has increased by 25% in Pabna Irrigation and Rural Development Project (PIRDP) and 27% in Meghna-Dhonagoda Irrigation Project (MDIP) during 2001-02. Net incremental food production is 94,353 metric tons. During Kharif-II, rice production increased by about 51% over the pre-CADP situation. Income-poverty has reduced by increasing agricultural income simply twice than before CADP (Mondal and Saleh, 2003).

Chapter Three
Methodology

3.1 Introduction

The study has mainly been performed by using secondary data. To do this study, it has been tried to find out two such regions where irrigation has been started earlier, has a comparatively longer record of data and is being expanded progressively. After going through the database of irrigation coverage provided by Agricultural Statistics Year Book of Bangladesh Bureau of Statistics (BBS), greater Rangpur and greater Dinajpur were selected as the study area. As a control area, Patuakhali with very little irrigation development was also selected.

3.2 Description of the Study Area

3.2.1 Location and Area

The study area, divided into two sub-areas of Greater Rangpur and Greater Dinajpur. Greater Dinajpur comprises of three districts namely Panchagarh, Thakurgaon and Dinajpur. This area lies approximately between latitudes $26^0$63' and $25^0$22' N and longitudes $88^0$08' and $89^0$30' east. This area is covered by Indian border from the northern and western side and by the districts of greater Rangpur from Eastern and Southern side. Only a small portion of the southern border of this study area is delineated with Joypurhat District of Greater Bogra. The Panchagarh, Thakurgaon and Dinajpur occupy gross areas of 140,500 ha. 180,900 ha and 343,800 ha respectively.

Greater Rangpur comprises of five districts such as Rangpur, Lalmonirhat, Kurigram, Nilphamari and Gaibandha. This part of the study area lies approximately between latitudes $26^0$27' and 25^0 N and longitudes $88^0$50' and $89^0$52' E. This area is bounded by Indian border in the North. greater Dinajpur in the west, Jamalpur in the East and Greater Bogra in the southern side. Total area of the districts Rangpur, Nilphamari, Kurigram, Lalmonirhat and Gaibandha is 230,800 ha, 164,100 ha, 229,600 ha, 124,200 ha and 217,900 ha respectively.

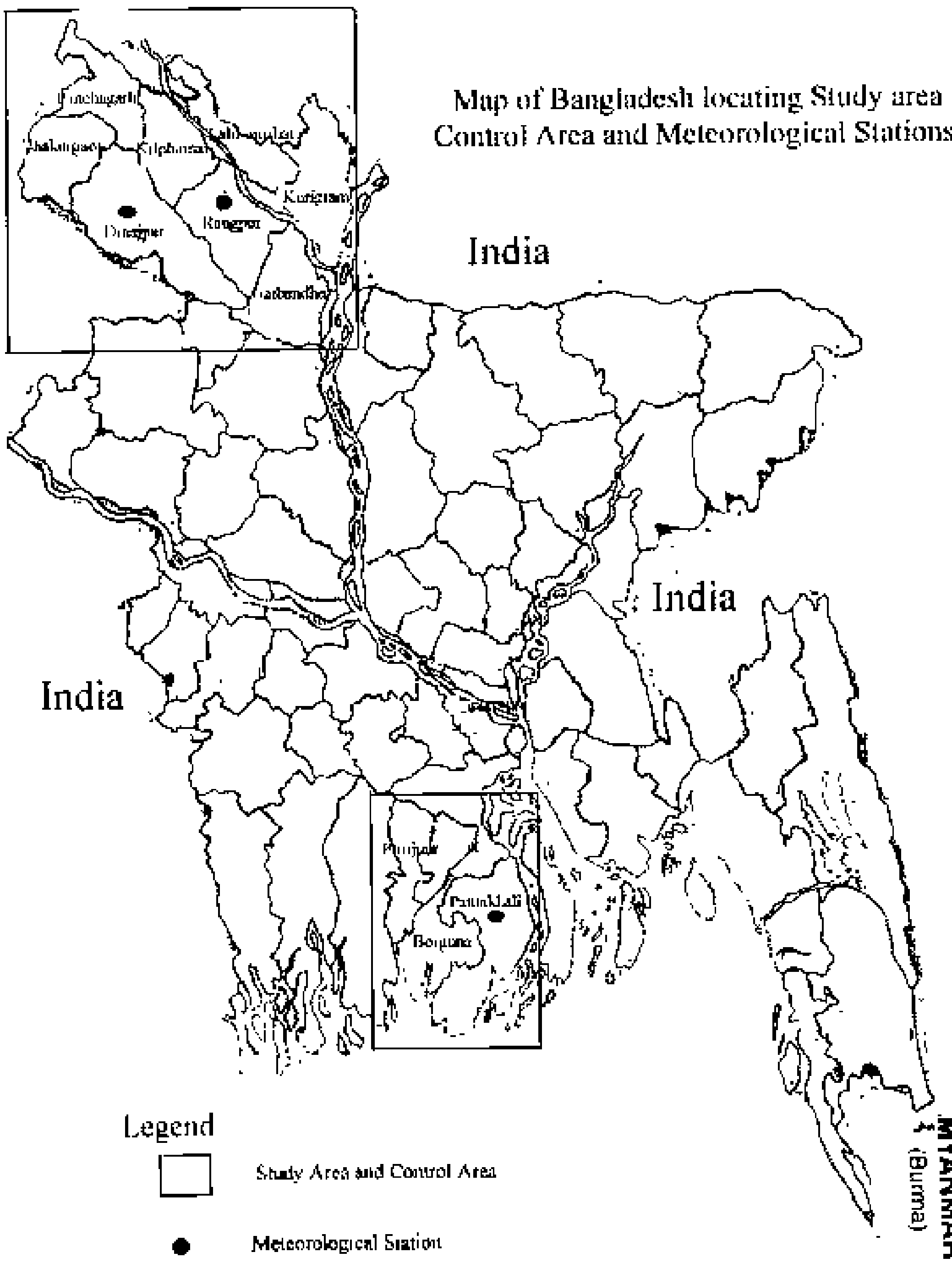

Figure 3.1: Map of the Location of the Study area and Control Area

The control area. Greater Patuakhali District comprises of three districts namely Patuakhali, Pirozpur and Barguna. It lies approximately between latitudes $21^0 47'$ and $22^0 53'$ N and longitudes $89^0 52'$ and $90^0 38'$ E. This area is bounded by Barisal district on the north, the Bay of Bengal on the south, Bhola and Jhalokathi district on the east, Bagerhat district on the west. Total area of the districts Patuakhali, Pirojpur and Barguna is 320,458 ha, 130,761 ha and 183131 ha respectively.

3.2.2 Climate

As Greater Rangpur and Greater Dinajpur are two adjacent greater districts, so there is no basic difference in climate of these two areas. The area experiences a tropical climate characterized by a very humid, wet south-west monsoon from June to November. This accounts for some 85% of the annual rainfall. During the period December to May a cool, dry north-east monsoon blows from central Asia bringing, initially, the lowest temperatures and humidities and, later on, convectional storms. In general terms the northern location of the study area is characterized by colder winters and hotter summers relative to the rest of Bangladesh.

The average maximum temperature of Dinajpur is 29.73^0C and average minimum temperature is 19.50^0C. Average mean temperature of this station is 24.61^0C. Annual precipitation and annual average relative humidity of this station is 1928 mm and 74.70% day respectively. 93% of the annual rainfall occurs in Monsoon and the Boro season gets only 5% of the annual rainfall. Potential evapo-transpiration is 1276 mm annually as well. (CIMMYT, 2003)

In Rangpur, the average maximum temperature is 29.35^0C and average minimum temperature is 19.54^0C. The average mean temperature of this station is 24.45^0C. Average relative humidity and annual potential evapo-transpiration of Rangpur is 78.33% day and 1258 mm respectively. Annual precipitation of Rangpur is 2112 mm as well which occurs mostly in Monsoon (92.67%) and very little rainfall (6.26%) during Boro season. (CIMMYT, 2003)

In Patuakhali, the average maximum temperature is 30.29^0C and average minimum temperature is 21.77^0C. The average mean temperature of this station is 26.03^0C. Average relative humidity and annual potential evapo-transpiration of Patuakhali is 82% day and 1269 mm respectively. Annual precipitation of Patuakhali is 2442 mm as well.

85% of the annual rainfall occurs in Monsoon and the Boro season gets only 8% of the annual rainfall. (CIMMYT, 2003)

3.2.3 Soil Type

A special type of soil which is found only in Greater Dinajpur district is known as Black Terai Soils. It is very dark grey to black sandy loams to clay loams. Top soils are strongly to very strongly acidic but the sub-soils are slightly acidic in reaction. Some other soil types are predominantly present in greater Dinajpur such as Non-calcareous Dark Grey floodplain soils, Non-Calcareous Grey Floodplain Soils and Non-Calcareous Brown floodplain Soils. Non-Calcareous Alluvium is present in Dinajpur and Panchagarh districts. Deep Red-brown Terrace Soils, Brown Mottled Terrace Soils, Shallow Grey Terrace Soils and Deep grey Terrace Soils are predominantly present only in Dinajpur District. (BARC, 2005)

The greater Rangpur is dominated with the soil type of Non-Calcareous Alluvium, Non-Calcareous Grey Floodplain Soils and Non-Calcareous Brown Floodplain Soils. Non-Calcareous Dark Grey floodplain Soils is also presently in all districts of Greater Rangpur but only in Lalmonirhat. Deep red brown terrace soils, Brown Mottled Terrace Soils, Shallow Grey Terrace Soils and Deep Grey Terrace Soils is predominantly present only in Rangpur and Gaibandha districts of Greater Rangpur. (BARC, 2005)

The greater Patuakhali contains the soil type of Ganges Tidal Floodplain and Young Meghna Estuarine floodplain. The Ganges Tidal Floodplain is characterized with the grey, slightly calcareous, heavy soils on river banks and grey to dark grey, non-calcareous, heavy silty clays in the extensive basins. Non-calcareous grey floodplain soil is the major component of general soil types. Acid sulphate soils also occupy significant part of the area where it is extremely acidic during dry season. In general, most of the top-soils are acidic and sub-soils are neutral to mildly alkaline. Young Meghna Estuarine Floodplain occupies young alluvial land in and adjoining the Meghna estuary. The major soils are grey to olive, deep, calcareous silt loan and silty clay loams. Calcareous alluvium and non-calcareous grey floodplain soils are the dominant general soil types. (BARC, 2005)

3.2.4 Agriculture

The climate and soils of this area are favorable for plant growth and a wide range of crops is cultivated. Net cultivated area in greater Dinajpur is 464,913 ha, which is 70% of the total area of this region. Among the net cultivated area 11.74% is single cropped, 64.71% is double cropped and the rest 23.55% is tripled cropped land. Cropping intensity of Dinajpur is 212.74% (DAE, 2006).

In greater Rangpur, the total area is 966600 ha and net cultivated area is 713,209 ha, it comprises 73.78% of the total area. Among the net cultivated area 8.97% is single cropped, 64.61% is doubled cropped and 26.42% is triple cropped land. Cropping intensity of greater Rangpur is 211.5% (DAE, 2006).

In the greater Patuakhali, the total area is 475,582 ha and net cultivated area is 325,524 ha which comprises of 68.45% of the total land. Single cropped, double cropped and triple cropped area of greater Patuakhali is 26.05%, 51.3% and 22.65% of the net cultivated area respectively. Cropping intensity of Patuakhali is 194.6% (DAE, 2006).

The high rainfall and floods occurring from April to September create conditions ideal for growing rice, the staple food. There are three rice seasons, the Aus and the Aman occurring in the early and late kharif which broadly correspond to the first and second halves of the wet season, and the Boro which occurs in the rabi or dry winter season. Within the study area topography and soil type are the main factors governinig a farmer's choice of which crop to grow. On the permeable ridge soils rice is not an ideal crop and farmers are effectively limited to a late planted Aus or early Aman; on the less permeable medium highland and lowland soils it may be possible to obtain both an Aus and Aman crop in the same year. Boro is grown extensively now a days with the help of irrigation. Wheat is also being cultivated but in a decreasing pace. Maize has started to be cultivated in the study area and very recently it is overtaking wheat, sugarcane and other winter crops very rapidly. All other crops occupy relatively small areas but some, tobacco for example, are important locally.

3.3 Data Collection

3.3.1 Secondary Data

The study has been mainly conducted by secondary data. Various data have been collected from different publications and reports of different organization. Name of the organization from where the secondary data have been collected and type of data are given below:

Irrigation Data

Region-wise data of irrigated area from 1969 to 2006 have been collected from different books and reports. The "Yearbook of Agricultural Statistics of Bangladesh" of different years by BBS has provided the majority of data on irrigation coverage. Few data on irrigated area have also been collected from the National Minor Irrigation Census of Department of Agriculture Extension (DAE). Survey reports on Irrigation Equipment and Irrigated Area by Bangladesh Agricultural Development Corporation have also provided some data of the recent years.

Climatic Data

The study required a huge amount of data on different parameters of the climate, both for the study area and control area. It required daily basis data on maximum, minimum and average temperature, relative humidity, evaporation of those three regions since the earliest available year (1949) until the latest available year (2007). The required climatic data have been collected for Rangpur, Dinajpur and Patuakhali stations from the Bangladesh Meteorological Department (BMD), Dhaka, and from Bangladesh Water Development Board (BWDB). However, for some climatic parameters in some stations data were available either from 1960, 1980 and 1986.

Soil Fertility Data

Soil fertility data like total nitrogen content, total carbon content, pH, exchangeable potassium and exchangeable phosphorus data of 1968 and 1995 of different sample sites of the study area have been collected from the "Integrated Soil Fertility and Fertilizer Management Project (SFFP Phase-II)" of Department of Agriculture Extension (DAE).

3.3.2 Primary Data

In order to corroborate the findings from the analyses of the secondary data, three Focus Group Discussions (FGD) were conducted in the study area. These focus group discussions (FGD) have been conducted in Dinajpur, Thakurgaon, and Nilphamari. The FGDs were conducted during July-September, 2007. In each FGD, the total number of participants was ten to fifteen. Purposively, these FGD were conducted with the local elderly farmers to know their perception about the impact of progressive irrigation development on soil fertility, land use, cropping pattern and practices.

Table 3.1: Data collection

Data Required	**Collected From**
Secondary Data	
Irrigation Data	BBS year book, NMIC report of DAE, Survey report of BADC
Climatic Data	BMD, BWDB, CLASIC project of IWFM, BUET
Soil Fertility Data	SFFP project of DAE
Primary Data	FGDs

3.4 Data Analysis

After collecting and preparing the data, analysis has been carried out. During data analysis statistical trend analysis, regression and correlation analysis and significance test have been performed.

Analysis of Irrigation Data

First year-wise irrigation data of the study area greater Rangpur and greater Dinajpur and that of the control area, Patuakhali have been plotted to see the trend of increment of irrigation coverage area in those area over the years.

Analysis of climatic data

Ten day average data of each climatic parameter of each station has been plotted against the years. Each climatic parameter, for instance maximum temperature, of each station has 3 ten day average data in every month, so in total 12 decadal data in a year for four months of irrigation period, January to April. Maximum temperature of January first decade for every year of a station has been plotted to see the trend of change in the maximum temperature of January first decade of that station. The same thing has also been applied for other stations. Subsequently the maximum temperature of the second decade of January for each station has been plotted. Data of other climatic parameters like minimum temperature, average temperature, evaporation data and relative humidity has also been analyzed in the same way.

Correlation between irrigation data and climatic data

The decadal data of a climatic parameter, for instance maximum temperature of January first decade, of a station has been plotted with the data of irrigation coverage area of the respective region and the correlation coefficient has been calculated from the graph to know the correlation between irrigation development and the change of that climatic parameter i.e. the impact of irrigation development on the change of the climatic parameter. This analysis has been performed for each station. The same correlation analysis has been performed for each decadal data of every climatic parameter of all stations with the data of irrigation coverage area of the respective region.

Correlation between irrigation data and soil fertility data

Soil fertility data of the study area during the year of 1967 and 1995, has been collected and tabulated to find out the comparison between the two periods of before irrigation and after irrigation. Later on it has been tried to discuss the reason behind the changes that took place in the soil samples of two periods.

Significance test

The significance tests of correlation coefficient, trend analysis and regression analysis of all the parameters with respect to year and irrigated area have been performed.

Chapter Four
Results and Discussion

4.1 Development of Irrigation Coverage

It is necessary to look at the trend of irrigation development in the study area and in the controlled area as well to assess the impact of any irrigation development. The following three figures show the trend-line of irrigation coverage area in the study area, Rangpur and Dinajpur, and in the controlled area, Patuakhali since 1969 until 2007. It is necessary to mention that the irrigation coverage area refers to the area irrigated by different modes of irrigation.

The Figure 4.1 shows that irrigation coverage area in Rangpur region was 60,850 ha in 1969, which is 8.5% of the total cultivable land in Rangpur, and it was increasing at a slower pace until 1978 (70,296 ha). Since 1978, the rate of increment of irrigation coverage got a very faster pace and consequently the figure turned up to 470,813 ha in 2006 which is 65.5% of the total cultivable area. So, on an average, the rate of increment of the irrigated area per annum was more than 1.5%.

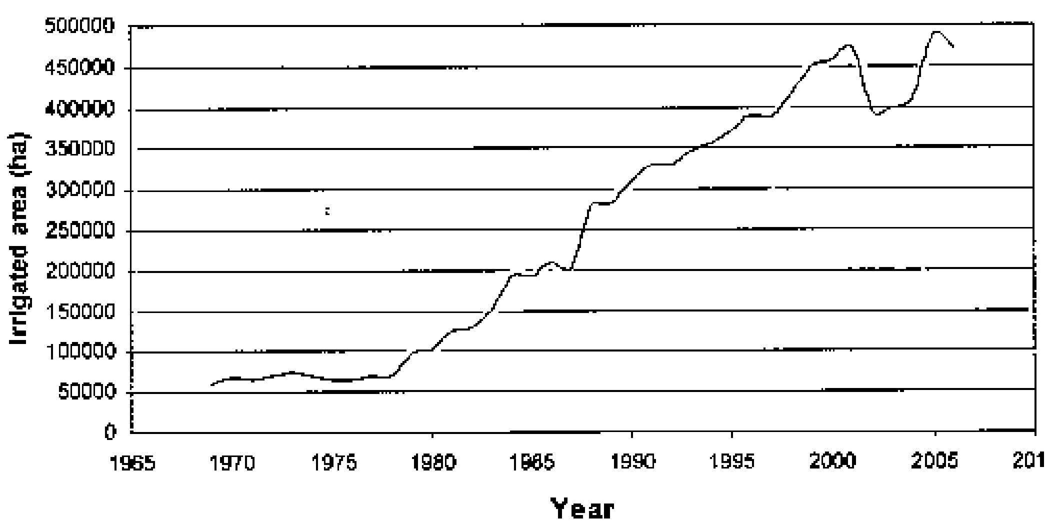

Figure 4.1. Year-wise increase in irrigated area by all different methods in Rangpur.

The progress of irrigation coverage of Dinajpur region (Figure 4.2) shows that the irrigated area in Dinajpur in 1969 was 39,312 ha, which was about 7.2% of the total cultivable area. It increased progressively over the years and in 2006 it became 391,573 ha which was 72% of the total cultivable area. It implies that irrigation coverage increased at a pace which was near about 2% per annum. From this graph it is also visible that this increment took place in two consecutive phases. Before 1985, the rate of increment was much slower (0.5% per annum) than that of the later phase (3.3% per annum).

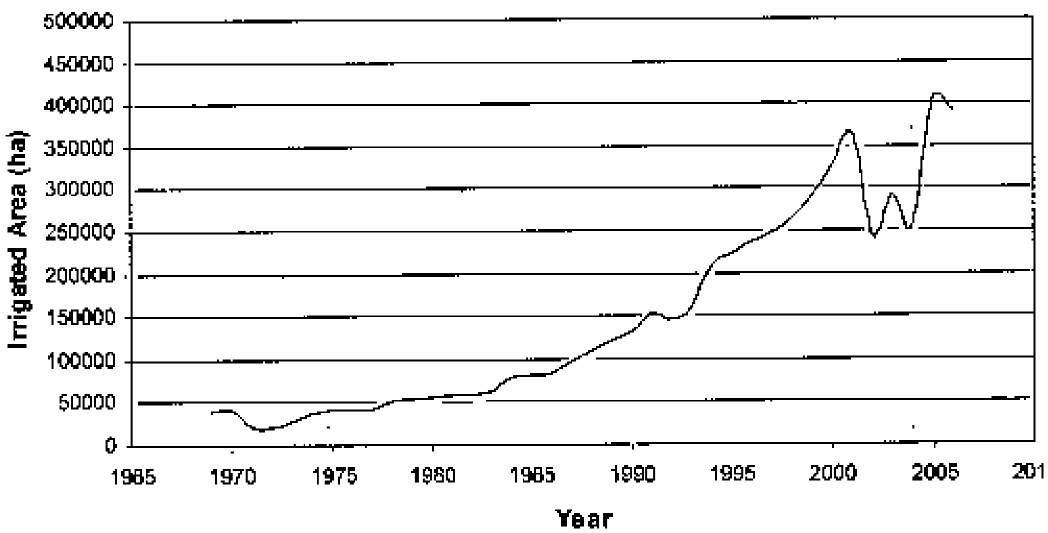

Figure 4.2. Year-wise increase in irrigated area by all different methods in Dinajpur.

