

**STUDY ON SPATIAL AND TEMPORAL VARIATION OF EVAPORATION AND
RELATED CLIMATIC PARAMETERS**

by

TANVIR AHMED

Roll No: 100516006P

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Department of Water Resources Engineering
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
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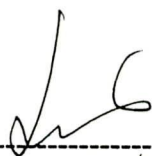
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The project work titled "Study on Spatial and Temporal Variation of Evaporation and Related Climatic Parameters" submitted by Tanvir Ahmed, Roll No: 100516006 P, Session: October 2005 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Water Resources Engineering.



Dr. Md. Sabbir Mostafa Khan
Associate Professor
Department of Water Resources Engineering
BUET, Dhaka

Chairman
(Supervisor)



Dr. M. A. Matin
Professor
Department of Water Resources Engineering
BUET, Dhaka

Member



Dr. Mohammad Shahjahan Mondal
Associate Professor
Institute of Water and Flood Management
BUET, Dhaka

Member

DECLARATION

This is to certify that this project work entitled “**Study on Spatial and Temporal Variation of Evaporation and Related Climatic Parameters**” has been done by me under the supervision of Dr. Md. Sabbir Mostafa Khan, Associate Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka. I do hereby declare that this project or any part of it has not been accepted elsewhere for the award of any degree or diploma from any other institution.

Signature of the candidate

A handwritten signature in blue ink, appearing to read 'T. Ahmed', is written above a horizontal dashed line.

Tanvir Ahmed

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Glossary and Abbreviation

BMD	Bangladesh Meteorological Department
BSH	Bright Sunshine Hour
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering and Technology
° C	Degree Centigrade
ET	Evapotranspiration
GIS	Geographic Information System
IWM	Institute of Water Modelling
KPa	Kilo Pascal
m/s	meter/second
MSE	Mean Square Error
P	Air Pressure
Rad	Radian
RF	Rainfall
R_a	Extraterrestrial Radiation
R_h	Relative Humidity
R_n	Net Radiation
R_{nl}	Net Long Wave Radiation
R_s	Shortwave or Solar Radiation
R_{s0}	Clear Sky Radiation
Rad	Radian
SWC	Surface Warning Centre
T	Temperature
WS	Wind Speed

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Abstract

Factors affecting the rate of evaporation from soil or water bodies can be broadly divided into two groups, meteorological factors and surface factors. The variation of evaporation and other climatic parameters related to it such as temperature, solar radiation, bright sunshine hour, wind speed, air pressure, relative humidity and rainfall of Bangladesh is the main objective of this study. Data of twenty five meteorological stations of Bangladesh have been collected to achieve the objectives. The source of these climatic data is the Bangladesh Meteorological Department (BMD). It is identified from analysis that in Bangladesh higher rate of evaporation occurs from the month of March to May and in April it is maximum. Minimum evaporation rate occurs in the months of December and January. In Bangladesh temperature is maximum in April or May. The variation of temperature is little from April to September. Temperature begins to decrease from the month of October and falls at lowest in January. It is also observed from the analysis that in most of the locations of Bangladesh the solar radiation is high in the month of April and May and low in the month of December and January. From the analysis it is found that air pressure is minimum in the month of June and in some locations in July. On the other hand the air pressure is maximum in December and in few locations it is in the month of January. The variation of air pressure is not that much significant. In Bangladesh the average annual humidity is 79%. In most of the locations maximum amount of humidity occurs in the month of July and minimum amount of humidity occurs in March. Average maximum length of bright sunshine hour occurs in the months between January and April as these months are almost cloud free. Minimum length of sunshine hours in all the locations was observed in July. From the analysis, it is found that maximum rate of rainfall occurs in the months of June and July at the time of full monsoon. Average annual maximum rainfall occurs in Sylhet (4100 mm) and minimum rainfall occurs in Rajshahi (1527 mm). The average annual total rainfall of the country is 2354 mm. It is also obtained from the study that in most of the locations wind speed is maximum in the month of April and minimum in the month of November.

The correlation coefficient between evaporation rate and the other climatic parameters are determined in the study. The correlation coefficient (r) between evaporation rate with solar radiation, temperature and wind speed is large and positive. It means evaporation rate is

increased with the increasing value of radiation, temperature and wind speed. On the other hand the value of r between evaporation rate and bright sunshine hour, relative humidity and pressure is small but in case of bright sunshine hour and rainfall it is positive and in case of relative humidity it is negative. Again the value of r between evaporation rate and bright sunshine hour is positive and medium.

Four approaches i) Energy Balance Method ii) Aerodynamic Method iii) Combined Aerodynamic and Energy Balance Method and iv) Priestly-Taylor Method have been used in this study for the computation of evaporation rate and their performance were evaluated. The best result was obtained from the Energy Balance method. Then Priestly-Taylor Method, Combined Method and the Aerodynamic Method respectively performed well. None of the above mentioned methods gives reasonable results in Bangladesh.

CHAPTER 1

INTRODUCTION



1.1. BACKGROUND OF THE STUDY

Evaporation is the process whereby liquid water is converted to water vapor and removed from the evaporative surface (FAO, 1998). Knowledge of evaporation is important to water resources engineers managing catchments for water supply and to irrigation engineers who need to replace the evaporation from crops with irrigation water. To climatologists evaporation is also an input to the atmosphere which can have an important influence on the global circulation and large-scale precipitation patterns (Gash, 2008). In Bangladesh, our agriculture is heavily dependent on irrigation especially during the dry season, therefore proper knowledge on evaporation and effective rainfall are very much important to improve the irrigation efficiency.

Evaporation depends on the interaction of the atmosphere with the vegetation and soil. The physical structure of the vegetation and soil is thus as important as the plant biochemistry. Water leaves the plants as transpiration through stomata, the same microscopic holes in the leaves which allow the carbon dioxide used in photosynthesis to enter. Plants can control the opening of the stomata depending on the strategy they have evolved to balance water loss with growth. In contrast, intercepted rainfall (interception) evaporates directly back into the atmosphere from the vegetation canopy and therefore depends only on the physical characteristics of the vegetation: its aerodynamic roughness and the depth of water that can be held on the leaves. Evaporation from soils is controlled by the amount of water in the soil and porosity (Gash, 2008).

Evaporation is a transfer of energy as well as a transfer of mass and is fundamentally constrained by the laws of conservation of energy and mass. These two constraints are exploited in both the measurement and the modelling of evaporation. Evaporation can be measured as the residual in a mass balance: for example the difference between rainfall and runoff on a catchment, or the change in soil moisture content of a confined block of soil (a lysimeter). Alternatively evaporation can be measured as the rate at which water

moves through the soil-vegetation-atmosphere continuum: for example from the flow of sap in tree trunks, or water vapor carried by eddies through the turbulent boundary layer (Gash, 2008).

Evaporation is an essential part of the water cycle. Solar energy drives evaporation of water from oceans, lakes, moisture in the soil, and other sources of water. In hydrology, evaporation and transpiration (which involves evaporation within plant stomata) are collectively termed evapotranspiration. Evaporation is caused when water is exposed to air and the liquid molecules turn into water vapor which rises up and forms clouds. Evaporation is the process by which a liquid becomes a gas. It usually occurs at the surface of a liquid.

If the air already has a high concentration of the substance evaporating, then the given substance will evaporate more slowly. If the air is already saturated with other substances, it can have a lower capacity for the substance evaporating. If fresh air is moving over the substance all the time, then the concentration of the substance in the air is less likely to go up with time, thus encouraging faster evaporation. This is result of the boundary layer at the evaporation surface decreasing with flow velocity, decreasing the diffusion distance in the stagnant layer. The stronger the forces keeping the molecules together in the liquid state, the more energy one must get to escape. In an area of less pressure, evaporation happens faster because there is less exertion on the surface keeping the molecules from launching themselves. A substance which has a larger surface area will evaporate faster as there are more surface molecules which are able to escape. If the substance is hotter, then evaporation will be faster. (Wikipedia, 2009)

Factors affecting the rate of evaporation from soil or water bodies can be broadly divided into two groups, meteorological factors and surface factors, either of which may be rate-limiting. The meteorological factors may, in turn, be subdivided into energy and aerodynamic variables. Energy is needed to change water from the liquid to the vapor phase; in nature, this is largely supplied by solar radiation. Aerodynamic variables, such as wind speed at the surface and vapor pressure difference between the surface and the lower atmosphere, control the rate of transfer of the evaporated water vapor (WMO, 2008).

Factors of importance include the amount and state of the water and also those surface characteristics that affect the transfer process to the air or through the body surface. Resistance to moisture transfer to the atmosphere depends, for example, on surface roughness; in arid and semi-arid areas, the size and shape of the evaporating surface is also extremely important. (WMO, 2008).

There are several indirect methods derived from point measurements or other calculations have been developed which provide reasonable results for computing evaporation rate. The water loss from a standard saturated surface is measured with evaporimeters, which may be classified into atmometers and pan or tank evaporimeters. These instruments do not measure directly either evaporation from natural water surfaces, actual evapotranspiration, or potential evapotranspiration. The values obtained cannot be used without proper adjustment to estimates reliable value of lake evaporation or of actual and potential evapotranspiration from natural surfaces.

Open water surface evaporation, which is influenced by energy to provide latent heat of vaporization and the ability to transport the vapor away from the evaporating surface, can be measured by several methods by knowing other climatic and physical parameters (Chow 1988). Some of the data are measured directly in weather stations and other parameters are related to commonly measured data and can be derived with the help of direct or empirical relationships. The choice of methods depends upon the meteorological data available and the needed accuracy of estimation.

The variation of evaporation and other climatic parameter related to evaporation such as temperature, radiation, bright sunshine hour, wind speed, air pressure, relative humidity and rainfall of Bangladesh is the major concern of the study. This study is also focused on the establishment of correlation between evaporation rate with other climatic parameter and of evaporation rate using various methods and to identify which methods are best suitable in context of Bangladesh during different seasons and different locations.

1.2. STUDY AREA

Bangladesh a land of worlds one of the largest deltaic fluvial system experienced a subtropical monsoon climate characterized by wide seasonal variations in rainfall,

moderately warm temperatures, and high humidity has been chosen for the study. Twenty five meteorological stations which nearly cover all part of the country are selected from the six divisions of Bangladesh as follows:

Table 1-1 : Project Area

Division	Upazillas
Rajshahi	Rangpur, Syedpur, Rajshahi, Dinajpur, Bogra, Ishurdi
Sylhet	Sylhet, Srimangal
Dhaka	Dhaka, Mymensingh, Tangail, Faripur
Khulna	Khulna, Jessore, Satkhira
Chittagong	Comilla, Chandpur, Feni, Cox's Bazar, Teknaf Rangamati, Maizdicourt
Barisal	Barisal, Patuakhali, Khepupara

1.3. OBJECTIVES OF THE STUDY

The main objective of the study is to determine the variation evaporation and other related climatic parameters of atmosphere both temporally and spatially and establishment of correlation among the climatic parameters. The specific objectives are as follows:

- i) Spatial variation of evaporation rate and related climatic parameters
- ii) Temporal variation of evaporation rate and related climatic parameters
- iii) To establish correlation between evaporation rate and other climatic parameters
- iv) To determine the evaporation rate using different methods
- v) To identify the accuracy of the different methods by comparing with actual evaporation rate data

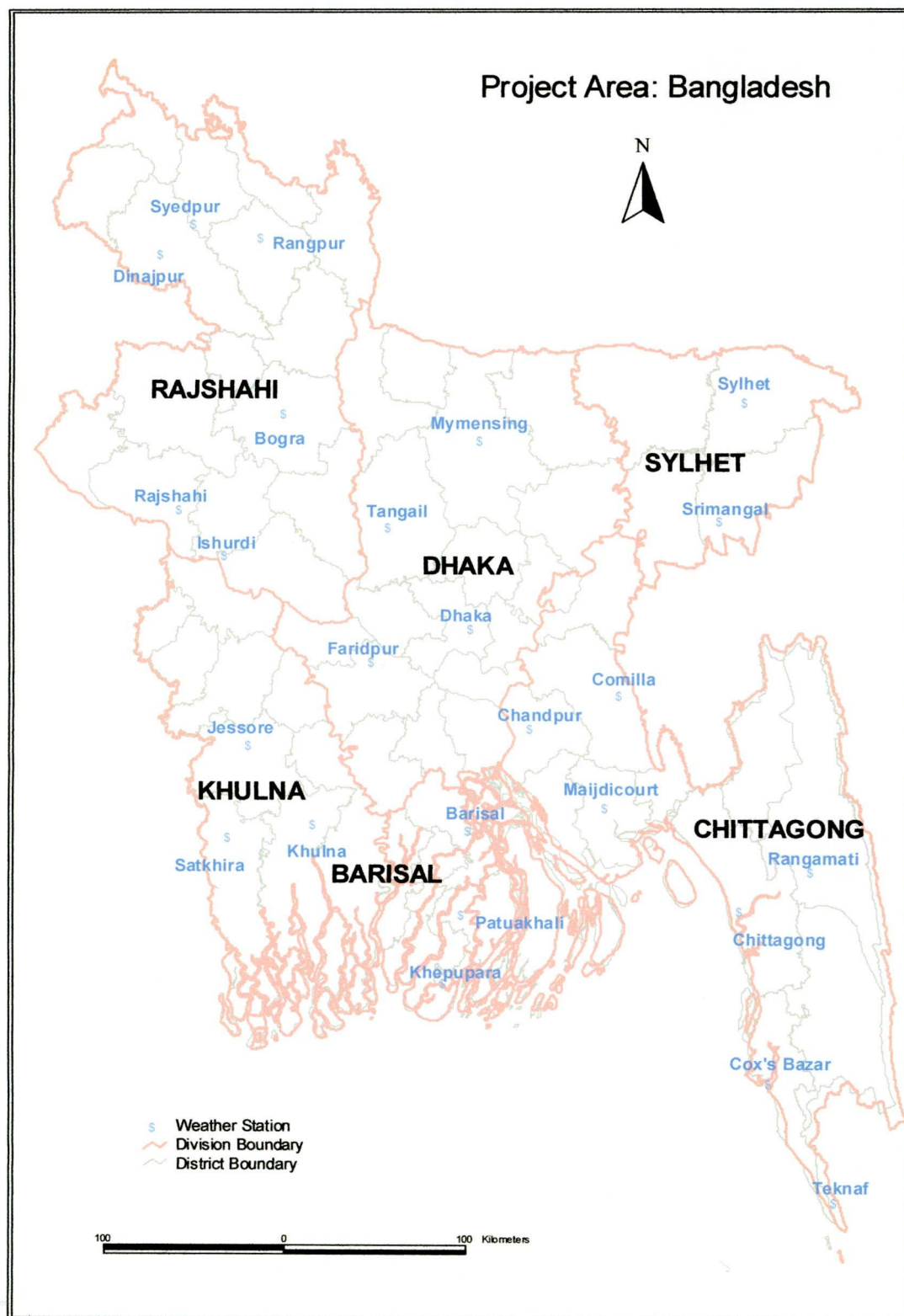


Figure 1-1: Study Area

CHAPTER 2

LITERATURE REVIEW

All over the world many studies and researches have been conducted on evaporation and other meteorological parameters. In this chapter some of the pioneering works of past researchers have been summarized in order to gain in depth knowledge on different meteorological parameters and the physical process involved behind the parameters, So that the study objectives can be fulfilled having proper conception about past knowledge

Efforts have been given to collect the reports of different study relate to evaporation and other climatic parameters like rainfall, temperature, net radiation, bright sunshine hour, relative humidity, air pressure and wind speed. A synopsis of some of the study report is given below:

FAO (1998) publication presents an updated procedure for calculating reference and crop evapotranspiration from meteorological data and crop coefficients. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculating the various parameters. The FAO Penman-Monteith method uses standard climatic data that can be easily measured or derived from commonly measured data. All calculation procedures have been standardized according to the available weather data and the time scale of computation. The calculation methods, as well as the procedures for estimating missing climatic data, are presented in this publication. Examples demonstrate the various calculation procedures throughout the publication. Most of the computations, namely all those required for the reference evapotranspiration and the single crop coefficient approach, can be performed using a pocket calculator, calculation sheets and the numerous tables given in the publication. The user may also build computer algorithms, either using a spreadsheet or any programming language. These guidelines are intended to provide guidance to project managers, consultants, irrigation engineers, hydrologists, agronomists, meteorologists

and students for the calculation of reference and crop evapotranspiration. They can be used for computing crop water requirements for both. irrigated and rainfed agriculture, and for computing water consumption by agricultural and natural vegetation.

The Agro-Climatic Survey of Bangladesh (Manalo 1976) described the characteristics features of the climatic regimes of the country. The appendix contains 25 tables dealing with meteorological and hydrological data, the histograms of monthly rainfall, statistical measures of a number of meteorological parameters have been tabulated. Rainfall variables are emphasized; measures of its central tendency, of its dispersion, of its extreme values and its medians are among the statistics presented. Some statistical characteristics of evaporation and relative humidity have been evaluated: vapor pressure, bright sunshine hour and cloudiness. Temperature and its extremes are tabulated, as well as the water balance regime. Wind speed in different units and time intervals, information on cyclones, the frequency distribution of cyclonic disturbances and remarkable cyclones which have struck Bangladesh.

Saleh et. al (1988) described three commonly used methods of predicting ET, namely, Modified Penman, Blaney-Criddle and Radiation methods were tested for their accuracy in predicting the actual rice ET is described. In absence of reasonable actual ET of rice data, the actual ET was estimated from pan evaporation. The accuracy of predictions was evaluated by calculating the coefficient of efficiency. The Modified Penman method best predicted the actual ET of rice, followed by Radiation and Blaney-Criddle methods.

BARC (1982) research provided some extremely useful information including ET of rice and some upland crops as well as net irrigation requirement of rice for different seasons in various parts of the country. As such the report may serve as a reference paper for irrigation planners, designers and executors. Long term rainfall probability analysis can provide a basis on which to plan cropping patterns and agronomic practices for more than 85% of cultivated land which remains under rain fed

agriculture. Data of rainfall, temperature, relative humidity, sunshine hours and wind speed had been used for the study.

Two equations for estimating grass reference ET were derived (Irmak et. al 2003) using the Food and Agriculture Organization Penman–Monteith (FAO56-PM) method as an index. The first equation, solar radiation (R_s) based, estimates ET from incoming radiation and maximum and minimum air temperature, and the second equation, net radiation (R_n) based, uses R_n and maximum and minimum air temperature. The equations were derived using 15 years (1980–1994) of daily ET_0 values estimated from the FAO Penman-Monteith method using the measured and carefully screened weather data from near Gainesville, Florida. The performance of the derived equations was evaluated for 6 validation years (1995–2000), including dry and wet years, for the same site and for other humid locations in the Southeast United States.

To grasp the temporal and spatial distribution characteristics of the pan evaporation amount in the Chao Phraya River basin, in the Kingdom of Thailand, researchers performed an analysis over a period of 19 years, from 1982 to 2000 (Tebakari et. al 2005). Geographic, seasonal, and annual changes were studied. As a result of performing trend tests on annual changes, negative trends were found in 24 out of 27 observation stations. Furthermore, nine of those locations had a significant negative trend. As a result of performing tests of concurrent rainfall over the same period, although there were positive trends in 8 locations and negative trends in 19 locations, no significant trend, either positive or negative was obtained. This result does not match a finding that precipitation increase decreases pan evaporation in the United States, a finding that can be derived from the complementary relationship.

IIHR (2004) compared the estimation of evaporation methods for riparian areas of the Rio Grande in New Mexico. This research compare evaporation estimates calculated using several well known methods and discuss their limitations. The method that had been used in this study are Blaney-Criddle Method, Penman Method, Priestley Taylor

Method, McNaughton Black Method, Penman-Montieth Method and Monin-Obukhov Method.

A detailed evaporation study (Rosenberry et. al 2007) was conducted at Mirror Lake, New Hampshire, northeastern USA. In this study evaporation was determined using 14 alternate evaporation methods during six open-water seasons and compared with values from the Bowen-ratio energy-budget (BREB) method. Values from the Priestley Taylor, deBruin Keijman, and Penman methods compared most favorably with BREB-determined values. All three methods require measurement of net radiation, air temperature, change in heat stored in the lake, and vapor pressure, making them relatively data intensive. Several of the methods had substantial bias when compared with BREB values and were subsequently modified to eliminate bias. Methods that rely only on measurement of air temperature, or air temperature and solar radiation, were relatively cost-effective options for measuring evaporation at this small New England lake, outperforming some methods that require measurement of a greater number of variables.

In a study (McCuen 1974) sensitivity and error analyses were used to examine the following objectives: (1) analyze the structure of commonly used evaporation models; (2) provide estimates of the effect of variation in meteorological factors on observed evaporation rates; and (3) estimate the effect of error in measurements of the meteorological factors. The results indicate error in evaporation estimates resulting from measurement error in meteorological factors is probably much less than five percent of the computer evaporation rate. Variation with both time and space of the importance of the different meteorological factors is demonstrated. The sensitivity analysis indicates that the Fractional-Evaporation Equivalent method is structurally inadequate and the Weather Bureau model is more flexible than the Penman model. However, the Penman model appears to provide more realistic estimates of the importance of the various meteorological factors.

Glover et. al (1957) stated the empirical relation between solar radiation and hours of bright sunshine in the high-altitude tropics. The relationship between total solar

radiation on a horizontal surface, as measured by a pyranometer, and hours of bright sunshine (n), as measured by a Campbell-Stokes recorder, has been examined and it is shown that there is little practical gain in weighting the hourly sunshine records by the sine of the apparent solar altitude.

The relationship between (Q) total solar radiation, as measured by a solarimeter, and hours of bright sunshine (n), as measured by a Campbell-Stokes recorder, has been examined (Viswanadham et. al 1969) on a monthly basis for three tropical stations Madras, Waltair and Nagpur. the agreement between the computed values and observed solar radiation is good.

A procedure was introduced by Smani (2000) to estimate solar radiation and subsequently reference crop evapotranspiration using minimum climatic data. The paper describes a modification to an original equation that uses maximum and minimum temperature to estimate solar radiation and reference crop ET. The proposed modification allows for the correction of errors associated with indirect climatic parameters affecting the local temperature range. The proposed modification also improves the accuracy of estimates of solar radiation from temperature.

Bouwer, et. al (2008) presented a method to assess spatial and temporal patterns of actual evaporation by relating water balance evaporation estimates to satellite-derived radiometric surface temperature. The method is applied to a heterogeneous landscape in the Krishna River basin in south India using 10-day composites of NOAA advanced very high-resolution radiometer satellite imagery. The surface temperature predicts the difference between reference evaporation and modelled actual evaporation well in the four catchments. A seemingly reasonable estimate of temporal and spatial patterns of evaporation can be made without the use of more complex and data-intensive methods; the method also constrains satellite estimates of evaporation by the annual water balance, thereby assuring accuracy at the seasonal and annual time-scales.

Kalma et. al (2008) reviewed methods for estimating evaporation from landscapes, regions and larger geographic extents, with remotely sensed surface temperatures, and highlights uncertainties and limitations associated with those estimation methods. Particular attention is given to the validation of such approaches against ground based flux measurements. An assessment of some 30 published validations shows an average root mean squared error value of about 50 W m^{-2} and relative errors of 15–30%. The comparison also shows that more complex physical and analytical methods are not necessarily more accurate than empirical and statistical approaches. This review also provides a discussion of temporal and spatial scaling issues associated with the use of thermal remote sensing for estimating evaporation.

In a study (Bandyopadhyay et. al 2008) solar radiation was thus estimated by different methods for 29 stations distributed throughout India. The methods compared were The estimated radiation values were then compared to measured Radiation (or Radiation estimated from measured sunshine hours) to check the suitability of these methods under Indian conditions. To understand the effect of solar radiation estimation on reference evapotranspiration, ET_0 , the internationally accepted FAO Penman–Monteith based method employed using both measured Radiation and estimated Radiation, were also compared.

In a study (Haider 1989) with the help of the previous records the distribution of the rainfall data and the probabilities of the number of rainy days can be found and the future predicted. The stud was based on Faisalabad district, India. The distribution of the rainfall data and the probabilities of the number of rainy days have been calculated for the three decades of each month along with the probabilities of a month.

Freyberger, et. al (2008) dealt with the estimation of trends in temperature series and on the computation of associated confidence intervals. Two main approaches that enable the researcher to derive confidence intervals that are reasonably robust to potential misspecification of the underlying time series model using on the one hand sub-sampling techniques, and on the other hand variance semi-parametric corrections for the variance estimator. Both approaches are then used for the estimation of a time

trend in the temperature time series data series for various European cities. The sample consists of annual mean temperature data from 37 cities with a range from 1830 until 2006. A significant rise in the temperature detected for most series. For most of the cities this average yearly temperature increases lies between 0.002 and 0.015°C

CHAPTER 3

METHODOLOGY

3.1. DATA COLLECTION

Bangladesh Meteorological Department is the authorized Government organization for all meteorological activities in Bangladesh. It maintains a network of surface and upper air observatories, radar and satellite stations, agro-meteorological observatories, geomagnetic and seismological observatories and meteorological telecommunication system. The Department has its headquarters in Dhaka with two regional centers i.e. Storm Warning Centre (SWC), Dhaka and Meteorological & Geo-Physical Centre (M & GC), Chittagong.

For the purpose of the study, necessary climatic data such as i) Evaporation Rate ii) Temperature iii) Solar Radiation iv) Wind Speed v) Air Pressure vi) Relative Humidity vii) Bright Sunshine Hour and viii) Rainfall of the different locations of Bangladesh have been collected from BMD. The above mentioned climatic data of twenty five meteorological stations of BMD have been collected for the purpose of the study.

All the data are received in soft format. The summary of available climatic data is given in Appendix A.

Table 3-1: Station Information

Serial No	Station Name	Establishment	Station No	Latitude	Longitude	Elevation
1	Barisal	1883	950	22.75	90.37	2.10
2	Bogra	1884	883	24.85	89.37	18.00
3	Chandpur	1964	941	23.27	90.70	5.50
4	Chittagong		977			
5	Comilla	1883	933	23.43	91.18	6.10
6	Cox's Bazar		992			2.10
7	Dhaka	1949	923	23.77	90.38	8.80
8	Dinajpur	1883	863	25.65	88.68	36.00
9	Faridpur	1883	929	23.60	89.85	8.20
10	Ishurdi	1963	907	24.13	89.05	14.00
11	Jessore		936			
12	Khepupara	1973	984	21.98	90.23	1.80
13	Khulna	1921	947	22.78	89.53	2.10
14	Maijdicourt	1951	953	22.87	91.10	4.90
15	Mymensing	1883	886	24.72	90.43	18.00
16	Patuakhali	1973	960	22.33	90.33	1.50
17	Rajshahi	1883	895	24.37	88.80	16.80
18	Rangamati	1957	966	22.53	92.20	62.50
19	Rangpur	1883	859	25.73	89.23	32.60
20	Satkhira	1871	946	22.72	89.08	4.00
21	Srimangal	1905	915	24.30	91.73	22.00
22	Syedpur		858			
23	Sylhet	1952	891	24.90	91.88	33.50
24	Taknaf	1977	998	20.87	92.30	5.00
25	Tangail		909			

3.1.1. Evaporation Rate

An evaporation pan is used to hold water during observations for the determination of the quantity of evaporation at a given location. Such pans are of varying sizes and shapes, the most commonly used being circular or square. The best known of the pans are the "Class A" evaporation pan and the "Sunken Colorado Pan.

Bangladesh Meteorological Department measures evaporation rate by using "Class A" evaporation pan. It is cylindrical with a diameter of 47.5 in (120.7 cm) and a depth of

10 in (25 cm). The pan rests on a carefully leveled, wooden base and is often enclosed by a chain link fence to prevent animals drinking from it. Evaporation is measured daily as the depth of water (in inches) evaporates from the pan. The measurement day begins with the pan filled to exactly two inches (5 cm) from the pan top. At the end of 24 hours, the amount of water to refill the pan to exactly two inches from its top is measured.



Figure 3-1: Evaporation Pan at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

If precipitation occurs in the 24-hour period, it is taken into account in calculating the evaporation. Sometimes precipitation is greater than evaporation, and measured increments of water must be dipped from the pan. The Class A Evaporation Pan is of limited use on days with rainfall events of $>30\text{mm}$ (203mm rain gauge) unless it is emptied more than once per 24 hours. Analysis of the daily rainfall and evaporation readings in areas with regular heavy rainfall events shows that almost without fail, on days with rainfall in excess of 30mm (203mm Rain Gauge) the daily evaporation is spuriously higher than other days in the same month where conditions more receptive to evaporation prevailed. The most common and obvious error is in daily rainfall events of $>55\text{mm}$ (203mm rain gauge) where the “Class A” Evaporation pan will likely overflow.

The less obvious, and therefore more concerning, is the influence of heavy or intense rainfall causing spuriously high daily evaporation totals without obvious overflow.

BMD measures evaporation rate two times in a day at an interval of 6 hours at 06.00 A.M and 12.00 P.M and the measured unit is millimeter. The evaporation rate data have been collected for twelve meteorological stations for the time period of 1983 to 2006. The summary of available evaporation rate data is given in Table A1 of Appendix A.

3.1.2. Temperature

BMD is used three types of thermometer for temperature measurement. These are i) dry bulb thermometer ii) wet bulb thermometer iii) Maximum thermometer and iv) Minimum thermometer for the measurement of maximum and minimum temperature of the day. To determine the daily average temperature dry bulb thermometer is used. Maximum and minimum thermometers are used for determining daily maximum and minimum temperature. Wet bulb thermometer is required for determining relative humidity.

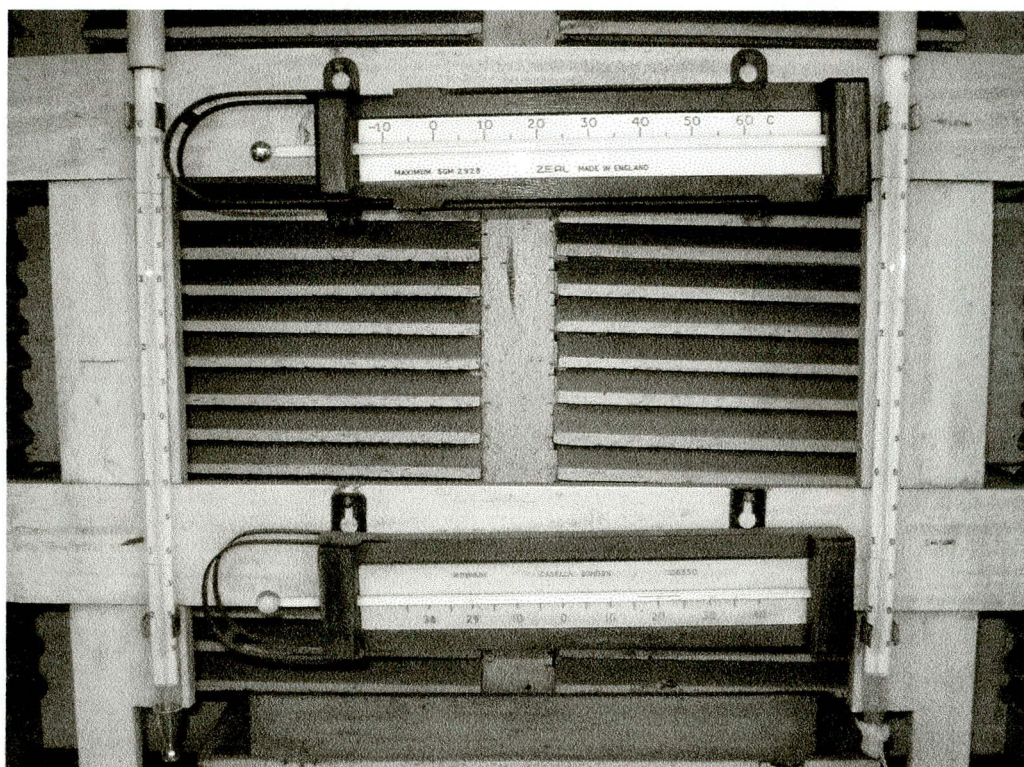


Figure 3-2: Different Types of Thermometer, at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

Temperature data have been collected for twenty five stations for the time period of 1975 to 2004. These are the daily average temperature in degree centigrade. Besides these the monthly average maximum and monthly minimum temperature data also

collected. The summary of available temperature data is given in Table A2 of Appendix A.

3.1.3. Solar Radiation

As the radiation penetrates the atmosphere, some of the radiation is scattered, reflected or absorbed by the atmospheric gases, clouds and dusts. The amount of radiation reaching a horizontal plane is known as the solar radiation, R_s . Because the sun emits energy by means of electromagnetic waves characterized by short wavelengths, solar radiation is also referred to as shortwave radiation.

BMD measures solar radiation by using Epy Pyranometer which is installed at a height of two meter from the ground surface. A pyranometer is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density from a field of view of 180 degrees. The solar radiation spectrum extends approximately from 300 to 2,800 nm. Pyranometers usually cover that spectrum with a spectral sensitivity that is as “flat” as possible.



Figure 3-3: Pyranometer at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

In order to attain the proper directional and spectral characteristics, a pyranometer's has mainly two components. A thermopile sensor with a black coating. This sensor absorbs all solar radiation, has a flat spectrum covering the 300 to 50,000 nanometer range, and has a near-perfect cosine response. The second one is a glass dome. This dome limits the spectral response from 300 to 2,800 nanometers (cutting off the part above 2,800 nm), while preserving the 180 degrees field of view. Another function of the dome is that it shields the thermopile sensor from convection.

The black coating on the thermopile sensor absorbs the solar radiation. This radiation is converted to heat. The heat flows through the sensor to the pyranometer housing. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.

The solar radiation data are available only for nine stations for the time period of 2001 to 2007. These are the daily data in cal/cm²/day. For the purpose of the study the unit of net radiation is converted to watt/m². The summary of available net radiation data is shown in Table A3 at Appendix A.

3.1.4. Wind Speed

An anemometer is a device which is used for measuring wind speed. A simple type of anemometer is the cup anemometer is used by BMD. BMD installed anemometer at different height from the ground surface. For agronomy purpose wind speed is measured at a height of two meter from the ground surface.

Anemometer consists of hemispherical cups each mounted on one end with horizontal arms. The air flow past the cups in any horizontal direction turned the cups in a manner that was proportional to the wind speed. Therefore, counting the turns of the cups over a set time period produced the average wind speed for a wide range of speeds.



Figure 3-4: Cup Anemometer (Left) and Wind Direction Measurement (Right) at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

Wind speed data have been collected for 12 stations for the time period of 2001 to 2006. The wind speed measures in two times in a day at interval of twelve hours at 12.00 A.M and 12.00 P.M. Wind speed is measured at a height of 2 meter from the ground surface in km/hour. In this study, the unit of wind speed is converted to m/s for computation of evaporation rate in Aerodynamic method. The summary of available wind speed data is shown in Table A4 of Appendix A.

3.1.5. Atmospheric Pressure

A barometer is an instrument used to measure atmospheric pressure. It can measure the pressure exerted by the atmosphere by using water, air, or mercury. Pressure tendency can forecast short term changes in the weather.

BMD measures air pressure with mercury barometer. A mercury barometer has a glass tube of about 30 inches (about 76 cm) in height, closed at one end, with an open mercury-filled reservoir at the base. Mercury in the tube adjusts until the weight of the mercury column balances the atmospheric force exerted on the reservoir. High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column. Low pressure allows the mercury to drop to a lower level in the column by lowering the force placed on the reservoir. Since higher temperature at the

instrument will reduce the density of the mercury, the scale for reading the height of the mercury is adjusted to compensate for this effect.

Air pressure data are available for twenty five stations for the time period of 1975 to 2006. Air pressure is measured eight times in a day at an interval of three hours and data measurement starts from 12.00 A.M. The measured unit of air pressure is Pascal. In this study the unit is converted to Kilo Pascal. The summary of available air pressure data is given in A5 of Appendix A.

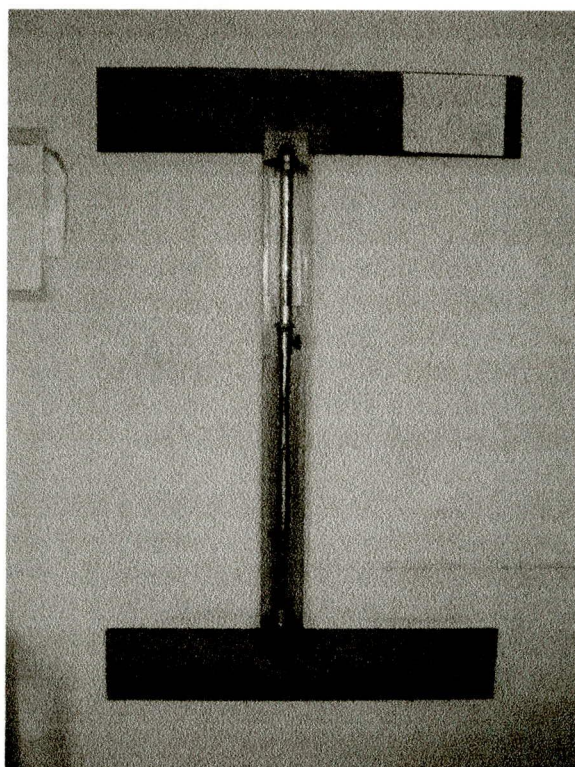


Figure 3-5: KP Barometer at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

3.1.6. Relative Humidity

Hygrometers are instruments used for measuring relative humidity. A simple form of a hygrometer is specifically known as a psychrometer and consists of two thermometers, one of which includes a dry bulb and the other of which includes a bulb that is kept wet to measure wet-bulb temperature. Evaporation from the wet bulb lowers the temperature, so that the wet-bulb thermometer usually shows a lower temperature than that of the dry-bulb thermometer, which measures dry-bulb

temperature. When the air temperature is below freezing, however, the wet bulb is covered with a thin coating of ice and yet may be warmer than the dry bulb. Relative humidity is computed from the ambient temperature as shown by the dry-bulb thermometer and the difference in temperatures as shown by the wet-bulb and dry-bulb thermometers. Relative humidity can also be determined by locating the intersection of the wet- and dry-bulb temperatures on a psychrometric chart. This instrument is setup in a secured compartment.



Figure 3-6: Wet Bulb Thermometer (Left) and Auto Humidity Recorder (Right)

Photograph is taken by Author (Date: 15/02/2009)

Relative humidity data are available for twenty four stations for the time period of 1975 to 2006. Relative humidity is also measured eight times in a day at an interval of three hours and data measurement starts from 12.00 A.M. The summary of available relative humidity data is given in Table A6 of Appendix A.

3.1.7. Bright Sunshine Hour

Bright sunshine is defined as the intensity of sunlight which sufficient to cast a shadow. Even though a thin overcast covers the sun, it can cast a shadow. Light is essential for photo-synthesis and an intensity of 1500-2500 foot candle usually sufficient for this purpose. BMD measures sunshine hour by using Sunshine Recorder.

A sunshine recorder consists of a quartz glass sphere, 4" (10.16 cm) in diameter, mounted on top of a 7' (2.2 m) stand. As sunlight passes through the sphere, it

becomes focused and burns a "line" through a piece of treated paper which is positioned beneath the quartz glass sphere.



Figure 3-7: Sunshine Recorder at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

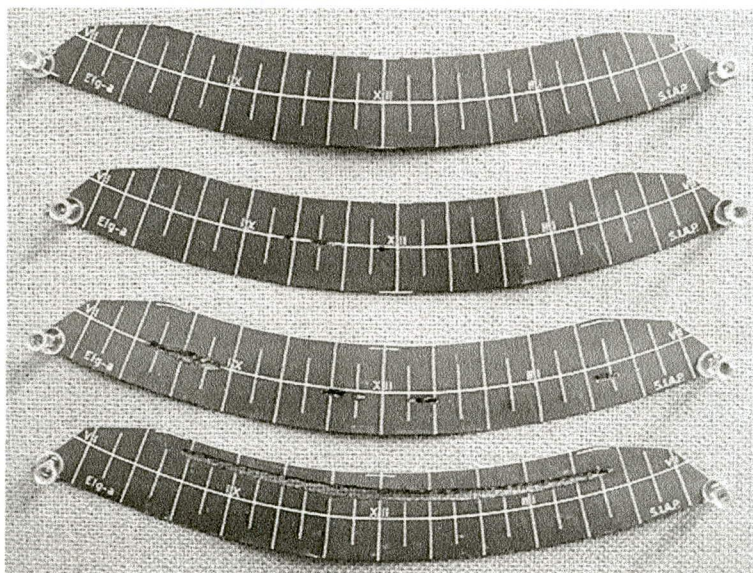


Figure 3-8: Paper Uses in Sunshine Recorder

Source: Internet

Any break in the "burn line" is indicative of cloud cover. The treated paper is marked in such a way that the time of cloud cover occurrence can be determined. Each paper above represents one 12-hour day. The Roman numerals on the paper denote the local time (XII is 12 noon; III is 3pm, etc.). These burn lines (or dots) represent times when sunshine occurred at the station.

Bright sunshine hour data are available for 24 stations for the time period of 1975 to 2007. These are daily data and the unit is hour. The summary of available bright sunshine hour data are given in Table A7 of Appendix A.

3.1.8. Rainfall

Rainfall data is measured by Manual Rain gauge and Self Recording Rain Gauge by BMD.

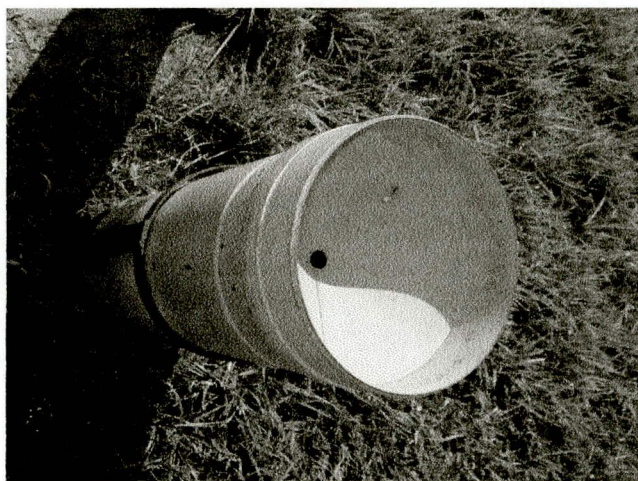


Figure 3-9: Manual Rain Gauge at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

The manual rain gauge consists of a funnel attached to a graduated cylinder that fits into a larger container. If the water overflows from the graduated cylinder the outside container will catch it. So when it is measured, the cylinder will be measured and then the excess will be put in another cylinder and measured. A metal pipe is attached to the container and can be adjusted to ensure the rain gauge is level. This pipe then fits over a metal rod that has been placed in the ground.

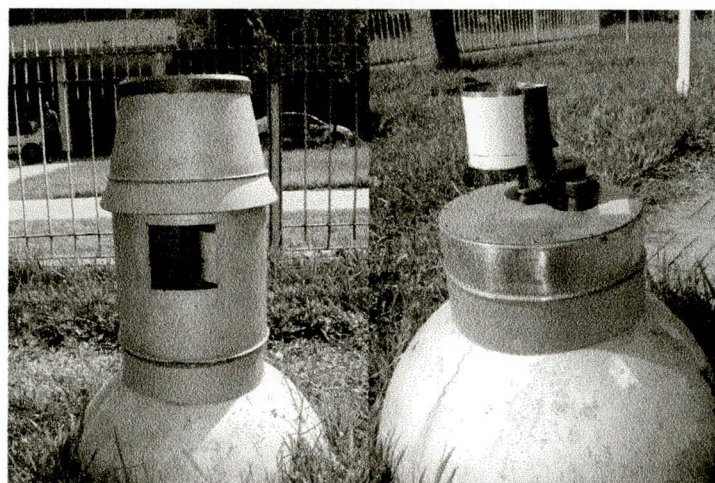


Figure 3-10: SR Rain Gauge at BMD, Dhaka

Photograph is taken by Author (Date: 15/02/2009)

The self recording or tipping bucket rain gauge consists of a large copper cylinder set into the ground. At the top of the cylinder is a funnel that collects and channels the

precipitation. Self recording rain gauge measures rainfall by means of electro magnetic signal.

Rainfall data is available for twenty five stations of Bangladesh for the time period of 1975 to 2004. Rainfall is measured on daily basis and unit is millimeter. The summary of rainfall data is shown in Table A8 of Appendix A.

3.2. DATA PROCESSING

The collected climatic are in complex format which were not suitable for analysis from the original dataset. At first the data were processed by using tools Microsoft Office Access 2003 to convert the data into daily average time series data. All the climatic data are checked thoroughly, and then the daily data of each station was plotted. From the visual observation the wrong data (abrupt values) have been discarded from the data set.

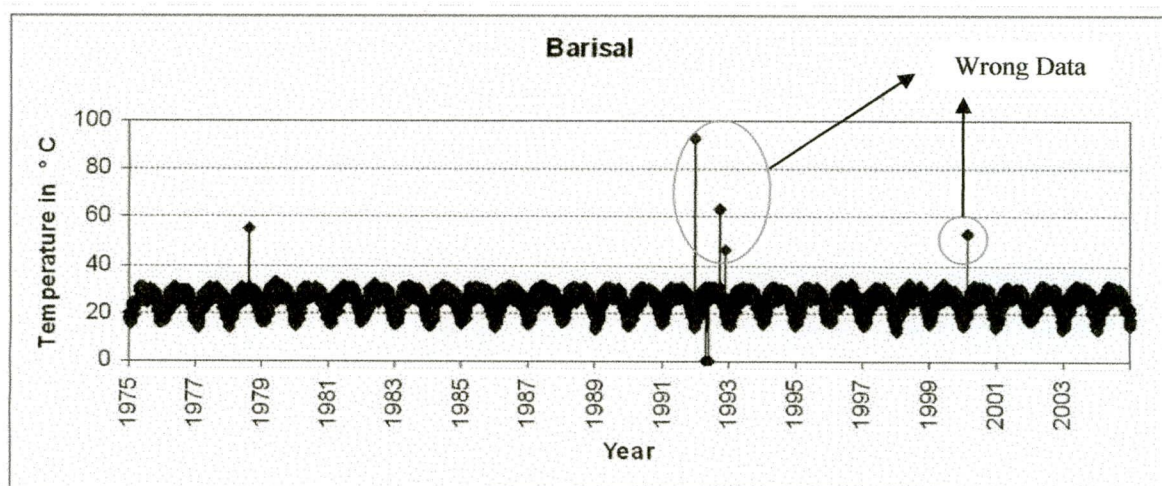


Figure 3-11: Temperature Data Correction

Some common error were found in data set like negative value (-1) or starry (**) sign instead of real value. May be it was due to punching error. These types of error were also deleted from data set. There were many punching errors like air pressure found 100014 Pascal which should be 10014 Pascal. These types of errors were corrected by proper analysis.

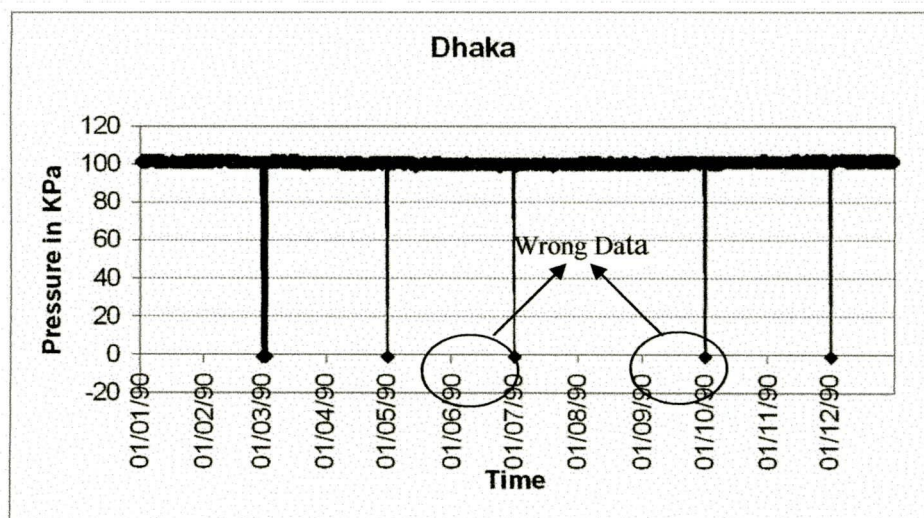


Figure 3-12: Pressure Data Correction

From visual observation of Evaporation rate and bright sunshine data, it was clear that the data were multiplied by 10 with the real value. By getting concern from the BMD official the evaporation rate and bright sunshine hour data were then divided by 10 to make them correct. Bright sunshine hour data greater than 14 hours is not feasible which are also discarded from analysis.

3.3. DATA ANALYSIS

3.3.1. Formulation of Temporal Variation

All the climatic data of different locations are analyze in the basis of monthly, yearly and seasonally. For seasonal variation the whole year is divided into three seasons based on the rainfall variation of Bangladesh. The southwest monsoon reaches full fury by July or August but it is most active from June to October. So this period is considered as monsoon season and the months March to May are considered as pre-monsoon. Again in dry season (November-February) as the monsoon diminish, the country starts a transition from soaking wet to almost bone-dry and the reliability of rainfall decreases sharply (Manalo 1976).

Table 3-2: Seasons in Bangladesh

Season	Month	
	From	To
Pre-Monsoon	March	May
Monsoon	June	October
Dry	November	February

The average monthly, annual and seasonal variation of all the climatic data have been computed from the historical daily time series data. For evaporation rate and rainfall the total average monthly, annual and seasonal variation are also computed to determine the total amount of evaporation and rainfall in different seasons and locations.

3.3.2. Formulation of Spatial Variation

For spatial variation the same locations are considered which are chosen for temporal variation. Maps of evaporation, temperature, radiation, wind speed, humidity, air pressure, bright sunshine hour and rainfall are prepared for seasonal and annual basis. As mentioned above, maps of three seasons, pre-monsoon, monsoon and dry season are prepared. For these purpose the technique of GIS is being used by using the software **Arc-View 3.2**. The extension that is required to prepare these maps is Arc-view 3.2 Spatial Analyst.

A GIS is a computer based technology for recording, manipulating, analyzing and is playing data such as digital maps, images or other information with a special reference such as latitude and longitude. Technique of GIS can be quite valuable in studying of spatial variation of any parameter by generating surface or creating contour lines.

For determining the spatial variation of different climatic parameter the following GIS data are used:

- i) Point Shape File: Location of each climatic station.
- ii) Polygon Shape file: Boundary file that represents the study location.

- iii) Attributes File: Each point shape files contain data about location and other information like seasonal and annual value of each climatic parameter.
- iv) Line Shape File: The GIS output in form of color contours, representing the spatial variation of climatic parameters.

The point shape file is prepared by knowing the latitude and longitude of weather stations collected from BMD. The point shape files are in WGS 84 projection system. The project area like project boundary and district boundary shape files were in Bangladesh Transverse Mercator (BTM) projection system. For comparison to be made between the point and polygon shape files all the data have geo-referenced to BTM projection system. Then the seasonal and annual variation of each climatic parameter were incorporated with the attribute table of point shape files.

