Characterization of pan evaporation with related climatological parameters of Bangladesh.

A Thesis Submitted in Partial Fulfilment of the Requirements for the Bachelor of Science Degree in Civil Engineering.

By

Syed Tanvir Ahmed (Student ID: 105420)

Md. Shafiul Islam Sojib (Student ID : 105442)

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Islamic University of Technology (IUT)

A Subsidiary Organ of OIC

Dhaka, Bangladesh.

APPROVAL

This is to certify that the thesis submitted by Syed Tanvir Ahmed Rafi and Md. Shafiul Islam Sojib entitled as "Characterization of pan evaporation with related climatological parameters of Bangladesh." has been approved, in partial fulfillment of the requirements for the Bachelor of Science degree in Civil and Environmental Engineering.

SUPERVISOR

Shakil Ahmed
Assistant professor
Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)
Board Bazar, Gazipur, Bangladesh.

DECLARATION

We hereby declare that the thesis entitled "CHARACTERIZATION OF PAN EVAPORATION WITH RELATED CLIMATOLOGICAL PARAMETERS OF BANGLADESH", has been performed by us and this work has not been submitted elsewhere for reward of any degree or diploma (except for publication).

NOVEMBER, 2014.

Syed Tanvir Ahmed (Student ID: 105420)

Md. Shafiul Islam Sojib (Student ID: 105442)

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We would like to express our deepest gratitude to our honourable teacher Ijaj Mahmud Chowdhury, lecturer of the Department of Civil and Environmental Engineering, Islamic university of technology (IUT) for his valuable advice, guidance and professional comments.

The authors also want to thank their course supervisor for providing valuable data of Pan Evaporation, Relative Humidity and radiation which were the nucleus of this comparative study.

ABSTRACT

Bangladesh is an agricultural country. Agriculture is the single largest producing sector of the economy since it comprises about 18.6% of the country's GDP and employs around 45% of the total labour force. It has around 8 million hectares of cultivable land and total irrigated land is around 56%. Agriculture determines people's lives and livelihood of this region.

Pan evaporation is a measurement that combines or integrates the effects of several climate elements: temperature, humidity, rain fall, drought dispersion, solar radiation. Pan evaporation measurements enable farmers to understand how much water their crops will need. It is an effective way to analyse the multidimensional impact of climate change on irrigation water requirement since pan evaporation measures the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open-water surface. The spatial distribution of seasonal variation of pan evaporation along with solar radiation and humidity was analysed, and solar radiation seemed to have the major influence on evaporation. The study also reveals that summer and spring are the seasons of highest evaporation in most of the regions. The characteristic trend and spatial distribution of seasonal pan evaporation correlated with related climatological factors developed in this study could aid the irrigation water resources development and planning.

Results of previous studies are analyzed and also enhanced the knowledge of this area. So this study is essential in worldwide especially in Bangladesh where agriculture plays a vital role to estimate the agricultural water demand in the changing environment for long term water resources and development.

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Chapter 1

INTRODUCTION

1.1 Background

Bangladesh is one of the largest deltas in the world which is highly vulnerable to climate change and global warming. Several studies indicated that climate is changing and becoming very unpredictable in the recent years in Bangladesh. The impact of climate change on agricultural production in Bangladesh is severe. The gradual increase in temperature, humidity and radiation hampers the production of crops. Besides, the other impacts of climate change such as - precipitation, drought, and salinity intrusion etc. are also responsible for the declining crop yields in Bangladesh. Moreover our agricultural land is decreasing as the population is increasing in an alarming rate. All these impacts have a negative effect on irrigation water requirement. It is known that agriculture is the main section of water use in Bangladesh. It plays a vital role in national economy, food security and labour force employment. So water demand in agricultural sector is very high. Without water people do not have a means of watering their crops and providing food for the fast growing population.

Bangladesh is a country with population of about 162 million in 2009 and is projected to be about 215 million in 2040 and here agriculture is the major sector for consumption of water. Demand for water will increase with the rising population for increased agricultural productivity particularly for growing demand of rice which consumes a lot of water. Therefore, it is essential to estimate the agricultural water demand in the changing environment for long term water resources development and planning. Pan evaporation is an effective way to analyse the multidimensional impact of climate change on irrigation water requirement since pan evaporation measures the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open-water surface. Using pan evaporation for estimating reference evapotranspiration is a common method, especially in American and Asian countries (Golubev et al., 2001; Liu et al., 2004).. The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period.

This paper reports studies on characterization and trend analysis of pan evaporation with related climatological factors in various regions of Bangladesh.

1.2 Objectives

The main objective of this study is to develop better understanding of some major parameters such as temperature, humidity and radiation which influences the pan evaporation. The study also distinguish the pan evaporation under climate change and analyse its future trends. This would help one to make a decision in agriculture water demand planning, adaptation of water and finally climate risk management strategies.

The main objectives are stated below:

1. Analyse the seasonal changes in pan evaporation, solar radiation and humidity at different regions of
   Bangladesh and identify the controlling parameter affecting pan evaporation by a comparative study.