In Patuakhali district, irrigation starred very late compared to Rangpur and Dinajpur. From Figure 4.3 it can be seen that it started only in 1986 and then irrigation coverage area was 14310 ha which was about 1.7% of the total cultivable area. From then on the irrigated area was more or less same over the years except in 1988. In the year 1999, the irrigation coverage area was 22,000 ha which comprise of 2.6% of the total cultivable land and in the year 2006 the irrigated area again went down to 5,639 ha which is less than 1% of the total cultivable land. So, compared to Rangpur and Dinajpur, very little of Patuakhali is under irrigation coverage.

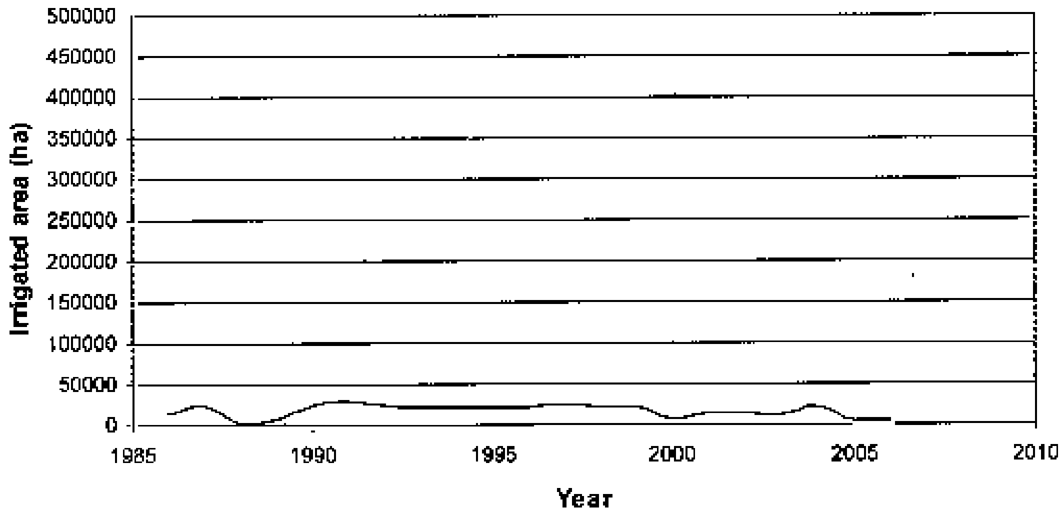

Figure 4.3. Year-wise increase in irrigated area by all different methods in Patuakhali.

4.2 Effect of Irrigation Development on Climatic Parameters

In order to study the effect of increase in irrigation coverage on temperature, the irrigation coverage was plotted against decadal maximum temperature and minimum temperature.

4.2.1 Effect of irrigation on Maximum Temperature

To assess the impact of irrigation development, the maximum temperature data has been plotted since 1969. The maximum temperature data before 1969 were also plotted to find out the normal trend line of maximum temperature without the effect of irrigation development as the irrigation development has been started progressively since 1970. Figures 4.4 and 4.5 show the trend line of maximum temperature for the first decade of January until 1969 and after 1969 (i.e., before and after irrigation development in Rangpur).

Figure 4.4 shows that the maximum temperature of Rangpur for the first decade of January was increasing at a rate of 0.44^0C per decade before the introduction of ground water irrigation. Figure 4.5 shows that since 1969 (i.e., after irrigation development) the maximum temperature was decreasing at a rate of 0.598^0C per decade.

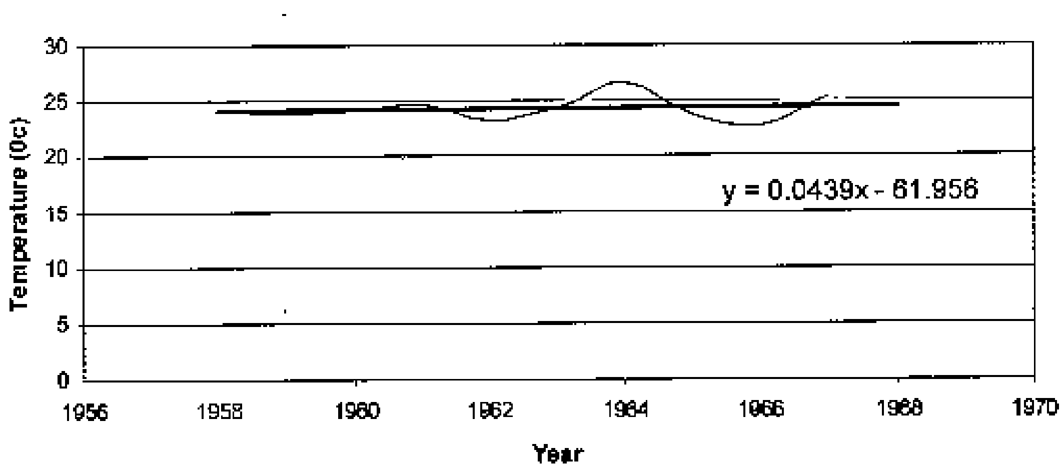

Figure 4.4. Trend line of maximum temperature for 1st decade of January of Rangpur before irrigation development.

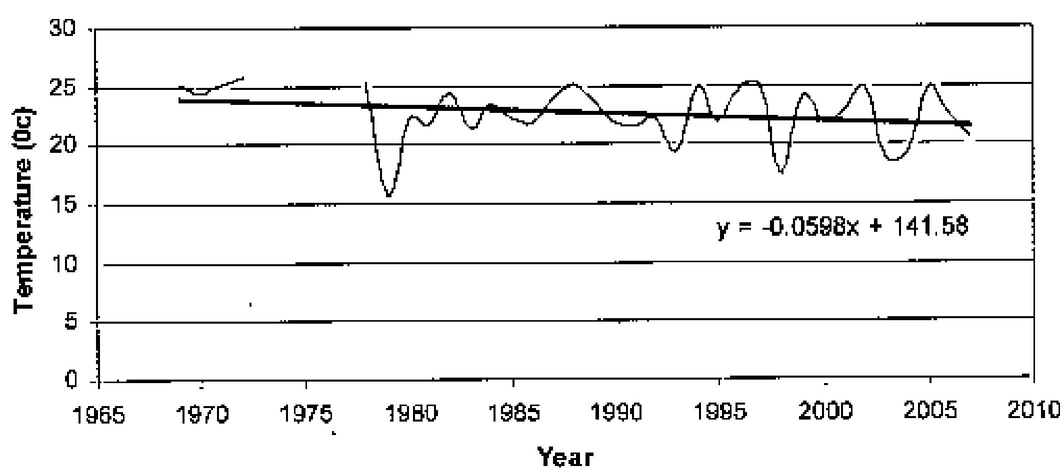

Figure 4.5. Trend line of maximum temperature for 1st decade of January of Rangpur after irrigation development.

From the above two figures, it can be concluded that the progressive irrigation development had a definite cooling effect on the environment as the maximum temperature decreased from a rate of 0.44^{0}C per decade before the development of irrigation to -0.6^{0}C per decade after the development of irrigation.

Figure 4.6 shows the trend line of maximum temperature of Dinajpur before irrigation development for the first decade of January. The trend line shows that the maximum temperature was decreasing at a rate of 0.48^{0}C per decade till 1968 (before the development of irrigation).

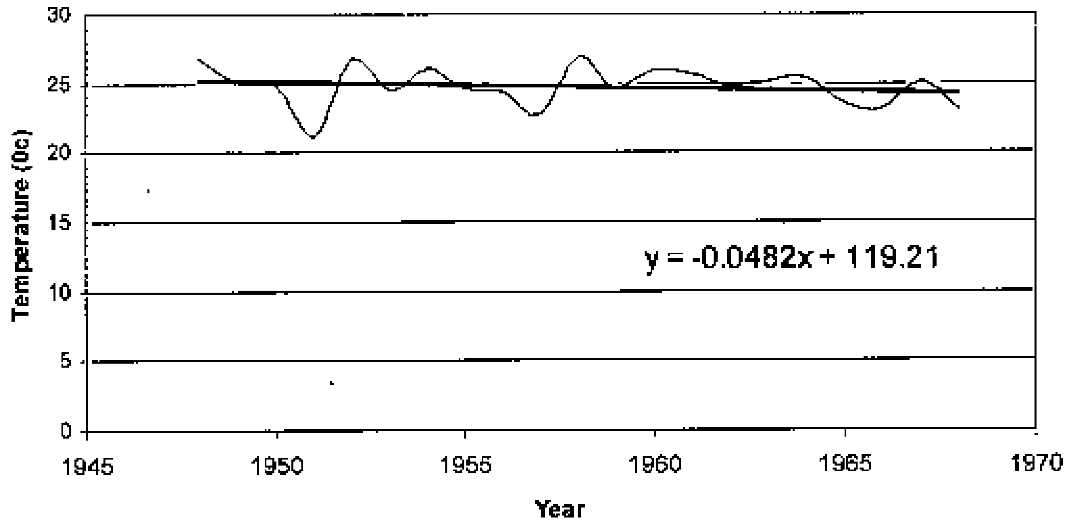

Figure 4.6. Trend line of maximum temperature for 1st decade of January of Dinajpur before irrigation development.

Figure 4.7 shows the trend line of maximum temperature since 1969 (i.e., after irrigation development). The trend line shows that the maximum temperature is decreasing at a rate of 1.01^{0}C per decade after the development of irrigation. So, like Rangpur, the increased irrigation coverage had a cooling effect on the environment and the maximum temperature has decreased at an increased rate in the recent years.

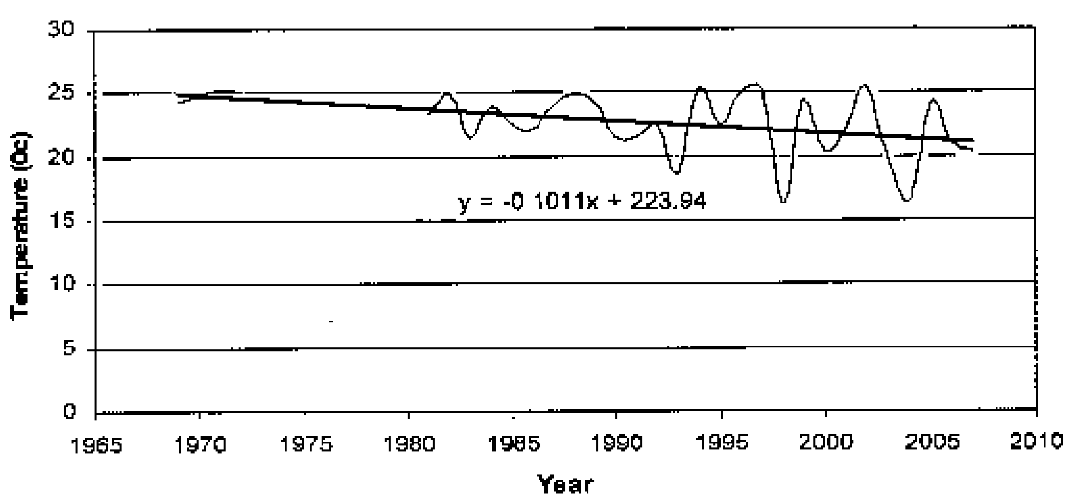

Figure 4.7. Trend line of maximum temperature for 1st decade of January of Dinajpur after irrigation development.

As the temperature data of Patuakhali station is available since 1975, so only the trend of maximum temperature was observed after the development of irrigation (Figure 4.8). In this period of time, the maximum temperature has decreased at a rate of 0.277^{0}C per decade.

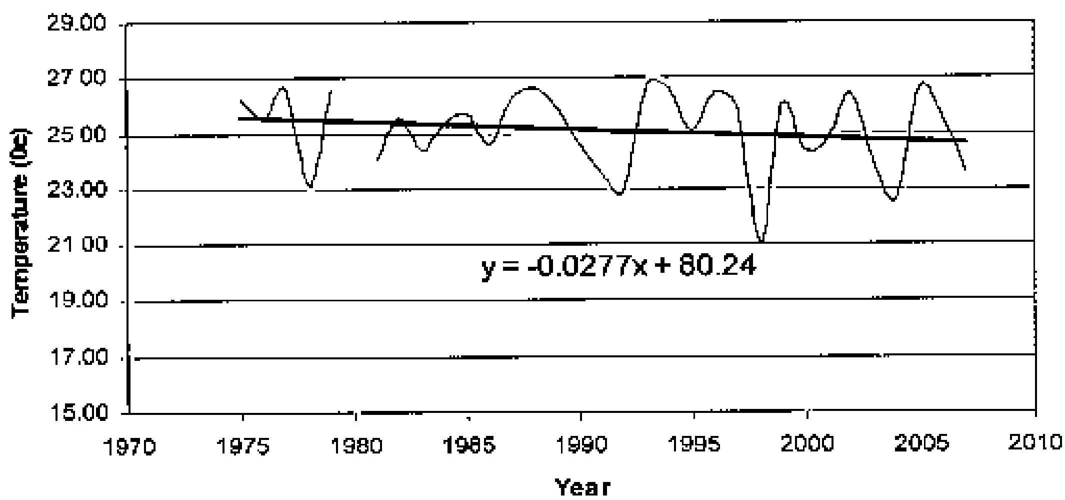

Figure 4.8. Trend line of maximum temperature for 1st decade of January of Patuakhali.

Although maximum temperature is declining at all the three stations, the rate of decline is much higher in Rangpur and Dinajpur compared to Patuakhali. The higher declining rate in Rangpur and Dinajpur may be attributed to the increased irrigation coverage in Rangpur and Dinajpur.

Progressive development of irrigated area was plotted against maximum temperature in order to study the correlation between the two. In Rangpur region (Figure 4.9), it was found that the maximum temperature is decreasing with the increase in irrigated area. The slope of the trend line shows that for every one lakh ha of increased irrigated area the maximum temperature of that region is decreased by 0.3^{0}C. But the correlation between them is very insignificant (t = -0.84452).

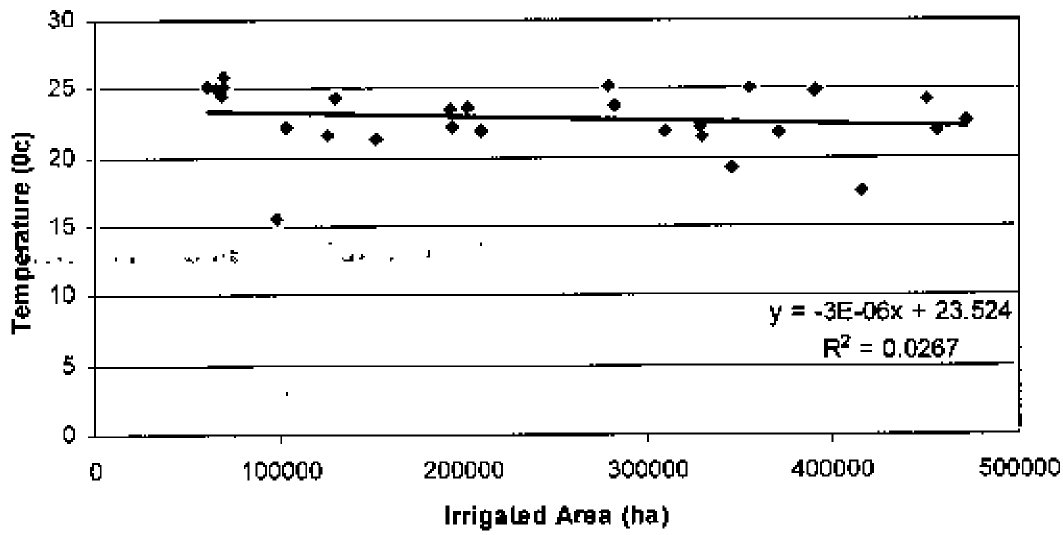

Figure 4.9. Correlation between maximum temperature of 1st decade of January and irrigated area of Rangpur.

Similarly, for Dinajpur (Figure 4.10), it has been found that for every one lakh ha of progressive irrigation development, the maximum temperature is reduced by 0.8^{0}C and the correlation between these two is insignificant (t = -1.68965).

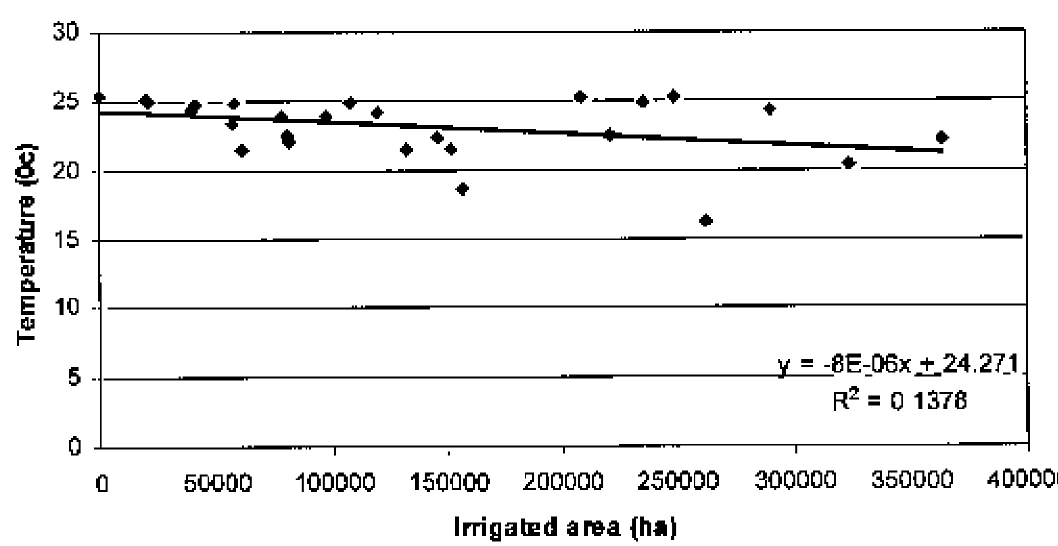

Figure 4.10. Correlation between maximum temperature of 1st decade of January and irrigated area of Dinajpur.

Figure 4.11 shows the correlation between maximum temperature of Patuakhali and the irrigated area of the region. From the figure, it can be seen that for every additional ten thousand ha of irrigation development, the maximum temperature has decreased by 0.8^{0}C. But the correlation between these two is very insignificant (t = -0.4512).

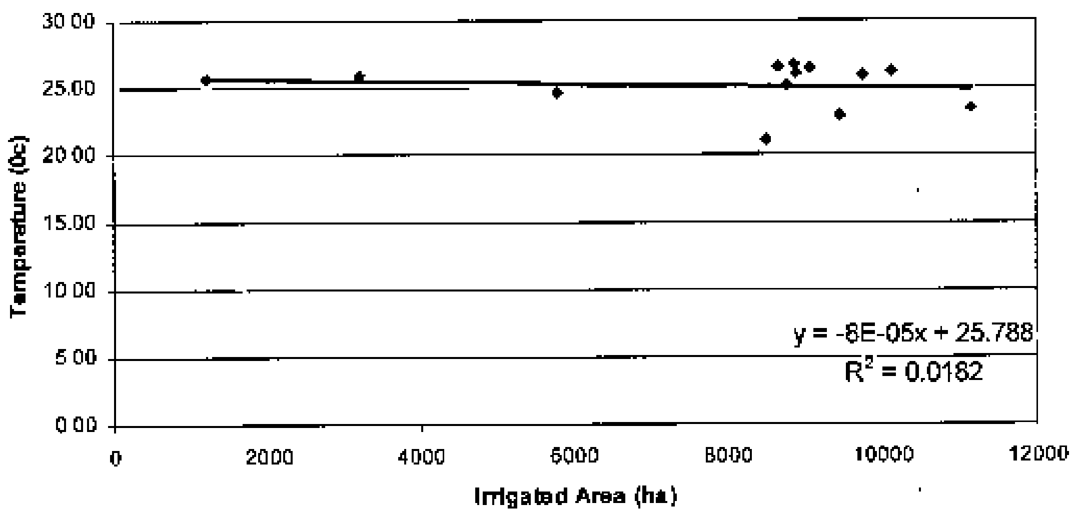

Figure 4.11. Correlation between maximum temperature of 1st decade of January and irrigated area of Patuakhali.

Similar trend line and correlation analysis of maximum temperature with irrigated area of the three stations, Rangpur, Dinajpur and Patuakhali, have been performed for rest of the decades of January, February, March and April. The slopes of the trend lines of maximum temperature, which indicate the rate of change of maximum temperature over the years, are shown in the Table 4.1.

Table 4.1: Rate of maximum temperature change over the years in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	(^{0}C/annum)	Significance	^{0}C/annum	Significance	^{0}C/annum	Significance
January 1st Decade	-0.0598	**	-0.1011	**	-0.0277	Not
January 2nd Decade	-0.0618	**	-0.0607	**	0.0071	Not
January 3rd Decade	-0.0384	*	-0.0207	*	0.0029	Not
February 1st Decade	-0.0156	Not	-0.0208	Not	0.0566	Not
February 2nd Decade	-0.0217	Not	-0.0245	Not	0.0355	Not
February 3rd Decade	-0.0409	**	-0.0495	**	0.0456	Not
March 1st sDecade	-0.0172	Not	-0.0468	**	0.0323	Not
March 2nd Decade	-0.0504	**	-0.0477	*	0.035	**
March 3rd Decade	-0.0394	*	-0.0238	Not	0.011	Not
April 1st Decade	-0.1032	**	—(data not available)	--	0.0216	Not
April 2nd Decade	-0.0699	**	-0.0205	Not	0.0538	**
April 3rd Decade	-0.1027	**	-0.0292	Not	0.0585	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level. Negative sign means that the maximum temperature is decreasing.

The coefficient of correlation analysis between maximum temperature of Rangpur, Dinajpur and Pataukhali and the irrigated area of the respective area are shown in the Table 4.2.