For the purpose of spatial variation “Contour” technique of Arc-View 3.2 software has been used. Contouring produces an output line theme from an input point or grid theme. The value of each line represents all contiguous locations with the same magnitude, or concentration of whatever the values on the input grid. The output theme will contain a field called Contour in its attribute table which lists the value of each contour. Since the lines are smoothed, a realistic representation of the surface contours is produced. Creates lines of constant value, contours, on a point or grid theme using a specified interval.

By using these contour techniques spatial variation maps of evaporation rate, temperature, radiation, wind speed, relative humidity, air pressure, bright sunshine hour and rainfall have been prepared by using average seasonal and annual average data.

3.3.3. Establishment of Correlation

In probability theory and statistics, correlation (often measured as a correlation coefficient) indicates the strength and direction of a linear relationship between two random variables. A number of different coefficients are used for different situations. The best known is the Pearson product-moment correlation coefficient, which is obtained by dividing the covariance of the two variables by the product of their

standard deviations. The correlation coefficient is denoted as “r” and the coefficient ranges from -1 to +1. The “r” can be expressed mathematically as:

$$r^2 = \frac{\left[\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y}) \right]^2}{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}$$

Where $x_1, x_2, \dots, x_n$ are Evaporation rate data

$\bar{x}$ = is the average of all Evaporation data

Where $y_1, y_2, \dots, y_n$ are any other climatic parameter

$\bar{y}$ = is the average of the other climatic data

n = total number of data set

A value of 1 show that a linear equation describes the relationship perfectly and positively, with all data points lying on the same line and with Y increasing with X. A score of -1 shows that all data points lie on a single line but that Y increases as X decreases. A value of 0 shows that a linear model is not needed, that there is no linear relationship between the variables.

To find out the co-relation between evaporation and other climatic parameters (temperature, radiation, wind speed, air pressure, humidity, bright sunshine hour and rainfall) at first the common location and the common period of data have been sorted out. The common locations for which the climatic data are available are Barisal, Bogra, Comilla, Dhaka, Dinjapur, Faridpur, Khulna, Mymensing, Rajshahi, Rangamati, Rangpur and Srimangal. The monthly average data for the period of 2000 to 2006 is considered to identify the relationship.

3.3.4. Estimation of Net Radiation

The radiation data that has been collected from field is solar radiation or short wave radiation which is measured by Pyranometer. For the computation of evaporation rate by different method value of net radiation is required. FAO (1998) describes the procedure to compute net radiation from other meteorological parameters include solar radiation, maximum and minimum temperature and relative humidity. The procedures for computing net radiation is described here.

Extraterrestrial Radiation

The solar radiation received at the top of the earth's atmosphere on a horizontal surface is called the extraterrestrial radiation, R_a . If the sun is directly overhead, the angle of incidence is zero and the extraterrestrial radiation is $0.0820 \text{ MJ/m}^2/\text{day}$. As seasons change, the position of the sun, the length of the day and, hence, R_a change as well. Extraterrestrial radiation is thus a function of latitude, date and time of day.

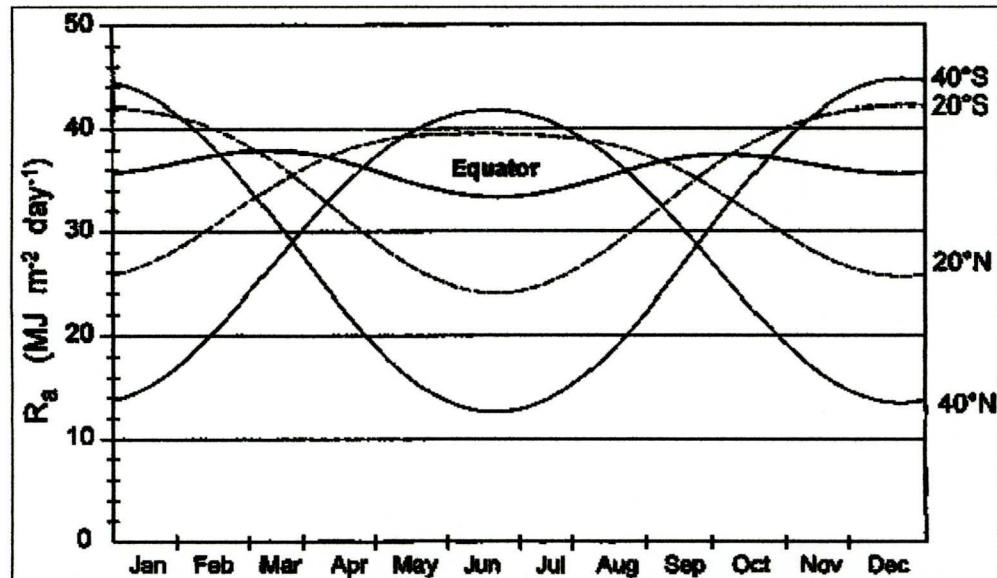


Figure 3-13: Annual Variation in Extraterrestrial Radiation (R_a) at the equator, 20 and 40° north and south

The following equation is used to determine the extraterrestrial radiation.

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [w_{sc} \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(w_s)]$$

Where

R_a = Extraterrestrial Radiation [$\text{MJ/m}^2/\text{day}$]

G_{sc} = Solar Constant = $0.0820 \text{ MJ/m}^2/\text{min}$

d_r = inverse relative distance Earth-Sun

w_s = Sunset Hour Angle

ϕ = Latitude (rad)

δ = Solar Declination

The latitude, ϕ , expressed in radians is positive for the northern hemisphere and negative for southern hemisphere. In case of Bangladesh latitude is always positive.

The conversion from decimal degree to radians is given by:

$$\text{Radians} = \frac{\pi}{180} (\text{decimal degree})$$

The Latitude at different stations of Bangladesh are given in Table 3-1

The inverse relative distance Earth-Sun, d_r , and the solar declination, δ , are calculated by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right)$$

Where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December). To determine the representative value of average monthly extraterrestrial radiations, R_a are determined on the 15th day of each month.

Table 3-3: 15th Day of the Year

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15	15	46	74	105	135	166	196	227	258	288	319	349

The sunset hour angle, w_s , is given by:

$$w_s = \arccos[-\tan(\phi)\tan(\delta)]$$

Table 3-4: Computed Extraterrestrial Radiation at Different Locations in MJ/m²/day

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	25.25	29.19	33.86	37.73	39.59	40.06	39.72	38.30	35.14	30.62	26.14	24.03
Bogra	24.06	28.20	33.21	37.53	39.76	40.43	40.00	38.26	34.66	29.75	25.01	22.80
Comilla	24.87	28.87	33.65	37.67	39.65	40.19	39.81	38.29	34.99	30.35	25.78	23.64
Dhaka	24.68	28.72	33.55	37.64	39.68	40.24	39.86	38.29	34.91	30.21	25.60	23.44
Faridpur	24.77	28.79	33.60	37.66	39.66	40.22	39.84	38.29	34.95	30.28	25.69	23.54
Khulna	25.23	29.18	33.85	37.73	39.59	40.07	39.72	38.30	35.13	30.61	26.12	24.01
Mymensing	24.14	28.26	33.25	37.54	39.75	40.41	39.98	38.27	34.69	29.81	25.08	22.88
Rangpur	23.56	27.77	32.92	37.43	39.82	40.57	40.11	38.23	34.45	29.37	24.53	22.28
Srimangal	24.38	28.46	33.38	37.59	39.72	40.34	39.93	38.28	34.79	29.98	25.31	23.13

Solar or Short Wave Radiation

The short wave or solar radiation data are measured value which is used for determination of temporal and spatial distribution of solar radiation for this study. The raw data are in cal/cm²/day which is converted to watt/m². For determination of net radiation the solar radiation data were converted MJ/m²/day and the conversion factor is 0.0864 to convert from watt/m² to MJ/m²/day.

Table 3-5: Measured Shortwave Radiation at Different Locations in MJ/m²/day

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	7.16	8.70	9.10	10.15	9.26	7.07	6.22	6.36	6.42	5.79	6.64	6.79
Bogra	6.61	8.62	10.47	10.57	10.29	8.82	8.25	8.64	8.28	7.54	7.58	6.94
Comilla	5.19	6.62	7.66	7.83	7.31	6.18	6.06	6.64	6.20	5.92	5.15	4.79
Dhaka	7.24	9.07	9.97	10.51	10.69	8.47	8.15	8.86	7.28	7.06	8.29	6.61
Faridpur	4.99	5.91	6.55	6.69	6.72	5.35	5.45	5.91	4.89	5.33	5.87	5.58
Khulna	8.17	10.93	11.02	11.66	12.20	10.06	9.87	9.70	8.90	8.43	9.31	8.24
Mymensing	5.00	6.40	7.34	7.77	7.80	5.90	5.81	7.09	5.82	5.57	6.04	5.32
Rangpur	5.08	6.70	7.99	7.59	7.90	6.47	6.84	6.94	6.50	5.81	6.47	5.53
Srimangal	6.70	8.08	9.00	9.70	8.94	7.22	7.55	8.69	8.06	7.57	7.43	6.92

Clear-sky solar radiation (R_{s0})

The calculation of the clear-sky radiation, R_{s0} when $n = N$, is required for computing net longwave radiation.

Where,

n = actual duration of sunshine hour

N = maximum possible duration of sunshine of daylight hours

R_{s0} is calculated by using the following equation

$$R_{s0} = (a_s + b_s) R_a$$

Where, $a_s + b_s$ = fraction of extraterrestrial radiation reaching the earth on clear sky days ($n = N$).

When calibrated value of a_s and b_s not available,

$$R_{s0} = (0.75 + 2 \times 10^{-5} z) R_a ; \text{ Where, } z = \text{station elevation above mean sea level (m).}$$

The value of z are given in Table 3-1.

Table 3-6: Computed Clear Sky Solar Radiation at Different Locations in MJ/m²/day

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	18.94	21.89	25.40	28.30	29.69	30.05	29.79	28.73	26.36	22.97	19.61	18.02
Bogra	18.06	21.16	24.92	28.16	29.84	30.34	30.02	28.71	26.01	22.32	18.77	17.11
Comilla	18.65	21.66	25.24	28.26	29.74	30.14	29.87	28.73	26.25	22.76	19.34	17.73
Dhaka	18.51	21.54	25.17	28.24	29.77	30.19	29.90	28.72	26.19	22.66	19.20	17.58
Faridpur	18.58	21.60	25.21	28.25	29.75	30.17	29.88	28.73	26.22	22.71	19.27	17.66
Khulna	18.92	21.88	25.39	28.30	29.69	30.05	29.79	28.73	26.35	22.96	19.59	18.01
Mymensing	18.11	21.21	24.95	28.17	29.83	30.32	30.00	28.71	26.03	22.37	18.82	17.17
Rangpur	17.68	20.85	24.71	28.10	29.89	30.45	30.11	28.70	25.86	22.05	18.41	16.73
Srimangal	18.29	21.36	25.05	28.21	29.81	30.27	29.97	28.73	26.11	22.50	18.99	17.36

Net Solar or Net Shortwave Radiation (R_{ns})

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is computed by

$$R_{ns} = (1 - \alpha)R_s$$

Where R_{ns} = Net Solar or Shortwave Radiation [$\text{MJ}/\text{m}^2/\text{day}$]

α = Albedo or canopy reflection coefficient.

In this study for water albedo value is taken as 0.03 (Okey, 1998; Ahrens, 2001)

R_s = The Incoming Solar Radiation [$\text{MJ}/\text{m}^2/\text{day}$].

Net Longwave Radiation (R_{nl})

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann Law. The net energy flux leaving the earth's surface is, however, less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. Water vapor, clouds, carbon dioxide and dust are absorbers and emitters of longwave radiation. Their concentration should be known when assessing the net outgoing flux. As humidity and cloudiness play an important role, the Stefan-Boltzmann law is corrected by these two factors when estimating the net outgoing flux of longwave radiation. It is thereby assumed that the concentration of the other absorbers are constant:

$$R_{nl} = \sigma \left[\frac{T_{\max}^4 + T_{\min}^4}{2} \right] \left(0.34 - 0.14 \sqrt{e_a} \right) \left(1.35 \frac{R_s}{R_{s0}} - 0.35 \right)$$

Where.

R_{nl} = Net Outgoing Longwave Radiation [$\text{MJ}/\text{m}^2/\text{day}$]

σ = Stefan- Boltzman Constant [4.903×10^{-9}]

$T_{\max}$ (Kelvin) = Maximum Absolute Temperature During the 24-Hours Period [$\text{K} = ^\circ\text{C} + 273.16$]

$T_{\min}$ (Kelvin) = Minimum Absolute Temperature During the 24-Hours Period [$\text{K} = ^\circ\text{C} + 273.16$]

Maximum and minimum temperature data are observed data measured by BMD in $^\circ\text{C}$

e_a = actual vapor pressure (kPa)

The relative humidity is R_h is the ratio of the actual vapor pressure to saturation value at a given temperature. (Chow 1988).

$$R_h = \frac{e_a}{e_s} ; \text{ where } e_s = \text{saturation vapor pressure}$$

For a given air temperature, there is a maximum moisture content the air can hold and the corresponding vapor pressure is called saturation vapor pressure. Over a water surface the saturation vapor pressure is related to the air temperature. An approximate equation for calculating e_s is :

$$e_s = 6.11 \exp\left(\frac{17.27T}{237.3 + T}\right)$$

Where, T = Temperature in Degree Centigrade. The average monthly temperature data used to determine e_s .

R_s/R_{s0} = Relative Shortwave Radiation (Limited to ≤ 1.0),

R_s = Measured Solar Radiation [$\text{MJ}/\text{m}^2/\text{day}$]

R_{s0} = Calculated Clear Sky Radiation [$\text{MJ}/\text{m}^2/\text{day}$]

An average of the maximum temperature to the fourth power and the minimum air temperature to the fourth power is commonly used in the Stefan-Boltzman equation for 24 hours time steps. The term $(0.34 - 0.14\sqrt{e_a})$ express the correction for air humidity, and will be smaller if the humidity increases. The effect of cloudiness is expressed by $(1.35 R_s/R_{s0} - 0.35)$. The term becomes smaller if the cloudiness increases and hence R_s decreases. The smaller the correction term, the smaller the net outgoing flux of long radiation.

Table 3-7: Computed Net Longwave Radiation at Different Locations in $\text{MJ}/\text{m}^2/\text{day}$

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	0.94	1.01	0.63	0.52	0.25	-0.11	-0.23	-0.17	-0.07	-0.04	0.51	0.89
Bogra	0.84	1.15	1.17	0.71	0.46	0.15	0.07	0.19	0.28	0.44	1.01	1.14
Comilla	0.15	0.35	0.28	0.10	-0.07	-0.26	-0.27	-0.13	-0.11	0.00	0.05	0.08
Dhaka	1.07	1.29	1.00	0.67	0.53	0.10	0.06	0.23	0.09	0.29	1.19	0.91
Faridpur	0.07	0.11	0.00	-0.13	-0.17	-0.37	-0.34	-0.24	-0.33	-0.13	0.30	0.43
Khulna	1.36	1.79	1.14	0.82	0.73	0.34	0.32	0.35	0.36	0.56	1.40	1.50
Mymensing	0.13	0.33	0.24	0.10	0.01	-0.30	-0.30	-0.06	-0.17	-0.05	0.40	0.38
Rangpur	0.22	0.48	0.48	0.07	0.03	-0.23	-0.15	-0.08	-0.04	0.02	0.63	0.54
Srimangal	0.86	0.95	0.73	0.54	0.23	-0.10	-0.04	0.20	0.24	0.43	0.89	1.06

Net Radiation (R_n)

The net radiation is computed by subtracting the net longwave radiation (R_{nl}) from net shortwave radiation (R_s)

$$R_n = R_{ns} - R_{nl}$$

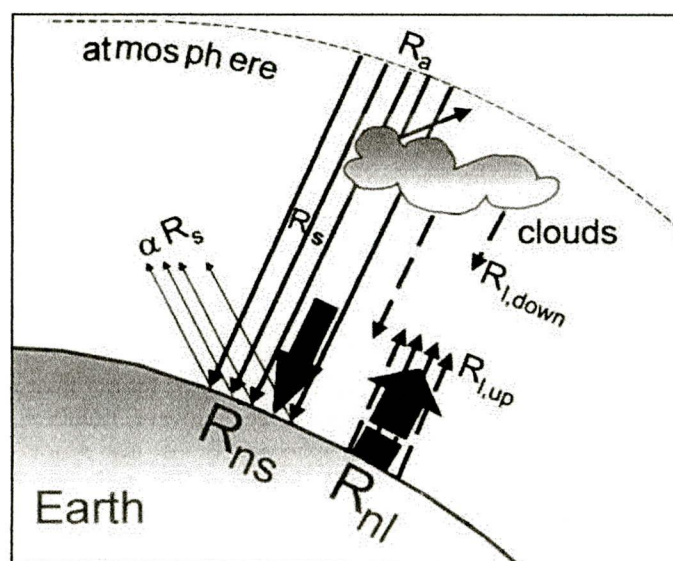


Figure 3-14: Various Component of Radiation

Table 3-8: Computed Net Radiation at Different Locations in MJ/m²/day

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	6.01	7.43	8.20	9.32	8.73	6.96	6.26	6.34	6.30	5.65	5.93	5.70
Bogra	5.57	7.22	8.98	9.54	9.53	8.41	7.93	8.19	7.75	6.87	6.34	5.59
Comilla	4.88	6.08	7.14	7.49	7.16	6.25	6.15	6.57	6.12	5.74	4.95	4.56
Dhaka	5.95	7.51	8.68	9.52	9.84	8.11	7.84	8.36	6.97	6.56	6.86	5.51
Faridpur	4.77	5.62	6.35	6.62	6.69	5.56	5.63	5.97	5.08	5.30	5.39	4.98
Khulna	6.56	8.81	9.55	10.50	11.11	9.42	9.25	9.06	8.27	7.62	7.63	6.49
Mymensing	4.72	5.88	6.88	7.44	7.55	6.02	5.93	6.94	5.81	5.46	5.45	4.78
Rangpur	4.71	6.02	7.28	7.29	7.64	6.51	6.79	6.81	6.34	5.61	5.65	4.82
Srimangal	5.65	6.89	8.00	8.87	8.44	7.10	7.36	8.22	7.57	6.91	6.31	5.65

The net radiation data are then converted to watt/m² for determination of evaporation rate by different methods.

3.4. DETERMINATION OF EVAPORATION RATE USING DIFFERENT METHODS:

Four approaches are used in determining the evaporation. They are

- i) Energy Balance Method
- ii) Aerodynamic Method
- iii) Combined Aerodynamic and Energy Balance Method
- iv) Priestley-Taylor Method

3.4.1. Energy Balance Method

In energy balance method continuity and energy equations are involved. In this method the equation for calculating evaporation is given by (Chow 1988),

$$E_r = \frac{1}{l_v \rho_w} (R_n - H_s - G)$$

Where,

R_n = Net Radiation Flux in watt/m²

H_s = Sensible Heat Flux in watt/m²

G = Ground Heat Flux in watt/m²

ρ_w = Water density in kg/m³

Latent Heat of Vaporization, $l_v = 2.501 \times 10^6 - 237T$

ρ_w can be directly calculated by an empirical equation (McCutcheon et. al. 1993)

$$\rho_w = 1000(1 - (T+288.9414)/(508929.2*(T+68.12963))*(T-3.9863)^2)$$

Where T = Air Temperature in degree Celsius

The value of sensible heat flux H_s and the Ground Heat Flux G are very small in compared to Net Radiation and can be neglected (FAO 1998). So both of these parameters are taken as zero. Then evaporation rate E_r calculated as the rate at which all the incoming net radiation is absorbed by evaporation:

$$E_r = \frac{R_n}{l_v \rho_w}$$

So, the only climatic data which are required to determine evaporation are net radiation and temperature. In this study the mean monthly value of net radiation and temperature are used to determine evaporation for the location of Barisal, Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Khulna, Mymensing, Rajshahi, Rangpur and Srimangal.

3.4.2. Aerodynamic Method

Besides the supply of heat energy, the second factor controlling the evaporation rate is the ability to transport vapor away from the surface. The transport rate is governed by the humidity gradient in the air near the surface and the wind speed across the surface,

and these two processes can be analyzed by coupling the equation for mass and momentum transport in air (Chow 1988).

In Aerodynamic Method the Evaporation Rate is given by

$$E_a = B(e_{as} - e_a)$$

Where, e_{as} = Saturated vapor pressure

e_a = Actual vapor pressure

The calculation procedure for e_{as} and e_a are given in section 3.3.4.

B = Vapor transfer co-efficient

B is computed by the following equation:

$$B = \frac{0.622k^2 \rho_a^2 u_2}{P \rho_w \left[\ln \left(\frac{z_2}{z_0} \right) \right]^2}$$

Where, k = Von Karman Constant

u_2 = Wind speed at 2 meter of height from the ground surface

P = Air pressure

ρ_a = Air density

z_0 = Roughness height

z_2 = Measured height of parameters

For water surface roughness height varies from 0.01 to 0.06 cm. Here the roughness height value is taken 0.06.

Air density is calculated by the following equation (Chow 1988):

$$P = \rho_a RT$$

Where, Gas constant, $R = \frac{8312}{m}$ (Daugherty, 1989), m = molecular weight of air = 29

So the climatic parameters that are required to computing evaporation from Aerodynamic method are temperature, relative humidity, air pressure and wind speed. The locations where Aerodynamic method is applied in this study are Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Khulna, Mymensing, Rajshahi, Rangpur and Srimangal as the common period of data are available.

3.4.3. Combined Aerodynamic and Energy Balance Method

Evaporation may be combined by the aerodynamic method when energy supply is not limiting and by energy balance method when vapor transport is not limiting. But, normally both these factors are limiting, so a combination of the two methods is needed. It can be shown that the evaporation rate computed from energy balance method (E_r) and the evaporation rate computed from aerodynamic method (E_a) can be combined to yield a weighted estimate of evaporation (Chow 1988) by E , by

$$E = \frac{\Delta}{\Delta + \gamma} E_r + \frac{\gamma}{\Delta + \gamma} E_a$$

$$\text{Where, } \gamma = \text{Psychrometric constant} = \frac{C_p K_h p}{0.622 l_v K_w}$$

C_p is the specific heat at constant pressure. In the study C_p is taken 1005 J/kg.K

The ratio K_h/K_w of the heat and vapor diffusivities is commonly taken to be 1.

$$\Delta = \text{Gradient of the saturated vapor pressure curve} = \frac{408 e_s}{(237.3 + T)^2}$$

e_s = Saturation vapor pressure

T = Temperature

The climatic parameters require computing evaporation rate by Combined Method are net radiation, air temperature, relative humidity, wind speed and air pressure. For Combined Method at first evaporation rate from Energy Balance Method and Aerodynamic Method need to be computed. In this study the locations where the Combined Method is applied are Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Khulna, Mymensing, Rangpur and Srimangal.

3.4.4. Priestley-Taylor Method

For evaporation over very large areas, energy balance considerations largely govern the evaporation rate. For such cases Priestley and Taylor (1972) found that the second term of the combination equation is approximately 30 percent of the first, so the combined aerodynamic and energy balance method can be written as the Priestley-Taylor evaporation equation

$$E = \alpha \frac{\Delta}{\Delta + \gamma} E_r$$

Where, $\alpha = 1.3$

Other investigators have confirmed the validity of this approach, with the value of α varying slightly from one location to another. The climatic data require for computing evaporation rate by Priestly-Taylor Method are net radiation, temperature and air pressure. The evaporation rate is computed by Priestly-Taylor method for the locations of Bogra, Comilla, Dhaka, Dinajpur, Faridpur, Khulna, Mymensing, Rangpur and Srimangal as common period of climatic data are available for this locations.

3.5. TESTING OF ACCURACY OF DIFFERENT PREDICTION METHODS

Several types of statistics provide useful numerical measures of the degree of agreement between computed and actual quantities. One of such estimation is Root Mean Square Error (RMSE) which is being used to evaluating the results of hydrologic simulation. An RMSE of zero (0) value meaning that the computed evaporation rate is completely match with the actual evaporation rate with perfect accuracy.

To determine the accuracy of computed evaporation rate, the RMSE of each method for various seasons is determined. The mathematical expression of RMSE is given below:

$$RMSE = \sqrt{\left(\sum_{i=1}^n \frac{(X_i - Y_i)^2}{n} \right)}$$

Where, $X_1, X_2 \dots \dots \dots X_n$ are computed evaporation rate

$Y_1, Y_2 \dots \dots \dots Y_n$ are actual evaporation rate

n is total number of observation.

CHAPTER 4

RESULT AND DISCUSSION

The study has mainly three different parts: i) Variation of evaporation rate and other climatic parameters. ii) Correlation between evaporation rate and other climatic parameters and iii) Computation of evaporation rate by using four different methods and identify the accuracy of these methods in context of Bangladesh. The out come from the study is described in this chapter.

4.1. SPATIAL AND TEMPORAL VARIATION OF CLIMATIC PARAMETERS

Evaporation Rate:

For the analysis of evaporation rate, only the data of twelve locations are available. MAP C5 in Appendix C represents the monthly variation of evaporation rate in different locations of Bangladesh. The average annual and seasonal (Pre-Monsoon, Monsoon, Dry Season) spatial variation of evaporation rate are shown in Figure C1, C2, C3 and C4 in Appendix C.

From analysis it is identified that in Bangladesh higher rate of evaporation occurs from the month of March to May and in April it is maximum. Minimum evaporation rate occurs in the month of December and January. The Figure 4-1 represents the monthly variation of evaporation rate in Dinajpur.

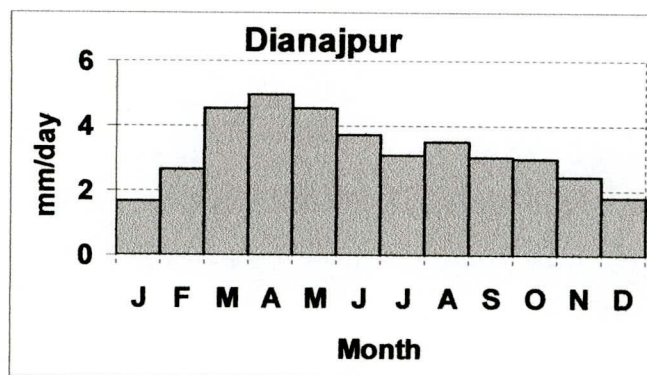


Figure 4-1: Monthly Variation of Evaporation rate at Dinajpur

Though temperature is not maximum in pre-monsoon but evaporation rate is high in this season because of less humidity and high radiation rate. In monsoon radiation rate is higher than dry period and humidity and temperature is maximum which makes the evaporation rate higher than dry period. Radiation is more influential over evaporation rate than humidity. The seasonal variation of evaporation rate at different locations of Bangladesh are represented in Figure 4-2.

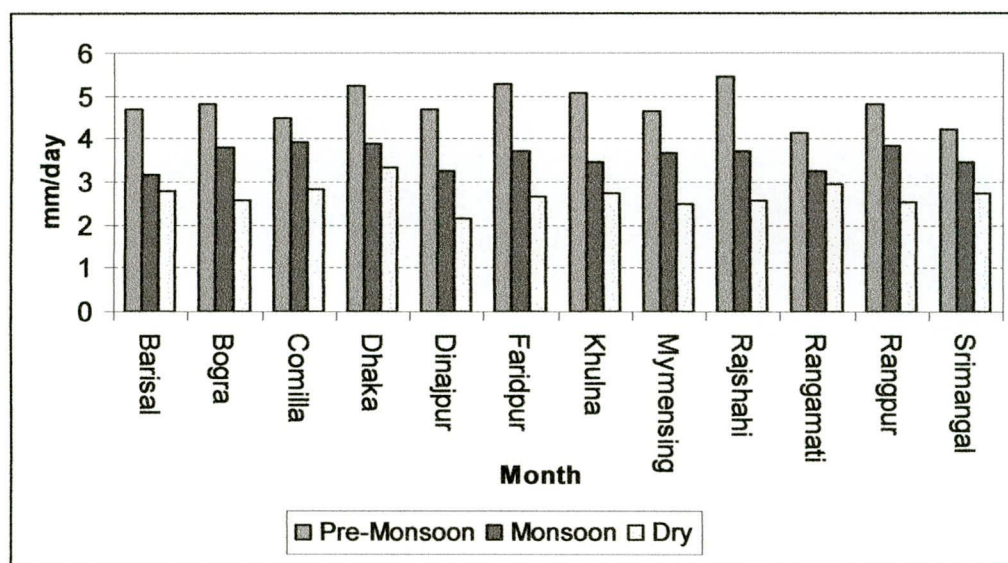


Figure 4-2: Seasonal Variation of Evaporation Rate at Different Locations

On an average the total amount of yearly evaporation is 1317 mm. Yearly maximum evaporation occurs in Dhaka (1477 mm) and yearly minimum evaporation occurs in Dinajpur (1184 mm).

The monthly average evaporation rate varies from 1.66 mm/day (Dinajpur, January) to 5.98 mm/day (Faridpur, April). The maximum difference between highest and lowest evaporation rate (3.84 mm/day) is found in Rajshahi area and the minimum difference between highest and lowest evaporation rate (1.75 mm/day) is found in Rangamati. The yearly variation of total evaporation at different locations of Bangladesh are presented in Figure 4-3.

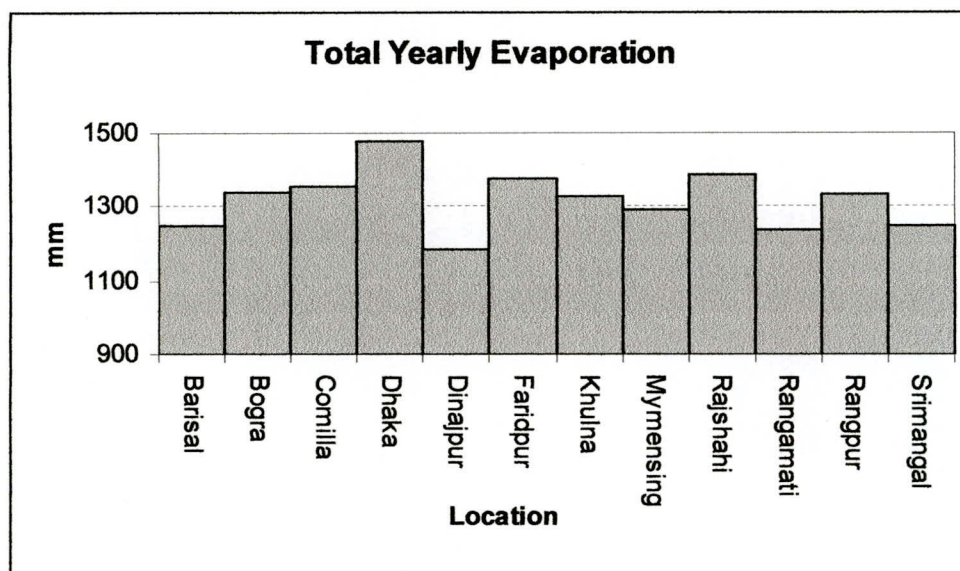


Figure 4-3: Total Yearly Average Evaporation

The entire monthly, seasonally and yearly variation of evaporation rate in different locations of Bangladesh are in tabulated form in Table B1 of Appendix B.

Temperature

Three sets of temperature data for 25 locations of Bangladesh have been analyzed. These are daily average temperature, monthly average maximum temperature and monthly average minimum temperature. Figure C10 in Appendix C represents the monthly variation of average temperature in different locations of Bangladesh. The average annual and seasonal (Pre-Monsoon, Monsoon, Dry Season) variation of temperature are shown in the Map C6, C7, C8 and C9 in Appendix C.

In Bangladesh maximum temperature observed in April or May. The variation of average temperature is little from April to September. Temperature begins to decrease from the month of October and falls at lowest in January. The average monthly temperature varies from 9.78° (Srimangal, January) to 35.92° (Rajshahi, April). Dinajpur, Ishurdi, Syedpur, Rajshahi, Rangpur, Srimangal, Satkhira and Jessore are the area where the variation of maximum and minimum temperature is very high. These locations can be identified as extreme temperature area. The range between maximum and minimum temperature is comparatively lower in Teknaf, Chittagong and Cox's Bazar. The monthly variation of average temperature in Jessore represents in Figure 4-4.

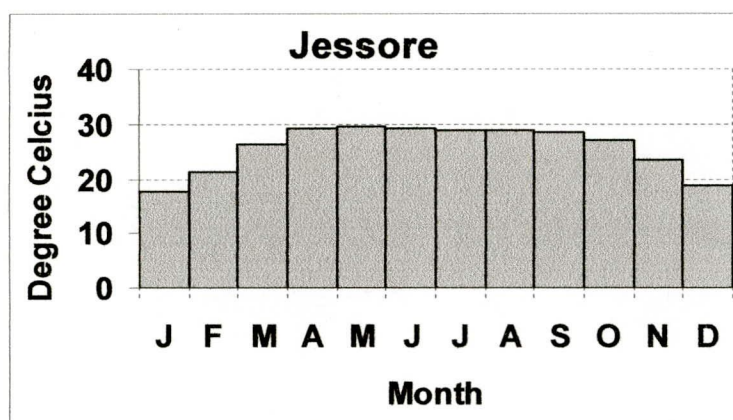


Figure 4-4: Monthly Variation of Average Temperature at Jessore

The maximum and minimum temperature at different locations of Bangladesh are tabulated in Table 4-1.

Table 4-1: Maximum and Minimum Temperature in Different Locations

Station Name	Maximum Temperature		Minimum Temperature	
	Temperature °C	Month	Temperature °C	Month
Barisal	33.40	Apr	11.80	Jan
Bogra	33.77	Apr	11.61	Jan
Chandpur	32.92	May	13.31	Jan
Chittagong	32.38	May	13.81	Jan
Comilla	32.37	May	12.00	Jan
Cox's Bazar	32.57	May	15.11	Jan
Dhaka	33.68	Apr	12.78	Jan
Dinajpur	32.92	Apr	10.25	Jan
Faridpur	34.17	Apr	12.19	Jan
Ishurdi	35.47	Apr	10.27	Jan
Jessore	35.64	Apr	11.29	Jan
Khepupara	32.58	May	13.71	Jan
Khulna	34.62	Apr	12.30	Jan
Maizdicourt	32.65	Apr	13.57	Jan
Mymensing	32.08	Apr	11.68	Jan
Patuakhali	33.09	Apr	13.47	Jan

Rajshahi	35.92	Apr	10.73	Jan
Rangamati	33.02	Apr	13.43	Jan
Rangpur	32.03	Aug	10.73	Jan
Satkhira	35.21	May	12.06	Jan
Srimangal	32.71	Apr	9.77	Jan
Syedpur	32.33	Aug	10.47	Jan
Sylhet	31.86	Aug	12.54	Jan
Tangail	33.73	Apr	11.26	Jan
Teknaf	32.17	May	15.00	Jan

In case of seasonal variation maximum average temperature occurs in monsoon seasons (June to October) where average temperature varies from 27.31 to 28.8 degree centigrade and minimum average temperature occurs in dry season (November to February) where average temperature varies from 19 to 23.4 degree centigrade. But few exceptions are found in Cox's Bazar and Teknaf where maximum average temperature observed in pre-monsoon season. The Figure 4-5 represents the seasonal variation of temperature at different locations of Bangladesh.

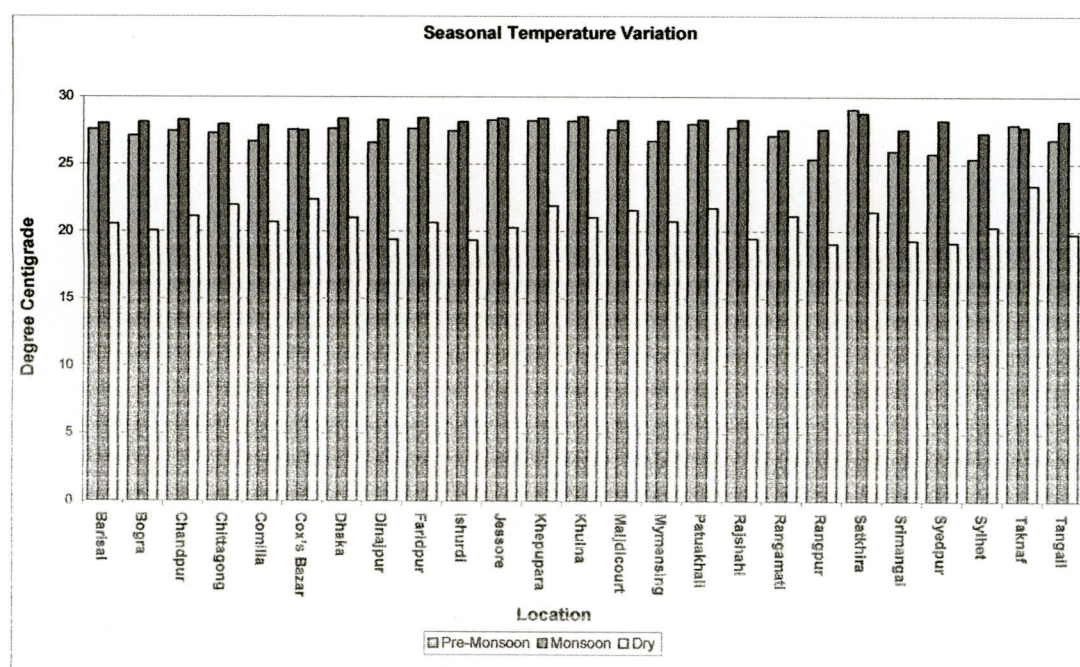


Figure 4-5: Seasonal Variation of Temperature at Different Locations of Bangladesh

Again the yearly variation of average minimum and maximum temperature in different locations are in between 19.5 to 31.5 degree centigrade. The yearly average maximum and minimum temperature at different locations of Bangladesh are represented in Figure 4-6.

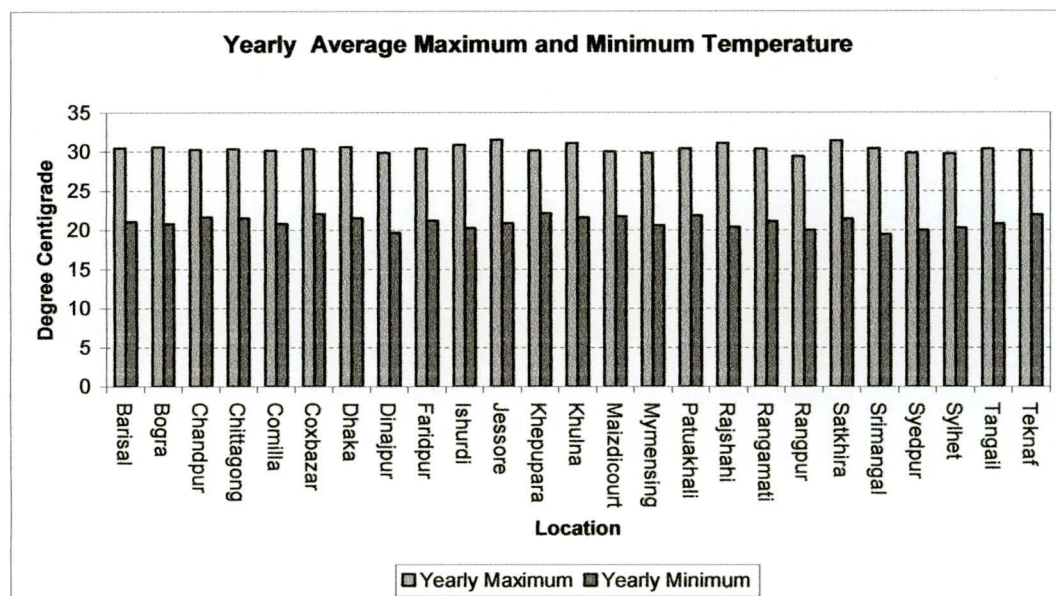


Figure 4-6: Yearly Average Maximum and Minimum Temperature at Different Locations of Bangladesh

From the analysis of historical temperature data it is identified that the temperatures of Bangladesh have increasing trend. The Figure 5-5 represents the increasing trend of temperature of Dhaka. The increase rate of temperature is $0.024^{\circ}\text{C}/\text{year}$. The temperature pattern of other five divisions of Bangladesh are presented in Appendix D.

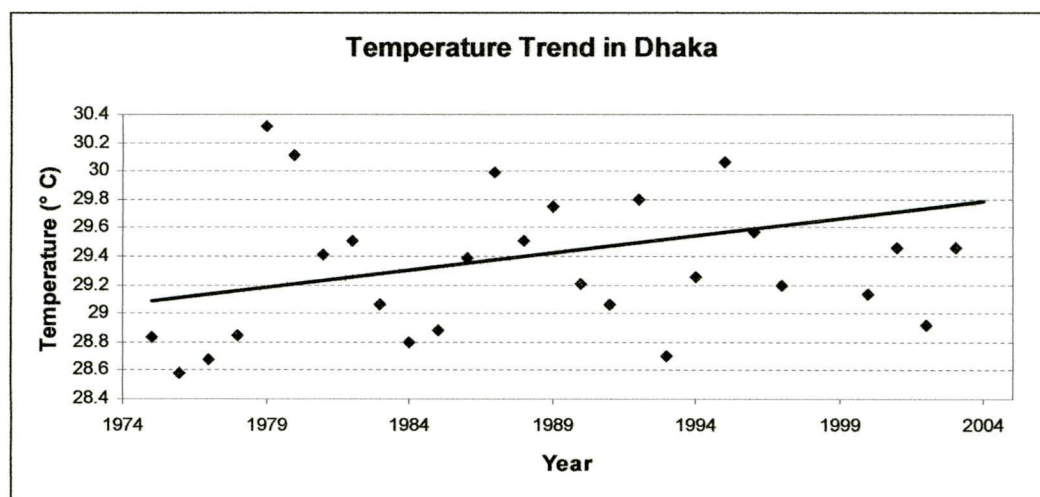


Figure 4-7: Temperature Trend in Dhaka

Solar Radiation

Solar radiation (Short Wave) data of only nine stations of Bangladesh are available. Figure C15 in Appendix C represents the monthly variation of radiation at different locations of Bangladesh. The average annual and seasonal (Pre- Monsoon, Monsoon, Dry Period) variation of radiation are shown in Figure C11, C12, C13 and C14 in Appendix C.

From the analysis it is observed that in most of the locations of Bangladesh the solar radiation is high in the month of April and May and low in the month of December and January. The temperature is also maximum at the time of highest radiation and minimum at the time of lowest radiation. The average monthly radiation rate varies from 55.40 w/m^2 (Comilla in December) to 141.26 w/m^2 (Khulna in May). The maximum difference between average monthly highest and lowest radiation rate observed in Barisal (Difference 50.41 watt/m^2). The Figure 4-8 represents the monthly variation of solar radiation at Dhaka.

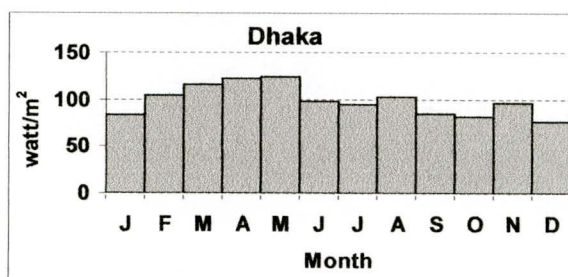


Figure 4-8: Monthly Variation of Solar Radiation at Dhaka

In Bangladesh average maximum radiation occurs in pre-monsoon season and average minimum radiation occurs in dry period. The variation of average radiation in monsoon and dry period is not significant. The seasonal variation of solar radiation at different locations of Bangladesh is represented in Figure 4-9.

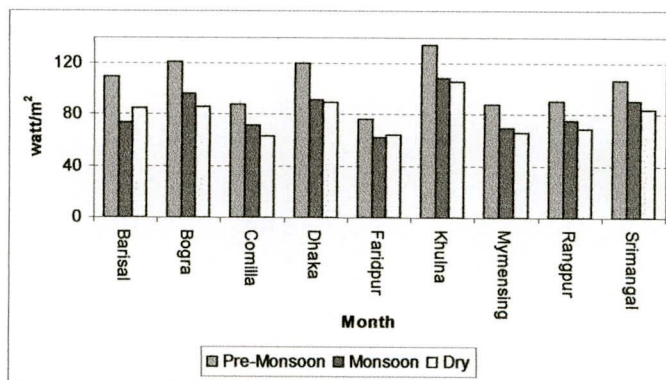


Figure 4-9: Seasonal variation of Net Radiation at Different Locations of Bangladesh

In Bangladesh average net radiation is 86.73 watt/m^2 . The Figure 4-10 represents the annual average net radiation at different locations of Bangladesh.

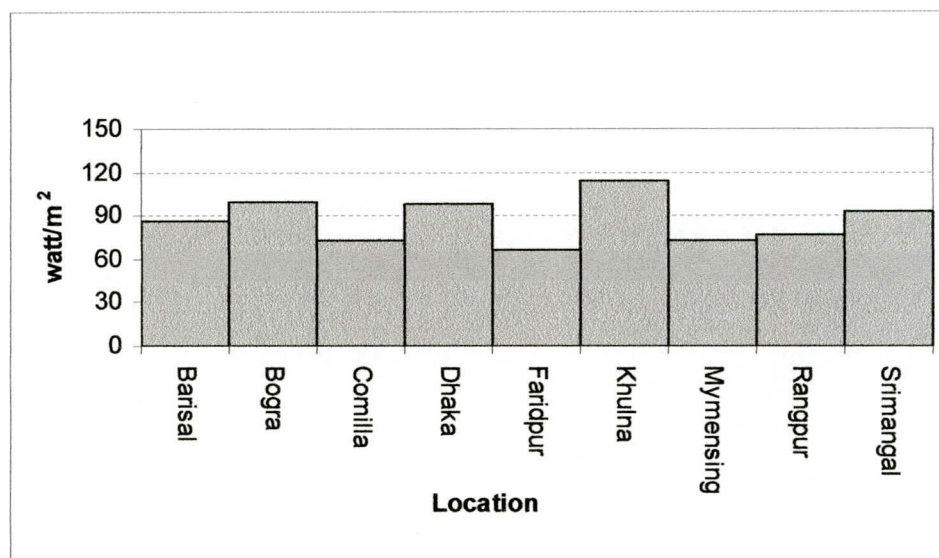


Figure 4-10: Annual Average Net Radiation at Different Locations

The entire monthly, seasonally and yearly variation of solar radiation at different location of Bangladesh are given in Table B4 of Appendix B.

Wind Speed

Wind Speed data of only twelve stations of Bangladesh are available. Figure C20 in Appendix C represents the monthly variation of wind speed at different locations of Bangladesh. The average annual and seasonal (Pre- Monsoon, Monsoon, Dry Period) and variation of wind speed are shown in Figure C16, C17, C18 and C19 in Appendix C.

In this study the wind speed measured at a height of two meter from the ground surface has been taken into consideration. From the analysis it is found that in most of the locations wind speed is maximum in the month of April and minimum in the month of November. The maximum intensity of wind speed observed in Rangamati (4.38 m/s, April) and minimum intensity of wind speed observed in Dinajpur (0.27 m/s, November). The Figure 4-11 represents the monthly variation of wind speed at Rangpur.

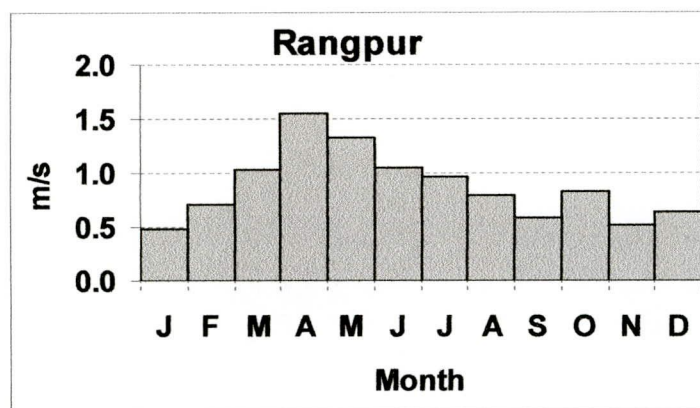


Figure 4-11: Monthly Variation of Wind Speed at Rangpur

In case of seasonal variation wind speed is maximum in pre-monsoon season and minimum in dry period. The Figure 4-12 represents the seasonal variation of wind speed at different locations of Bangladesh.

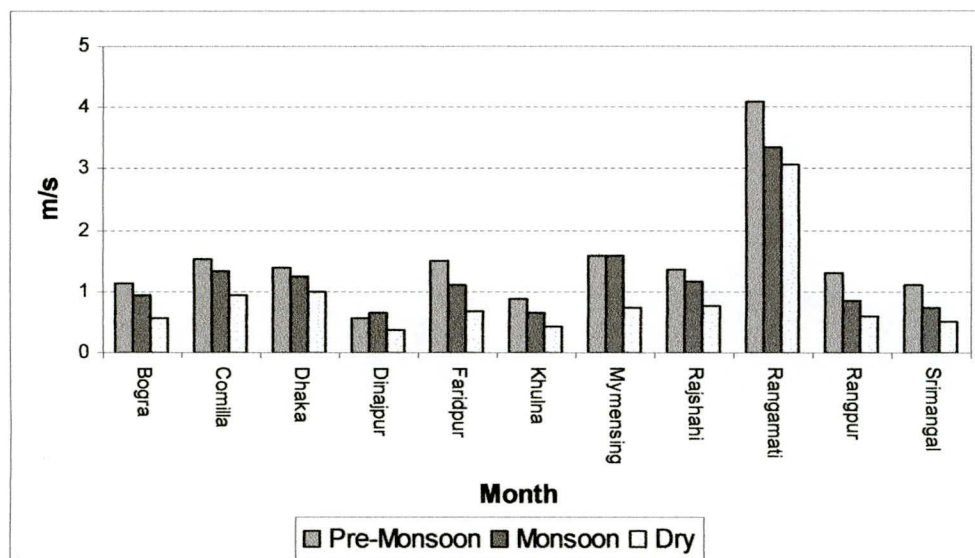


Figure 4-12: Seasonal Variation of Wind Speed

The average annual wind speed is 1.18 m/s. The Figure 4-13 represents the spatial variation of annual average wind speed at different locations.