2. Evaluation of long-term changes in pan evaporation in different regions of Bangladesh.

3. Analysis of spatial distribution of mean seasonal pan evaporation in different regions of Bangladesh.

It must be mentioned that, the study only includes eight stations of the whole country for assessment and hence does not really exhibit the trends for the whole country due to the unavailability of data. The study is limited to the period from 1988-2010. More significant results would have obtained if a wider range of data was used. The result, thereby, exhibit the very recent trends and not very long term trends.

1.3 Outline of Methodology

The following methods were undertaken during our study-

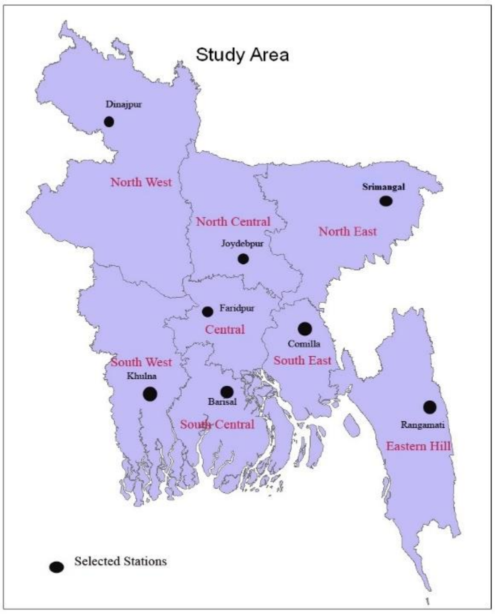
a) Data collection:

At first the data were collected from different hydro-meteorological stations of Bangladesh Meteorological Department (BMD). Bangladesh Meteorological Department (BMD) is a government organization under the administrative control of the Ministry of Defence. The data were available for a 23 year period which ranges from 1988-2010. For our study, data from 2001-2010 were needed.

b) Selecting the study areas:

For selecting the locations of study area only few areas were considered. For our analysis purpose only eight regions were selected. They are

Sl. No.	Zone	District Name
1	North West	Dinajpur
2	North Central	Joydebpur
3	North East	Srimangal
4	Central	Faridpur
5	South West	Khulna
6	South Central	Barisal
7	South East	Comilla
8	Eastern Hill	Rangamati



c) Data analysis:

After selection of the study areas data were analyzed. The data was analyzed by two steps. For analyzing data some steps were followed –

By Using Excel:

- The data for selected zones were organized season wise in an MS excel sheet.
- The range of the data was selected as 10^{th} of mm/day.
- The average pan evaporation of daily pan evaporation of a month was taken.
- For one season average of three months were taken.
- Data for humidity and radiation will be analyzed by the previous procedures.

By Using ArcGIS:

ArcGIS is a geographic information system (GIS) for working with map and geographic information. It is used for creating and using maps, compiling geographic data, analysing mapped information, sharing and discovering geographic information.

For developing maps some steps were followed -

- A shape file was created. The shape file includes Bangladesh map indicating the selected eight zones.
- The average pan evaporation data was put into the attribute table.
- All necessary symbols were denoted on the map.
- Finally, the map with corresponding data was imported from the GIS tools

d) Assessment of seasonal variation:

To analyse the seasonal variation data of pan evaporation, radiation and humidity were collected for the year of 2001-2010. For our study each year is divided into four seasons. They are as follows-

- Spring: February-April
- Summer: May-July
- Autumn: August-October
- Winter: November-January

For each season the average data were taken and placed the values in the attribute table of ArcGIS map. After that relation between pan evaporation and related climatological factors were evaluated.

e) Trend analysis of daily pan evaporation and humidity

To analyse the changing pattern of pan evaporation as an effect of climate change, spatial distribution of normalized value of average daily pan evaporation for four seasons (Spring, Summer, Autumn and Winter) of one span year (2001 to 2010) relative to long term daily pan evaporation of 24 years (1987 to 2010) are plotted using ArcGIS 9.3.

To facilitate the trend analysis of pan evaporation, the average daily pan evaporation of four seasons for the period of 1987 to 2010 has been plotted for different regions in Excel. “2 year moving average curve” is adopted to overcome the effect of any missing data. The trend of average daily pan evaporation has been analyzed assuming a linear variation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The main objective of this study is to Analyse the seasonal changes in pan evaporation, solar radiation and humidity at different regions of Bangladesh and identify the controlling parameter affecting pan evaporation by a comparative study. This chapter presents an overview of some major climatological factors and provides a clear idea of evaporation, an effective way to measure evaporation, and some other minor factors affecting crop water requirement. This chapter presents a detail discussion on previous research works conducted on temporal and spatial variation of pan evaporation with related climatological factors in Bangladesh. The results of previous studies were analysed to identify and enhance the knowledge in this area.

2.2 Evaporation

Evaporation is the process by which water changes from a liquid to a gas or vapour. Evaporation is the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapour. Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the atmosphere via evaporation. Some factors such as wind, heat, vapour pressure and sun shine time affects evaporation. Evaporation is greatest on hot, windy, dry, sunny days; and is greatly reduced when clouds block the sun and when air is cool, calm, and humid.

There are two types of measuring evaporation.

1. Water balance methods
2. By using water balance maintenance equations (Evaporimeter)

There are two types of evaporimeter.