Table 4.2: Correlation of maximum temperature with the irrigated area in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	R^2	Significance	R^2	Significance	R^2	Significance
January 1st Decade	0.0267	Not	0.1378	Not	0.0182	Not
January 2nd Decade	0.092	**	0.1319	Not	0.4599	**
January 3rd Decade	0.0073	Not	4E-05	Not	0.0003	Not
February 1st Decade	0.0223	Not	0.001	Not	0.1993	Not
February 2nd Decade	0.0338	Not	0.078	Not	0.0225	Not
February 3rd Decade	0.0218	Not	0.0186	Not	0.0204	Not
March 1st Decade	0.0152	Not	0.014	Not	0.0003	Not
March 2nd Decade	0.0225	Not	0.0008	Not	0.112	Not
March 3rd Decade	0.0276	Not	0.0014	Not	0.0395	Not
April 1st Decade	0.1085	**	(Data not available)	---	0.1051	Not
April 2nd Decade	0.0105	Not	0.0209	Not	0.0593	Not
April 3rd Decade	0.0786	Not	0.0004	Not	0.0106	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level.

From the Table 4.1, it can be seen that the trend line of maximum temperature of all twelve decades of the irrigation period in Rangpur shows clearly a declining trend. In Rangpur, the rate of maximum temperature reduction of different decades over the years ranges from 0.0156 degree Celsius per year to 0.1032 degree Celsius per year. The lowest rate of reduction occurred in 1st decade of February and the highest one occurred in 1st decade of April.

To find out the average rate of decrease in maximum temperature over the years in Rangpur during irrigation period, the average annual maximum temperature has been calculated by averaging the maximum temperatures of February, March and April and plotted against the respective year. The data of January have been omitted purposively to consider the irrigation period when irrigation takes place in full swing. The graph (Figure 4.12) shows that the annual average of maximum temperature is decreasing at a rate of 0.0495^{0}C per year, i.e., only over ten years of time period the maximum temperature of Rangpur during irrigation time has decreased by about 0.5^{0}C on an average.

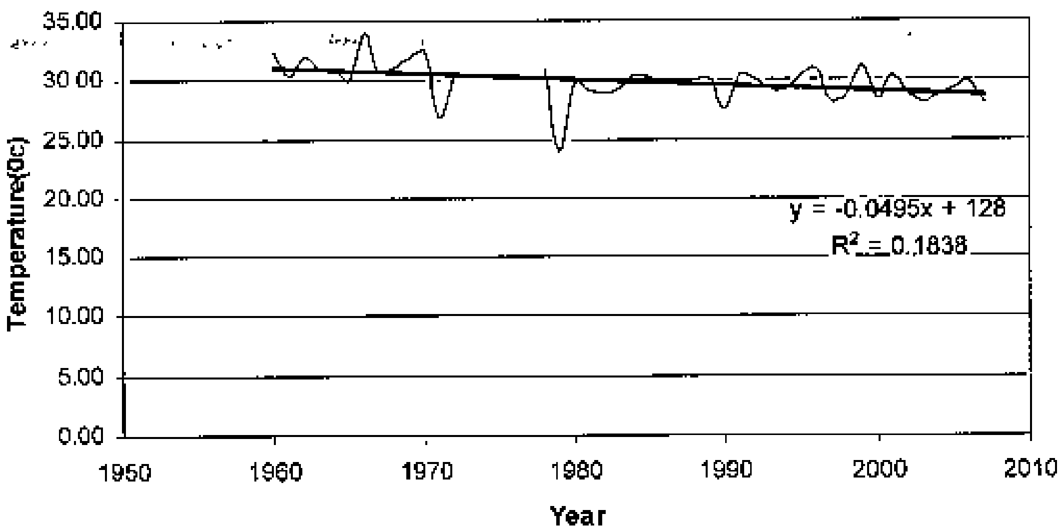

Figure 4.12. Trend-line of annual average of maximum temperature in Rangpur.

The trend line of maximum temperature of Dinajpur of all the twelve decades also shows declining rate (Table 4.1). Here in Dinajpur, the rate of reduction ranges from 0.0205 degree Celsius per annum to 0.1011 degree Celsius per annum. The lowest rate occurred in 2nd decade of April and the highest rate occurred in 1st decade of January. To find out the average rate of maximum temperature change over the years in Dinajpur during irrigation period, a similar trend line has been drawn with the annual average data of maximum temperature of Dinajpur district. Here also the annual average has been calculated by averaging the data of three months, February to April. The trend line has been shown in Figure 4.13.

The trend-line of Figure 4.13 shows that the annual average of maximum temperature of Dinajpur is decreasing at a rate of 0.0459^{0}C per year. That means the maximum temperature of Dinajpur has decreased by 0.46^{0}C over ten years of time.

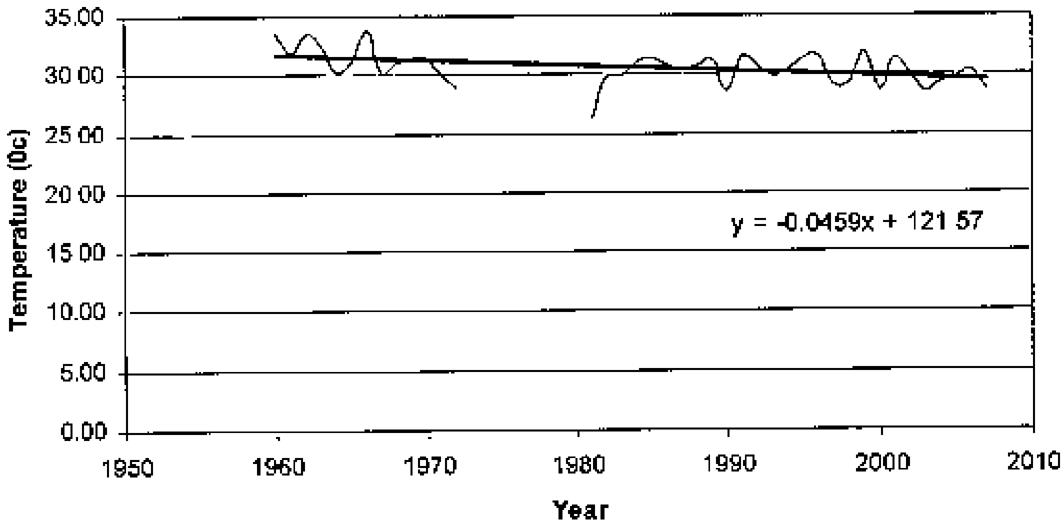

Figure 4.13. Trend-line of annual average of maximum temperature in Dinajpur.

The trend line of maximum temperature of Patuakhali of all the twelve decades shows increasing rates except for the 1st decade of January. The rate of increment ranges from 0.0029 degree Celsius per year to 0.0585 degree Celsius per year. The lowest rate of increment occurred in January 3rd decade and the highest rate of increment occurred in April 3rd decade. In the 1st decade of January, the maximum temperature is decreasing over the years at a rate of 0.0277 degree Celsius.

From the preceding analysis, it can be seen that irrigation has developed with the years in Rangpur and in Dinajpur but in Patuakhali it has remained the same over the years. Irrigation development means more agrarian area is covered with standing water during dry period which used to remain dry before irrigation development at the same time of the year. This irrigated area is a source for potential evapo-transpiration. More irrigated area means more evapo-transpiration. While the water from irrigated area is evaporated, it is transformed from water to water vapor. Water vapor is an important element in climate change because it exists in many forms and transformation from one form to another exchanges a large amount of heat energy (IPCC, 2001). To transform water into water vapor during evapotranspiration in the day time, it requires a lot of latent heat and this latent heat is collected from the neighboring air. As the neighboring air provides latent heat to the transformation process so ultimately it looses its heat energy and the air temperature becomes lower. All these take place during day time and the maximum temperature is also recorded during daytime, so ultimately this process affects the maximum temperature. As a result, the maximum temperature is decreased in the area where irrigation is practiced widely. The decrease in maximum temperature trend line of Rangpur and Dinajpur of both 10-day average and annual average proves this statement. On the other hand, as the irrigated area in Patuakhali has remained same over the years, so the maximum temperature is increasing over the years except the 1^{st} decade of January in Table 4.1.

Table 4.1 shows that the yearly decrease of maximum temperature is significant for most of the decades at Rangpur and Dinajpur. But at Patuakhali, the yearly increase is not significant at ten out of twelve decades. Table 4.2 shows that the correlation coefficients of maximum temperature with irrigated area are not significant at Rangpur, Dinajpur and Patuakhali. The analysis of climatic parameters of Dhaka, Jessore, Bogra and Chandpur performed by Nasrin (2008) has revealed that maximum temperature has increasing trends of 0.2^0C, 0.2^0C and 0.1^0C per decade for Dhaka, Jessore and Chandpur, respectively. Bogra has decreasing trend of 0.2^0C. Bogra has similarity with Rangpur and Dinajpur in terms of irrigation development and geographical location. So the decreasing trend of maximum temperature in Bogra is consistent with the findings of the present study.

4.2.2 Effect of Irrigation on Minimum Temperature:

To assess the impact of irrigation development, the year-wise minimum temperature data of ten day average of the month January, February, March and April have been plotted since 1969. The minimum temperature data before 1969 were also plotted to find out the trend line of minimum temperature without the effect of irrigation as the irrigation development started since 1970.

Figure 4.14 shows the trend line of minimum temperature for the first decade of January until 1969 (i.e., before irrigation development in Rangpur). Figure 4.14 shows that the minimum temperature of Rangpur for the first decade of January was decreasing at a rate of 1.77^0C per decade before the introduction of irrigation.

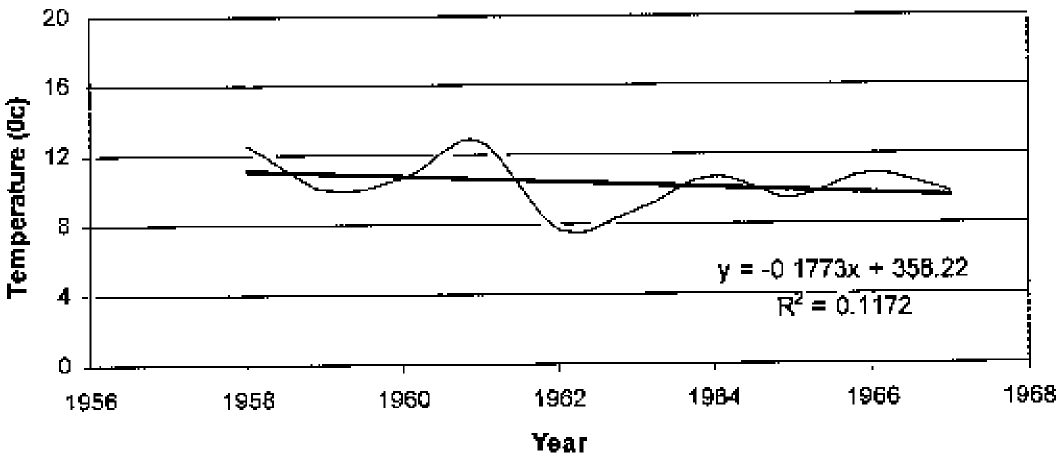

Figure 4.14. Trend-line of minimum temperature for 1st decade of January of Rangpur before irrigation development.

Figure 4.15 shows the trend line of minimum temperature for the first decade of January since 1969 (i.e., after irrigation development in Rangpur). Figure 4.15 shows that the minimum temperature of Rangpur for the first decade of January after irrigation development was increasing at a rate of 0.593 ^{0}C per decade.

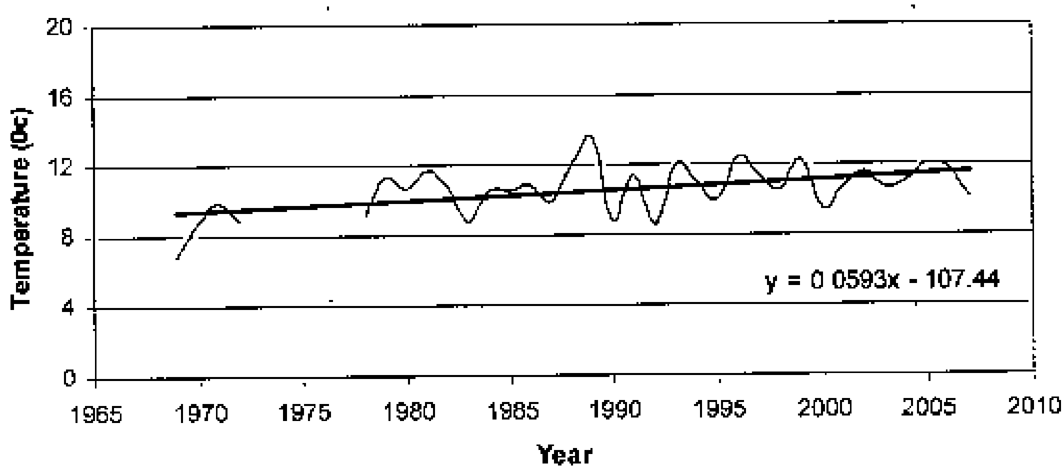

Figure 4.15. Trend-line of minimum temperature for 1st decade of January of Rangpur after irrigation development.

From the above two figures, it can be concluded that the progressive irrigation development in Rangpur had a definite warming effect on the environment as the minimum temperature increased from a rate of -1.77^{0}C per decade before the development of irrigation to 0.593^{0}C per decade after the development of irrigation.

Figure 4.16 shows the trend line of minimum temperature of Dinajpur before irrigation development for the first decade of January. The trend line shows that the minimum temperature was increasing at a rate of 1.03^{0}C per decade till 1969 (i.e., before the development of irrigation).

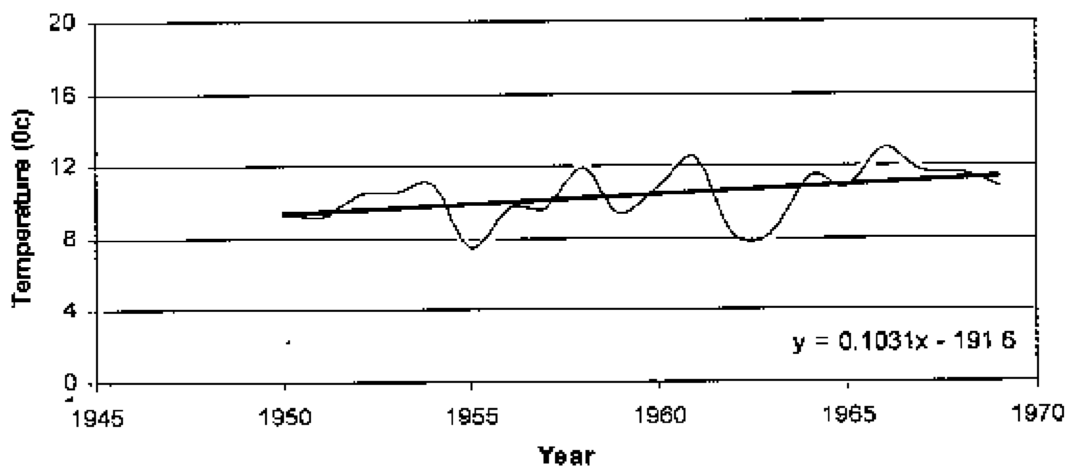

Figure 4.16. Trend line of minimum temperature for 1st decade of January of Dinajpur before irrigation development.

Figure 4.17 shows the trend line of minimum temperature since 1980 (although irrigation development started since 1970) as the data during 1972 to 1980 were not available. The trend line shows that the minimum temperature is increasing at a rate of 0.011^{0}C per decade after the development of irrigation. So, the minimum temperature has increased at a very slower rate in the recent years.

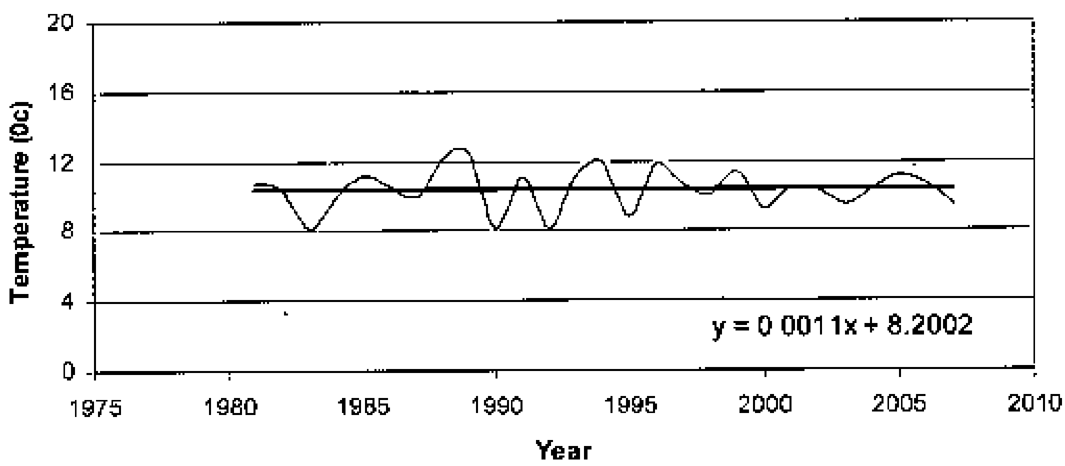

Figure 4.17. Trend line of minimum temperature for 1st decade of January of Dinajpur after irrigation development.

As the temperature data of patuakhali station is available since 1975, so only the trend of minimum temeprature was observed after the development of irrigation (Figure 4.18). In this period of time, the minimum temperature has increased at a rate of 0.023 degree celsius per decade.

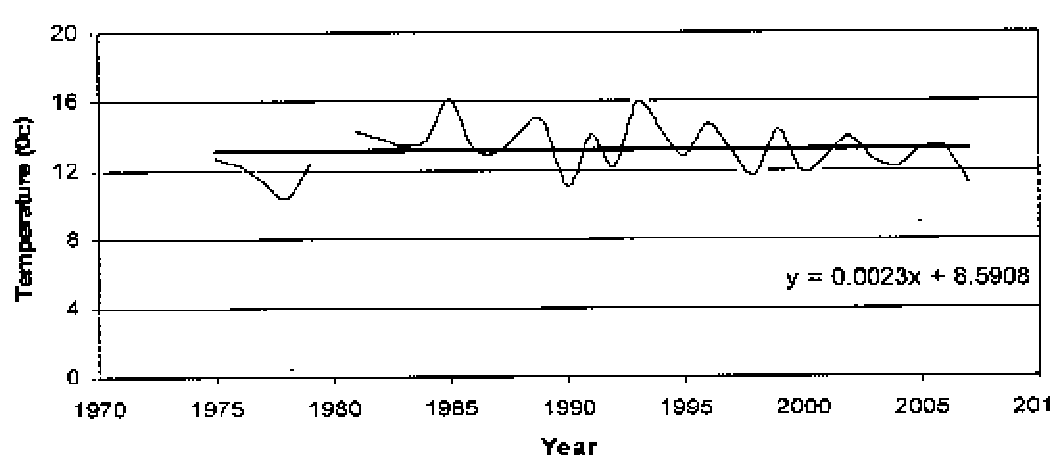

Figure 4.18. Trend line of minimum temperature for 1st decade of January of Patuakhali.

From the above figures, it has been found that the minimum temperature is increasing at all the three stations after the irrigation development. The rate of increment is similar and much slower in Dinajpur and Patuakhali compared to Rangpur. As the rate of minimum temperature increment is not consistent in the study area, so it can not be concluded that irrigation development has attributed effect on the minimum temeprature change.

Progressive development of irrigated area was plotted against minimum temperature in order to study the correlation between the two. In Rangpur region (Figure 4.19), it was found that the minimum temperature is increasing with the increase in irrigated area. The slope of the trend line shows that for every one lac ha of increased irrigated area the minimum temperature of that region is increased by 0.2^{0}C. The regression coefficient is 0.156 which indicates that the variability of minimum temperature is explained due to change of the irrigated area by only 15.6%. From the significance test it has been found that the correlation between these two variables is significant (t = 2.19).

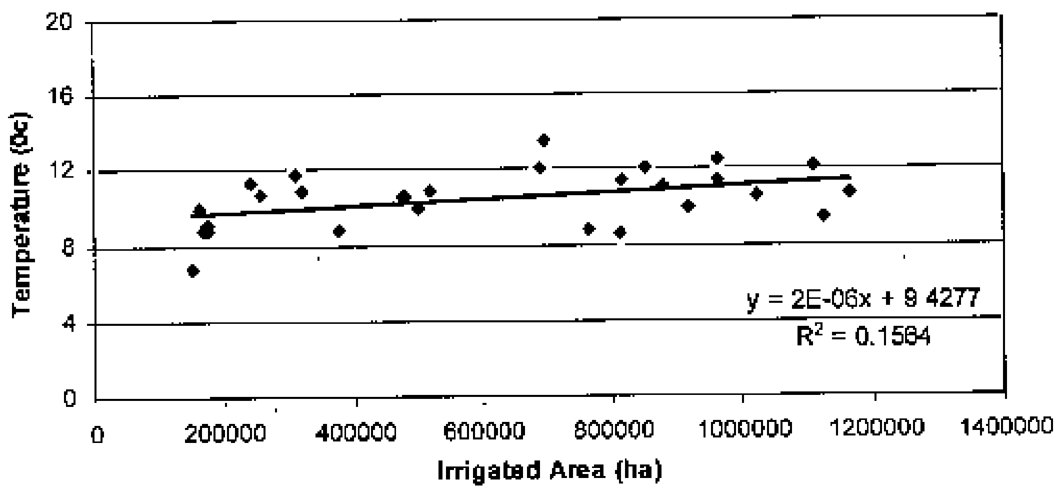

Figure 4.19. Correlation between minimum temperature of 1st decade of January and irrigated area of Rangpur.