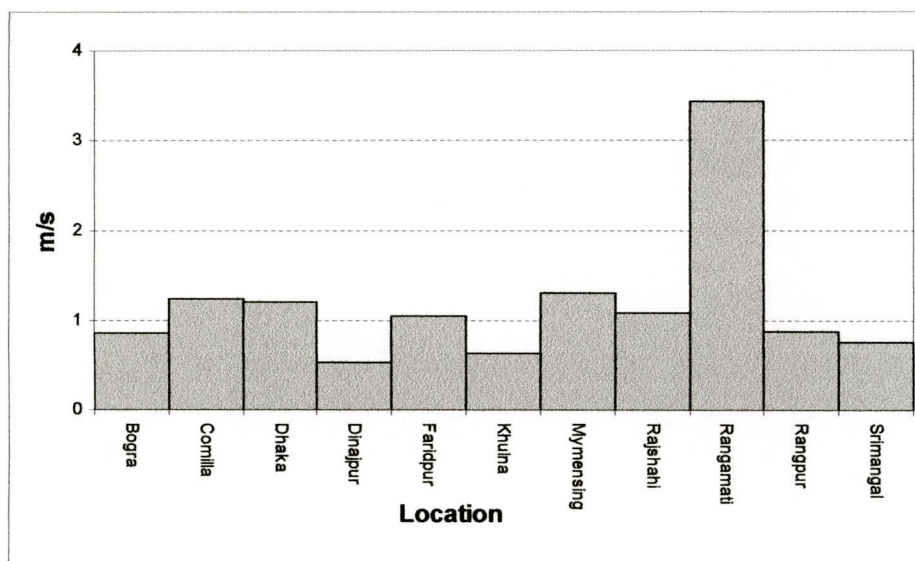


Figure 4-13: Spatial Variation of Annual Average Wind Speed

Air Pressure

Air pressure data of twenty four locations are available. MAP C25 in Appendix C represents the monthly variation of air pressure in different locations of Bangladesh. The average annual and seasonal (Pre-Monsoon, Monsoon, Dry Season) spatial variation of air pressure are shown in Figure C21, C22, C23 and C24 in Appendix C.

From the analysis it is found that air pressure is minimum in the month of June and in some locations in July. On the other hand the air pressure is maximum in December and in few locations it is in the month of January. The variation of air pressure is not that much significant. The average monthly air pressure varies from 99.96 kPa (Dinajpur in June) to 101.60 kPa (Rajshahi in December). The Figure 4-14 represents the monthly variation of air pressure at Bogra.

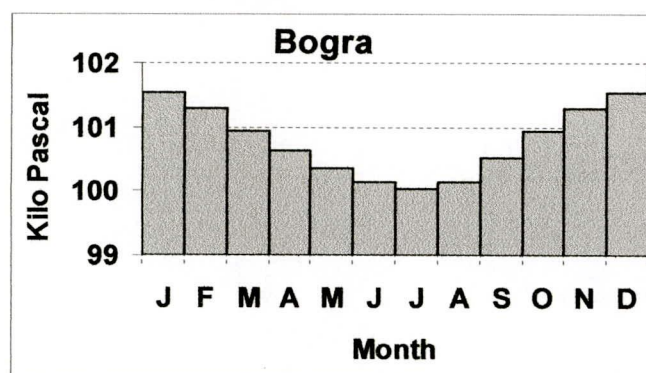


Figure 4-14: Monthly Variation of Air Pressure at Bogra

Average annual air pressure is 100.81 kPa and varies from 100.75 kPa to 100.93 kPa. The Figure 4-15 represents annual average air pressure at different locations of Bangladesh.

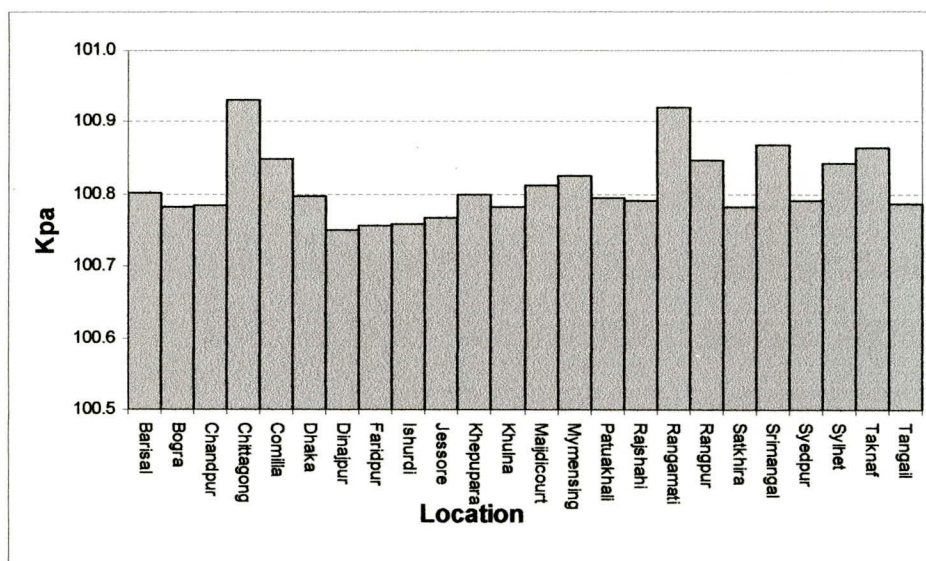


Figure 4-15: Annual Variation of Air Pressure at Different Locations

In Bangladesh air pressure is maximum in dry period and minimum in monsoon season. The Figure 4-16 represents the seasonal variation of air pressure at different locations of Bangladesh.

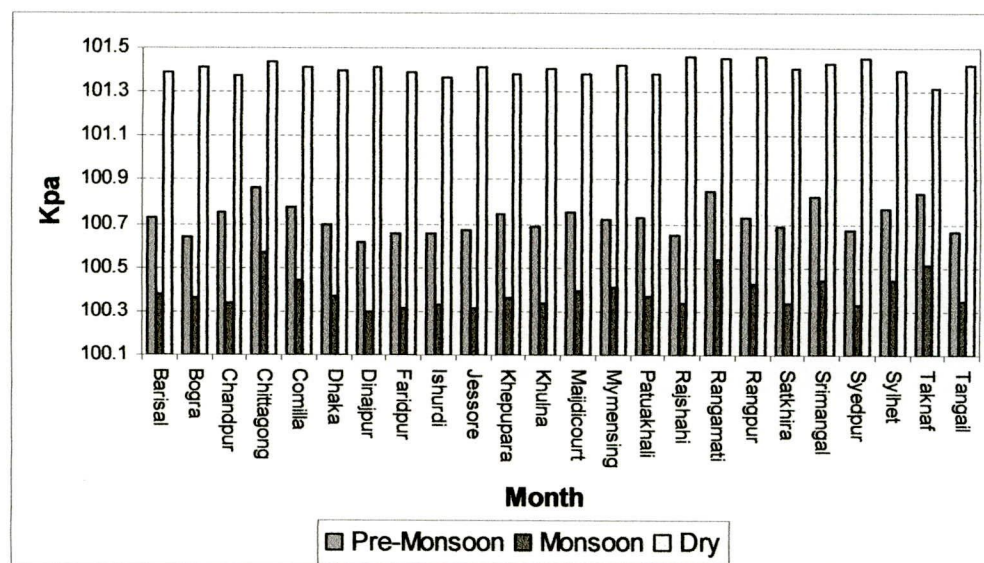


Figure 4-16: Seasonal Variation of Air Pressure at Different Locations

Relative Humidity

Relative humidity data of 25 stations of Bangladesh are available. Figure C30 in Appendix C represents the monthly variation of relative humidity at different

locations of Bangladesh. The average seasonal (Pre- Monsoon, Monsoon, Dry Period) and average annual relative humidity are shown in Figure C26, C27, C28 and C29 in Appendix C.

In Bangladesh the average annual humidity is 79%. In most of the locations maximum amount of humidity occurs in the month of July but in very few locations it is observed in the month of August and September. Again minimum amount of humidity occurs in March and in some locations it is observed in January and February. The range of relative humidity varies from 60% (Ishwardi, March) to 89% (Teknaf, July). The monthly variation relative humidity at Patuakhali represents in Figure 4-17.

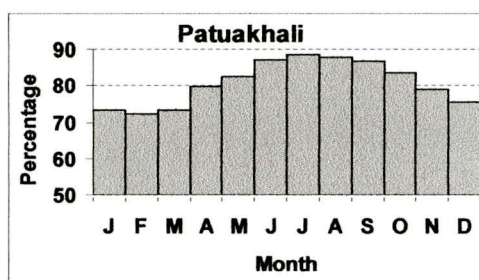


Figure 4-17: Monthly Variation of Relative Humidity at Patuakhali

The maximum difference between maximum and minimum relative humidity observed in Rajshahi (Difference 26%). In monsoon season humidity is high due to rainfall. The average seasonal variation of solar radiation at different locations of Bangladesh is represented in Figure 4-18.

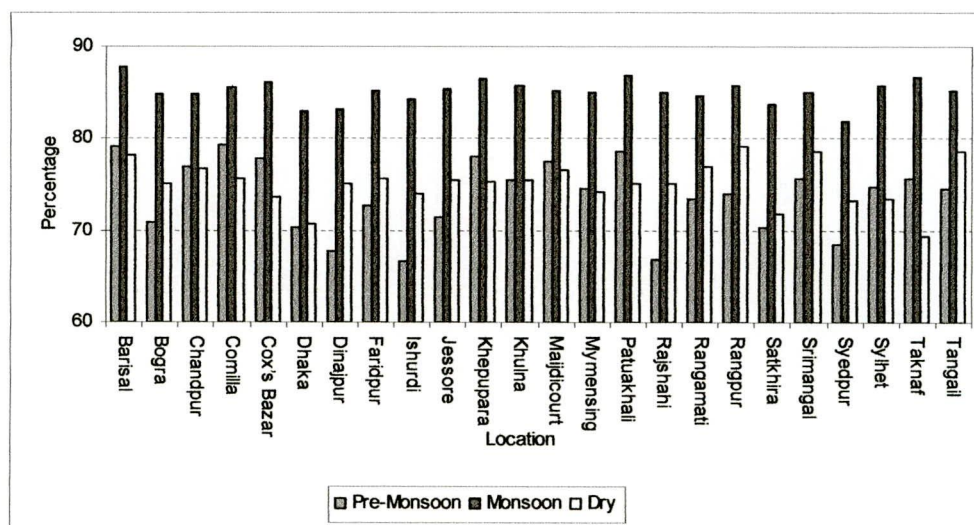


Figure 4-18: Average Seasonal Variation of Radiation at Different Locations

Figure 4-19 represents the yearly variation of relative humidity at different locations of Bangladesh.

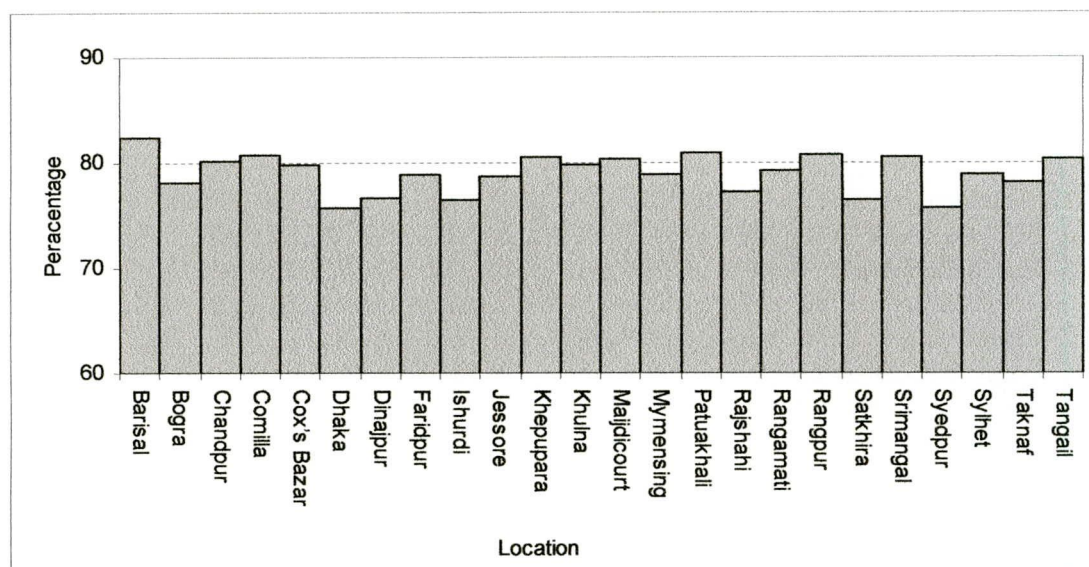


Figure 4-19: Average Annual Relative Humidity at Different Locations

Bright Sunshine Hour

Bright sunshine hour data of twenty four stations of Bangladesh are available. Figure C35 in Appendix C represents the monthly variation of bright sunshine hour at different locations of Bangladesh. The average annual and seasonal (Pre- Monsoon, Monsoon, Dry Period) maps of bright sunshine hour are shown in Figure C31, C32, C33 and C34 in Appendix C.

From the analysis it is observed that in Bangladesh the average maximum length of bright sunshine occurs in the months between January and April as these months are almost cloud free. Though temperature is maximum in the month of April and May but bright sunshine hour in only some locations is observed maximum in April. Sylhet and Maizdicourt, in these two locations bright sunshine hour are observed maximum in the month of December. In coastal region such as Cox's Bazar and Teknaf the length of bright sunshine hour is highest (9.11 and 9.34 hour) in comparison to other locations of Bangladesh. Minimum number of sunshine hour in all the locations observed in July as maximum amount of rainfall occurs in this month and sky becomes cloudy most of the time. The average minimum number of sunshine hour

found in Patuakhali (2.74 hours in July). Figure 4-20 represents the month variation of bright sunshine hour at sylhet.

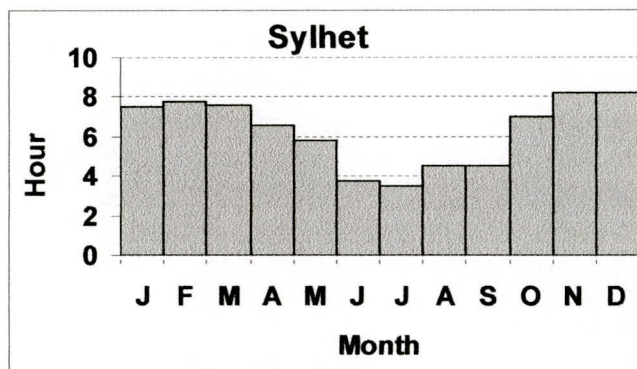


Figure 4-20: Monthly Variation of BSH at Sylhet

The average annul sunshine hour varies between 5.58 to 7.19 hour. The Figure 4-21 represents the yearly variation of sunshine hour at different locations.

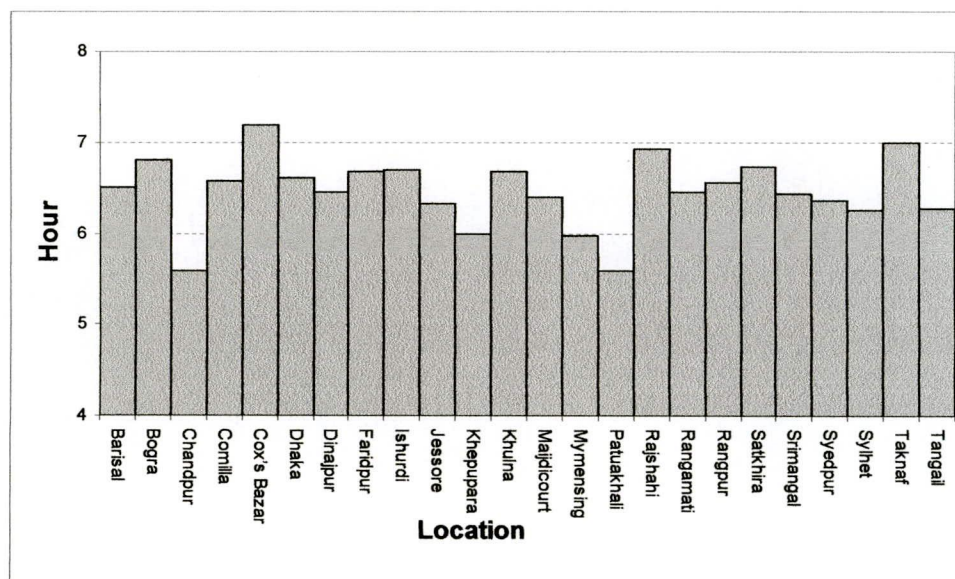


Figure 4-21: Annual Variation of Sunshine Hour at Different Locations

Due to cloudy weather sunshine hour is minimum in monsoon season and there is almost no variation during pre-monsoon and dry period. The Figure 4-22 represents the seasonal variation of bright sunshine hour at different locations of Bangladesh.

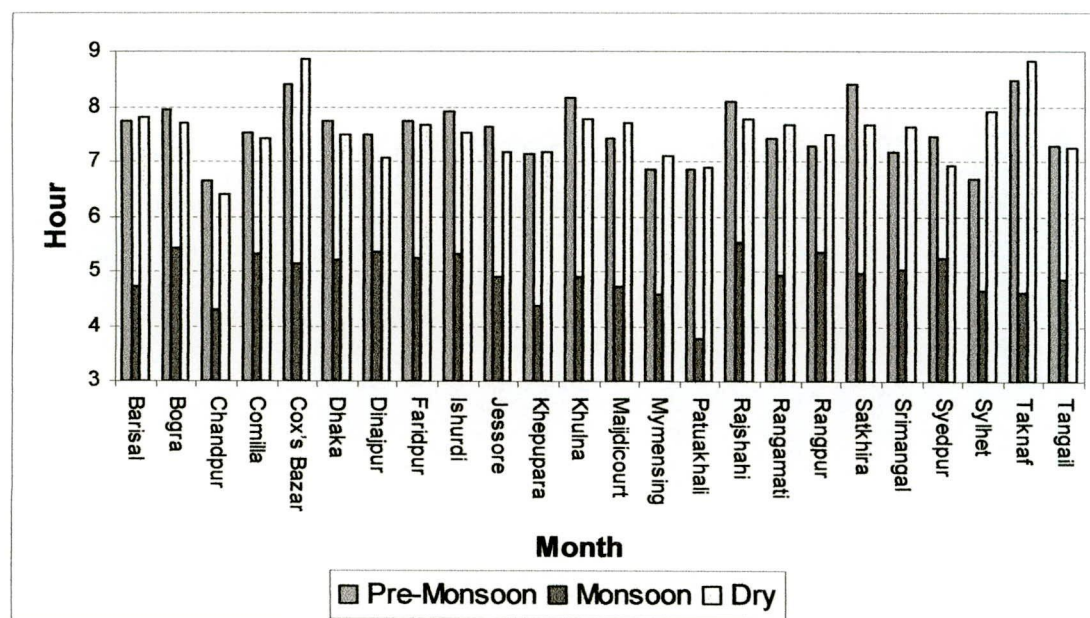


Figure 4-22: Seasonal Variation of Bright Sunshine Hour at Different Locations

Rainfall

Rainfall data of 25 stations of Bangladesh are available. Figure C40 in Appendix C represents the monthly variation of variation rainfall rate (mm/day) at different locations of Bangladesh. The average seasonal (Pre- Monsoon, Monsoon, Dry Period) and average annual rainfall rate are shown in Figure C36, C37, C38 and C39 in Appendix C.

From the analysis it is found that maximum rate of rainfall occurs in the month of June and July at the time of full monsoon and minimum rate of rainfall occurs in the month of December and January. The Figure 4-23 represents the monthly variation of rainfall at Mymensingh.

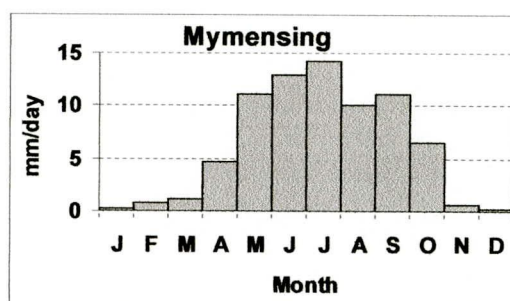


Figure 4-23: Monthly Variation of Rainfall at Mymensingh

Rainfall mainly occurs in monsoon season and average rainfall varies from 1240 mm to 3500 mm. Maximum rainfall occurs in monsoon season in Teknaf. In pre-monsoon period average rainfall is 445 mm but in Sylhet it exceeds 1000 mm. In dry period in fact there very little amount of rainfall (average 79 mm). The average annual total rainfall of the country is 2354 mm. The seasonal variation of rainfall at different locations of Bangladesh is represented in Figure 4-24.

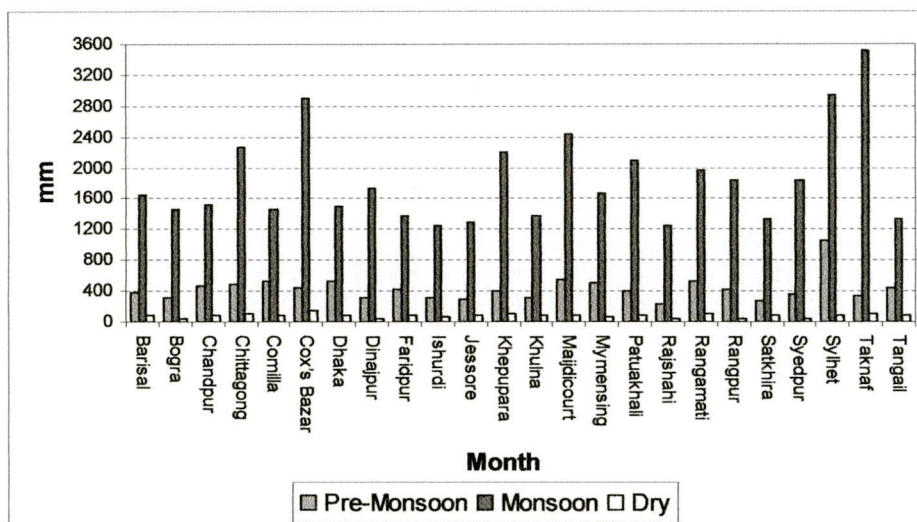


Figure 4-24: Seasonal Variation of Rainfall at Different Locations

Average annual maximum rainfall occurs in Sylhet (4100 mm) and minimum rainfall occurs in Rajshahi (1527 mm). So Rajshahi is the driest part of the country. The annual variation total rainfall at different location of Bangladesh is represented in Figure 4-25.

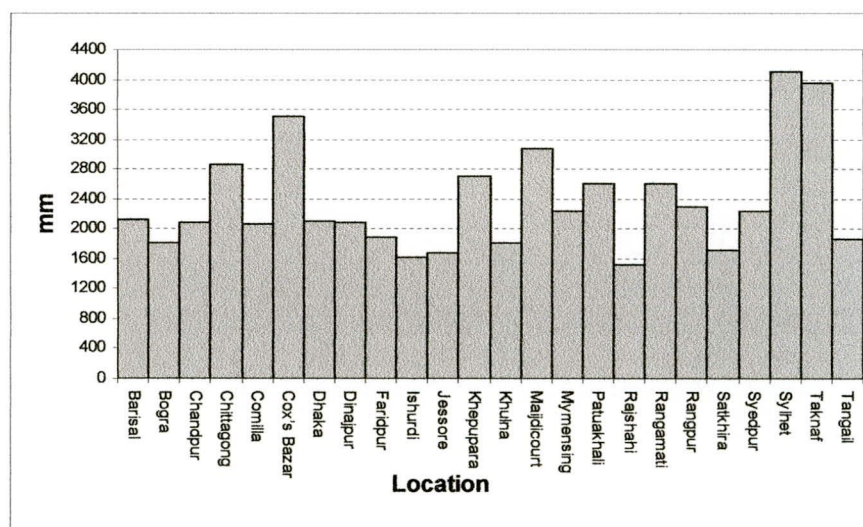


Figure 4-25: Annual variation of Rainfall at different Location

4.2. CO-RELATION BETWEEN EVAPORATION RATE AND OTHER CLIMATIC PARAMETERS

The correlation coefficient (r) between evaporation and other climatic parameters are given in Table 4-2.

Table 4-2: Correlation between Evaporation Rate and Other Climatic Parameters

Station Name	r						
	R_s	T	P	BSH	WS	RH	RF
Bogra	0.72	0.78	-0.61	-	0.77	-0.08	0.32
Comilla	0.67	0.78	-0.62	0.02	0.37	0.32	0.13
Dhaka	0.72	0.58	-0.34	0.42	0.50	-0.36	-0.05
Dinajpur	-	0.66	-0.57	0.19	0.59	-0.34	0.12
Faridpur	0.84	0.58	-0.40	0.24	0.78	-0.39	0.04
Khulna	0.74	0.57	-0.36	0.15	0.77	-0.29	0.04
Mymensingh	0.60	0.72	-0.66	-0.12	0.66	0.10	0.31
Rajshahi	-	0.73	-0.57	0.13	0.64	-0.42	0.15
Rangamati	-	0.23	-0.14	0.11	0.46	-0.27	-0.24
Rangpur	0.63	0.75	-0.69	-0.10	0.56	-0.02	0.32
Srimangal	0.72	0.65	-0.45	0.03	0.51	-0.36	0.30
Average	0.70	0.64	-0.49	0.11	0.51	-0.19	0.13

* R_s = Solar Radiation (w/m^2), T= Temperature ($^{\circ}\text{C}$), P= Air Pressure (kPa), BSH = Bright Sunshine Hour (h), WS = Wind Speed (m/s), RH = Relative Humidity (%), R = Rainfall (mm)

The correlation coefficient (r) between evaporation rate with other climatic parameters are divided in to three categories. These are Small Correlation, Medium Correlation and Large Correlation and the range of value of r are given in the Table 4-3 below:

Table 4-3: Size of Correlation

Correlation	Negative	Positive
Small	-0.3 to -0.1	0.1 to 0.3
Medium	-0.5 to -0.3	0.3 to 0.5
Large	-1.0 to -0.5	0.5 to 1.0

From Table 4-2 it is found that the correlation between evaporation rate with radiation, temperature and wind speed is positive and the value of r is large in maximum locations. That is if the value of radiation, temperature and wind speed are increased, evaporation rate will also be increased. The Figures 4-26, 4-27 and 4-28 represent the correlation between evaporation rate with solar radiation, temperature and wind speed at Bogra, Comilla and Srimangal.

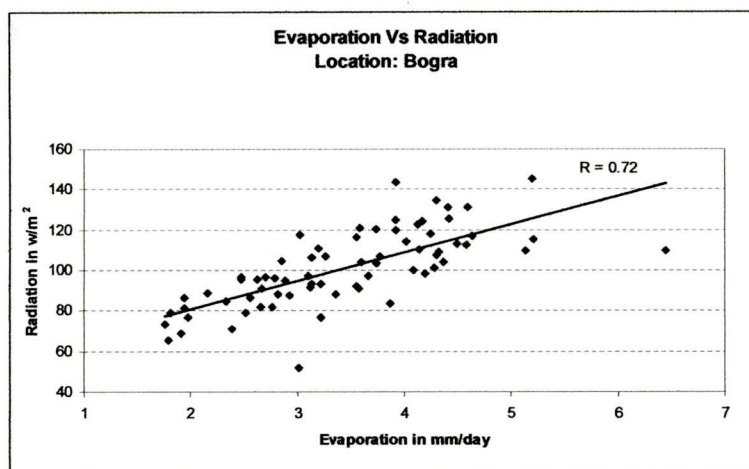


Figure 4-26: Correlation between Evaporation Rate and Solar Radiation

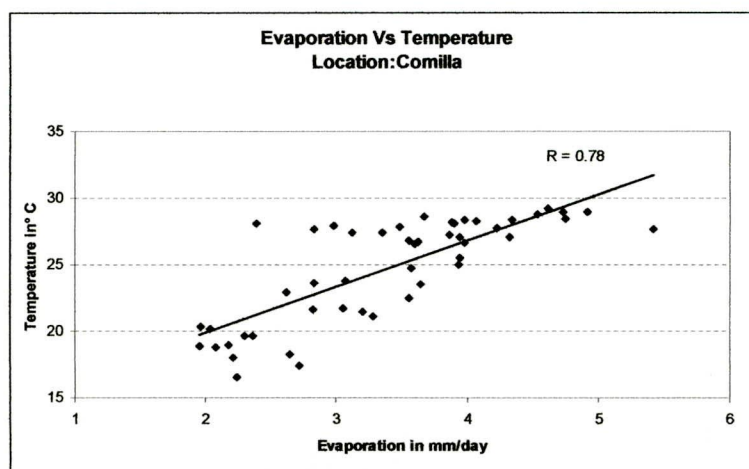


Figure 4-27: Correlation between Evaporation Rate and Temperature

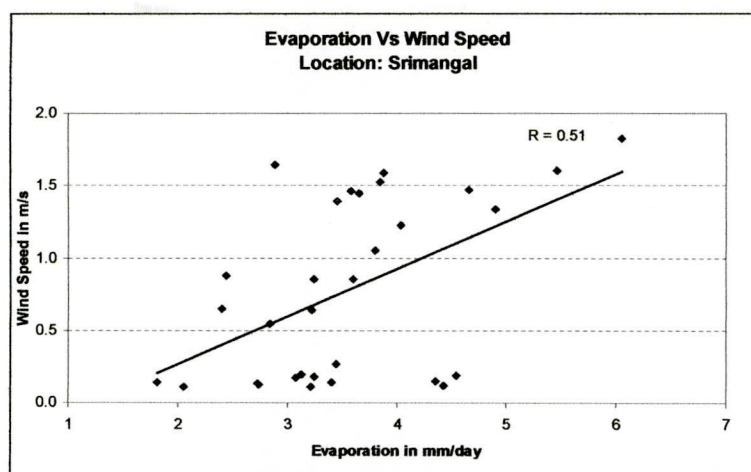


Figure 4-28: Correlation between Evaporation Rate and Wind Speed

Again the evaporation rate will decrease with the increase value of air pressure and the value of r is varying with locations between medium to large. The Figure 4-29 represents the correlation between evaporation rate and air pressure at Rangpur.

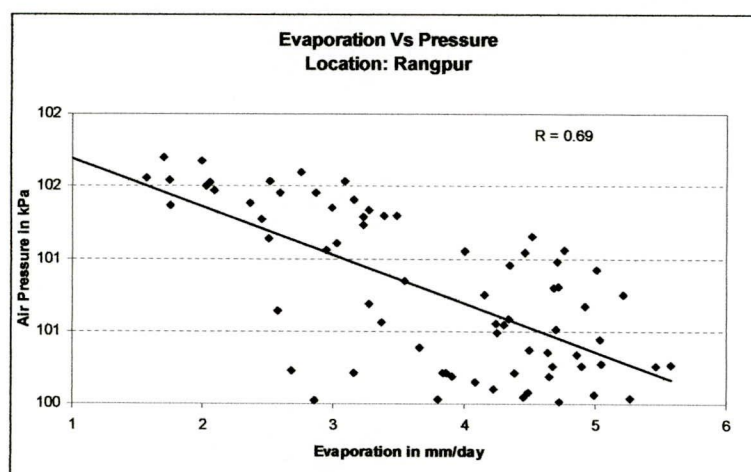


Figure 4-29: Correlation between Evaporation Rate and Air Pressure

Though the average value of r is positive and small in case of bright sunshine hour and rainfall but it changes with locations. That means there is no good correlations between evaporation rate with bright sunshine hour and rainfall and there are some other parameters which have influenced in this case. The Figures 4-30 and 4-31 represent the correlation between evaporation rate with bright sunshine hour and rainfall at Rajshahi and Dinajpur.

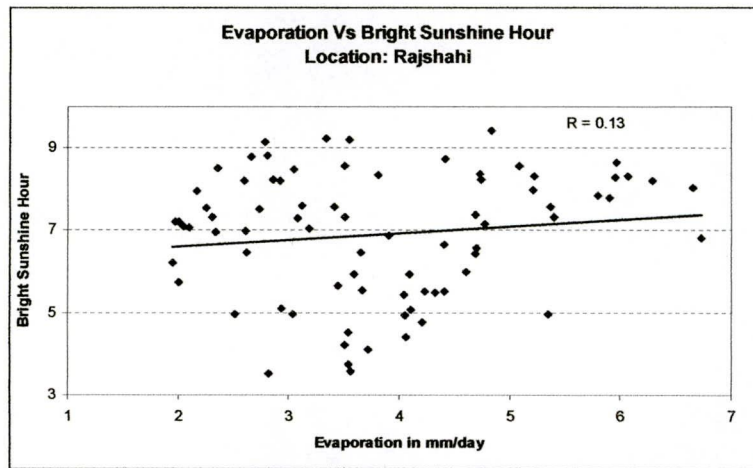


Figure 4-30: Correlation between Evaporation Rate and Bright Sunshine Hour

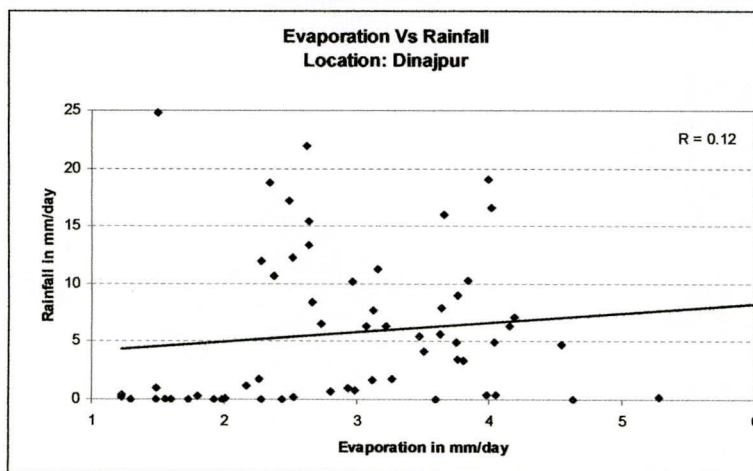


Figure 4-31: Correlation between Evaporation and Rainfall

The same thing can also be said in case of relative humidity but in this case the average value of r is negative.

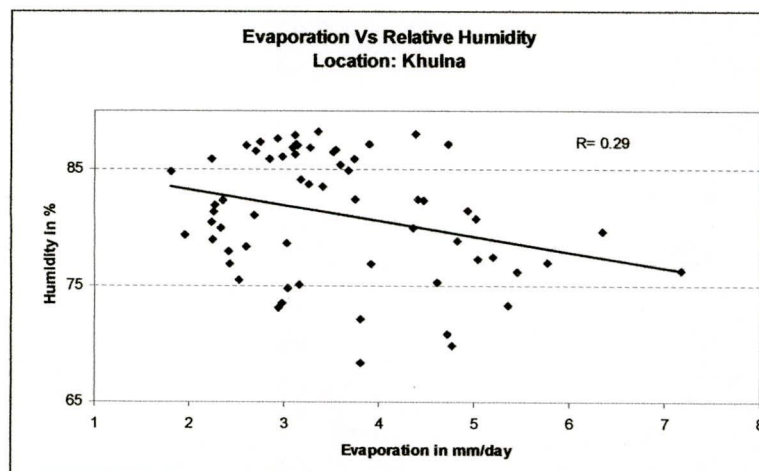


Figure 4-32: Correlation between Evaporation Rate and Relative Humidity

The correlation between evaporation rates with other climatic parameters can be summarized as in Table 4-4.

Table 4-4: Correlation Summary

R_s	T	P	BSH	WS	RH	RF
Positive	Positive	Negative	Positive	Positive	Negative	Positive
Large	Large	Medium	Small	Large	Small	Small

4.3. COMPUTATION OF EVAPORATION RATE USING DIFFERENT METHODS

Four approaches : i) Energy Balance Method ii) Aerodynamic Method iii) Combined Aerodynamic and Energy Balance Method and iv) Priestly-Taylor method have been used in this study for the computation of evaporation rate. In order to study the effectiveness of these methods used in prediction evaporation rate, it is necessary to compare the predictions with the actual evaporation rate. The evaporation rate computed with different methods and actual evaporation rate are given in Table E in Appendix E. The Figure below represents the comparison of evaporation rate computed by different methods with the actual evaporation in Dhaka. The other comparison plots with computed evaporation rates with different methods are given in Appendix F.

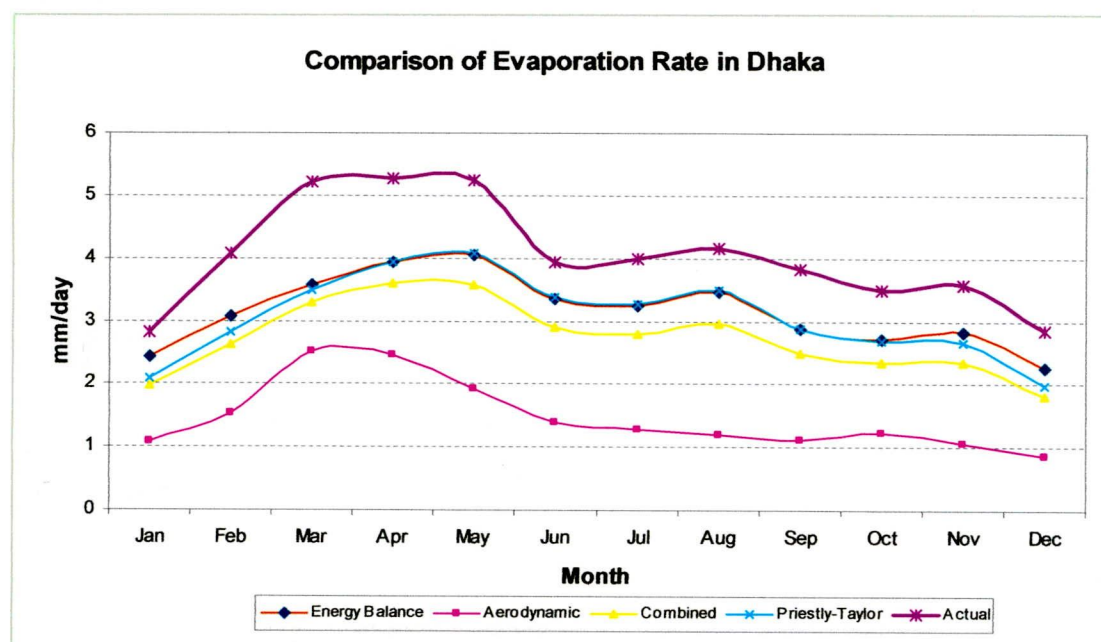


Figure 4-33: Comparison of Evaporation Rate in Dhaka by Different Method

4.4. PERFORMANCE EVALUATION OF DIFFERENT PREDICTION METHODS

Several types of statistics provide useful numerical measures of the degree of agreement between computed and actual quantities. One of such estimation is Root Mean Square Error (RMSE) which is being used to evaluating the results of hydrologic simulation. An RMSE of zero (0), meaning that the computed value is completely match with the actual one with perfect accuracy. The RMSE value between the computed and actual evaporation rate of different seasons in Bangladesh are given in Table 4-5.

Table 4-5: Mean Value between Computed and Actual Evaporation Rate

Computed Method	RMSE All Months	Pre-monsoon	Monsoon	Dry
Energy Balance	1.02	1.50	0.93	0.42
Aerodynamic	2.67	3.11	2.79	2.06
Combined	1.40	1.90	1.35	0.90
Priestly-Taylor	1.14	0.91	0.67	0.61

From Table 4-5 it is found that among the all four methods Energy Balance Method best predicted the actual evaporation rate followed by Priestly-Taylor, Combined and Aerodynamic method. Computed evaporation from Aerodynamic method does not give good agreement with the actual evaporation rate. Again these computed evaporation rate gives good prediction during dry season followed by monsoon and pre-monsoon season.

The correlation coefficient (r) among the computed and actual value are given in the table below in different stations gives a satisfactory value which indicates that the pattern of computed evaporation rate follows the actual evaporation rate. It is also clearly observed from the comparison plots in Appendix F.

Table 4-6 represents the correlation Coefficient (r) between computed and actual evaporation rate at different locations of Bangladesh.

Table 4-6: Correlation Coefficient (r) between Computed and Actual Evaporation Rate

Station Name	Computation Method	r	Station Name	Computation Method	r
Barisal	Energy Balance	0.95	Khulna	Energy Balance	0.91
	Aerodynamic	-		Aerodynamic	0.96
	Combined	-		Combined	0.93
	Priestly-Taylor	0.97		Priestly-Taylor	0.90
Bogra	Energy Balance	0.99	Mymensingh	Energy Balance	0.94
	Aerodynamic	0.89		Aerodynamic	0.96
	Combined	0.99		Combined	0.97
	Priestly-Taylor	0.99		Priestly-Taylor	0.96
Comilla	Energy Balance	0.93	Rajshahi	Energy Balance	-
	Aerodynamic	0.74		Aerodynamic	0.87
	Combined	0.94		Combined	-
	Priestly-Taylor	0.97		Priestly-Taylor	-
Dhaka	Energy Balance	0.95	Rangpur	Energy Balance	0.96
	Aerodynamic	0.91		Aerodynamic	0.86
	Combined	0.97		Combined	0.99
	Priestly-Taylor	0.93		Priestly-Taylor	0.95
Dinajpur	Energy Balance	0.93	Srimangal	Energy Balance	0.92
	Aerodynamic	0.91		Aerodynamic	0.86
	Combined	0.94		Combined	0.94
	Priestly-Taylor	0.91		Priestly-Taylor	0.98
Faridpur	Energy Balance	0.91			
	Aerodynamic	0.94			
	Combined	0.97			
	Priestly-Taylor	0.93			

In Energy Balance method, the main parameters which are involved are the net radiation and temperature. Net radiation data is computed from measured solar radiation data. Though this method gives good results in comparison to other methods but still the computed result is under estimated in compare to actual evaporation rate.

BMD measures solar radiation only one time in a day by using pyranometer. Solar radiation does not vary that much on a clear sky day but on partly cloudy days solar radiation varies on large scale from minute to minute. So radiation data measures only one time in a day does not give representative value of average daily solar radiation. Again continuous measuring of solar radiation is laborious job. This is the probable reason behind error for measuring evaporation rate by Energy Balance Method. The Aerodynamic method gives worst result in computing evaporation rate. In this method lots of parameters are involved like wind speed, air pressure, relative humidity and temperature. The equation involved in this method is restricted for neutral stability conditions, i.e., where temperature, air pressure and wind speed distribution follow nearly adiabatic conditions (no heat exchange). As there is limitation and more parameters are involved, may be this is the probable reason of giving underestimated value of computed evaporation. As wind speed largely varies with time to time, so there is a possibility to get good results for short time period which is not done in this study. The Combined and Priestly-Taylor methods are dependent on Energy Balance and Aerodynamic method. As Energy Balance and Aerodynamic method does not give good results so the other two methods do not give good agreement with the actual evaporation rate.

Finally it can say that no method gives reasonable value of evaporation rate in Bangladesh.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. GENERAL

This study is based on the spatial and temporal variation of evaporation rate and related climatic parameters such as temperature, solar radiation, wind speed, air pressure, relative humidity, bright sunshine hour and rainfall. Arc-View 3.2 GIS tool has been used for creating maps of spatial variation of different climatic parameters for different seasons. The correlation between evaporation rate with the other climatic parameters are also determined by means of Pearson Product Moment Correlation Coefficient. Energy Balance Method, Aerodynamic Method, Combined Energy Balance and Aerodynamic Method and Priestley-Taylor Method have been used for determination of evaporation rate by using other climatic parameters. The computed evaporation rate has been compared with the actual observed evaporation rate and performance evaluation of each method have also identified by estimation of Mean Square Error (MSE).

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5.2. CONCLUSION

This Study supports the following conclusions:

1. In Bangladesh higher rate of evaporation occurs from the month of March to May and in April it is maximum. Minimum evaporation rate occurs in the months of December and January. Yearly maximum evaporation rate occurs in Dhaka (1477 mm) and yearly minimum evaporation occurs in Dinajpur (1184 mm).
2. In Bangladesh temperature is maximum in April or May. The variation of temperature is little from April to September. Temperature begins to decrease from the month of October and falls at lowest in January. The average monthly temperature varies from 9.78°C (Srimangal, January) to 35.92°C (Rajshahi, April).

3. In most of the locations of Bangladesh the solar radiation is high in the month of April and May and low in the month of December and January. The average monthly radiation rate varies from 55.40 watt/m² (Comilla in December) to 141.26 watt/m² (Khulna in May).

4. The air pressure is minimum in the month of June and in some locations in July. On the other hand the air pressure is maximum in December and in few locations it is in the month of January. The variation of air pressure is not that much significant.

5. In Bangladesh the average annual humidity is 79%. In most of the locations maximum amount of humidity occurs in the month of July minimum amount of humidity occurs in March. The range of relative humidity varies from 60% (Teknaf in July) to 89% (Ishurdi in January).

6. Average maximum length of bright sunshine hour occurs in the months between January and April as these months are almost cloud free. In coastal region such as Cox's Bazar and Teknaf the length of bright sunshine hour is highest (9.11 and 9.34 hours) in comparison to other locations of Bangladesh. Minimum number of sunshine hour in all the locations was observed in July. The average minimum number of sunshine hour found in Patuakhali (2.74 hours, July).

7. The maximum rate rainfall occurs in the months of June and July at the time of full monsoon. Average annual maximum rainfall occurs in Sylhet (4100 mm) and minimum rainfall occurs in Rajshahi (1527 mm). The average annual total rainfall of the country is 2354 mm.

8. The wind speed is maximum in the month of April and minimum in the month of November. The maximum intensity of wind speed observed in Rangamati (4.38 m/s, April) and minimum intensity of wind speed observed in Dinajpur (0.27 m/s, November). The average annual wind speed is 1.18 m/s.

9. The correlation coefficient (r) between evaporation rate with solar radiation, temperature and wind speed is large and positive. Evaporation rate will be increased with the increasing value of radiation, temperature and wind speed.
10. On the other hand the correlation coefficient (r) between evaporation rate with bright sunshine hour, relative humidity and rainfall is small but in case of bright sunshine hour and rainfall it is positive and for relative humidity it is negative.
11. Again for air pressure the correlation coefficient is medium and negative. Evaporation rate will be decreased with the increasing value of air pressure.
12. The accuracy of computing evaporation rate by i) Energy Balance Method ii) Aerodynamic Method iii) Combined Method and iv) Priestly-Taylor Method is evaluated by calculating the mean square error (MSE).
13. Energy Balance Method best predicted the actual evaporation rate followed by Priestly-Taylor, Combined and Aerodynamic Method. Computed evaporation from Aerodynamic Method does not give good agreement with the actual evaporation rate. In Energy balance method only temperature and radiation data are required. But in general no method is gives reasonable value in comparison to actual evaporation rate in Bangladesh.
14. These computed evaporation rate gives good prediction during dry season followed by monsoon and pre-monsoon season.
15. The correlation coefficient (r) between the computed and actual evaporation rate gives a satisfactory value which indicates that the pattern of computed evaporation rate follows the actual evaporation rate.

5.3. RECOMMENDATION

The recommendations for future investigations and study can be as follows:

1. The climatic data collected for the study can be used in model like PRECIS to determine evaporation rate and the simulated evaporation rate can be compared with this study.
2. Solar radiation can be calculated with Angstrom formula for which the duration of sunshine (hour) is required. For Bangladesh this formula can be evaluated by comparing with the known value of solar radiation.
3. Trend of temperature is only determined in this study. Trend analysis of other climatic parameters can be determined with the historical data.
4. The global warming and global dimming of different parts of Bangladesh can be identified by using temperature and solar radiation data.