- Those that measure the evaporation rate from a free water surface (using pan)
- Those that measure it from a continuously wet porous surface.

2.3 Pan Evaporation

Pan evaporation is a measurement that combines or integrates the effects of several climate elements: temperature, humidity, rain fall, drought dispersion, solar radiation. Pan evaporation measurements enable farmers and ranchers to understand how much water their crops will need.

An evaporation pan is used to hold water during observations for the determination of the quantity of evaporation at a given location. The pan can be circular or square in size. The best known of the pans are the "Class A" evaporation pan and the "Sunken Colorado Pan".

Class A evaporation pan, a cylinder with a diameter of 47.5 in (120.7 cm) that has a depth of 10 in (25 cm). 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. If precipitation occurs in the 24-hour period, it is taken into account in calculating the evaporation. Evaporation cannot be measured in a Class A pan when the pan's water surface is frozen.

Fig : 1 : Class A pan evaporation

The most common and obvious error is if the rainfall is avobe 55mm (203mm rain gauge). then the Class A Evaporation pan will 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.

hTe sunken Colorado pan is square, 1 m (3 ft) on a side and 0.5 m (18 in.) deep and made of unpainted galvanized iron. As the name suggests, it is buried in the ground to within about 5 cm (2 in.) of its rim. Evaporation from a Sunken Colorado Pan can be compared with a Class A pan using conversion constants. The pan coefficient, on an annual basis, is about 0.8.

2.4 Major factors affecting irrigation water requirement

Bangladesh is one of the largest deltas in the world which is highly vulnerable to climate change and global warming. The impact of climate change on agricultural production in Bangladesh is severe. The gradual increase in temperature, humidity and radiation hampers the production of crops. Some minor factors such as precipitation, drought, salinity intrusion etc. are also responsible for gradual decreasing of rice yield in Bangladesh. Moreover the gradual and rapid increasing of population decrease the agricultural land. All this factors have a negative and acute impact on irrigation water requirement.

Some major factors which affect irrigation water requirement are discussed here.

a) Humidity:

Humidity is the amount of water vapor in the air. Water vapor is the gaseous state of water and is invisible. Humidity indicates the likelihood of precipitation, dew, or fog. There are three main measurements of humidity: absolute, relative and specific. Absolute humidity is the water content of air. Relative humidity, expressed as a percent, measures the current absolute humidity relative to the maximum for that temperature. Specific humidity is a ratio of the water vapour content of the mixture to the total air content on a mass basis.

Humidity refers to a percent ratio between the amount of water vapour in the atmosphere and the highest possible vapour concentration at that temperature. If the atmosphere is saturated then the relative humidity is 100 percent. Rate of evaporation depends on both the heat available to the liquid and the strength of the intermolecular forces between the molecules. Evaporation can be faster on sunny days not just because of the extra heat, but also because sunny days are often drier and so have lower relative humidity. In a word, the more humidity there is in the air, the less space for evaporation there will be. And vice versa.

b) Radiation:

Natural radiation is often beneficial to plant growth. It is necessary for many plants to receive some form of non-ionizing radiation. Radiation that produces light in order for photosynthesis to occur is a positive effect that radiation has on plant life. However, according to the Environmental Literacy Council, ionized radiation that occur from nuclear material may result in weakening of seeds and frequent mutations. Various studies indicate that a rise of 10°C to 20°C, in combination with lower solar radiation, causes sterility in rice spikelet, and high temperature was found to reduce yields of HYVs of aus, aman and boro rice in all study locations and in all seasons in Bangladesh.

c) Temperature:

The effects of maximum temperature would drastically reduce rice yield at all selected locations. Boro rice yields reduce at range of 2.6 to 13.5% due to increase 20°C maximum temperature and 0.11 to 28.7% for 40°C maximum temperature (base year 2008). The average value (average percentage change of rice yield for 6 locations) of Boro rice yield reduction is 6.10% and 16.0% in case of 20°C and 40°C for increasing maximum temperature, respectively. As like as maximum temperature, minimum temperature have also negative impacts on Boro rice yields that reduce 0.40 to 13.1% due to increase 20°C and 0.11 to 15.5% for 40°C minimum temperature. The average figure of yield reduction for minimum temperature is 4.2% for 20°C and 8.5% for 40°C. Therefore, maximum temperature is more vulnerable and negative impact on rice yield compared to the minimum temperature.

d) Population growth:

Population growth rate in Bangladesh is two million people per year and the population will reach 233.2 million by 2050, going by the current trend. Bangladesh will require more than 55.0 million tons of rice per year to feed its people by the year 2050. In 2007- 2008, Boro rice production contributed 58% to the total rice production. In the coming decades, agriculture of Bangladesh will face a great challenge to feed its growing population as the food demand will increase with increasing population in Bangladesh.

2.5 Geographic information system (GIS):

A **geographic information system** (**GIS**) is a computer system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data. It is a tool that uses the power of the computer to pose and answer geographic questions. The user guides the program to arrange and display data about places on the planet in a variety of ways - including maps, charts and tables. The hardware and software allows the users to see and interact with data in new ways by blending electronic maps and databases to generate color-coded displays. Users can zoom in and out of maps freely, add layers of new data, and study detail and relationships.