Similarly, for Dinajpur (Figure 4.20) it has been found that for every ten million ha of progressive irrigation development, the minimum temperature is reduced by 0.5^{0}C and the regression co-efficient (9E^{-05}) shows that the variability of minimum temperature is not at all explained by the change in the amount of area irrigated. From the significance test it has been found that the correlation between temperature and irrigated area in Dinajpur is very insignificant (t = -0.24) as well.

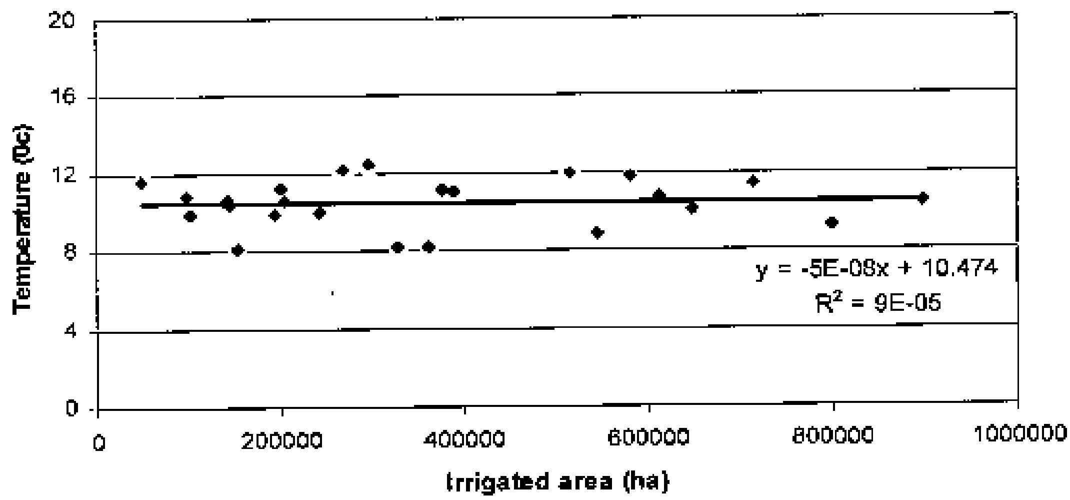

Figure 4.20. Correlation between minimum temperature of 1st decade of January and irrigated are of Dinajpur.

Figure 4.21 shows that the regression coefficient between minimum temperature of Patuakhali and the irrigated area of this region is $8E^{-05}$, which indicates that the variability of minimum temperature is not at all explained by the variability of irrigated area. It has been found from the significance test that the correlation between these two in Patuakhali is very insignificant (t= -0.703). From the figure, it can be seen that for every additional one lac ha of irrigated area expansion, the minimum temperature has decreased by 0.1 degree Celsius.

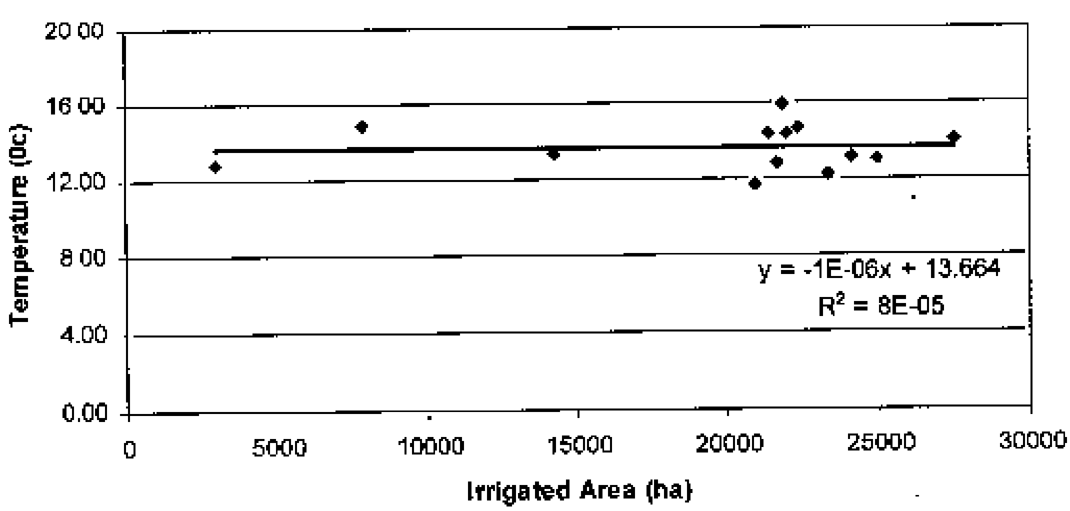

Figure 4.21. Correlation between minimum temperature of 1st decade of January and irrigated are of Patuakhali.

Similar trend line and correlation analysis of minimum temperature of the three stations, Rangpur, Dinajpur and Patuakhali, have been performed for rest of the decades of January, February, March and April. The slopes of the trend lines of minimum temperature, which indicate the rate of change of minimum temperature over the years, are shown in the Table 4.3.

Table 4.3: Rate of Minimum Temperature change over the years in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	^{0}C/annum	Significance	^{0}C/annum	Significance	^{0}C/annum	Significance
January 1st Decade	0.0434	**	0.0011	Not	0.0023	Not
January 2nd Decade	0.0179	Not	-0.0025	Not	-0.011	Not
January 3rd Decade	0.0132	Not	0.0022	Not	-0.0166	Not
February 1st Decade	0.0394	**	0.0183	Not	0.0121	Not
February 2nd Decade	0.057	**	0.0422	**	0.0383	Not
February 3rd Decade	0.0532	**	0.0298	Not	0.0615	*
March 1st Decade	0.0368	**	0.0178	Not	-0.0044	Not
March 2nd Decade	0.054	**	0.0171	Not	0.0004	Not
March 3rd Decade	0.0555	**	0.0206	Not	0.0172	Not
April 1st Decade	0.0435	**	0.0162	Not	-0.004	Not
April 2nd Decade	0.0227	Not	0.0022	Not	0.034	Not
April 3rd Decade	0.0064	Not	0.0011	Not	0.0012	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level. 'Not' means not significant at 95% confidence level. Negative sign means that the maximum temperature is decreasing.

The correlation between minimum temperature and the irrigated area of the three stations have been analyzed and are shown in the Table 4.4.

Table 4.4: Correlation between minimum temperature and irrigated area in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	R^2	Significance	R^2	Significance	R^2	Significance
January 1st Decade	0.156	**	9E-05	Not	8E-05	Not
January 2nd Decade	0.0001	Not	0.0272	Not	0.2821	Not
January 3rd Decade	0.0023	Not	0.0051	Not	0.0264	Not
February 1st Decade	0.124	**	0.0709	Not	0.0125	Not
February 2nd Decade	0.1787	**	0.0612	Not	0.0029	Not
February 3rd Decade	0.157	**	0.006	Not	0.0612	Not
March 1st Decade	0.1475	**	0.0378	Not	0.0559	Not
March 2nd Decade	0.1894	**	0.0014	Not	0.0548	Not
March 3rd Decade	0.1475	**	0.0022	Not	0.0438	Not
April 1st Decade	0.1122	**	0.0017	Not	0.0041	Not
April 2nd Decade	0.1824	**	0.043	Not	0.0191	Not
April 3rd Decade	0.0875	Not	0.0409	Not	0.0002	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level.

From the table above it can be seen that the trend line of minimum temperature of all twelve decades of the irrigation period in Rangpur shows clearly an increasing trend. In Rangpur, the rate of increase of minimum temperature of different decades ranges from 0.0064°C to 0.057°C per year. The lowest rate of increment occurred in 3rd decade of April and the highest one occurred in 2nd decade of February.

To find out the average rate of increase in minimum temperature over the years in Rangpur during the irrigation period, the average annual minimum temperature has been calculated by averaging the minimum temperature of February, March and April and plotted against the respective year (Figure 4.22). The temperature data of January have been omitted purposively to consider the period when irrigation takes place in full swing. The figure shows that the annual average of minimum temperature is increasing at a rate of 0.0489^{0}C per annum, i.e., only over ten years of time period the minimum temperature of Rangpur during irrigation time has increased by about 0.5^{0}C on an average.

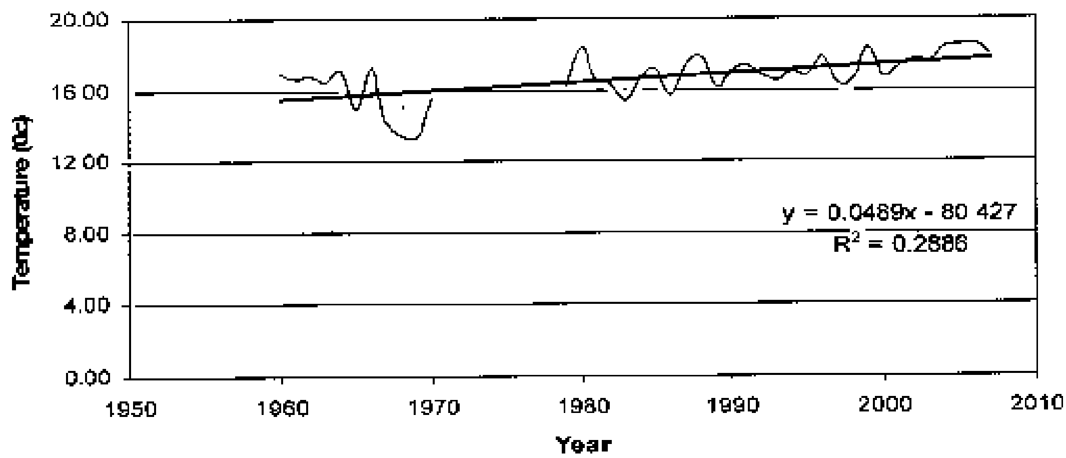

Figure 4.22. Trend-line of annual average of Minimum Temperature in Rangpur.

The trend line of minimum temperature of Dinajpur of all the twelve decades also shows increasing trend except the trend line of January 2nd decade where the rate of minimum temperature shows declining trend. Among the other eleven decades the rate of increment ranges from 0.0011^{0}C per annum to 0.0422^{0}C per annum. The lowest rate occurred in 1st decade of January and 3rd decade of April and the highest rate of temperature increment occurred in 2nd decade of February.

To find out the average rate of minimum temperature changes over the years in Dinajpur during irrigation period, a similar trend line like Rangpur has been drawn with the annual average data of minimum temperature. Here also the annual average has been calculated by averaging the data of three months, February, March and April. The trend line has been shown in Figure 4.23.

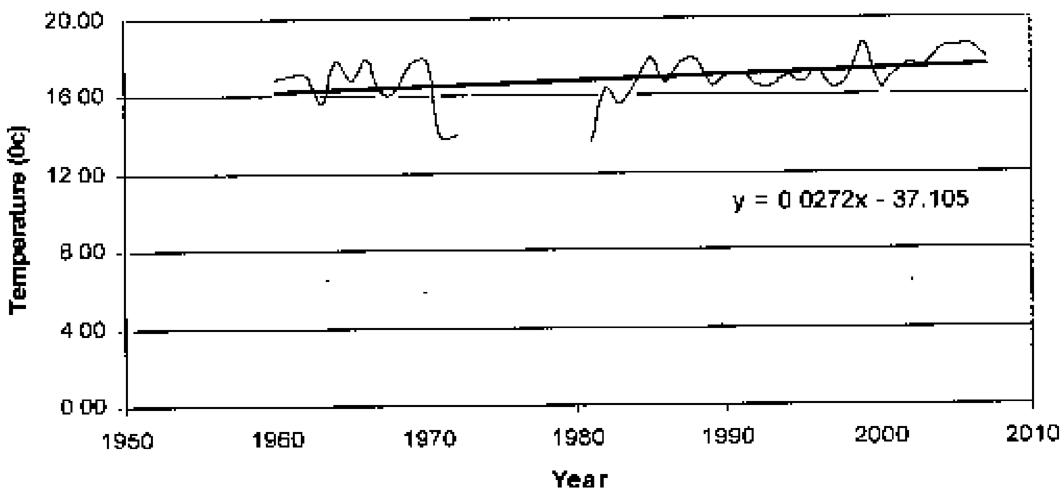

Figure 4.23. Trend-line of annual average of Minimum Temperature in Dinajpur.

Figure 4.23 shows that the annual average of minimum temperature of Dinajpur is increasing at a rate of 0.0272^{0}C per year, which indicates that the minimum temperature of Dinajpur has increased by 0.27^{0}C over ten years period of time.

The trend-line of minimum temperature of Patuakhali of all twelve decades shows both increasing and decreasing rates. Among the twelve decades, the minimum temperature in Patuakhali decreased in four decades and increased in the rest eight decades. The minimum temperature decreased in second and third decade of January, 1st decade of March and in 1st decade of April. As very little of Patuakhali is irrigated, the minimum temperature does no show any trend.

It has been analyzed and discussed earlier that irrigation has developed with the years in Rangpur and in Dinajpur but in Patuakhali it has nearly remained the same over the years. Irrigation development means more agrarian area is covered with standing water during dry period which used to remain dry before irrigation development at the same time of the year. When solar radiation strikes dry land, the energy is absorbed in a thin layer that heats relatively rapidly. Likewise, it readily gives up its heat to the atmosphere. When radiant energy is absorbed by land, most of the net radiation is used for sensible heat transfer or ground heat transfer, only small amounts are used for latent heat transfer. As sensible heat transfer into the air is the dominant heat transfer, air temperatures increase over the land. Over water, much of the net radiation is used for evaporation. With little energy used for sensible heat transfer, air over water remains cooler than that over land.

Moreover, the specific heat of water is higher than that of land. Specific heat is the amount of energy required to raise the temperature of one gram of substance through one degree Celsius. Water has a specific heat that is five times greater than land. This means that it takes five times more energy to heat one gram of water than one gram of land. So if adjacent land and water receive the same amount of heat, the water will warm much slower than land, and give up its heat much more slowly than land (Ritter, 2006). As water gives up its heat much more slowly than land so during night time the land cover with dry land gives up its heat quickly and become cool but the land cover with standing water still hold up the heat and become slowly cooler at night. Thus, the average night time temperature i.e., minimum temperature over the standing water covered land is higher than that of dry land. This indicates that shifting a land cover from dry land to irrigated land increases the minimum temperature of that area. Increment of irrigated area over the years in an area also increases the minimum temperature of that area over the years. The increase in minimum temperature trend line of Rangpur and Dinajpur of both 10-day average and annual average proved this assertion.

Table 4.3 shows that the yearly increase of minimum temperature is significant for most of the decades at Rangpur. But at Dinajpur and Patuakhali, the yearly increase is not significant at eleven out of twelve decades. Table 4.4 shows that the correlation coefficients of minimum temperature with irrigated area are significant at Rangpur, but not significant at Dinajpur and Patuakhali. Long-term trend analysis by using data of all stations of Bangladesh from 1948 to 2007 by IWFM (2008) also shows that the minimum temperature is increasing over the years in all twelve months. The analysis of climatic parameters of Dhaka, Jessore, Bogra and Chandpur performed by Nasrin (2008) has revealed that minimum temperature has increasing trends of 0.6^0C, 0.2^0C, 0.2^0C and 0.1^0C per decade for Dhaka, Jessore, Chandpur and Bogra, respectively. So the findings of other studies related to minimum temperature are consistent with the findings of the present study.

4.2.3 Effect of irrigation on Relative Humidity

To assess the impact of irrigation development, the relative humidity data has been plotted since 1969. The relative humidity data before 1969 were also plotted to find out the normal trend line of relative humidity without the effect of irrigation development as the irrigation development has been started progressively since 1970. Figures 4.24 and

4.25 show the trend line of relative humidity for the first decade of January until 1969 and after 1969 (i.e., before and after irrigation development in Rangpur).

Figure 4.24 shows that the relative humidity of Rangpur for the first decade of January was decreasing at a rate of 3.95% per decade before the introduction of ground water irrigation. Figure 4.25 shows that since 1969 (i.e., after irrigation development) the relative humidity was decreasing at a rate of 0.46% per decade.

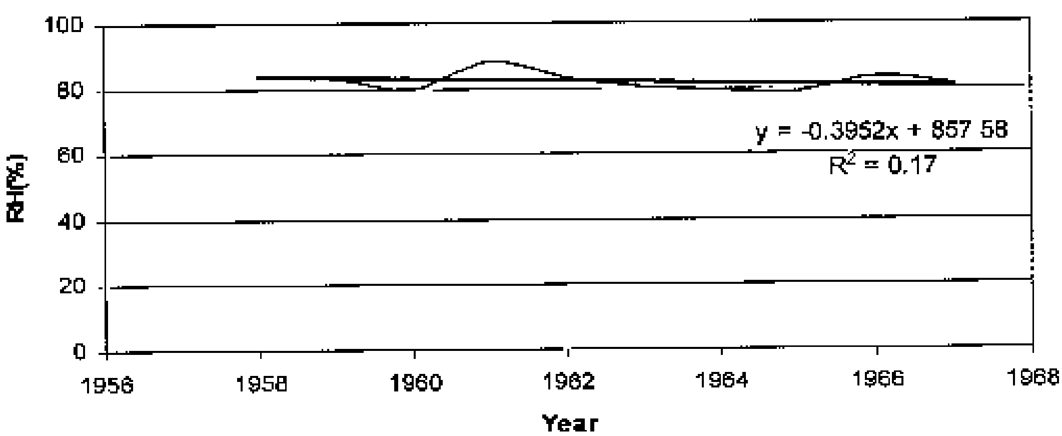

Figure 4.24. Trend line of relative humidity for 1st decade of January of Rangpur before irrigation development.

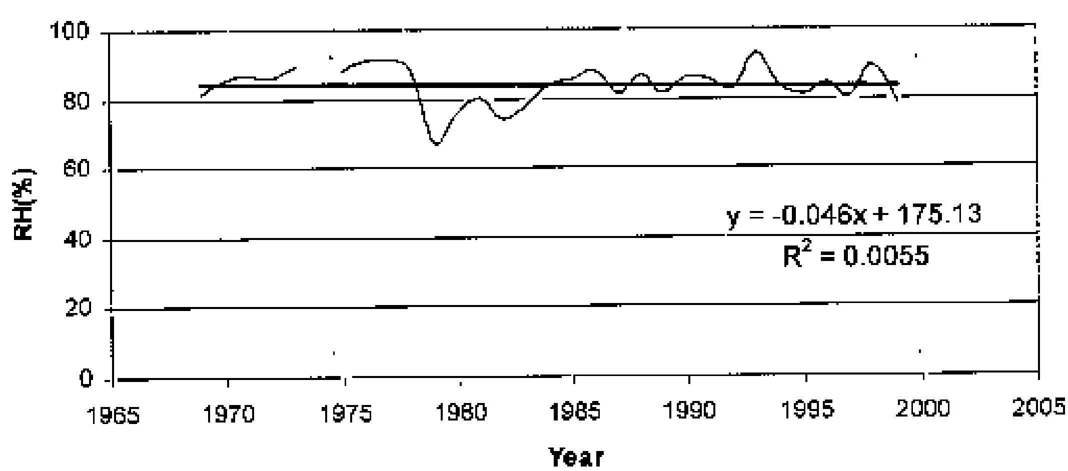

Figure 4.25. Trend line of relative humidity for 1st decade of January of Rangpur after irrigation development.

From the above two figures, it can be concluded that the progressive irrigation development had a definite humid effect on the environment as the relative humidity increased from a rate of -3.95% per decade before the development of irrigation to −0.46% per decade after the development of irrigation i.e., the relative humidity is decreasing at a much slower rate during the period of after irrigation development compared to that of before irrigation development.

Figure 4.26 shows the trend line of relative humidity of Dinajpur before irrigation development for the first decade of January. The trend line shows that the relative humidity was increasing at a rate of 2.31% per decade till 1968 (before the development of irrigation).

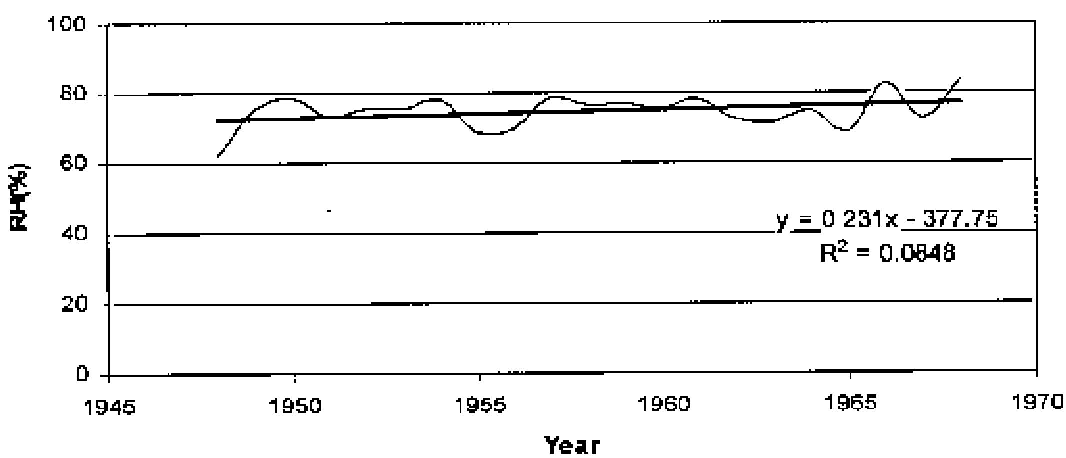

Figure 4.26. Trend line of relative humidity for 1st decade of January of Dinajpur before irrigation development.

Figure 4.27 shows the trend line of relative humidity since 1969 (i.e., after irrigation development). The trend line shows that the relative humidity is increasing at a rate of 4.3% per decade after the development of irrigation. So, the increased irrigation coverage had a humid effect on the environment and the relative humidity has increased at an increased rate in the recent years.