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APPENDIX A
SUMMARY OF AVAILABLE DATA

Table A 1: Summary of Available Evaporation Rate Data

SL No	Evaporation Station		Year																									
	ID	Name	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06		
1	950	Barisal																										
2	883	Bogra																										
3	933	Comilla																										
4	923	Dhaka																										
5	863	Dinajpur																										
6	929	Faridpur																										
7	947	Khulna																										
8	886	Mymensing																										
9	895	Rajshahi																										
10	966	Rangamati																										
11	859	Rangpur																										
12	915	Srimangal																										

Data Available ☒

Data Missing ☐

Table A2: Summary of Available Daily Average Temperature Data

SL No	Temperature Station			Year																															
	ID	Name	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04			
1	950	Barisal																																	
2	883	Bogra																																	
3	941	Chandpur																																	
4	977	Chittagong																																	
5	933	Comilla																																	
6	992	C Bazar																																	
7	923	Dhaka																																	
8	863	Dinajpur																																	
9	929	Faridpur																																	
10	907	Ishurdi																																	
11	936	Jessore																																	
12	984	Khepupara																																	
13	947	Khulna																																	
14	953	Maijdicourt																																	
15	886	Mymensing																																	
16	960	Patuakhali																																	
17	895	Rajshahi																																	
18	966	Rangamati																																	
19	859	Rangpur																																	
20	946	Satkhira																																	
21	915	Srimangal																																	
22	858	Syedpur																																	
23	891	Sylhet																																	
24	909	Tangail																																	
25	998	Teknaf																																	

Data Available 

Data Missing 

Table A3: Summary of Available Solar Radiation Data

SL No	Radiation Station		Year						
	ID	Name	01	02	03	04	05	06	07
1	950	Barisal							
2	883	Bogra							
3	933	Comilla							
4	923	Dhaka							
5	929	Faridpur							
6	947	Khulna							
7	886	Mymensing							
8	859	Rangpur							
9	915	Srimangal							

Table A4: Summary of Available Wind Speed Data

SL No	Wind Speed Station		Year					
	ID	Name	01	02	03	04	05	06
1	883	Bogra						
2	933	Comilla						
3	923	Dhaka						
4	863	Dinajpur						
5	929	Faridpur						
6	947	Khulna						
7	886	Mymensing						
8	895	Rajshahi						
9	966	Rangamati						
10	859	Rangpur						
11	915	Srimangal						

Data Available Data Missing 

Table A5: Summary of Available Air Pressure Data

SL No	Air Pressure Station		Year																																
	ID	Name	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
1	950	Barisal																																	
2	883	Bogra																																	
3	941	Chandpur																																	
4	977	Chittagong																																	
5	933	Comilla																																	
6	923	Dhaka																																	
7	863	Dinajpur																																	
8	929	Faridpur																																	
9	907	Ishurdi																																	
10	936	Jessore																																	
11	984	Khepupara																																	
12	947	Khulna																																	
13	953	Maijdicourt																																	
14	886	Mymensing																																	
15	960	Patuakhali																																	
16	895	Rajshahi																																	
17	966	Rangamati																																	
18	859	Rangpur																																	
19	946	Satkhira																																	
20	915	Srimangal																																	
21	858	Syedpur																																	
22	891	Sylhet																																	
23	909	Tangail																																	
24	998	Teknaf																																	

Data Available 

Data Missing 

Table A6: Summary of Available Relative Humidity Data

SL No	Humidity Station		Year																																
	ID	Name	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
1	950	Barisal																																	
2	883	Bogra																																	
3	941	Chandpur																																	
4	933	Comilla																																	
5	992	C Bazar																																	
6	923	Dhaka																																	
7	863	Dinajpur																																	
8	929	Faridpur																																	
9	907	Ishurdi																																	
10	936	Jessore																																	
11	984	Khepupara																																	
12	947	Khulna																																	
13	953	Maijdicourt																																	
14	886	Mymensing																																	
15	960	Patuakhali																																	
16	895	Rajshahi																																	
17	966	Rangamati																																	
18	859	Rangpur																																	
19	946	Satkhira																																	
20	915	Srimangal																																	
21	858	Syedpur																																	
22	891	Sylhet																																	
23	909	Tangail																																	
24	998	Teknaf																																	

Data Available 

Data Missing 

Table A7: Summary of Available Bright Sunshine Hour Data

SL No	BSH Station		Year																																		
	ID	Name	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07		
1	950	Barisal																																			
2	883	Bogra																																			
3	941	Chandpur																																			
4	933	Comilla																																			
5	992	Cox's Bazar																																			
6	923	Dhaka																																			
7	863	Dinajpur																																			
8	929	Faridpur																																			
9	907	Ishurdi																																			
10	936	Jessore																																			
11	984	Khepupara																																			
12	947	Khulna																																			
13	953	Majdicourt																																			
14	886	Mymensing																																			
15	960	Patuakhali																																			
16	895	Rajshahi																																			
17	966	Rangamati																																			
18	859	Rangpur																																			
19	946	Satkhira																																			
20	915	Srimangal																																			
21	858	Syedpur																																			
22	891	Sylhet																																			
23	909	Tangail																																			
24	998	Teknaf																																			

Data Available Data Missing 

Table A8: Summary of Available Rainfall Data

SL No	Rainfall Station		Year																																			
	ID	Name	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04						
1	950	Barisal																																				
2	883	Bogra																																				
3	941	Chandpur																																				
4	977	Chittagong																																				
5	933	Comilla																																				
6	992	C Bazar																																				
7	923	Dhaka																																				
8	863	Dinajpur																																				
9	929	Faridpur																																				
10	907	Ishurdi																																				
11	936	Jessore																																				
12	984	Khepupara																																				
13	947	Khulna																																				
14	953	Majdicourt																																				
15	886	Mymensing																																				
16	960	Patuakhali																																				
17	895	Rajshahi																																				
18	966	Rangamati																																				
19	859	Rangpur																																				
20	946	Satkhira																																				
21	915	Srimangal																																				
22	858	Syedpur																																				
23	891	Sylhet																																				
24	909	Tangail																																				
25	998	Taknaf																																				

Data Available Data Missing 

APPENDIX B
TEMPORAL VARIATION OF CLIMATIC PARAMETERS

Table B1: Average Monthly, Annual and Seasonal Variation of Evaporation Rate (mm/day) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Dry
Barisal	2.45	3.27	4.41	5.04	4.57	3.37	3.07	3.11	3.05	3.25	2.87	2.54	3.42	4.67	3.17	2.78
Bogra	2.19	3.02	4.51	5.05	4.83	4.31	3.85	4.02	3.49	3.40	2.88	2.30	3.65	4.80	3.81	2.60
Comilla	2.44	3.10	4.14	4.77	4.57	4.12	3.98	4.10	4.06	3.44	3.19	2.52	3.70	4.49	3.94	2.81
Dhaka	2.82	4.09	5.22	5.27	5.25	3.93	3.99	4.15	3.81	3.50	3.57	2.86	4.04	5.25	3.88	3.33
Dinajpur	1.66	2.66	4.52	5.00	4.53	3.74	3.06	3.50	3.00	2.95	2.45	1.77	3.24	4.68	3.25	2.14
Faridpur	2.30	3.30	5.01	5.98	4.91	4.18	3.53	3.78	3.55	3.47	2.96	2.17	3.76	5.30	3.70	2.68
Khulna	2.44	3.15	4.55	5.48	5.14	3.90	3.49	3.37	3.29	3.37	2.91	2.51	3.63	5.06	3.48	2.75
Mymensing	2.15	2.96	4.33	4.96	4.59	3.86	3.76	3.87	3.56	3.36	2.62	2.25	3.52	4.63	3.68	2.49
Rajshahi	2.13	3.08	4.91	5.96	5.53	4.45	3.84	3.71	3.41	3.29	2.85	2.26	3.79	5.47	3.74	2.58
Rangamati	2.82	3.43	4.23	4.27	3.98	3.19	2.94	3.25	3.51	3.47	2.99	2.52	3.38	4.16	3.27	2.94
Rangpur	1.90	3.08	4.76	5.06	4.64	4.26	3.99	4.08	3.46	3.36	2.99	2.24	3.65	4.82	3.83	2.55
Srimangal	2.32	3.21	4.26	4.48	3.96	3.49	3.37	3.42	3.48	3.48	2.92	2.53	3.41	4.23	3.45	2.74

Table B2: Average Total Monthly, Annual and Seasonal Variation of Evaporation (mm) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Dry
Barisal	76	95	137	151	142	101	95	96	92	101	86	79	1250	430	485	336
Bogra	68	88	140	152	150	129	119	125	105	105	86	71	1337	441	583	313
Comilla	76	90	128	143	142	124	123	127	122	107	96	78	1355	413	602	340
Dhaka	88	119	162	158	163	118	124	129	114	108	107	89	1477	483	593	402
Dinajpur	52	77	140	150	140	112	95	108	90	91	74	55	1185	430	497	257
Faridpur	71	96	155	179	152	125	109	117	106	108	89	67	1376	487	566	323
Khulna	76	91	141	164	159	117	108	104	99	104	87	78	1330	465	533	332
Mymensing	67	86	134	149	142	116	116	120	107	104	79	70	1289	425	563	301
Rajshahi	66	89	152	179	172	133	119	115	102	102	86	70	1385	503	572	311
Rangamati	87	99	131	128	123	96	91	101	105	108	90	78	1238	383	501	355
Rangpur	59	89	148	152	144	128	124	126	104	104	90	70	1336	443	586	307
Srimangal	72	93	132	134	123	105	105	106	104	108	87	78	1247	389	528	331

Table B3: Average Monthly, Annual and Seasonal Variation of Temperature (Degree Centigrade) at Different Locations of Bangladesh

Station Name	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Pre-Monsoon	Monsoon	Dry
Barisal	17.94	21.32	25.87	28.18	28.76	28.50	28.12	28.27	28.14	27.18	23.67	19.23	25.42	27.60	28.04	20.54
Bogra	17.86	20.93	25.22	27.98	28.18	28.68	28.57	28.87	28.06	26.42	22.69	18.67	25.22	27.12	28.12	20.03
Chandpur	18.60	21.44	25.75	27.99	28.62	28.64	28.36	28.60	28.44	27.49	24.25	20.08	25.64	27.45	28.31	21.09
Chittagong	19.68	22.17	25.66	27.74	28.54	28.19	27.85	28.00	28.18	27.59	24.87	21.03	25.79	27.32	27.96	21.94
Comilla	18.36	21.30	25.03	27.08	27.95	28.19	27.97	28.26	28.02	26.97	23.55	19.50	25.18	26.69	27.88	20.68
Cox's Bazar	20.34	22.58	25.89	28.11	28.72	27.64	27.32	27.43	27.72	27.52	25.00	21.58	25.82	27.57	27.53	22.38
Dhaka	18.50	21.69	26.19	28.24	28.50	28.77	28.55	28.83	28.42	27.32	23.98	19.81	25.73	27.65	28.38	21.00
Dinajpur	16.64	19.77	24.37	27.29	28.09	28.88	28.70	29.14	28.20	26.68	22.72	18.44	24.91	26.58	28.32	19.39
Faridpur	17.97	21.11	25.88	28.44	28.66	28.74	28.55	28.87	28.61	27.47	23.91	19.48	25.62	27.66	28.45	20.62
Ishurdi	16.62	19.78	25.00	28.62	28.79	28.85	28.43	28.66	28.18	26.63	22.67	18.21	25.66	27.47	28.15	19.32
Jessore	17.72	21.23	26.14	29.13	29.58	29.13	28.66	28.71	28.41	27.12	23.28	18.81	26.20	28.28	28.41	20.26
Khepupara	19.61	22.68	26.60	28.70	29.37	29.25	28.40	28.35	28.38	27.63	24.55	20.71	25.93	28.22	28.40	21.89
Khulna	18.42	21.75	26.36	28.88	29.40	29.07	28.69	28.76	28.53	27.64	24.18	19.69	25.90	28.21	28.54	21.01
Maijdicourt	19.08	21.78	25.80	28.15	28.78	28.51	28.14	28.39	28.43	27.87	24.74	20.65	25.36	27.58	28.27	21.56
Mymensing	18.24	21.01	25.11	27.32	27.73	28.45	28.42	28.82	28.27	27.24	23.94	19.73	25.99	26.72	28.24	20.73
Patuakhali	19.29	22.37	26.42	28.45	29.14	28.76	28.31	28.43	28.33	27.69	24.59	20.57	25.21	28.00	28.30	21.71
Rajshahi	16.81	19.96	25.16	28.86	29.11	29.08	28.57	28.78	28.36	26.74	22.76	18.32	25.33	27.71	28.30	19.46
Rangamati	18.79	21.54	25.57	27.67	28.14	27.80	27.42	27.73	27.74	27.05	23.96	20.26	24.18	27.13	27.55	21.14
Rangpur	16.62	19.19	23.47	25.79	26.83	27.95	28.00	28.47	27.60	25.93	22.20	18.30	26.41	25.37	27.59	19.08
Satkhira	18.91	22.45	27.11	29.77	30.38	29.69	28.96	28.90	28.68	27.76	24.38	20.02	25.60	29.09	28.80	21.44
Srimangal	16.68	19.91	24.12	26.67	27.11	27.85	27.93	28.14	27.63	26.28	22.36	18.25	24.41	25.97	27.56	19.30
Syedpur	15.99	19.52	23.77	25.94	27.62	28.49	28.81	29.38	28.20	26.38	22.52	18.52	24.60	25.78	28.25	19.14
Sylhet	18.33	20.31	23.93	25.69	26.57	27.37	27.55	28.01	27.41	26.23	23.14	19.48	24.52	25.40	27.31	20.32
Taknaf	21.61	23.49	26.31	28.35	29.08	27.77	27.49	27.53	27.96	27.91	25.77	22.74	26.33	27.91	27.73	23.40
Tangail	16.93	20.35	24.69	27.67	28.08	28.58	28.47	28.73	28.20	26.86	23.11	18.77	25.02	26.81	28.17	19.79

Table B4: Average Monthly, Annual and Seasonal Variation of Solar Radiation (Watt/m²) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-monsoon	Monsoon	Dry
Barisal	82.93	100.70	105.38	117.44	107.14	81.81	71.95	73.65	74.29	67.03	76.90	78.61	86.49	109.98	73.75	84.79
Bogra	76.46	99.82	121.21	122.33	119.14	102.07	95.43	99.98	95.86	87.28	87.72	80.28	98.96	120.89	96.12	86.07
Comilla	60.03	76.65	88.62	90.59	84.60	71.53	70.15	76.87	71.75	68.49	59.57	55.40	72.85	87.93	71.76	62.91
Dhaka	83.77	105.00	115.45	121.66	123.69	98.01	94.33	102.54	84.24	81.75	95.98	76.55	98.58	120.26	92.17	90.32
Faridpur	57.79	68.39	75.77	77.38	77.77	61.89	63.02	68.43	56.65	61.67	67.90	64.55	66.77	76.97	62.33	64.66
Khulna	94.52	126.46	127.50	135.00	141.26	116.39	114.18	112.27	102.97	97.58	107.78	95.37	114.27	134.59	108.68	106.03
Mymensing	57.93	74.08	84.95	89.97	90.23	68.23	67.22	82.08	67.40	64.47	69.87	61.62	73.17	88.38	69.88	65.87
Rangpur	58.82	77.56	92.49	87.83	91.45	74.91	79.20	80.34	75.24	67.19	74.89	64.02	77.00	90.59	75.38	68.82
Srimangal	77.59	93.57	104.15	112.21	103.47	83.51	87.33	100.52	93.23	87.62	85.99	80.07	92.44	106.61	90.45	84.31

Table B5: Average Monthly, Annual and Seasonal Variation of Wind Speed (m/s) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Pre-monsoon	Monsoon	Dry
Bogra	0.62	0.75	0.96	1.22	1.20	1.16	1.14	1.12	0.75	0.53	0.46	0.47	0.86	1.13	0.94	0.58
Comilla	1.08	1.23	1.33	1.67	1.62	1.64	1.73	1.37	1.01	0.88	0.67	0.76	1.25	1.54	1.33	0.93
Dhaka	1.11	1.09	1.28	1.46	1.45	1.38	1.43	1.19	1.18	1.08	0.89	0.89	1.20	1.40	1.25	0.99
Dinajpur	0.33	0.49	0.57	0.59	0.58	0.79	0.80	0.52	0.48	0.62	0.27	0.41	0.54	0.58	0.64	0.37
Faridpur	0.78	0.94	1.27	1.77	1.48	1.37	1.42	1.22	0.88	0.61	0.42	0.54	1.06	1.51	1.10	0.67
Khulna	0.47	0.53	0.61	1.02	0.97	0.78	0.78	0.63	0.57	0.44	0.36	0.38	0.63	0.87	0.64	0.43
Mymensing	0.73	1.07	1.29	1.68	1.79	1.93	1.93	1.83	1.35	0.97	0.63	0.56	1.31	1.59	1.60	0.75
Rajshahi	0.84	0.93	1.14	1.49	1.47	1.36	1.42	1.34	1.08	0.66	0.54	0.81	1.09	1.37	1.17	0.78
Rangamati	3.48	3.48	3.83	4.38	4.04	3.63	3.68	3.15	3.18	3.09	2.67	2.65	3.44	4.08	3.34	3.07
Rangpur	0.49	0.71	1.04	1.55	1.33	1.05	0.97	0.79	0.59	0.82	0.52	0.64	0.88	1.31	0.84	0.59
Srimangal	0.38	0.74	1.20	1.07	1.08	1.03	0.82	0.81	0.44	0.56	0.33	0.65	0.76	1.12	0.73	0.52

Table B6: Average Monthly, Annual and Seasonal Variation of Air Pressure (Kilo Pascal) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Pre-monsoon	Monsoon	Dry
Barisal	101.50	101.29	101.02	100.74	100.43	100.07	100.11	100.19	100.56	100.95	101.27	101.51	100.80	100.73	100.38	101.39
Bogra	101.52	101.30	100.93	100.64	100.35	100.14	100.03	100.15	100.54	100.95	101.29	101.55	100.78	100.64	100.36	101.42
Chandpur	101.43	101.29	101.04	100.77	100.45	100.05	100.14	100.21	100.32	100.96	101.28	101.47	100.78	100.75	100.34	101.37
Chittagong	101.52	101.42	101.07	100.94	100.58	100.35	100.36	100.41	100.75	100.98	101.31	101.49	100.93	100.87	100.57	101.43
Comilla	101.51	101.33	101.05	100.79	100.50	100.15	100.18	100.26	100.62	100.99	101.29	101.52	100.85	100.78	100.44	101.41
Dhaka	101.51	101.31	100.99	100.70	100.41	100.06	100.10	100.19	100.56	100.96	101.28	101.50	100.80	100.70	100.37	101.40
Dinajpur	101.51	101.28	100.91	100.61	100.34	99.96	99.97	100.11	100.48	100.96	101.31	101.55	100.75	100.62	100.30	101.41
Faridpur	101.48	101.29	100.96	100.66	100.35	99.98	100.04	100.11	100.51	100.93	101.26	101.50	100.76	100.65	100.31	101.39
Ishurdi	101.55	101.00	100.98	100.65	100.35	99.97	100.04	100.15	100.53	100.99	101.32	101.57	100.76	100.66	100.33	101.36
Jessore	101.52	101.30	100.98	100.67	100.36	99.99	100.01	100.11	100.52	100.94	101.28	101.53	100.77	100.67	100.31	101.41
Khepupara	101.49	101.31	101.03	100.76	100.43	100.07	100.08	100.17	100.55	100.96	101.22	101.50	100.80	100.74	100.37	101.38
Khulna	101.50	101.30	101.00	100.70	100.36	100.01	100.06	100.14	100.53	100.97	101.29	101.53	100.78	100.69	100.34	101.40
Maijdicourt	101.47	101.30	101.02	100.77	100.46	100.10	100.16	100.22	100.57	100.94	101.26	101.49	100.81	100.75	100.40	101.38
Mymensing	101.54	101.30	101.03	100.74	100.40	100.11	100.13	100.22	100.60	101.00	101.27	101.57	100.83	100.72	100.41	101.42
Patuakhali	101.48	101.31	101.02	100.74	100.42	100.07	100.11	100.17	100.54	100.95	101.25	101.49	100.80	100.73	100.37	101.38
Rajshahi	101.57	101.35	100.98	100.64	100.34	99.99	100.03	100.14	100.53	101.00	101.34	101.60	100.79	100.65	100.34	101.46
Rangamati	101.54	101.4	101.10	100.88	100.57	100.28	100.31	100.36	100.70	101.05	101.34	101.56	100.92	100.85	100.54	101.45
Rangpur	101.55	101.35	100.99	100.73	100.46	100.11	100.13	100.24	100.61	101.04	101.36	101.59	100.85	100.73	100.42	101.46
Satkhira	101.54	101.34	101.01	100.69	100.37	100.01	100.05	100.14	100.53	100.97	101.18	101.56	100.78	100.69	100.34	101.40
Srimangal	101.52	101.36	101.07	100.84	100.57	100.00	100.27	100.34	100.60	100.99	101.31	101.54	100.87	100.83	100.44	101.43
Syedpur	101.56	101.35	100.93	100.73	100.36	100.02	100.03	100.15	100.43	101.02	101.34	101.55	100.79	100.67	100.33	101.45
Sylhet	101.46	101.31	101.02	100.78	100.50	100.17	100.19	100.26	100.61	100.98	101.28	101.52	100.84	100.77	100.44	101.39
Taknaf	101.39	101.26	101.07	100.87	100.58	100.28	100.31	100.35	100.65	100.99	101.20	101.41	100.86	100.84	100.52	101.32
Tangail	101.48	101.44	100.95	100.68	100.37	100.04	100.04	100.19	100.53	100.95	101.28	101.50	100.79	100.67	100.35	101.42

Table B7: Average Monthly, Annual and Seasonal Variation of Relative Humidity (%) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-monsoon	Monsoon	Dry
Barisal	77.21	75.31	74.74	79.60	82.96	87.70	89.06	88.65	88.01	85.51	81.40	79.06	82.43	79.10	87.78	78.24
Bogra	75.75	69.55	64.22	70.16	78.32	84.08	86.26	85.34	86.27	82.46	77.53	77.23	78.10	70.90	84.88	75.01
Chandpur	76.70	73.21	72.76	77.39	80.47	84.76	86.14	85.32	85.06	82.49	78.88	78.37	80.13	76.87	84.76	76.79
Comilla	73.86	73.60	76.05	80.43	81.70	85.69	86.88	85.85	85.99	83.75	79.39	75.87	80.75	79.39	85.63	75.68
Cox's Bazar	71.91	71.36	74.95	78.20	80.61	86.67	88.32	87.57	85.63	82.16	77.14	74.07	79.88	77.92	86.07	73.62
Dhaka	70.84	64.70	62.18	71.27	77.51	83.28	84.74	83.23	83.73	79.67	73.87	73.08	75.68	70.32	82.93	70.62
Dinajpur	76.81	69.37	61.33	65.98	75.82	81.28	84.43	83.82	85.37	81.51	76.93	77.23	76.66	67.71	83.28	75.08
Faridpur	76.04	70.89	66.15	72.40	79.74	85.85	87.37	85.69	85.35	81.93	77.85	77.60	78.90	72.76	85.24	75.60
Ishurdi	74.68	68.83	60.31	64.72	74.73	82.66	86.02	85.25	85.25	82.09	76.86	75.31	76.39	66.58	84.26	73.92
Jessore	75.59	71.21	67.02	71.08	76.37	84.07	87.37	86.83	86.42	82.70	78.08	76.91	78.64	71.49	85.48	75.45
Khepupara	72.95	72.25	74.78	78.58	80.51	85.90	88.06	87.50	86.76	84.63	79.84	75.90	80.64	77.96	86.57	75.24
Khulna	74.67	71.98	70.81	76.03	79.79	85.43	87.29	86.66	86.68	82.91	78.63	76.65	79.79	75.55	85.80	75.48
Majdicourt	75.91	74.28	74.04	77.77	80.70	85.62	87.08	86.28	85.16	82.10	78.49	77.82	80.44	77.50	85.25	76.62
Mymensing	74.15	69.40	67.98	74.63	80.73	85.42	86.54	85.22	85.95	82.47	77.34	76.08	78.83	74.45	85.12	74.24
Patuakhali	73.38	72.26	73.51	79.82	82.53	87.12	88.65	87.95	86.97	83.73	79.12	75.39	80.87	78.62	86.88	75.04
Rajshahi	75.97	69.80	60.85	64.41	75.07	83.33	87.54	86.41	85.82	82.37	77.69	76.73	77.17	66.78	85.10	75.05
Rangamati	75.99	69.93	68.60	73.18	78.33	84.13	85.75	85.13	84.71	83.49	81.78	80.06	79.26	73.37	84.64	76.94
Rangpur	80.36	75.21	67.51	73.57	80.75	85.24	86.51	85.51	87.14	84.75	80.82	80.47	80.65	73.95	85.83	79.21
Satkhira	71.61	68.46	66.40	70.57	73.94	81.55	85.24	85.63	85.32	80.86	74.71	72.58	76.40	70.30	83.72	71.84
Srimangal	78.85	72.83	70.89	75.17	80.60	84.60	85.15	85.01	86.04	84.63	81.86	81.12	80.56	75.55	85.09	78.67
Syedpur	76.03	68.58	61.24	67.64	76.37	81.81	83.33	82.57	83.20	79.06	74.33	74.17	75.69	68.42	81.99	73.28
Sylhet	73.59	68.35	67.30	75.72	81.19	86.59	87.12	85.78	86.13	82.83	77.13	74.48	78.85	74.73	85.69	73.39
Taknaf	66.18	66.64	71.25	76.39	79.42	87.55	89.10	88.85	86.12	82.12	75.14	69.47	78.19	75.69	86.75	69.36
Tangail	78.86	74.27	69.52	74.15	80.13	84.92	86.09	85.37	86.02	83.57	80.71	80.51	80.34	74.60	85.19	78.59

Table B8: Average Monthly, Annual and Seasonal Variation of Bright Sunshine (Hour) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-monsoon	Monsoon	Dry
Barisal	7.75	8.20	8.09	8.09	7.01	3.98	3.65	4.31	4.76	6.94	7.71	7.57	7.73	7.73	4.73	7.81
Bogra	7.18	8.02	8.69	7.92	7.18	5.07	4.26	5.18	5.25	7.29	7.95	7.62	7.93	7.93	5.41	7.69
Chandpur	5.92	6.97	6.99	7.11	5.88	3.56	3.42	3.92	4.36	6.14	6.71	6.03	6.66	6.66	4.28	6.41
Comilla	7.09	7.76	7.96	7.79	6.87	4.83	4.37	5.22	5.29	6.87	7.63	7.20	7.54	7.54	5.32	7.42
Cox's Bazar	9.05	9.11	9.02	8.69	7.45	4.04	3.58	4.56	5.93	7.59	8.39	8.83	8.39	8.39	5.14	8.85
Dhaka	7.20	7.85	8.13	7.99	7.09	4.83	4.19	5.18	5.05	6.84	7.58	7.39	7.74	7.74	5.22	7.50
Dinajpur	5.81	7.38	8.24	7.35	6.89	4.91	4.28	5.26	5.15	7.10	7.92	7.11	7.50	7.50	5.34	7.06
Faridpur	7.27	8.02	7.97	8.00	7.26	4.95	4.30	5.04	5.06	6.96	7.72	7.67	7.74	7.74	5.26	7.67
Ishurdi	7.02	7.93	8.15	8.25	7.38	5.10	4.16	5.04	5.09	7.14	7.74	7.35	7.93	7.93	5.31	7.51
Jessore	6.92	7.57	7.75	7.91	7.25	4.75	3.90	4.51	4.72	6.53	7.18	6.97	7.64	7.64	4.88	7.16
Khepupara	7.07	7.53	7.49	7.55	6.37	3.84	3.48	4.09	4.50	5.87	6.96	7.11	7.14	7.14	4.36	7.17
Khulna	7.54	8.08	8.28	8.55	7.66	4.53	3.72	4.47	4.80	6.99	7.70	7.79	8.16	8.16	4.90	7.78
Majdicourt	7.57	7.80	7.89	7.73	6.63	3.97	3.34	4.42	4.94	6.94	7.59	7.89	7.42	7.42	4.72	7.71
Mymensing	6.39	7.32	7.31	7.06	6.17	4.05	3.67	4.48	4.13	6.48	7.62	7.07	6.85	6.85	4.56	7.10
Patuakhali	6.87	7.27	7.57	7.10	5.90	2.95	2.74	3.60	3.91	5.62	6.53	6.88	6.85	6.85	3.76	6.89
Rajshahi	7.10	8.21	8.42	8.30	7.53	5.45	4.34	5.18	5.31	7.44	8.10	7.70	8.08	8.08	5.54	7.78
Rangamati	7.54	8.20	7.98	7.90	6.36	4.35	3.61	4.81	5.26	6.56	7.35	7.58	7.41	7.41	4.92	7.67
Rangpur	6.62	7.67	8.01	7.22	6.64	4.98	4.28	5.22	5.09	7.20	8.30	7.44	7.29	7.29	5.36	7.51
Satkhira	7.37	8.00	8.44	8.77	8.00	4.50	3.78	4.57	5.13	6.92	7.60	7.70	8.40	8.40	4.98	7.67
Srimangal	6.99	7.95	7.68	7.56	6.24	4.45	4.21	4.96	4.84	6.66	7.90	7.74	7.16	7.16	5.02	7.65
Syedpur	5.77	7.36	8.28	7.38	6.76	4.67	4.42	4.95	5.02	7.20	7.66	6.87	7.47	7.47	5.25	6.92
Sylhet	7.51	7.80	7.61	6.58	5.83	3.74	3.52	4.52	4.54	6.98	8.17	8.17	6.68	6.68	4.66	7.91
Taknaf	9.34	9.08	9.07	8.97	7.35	3.56	2.92	3.85	5.29	7.49	8.07	8.85	8.46	8.46	4.62	8.84
Tangail	6.68	7.61	7.77	7.69	6.40	4.34	4.00	4.68	4.52	6.76	7.52	7.21	7.29	7.29	4.86	7.25

Table B9: Average Monthly, Annual and Seasonal Variation of Rainfall (mm/day) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Dry
Barisal	0.30	0.89		3.95	6.98	13.95	13.35	11.72	9.22	5.44	1.60	0.24	6.15	5.47	10.74	0.76
Bogra	0.25	0.46	0.63	2.61	6.83	10.66	12.98	9.20	10.15	4.56	0.41	0.35	4.92	3.35	9.51	0.37
Chandpur	0.20	0.75	1.96	4.85	8.54	12.33	13.11	11.03	9.24	4.37	1.39	0.24	5.67	5.12	10.02	0.64
Chittagong	0.16	0.85	1.66	4.56	9.67	19.86	22.80	16.01	8.63	6.57	2.17	0.41	7.78	5.30	14.77	0.90
Comilla	0.22	0.94	2.03	4.92	10.12	11.89	13.34	9.84	7.98	4.85	1.32	0.33	5.65	5.69	9.58	0.70
Cox's Bazar	0.15	0.64	1.02	3.79	9.78	26.65	28.76	21.01	11.83	6.82	3.49	0.46	9.53	4.86	19.02	1.18
Dhaka	0.23	0.83	2.06	4.87	10.30	11.50	11.60	9.55	10.66	5.70	1.09	0.40	5.73	5.74	9.80	0.64
Dinajpur	0.37	0.41	0.43	2.45	7.17	11.74	15.21	11.71	13.32	4.87	0.30	0.33	5.69	3.35	11.37	0.35
Faridpur	0.20	1.03	1.59	4.24	8.15	11.40	10.42	9.42	8.78	5.14	1.13	0.38	5.16	4.66	9.03	0.69
Ishurdi	0.20	0.75	0.98	3.00	6.29	9.67	10.78	7.40	9.53	3.24	0.59	0.29	4.39	3.42	8.12	0.46
Jessore	0.43	0.93	1.37	2.51	5.72	10.58	10.05	8.82	8.56	4.21	0.98	0.45	4.55	3.20	8.44	0.70
Khepupara	0.20	0.85	1.48	3.21	8.45	16.88	19.27	15.67	12.16	7.76	2.03	0.24	7.35	4.38	14.35	0.83
Khulna	0.37	1.35	1.66	2.79	6.21	11.85	9.75	10.55	8.81	4.28	1.19	0.25	4.92	3.55	9.05	0.79
Majdicourt	0.32	0.89	2.41	4.90	10.88	17.82	23.65	19.05	12.58	6.11	1.62	0.24	8.37	6.06	15.84	0.77
Mymensing	0.22	0.74	1.14	4.67	11.05	12.87	14.16	9.99	11.12	6.54	0.59	0.31	6.12	5.62	10.94	0.46
Patuakhali	0.24	0.80	1.27	3.94	8.02	18.32	17.53	14.94	12.08	5.83	1.93	0.19	7.09	4.41	13.74	0.79
Rajshahi	0.32	0.59	0.71	2.18	4.51	8.68	10.41	8.25	9.57	3.93	0.47	0.35	4.17	2.47	8.17	0.43
Rangamati	0.15	0.81	1.92	4.63	10.62	17.17	18.95	13.85	9.68	5.03	1.96	0.42	7.10	5.72	12.94	0.84
Rangpur	0.26	0.39	0.76	3.95	9.03	15.22	15.84	11.22	12.71	5.18	0.27	0.30	6.26	4.58	12.04	0.31
Satkhira	0.40	1.35	1.26	2.97	5.05	9.84	11.17	9.39	9.31	4.25	1.03	0.26	4.69	3.09	8.79	0.76
Srimangal	0.15	0.96	2.66	6.95	13.35	14.79	11.05	10.11	9.49	5.31	1.21	0.46	6.37	7.65	10.15	0.69
Syedpur	0.36	0.28	1.00	3.25	7.68	15.14	14.38	10.44	14.59	5.62	0.36	0.24	6.11	3.98	12.03	0.31
Sylhet	0.21	1.20	4.46	12.18	18.08	25.25	26.95	19.54	17.79	7.06	1.05	0.41	11.18	11.57	19.32	0.72
Taknaf	0.06	0.52	0.49	2.18	8.47	32.34	32.13	29.19	13.91	7.10	2.60	0.26	10.77	3.72	22.93	0.86
Tangail	0.21	1.00	1.58	4.33	8.81	10.24	10.65	8.16	10.02	4.65	0.99	0.40	5.09	4.91	8.74	0.65

Table B10: Average Monthly, Annual and Seasonal Variation of Total Rainfall (mm/day) at Different Locations of Bangladesh

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Pre-Monsoon	Monsoon	Dry
Barisal	9.20	24.90	50.17	118.50	216.53	418.63	414.00	363.37	276.57	168.67	47.87	7.53	2115.93	385.20	1641.23	89.50
Bogra	7.60	12.77	19.50	78.20	211.63	319.77	402.30	285.33	304.40	141.40	12.33	10.83	1806.07	309.33	1453.20	43.53
Chandpur	6.14	20.93	60.79	145.46	264.64	369.93	406.43	341.86	277.32	135.50	41.61	7.39	2078.00	470.89	1531.04	76.07
Chittagong	5.03	23.70	51.40	136.93	299.63	595.90	706.73	496.27	259.03	203.57	65.10	12.57	2855.87	487.97	2261.50	106.40
Comilla	6.97	26.31	62.97	147.72	313.76	356.66	413.41	305.07	239.38	150.31	39.72	10.21	2072.48	524.45	1464.83	83.21
Cox's Bazar	4.57	17.87	31.50	113.77	303.17	799.40	891.70	651.30	354.97	211.53	104.67	14.40	3498.83	448.43	2908.90	141.50
Dhaka	7.10	23.23	63.90	146.20	319.27	345.03	359.53	296.20	319.77	176.60	32.83	12.30	2101.97	529.37	1497.13	75.47
Dinajpur	11.42	11.54	13.25	73.38	222.38	352.33	471.50	362.96	399.58	151.00	8.88	10.38	2088.58	309.00	1737.38	42.21
Faridpur	6.33	28.73	49.33	127.30	252.63	342.03	322.97	291.87	263.40	159.40	33.97	11.77	1889.73	429.27	1379.67	80.80
Ishurdi	6.10	20.87	30.40	89.90	195.00	290.13	334.13	229.30	285.97	100.53	17.60	9.07	1609.00	315.30	1240.07	53.63
Jessore	13.38	25.93	42.41	75.45	177.28	317.45	311.55	273.28	256.72	130.55	29.34	13.86	1667.21	295.14	1289.55	82.52
Khepupara	6.10	23.83	45.87	96.40	262.00	506.50	597.23	485.63	364.67	240.70	61.03	7.53	2697.50	404.27	2194.73	98.50
Khulna	11.38	37.69	51.52	83.55	192.45	355.52	302.17	326.90	264.21	132.76	35.62	7.72	1801.48	327.52	1381.55	92.41
Maijdicourt	9.93	24.89	74.86	146.93	337.29	534.68	733.29	590.50	377.46	189.50	48.64	7.50	3075.46	559.07	2425.43	90.96
Mymensing	6.70	20.60	35.33	140.10	342.67	386.07	439.07	309.57	333.47	202.83	17.83	9.57	2243.80	518.10	1671.00	54.70
Patuakhali	7.52	22.41	39.48	118.07	248.55	549.72	543.48	463.28	362.45	180.69	57.90	5.86	2599.41	406.10	2099.62	93.69
Rajshahi	9.87	16.60	22.10	65.43	139.73	260.40	322.83	255.90	287.03	121.87	14.23	10.87	1526.87	227.27	1248.03	51.57
Rangamati	4.80	22.77	59.60	138.80	329.13	515.20	587.40	429.47	290.33	155.83	58.93	13.13	2605.40	527.53	1978.23	99.63
Rangpur	8.17	11.03	23.50	118.40	279.90	456.63	491.10	347.93	381.30	160.73	8.20	9.27	2296.17	421.80	1837.70	36.67
Satkira	12.30	37.80	39.13	89.00	156.43	295.23	346.33	290.97	279.40	131.63	30.83	7.97	1717.03	284.57	1343.57	88.90
Srimangal	4.55	26.86	82.38	208.52	413.72	443.69	342.55	313.41	284.83	164.76	36.41	14.17	2335.86	704.62	1549.24	82.00
Syedpur	11.29	7.71	31.14	97.50	238.21	454.29	445.64	323.50	437.64	174.14	10.71	7.43	2239.21	366.86	1835.21	37.14
Sylhet	6.63	33.60	138.40	365.40	560.43	757.43	835.50	605.77	533.60	218.97	31.37	12.80	4099.90	1064.23	2951.27	84.40
Taknaf	1.71	14.50	15.32	65.50	262.68	970.14	995.93	904.79	417.36	219.96	78.07	8.04	3954.00	343.50	3508.18	102.32
Tangail	6.61	27.94	48.89	130.00	273.11	307.11	330.22	252.83	300.56	144.00	29.56	12.50	1863.33	452.00	1334.72	76.61

APPENDIX C
SPATIAL VARIATION OF CLIMATIC PARAMETERS

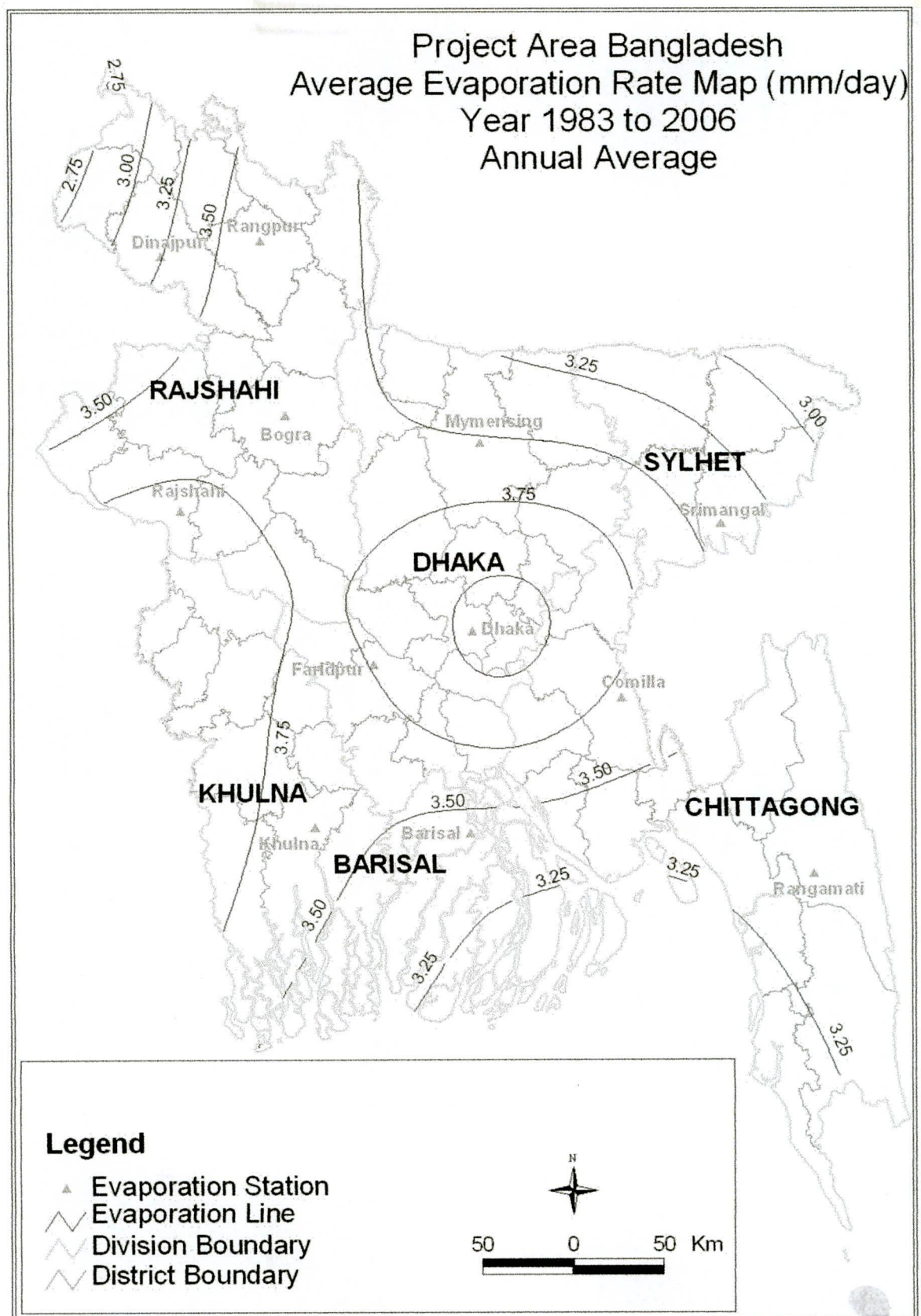


Figure C1: Annual Average Evaporation Rate Map

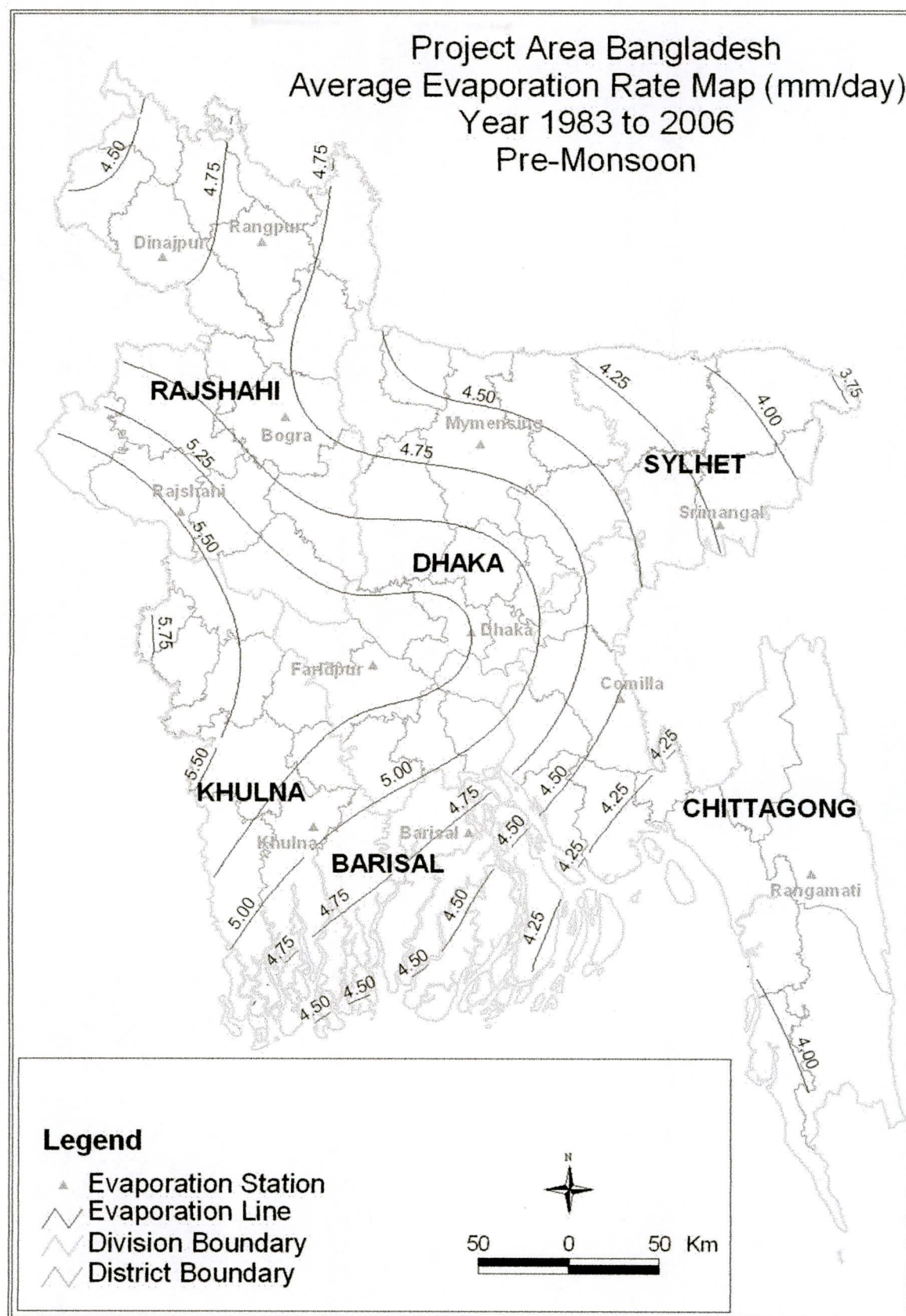


Figure C2: Average Evaporation Rate Map for Pre-Monsoon

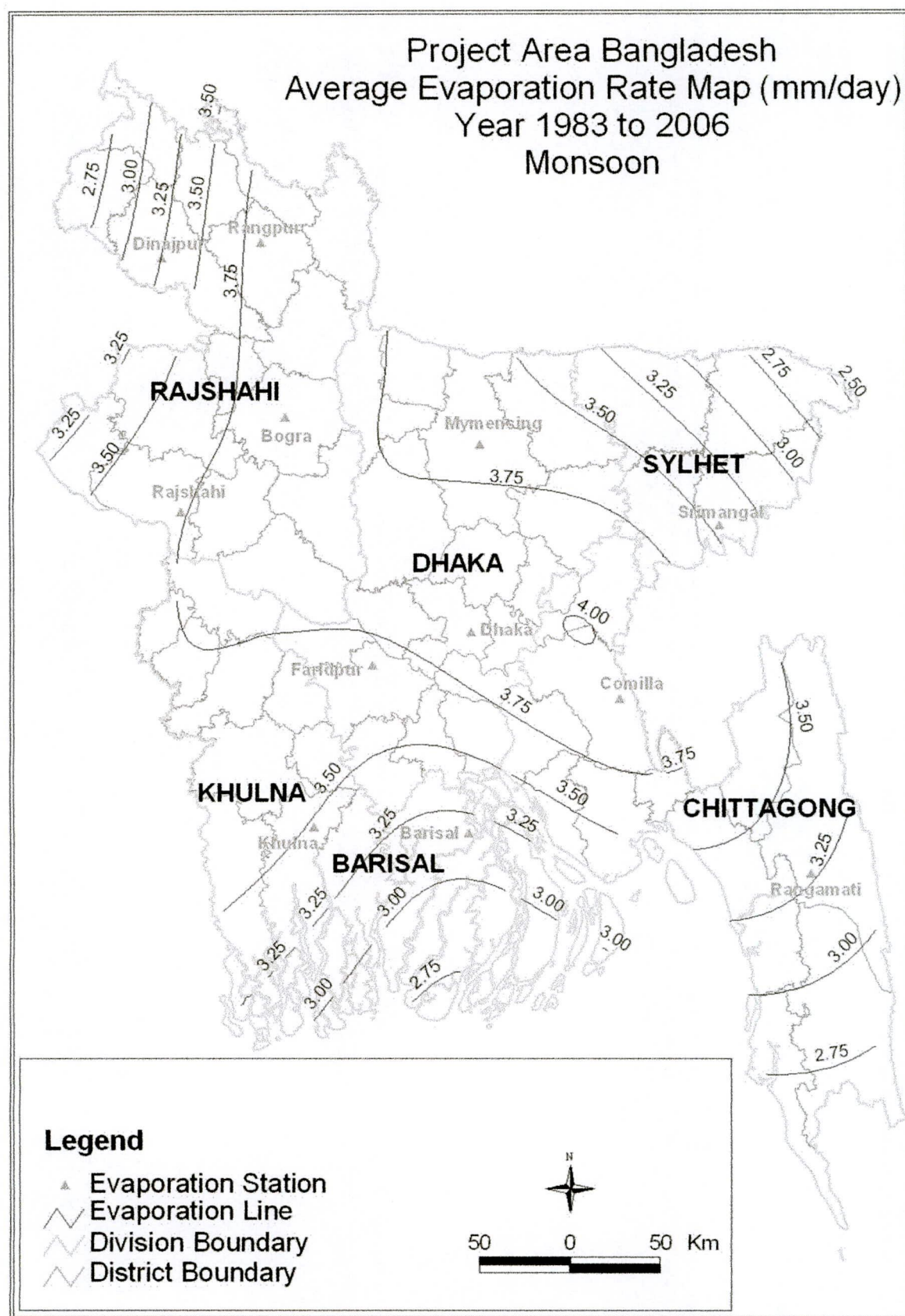


Figure C3: Average Evaporation Rate Map for Monsoon

Project Area Bangladesh
Average Evaporation Rate Map (mm/day)
Year 1983 to 2006
Dry Period

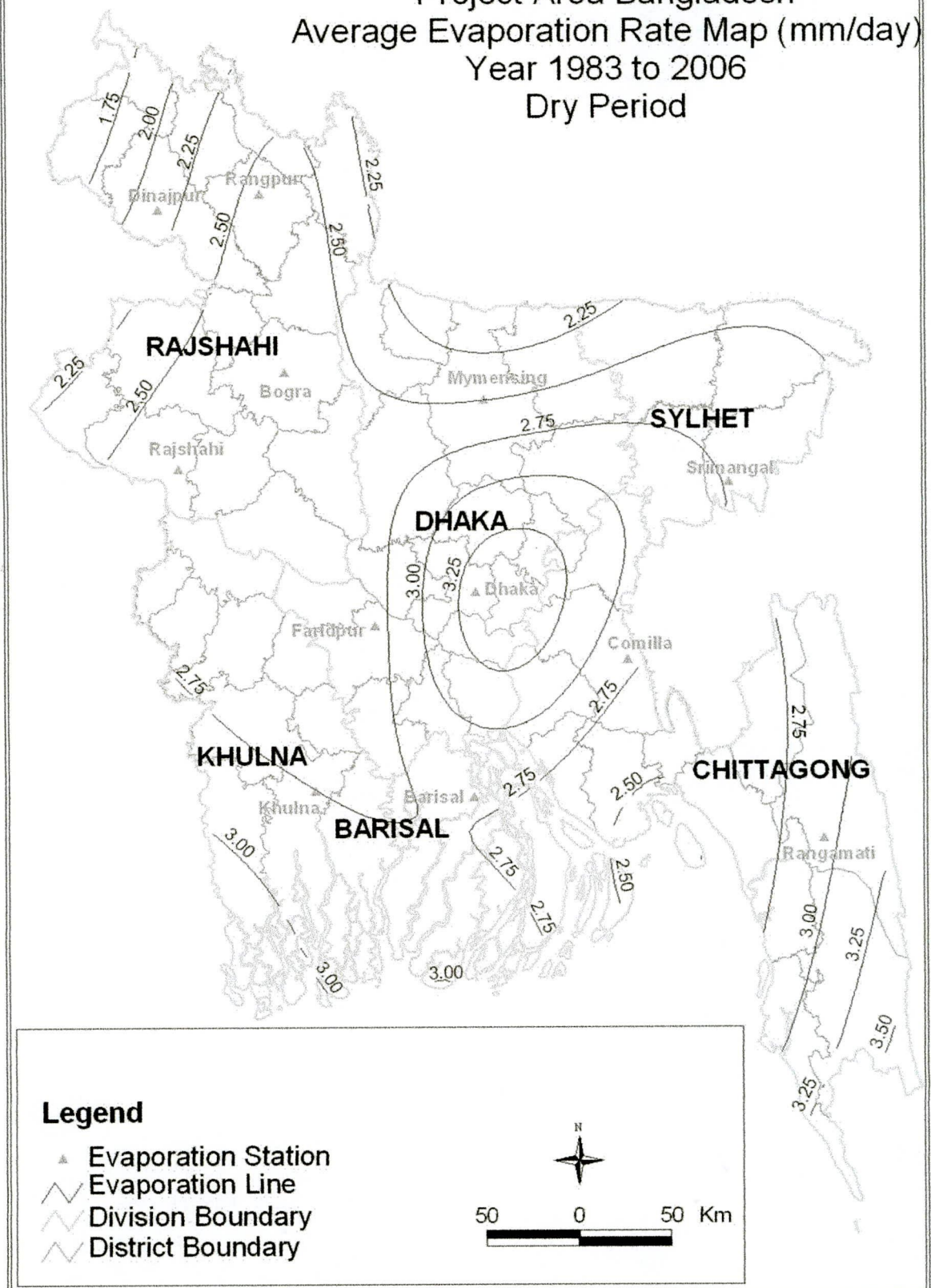
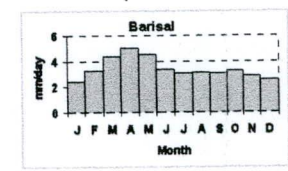
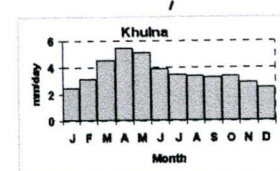
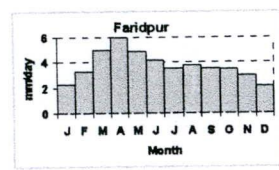
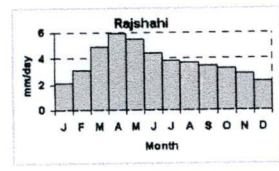
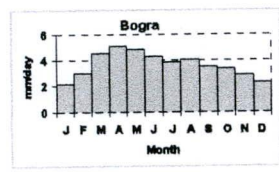
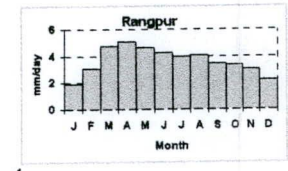
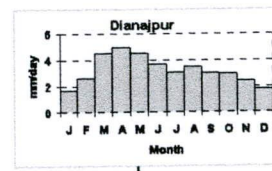