2.6 Why is GIS Needed?

Once GIS is Implemented, the following benefits are expected:

- Geospatial data are better maintained in a standard format.
- Revision and updating are easier.
- Geospatial data and information are easier to search, analyze and represent.
- Geospatial data can be shared and exchanged freely.
- Productivity of the stall is improved and more efficient.
- Time and money are saved.
- Better decision can be made.

2.7 Applications of GIS:

The implementation of a GIS is often driven by jurisdictional (such as a city), purpose, or application requirements. Generally, a GIS implementation may be custom-designed for an organization. Hence, a GIS deployment developed for an application, jurisdiction, enterprise, or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose.

GIS provides, for every kind of location based organization, a platform to update geographical data without wasting time to visit the field and update a database manually. GIS when integrated with other powerful enterprise solutions helps creating powerful decision support system at enterprise level.

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS, and usage in the fields of science, government, bussiness, and industry with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, climatology, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services, which allows GPS-enabled mobile devices to display their location in relation to fixed objects (nearest restaurant, gas station, fire hydrant) or mobile objects (friends, children, police car), or to relay their position back to a central server for display or other processing.

Chapter 3

RESULTS AND DISCUSSIONS

3.1 Seasonal variation of daily pan evaporation:

To analyze seasonal variation of pan evaporation with related climatological factors in various regions, GIS map was plotted in Fig.2, 3 and 4 showing seasonal variations of pan evaporation, radiation and humidity respectively. For the analysis, a year was divided into four seasons: Winter consisting of November to January, Spring consisting of February to April, Summer consisting of May to July and Autumn consisting of August to October.

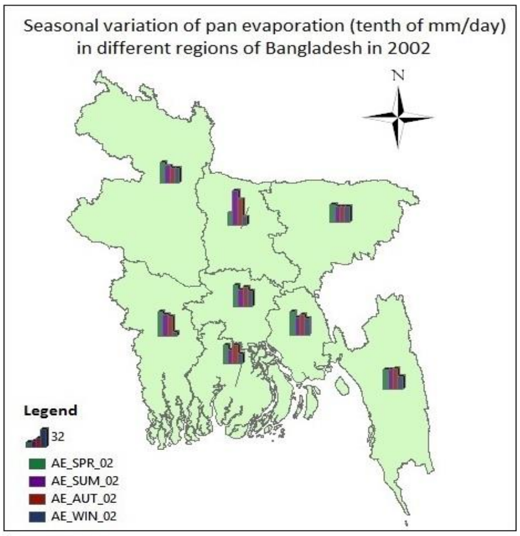


Fig : 2 (a) : Seasonal variation of daily pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2002

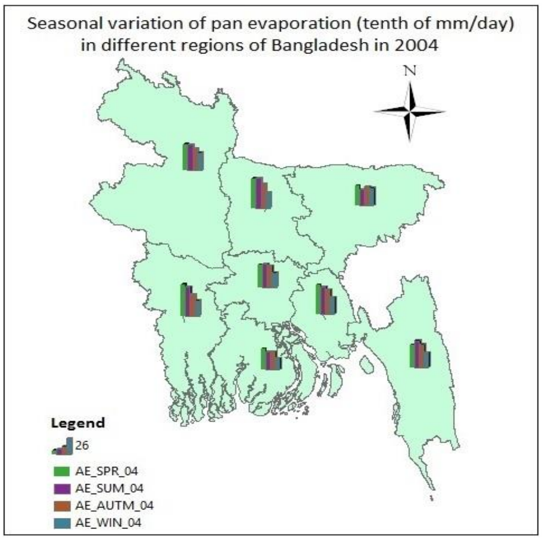


Fig : 2 (b) : Seasonal variation of daily pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2004

Seasonal variation of daily pan evaporation in different regions for the year 2002 and 2004 are shown in Fig. 2(a) and (b) respectively. From Fig. 2(a) and (b) it is clear that daily pan evaporation shows a roughly similar seasonal distribution pattern in both the year 2002 and 2004 in all regions. Almost all over the regions, Spring is the season which shows the maximum daily pan evaporation (except North Central in fig. 2/a and Eastern Hill in fig. 2/b) and Winter shows the minimum daily pan evaporation where Summer and Autumn were found the seasons of highest daily pan evaporation and Winter was found the season of lowest daily pan evaporation.