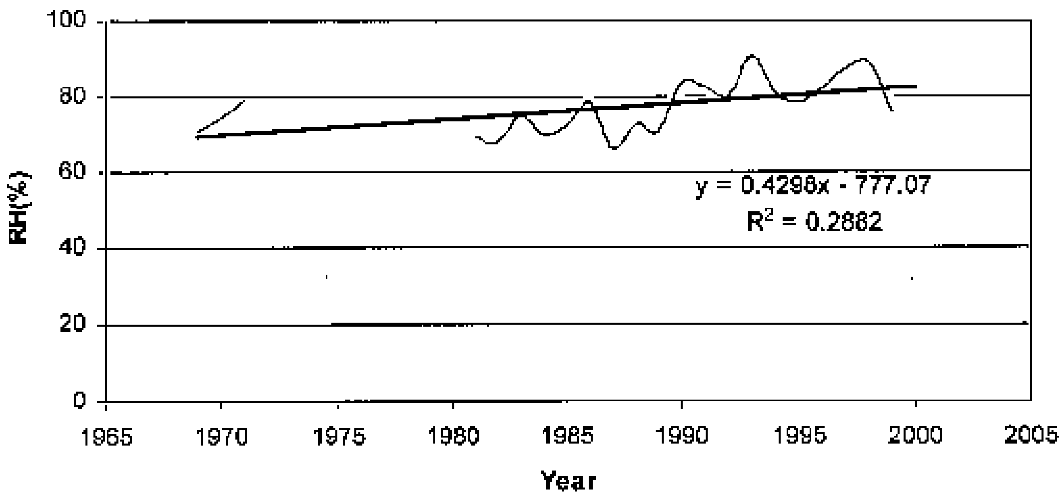

Figure 4.27. Trend line of relative humidity for 1st decade of January of Dinajpur after irrigation development.

As the relative humidity data of Patuakhali station is available since 1975, so only the trend of relative humidity was observed after the development of irrigation (Figure 4.28). In this period of time, the relative humidity has increased at a rate of 10% per decade.

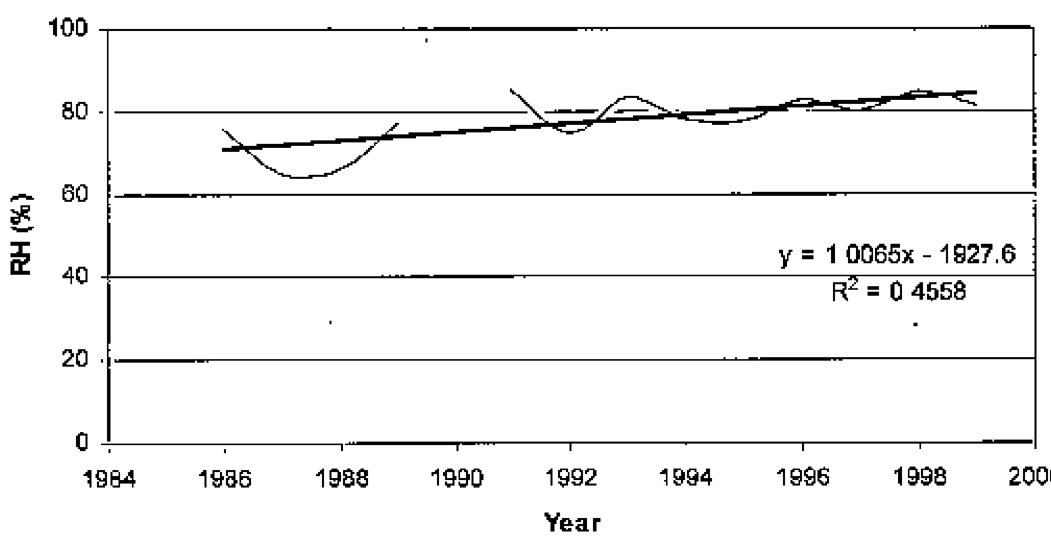

Figure 4.28. Trend line of relative humidity for 1st decade of January of Patuakhali.

Although relative humidity is declining at Rangpur station during both the period but the rate of reduction is much slower during the later period which means that the rate of change in relative humidity has increased in Rangpur after the development of irrigation.

Relative humidity is increasing in Dinajpur at a considerable rate. However, the relative humidity has increased at much faster rate in Patuakhali compared to Rangpur and Dinajpur. As there is no pattern in the variation of relative humidity in the study area and in the control area so it can not be concluded that relative humidity is attributed to the increased irrigation coverage in Rangpur and Dinajpur.

Progressive development of irrigated area was plotted against relative humidity in order to study the correlation between the two. In Rangpur region (Figure 4.29), it was found that the relative humidity is decreasing with the increase in irrigated area. The slope of the trend line shows that for every ten lakh ha of increased irrigated area the relative humidity of that region is decreased by 0.2%. But the correlation between them is very insignificant (t = -0.04887).

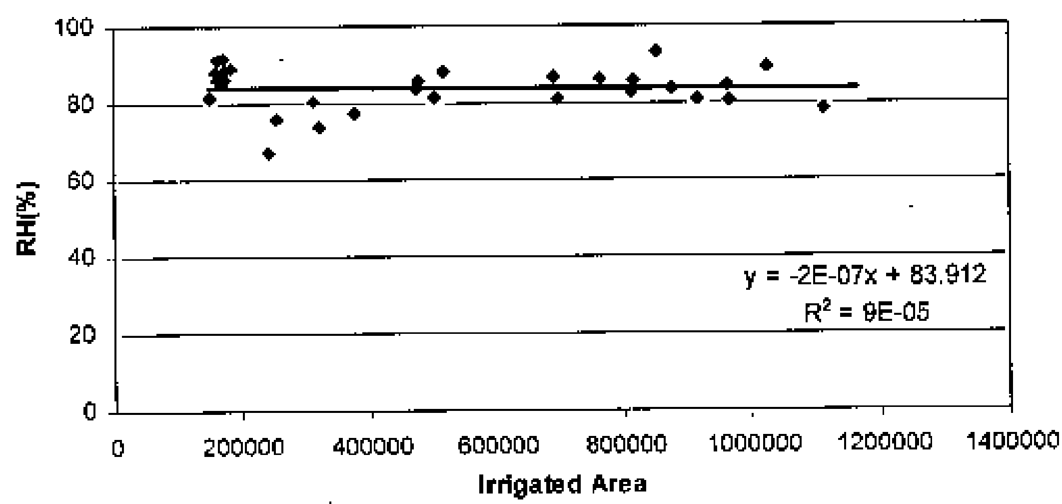

Figure 4.29. Correlation between relative humidity of 1st decade of January and irrigated area of Rangpur.

Similarly, for Dinajpur (Figure 4.30), it has been found that for every ten thousand ha of progressive irrigation development, the relative humidity is increased by 0.2% and the correlation between these two is significant (t = 3.449).

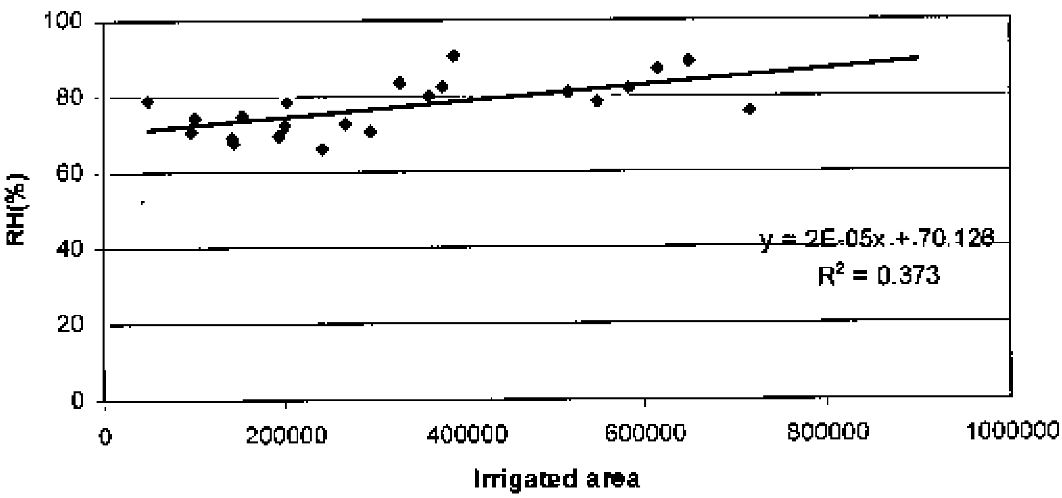

Figure 4.30. Correlation between relative humidity of 1st decade of January and irrigated area of Dinajpur.

Figure 4.31 shows the correlation between relative humidity of Patuakhali and the irrigated area of the region. From the figure, it can be seen that for every additional ten thousand ha of irrigation development, the relative humidity has increased by 4%. But the correlation between these two is insignificant (t = 1.69).

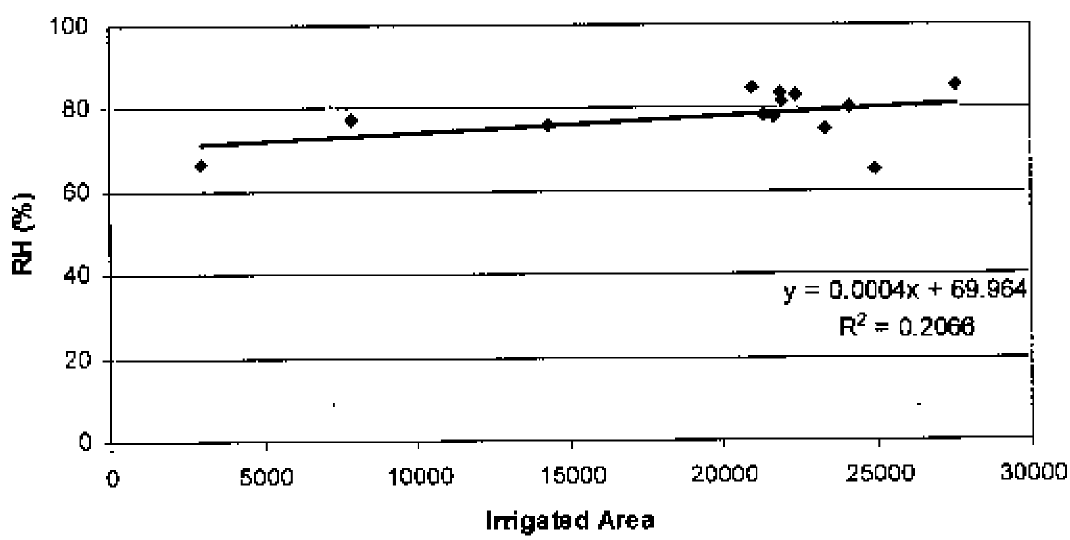

Figure 4.31. Correlation between relative humidity of 1st decade of January and irrigated area of Patuakhali.

Similar trend line and correlation analysis of relative humidity with irrigated area of the three stations, Rangpur, Dinajpur and Patuakhali, have been performed for rest of the decades of January, February, March and April. The slopes of the trend lines of relative humidity, which indicate the rate of change of relative humidity over the years, are shown in the Table 4.5.

Table 4.5: Rate of relative humidity change over the years in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	Trend (% per annum)	Significance	(% per annum)	Significance	(% per annum)	Significance
January 1st Decade	0.0234	Not	0.1425	**	1.0065	**
January 2nd Decade	0.0736	Not	0.1222	**	0.6775	*
January 3rd Decade	0.0129	Not	0.07	Not	0.1556	Not
February 1st Decade	0.0294	Not	0.019	Not	-0.0887	Not
February 2nd Decade	0.0348	Not	0.1287	**	0.2896	Not
February 3rd Decade	0.0168	Not	0.1235	*	0.4888	Not
March 1st Decade	-0.0889	Not	0.0721	Not	-0.5039	Not
March 2nd Decade	-0.0475	Not	0.1136	**	-0.2857	Not
March 3rd Decade	0.0448	Not	0.1997	Not	0.9887	**
April 1st Decade	0.0913	Not	0.1514	Not	0.0862	Not
April 2nd Decade	0.0755	Not.	0.1792	*	0.0811	Not
April 3rd Decade	0.2305	Not	0.2688	**	-0.0716	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level. Negative sign means that the relative humidity is decreasing.

The coefficient of correlation analysis between relative humidity of Rangpur, Dinajpur and Pataukhali and the irrigated area of the respective area are shown in the Table 4.6.

Table 4.6: Correlation between Relative Humidity and irrigated area in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	R^2	Significance	R^2	Significance	R^2	Significance
January 1st Decade	9E-05	Not	0.373	**	0.2066	Not
January 2nd Decade	0.001	Not	0.337	**	0.068	Not
January 3rd Decade	0.0511	Not	0.0964	Not	0.1304	Not
February 1st Decade	0.0612	Not	0.2328	**	0.1021	Not
February 2nd Decade	0.1181	*	0.1255	*	0.003	Not
February 3rd Decade	0.0501	Not	0.1523	*	0.0019	Not
March 1st Decade	0.0327	Not	0.0663	Not	0.0721	Not
March 2nd Decade	0.0531	Not	0.0423	Not	0.0098	Not
March 3rd Decade	0.0036	Not	0.0867	Not	0.1952	Not
April 1st Decade	0.0014	Not	0.2025	**	0.1327	Not
April 2nd Decade	0.1321	**	0.0074	Not	0.0843	Not
April 3rd Decade	0.0131	Not	0.1615	*	0.1171	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level.

From the Table 4.5, it can be seen that the trend line of relative humidity of all twelve decades of the irrigation period in Rangpur shows clearly an increasing trend except in March 1st and 2nd decade. In Rangpur, the rate of relative humidity reduction of different decades over the years ranges from 0.0129% per year to 0.2305% per year. The lowest rate of increment occurred in 3rd decade of January and the highest one occurred in 3rd decade of April. During 1st and 2nd decade March, the relative humidity reduced at a rate of 0.0889% and 0.0475% per year respectively.

To find out the average rate of change in relative humidity over the years in Rangpur during irrigation period, the average annual relative humidity has been calculated by averaging the relative humidity of February, March and April and plotted against the respective year. The data of January have been omitted purposively to consider the irrigation period when irrigation takes place in full swing. The graph (Figure 4.32) shows that the annual average of relative humidity is increasing at a rate of 0.0137% per year, i.e., over ten years of time period the relative humidity of Rangpur during irrigation time has increased by only about 0.137% on an average.

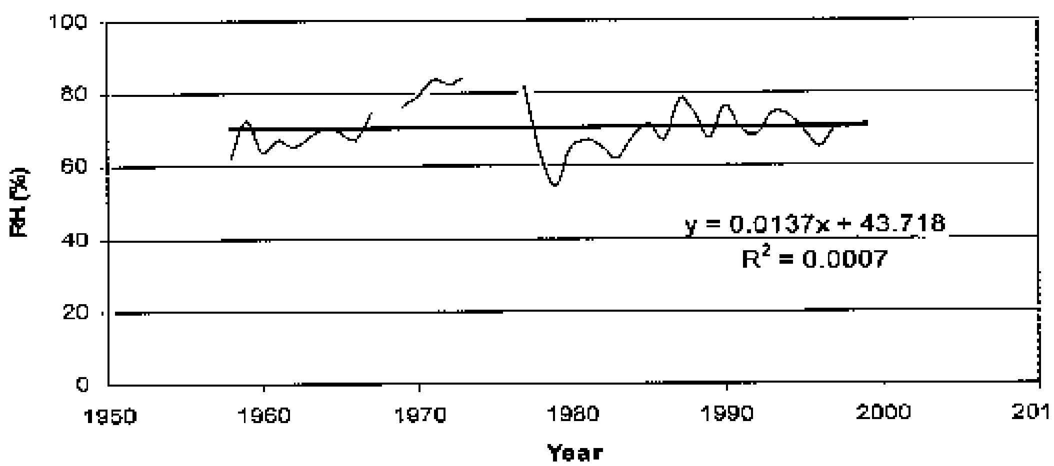

Figure 4.32. Trend-line of annual average of relative humidity in Rangpur.

The trend line of relative humidity of Dinajpur of all the twelve decades also show increasing rate (Table 4.5). Here in Dinajpur, the rate of increment ranges from 0.019% per annum to 0.2688% per annum. The lowest rate occurred in 1st decade of February and the highest rate occurred in 3rd decade of April. To find out the average rate of relative humidity change over the years in Dinajpur during irrigation period, a similar trend line has been drawn with the annual average data of relative humidity of Dinajpur district. Here also the annual average has been calculated by averaging the data of three months, February to April. The trend line has been shown in figure 4.33.

The trend-line of Figure 4.33 shows that the annual average of relative humidity of Dinajpur is increasing at a rate of 0.1275% per year. That means the relative humidity of Dinajpur has increased by 1.275% over ten years of time.

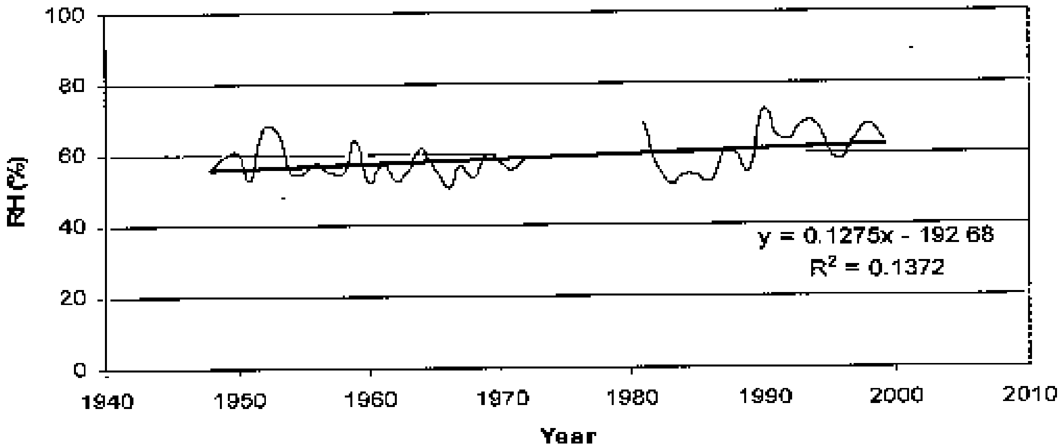

Figure 4.33. Trend-line of annual average of relative humidity in Dinajpur.

The trend line of relative humidity of Patuakhali of all the twelve decades show both increasing and declining rates. Among the twelve decades, the relative humidity in Patuakhali decreased in four decades and increased in the rest eight decades. The relative humidity reduction occurs dispersedly in 1st decade of February, 1st and 2nd decade of March and 3rd decade of April. The rate of reduction ranges from 0.0716% per annum to 0.5039% per year. On the other hand, the rate of increment ranges from 0.0811% per year to 1.0065% per annum. The lowest rate of increment occurred in the 2nd decade of April and the highest one occurred in 1st decade of January. As very little of Patuakhali is irrigated, the relative humidity does not show any trend.

From the preceding analysis, it can be seen that irrigation has developed with the years in Rangpur and in Dinajpur but in Patuakhali it has remained the same over the years. Irrigation development means more agrarian area is covered with standing water during dry period which used to remain dry before irrigation development at the same time of the year. Relative humidity is the ratio of the actual amount of water vapor in the air to the amount it could hold when saturated or the ratio of the actual vapor pressure to the saturation vapor pressure. With increase in irrigation more water area is available for evaporation which resulted in increase in actual water vapor in the atmosphere. This resulted in increase of the relative humidity in Rangpur and Dinajpur. As explained earlier, the increase in water vapor in the air resulted in the decrease of air temperature. As the irrigated area in Patuakhali has remained same over the years, so the relative humidity does not show any definite trend.

4.2.4 Effect of irrigation on Evaporation

To assess the impact of irrigation development, the evaporation data has been plotted since 1980 as the evaporation data before 1980 were not available. Figure 4.34 shows the trend line of evaporation for the first decade of January.

Figure 4.34 shows that the evaporation of Rangpur for the first decade of January was decreasing at a rate of 0.005 mm per annum i.e., evaporation was decreasing at a rate of 0.05 mm per decade which is negligible.

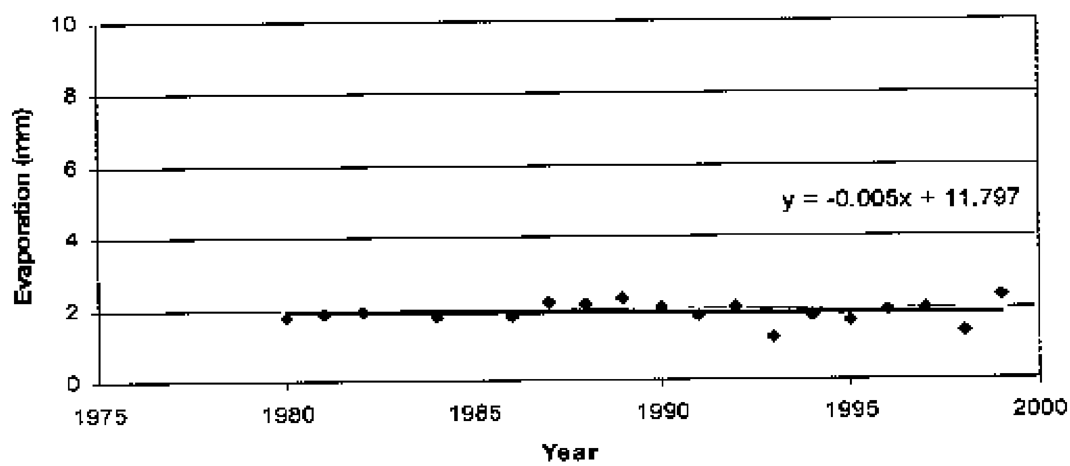

Figure 4.34. Trend line of evaporation for 1st decade of January of Rangpur.