Figure C4: Average Evaporation Rate Map for Dry Period



AVERAGE MONTHLY VARIATION OF EVAPORATION RATE AT DIFFERENT LOCATIONS

YEAR: 1983-2006

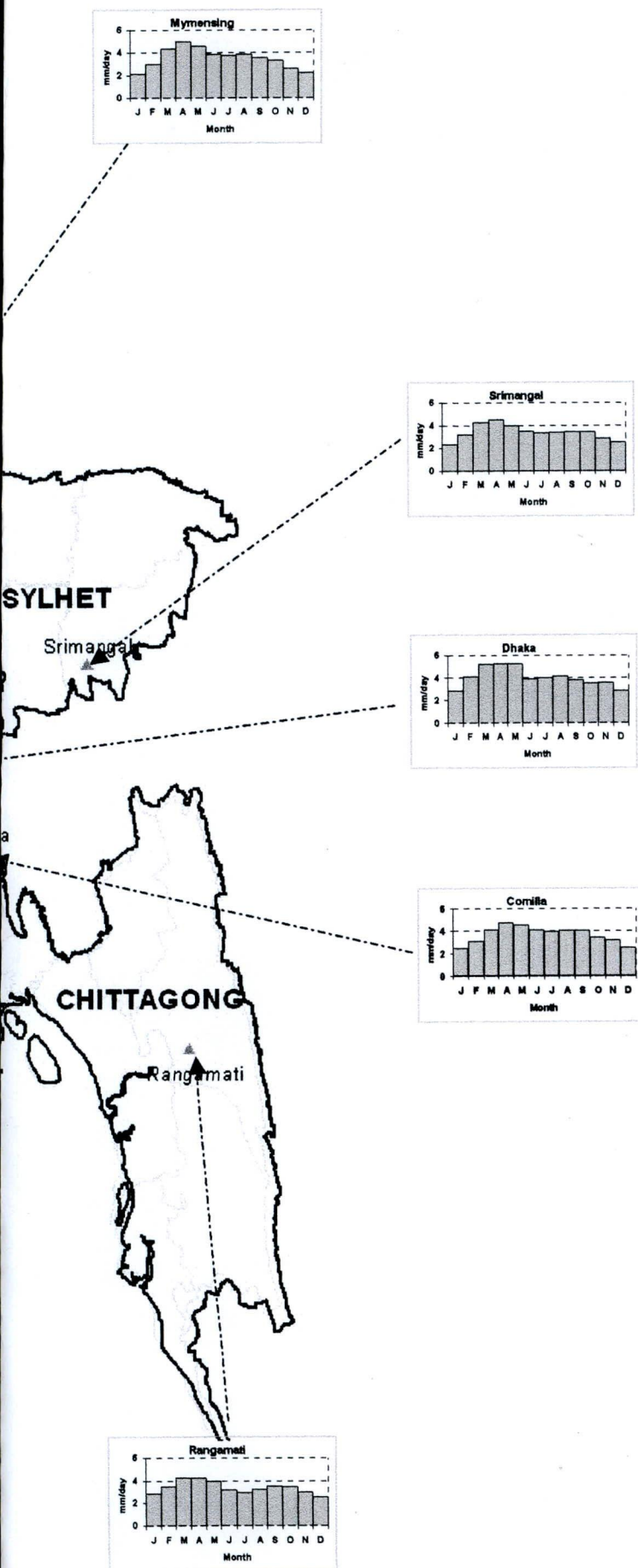


FIGURE NO: C5

Project Area Bangladesh
Average Temperature Map (°C)
Year 1975 to 2004
Annual Average

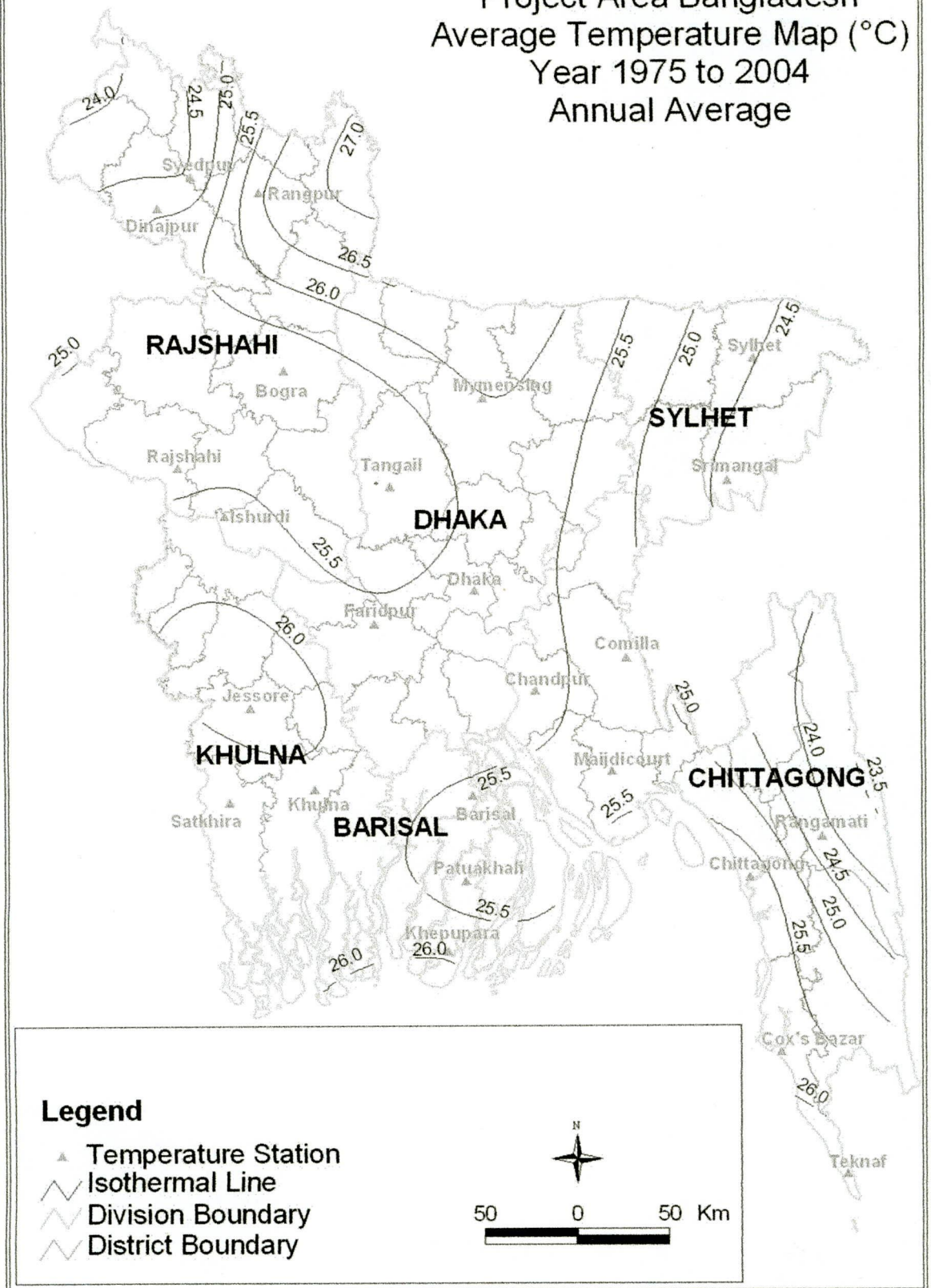


Figure C6: Annual Average Temperature Map

Project Area Bangladesh
Average Temperature Map (°C)
Year 1975 to 2004
Pre-Monsoon

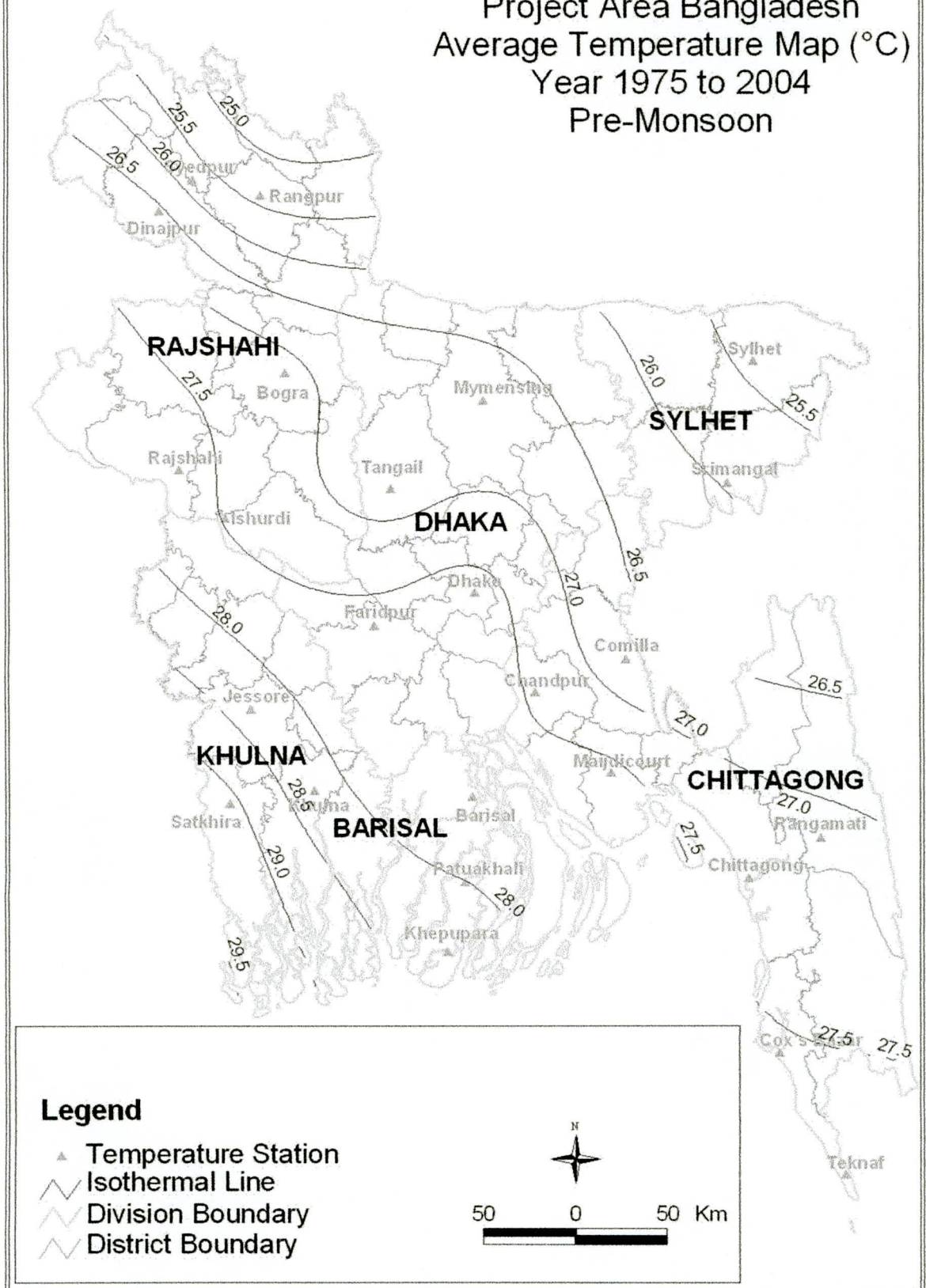


Figure C7: Average Temperature Map for Pre-Monsoon

Project Area Bangladesh
Average Temperature Map (°C)
Year 1975 to 2004
Monsoon

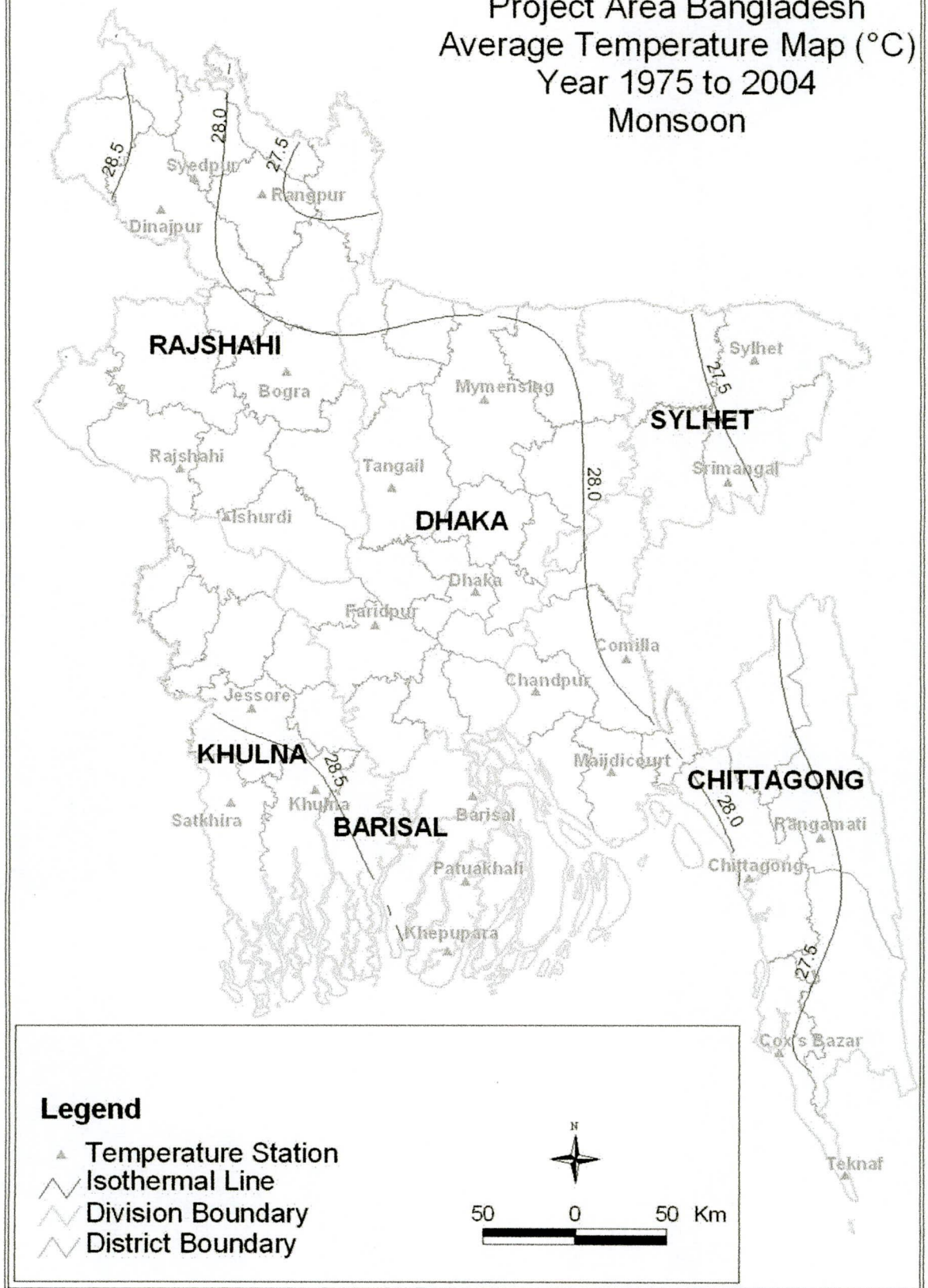


Figure C8: Average Temperature Map for Monsoon

Project Area Bangladesh
Average Temperature Map (°C)
Year 1975 to 2004
Dry Period

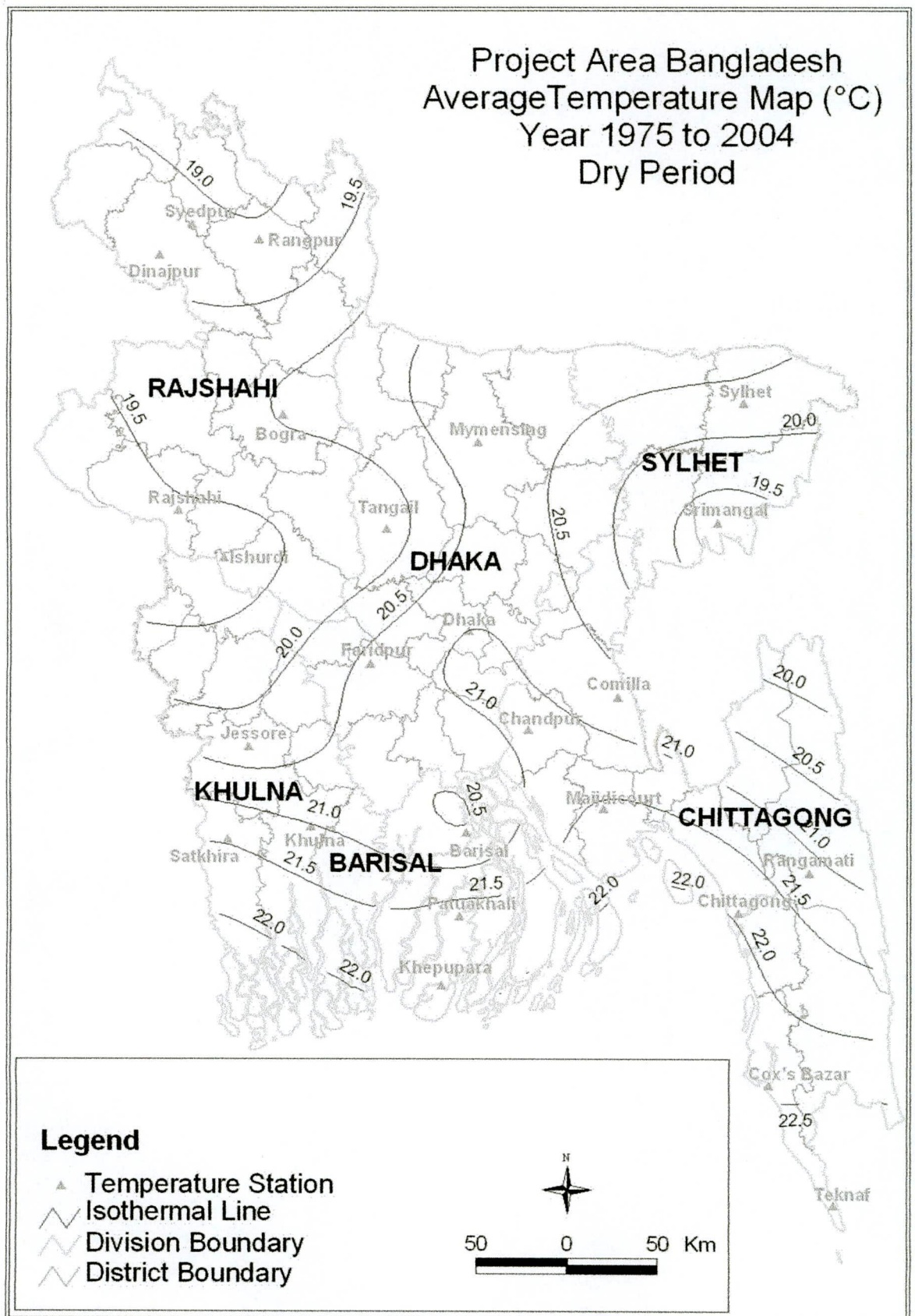
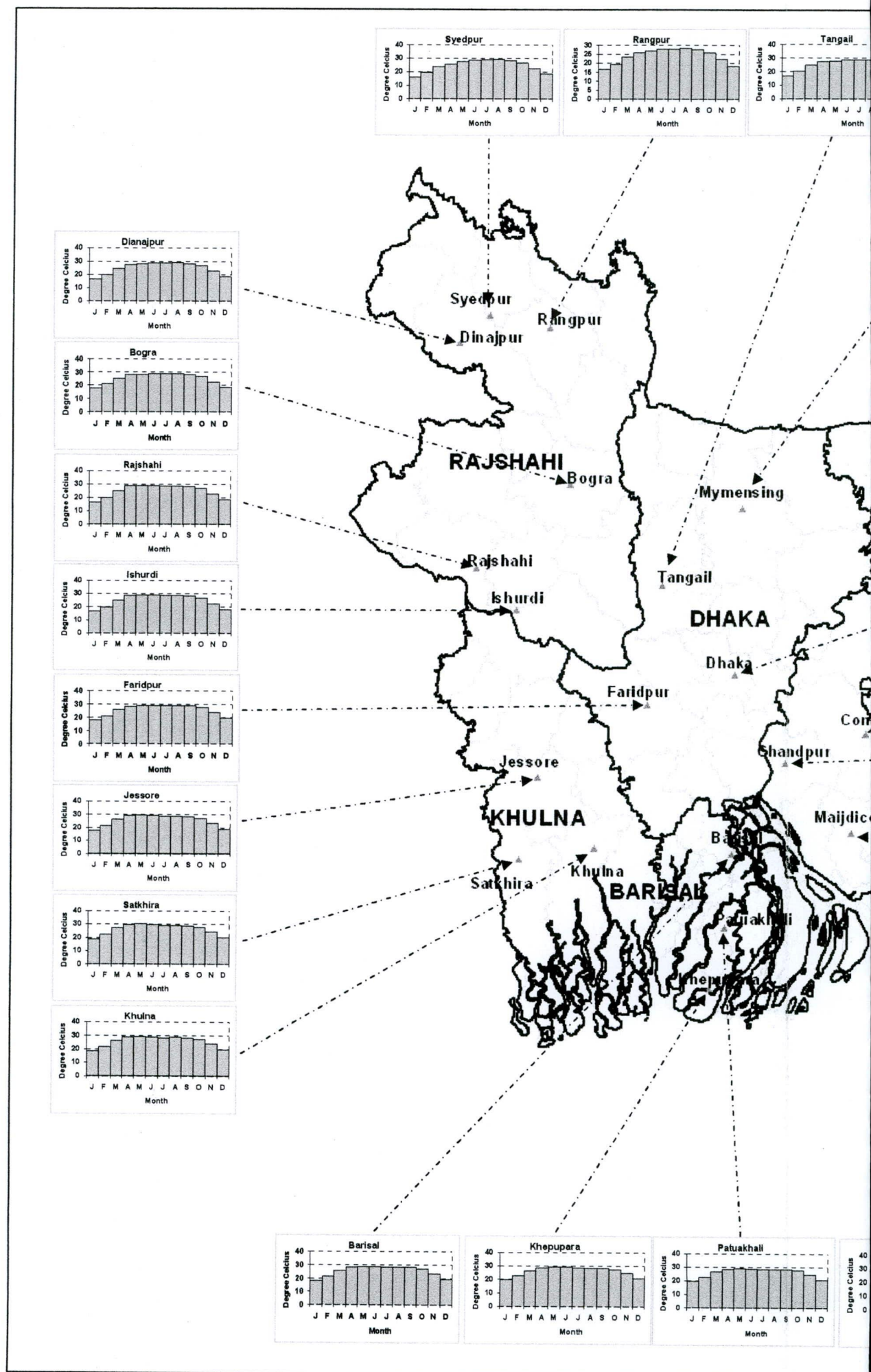
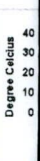
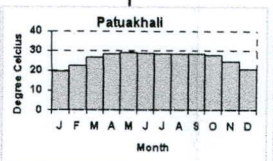
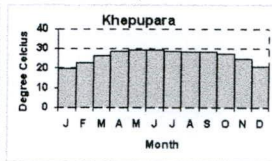
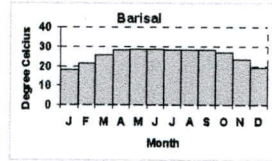
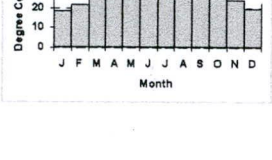
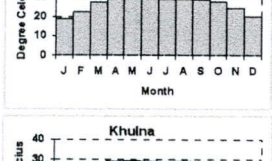
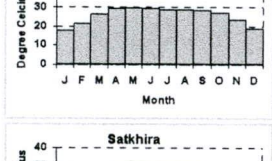
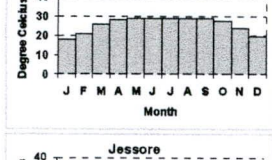
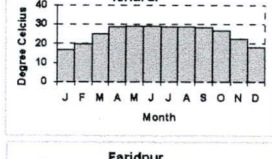
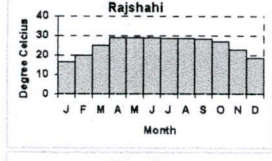
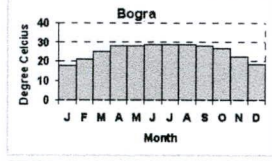
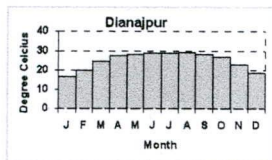
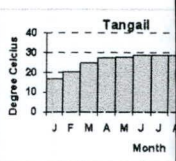
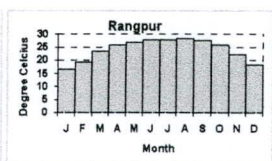
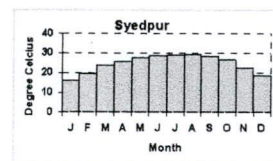


Figure C9: Average Temperature Map for Dry Period



AVERAGE MONTHLY VARIATION OF TEMPERATURE AT DIFFERENT LOCATIONS

YEAR: 1975 – 2004

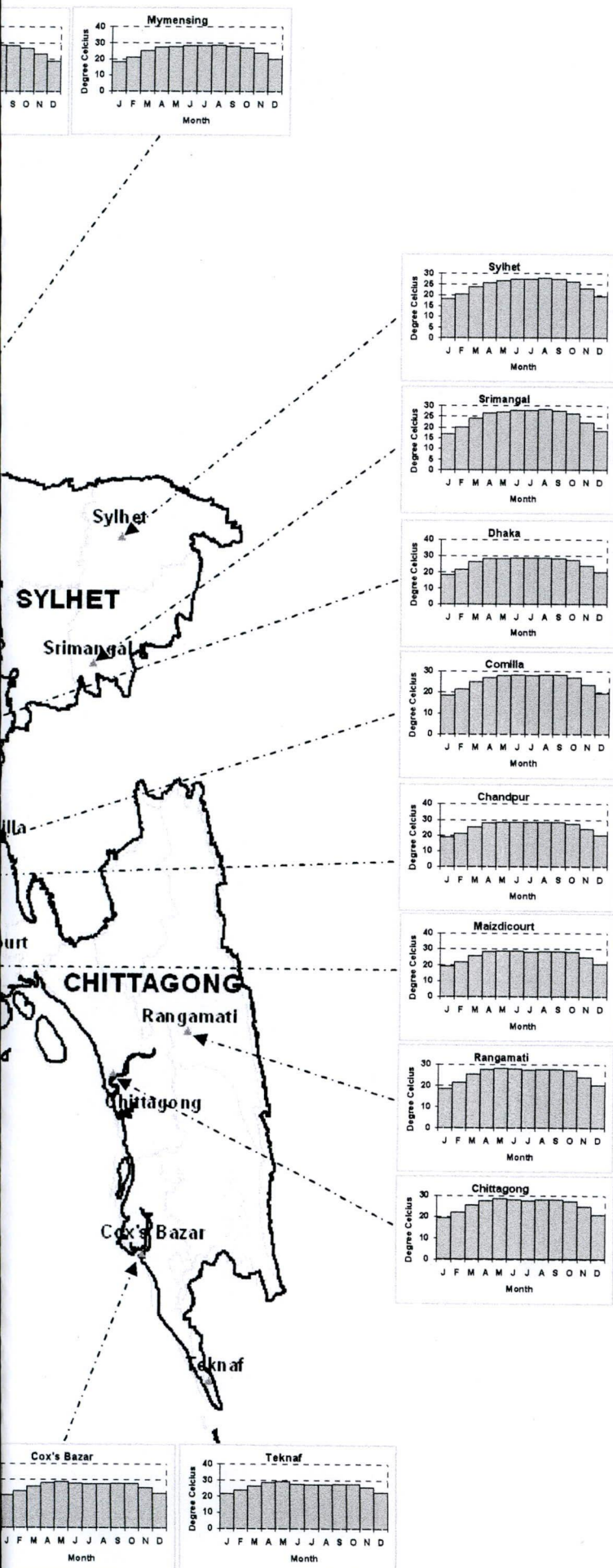


FIGURE NO: C10

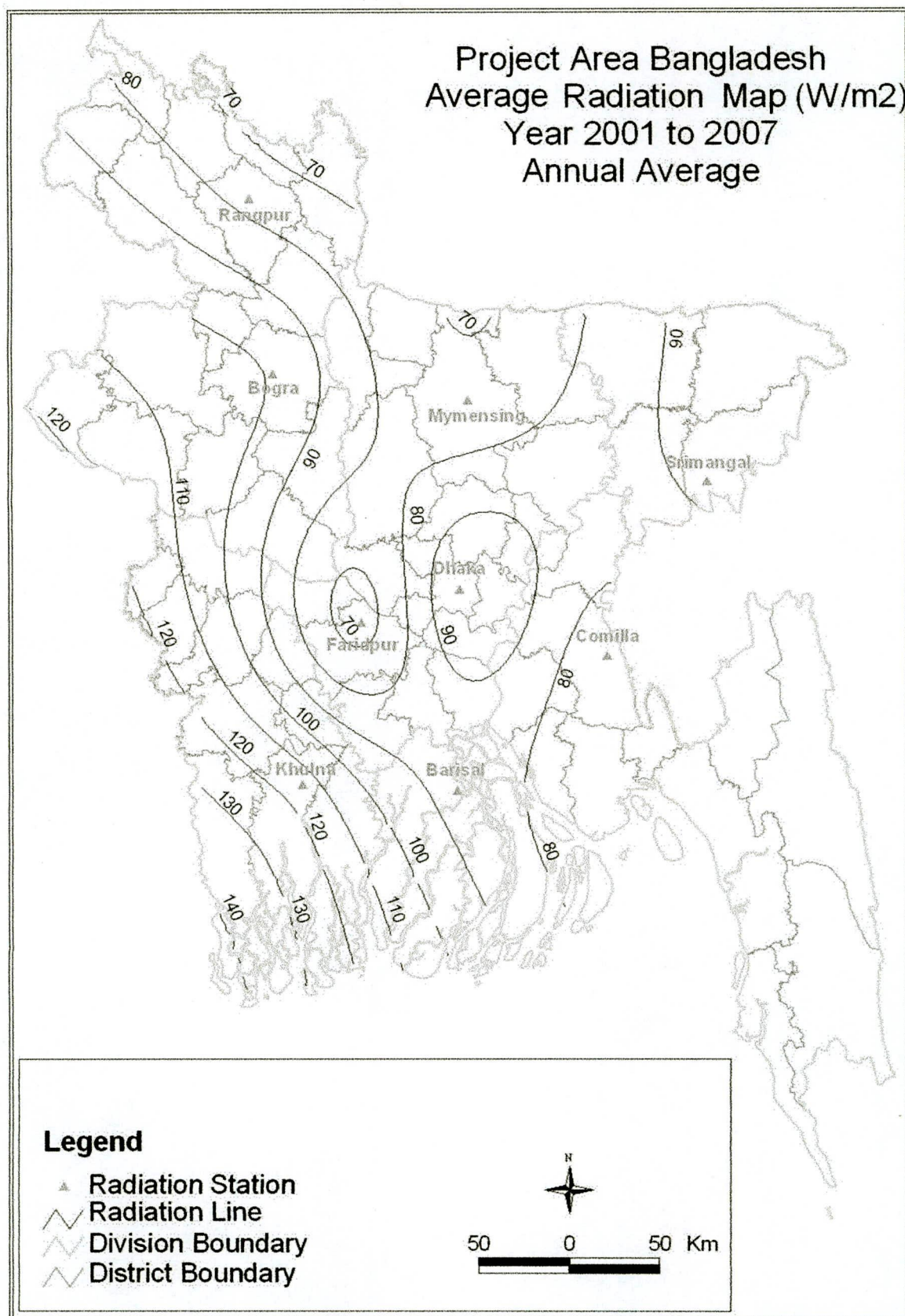


Figure C11: Annual Average Radiation Map

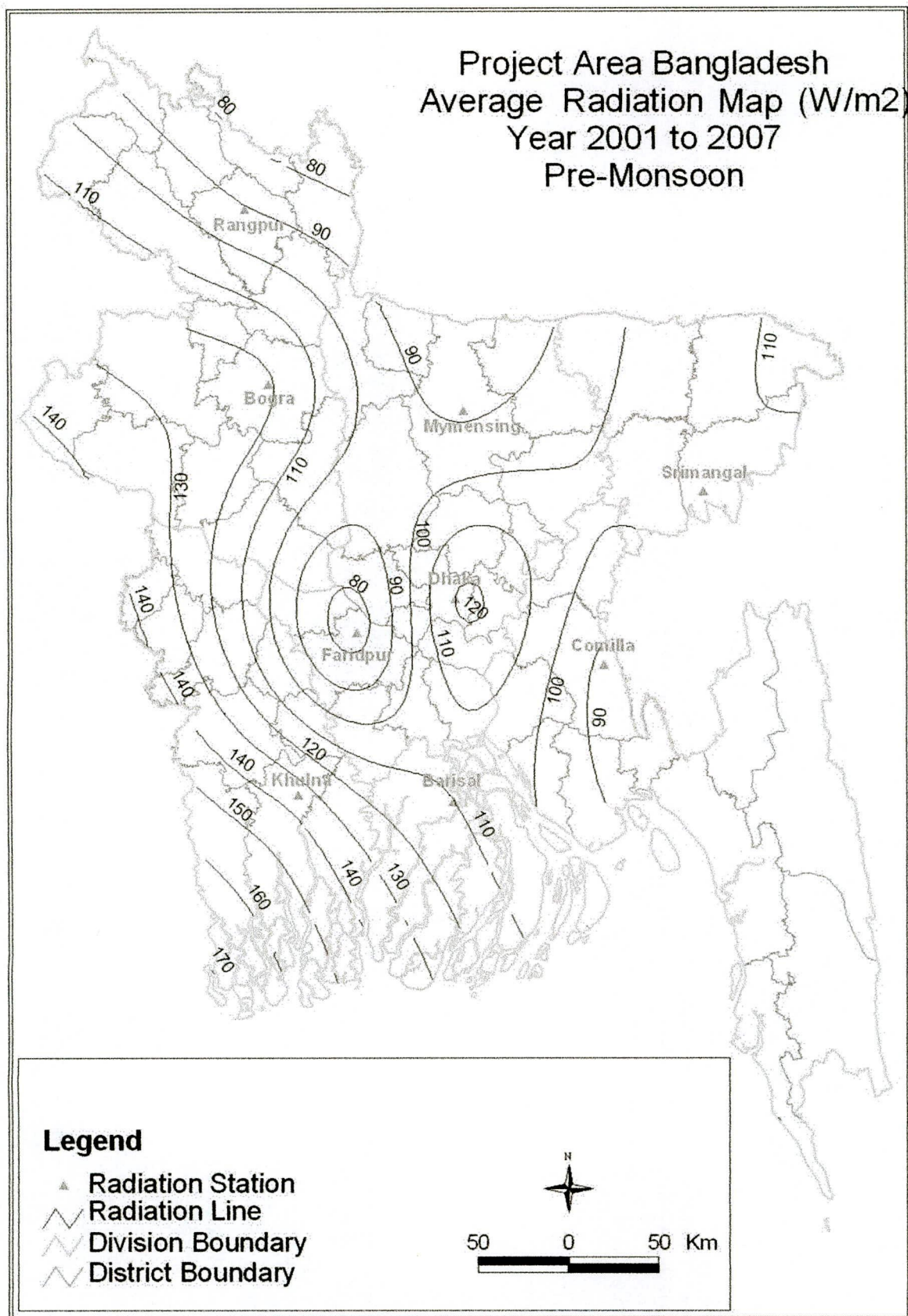


Figure C12: Average Radiation Map for Pre-Monsoon

Project Area Bangladesh
Average Radiation Map (W/m²)
Year 2001 to 2007
Monsoon

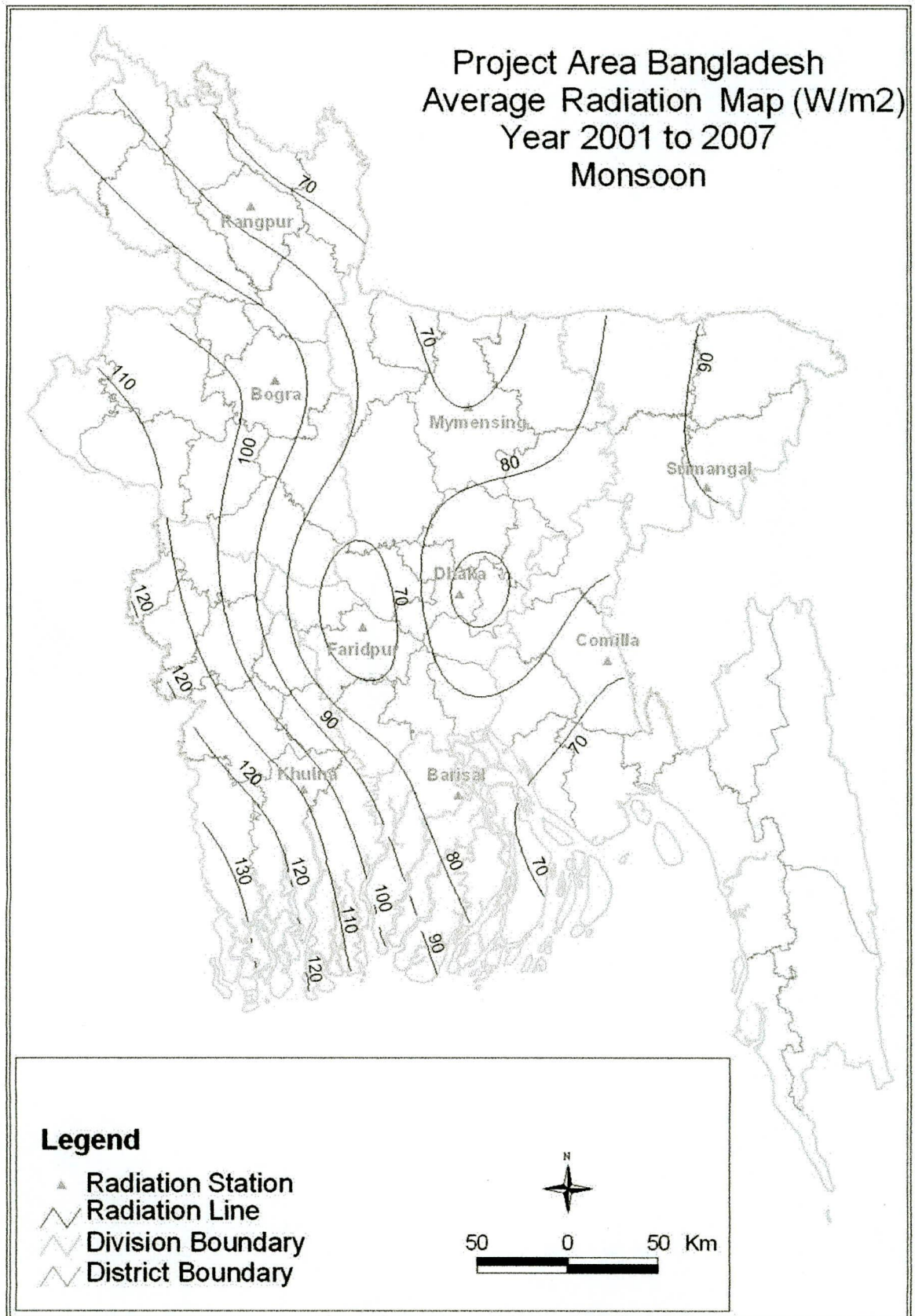


Figure C13: Average Radiation Map for Monsoon

Project Area Bangladesh
Average Radiation Map (Watt/m²)
Year 2001 to 2007
Dry Period

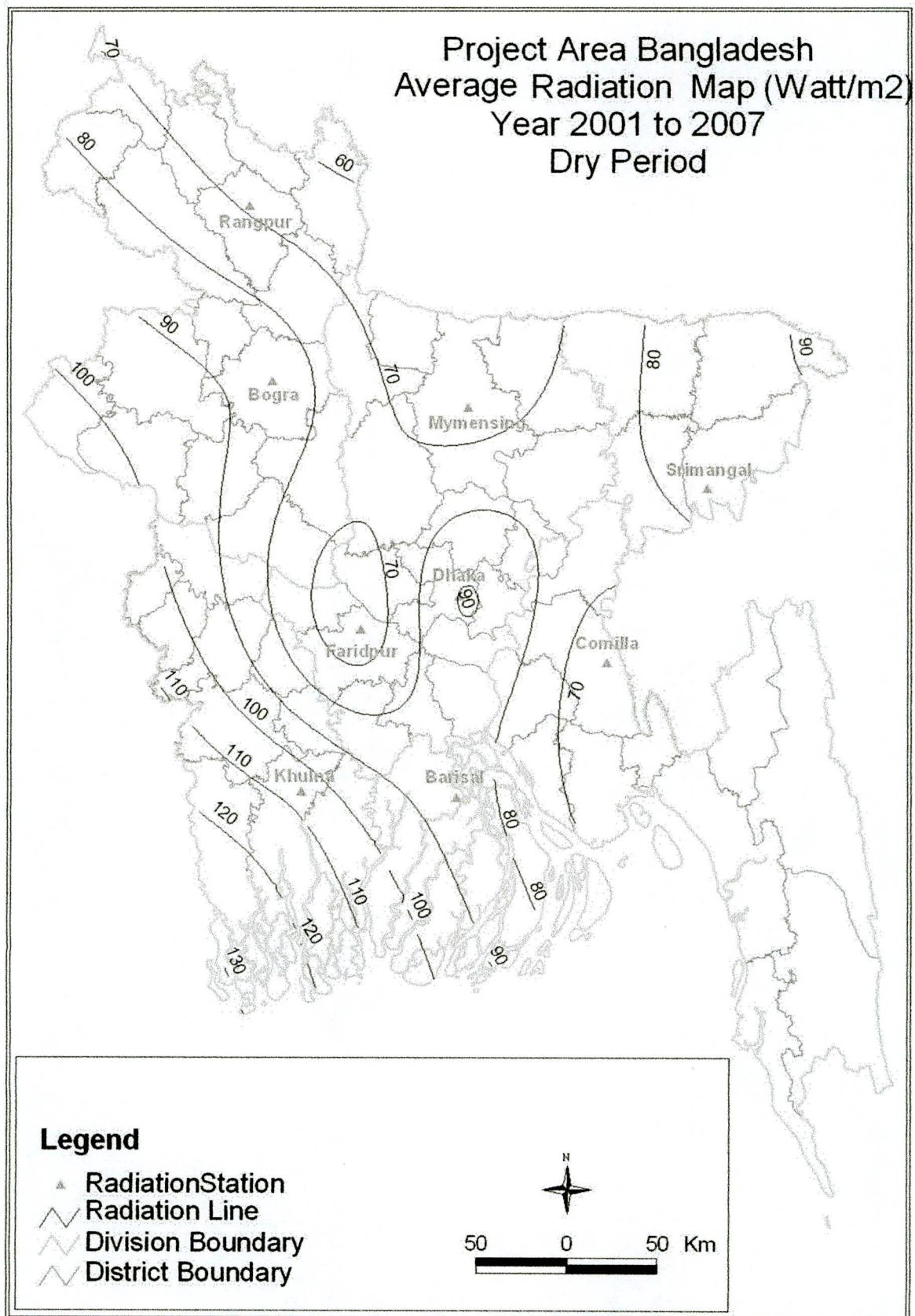
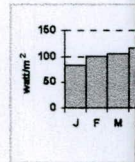
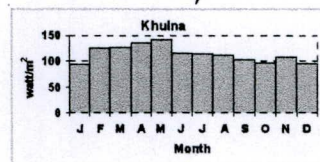
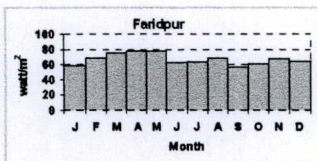
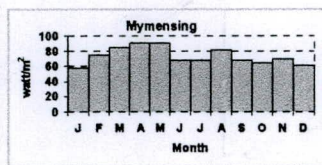
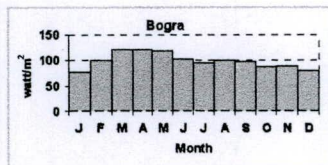
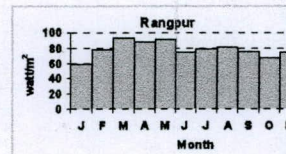


Figure C14: Average Radiation Map for Dry Period



AVERAGE MONTHLY VARIATION OF SOLAR RADIATION AT DIFFERENT LOCATIONS

YEAR: 2001-2007

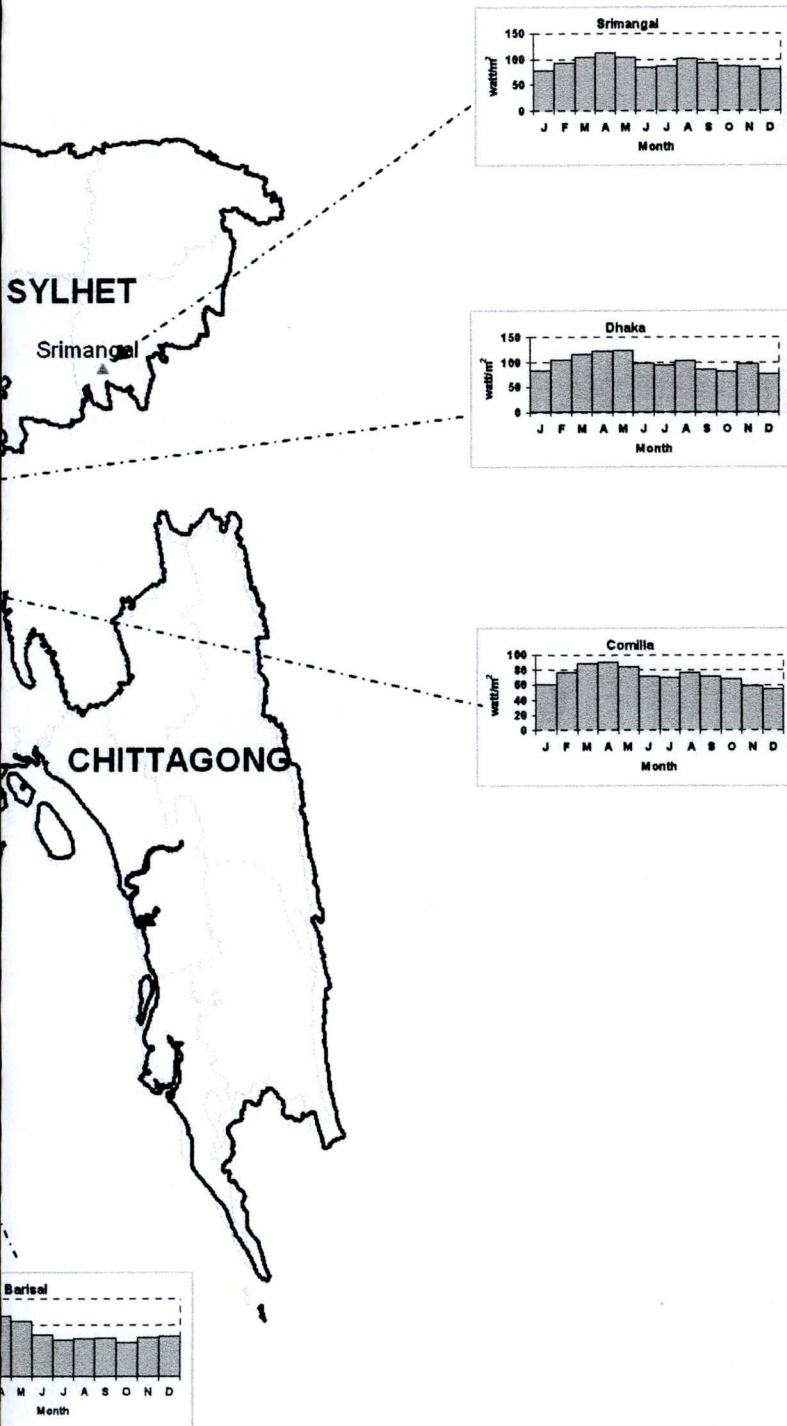


FIGURE NO: C15

Project Area Bangladesh
Average Wind Speed Map (m/s)
Year 2001 to 2006
Annual Average

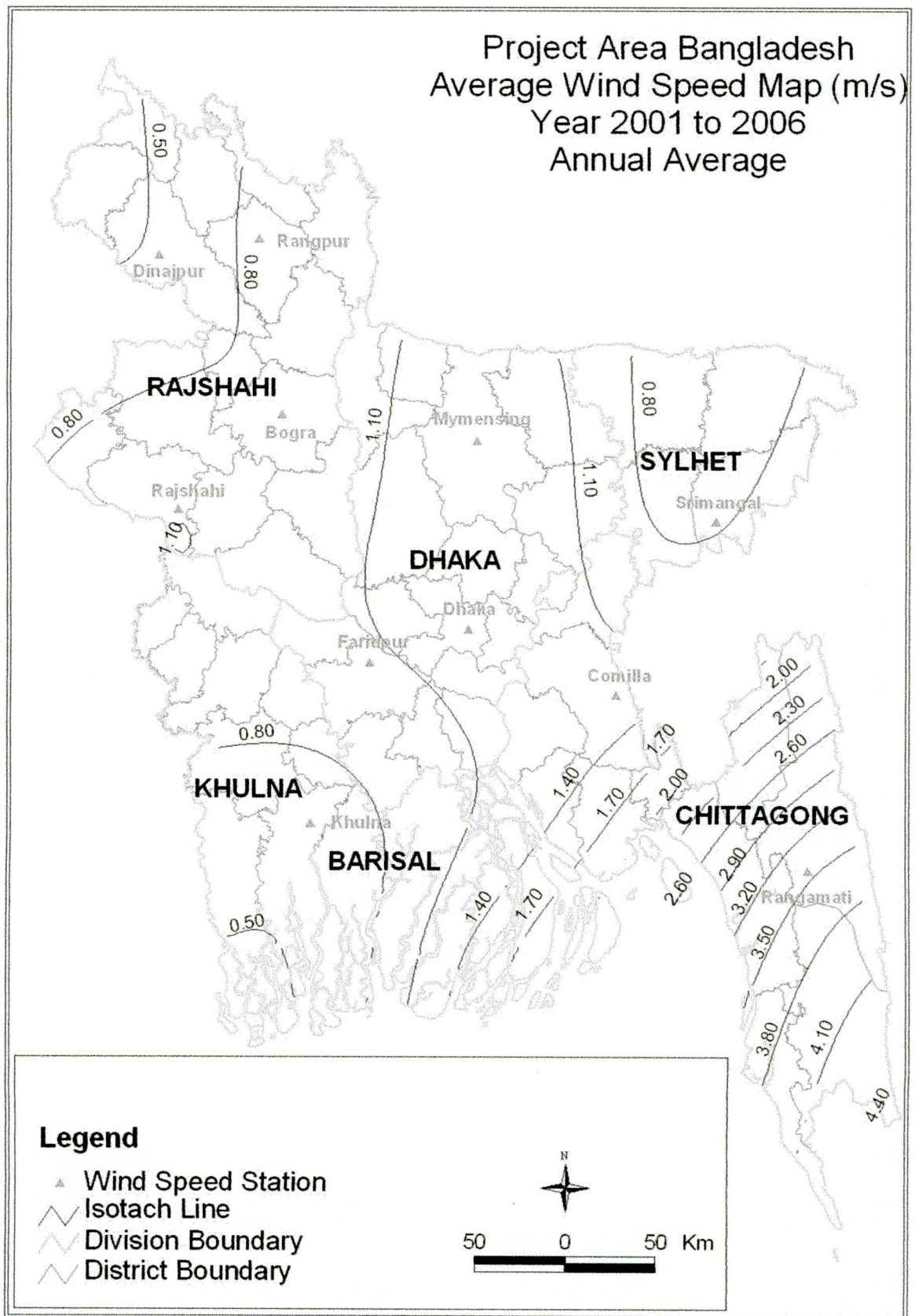


Figure C16: Annual Average Wind Speed Map

Project Area Bangladesh
Average Wind Speed Map (m/s)
Year 2001 to 2006
Pre-Monsoon