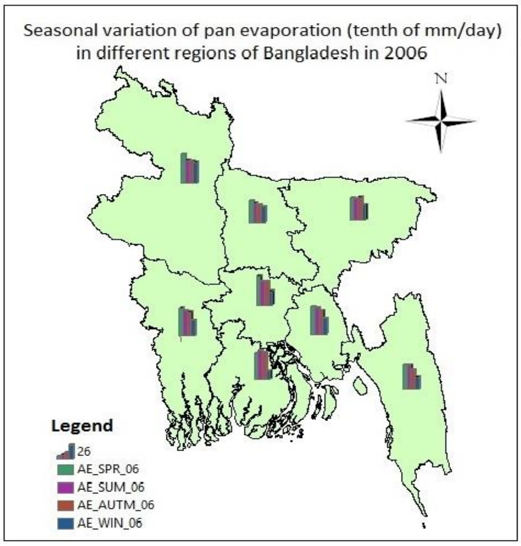


Fig : 2 (c) : Seasonal variation of daily pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2006

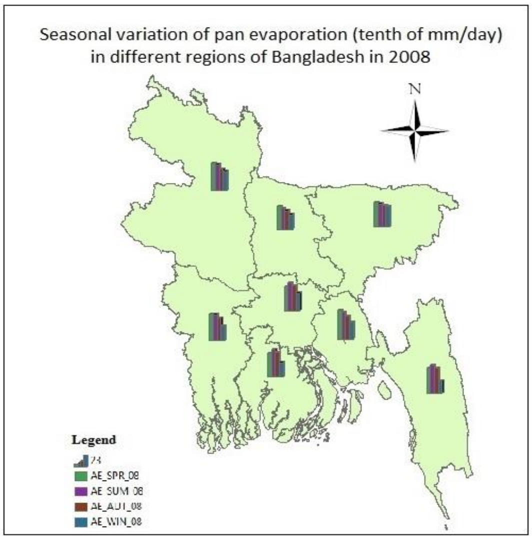


Fig : 2 (d) : Seasonal variation of daily pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2008

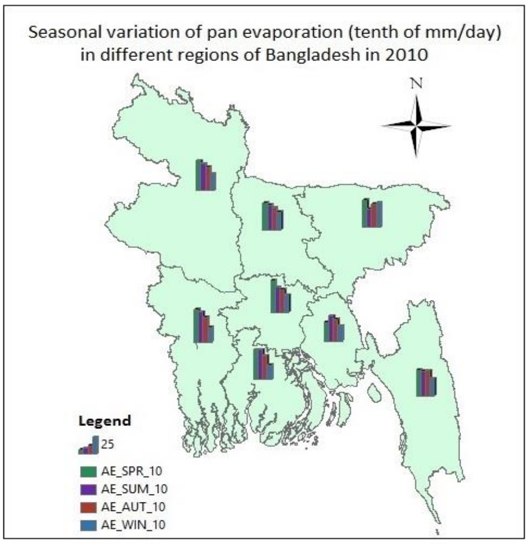


Fig : 2 (e) : Seasonal variation of daily pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2010

Seasonal variation of daily pan evaporation in different regions for the year 2006, 2008 and 2010 are shown in Fig. 2(c) 2(d) and 2(e) respectively. From those figures it is clear that daily pan evaporation shows a roughly similar seasonal distribution pattern in 2006, 2008 and 2010 in all regions. Almost all over the regions, Spring is the season which shows the maximum daily pan evaporation except Central and Eastern Hill in fig, 2(d) and South East in fig. 2(e) and Winter shows the minimum daily pan evaporation except North East region in fig. 2(e) where Summer and Autumn were found the seasons of highest daily pan evaporation and Winter was found the season of lowest daily pan evaporation.

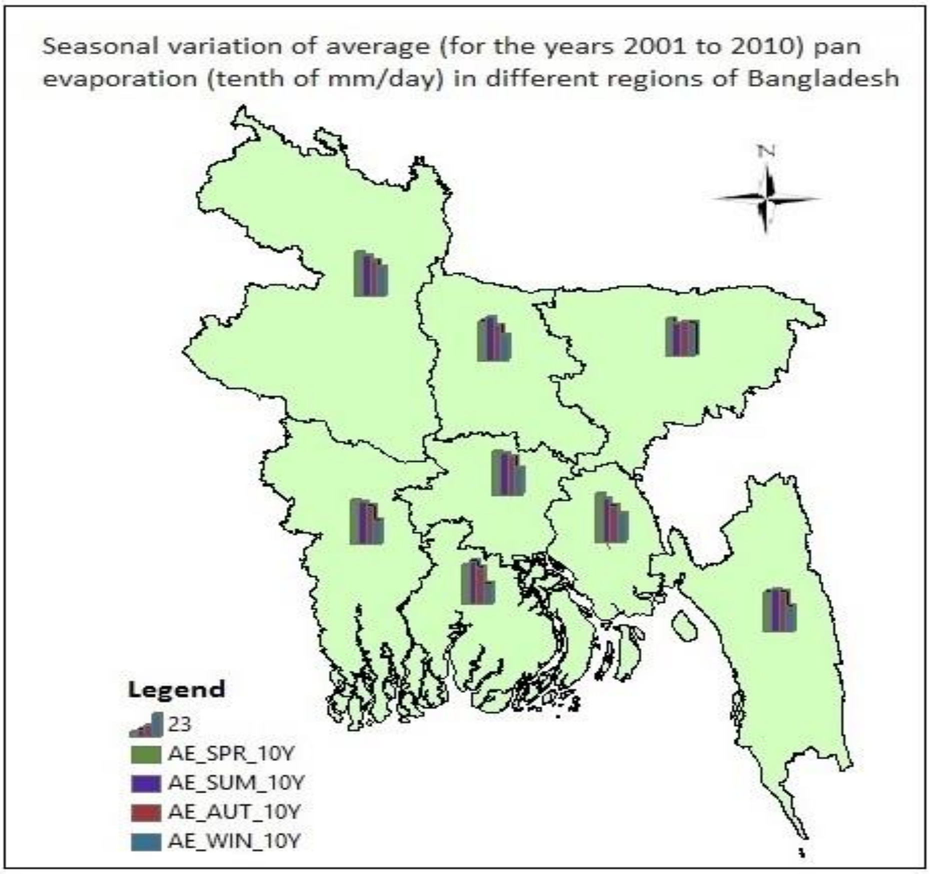


Fig : 2 (f) : Seasonal variation of average (for the years 2001 to 2010) pan evaporation (tenth of mm/day) in different regions of Bangladesh