Figure 4.35 shows the trend line of evaporation of Dinajpur since 1980 for the first decade of January. The trend line shows that the evaporation was decreasing at a rate of 0.123mm per decade.

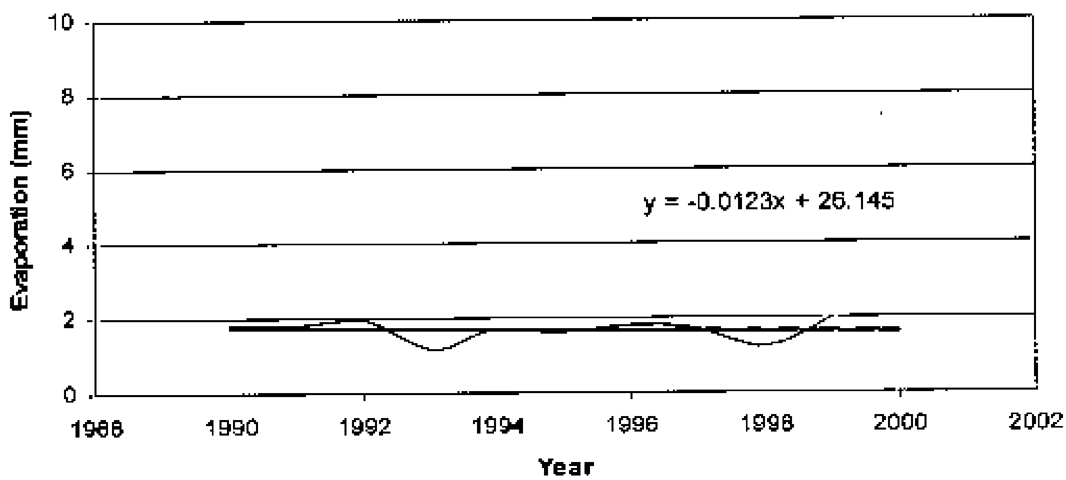

Figure 4.35. Trend line of evaporation for 1st decade of January of Dinajpur.

Figure 4.36 shows the trend line of evaporation of Patuakhali for the first decade of January. It shows that the evaporation has decreased at a rate of 0.365 mm per decade.

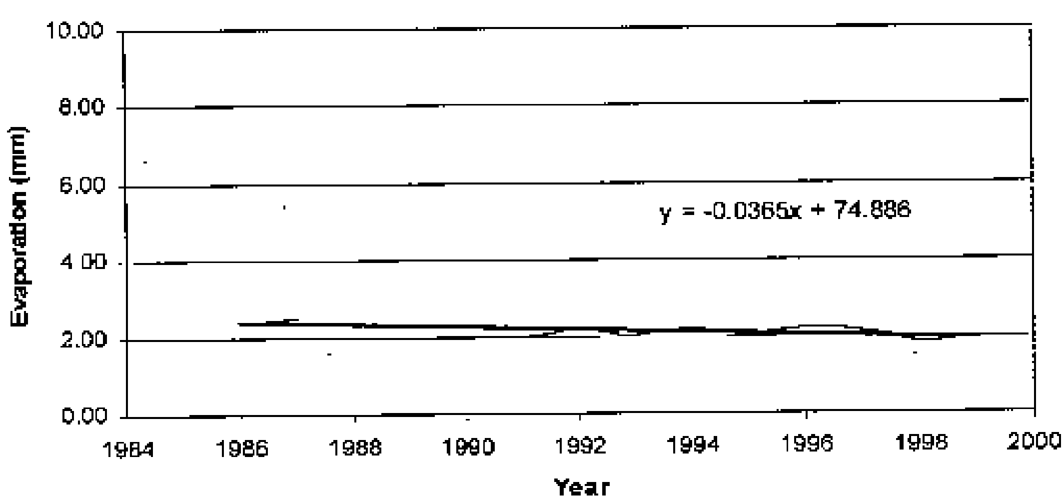

Figure 4.36. Trend line of evaporation for 1st decade of January of Patuakhali.

Although evaporation is declining at all the three stations but the rate of reduction is very minimal in Rangpur and Dinajpur compared to Patuakhali. As there is no pattern in the variation of relative humidity in the study area and in the control area so it can not be concluded that relative humidity is attributed to the increased irrigation coverage in Rangpur and Dinajpur.

Progressive development of irrigated area was plotted against evaporation in order to study the correlation between these two. In Rangpur region (Figure 4.37), it was found that the evaporation is decreasing with the increase in irrigated area. The slope of the trend line shows that for every ten million ha of increased irrigated area the evaporation of that region is decreased by 0.9mm. But the correlation between them is very insignificant (t = -0.3413).

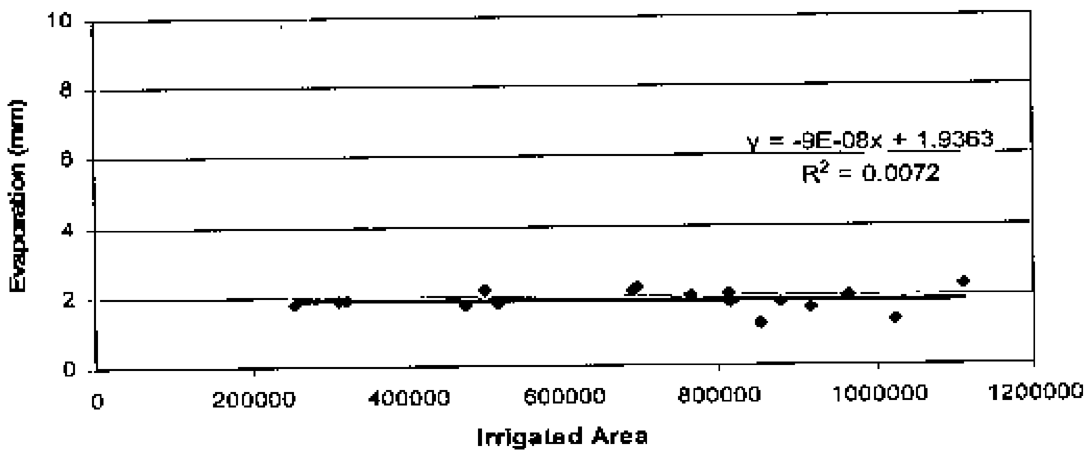

Figure 4.37. Correlation between evaporation of 1st decade of January and irrigated area of Rangpur.

Similarly, for Dinajpur (Figure 4.38), it has been found that for every ten million ha of progressive irrigation development, the evaporation is decreased by 0.8mm and the correlation between these two is insignificant (t = -0.11).

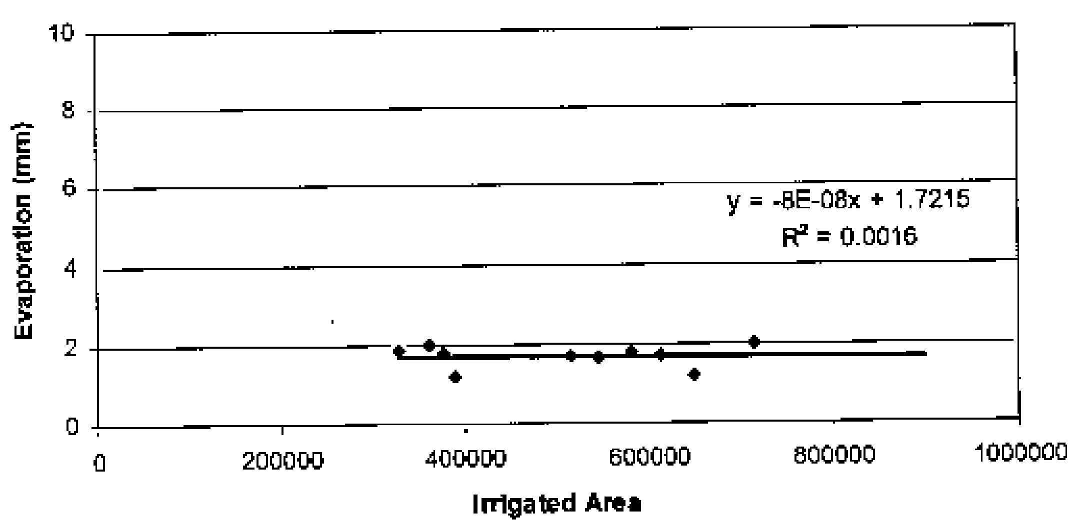

Figure 4.38. Correlation between evaporation of 1st decade of January and irrigated area of Dinajpur.

Figure 4.39 shows the correlation between evaporation of Patuakhali and the irrigated area of the region for the first decade of January. From the figure, it can be seen that for every additional ten thousand ha of irrigation development, the evaporation has decreased by 0.2 mm per annum. The correlation between these two is significant at 90% confidence level.

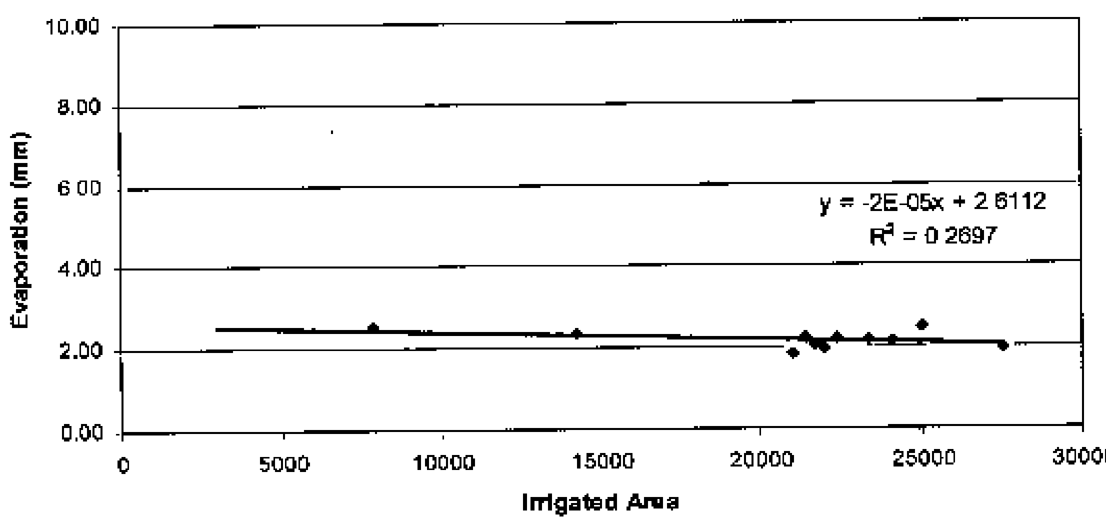

Figure 4.39. Correlation between evaporation of 1st decade of January and irrigated area of Patuakhali.

Similar trend line and correlation analysis of evaporation with irrigated area of the three stations, Rangpur, Dinajpur and Patuakhali, have been performed for rest of the decades of January, February, March and April. The slopes of the trend lines of evaporation, which indicate the rate of change of evaporation over the years, are shown in the Table 4.7.

Table 4.7: Rate of evaporation change over the years in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	(mm)	Significance	(mm)	Significance	(mm)	Significance
January 1st Decade	-0.005	Not	-0.0123	Not	-0.0365	**
January 2nd Decade	-0.0064	Not	-0.0345	Not	-0.0175	Not
January 3rd Decade	-0.0096	Not	-0.0253	Not	-0.0211	*
February 1st Decade	0.0055	Not	-0.0277	Not	-0.0394	**
February 2nd Decade	0.0191	Not	-0.0184	Not	-0.0114	Not
February 3rd Decade	0.0064	Not	0.0264	Not	-0.0222	Not
March 1st Decade	0.0198	*	-0.0315	Not	0.0037	Not
March 2nd Decade	0.0046	Not	0.0082	Not	-0.0268	Not
March 3rd Decade	-0.0013	Not	-0.1049	Not	-0.0726	**
April 1st Decade	-0.0532	*	-0.1027	*	-0.07	**
April 2nd Decade	0.0268	Not	-0.1439	Not	-0.0138	Not
April 3rd Decade	-0.0086	Not	-0.062	Not	0.037	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level. Negative sign means that the maximum temperature is decreasing.

The coefficient of correlation analysis between evaporation of Rangpur, Dinajpur and Pataukhali and the irrigated area of the respective area are shown in the Table 4.8.

Table 4.8: Correlation between Evaporation and irrigated area in Rangpur, Dinajpur and Patuakhali.

Name of the Decade	Rangpur		Dinajpur		Patuakhali	
	R^2	Significance	R^2	Significance	R^2	Significance
January 1st Decade	0.0072	Not	0.0016	Not	0.2697	Not
January 2nd Decade	0.0413	Not	0.1189	Not	0.0181	Not
January 3rd Decade	0.0408	Not	0.0523	Not	0.4462	**
February 1st Decade	0.0247	Not	0.0472	Not	0.5254	**
February 2nd Decade	0.1122	Not	0.0078	Not	0.0644	Not
February 3rd Decade	0.0157	Not	0.0958	Not	0.0592	Not
March 1st Decade	0.1937	**	0.0891	Not	0.1232	Not
March 2nd Decade	0.0064	Not	0.0002	Not	0.081	Not
March 3rd Decade	5E-05	Not	0.1618	Not	0.2708	Not
April 1st Decade	0.1517	Not	0.4121	**	0.281	Not
April 2nd Decade	0.0443	Not	0.256	Not	0.0236	Not
April 3rd Decade	0.0026	Not	0.1165	Not	0.0007	Not

NB: ** means significant at 95% confidence level, * means significant at 90% confidence level, 'Not' means not significant at 95% confidence level.

From the table 4.7, it can be seen that the trend line of evaporation of all twelve decades of the irrigation period in Rangpur shows both increasing and decreasing trend. In Rangpur, among the twelve decades the rate of evaporation decreases in six decades and it increases in the rest six decades. The rate of reduction of different decades over the years ranges from 0.0013 mm per year to 0.0532 mm per year. The lowest rate of reduction occurred in 3rd decade of March and the highest one occurred in 1st decade of April. The rate of increment of evaporation ranges from 0.0046 mm per year to 0.0268 mm per year. The highest and lowest rate of increment occurred in 2nd decade of April and 2nd decade of March respectively.

To find out the average rate of change in evaporation over the years in Rangpur during irrigation period, the average annual evaporation has been calculated by averaging the evaporation of February, March and April and plotted against the respective year. The data of January have been omitted purposively to consider the irrigation period when irrigation takes place in full swing. The graph (Figure 4.40) shows that the annual average of evaporation is decreasing at a rate of 0.0038 mm per year, i.e., over ten years of time period the evaporation of Rangpur during irrigation time has decreased by about 0.038 mm on an average.

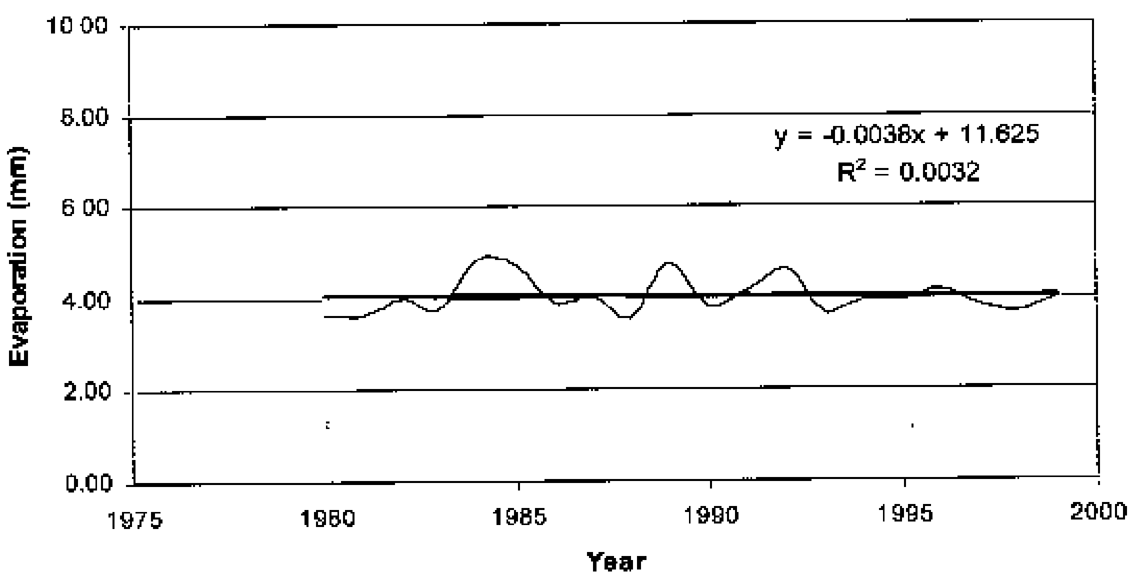

Figure 4.40. Trend-line of annual average of evaporation in Rangpur.

The trend line of evaporation of Dinajpur of all the twelve decades shows declining rate except 3rd decade of February and 2nd decade of March (Table 4.7). Here in Dinajpur, the rate of reduction ranges from 0.0123 mm per annum to 0.1439 mm per annum. The lowest rate occurred in 1st decade of January and the highest rate occurred in 2nd decade of April. To find out the average rate of evaporation change over the years in Dinajpur during irrigation period, a similar trend line has been drawn with the annual average data of evaporation of Dinajpur district. Here also the annual average has been calculated by averaging the data of three months, February to April. The trend line has been shown in figure 4.41.

The trend-line of Figure 4.41 shows that the annual average of evaporation of Dinajpur is decreasing at a rate of 0.0507 mm per year. That means the evaporation of Dinajpur has decreased by 0.507 mm over ten years of time.

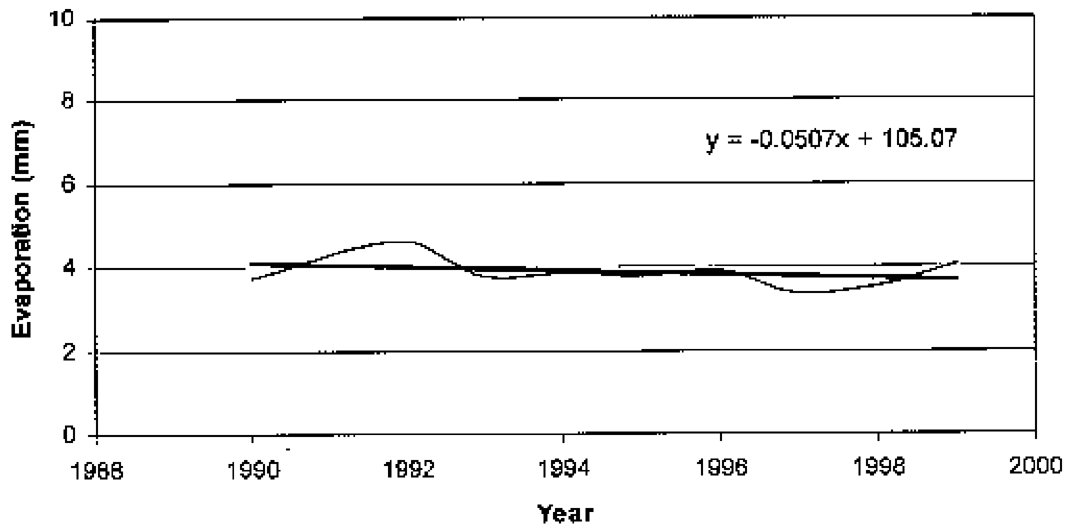

Figure 4.41. Trend-line of annual average of evaporation in Dinajpur.

The trend line of evaporation of Patuakhali of all the twelve decades shows both declining rates except for 1st decade of March and 3rd decade of April (Table 4.7). The evaporation reduction ranges from 0.0114 mm per to 0.0726 mm per year. The highest rate of reduction occurred in 3rd decade of March and the lowest one occurred in 2nd decade of February.

From the preceding analysis, it can be seen that irrigation has developed with the years in Rangpur and in Dinajpur but in Patuakhali it has remained the same over the years. Irrigation development means more agrarian area is covered with standing water during dry period which used to remain dry before irrigation development at the same time of the year.

Evaporation from the land surface includes evaporation from open water, soil, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available. The primary meteorological controls on evaporation from a well-watered surface (often known as potential evaporation) are the amount of energy available (characterized by net radiation), the moisture content of the air (humidity—a function of water vapor content and air temperature), and the rate of movement of air across the surface (a function of windspeed). Increasing temperature generally results in an increase in potential evaporation, largely because the water-holding capacity of air is increased. In humid regions, however, atmospheric moisture content is a major limitation to evaporation, so changes in humidity have a very large effect on the rate of evaporation (IPCC, 2001).

Irrigated surfaces are supposed to have more evaporation compared to dry land surface as the irrigated area is a source for potential evapo-transpiration. From the discussion on "the effect of irrigation development on maximum temperatures", it has been found that the maximum temperature i.e., the day time temperature is decreasing over the year in irrigated area compared to non-irrigated area due to increasing evaporation during day time. However, the trend-line of evaporation shows that evaporation is decreasing over the years in Dinajpur and Patuakhali. There is no definite trend in Rangpur. Evaporation mainly depends upon temperature, sunshine hours, humidity and wind speed. Increase in relative humidity which resulted due to increased water vapor in the atmosphere resulted in decrease in the evaporation from pan. Moreover, the decrease in sunshine hour also resulted in the decreased evaporation. The analysis of sunshine duration data revealed that the winter, dry season, summer and monsoon sunshine are declining at a rate of 5.7%, 5.0%, 3.9% and 3.8% respectively in every 10 years for the entire Bangladesh. There are some spatial patterns in the declining rates – the rates increased from south to north and east to west. So the most decline in sunshine duration occurred in North-west region. For example, the sunshine durations in the first 10-day period of January were 9.0 hours a day during the period 1961-1975 and that came down to 5.8 hours a day during the period of 1991-2006 in the north-west station (IWFM, 2008). It is assumed that although the rate of evaporation increases in the irrigated area during day time but the overall evaporation in a day decreased over time because of significant reduction of sunshine hours.