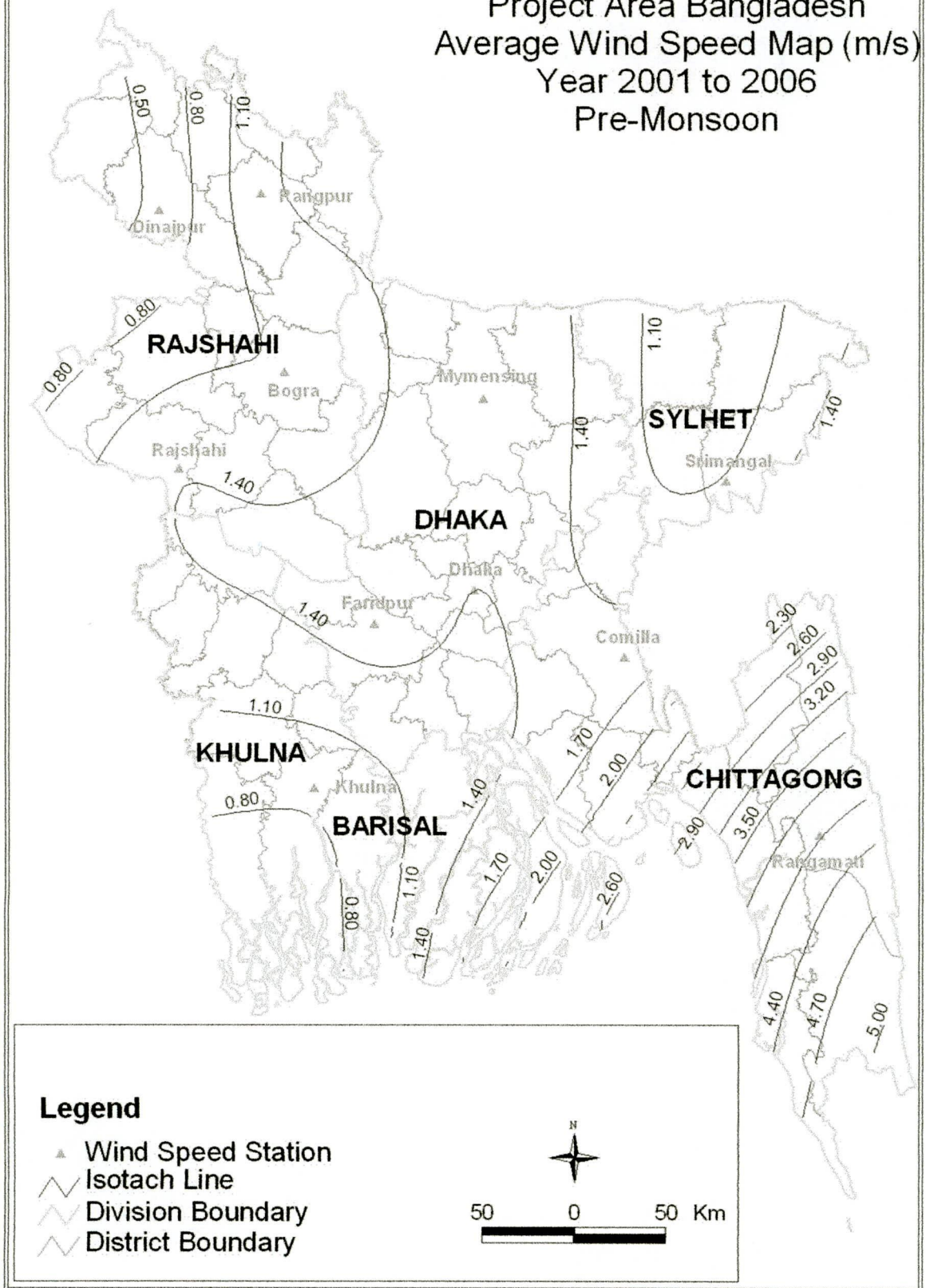


Figure C17: Average Wind Speed Map for Pre-Monsoon

Project Area Bangladesh
Average Wind Speed Map (m/s)
Year 2001 to 2006
Monsoon

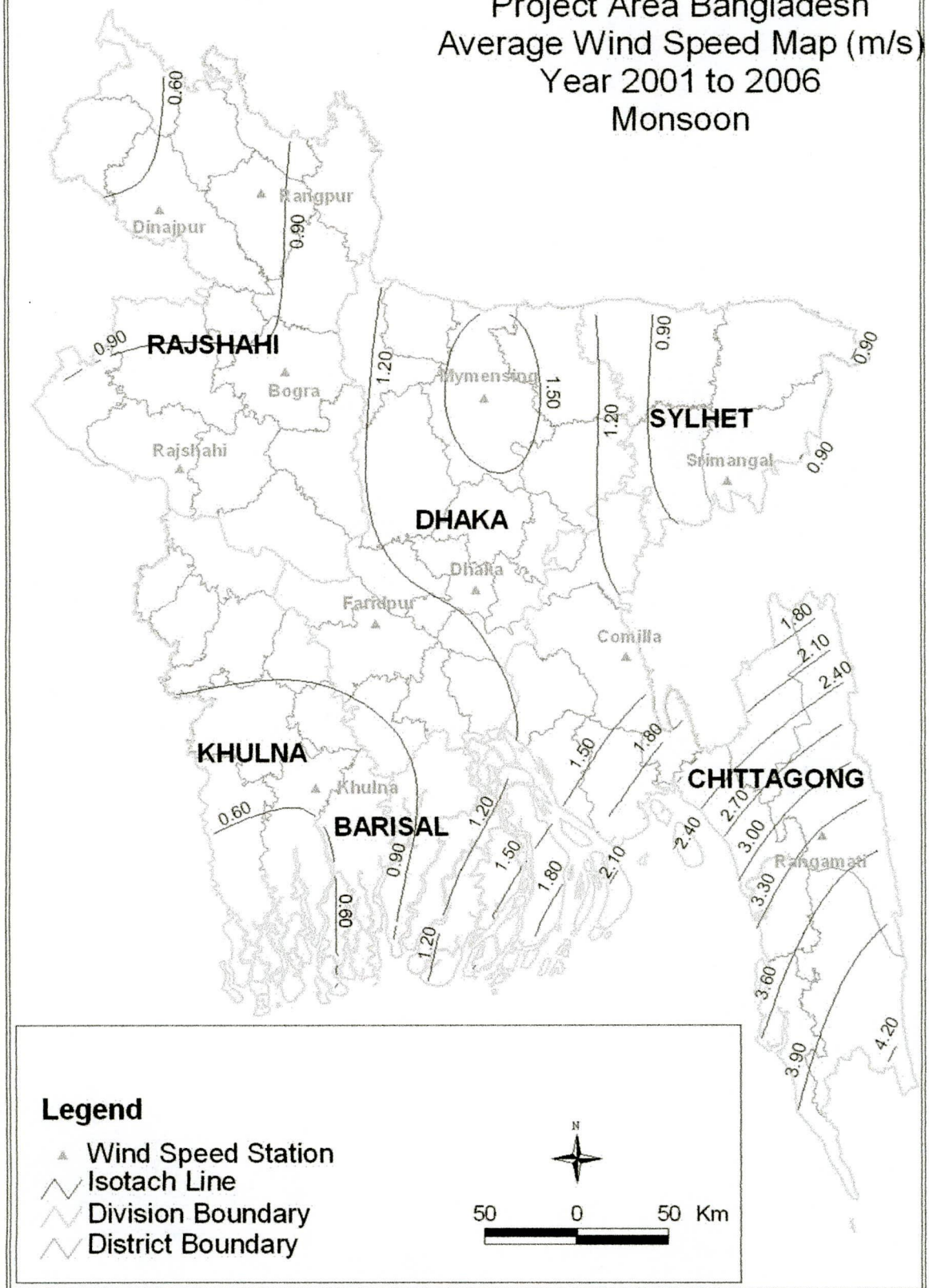


Figure C18: Average Wind Speed Map for Monsoon

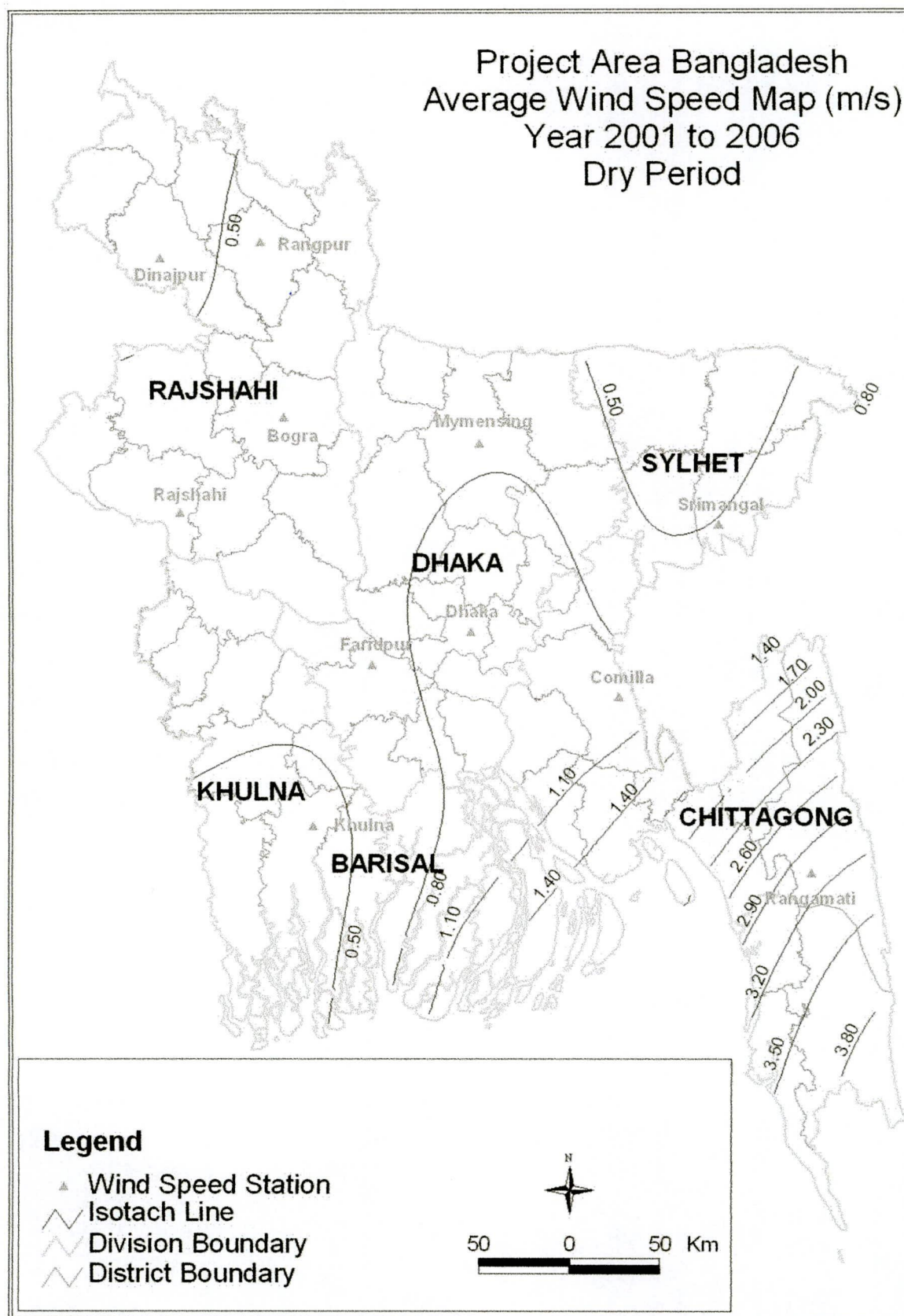
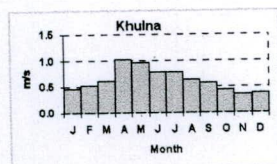
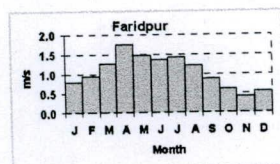
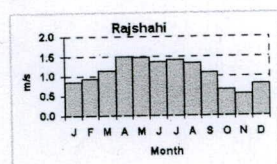
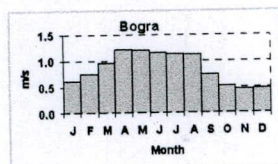
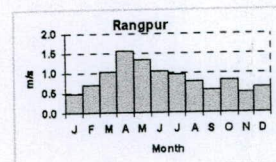
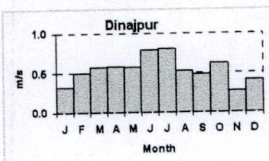
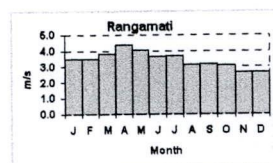
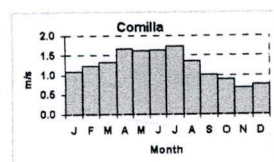
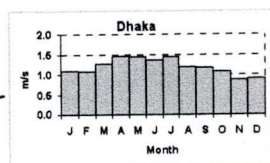
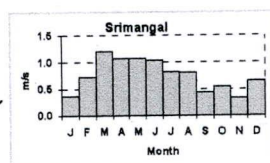
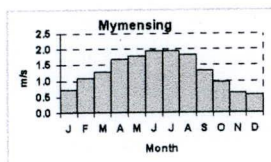


Figure C19: Average Wind Speed Map for Dry Period





AVERAGE MONTHLY VARIATION OF WIND SPEED AT DIFFERENT LOCATIONS

YEAR: 2001-2006



FIGURE NO: C20

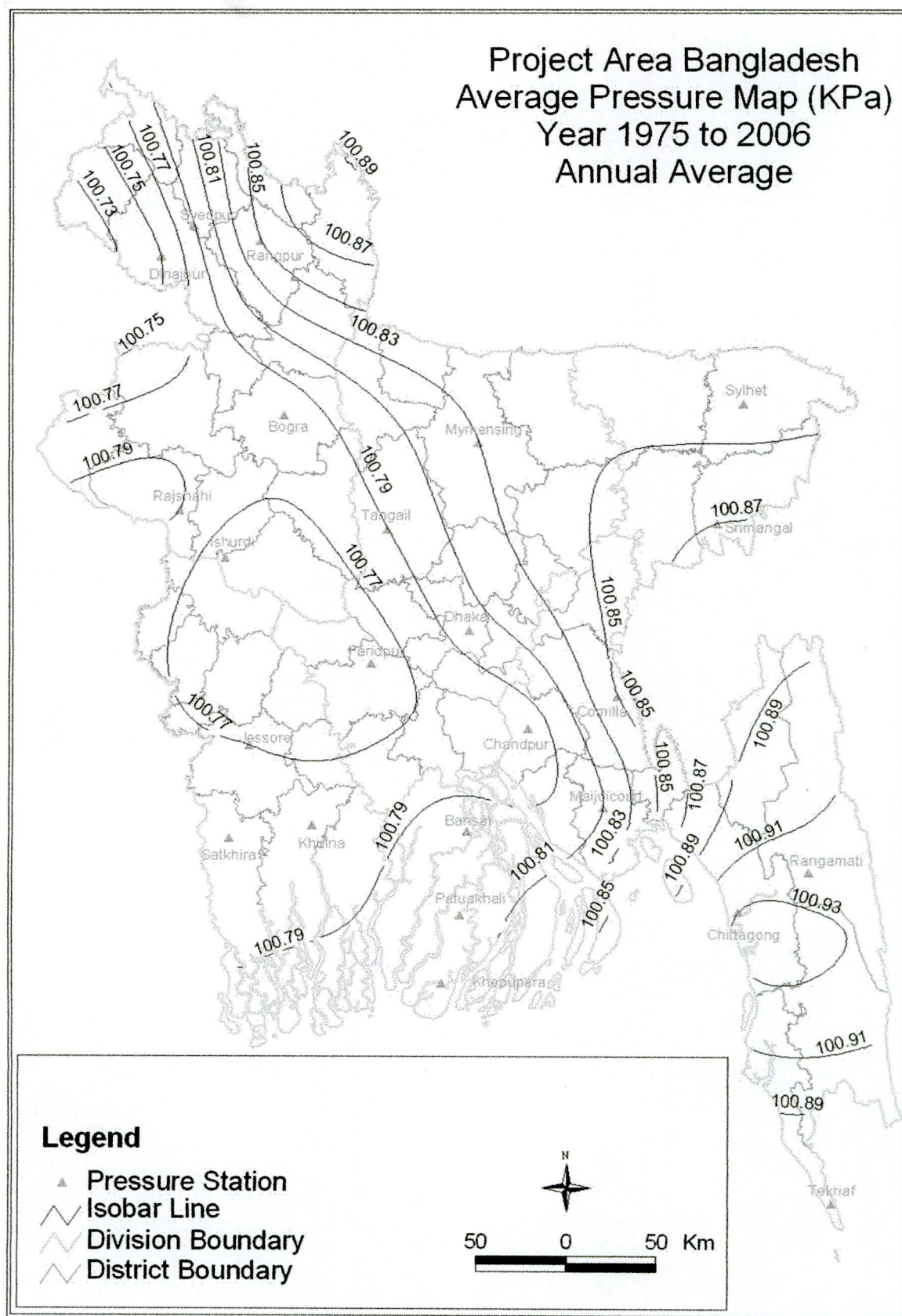


Figure C21: Annual Average Air Pressure Map

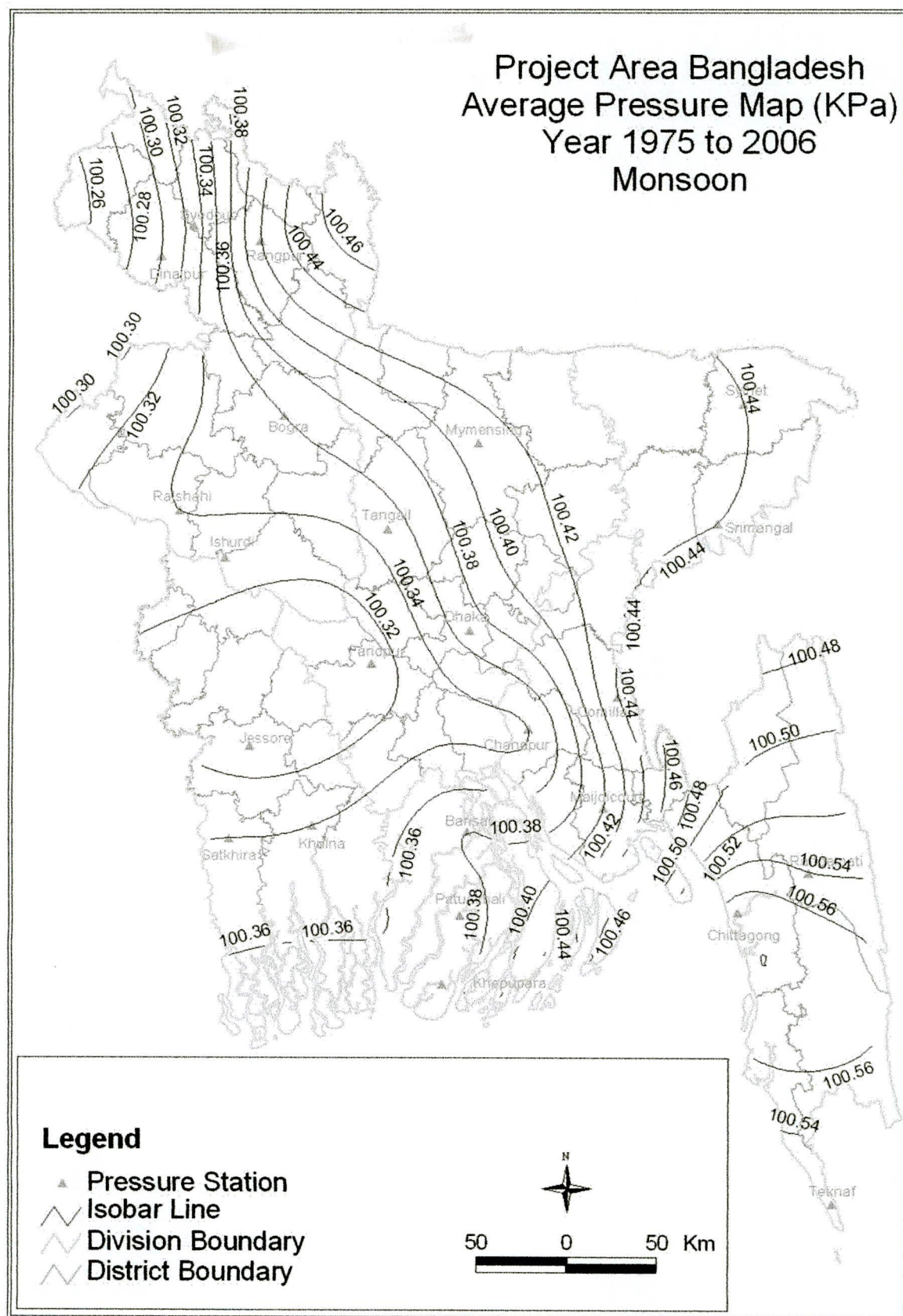


Figure C23: Average Air Pressure Map for Monsoon

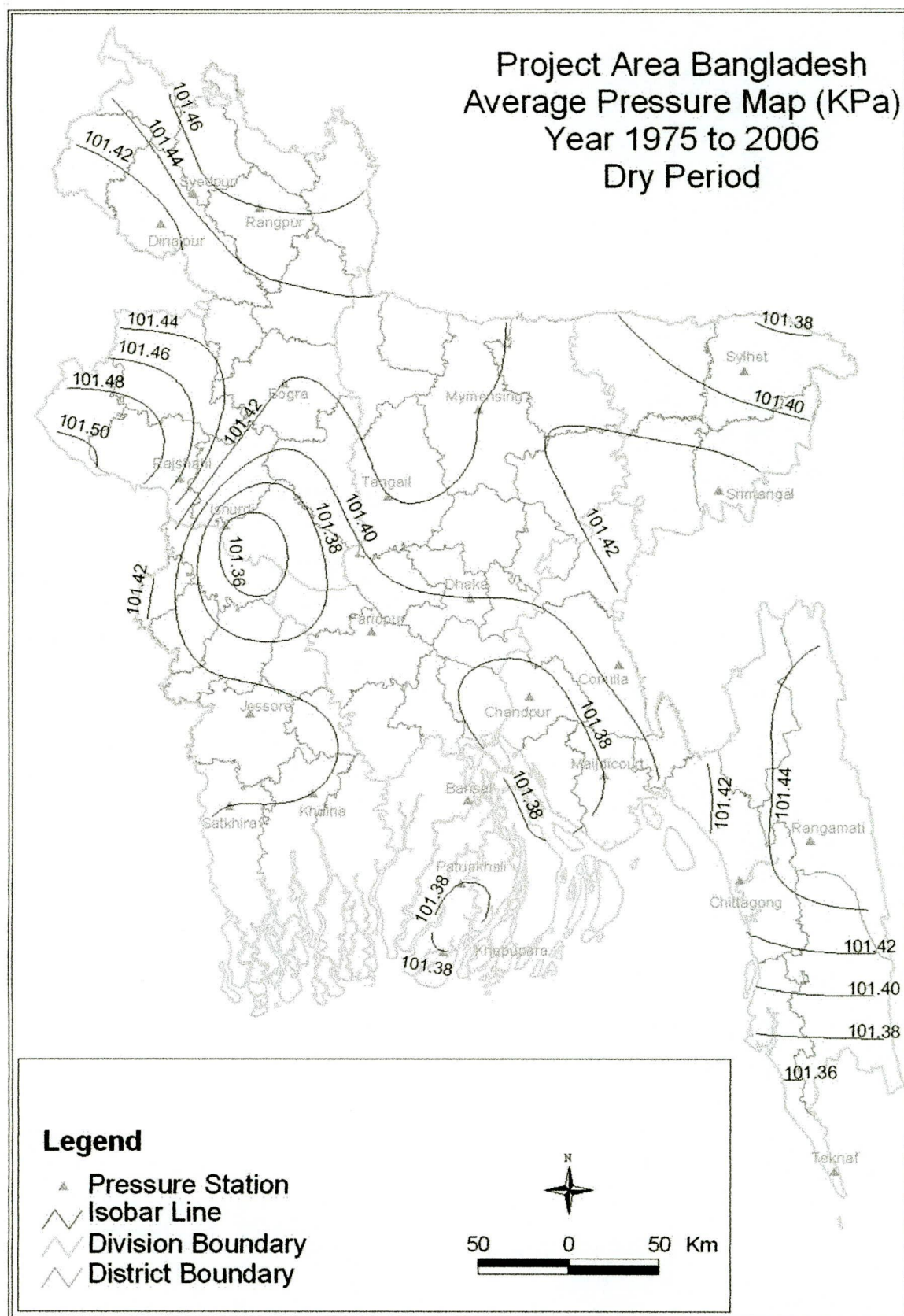
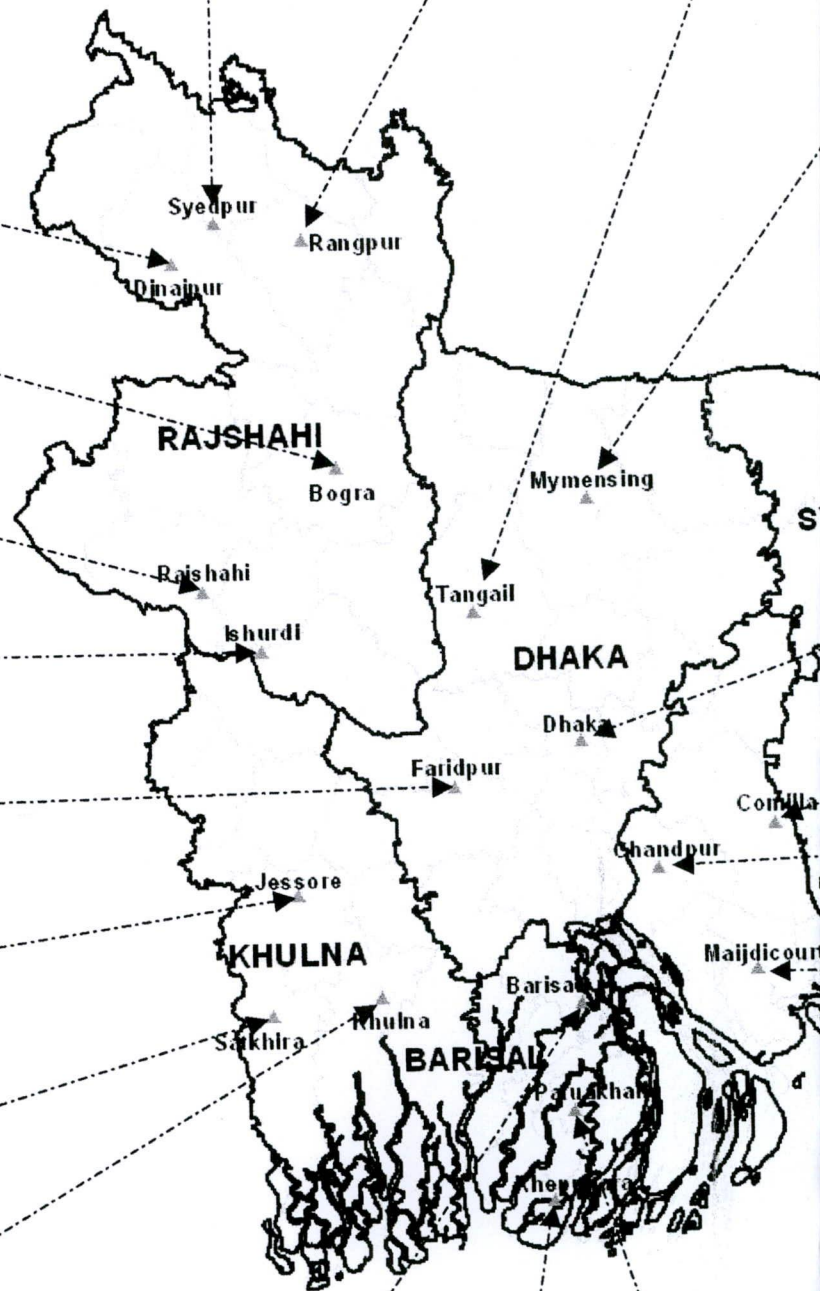
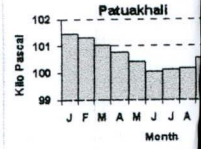
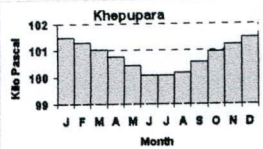
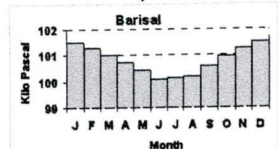
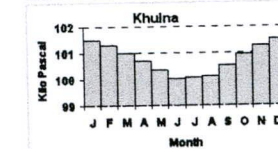
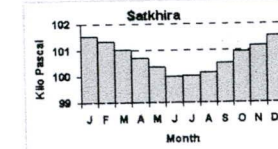
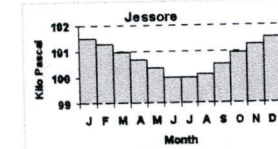
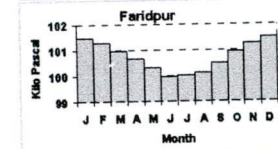
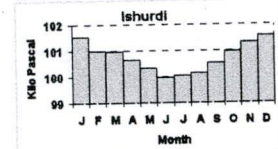
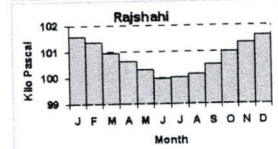
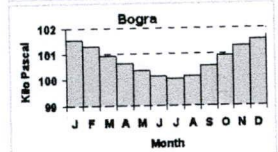
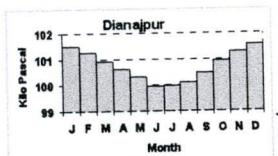
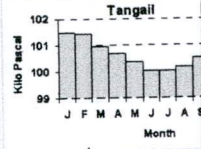
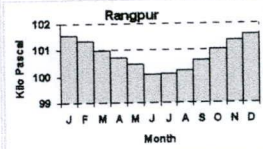
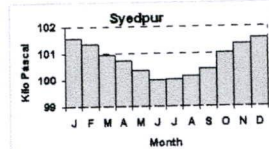


Figure C24: Average Air Pressure Map for Dry Period



AVERAGE MONTHLY VARIATION OF AIR PRESSURE AT DIFFERENT LOCATIONS

YEAR: 1975 – 2006

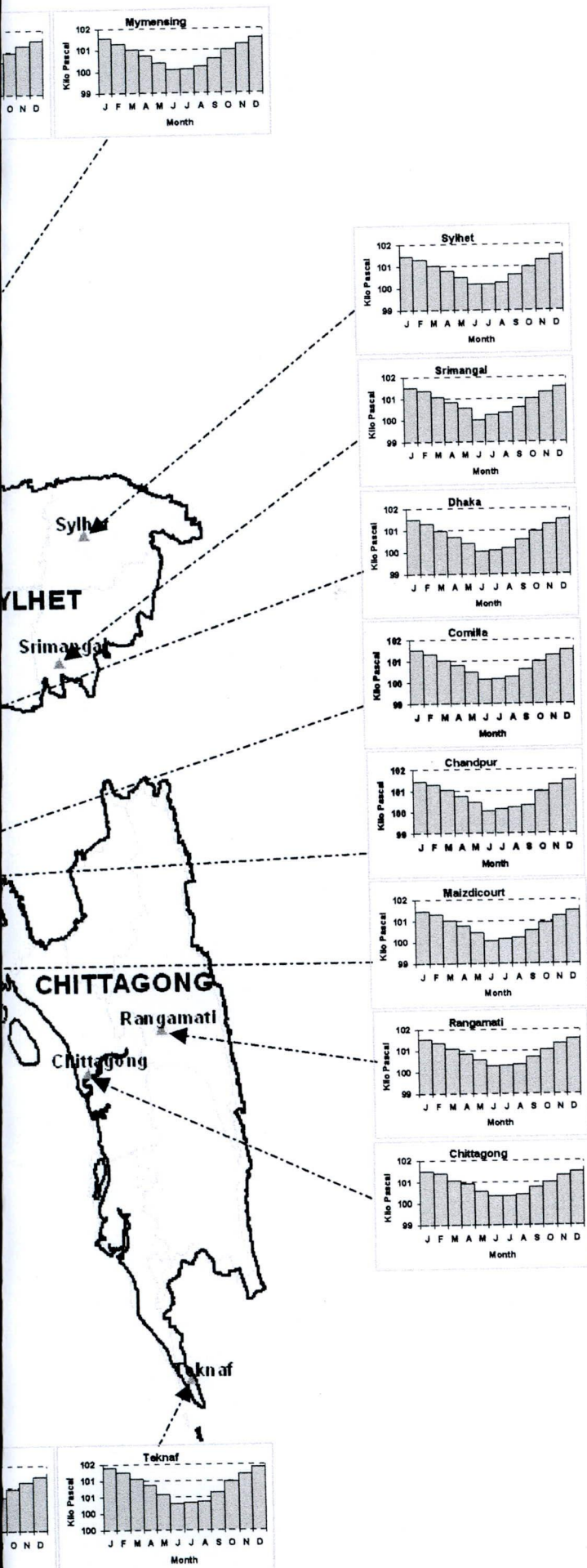


FIGURE NO: C25

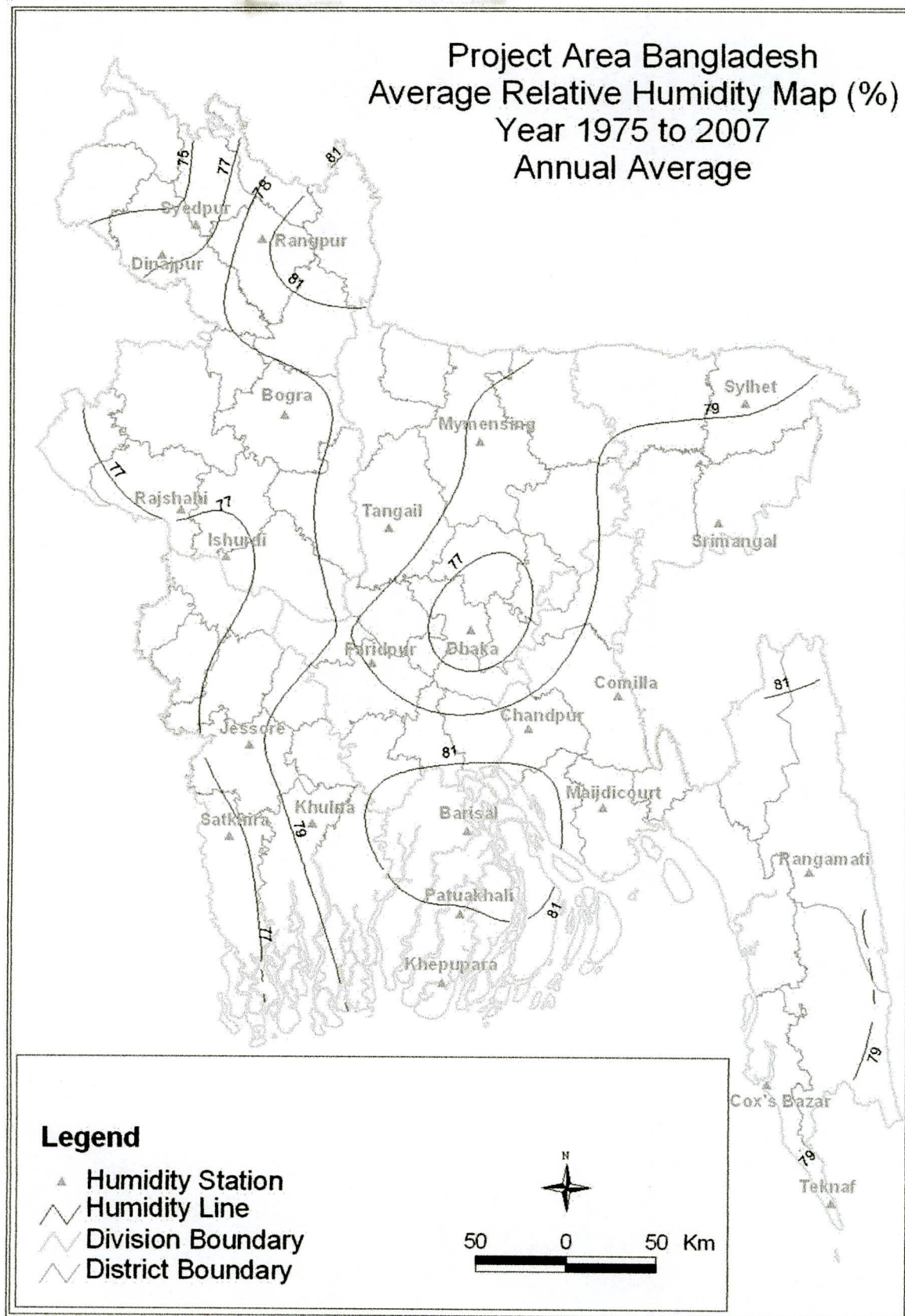


Figure C26: Annual Average Relative Humidity Map

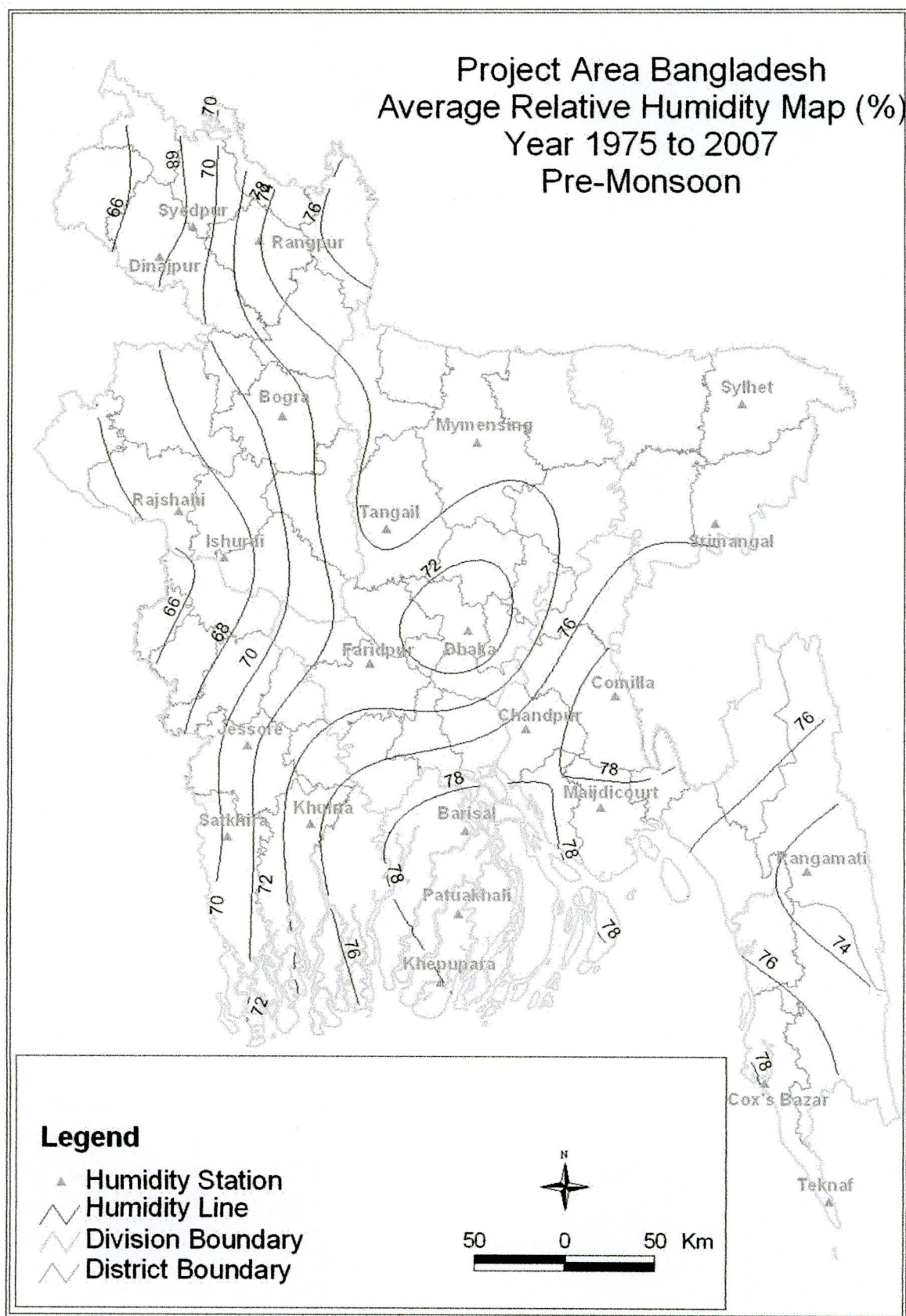


Figure C27: Average Relative Humidity Map for Pre-Monsoon

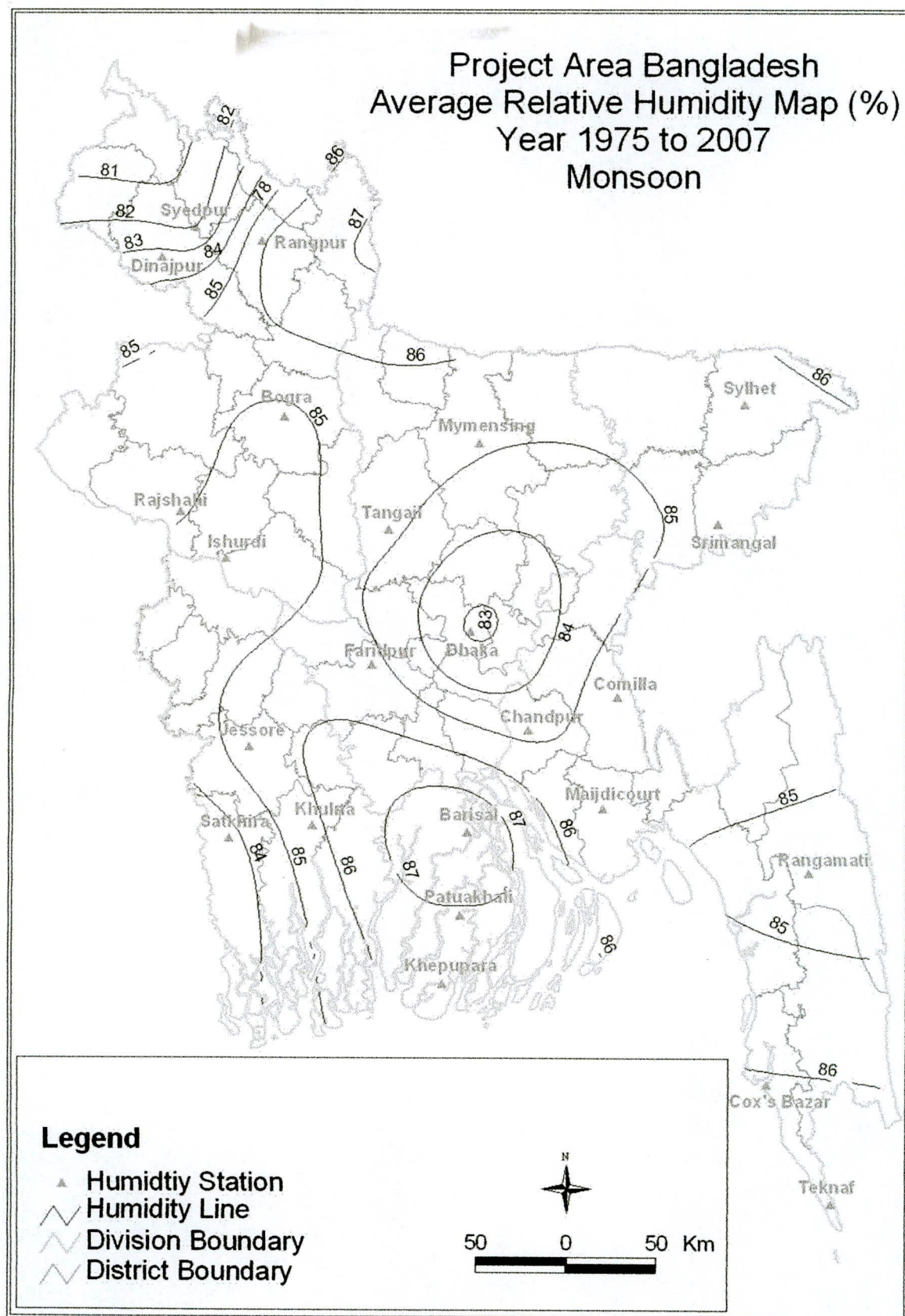


Figure C28: Average Relative Humidity Map for Monsoon

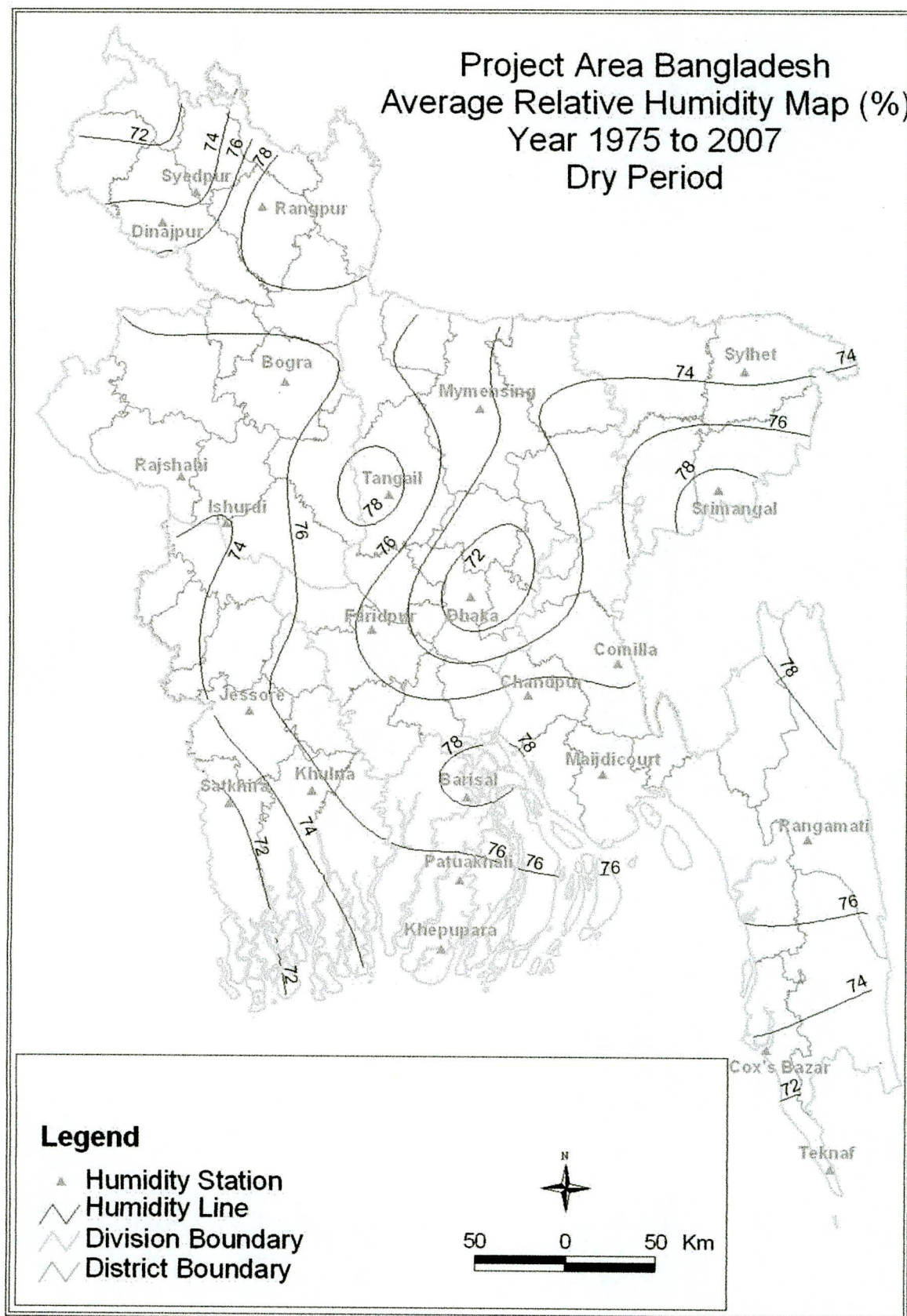
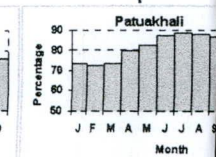
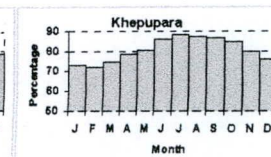
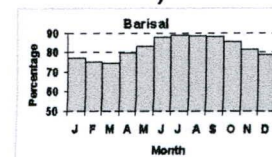
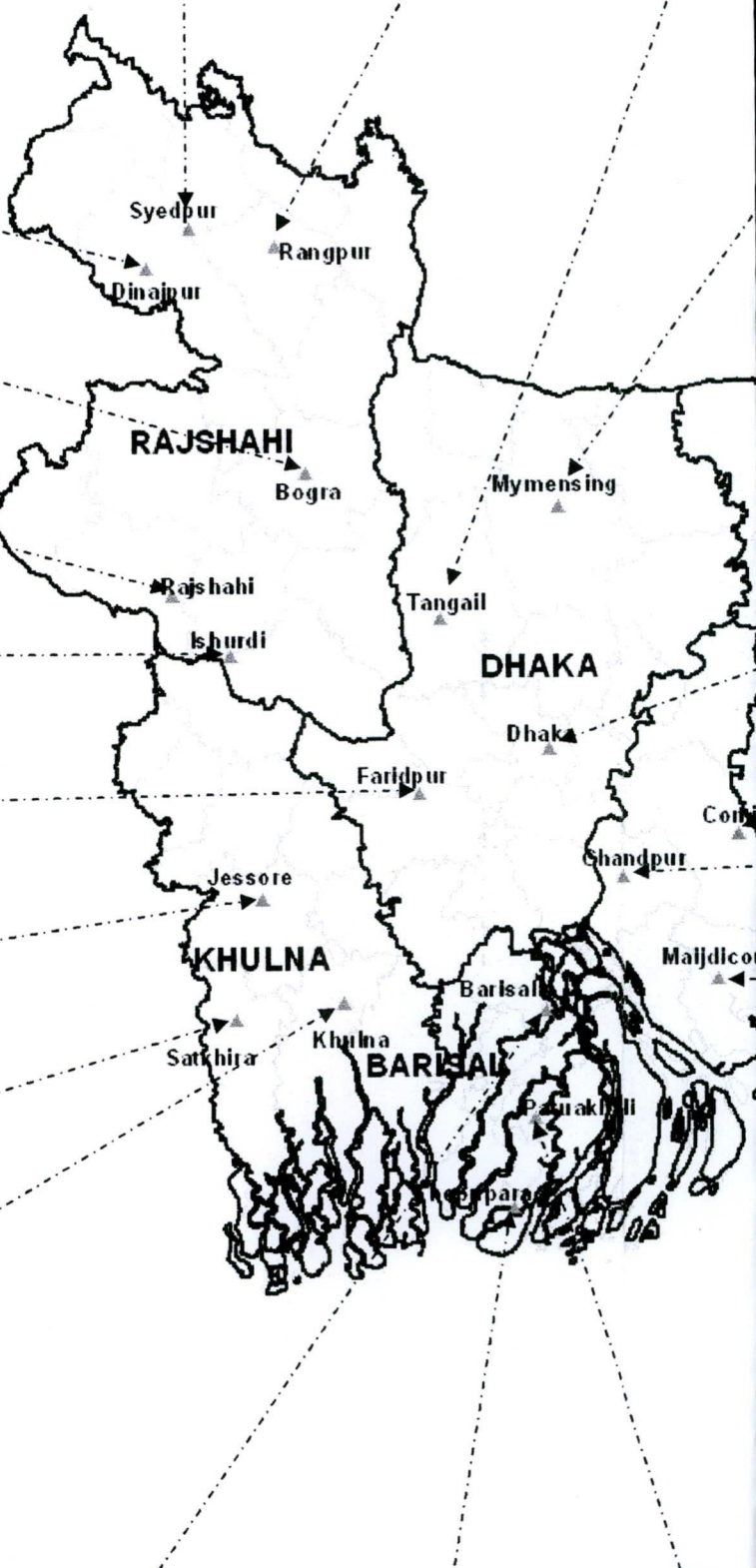
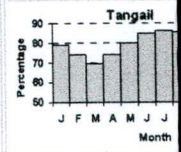
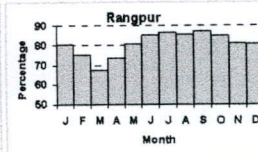
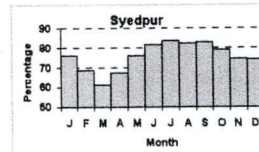
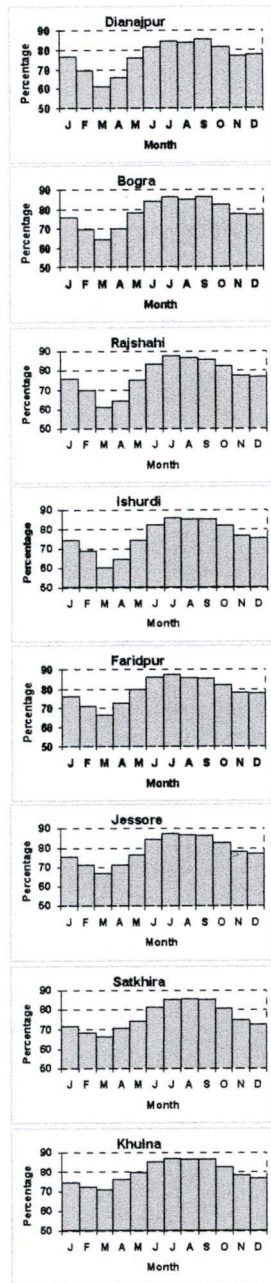
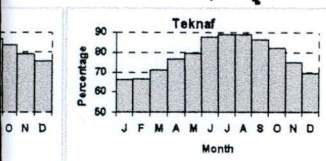
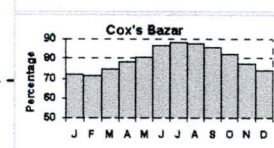
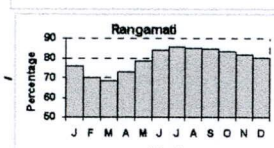
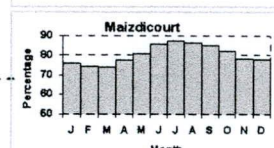
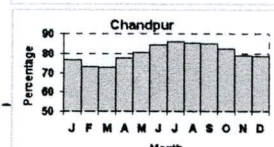
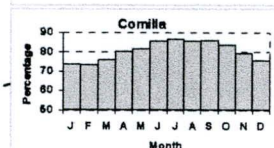
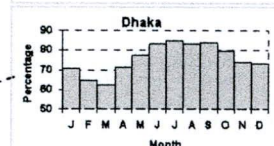
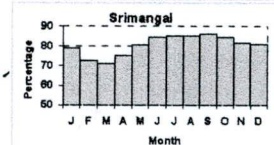
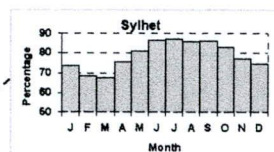
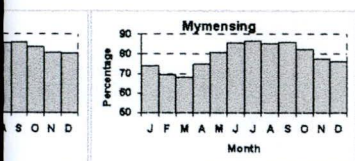