In figure 2(f), the seasonal variation of average (for the years 2001 to 2010) pan evaporation (tenth of mm/day) in different regions of Bangladesh is plotted. From this figure, it is clear that daily pan evaporation shows a roughly similar seasonal distribution pattern in all regions. Almost all over the regions, Spring is the season which shows the maximum daily pan evaporation (except North central and south central regions) and Winter shows the minimum daily pan evaporation except North East region where Summer and Autumn were found the seasons of highest daily pan evaporation and Winter was found the season of lowest daily pan evaporation.

3.2 Seasonal variation of humidity

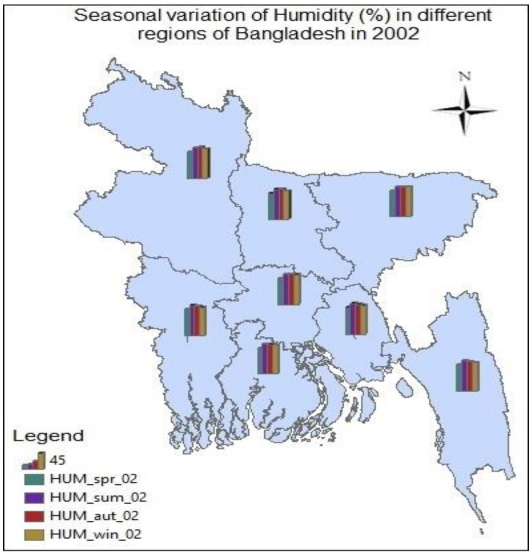


Fig : 3 (a) : Seasonal variation of humidity (%) in different regions of Bangladesh in 2002

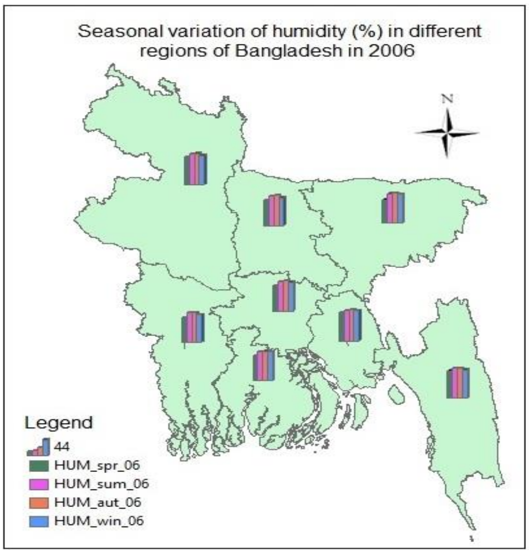


Fig : 3 (b) : Seasonal variation of humidity (%) in different regions of Bangladesh in 2006

Seasonal variation of humidity in different regions for the year 2002 and 2006 are shown in Fig. 3(a) and 3(b) respectively. From Fig. 3(a) it is clear that, almost all over the regions, Summer is the season which gives the maximum humidity in all regions except North West region of Bangladesh. Also Spring shows the minimum humidity for all regions. From Fig. 3(b) it is clear that, Autumn is the season which gives the maximum humidity for all regions. Also Spring shows the minimum humidity for all regions in 2006.

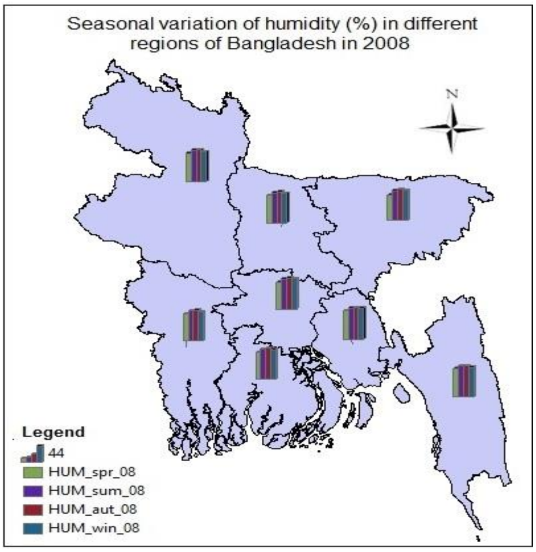


Fig : 3 (c) : Seasonal variation of humidity (%) in different regions of Bangladesh in 2008