4.2.5 Summary of Effect of Irrigation Development on Climatic Parameters

From the above results, it has been found that the maximum temperature is decreasing in Rangpur and Dinajpur at a rate of 0.5^0C and 0.46^0C per decade respectively where irrigation development has taken place progressively while in Patuakhali with no irrigation development, the maximum temperature is increasing over the years at a rate of 0.237^0C per decade. The minimum temperature is increasing over the years in Rangpur and Dinajpur at a rate of 0.5^0C and 0.27^0C per decade but in case of Patuakhali, it does not show any definite trend. As the maximum temperature is decreasing and minimum temperature is increasing in the irrigated area, so the diurnal variation of temperature is also decreasing in the area where progressive irrigation development has been taken place. Although, the evaporation is supposed to have increased over time with the increase in irrigated area but it has been observed that the rate of evaporation is decreasing over time at a rate of 0.038 mm and 0.507 mm per decade in Rangpur and Dinajpur respectively. It is assumed that the rate of evaporation has increased in the irrigated area, as the irrigation water provides a source for potential evapo-transpiration, but it occurred only during the time when sunshine is available. However, from another study it has been found that sunshine duration has declined in the north-west region in the recent years to a great extent which ultimately reduced the total evaporation in a day. Further studies are required to confirm and explain the evaporation effect within the suushine hours. In case of effect of irrigation development on relative humidity, it has been found that the relative humidity is increasing over the years at a rate of 0.137% and 1.275% per decade in Rangpur and Dinajpur respectively. The relative humidity of Patuakhali does not show any definite trend.

4.3 Effect of Irrigation Development on Land Use and Cropping Pattern

Land use is largely dependent on the human demand, changes of the land cover and cropping pattern practiced in that area. Cropping pattern normally changes because of profitability of the crops, suitability of the soil and climate and availability of irrigation water. Before the sixties, when irrigation was not available, most of the arable land remained fallow during Rabi season and only some crops with less water requirement and grown with residual soil moisture, were cultivated. With the development of irrigation, the cropping pattern has been changed. The extent to which the cropping pattern of Rangpur has changed over the years with irrigation development has been analyzed based on secondary data and the patterns are shown in Table 4.9. Similarly, the changes of cropping pattern of Dinajpur over the years with irrigation development has been analyzed and shown in the Table 4.10.

The Table 4.9 and 4.10 show the major cropping patterns in three different periods in Rangpur and Dinajpur respectively. From the Table 4.9, it can be seen that during late sixties, 1, 36,500 hectares land were cultivated in Rangpur in the Kharif 2 season among 1.77.984 hectares of net cultivable land (BADC, 2004) which indicates that most of the arable land were cultivated in the Kharif 2 season. On the other hand in Dinajpur, 2, 71,500 hectares land were cultivated in the Kharif 2 season from 2, 72,912 hectares of net cultivable land (BADC, 2004) during late sixties, which indicates that almost all of the arable land were cultivated in the Kharif 2 season. In mid eighties, late nineties and present decade also, the area under cultivation in Rangpur was more or less same i.e. over the years, the area under cultivation during Kharif-2 season has not been changed significantly. In the same three consecutive periods, the area under cultivation in Dinajpur during Kharif 2 season reduced to a little extent but that was also 90% of the total net cultivable land. But significant change has been found in the Rabi season in both the regions.

During sixties while irrigation has not been developed, only a small portion of the cultivable land was cultivated and most of the arable land remained fallow in Rangpur and in Dinajpur as well. Pulses and vegetables which require less water were cultivated only in 11,600 hectares and 4,111 hectares of land which comprise only 6.5% and 1.5% of the total cultivable area of Rangpur and Dinajpur respectively. After irrigation development, the cultivable area is being increased progressively.

Table 4.9. Major Cropping pattern in four different periods in Rangpur

Name of the decade	Rabi season	Acreage (hectares)	Kharif 1	Acreage (hectares)	Kharif 2	Acreage (hectares)
Late Sixties	Fallow	0	B-Aus	68,400	T.Aman	68,400
	Fallow	0	Fallow	0	T. Aman	39,500
	Fallow	0	Jute	20,000	T. Aman	20,000
	Mustard	5,600	B-Aus	5,600	T. Aman	5,600
	Potato	3,000	Jute	3,000	Fallow	0
	Vegetable	2,000	Vegetable	2,000	B. Aman	2,000
	Pulses	1,000	B. Aus/Jute	1,000	T. Aman	1,000
Total		**11,600**		**1,00,000**		**1,36,500**
Mid Eighties	Fallow	0	Fallow	0	T. Aman	32,244
	Fallow	0	B.Aus	65,973	T. Aman	65,973
	Fallow	0	Jute	10,625	T. Aman	10,625
	Wheat	15,375	Jute	15,375	T. Aman	15,375
	Boro	9,500	Fallow	0	T. Aman	9,500
	Potato	4,027	B. Aus	4,027	T. Aman	4,027
	Mustard	3,038	T. Aus	3,038	T. Aman	3,038
	Vegetable	1,400	Vegetable	1.400	T. Aman	1,400
Total		**33,340**		**1,00,438**		**1,42,182**
Late Nineties	Boro	83,485	Fallow	0	T. Aman	83,485
	Potato	17,750	Fallow	0	T. Aman	17,750
	Potato	4,250	Jute	4,250	T. Aman	4,250
	Wheat	14,350	Jute	14,350	T. Aman	14,350
	Wheat	9,650	Fallow	0	T. Aman	9,650
	Wheat	11,778	Fallow	0	Fallow	0
	Mustard	4,200	Fallow	0	T. Aman	4,200
	Vegetable	3,050	Vegetable	3,050	Fallow	0
Total		**1,48,513**		**21,650**		**1,33,685**
Present decade (2004-05)	Boro	64,910	Fallow	0	T. Aman	64,910
	Potato	16,852	Boro/Aus/Jute	16,852	T. Aman	16,852
	Wheat	9,240	Jute/ vege	9,240	T. Aman	9240
	Mustard	3,352	Boro/Aus	3,352	T. Aman	3,352
	Boro	3,950	Fallow	0	Fallow	0
Total		**1,50,999**		**29,444**		**1,53,760**

Source: Department of Agriculture Extension (DAE), Rangpur, 2006

Table 4.10. Cropping pattern in four consecutive decades in Dinajpur

Name of the decade	Rabi season	Acreage (hectares)	Kharif 1	Acreage (hectares)	Kharif 2	Acreage (hectares)
Late Sixties	Fallow	0	Jute	50,400	T. Aman	50,400
	Fallow	0	B. Aus	2,15,400	T. Aman	2,15,400
	Vegetable	1,566	B. Aus	1,566	Fallow	0
	Fallow	0	B. Aus	460	Fallow	0
	Vegetable	2,000	Jute	2,000	Fallow	0
	Fallow	0	Jute	500	Fallow	0
	Pulses	545	Fallow	0	T. Aman	545
	Fallow	0	Fallow	0	T. Aman	5,155
Total		**4,111**		**2,70,326**		**2,71,500**
Mid Eighties	Boro	1,24,430	Fallow	0	T. Aman	1,24,430
	Wheat	45,225	Jute	45,225	T. Aman	45,225
	Wheat	24,775	Fallow	0	T. Aman	24,775
	Potato	9500	T. Aus	9500	T. Aman	9500
	Vegetable	1,200	T. Aus	1200	T. Aman	1200
	Boro	570	Summer Vegetables	570	T. Aman	570
	Fallow	0	Fallow	0	T. Aman	21626
Total		**2,05,700**		**56,495**		**2,27,326**
Late Nineties	Boro	1,52,185	Fallow	0	T. Aman	1,52,185
	Wheat	4,405	Jute	4,405	T. Aman	4,405
	Wheat	33,392	Fallow	0	T. Aman	33,392
	Maize	22,000	Fallow	0	T. Aman	22,000
	Boro	1215	Summer Vegetables	1215	T Aman	1215
	Potato	12,080	T. Aus	12,080	T. Aman	12,080
	Potato	11,279	Fallow	0	T. Aman	11,279
	Vegetables	1,400	T. Aus	1400	T. Aman	1400
	Fallow	0	Fallow	0	T. Aman	14,444
Total		**2,37,956**		**19,100**		**2,52,400**
Present Decade (2004-05)	Boro	151515	Fallow	0	T. Aman	1,51,515
	Wheat	29,942	Fallow		T. Aman	29,942
	Boro/Wheat	19,390	Dhaincha	19,390	T. Aman	19,390
	Wheat	8854	Aus	8854	T. aman	8,854
	Potato	6794	Boro	6794	T. Aman	6,794
	Mustard	5069	T. Aus	5069	T. Aman	5,069
Total		**2,38,635**		**43,155**		**2,47,442**

Source: Department of Agriculture Extension (DAE), Dinajpur, 2006

During mid eighties, 33,340 hectares of land were cultivated during Rabi season in Rangpur which comprise of near about 19% of the total cultivable area. In Dinajpur, during mid eighties, 205,700 ha of land were cultivated during Rabi season which comprise of near about 76% of the total cultivable area of Dinajpur. Boro rice and wheat have been introduced during that time. The increment of cultivation during rabi season which took place in between late sixties and mid eighties was because of the introduction of these two crops, wheat and Boro rice. From the cropping pattern of late sixties and mid eighties of Rangpur and Dinajpur, it has been found that the farmers of Dinajpur became aware about the necessity and usefulness of irrigation and they adopted practicing irrigation very quickly.

In late nineties while ground water irrigation was practiced in full swing the cropping pattern was largely been changed and more areas came under cultivation in Rangpur. In this time period, 148,513 hectares land was cultivated which is about 83% of the total cultivable land in Rangpur district. In Dinajpur, 237,956 ha land were cultivated during Rabi season in late nineties which is about 87% of the total cultivable land in Dinajpur district. High irrigation requirement crop, Boro rice, has been increased sharply from 9,500 hectares in mid eighties to 83,485 hectares in late nineties in Rangpur. In late nineties, the Boro rice was cultivated in the 55% of the cultivated area which comprise of 47% of the net cultivable area of Rangpur. In Dinajpur, Boro rice has been cultivated in 125,000 ha of land in mid eighties and in 153,400 ha of land in late nineties. In mid eighties, Boro rice was cultivated in 46% of the net cultivable area and in the late nineties it was cultivated in 57% of the net cultivable area. In the present decade, no major changes have been taken place compared to the late nineties.

Potato and wheat cultivation has also been changed manifold in the nineties and present decade compared to the eighties in Rangpur and in Dinajpur. Wheat cultivation has been reduced to half from mid eighties to present decade both in Rangpur and in Dinajpur although it had been increased during late nineties in Rangpur but potato cultivation has been increased manifold during this time period in both the regions. It is also important to notice that Boro rice cultivation has brought a change in the cropping pattern. Before the introduction of Boro rice, while mustard and pulses were cultivated, three crops could be cultivated in a year in the Rangpur region. But after the initiation of Boro rice, the Kharif 1 season remains fallow because in between Boro and Aman there remains very short span of time for any additional crop to be grown. Only some short duration summer vegetables can be grown in between these two crops and these vegetables were grown only in high land which is a small portion of the total cultivable land. It has been found that during late sixties while irrigation was not practiced in the Rabi season then Aus, Jute and some summer vegetables were cultivated and they covered 100,000 hectares and 2, 70,326 hectares of land in Rangpur and Dinajpur (56% and 98% of the net cultivable area) respectively in Kharif I season. In mid eighties also the Aus, Jute and summer vegetable were cultivated widely in the Kharif I season and these crops occupied 100,438 hectares of land in Rangpur but in Dinajpur, it had been reduced to 56,495 ha of land (21% of the total cultivable land). In the late nineties, when Boro rice started to be grown widely, then crop cultivation during Kharif 1 season felt down sharply to 21,650 hectares in Rangpur (12% of the net cultivable land) and 19,100 ha in Dinajpur (7% of the net cultivable area). In the present decade, it again has gone up to 29,444 ha and 43,155 ha in Rangpur and in Dinajpur respectively.

The Table 4.11 shows the major five cropping patterns in four different periods at Patuakhali. From this table it can be seen that during late sixties, 73,370 hectares land were cultivated in the Rabi season from 2,24,689 hectares of net cultivable land (BADC, 2004) which indicates that near about 33% of the arable land was cultivated in the Rabi season during late sixties. During that time, Khesari was the major crop in rabi season. Chili and sweet potato were also cultivated at that time during Rabi season. In mid eighties and late nineties, the same type of crops was cultivated during Rabi season. The area under cultivation during this season in mid eighties and late nineties reduced to 59265 hectares and 50,270 hectares of land respectively. In the present decade (2004-05), during Rabi season Mungbean is being cultivated instead of Sweet potato and chili. In the present decade, 64,618 hectares of land is being cultivated which comprises of 29% of net cultivable land. T. Aman is being cultivated During Kharif 2 season throughout the all decades. Area under cultivation during Rabi season is being decreased steadily. In late sixties the area under T. Aman cultivation was 1, 60,500 hectares and it reduced to 1, 31,412 hectares of land in the present decade. The progress of cultivation has only been found in the Kharif I season. In late sixties, B. Aus was cultivated only in 7,245 hectares of land. In mid eighties, the B. Aus was cultivated in 35,470 hectares of land. In late nineties, B. Aus was replaced by T. Aus and it was cultivated in 36,855 hectares of land. In the present decade the area under T. Aus cultivation is being increased to 66,843 hectares. From the trend line of irrigation development in Patuakhali district, it has been found that irrigated area remains same over the years since 1975 i.e. irrigation has not been developed in Patuakhali district unlike Rangpur and Dinajpur. From the cropping pattern table also it has been found that except for kharif 1 season no major changes have taken place in the cropping pattern since late sixties.

Cropping intensity in Rangpur is 227% in the present decade with the development of irrigation. In Dinajpur, the cropping intensity is 212.74% in the present decade. In Patuakhali the cropping intensity is 200.34% in the present decade. So the cropping intensity in Rangpur and Dinajpur, progressive development of irrigation has taken place, is 12 to 27% higher compared to Patuakhali where irrigation has not been developed.

Table 4.11: Cropping patterns in three consecutive decades in Patuakhali.

Name of the decade	Rabi season	Acreage (hectares)	Kharif 1	Acreage (hectares)	Kharif 2	Acreage (hectares)
Late Sixties	Fallow	-	Fallow	-	T. Aman	79,885
	Khesari	37,915	Fallow	-	T. Aman	37,915
	Sweet Potato	25,125	Fallow	-	T. Aman	25,125
	Chili	10,330	Fallow	-	T. Aman	10,330
	Fallow	-	B. Aus	7,245	T. Aman	7,245
Total		**73,370**		**7,245**		**1,60,500**
Mid Eighties	Fallow	-	Fallow	-	T. Aman	70,350
	Khesari	25,255	B. Aus	25,255	T. Aman	25,255
	Sweet Potato	20,145	Fallow	-	T. Aman	20,145
	Chili	13,885	Fallow	-	T. Aman	13,885
	Fallow	-	B. Aus	10,215	T. Aman	10,215
Total		**59,285**		**35,470**		**1,39,850**
Late Nineties	Fallow	-	Fallow	-	T. Aman	62,325
	Khesari	22,190	T. Aus	22,190	T. Aman	22,190
	Sweet Potato	15,210	Fallow	-	T. Aman	15,210
	Chili	12,870	Fallow	-	T. Aman	12,870
	Fallow	-	T. Aus	14,665	T. Aman	14,665
Total		**50,270**		**36,855**		**1,27,260**
Present decade (2004-05)	Fallow	-	Fallow	-	T. Aman	49,779
	Khesari	20,775	T. Aus	20,775	T. Aman	20,775
	Mung	20,066	T. Aus	20,066	T. Aman	20,066
	Fallow	-	T. Aus	17,015	T. Aman	17,015
	Mung	14,790	Fallow	-	T. Aman	14,790
	Vegetables	8,987	Aus	8,987	T. Aman	8,987
Total		**64,618**		**66,843**		**1,31,412**

Source: Department of Agriculture Extension (DAE), Patuakhali, 2007

4.3.1 Summary of Effect of Irrigation Development on Cropping Pattern

From the discussion above, it has been found that there is a positive relationship between irrigation development and cropping pattern changes. With the advent and development of irrigation, the fallow land has come under cultivation during Rabi season. Mostly Boro rice is being cultivated with the development of irrigation. Irrigation development has also encouraged the cultivation of Potato and wheat. Potato cultivation has been increased significantly in the recent decades. Wheat has been introduced in Bangladesh during mid-eighties. The cultivation of wheat has been increased in Rangpur during the decade of late nineties but it has again been reduced in the recent decades. Majority of the fallow land in Dinajpur came under boro cultivation and a significant portion came under wheat cultivation during Rabi seasons in Mid eighties. But wheat cultivation reduced to half in late nineties in Dinajpur as the rest half was replaced by maize cultivation. There is common perception that with the development of irrigation, cropping pattern has been shifted from diversified cropping to mono cropping which is not true. Boro, wheat and potato are being cultivated in the land which remained fallow before the development of irrigation. Mustard, vegetables, pulses etc. which were cultivated that time are still being cultivated. Interestingly, the ground water irrigation development has brought changes in the cropping pattern of Kharif I season. Where irrigation has developed progressively, the area under cultivation during Kharif 1 season has shrunken because in between Boro rice and T. Aman there does not remain enough time for B.Aus or T.Aus to be cultivated which is the major crop in Kharif I season. In the Kharif-2 season, only a cingle crop, T. Aman, is being cultivated throughout the decades in Rangpur and Dinajpur. However, in Patuakhali, no change in the cropping pattern has been observed over the decades. Cropping intensity in Rangpur, Dinajpur and in Patuakhali in the present decade is 227%, 212.74% and 200.34% respectively. Cropping intensity in Rangpur and Dinajpur is 12 to 27% higher compared to Patuakhali where irrigation has not been developed.

4.4 Effect of Irrigation Development on Soil Fertility

Soil fertility is the characteristic of soil that supports abundant plant life. Soil Fertility is the capability or ability of soils to supply elements essential for plant growth without a toxic concentration of any element. It is the inherent capacity of a soil to supply 14 of the 17 essential nutrient elements to the growing crop. It is the quality of soil that enables it to provide compounds or elements in adequate amounts and in proper balance for the growth of specified plants when other growth factors like light, moisture, temperature and the physical conditions of the soils are favorable.

Soil quality changes slowly because of natural processes such as weathering and more rapidly under human activity; land use, farming practices and irrigation. Cropping systems have undergone some changes since 1973 due to the adoption of high yielding varieties along with increased use of irrigation and fertilizer application (Huq et al. 1990). In this section, it has been tried to identify the impact of long term irrigation on soil quality. Impact has been assessed only in the greater Rangpur and greater Dinajpur but not in Patuakhali as the progressive development of irrigation has been taken place in greater Rangpur and greater Dinajpur.

Table 4.12 illustrates the differential amount of total carbon stored in the 0-15 cm and 0-100 cm layers in 1967 and 1995. Only Barind Tract (BT), i.e. Chandra and Belabo of Greater Rangpur, the amount of carbon stored in the 0-100 cm layers increased (3.76 t C ha^{-1}) in 1995. In other units, the amount of carbon stored in the 0-100 cm layers decreased in 1995. However, some increase in the amount of element in the top 0-15 cm layers was observed for Pirgacha and Kaunia i.e., Teesta Floodplain. In the Teesta flood plain the amount of carbon stored was increased by 0.73 t ha^{-1}. Decrease in the amount of carbon stored for Old Himalayan Piedmont plain (OHP) which covers the greater Dinajpur in the above table was recorded as 3 t C ha^{-1}in the 0-15 cm layers of soil. Increase in the amount of carbon was observed in the soils of Barind tract as well (2.58 t C ha^{-1}).

As in the case of total carbon, total nitrogen content for these soils was generally low. Both carbon and nitrogen are mostly derived from organic matter decomposition, hence the similarity in the trends for the contents of these two elements. Table 4.12 shows the amount of nitrogen in the 0-15 cm and 0-100 cm layers in 1967 and 1995. The amount of nitrogen stored at these depths was also higher in 1995 for Chandra and Belabo. The amount of nitrogen stored in all the other physiographic units was lower in 1995. Changes in the amount of nitrogen stored were similar to those of carbon, which showed a higher decrease for the 0-100 cm than 0-15 cm layers. For Greater Dinajpur the fall in the amount of nitrogen stored was minimal which was recorded as 0.65 t N ha^{-1}in 0-100 cm soil layers. Increase in nitrogen content occurred only in the soils of Barind tract (0.775 t N ha^{-1}in 0-100 cm soil layers 0.27 t N ha^{-1} in 0-15 cm soil layers).

Table 4.12. Total carbon and total nitrogen contents in 0-15 cm and 0-100 cm soil layers of different soil profiles during the period 1967-1995 in Rangpur and Dinajpur.