Figure C29: Average Relative Humidity Map for Dry Period





AVERAGE MONTHLY VARIATION OF RELATIVE HUMIDITY AT DIFFERENT LOCATIONS

YEAR: 1975 – 2004



FIGURE NO: C30

Project Area Bangladesh
Average Bright Sunshine Hour Map (h)
Year 1975 to 2007
Annual Average

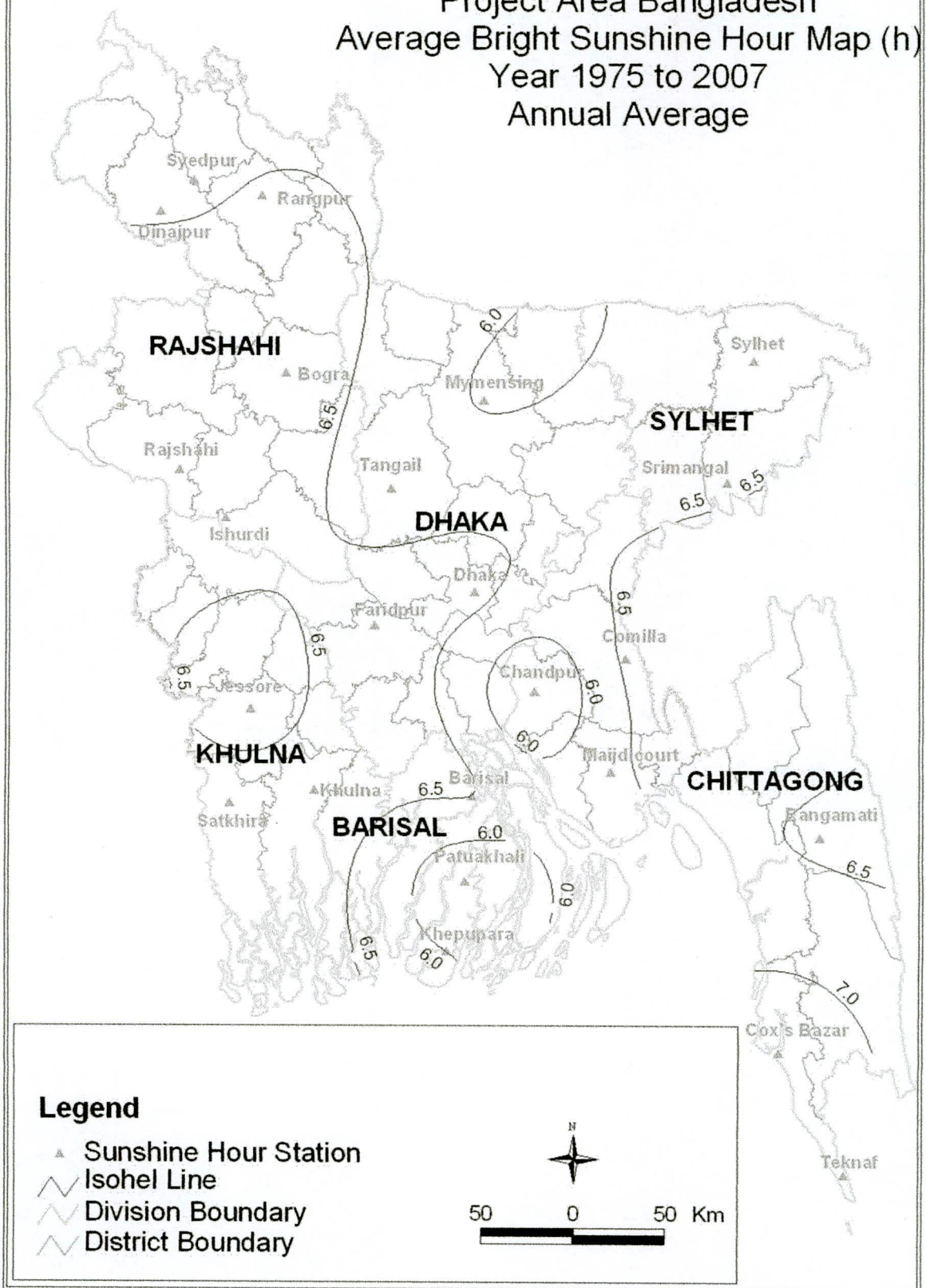


Figure C31: Annual Average Bright Sunshine Hour Map

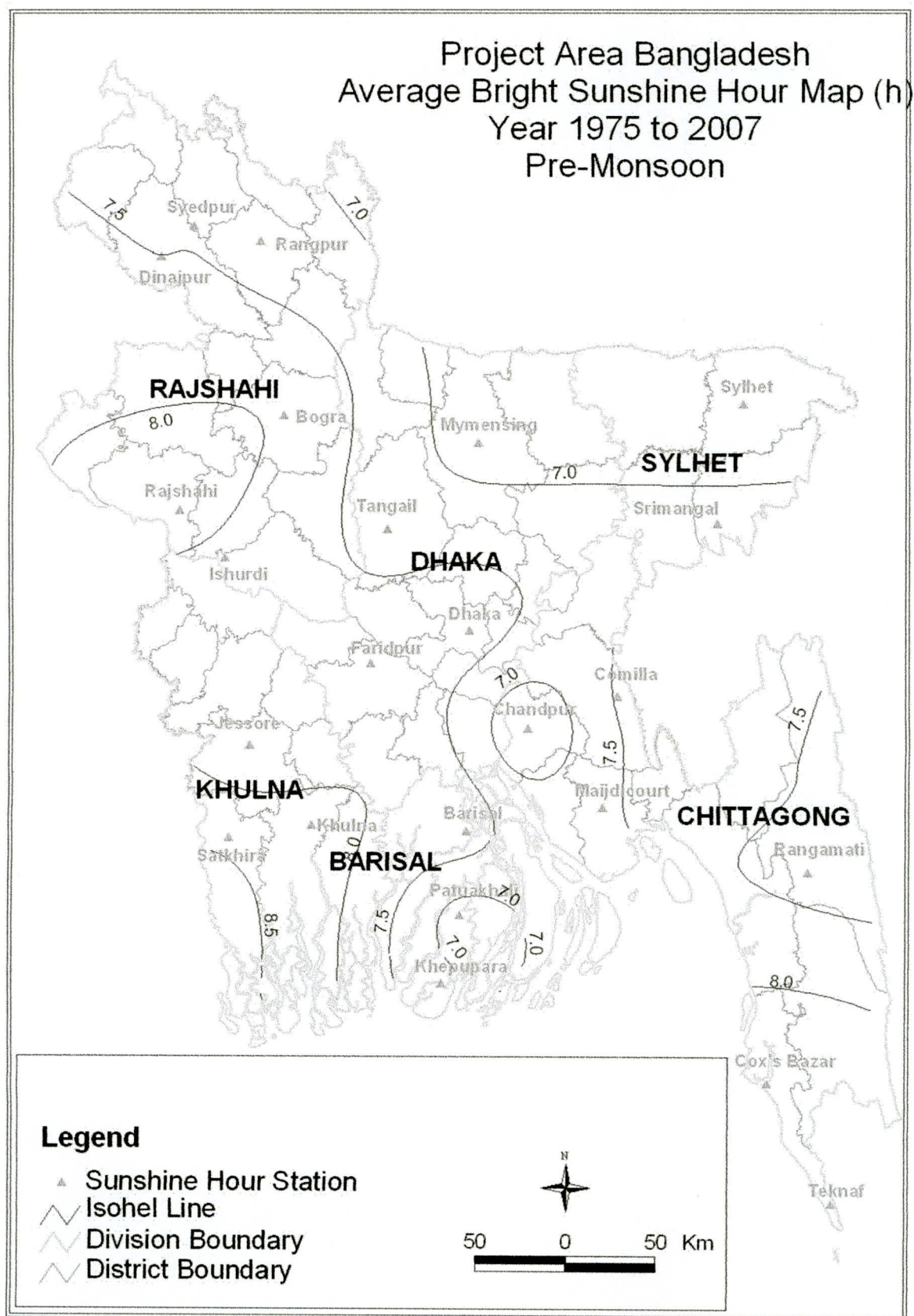


Figure C32: Average Bright Sunshine Hour Map for Pre-Monsoon

Project Area Bangladesh
Average Bright Sunshine Hour Map (h)
Year 1975 to 2007
Monsoon

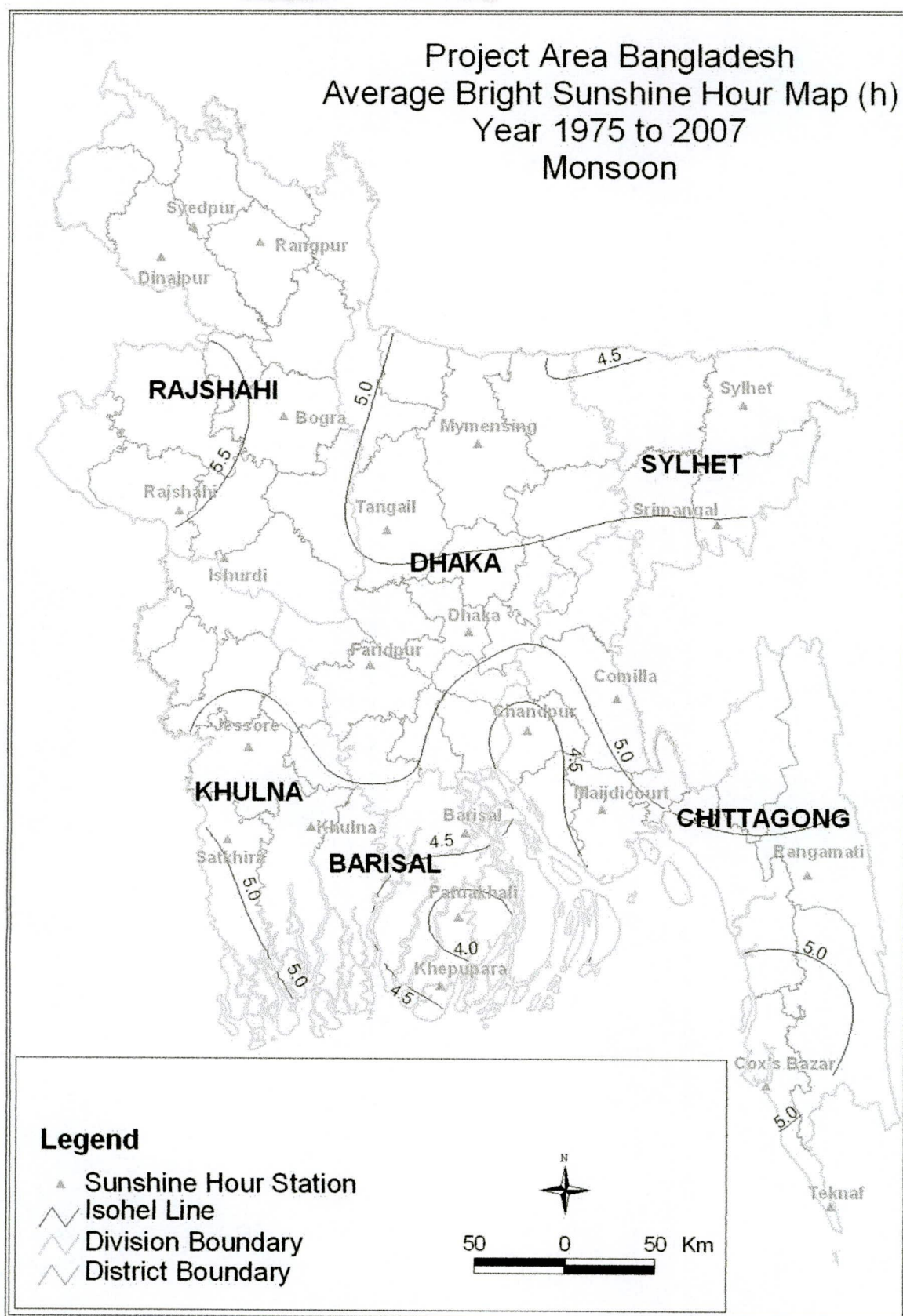


Figure C33: Average Bright Sunshine Hour Map for Monsoon

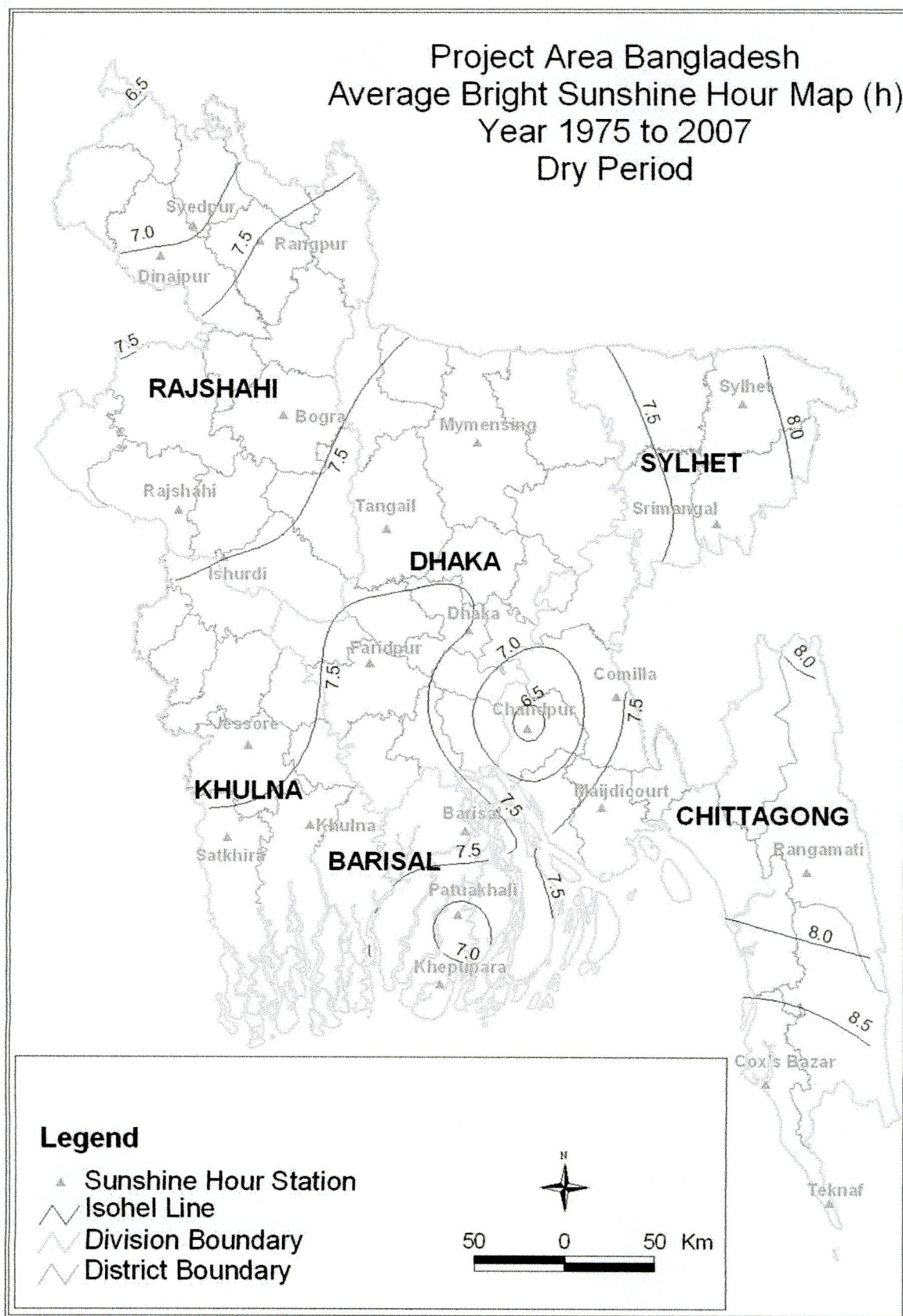
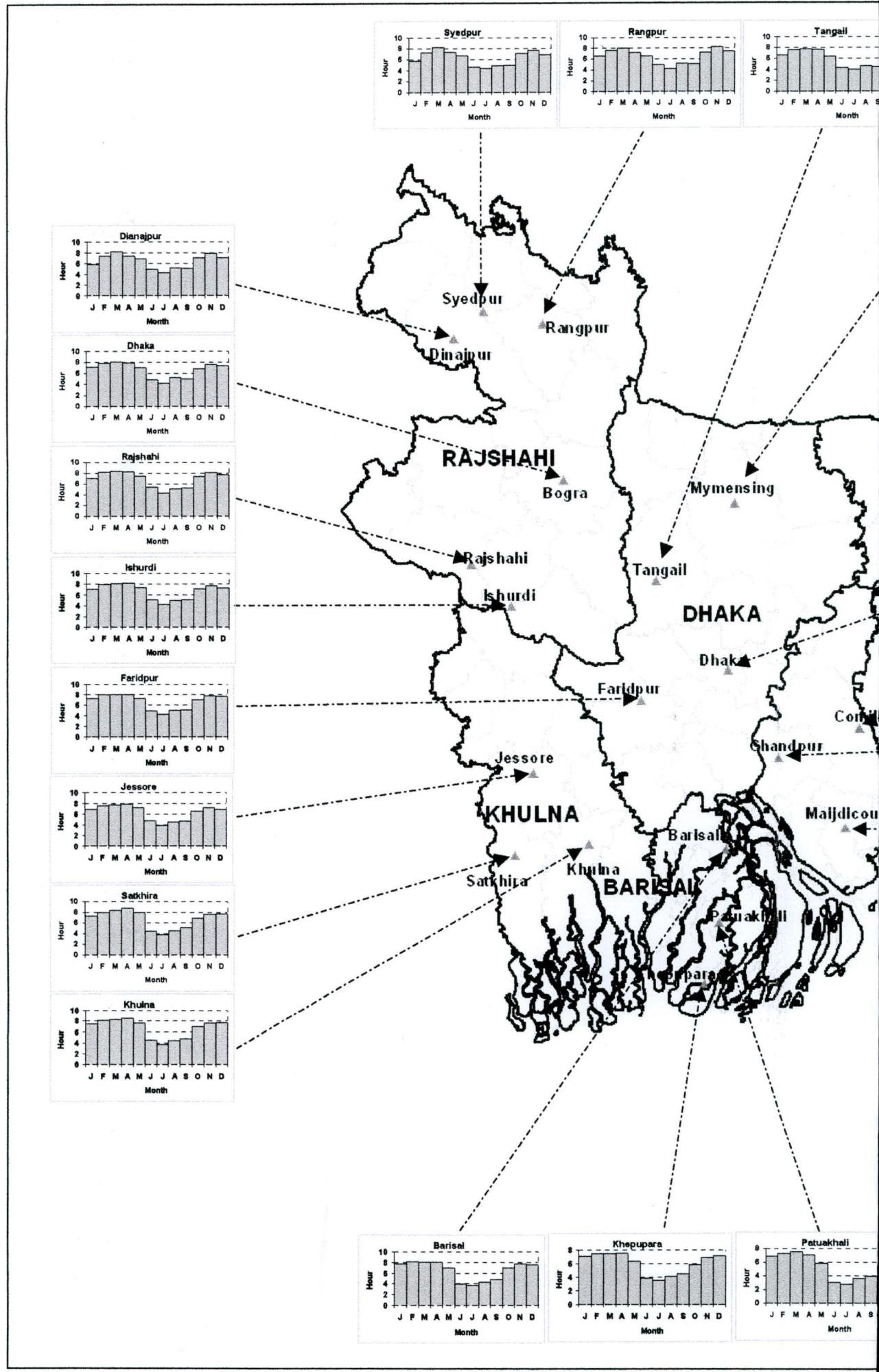
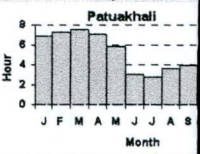
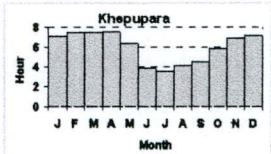
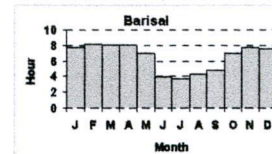
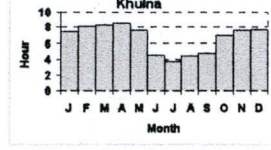
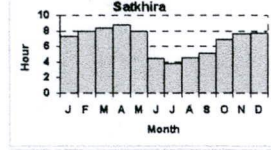
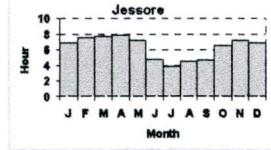
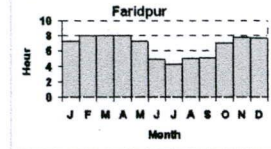
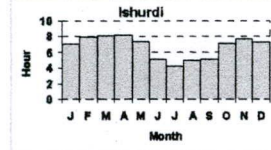
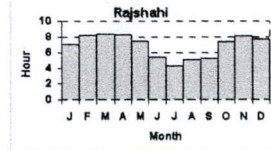
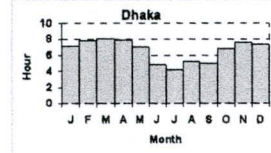
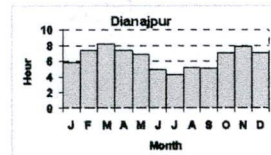
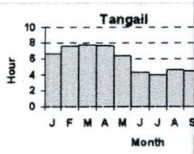
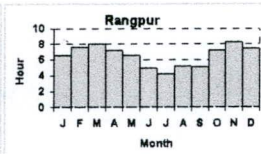
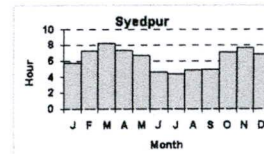


Figure C34: Average Bright Sunshine Hour Map for Dry Period



AVERAGE MONTHLY VARIATION OF BRIGHT SUNSHINE HOUR AT DIFFERENT LOCATIONS

YEAR: 1975 – 2004

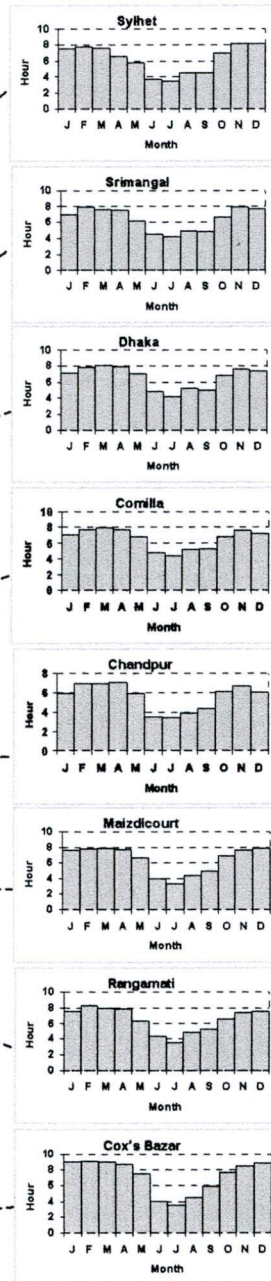
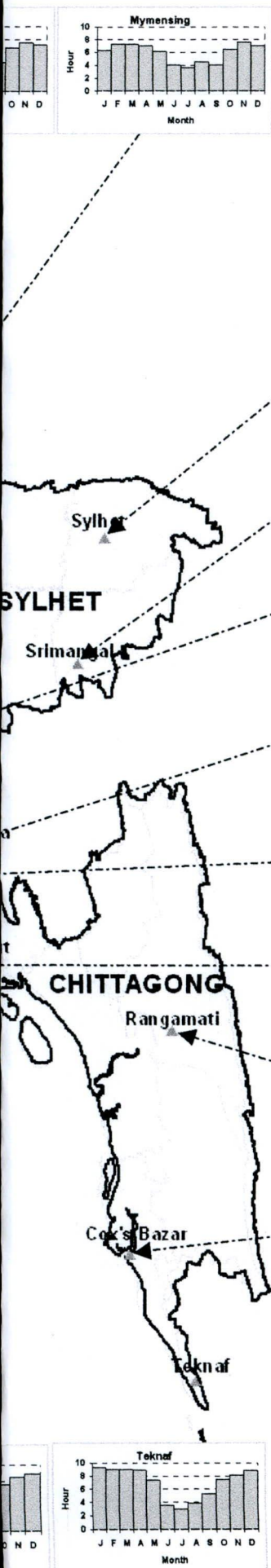


FIGURE NO: C35

Project Area Bangladesh
Average Rainfall Map (mm/day)
Year 1975 to 2004
Annual Average

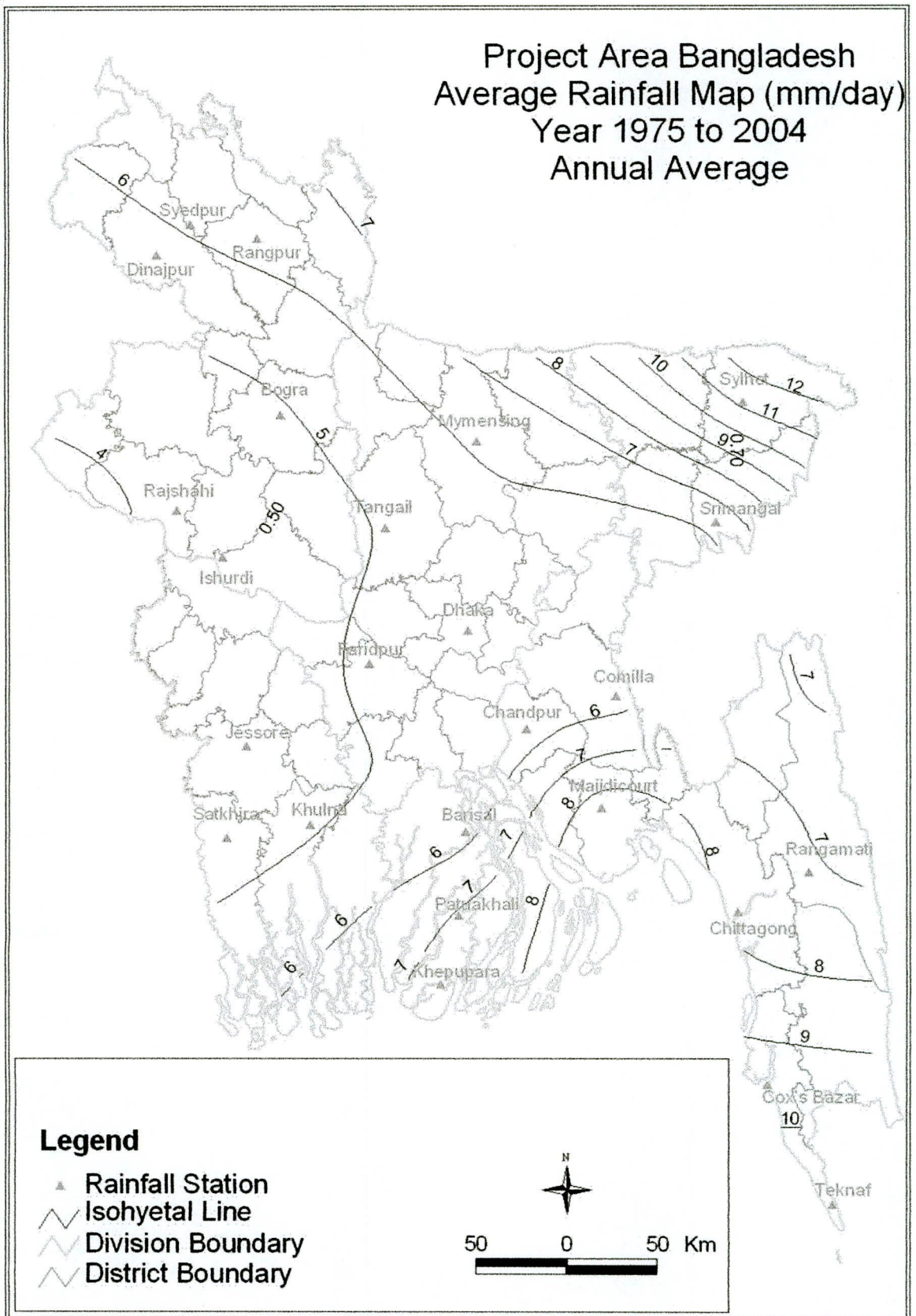


Figure C36: Annual Average Rainfall Map

Project Area Bangladesh
Average Rainfall Map (KPa)
Year 1975 to 2004
Pre-Monsoon

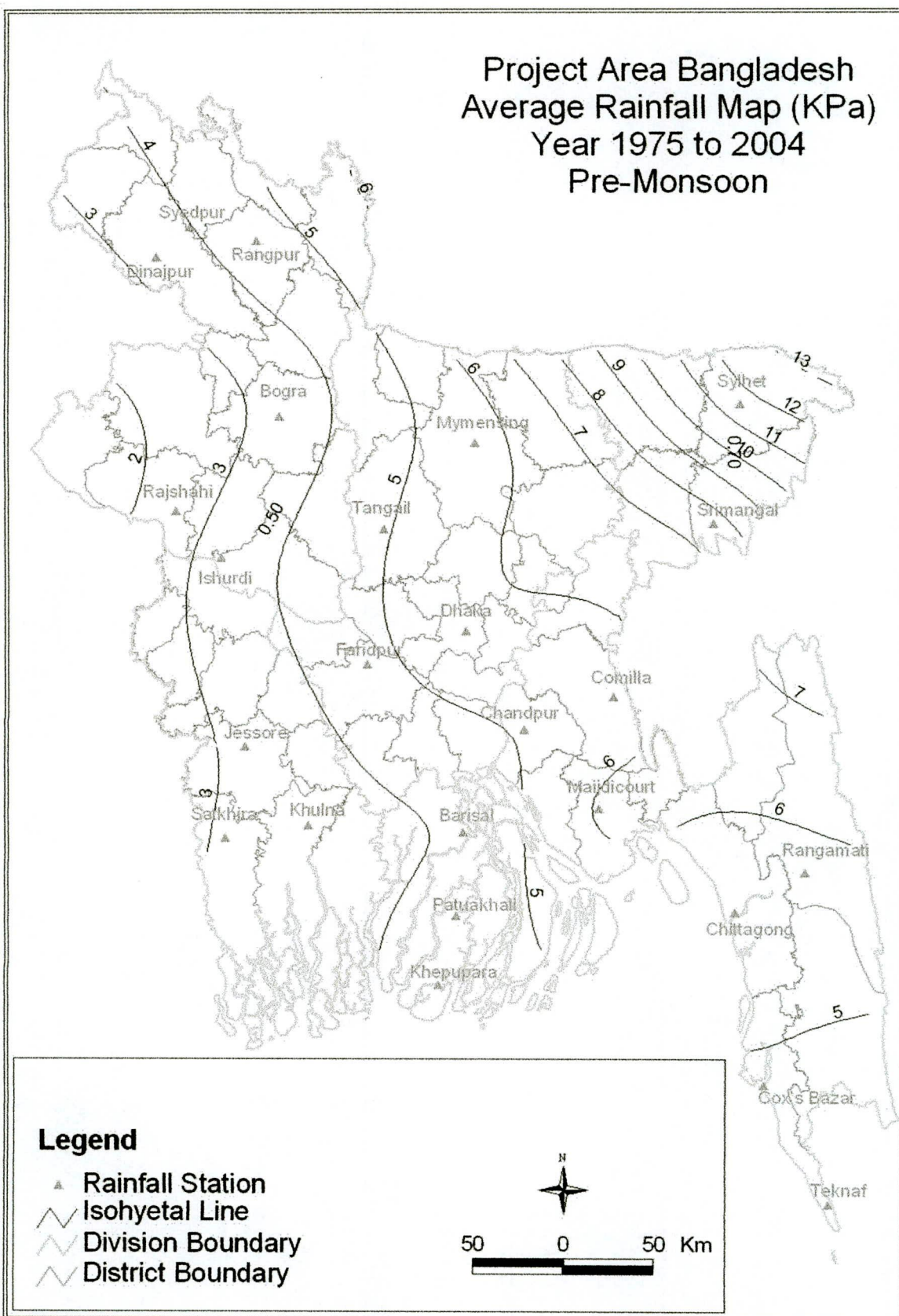


Figure C37: Average Rainfall Map for Pre-Monsoon

Project Area Bangladesh
Average Rainfall Map (mm/day)
Year 1975 to 2004
Monsoon

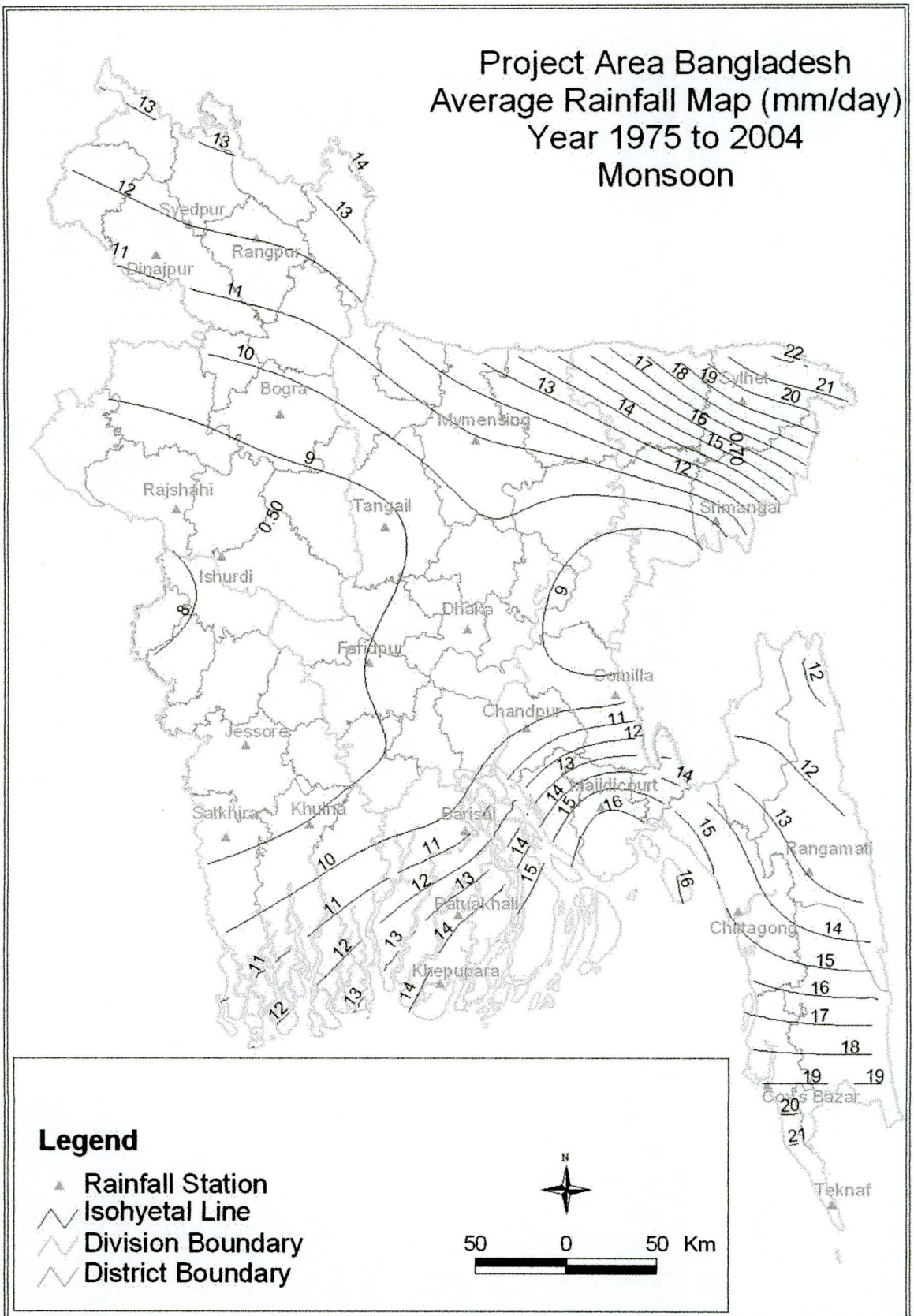


Figure C38: Average Rainfall Map for Monsoon

Project Area Bangladesh
Average Rainfall Map (mm/day)
Year 1975 to 2004
Dry Period

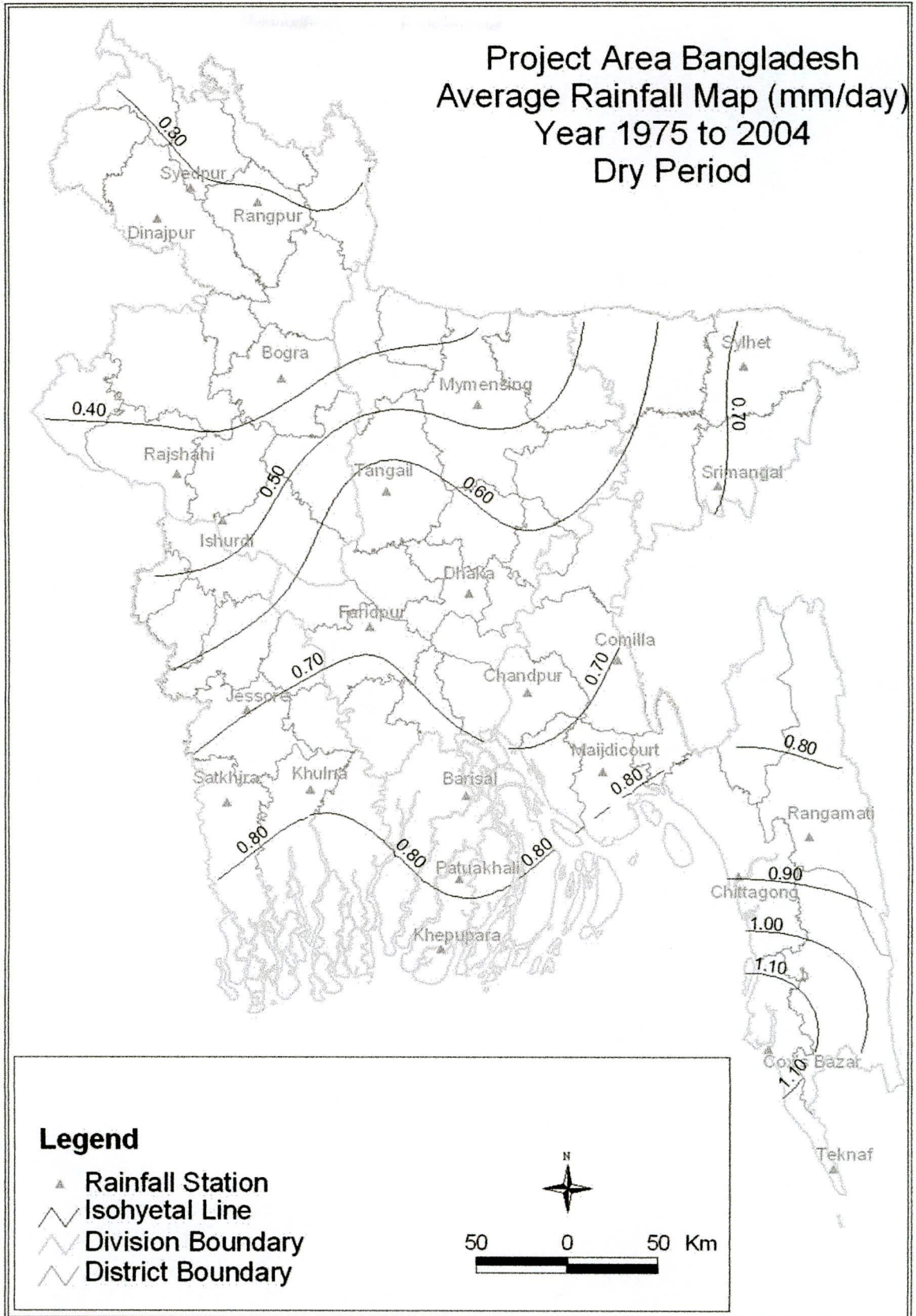
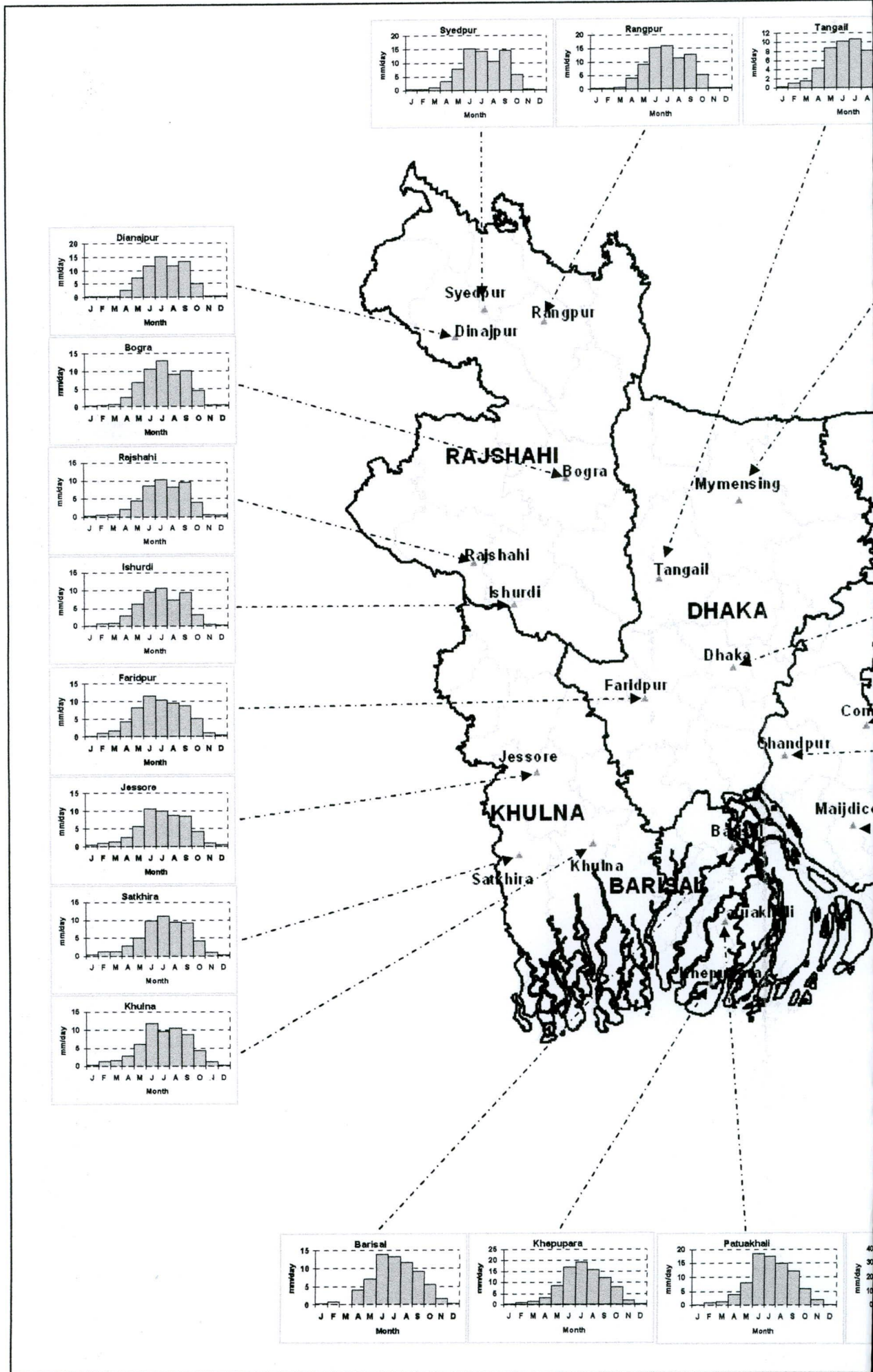
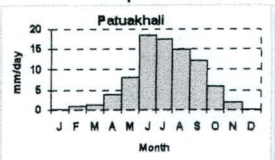
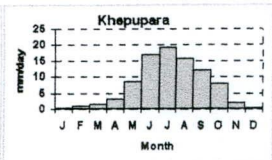
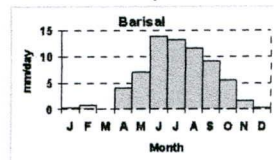
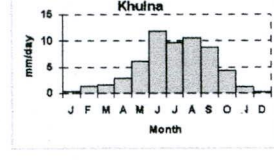
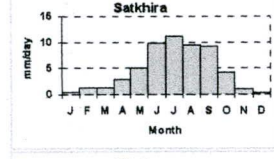
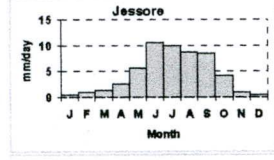
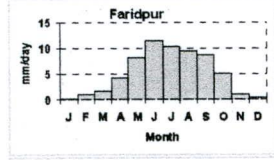
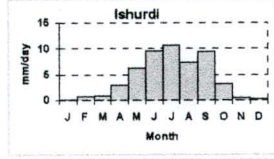
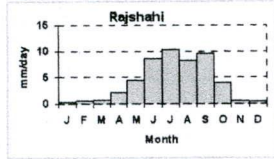
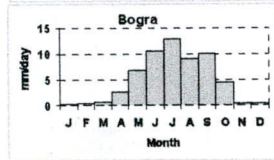
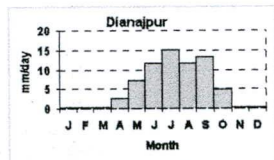
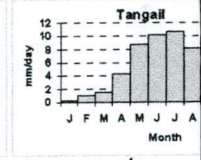
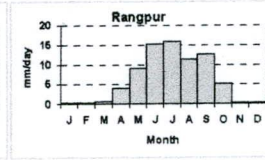
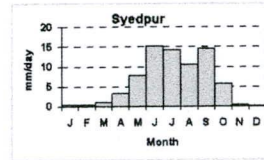