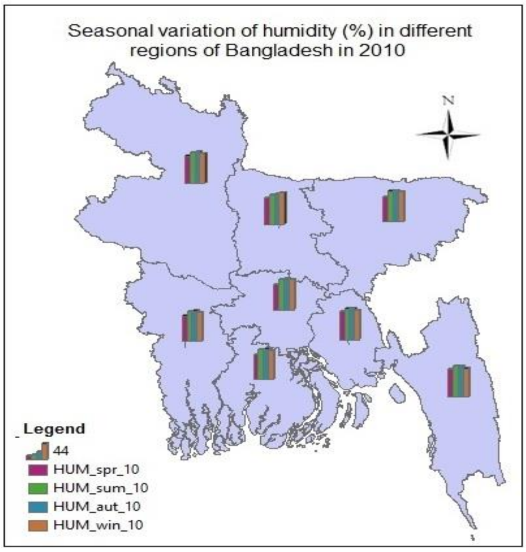


Fig : 3 (d) : Seasonal variation of humidity (%) in different regions of Bangladesh in 2010

Seasonal variation of humidity in different regions for the year 2008 and 2010 are shown in Fig. 3(c) and 3(d) respectively. From Fig. 3(c) it is clear that, autumn is the season which gives the maximum humidity in all regions except South East region of Bangladesh. Also spring shows the minimum humidity for all regions. From Fig. 3(d), for the year 2010, it is quite clear that autumn gives the maximum humidity for all the regions expect for the North Central region of Bangladesh. Also spring shows the minimum humidity for all regions in 2010.

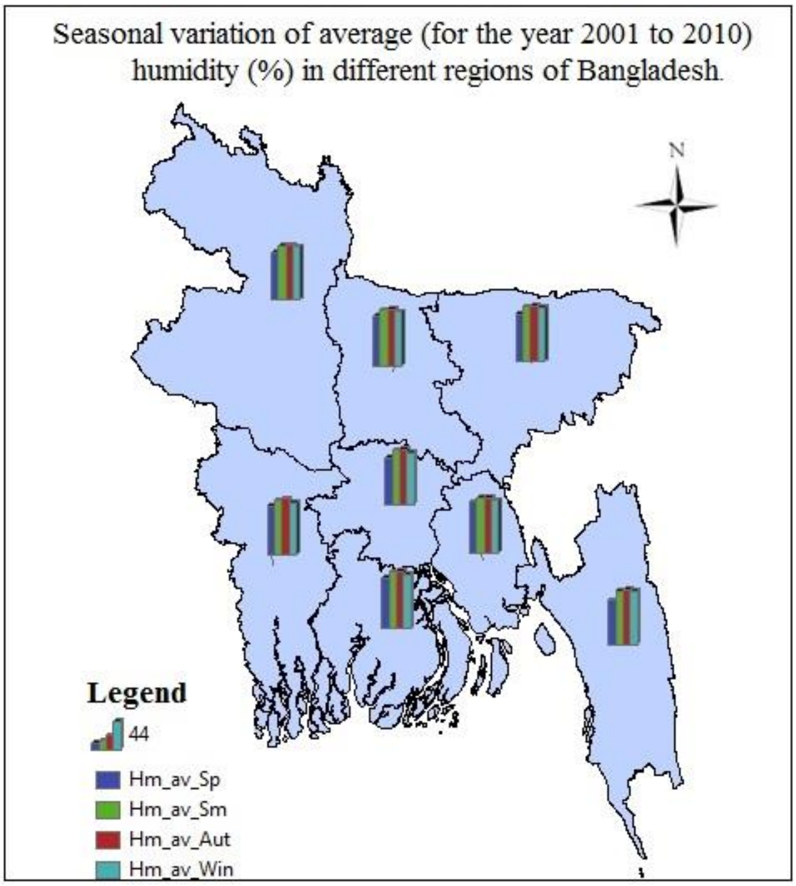


Fig : 3 (e) : Seasonal variation of average (for the year 2001 to 2010) humidity (%) in different regions of Bangladesh

Seasonal variation of average (for the year 2001 to 2010) humidity in different regions are shown in Fig. 3(e). From Figure it is clear that, autumn is the season which gives the maximum humidity in all regions of Bangladesh. Also spring shows the minimum humidity for all regions.

3.3 Seasonal variation of radiation

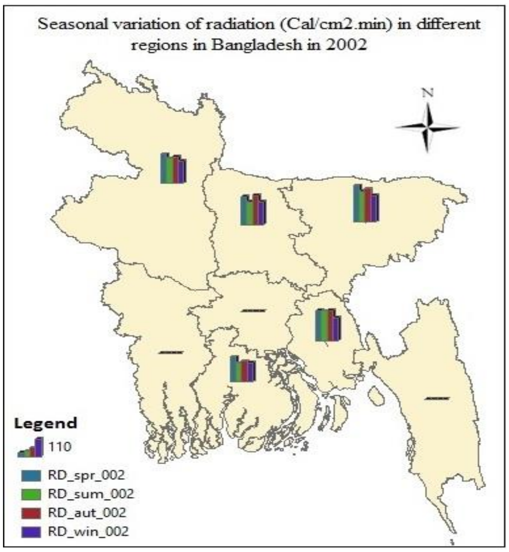


Fig : 4 (a) : Seasonal variation of radiation (Cal/cm².min) in different regions of Bangladesh in 2002