Name of the Area		Total Carbon (t ha^{-1})				Total Nitrogen (t ha^{-1})			
		0-15 cm		0-100 cm		0-15 cm		0-100 cm	
		1967	**1995**	**1967**	**1995**	**1967**	**1995**	**1967**	**1995**
G. Dinajpur	Atwari (OHP)	30.96	31.97	100.11	87.51	3.25	3.53	7.76	8.07
	Jagdal (OHP)	17.51	10.50	50.92	36.64	1.97	0.99	4.91	3.30
G. Rangpur	Pirgacha (TF)	10.95	14.66	45.00	37.35	1.11	1.08	4.71	2.84
	Kaunia (TF)	16.54	14.29	59.18	41.46	1.73	1.63	4.93	4.22
	Chandra (BT)	13.39	16.29	46.41	49.95	1.38	1.81	5.81	7.30
	Belabo (BT)	12.84	15.10	51.99	55.96	1.41	1.52	6.98	7.04

Source: Mohsin ali, 1997

At the series level, the sharp fall in the carbon content in the Jagdal soil series as well as in the Atwari soil series (OHP) was attributed to the change in the cropping system (sugarcane or T. aman in 1967 and T. aman-wheat in 1995). The introduction of irrigation in this area has led to change in cropping pattern. Although it has increased the cropping intensity but the ground crop residues of the crop systems of 1995 are more or less collected for other uses while the larger quantity of roots were left in the soil by sugarcane. This may explain why the carbon content of the soil declined when sugarcane was no longer produced (Ali et al., 1997). Eswaran et al. (1995) reported a fall of 1.08 and 1.77 kg m^{-3} in organic carbon from two cultivated sites subjected to different farming systems compared to non-cultivated/ grass and shrub plots. Total carbon content increased in the Pleistocene terrace soils of Chandra and Belabo series (BT) in greater Rangpur. The amount of carbon also increased in the 0-15 cm layers in the Pirgacha series (TF) in greater Rangpur. Changes in cropping pattern due to introduction of irrigation may have contributed to the addition of more plant residues and slow organic matter decomposition under acidic soil conditions, hence the increase of the carbon content in these soils.

The sharp fall of total nitrogen may be due to the changes in cropping systems. Biological fixation of nitrogen by micro-organisms, especially blue green algae is a major source of nitrogen for floodplain crops (especially rice). Spatial variation of blue green algae abundance could partly explain the difference in the changes of the nitrogen content in the studied solids. The lower decrease of the total nitrogen contents in the 0-15 cm layers may be due to differences in soil characteristics at different depths, hydrological conditions, differences in soil characteristics at different depths, hydrological conditions, changes in cropping systems and other management practices.

Table 4.13 illustrates the mean changes of soil pH and exchangeable acidity in six locations of greater Rangpur and greater Dinajpur in the 0-15 cm and 0-100 cm soil layers during the period 1967-1995. Soil pH showed a decline in the 0-15 cm layers in all the physiographic units. Changes in pH in that layer ranges from 0.02 to 0.34 units. Soil pH also has declining rate over the 27 year period in the 0-100 cm layers but in this case the changes took place in more or less uniform manner, around 0.20 units.

Table 4.13. Changes in Soil pH and Exchangeable acidity within 0-15 cm and 0-100 cm soil layers of different profiles during the period 1967-1995 in Rangpur and Dinajpur.

Name of the Area		Soil pH (water)				Exchangeable acidity (kmol ha^{-1})			
		0-15 cm		0-100 cm		0-15 cm		0-100 cm	
		1967	**1995**	**1967**	**1995**	**1967**	**1995**	**1967**	**1995**
G. Dinajpur	Atwari (OHP) Jagdal (OHP)	5.51	5.49	5.96	5.80	7.34	8.24	22.21	30.81
G. Rangpur	Pirgacha (TF) Kaunia (TF)	5.47	5.35	5.88	5.63	10.81	11.76	40.53	38.74
	Chandra (BT) Belabo (BT)	5.50	5.16	5.42	5.20	9.18	9.52	39.56	99.73

Source: Mohsin ali, 1997

Exchangeable acidity showed an opposite trend of change to that of soil pH. All the physiographic units showed an increase in exchangeable acidity except for Pirgacha and Kaunia (Teesta Flood plain) soil series which showed a decrease in the 0-100 cm layers. The increase in exchangeable acidity in the 0-15 cm layers was moderate. Exchangeable acidity for the 0-100 cm layers increased moderately (8.60 kmol ha^{-1}) in greater Dinajpur (Old Himalayan piedmont plain) and sharply (60.17 kmol ha^{-1}) in Chandra and Belabo (Barind tract) of greater Rangpur. Exchangeable acidity decreased slightly (1.8 kmol ha^{-1}) in the silty soils of Tista floodplain which comprises of Pirgacha and Kaunia.

Changes in soil pH showed a decrease during the period 1967-1995. The increases in exchangeable acidity and the depletion of exchangeable bases may account for this general decline in soil pH. The development of irrigation has introduced Boro rice cultivation which requires nitrogenous fertilizer. Excessive use of nitrogenous fertilizers without the addition of lime also contributed to this decline in soil pH. A similar observation was reported by Alan (1993) in long term experiments at Rothamsted. Pierre et al. (1970) also reported that the application of nitrogenous fertilizers led to a decrease of the pH in both surface soils and sub-soils in West Africa.

The decrease in pH accompanying ferrolysis (Brinkman, 1970 as reported by Shaheed, 1994) may explain the observed increases in exchangeable acidity in the highly weathered terrace soils of Chandra and Belabo (Barind Tract). Human interference like land leveling for irrigation resulting in the lifting of the lower acidic red terrace soils in Barind tract could be another reason for this change in exchangeable acidity. Shaheed (1994) reported that rain water leaching caused the removal of bases and rather strong acidification (pH 4.6-5.0) in the piedmont plains and promoted the increase in exchangeable acidity in Old Himalyan Piedmont plain i.e. in greater Dinajpur.

Table 4.14 shows the changes in the contents of exchangeable potassium K and exchangeable Phosphorus (P) in the 0-15 cm and 0-100 cm layers during the period 1967-1995. All the physiographic units showed a decline in the amount of exchangeable K stored at these layers except for the 0-100 cm layers of greater Dinajpur where an increase was observed. The decrease in the content of exchangeable K was higher in the 0-15 cm layers of all the physiographic units. Exchangeable K content in the 0-100 cm layers declined in all the physiographic units except in greater Dinajpur which showed an increase of 2.1 kmol ha^{-1}. Serious depletion of this element was observed in Pirgacha and Kaunia (TF) where the exchangeable K contents were relatively lower (<15 kmol ha^{-1}) in 1967. The soils of Chandra and Belabo soil series (BT) showed relatively low decrease (13%) of this nutrient element. Mean exchangeable K level of Bangladesh soils showed a decrease of 3.4 kmol ha^{-1} within this period.

The changes in the level of available phosphorus varied markedly (either positive or negative) in the 0-15 cm and 0-100 cm layers in the different physiographic units during the period 1967-95.

Table 4.14. Changes in Exchangeable K and available P within 0-15 cm and 0-100 cm soil layers of different profiles during the period 1967-1995 in Rangpur and Dinajpur.

Name of the Area		Exchangeable K (kmol ha^{-1})				Available P (kg ha^{-1})			
		0-15 cm		0-100 cm		0-15 cm		0-100 cm	
		1967	**1995**	**1967**	**1995**	**1967**	**1995**	**1967**	**1995**
G. Dinajpur	Atwari (OHP)	2.61	1.53	10.72	12.78	87.69	98.25	246.49	236.65
	Jagdal (OHP)								
G. Rangpur	Pirgacha (TF)	3.53	1.64	14.21	8.65	110.12	123.70	357.14	431.23
	Kaunia (TF)								
	Chandra (BT)	3.27	1.88	28.21	24.44	42.57	39.89	131.61	78.91
	Belabo (BT)								

Source: Mohsin ali, 1997

The 0-100 cm soil layers of Kaunia and Pirgacha (Tista Floodplain) showed an improvement in phosphorus availability by 74.1 in kg P_2O_5 ha^{-1} during 1967-1995. On the contrary, available phosphorus contents decreased by 9.84 and 52.7 in kg ha^{-1} in the soils of greater Dinajpur and Barind tract of greater Rangpur respectively. Based on the data of 1967, the soils of Chandra and Belabo soil series showed a severe decline (>40%) in available phosphorus. The decreases in phosphorus availability were lower (4%) in greater Dinajpur.

All the physiographic units showed a decline in the content of exchangeable K except for greater Dinajpur which showed an increase in the content of exchangeable K (Table 4.14). The decrease in the exchangeable K is more related to leaching losses (Cresser et al. 1993) and/or plant uptake. Development of irrigation has introduced high yielding crop varieties which resulted in an increased use of N:P:K fertilizers (Huq et al. 1990) with the concomitant uptake and leaching of these base cations. Apart from leaching, plant uptake played an important role in the depletion of this nutrient. The increase in the content of exchangeable K in greater Dinajpur was possibly due to the effects of parent material and/or irrigation. Serious depletion (>30%) of exchangeable K in Chandra and Belabo soil series was presumably due to the same reasons namely leaching and inadequate fertilization.

The available phosphorus level seemed to be affected mostly by the soil characteristics and land management practices adopted by the farming community. The increase in phosphorus availability in Pirgacha and Kaunia (TF) may be due to the addition of fertilizer phosphorus. Except for plant uptake, most of the phosphorus remained within the sampling zone since phosphorus does not leach easily. Anaerobic conditions of the paddy rice systems of cultivation of these soils (Islam 1999) may account for the enhanced phosphorus availability as reported by Kyuma and Wakatsuki (1995). The decrease in phosphorus availability in greater Dinajpur might be associated with fixation, plant uptake and inadequate phosphorus fertilization. Serious decline of the level of available phosphorus in Chandra and Belabo soil series (BT) may be due to the inadequate phosphorus fertilization and phosphate fixation in acidic terrace soil (mean pH< 5.2; table 4.14).

4.4.1 Summary of Effect of Irrigation Development on Soil Fertility

The carbon content in the 0-15 cm layer mostly increased in all sampling units in the irrigated area except in two sampling sites. The sharp fall in the carbon content in the Jagdal soil series as well as in the Atwari soil series (OHP) in 0-15 cm layers was attributed to the change in the cropping system (sugarcane or T. aman in 1967 and T. aman-wheat in 1995). In the 0-100 cm soil layers, the total carbon content mostly decreased but only in the Barind Tract, it has increased to some extent. Changes in cropping pattern due to introduction of irrigation may have contributed to the addition of more plant residues and slow organic matter decomposition under acidic soil conditions, hence the increase of the carbon content in these soils. The sharp fall of total nitrogen may be due to the changes in cropping systems. Biological fixation of nitrogen by micro-organisms, especially blue green algae is a major source of nitrogen for floodplain crops (especially rice). Spatial variation of blue green algae abundance could partly explain the difference in the changes of the nitrogen content in the studied solids. Soil pH showed a decline in the 0-15 cm layers in all the physiographic units. Changes in pH in that layer ranges from 0.02 to 0.34 units. Soil pH also has declining rate over the 27 year period in the 0-100 cm layers. Exchangeable acidity showed an opposite trend of change to that of soil pH. All the physiographic units showed an increase in exchangeable acidity except for Pirgacha and Kaunia (Teesta Flood plain) soil series which showed a decrease in the 0-100 cm layers. All the physiographic units showed a decline in the content of exchangeable K except for greater Dinajpur which showed an increase in the content of exchangeable K. Development of irrigation has introduced high yielding crop varieties which resulted in an increased use of N:P:K fertilizers with the concomitant uptake and leaching of these base cations. The increase in the content of exchangeable K in greater Dinajpur was possibly due to the effects of parent material and/or irrigation. The available phosphorus level seemed to be affected mostly by the soil characteristics and land management practices adopted by the farming community. The increase in phosphorus availability in Pirgacha and Kaunia (TF) may be due to the addition of fertilizer phosphorus. The decrease in phosphorus availability in greater Dinajpur might be associated with fixation, plant uptake and inadequate phosphorus fertilization. Serious decline of the level of available phosphorus in Chandra and Belabo soil series (BT) may be due to the inadequate phosphorus fertilization and phosphate fixation in acidic terrace soil.

4.5 Findings from the Focus Group Discussion (FGD)

4.5.1 FGD at Dinajpur

Farmers have mentioned that irrigation has been mainly started during 80s in their area. Before irrigation, during dry period they did not have any opportunity to work in agricultural field. After the introduction of irrigation all the land came under cultivation during the dry period. It is good in a sense that land utilized has increased as it does not remain fallow during the dry period. With irrigation they can produce more crops to ensure food security and created ample employment and income opportunities. However, irrigation has negative impacts on soil fertility, climatic parameters and on ground water level.

Impact on soil fertility:

Utilization of land in every season does not give the land any time to reinvigorate which resulted in reduction of soil-fertility over time. Moreover, during the irrigation season almost in every patch of land high yielding variety of rice is being cultivated which require higher dosage of chemical fertilizer. So uses of chemical fertilizer instead of cow-dung and bio-fertilizer decreased the soil fertility as well. Application of pesticide also leads to decline soil fertility.

Impact on climatic parameters:

According to the farmers after the introduction of ground water irrigation the day time temperature has reduced to a little extent. The pattern of occurring extreme event like thunder storm has changed and the rainfall pattern has also been changed. During dry period there was a hot dry westerly wind blowing from west to east at the time of early to mid noon but it has been reduced by 50% now a days compared to the previous years.

Impact on water level:
After the introduction of ground water irrigation, people of this region are facing serious problem in drawing water from hand tube-well during the irrigation season. Before irrigation season they could get water only by boring pipe upto 10 meter depth but now they need to bore more than 30 meter to get water.

There is a small river in their area. They mentioned that water remained in the river bed even during dry period but now a day the river bed become completely dry during the dry period i.e. during irrigation period.

4.5.2 FGD at Thakurgaon:

Farmers of Thakurgaon have informed that Boro cultivation has been started since the middle of eighties after the introduction of irrigation. Before irrigation development the cropping pattern of this area was Aman-fallow-kown/Till/ Jute; but after the introduction of ground water irrigation majority of the land was occupied with the cropping pattern like Aman-Boro-Fallow. Likewise the farmers of Dinajpur, they have also mentioned that the changed cropping pattern has positive impact on food security, employment and income opportunities as well as some negative impacts on soil fertility, climatic parameters and on ground water level.

Impact on soil fertility:
Soil fertility has been reduced as the land is being cultivated continuously with the advent of irrigation. The cultivation of grain crops again and again throughout the year has led to reduction of soil fertility. High nutrient requiring crop like high yielding variety of rice is being cultivated after the introduction of irrigation almost in every patch of land. So, excessive use of chemical fertilizer to cultivate HYV rice decreased the soil fertility as well. According to the farmers the water holding capacity of the soil is also decreasing over time after the introduction of irrigation.

Impact on climatic parameters:

Before irrigation development, it was too dry and the temperature was too high during the dry period. The heat of the sun at the early and mid noon was intolerable. The soil became too hot. At the time between 11 am to 2 pm, people and cattle cannot stay under the direct sunlight. But now, after the widespread practice of ground water irrigation temperature has fallen down to some extent because of green covered land instead of barren land and standing irrigation water. Because of this standing water and green crop, the dryness of weather has also been reduced. Westerly hot wind is also absent after the initiation of ground water irrigation which was prevalent during the dry season when the land remained barren. Twenty to thirty years ago untimely rains i.e. rains in the month of April (Chaitra) never occurred but now sometimes it occurs.

Impact on water level:

Earlier water was retained in the rivers, ponds, khals and canals but after the irrigation development no water remains in the water bodies during irrigation period. Water level has fallen down due to excessive withdrawal of ground water for irrigation so hand tube-well and Shallow Tube- well can not draw water easily during the period of irrigation.

4.5.3 FGD at Nilphamari:

Farmers of Nilphamari have mentionaed that before irrigation development the cropping pattern of Nilphamari was T Aman -Jute/Pulses/; early B Aman- fallow or T-Aman-fallow – Late B Aman but after the development of ground water irrigation the cropping pattern is mostly T Aman- Boro-Fallow is mostly practiced.

Impact on climatic parameters:

During the month of March and April (Falgun and Chaitra) which is dry period, the temperature was too high before irrigation development but now after the development of irrigation the temperature has reduced to some extent. Hot westerly wind which used to blow during this dry period before the introduction of irrigation has been reduced to a great extent. Thunderstorm along with rain and sleet was very common phenomenon during this season but after the introduction of irrigation there are fewer storms.

Impact on water level:

Ground water table has dropped down so hand tube-wells generally do not provide water.

4.5.4. Summary of FGDs

From the findings above it has been found that the maximum temperature has decreased to some extent after the development of irrigation. Because of the standing water and green crops, the dryness of weather has also been reduced. Westerly hot wind is also absent after the initiation of ground water irrigation which was prevalent during the dry season when the land remained barren. Soil fertility has been reduced as the land is being cultivated continuously with the advent of irrigation. The cultivation of grain crops again and again throughout the year has led to reduction of soil fertility. High nutrient requiring crop like high yielding variety of rice is being cultivated after the introduction of irrigation almost in every patch of land. So, excessive use of chemical fertilizer to cultivate HYV rice decreased the soil fertility as well. Before irrigation development the cropping pattern of this area was Aman-fallow-kown/Till/ Jute; but after the introduction of ground water irrigation majority of the land was occupied with the cropping pattern like Aman-Boro-Fallow. Water level has fallen down due to excessive withdrawal of ground water for irrigation so hand tube-well and Shallow Tube- well can not draw water easily during the period of irrigation.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

Irrigation has boosted up agricultural production significantly to meet the food requirements of the country but simultaneously it may have exerted some impacts on environment. The present study investigates the effect of progressive development of irrigation on the climatic parameters such as on maximum temperature, minimum temperature, evaporation and on relative humidity. It has also investigated the effect of irrigation development on the land use and cropping pattern and on the soil fertility as well. In most past studies, the effect of all climatic variables on irrigation and irrigation water requirement has been investigated but the effect of irrigation development on climatic variables was not taken into consideration. The study investigates the long term trends in climatic variables before and after the development of irrigation and their correlation with the progressive development of irrigation from 1969 to 2006 at Rangpur and Dinajpur where irrigation has been developed progressively. The same analysis has been performed in Patuakhali also to get a comparison between irrigated and non-irrigated area. The findings show that the effect of irrigation development on climatic parameters is consistent with the general perception and previous findings in case of temperature but is quite different from what is generally thought in case of evaporation and soil fertility. The specific conclusions drawn from this study are summarized below:

1. The trend line of maximum temperature shows that the maximum temperature is decreasing in Rangpur and Dinajpur at a rate of 0.5^0C and 0.46^0C per decade respectively where irrigation development has been taken place progressively while in Patuakhali with no irrigation development, the maximum temperature is increasing over the years at a rate of 0.237^0C per decade.

2. The minimum temperature is increasing over the years in Rangpur and Dinajpur at a rate of 0.5^0C and 0.27^0C per decade but in case of Patuakhali, it does not show any definite trend.

3. Although, the evaporation is supposed to be increased over time with the increase in irrigated area but it has been observed that the rate of evaporation is decreasing

over time at a rate of 0.038 mm and 0.507 mm per decade in Rangpur and Dinajpur respectively. It is assumed that the rate of evaporation has increased in the irrigated area, as the irrigation water provides a source for potential evapo-transpiration, but it occurred only during the time when sunshine is available. However. from another study it has been found that sunshine duration has declined in the north-west region in the recent years.

4. In case of effect of irrigation development on relative humidity, it has been found that the relative humidity is increasing over the years at a rate of 0.137% and 1.275% per decade in Rangpur and Dinajpur respectively. The relative humidity of Patuakhali does not show any definite trend.

5. The findings of the study suggest that the progressive development of irrigation in the last forty years had no adverse impact on the climatic parameters except that it has reduced the diurnal variation of temperature in the irrigated areas.

6. Cropping intensity in Rangpur, Dinajpur and in Patuakhali in the present decade is 227%, 212.74% and 200.34% respectively. Cropping intensity in Rangpur and Dinajpur is 12 to 27% higher compared to Patuakhali where irrigation has not been developed over the years. Mostly Boro rice is being cultivated with the development of irrigation. Where irrigation has developed progressively, the area under cultivation during Kharif 1 season has shrunken because in between Boro rice and T. Aman there does not remain enough time for B.Aus or T.Aus to be cultivated which is the major crop in Kharif 1 season. However, in Patuakhali, no change in the cropping pattern has been observed over the decades.

7. The carbon content in the 0-15 cm layer mostly increased in the study area. The study area experiences a sharp fall in the total nitrogen content which may be due to the changes in cropping systems. All the physiographic units showed a decline in the content of exchangeable K except for greater Dinajpur which showed an increase in the content of exchangeable K. Changes in the phosphorus availability in the study area is mixed. Phosphorus availability increased in Pirgacha and Kaunia (TF) but decreased in greater Dinajpur. Serious decline of the level of available phosphorus occurred in Chandra and Belabo soil series (BT). Soil pH showed a decline in the 0-15 cm layers in all the physiographic units. Exchangeable acidity showed an opposite trend of change to that of soil pH.

8. The findings from FGDs, also corroborate the findings of the analysis. From the FGDs, it has been found that the maximum temperature is decreasing with the development of irrigation. Because of this standing water and green crop, the dryness of weather has also been reduced. Soil fertility has been reduced as the land is being cultivated continuously with the advent of irrigation. Before irrigation development the cropping pattern of this area was Aman-fallow-kown/Till/ Jute; but after the introduction of ground water irrigation majority of the land was occupied with the cropping pattern like Aman-Boro-Fallow.

5.2 Recommendations

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

1. Climatic variables at two stations with progressive irrigation development were investigated for trends in this study. Further studies should analyze data at other similar stations to make a general inference.

2. The relationship between increases in irrigated area with the decrease in evaporation could not be clearly explained. Further study is required to confirm and explain the evaporation effect with the sunshine hours.

3. As the irrigation is directly related with cropping pattern and hence with the soil fertility so the cropping pattern has to be chosen carefully to avoid the adverse impacts on soil fertility.

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