Figure C39: Average Rainfall Map for Dry Period



AVERAGE MONTHLY VARIATION OF RAINFALL AT DIFFERENT LOCATIONS

YEAR: 1975 – 2004

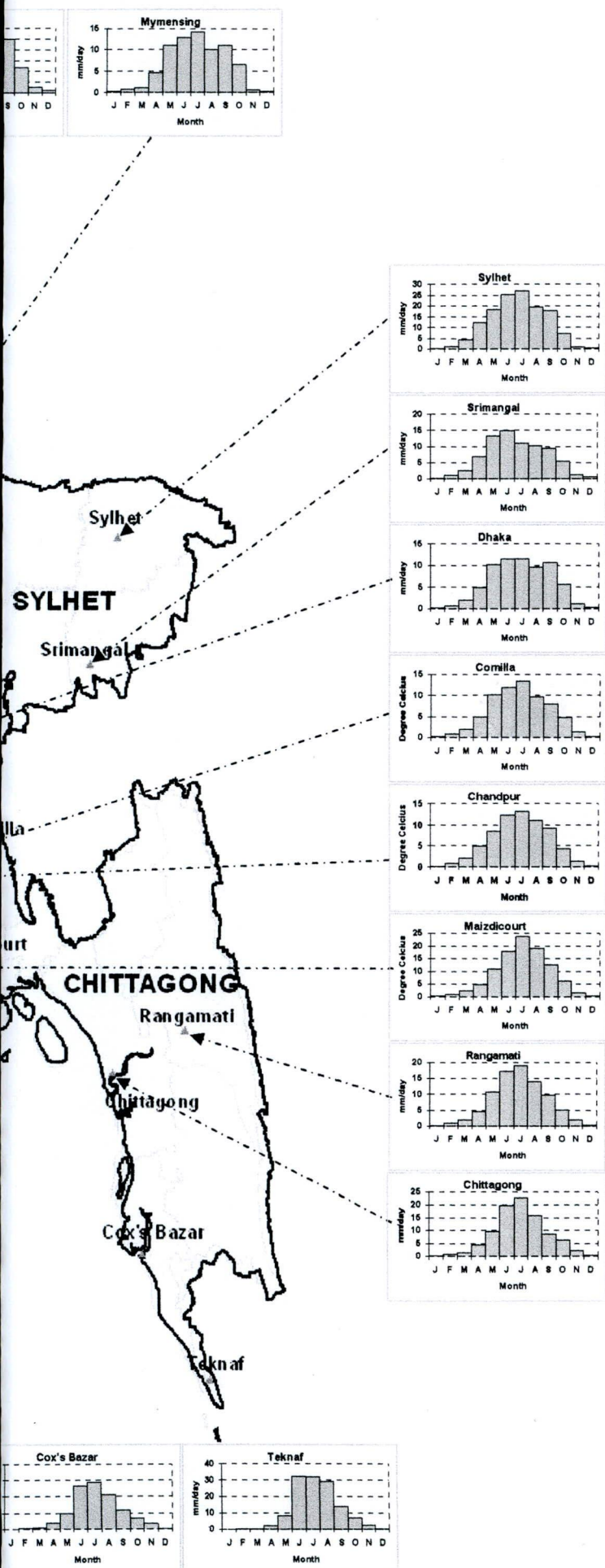


FIGURE NO: C40

APPENDIX D

TEMPERATURE TREND

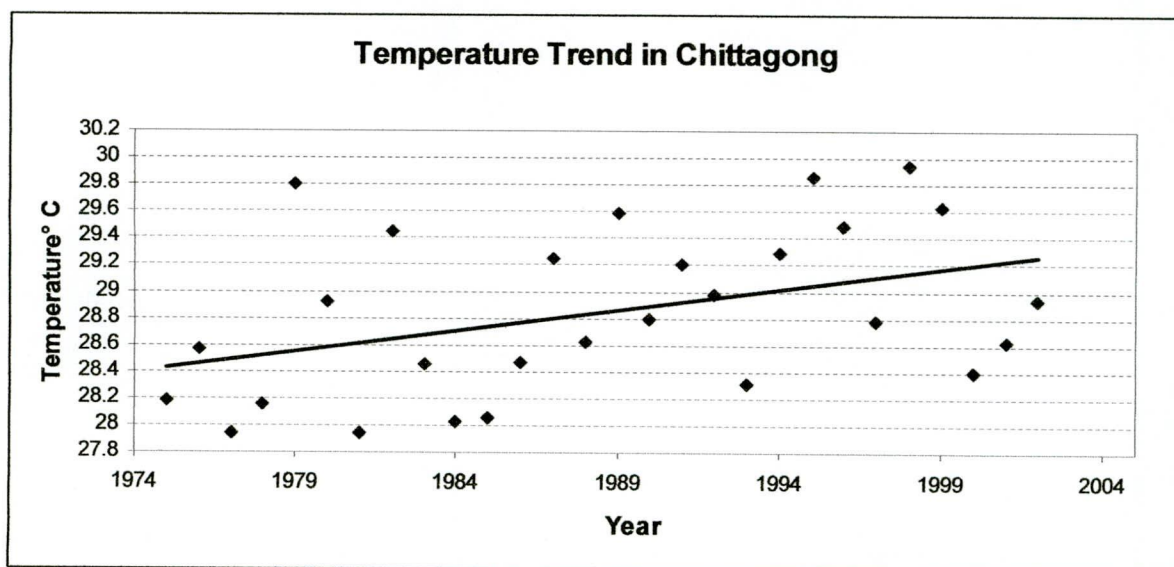
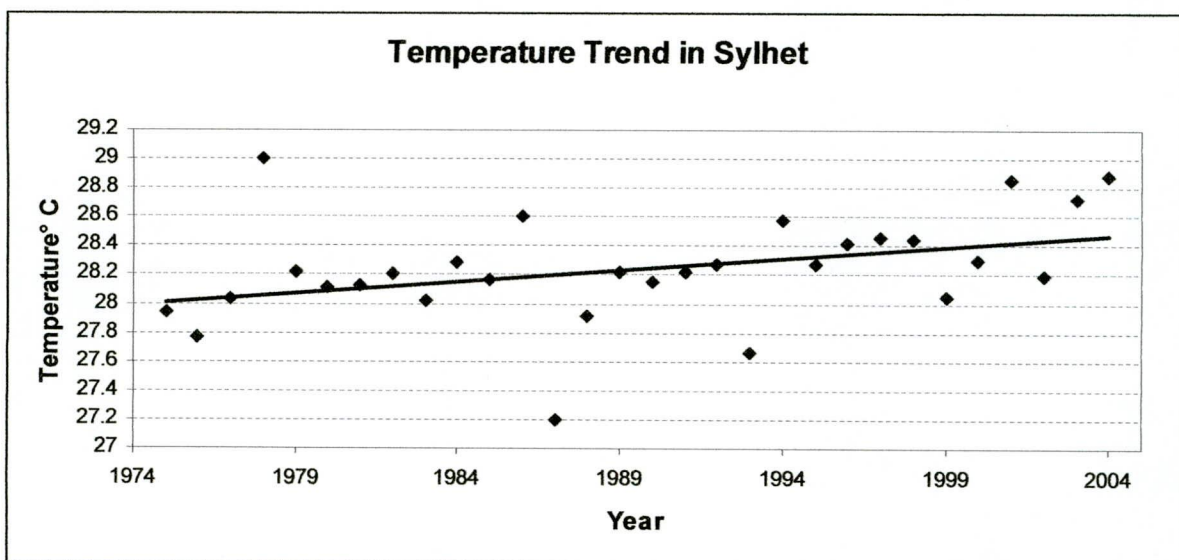
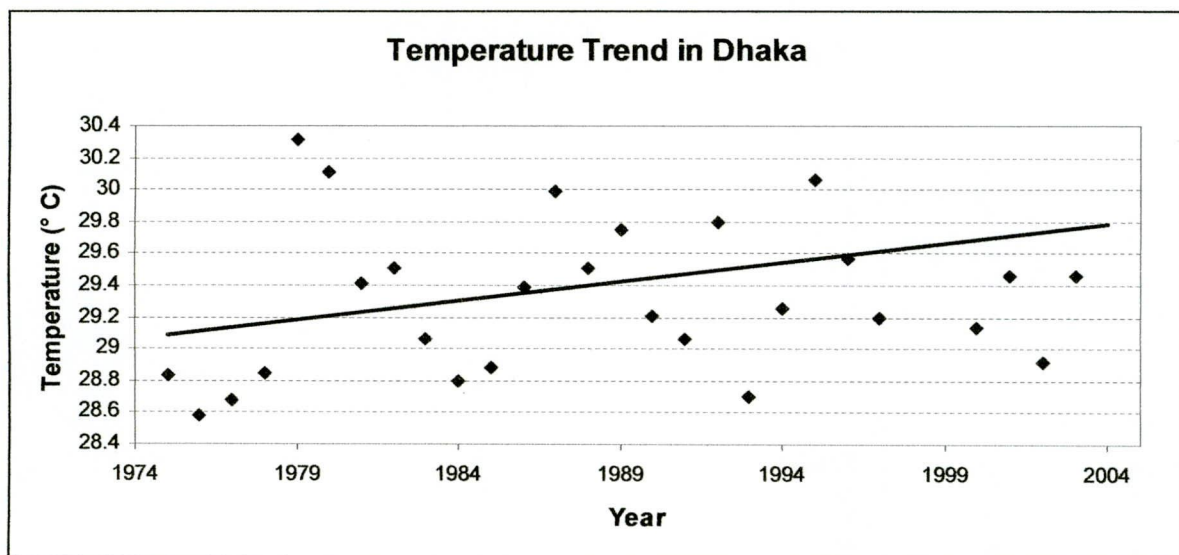


Figure D1: Temperature Trend in Dhaka, Shylhet and Chittagong

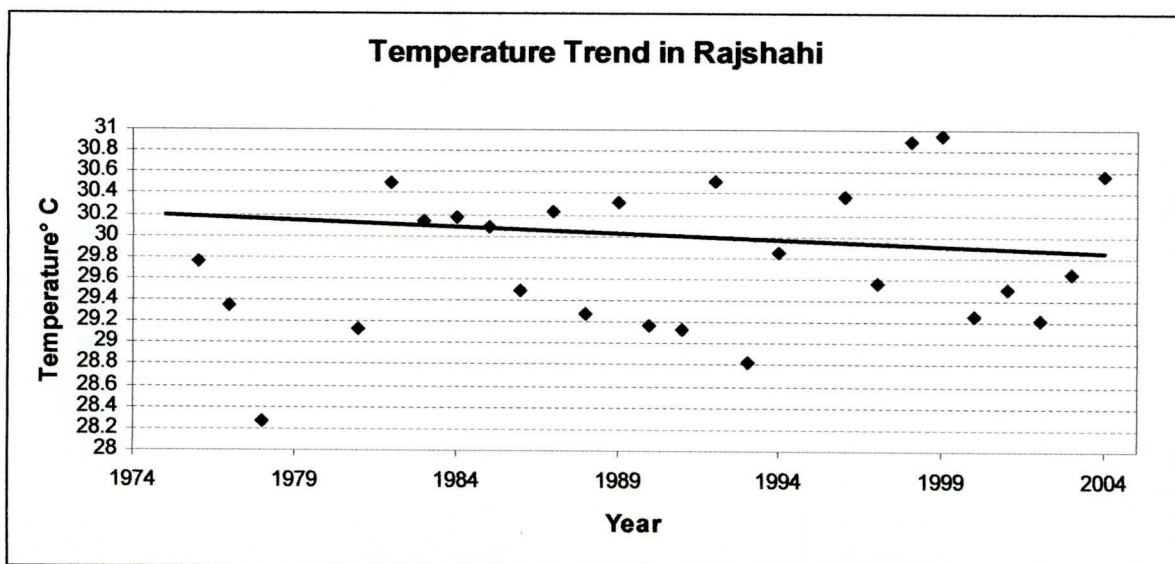
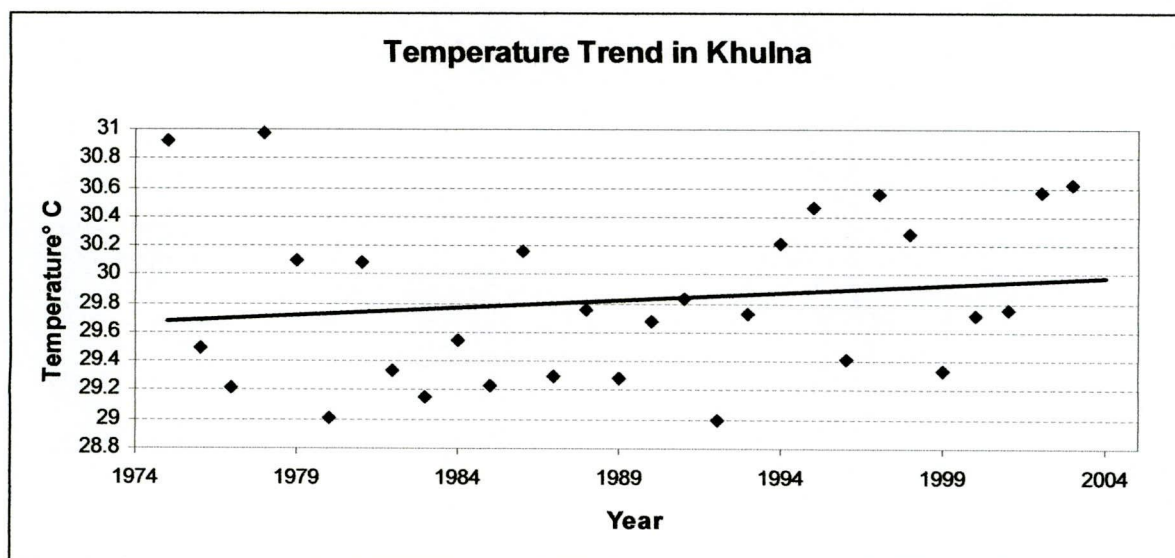
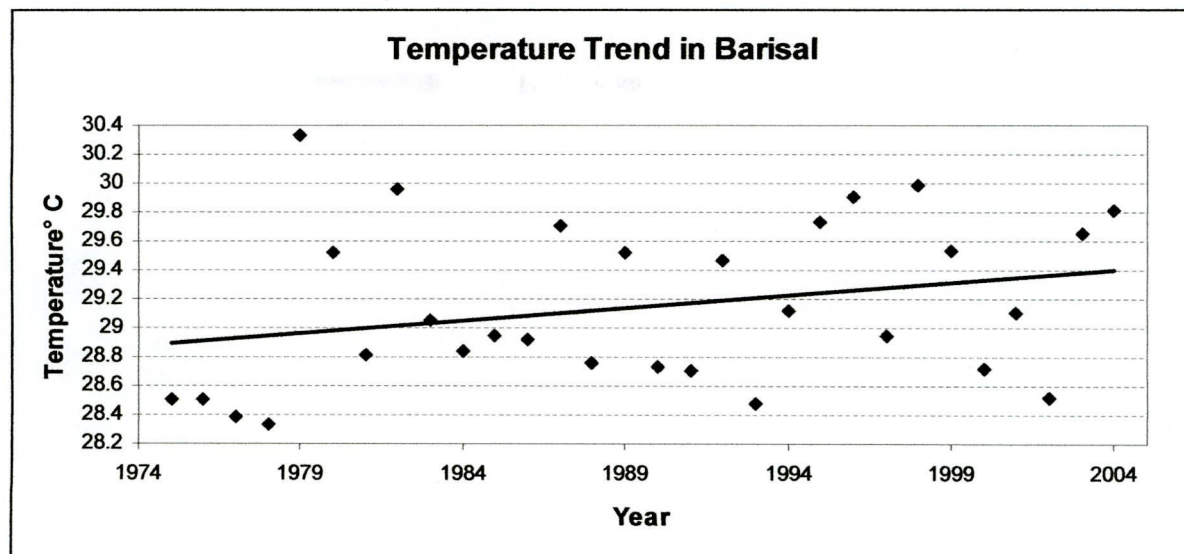


Figure D1: Temperature Trend in Barisal, Khulna and Rajshahi

APPENDIX E
COMPUTATION OF EVAPORATION RATE

Figure E1: Evaporation Computation by Different Method

Station Name	Computation Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barisal	Actual	2.45	3.27	4.41	5.04	4.57	3.37	3.07	3.11	3.05	3.25	2.87	2.54
	Energy Balance	2.92	3.56	3.74	4.19	3.82	2.92	2.56	2.63	2.65	2.39	2.73	2.77
	Aerodynamic	-	-	-	-	-	-	-	-	-	-	-	-
	Combined	-	-	-	-	-	-	-	-	-	-	-	-
	Priestly-Taylor	-	-	-	-	-	-	-	-	-	-	-	-
Bogra	Actual	2.19	3.02	4.51	5.05	4.83	4.31	3.85	4.02	3.49	3.40	2.88	2.30
	Energy Balance	2.69	3.53	4.30	4.36	4.25	3.64	3.40	3.57	3.42	3.10	3.11	2.83
	Aerodynamic	0.49	0.88	1.69	2.09	1.51	1.10	0.93	0.99	0.59	0.49	0.44	0.36
	Combined	1.94	2.72	3.63	3.83	3.61	3.07	2.84	2.99	2.76	2.46	2.34	2.01
	Priestly-Taylor	1.94	2.72	3.63	3.83	3.61	3.07	2.84	2.99	2.76	2.46	2.34	2.01
Comilla	Actual	2.44	3.10	4.14	4.77	4.57	4.12	3.98	4.10	4.06	3.44	3.19	2.52
	Energy Balance	2.11	2.71	3.15	3.22	3.01	2.55	2.50	2.74	2.56	2.44	2.11	1.95
	Aerodynamic	0.93	1.28	1.55	1.78	1.70	1.36	1.30	1.13	0.81	0.78	0.62	0.65
	Combined	1.49	2.10	2.73	2.77	2.57	2.17	2.08	2.27	2.04	1.95	1.59	1.45
	Priestly-Taylor	1.83	2.46	3.02	3.18	3.01	2.55	2.49	2.74	2.55	2.40	1.98	1.72
Dhaka	Actual	2.82	4.09	5.22	5.27	5.25	3.93	3.99	4.15	3.81	3.50	3.57	2.86
	Energy Balance	2.95	3.71	4.10	4.34	4.41	3.50	3.36	3.66	3.00	2.91	3.40	2.70
	Aerodynamic	1.08	1.54	2.51	2.45	1.92	1.38	1.30	1.20	1.13	1.22	1.06	0.87
	Combined	2.32	3.07	3.70	3.90	3.84	3.02	2.89	3.11	2.57	2.50	2.76	2.12
	Priestly-Taylor	2.56	3.39	4.00	4.34	4.43	3.53	3.38	3.69	3.01	2.88	3.22	2.39
Dinajpur	Actual	1.66	2.66	4.52	5.00	4.53	3.74	3.06	3.50	3.00	2.95	2.45	1.77
	Energy Balance	2.07	2.74	3.28	3.13	3.26	2.67	2.82	2.87	2.68	2.39	2.65	2.25
	Aerodynamic	0.23	0.55	1.03	1.10	0.81	0.89	0.74	0.52	0.41	0.61	0.26	0.31
	Combined	1.41	2.04	2.68	2.64	2.69	2.27	2.35	2.35	2.16	1.95	1.97	1.60
	Priestly-Taylor	1.73	2.43	3.12	3.10	3.26	2.69	2.84	2.90	2.68	2.34	2.46	1.95
Faridpur	Actual	2.30	3.30	5.01	5.98	4.91	4.18	3.53	3.78	3.55	3.47	2.96	2.17
	Energy Balance	2.03	2.42	2.69	2.76	2.77	2.21	2.25	2.44	2.02	2.20	2.41	2.28
	Aerodynamic	0.61	1.07	2.19	2.88	1.79	1.16	1.07	1.05	0.77	0.62	0.43	0.43
	Combined	1.55	2.01	2.56	2.79	2.55	1.97	1.98	2.13	1.74	1.82	1.87	1.68
	Priestly-Taylor	1.74	2.19	2.61	2.77	2.79	2.23	2.26	2.46	2.03	2.18	2.28	2.01
Khulna	Actual	2.44	3.15	4.55	5.48	5.14	3.90	3.49	3.37	3.29	3.37	2.91	2.51
	Energy Balance	3.33	4.47	4.53	4.82	5.04	4.15	4.07	4.00	3.67	3.48	3.82	3.36
	Aerodynamic	0.40	0.60	0.94	1.48	1.22	0.70	0.59	0.51	0.45	0.43	0.35	0.32
	Combined	2.35	3.33	3.64	4.07	4.20	3.38	3.28	3.21	2.93	2.76	2.88	2.39
	Priestly-Taylor	2.88	4.09	4.43	4.85	5.11	4.19	4.10	4.03	3.68	3.45	3.62	2.97
Mymensing	Actual	2.15	2.96	4.33	4.96	4.59	3.86	3.76	3.87	3.56	3.36	2.62	2.25
	Energy Balance	2.04	2.62	3.02	3.20	3.21	2.43	2.40	2.93	2.40	2.30	2.48	2.17
	Aerodynamic	0.62	1.27	2.03	2.36	1.95	1.66	1.53	1.63	1.10	0.93	0.65	0.48
	Combined	1.56	2.21	2.76	3.00	2.92	2.25	2.20	2.64	2.10	1.97	1.98	1.63
	Priestly-Taylor	1.76	2.37	2.90	3.16	3.19	2.44	2.41	2.95	2.40	2.27	2.34	1.92

Station Name	Computation Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rajshahi	Actual	2.15	2.96	4.33	4.96	4.59	3.86	3.76	3.87	3.56	3.36	2.62	2.25
	Energy Balance	-	-	-	-	-	-	-	-	-	-	-	-
	Aerodynamic	0.61	1.02	2.19	3.20	2.23	1.39	1.05	1.09	0.90	0.62	0.52	0.62
	Combined	-	-	-	-	-	-	-	-	-	-	-	-
	Priestly-Taylor	-	-	-	-	-	-	-	-	-	-	-	-
Rangpur	Actual	1.90	3.08	4.76	5.06	4.64	4.26	3.99	4.08	3.46	3.36	2.99	2.24
	Energy Balance	2.07	2.73	3.28	3.12	3.25	2.67	2.82	2.86	2.68	2.39	2.65	2.25
	Aerodynamic	0.29	0.61	1.50	2.08	1.38	0.89	0.75	0.67	0.43	0.64	0.42	0.41
	Combined	1.43	2.04	2.79	2.86	2.80	2.26	2.34	2.36	2.15	1.96	2.00	1.63
	Priestly-Taylor	1.73	2.40	3.08	3.03	3.20	2.66	2.82	2.87	2.66	2.34	2.44	1.94
Srimangal	Actual	2.32	3.21	4.26	4.48	3.96	3.49	3.37	3.42	3.48	3.48	2.92	2.53
	Energy Balance	2.73	3.30	3.69	3.99	3.68	2.98	3.11	3.58	3.32	3.11	3.04	2.82
	Aerodynamic	0.24	0.69	1.56	1.35	1.12	0.91	0.70	0.71	0.35	0.44	0.25	0.40
	Combined	1.84	2.45	3.10	3.32	3.06	2.50	2.55	2.93	2.62	2.44	2.23	2.01
	Priestly-Taylor	2.28	2.90	3.47	3.87	3.62	2.97	3.10	3.59	3.30	3.02	2.80	2.43

APPENDIX F
COMPARISON PLOTS OF EVAPORATION RATE

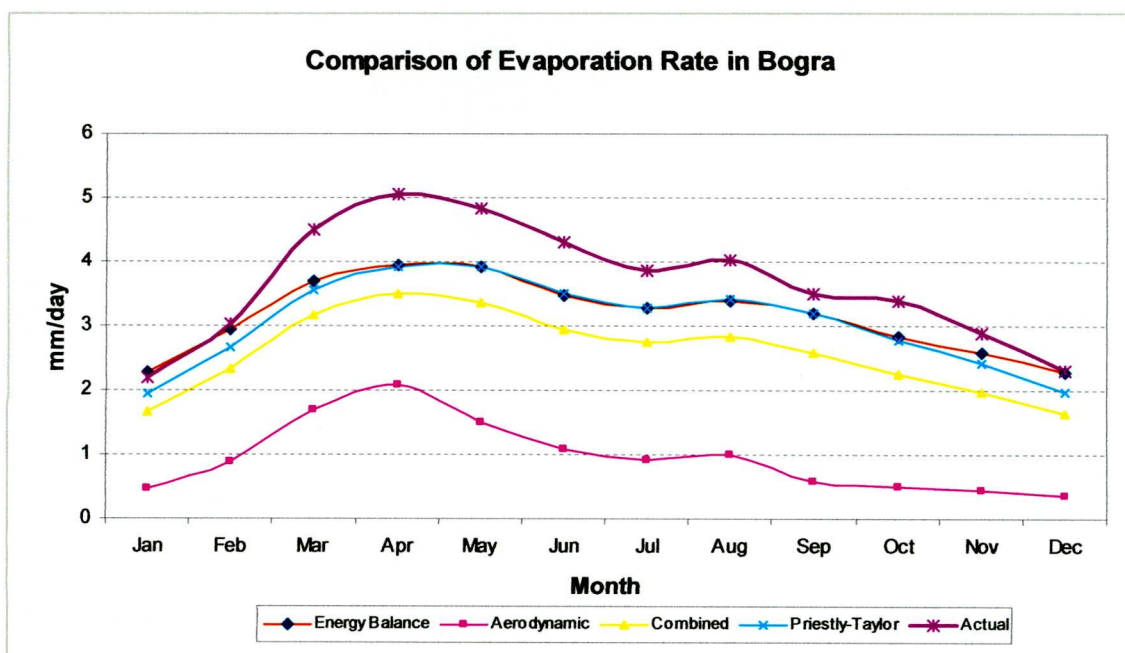
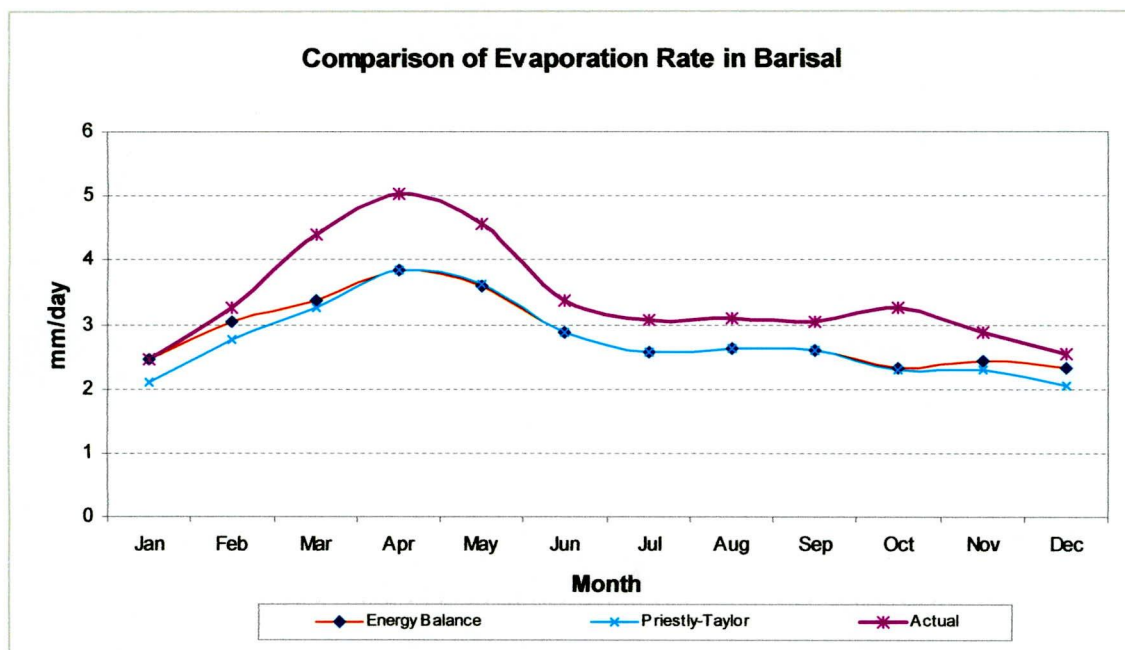


Figure F1: Comparison of Evaporation Rate by Different Methods in Barisal and Bogra

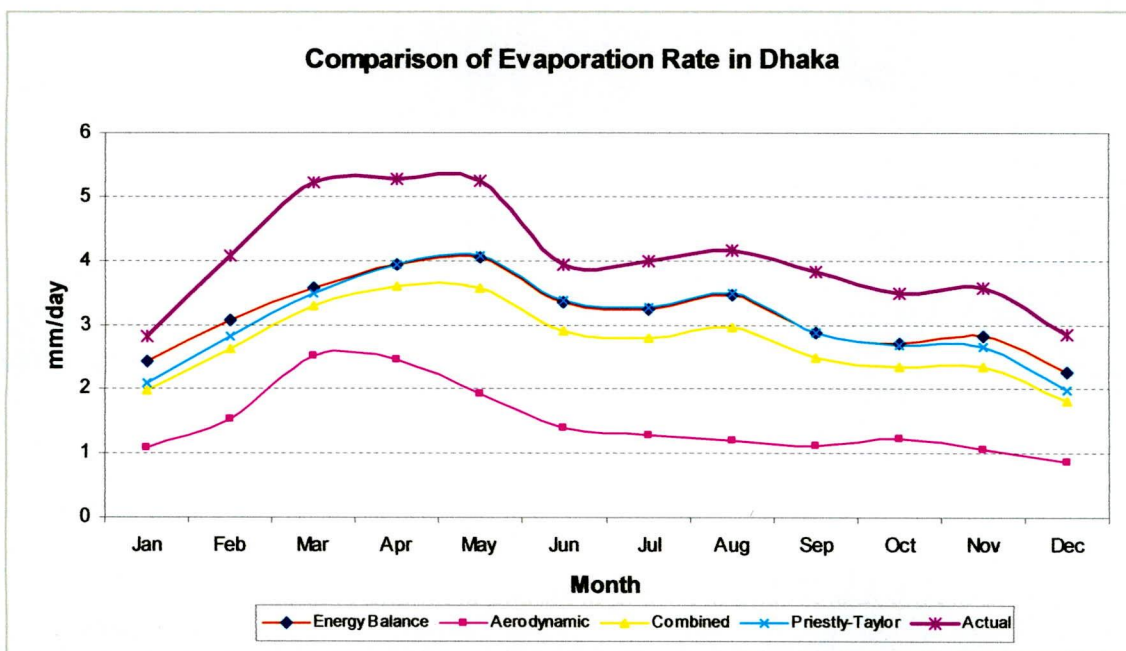
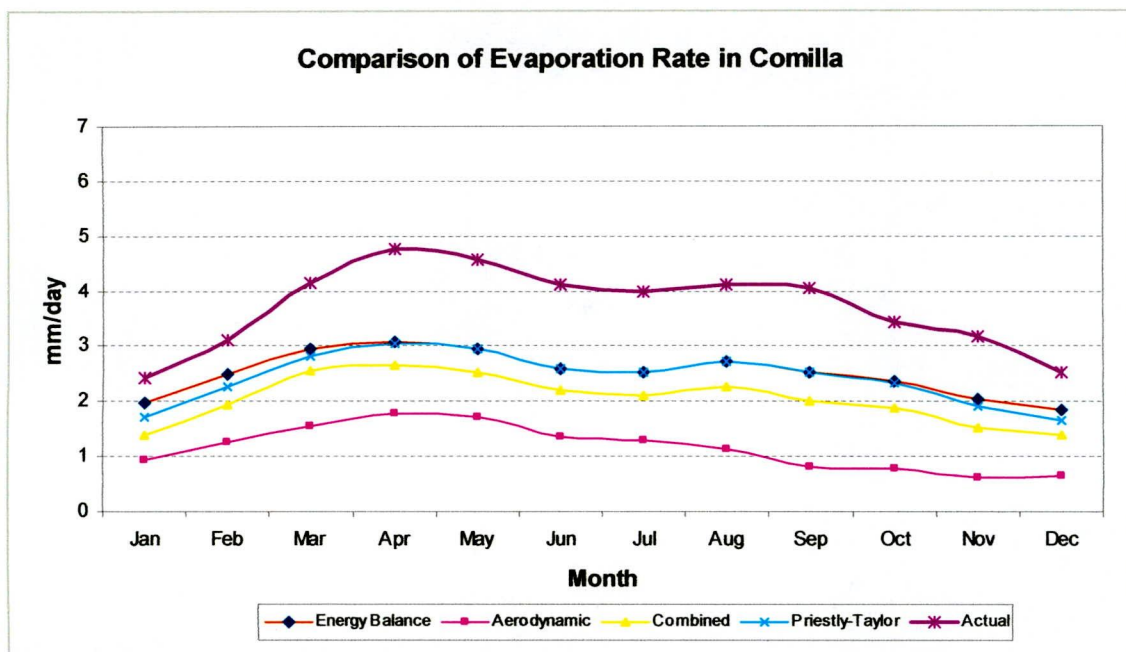


Figure F2: Comparison of Evaporation Rate by Different Methods in Comilla and Dhaka

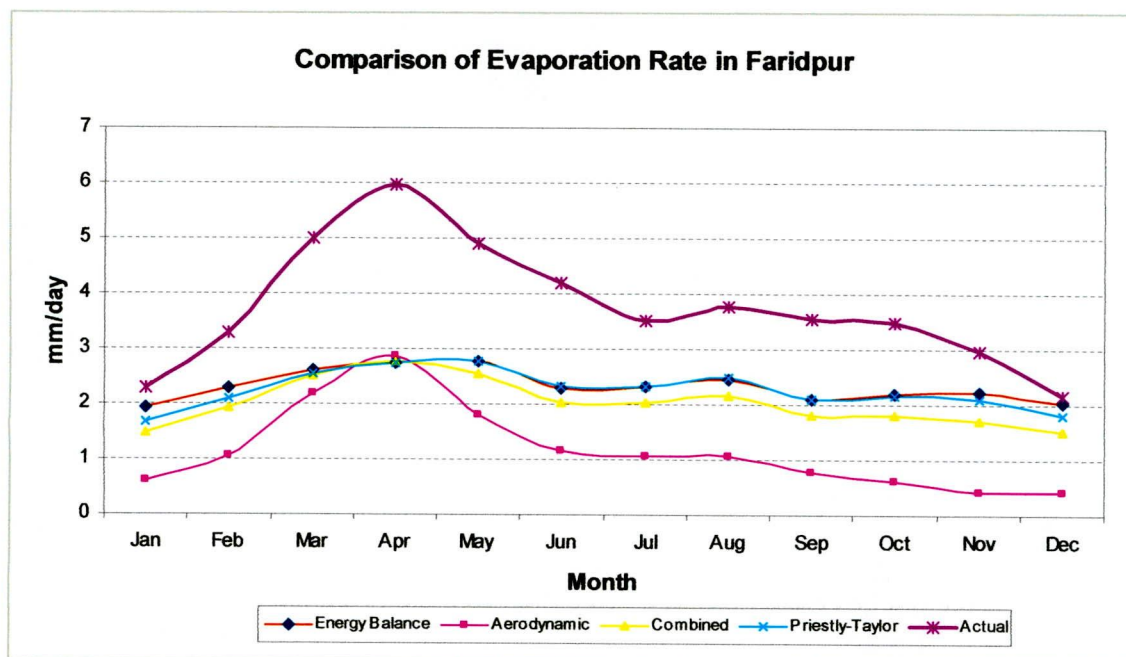
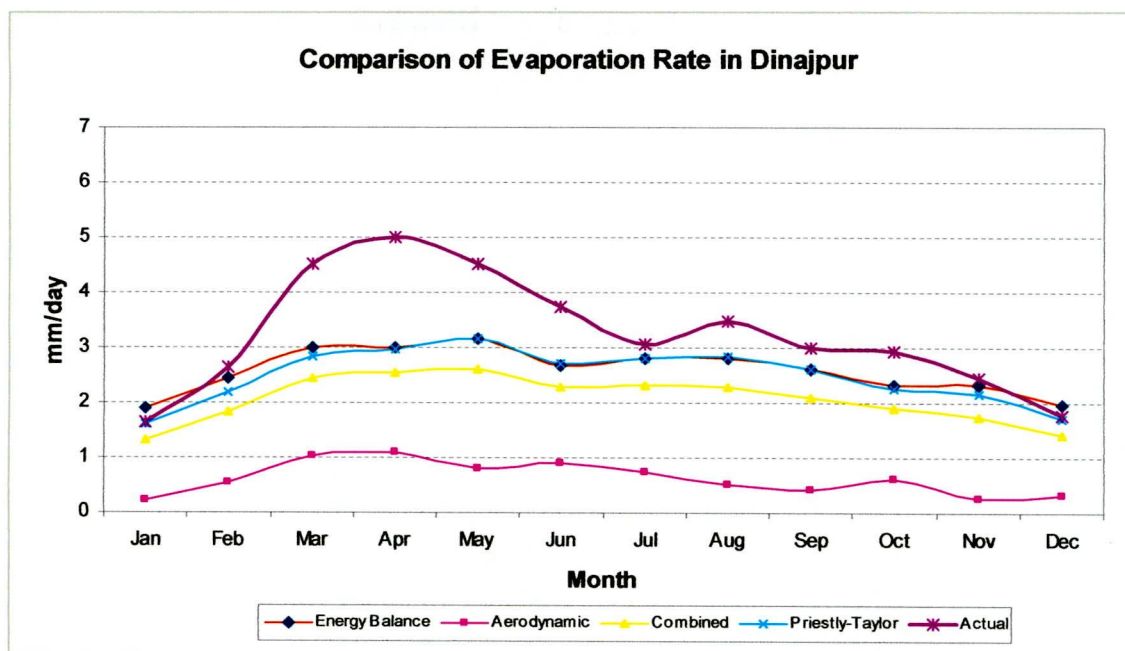


Figure F3: Comparison of Evaporation Rate by Different Methods in Dinajpur and Faridpur

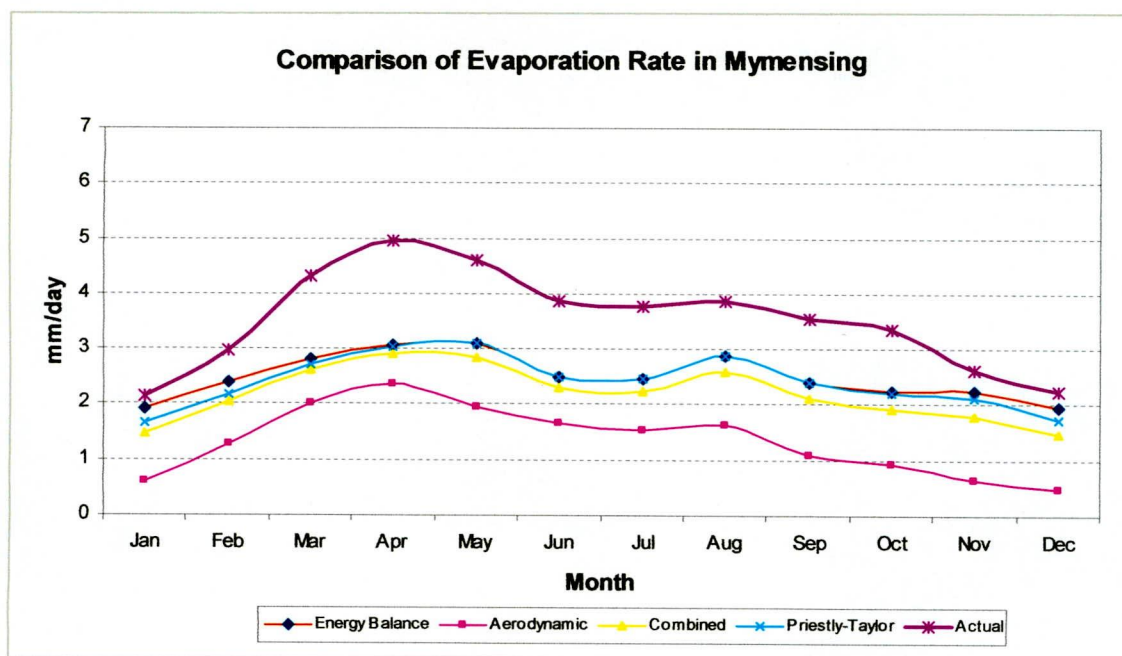
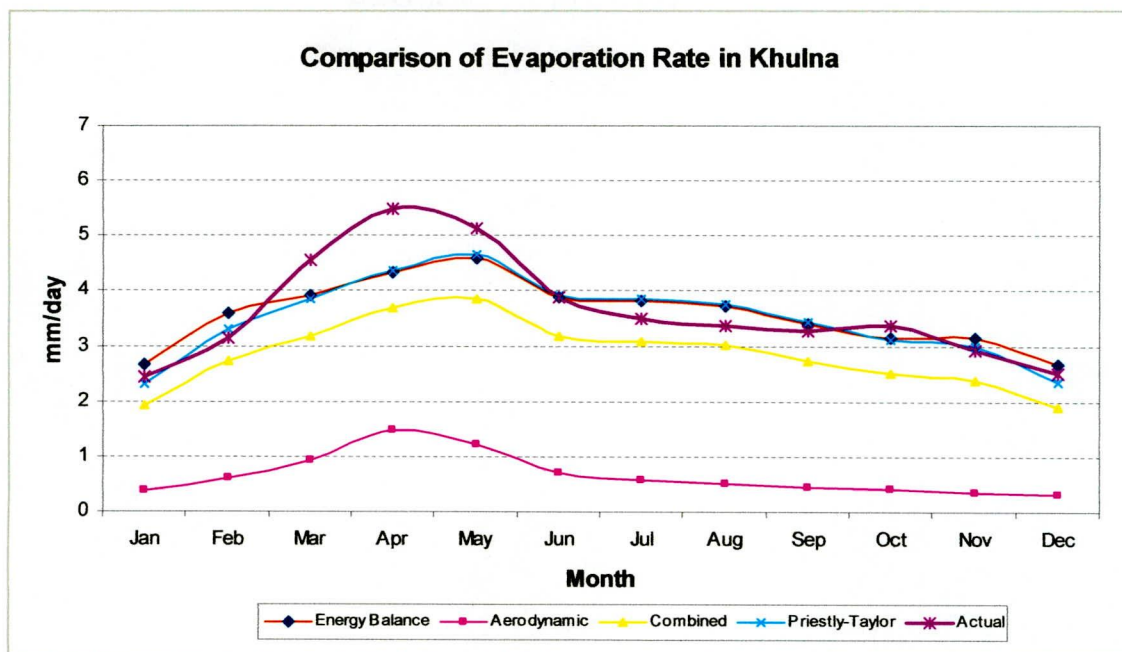


Figure F4: Comparison of Evaporation Rate by Different Methods in Khulna and Mymensing

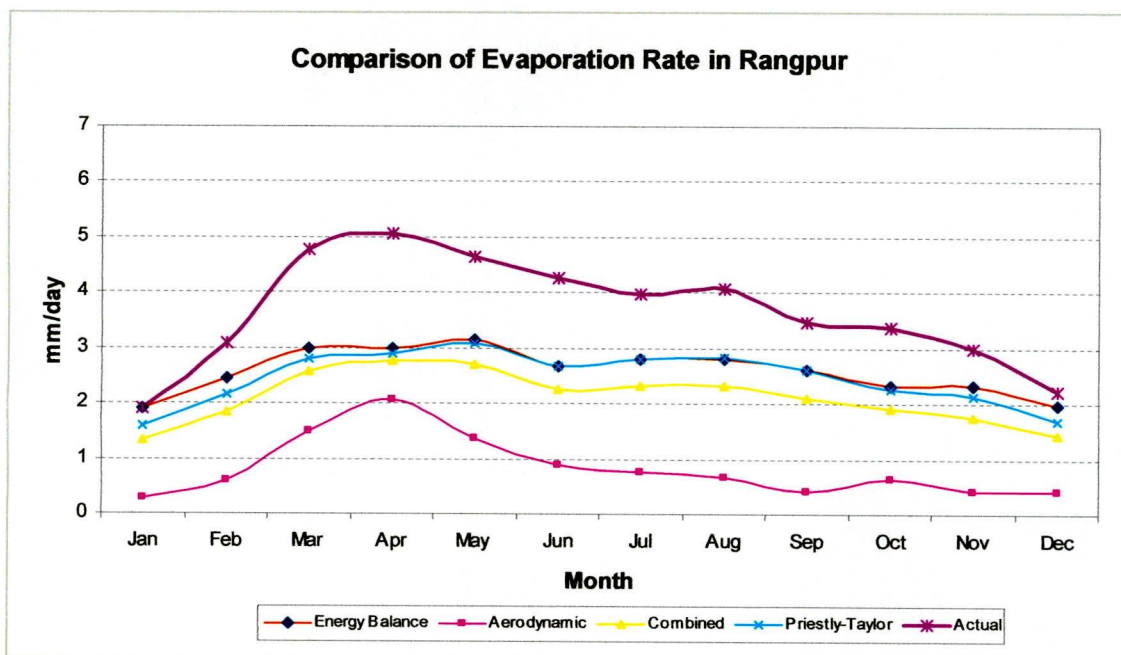
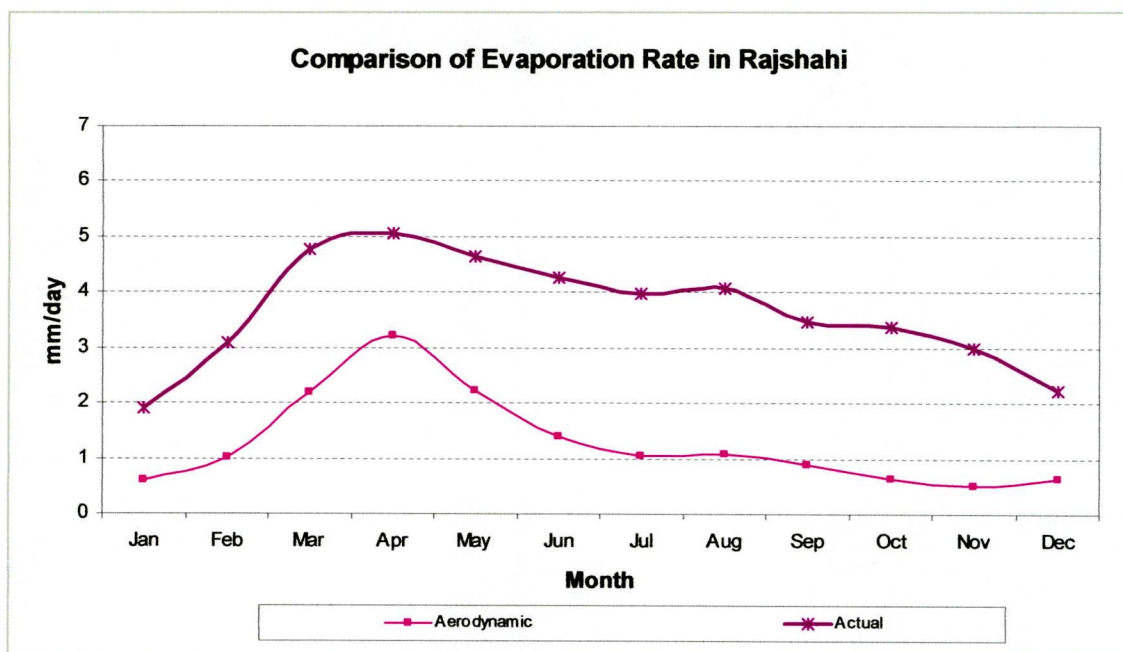


Figure F5: Comparison of Evaporation Rate by Different Methods in Rajshahi and Rangpur

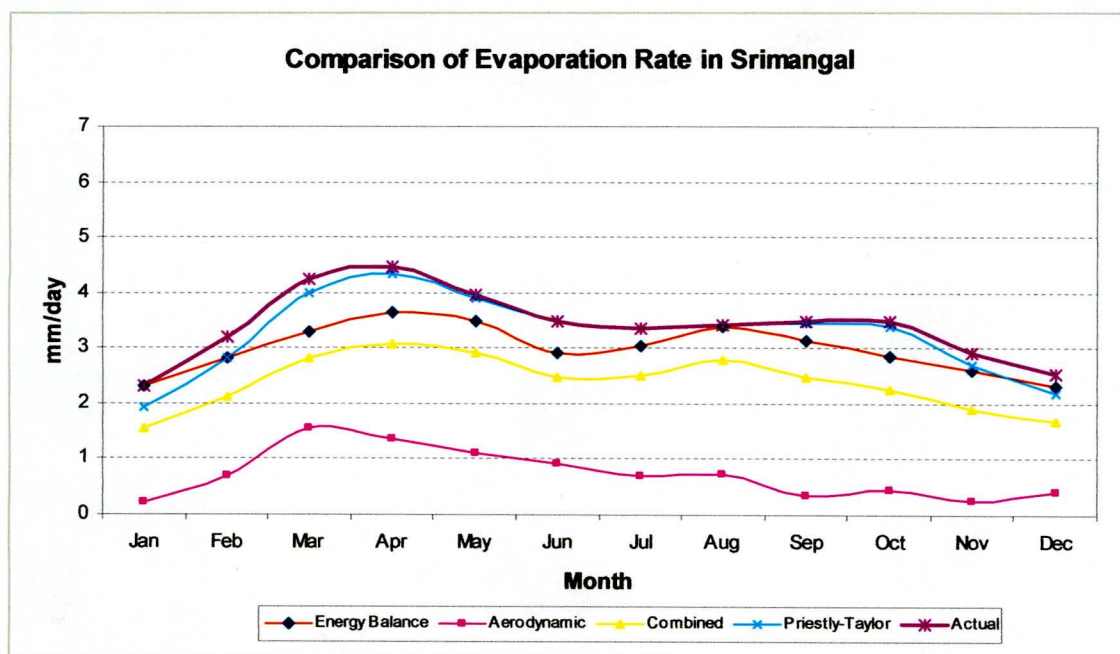


Figure F5: Comparison of Evaporation Rate by Different Methods in Srimangal