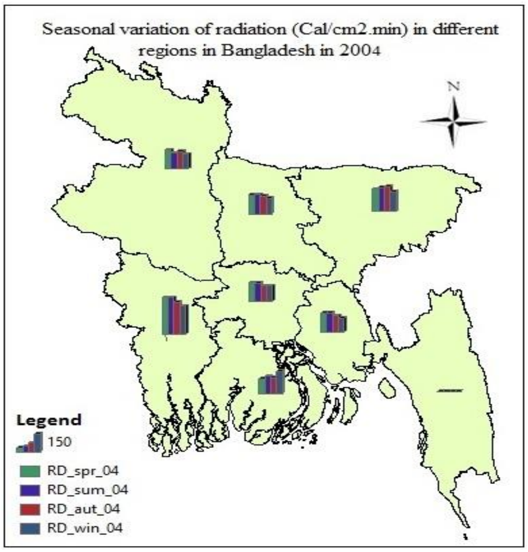


Fig : 4 (b) : Seasonal variation of radiation (Cal/cm².min) in different regions of Bangladesh in 2004

In Fig. 4(a) & 4(b) we can see the seasonal variation of radiation in different regions for the year 2002 & 2004. For Fig. 4(a) the data of South Central, Central & Eastern Hill regions were not available. So for this year the work was done for only rest of the 5 regions. The figure shows that, Spring gives the maximum radiation for all the regions of Bangladesh except for the North Central region where Autumn gives the maximum radiation. Also Winter gives the minimum radiation for all the regions of Bangladesh for the year 2002. For Fig. 4(b) data for the Eastern Hill region were not available so the work was done for rest of the 7 regions. The figure shows that Spring gives the highest radiation for all regions of Bangladesh except for North East & South Central region where Autumn & Winter gives the maximum radiation respectively. Also Winter gives the minimum radiation for all regions of Bangladesh except for the South Central region for the year 2004.

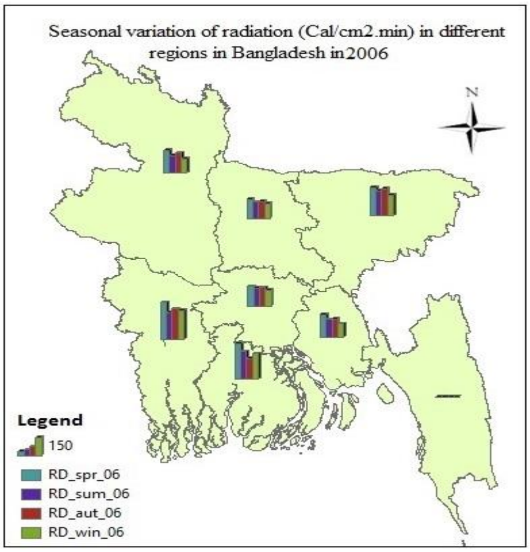


Fig : 4 (c) : Seasonal variation of radiation (Cal/cm².min) in different regions of Bangladesh in 2006

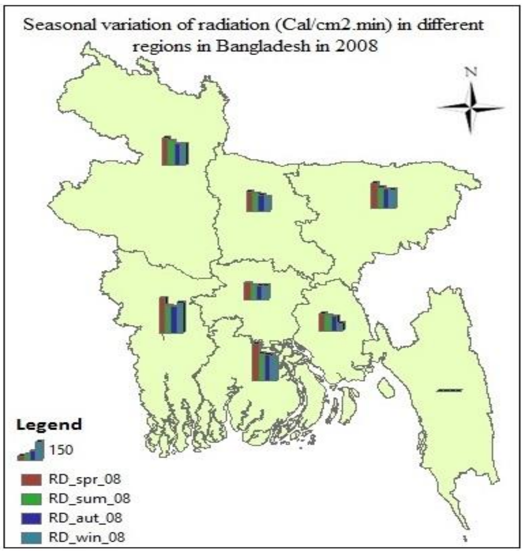


Fig : 4 (d) : Seasonal variation of radiation (Cal/cm².min) in different regions of Bangladesh in 2008

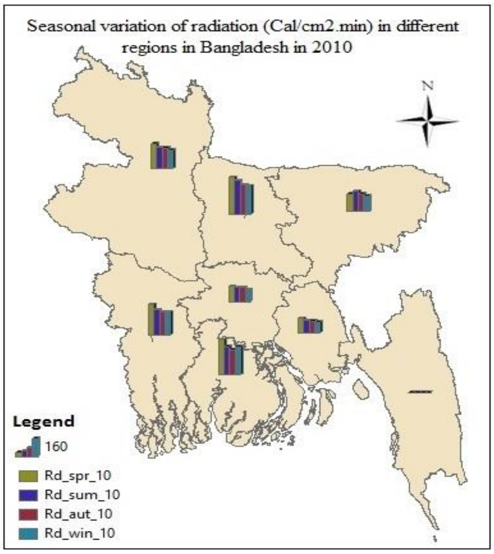


Fig : 4 (e) : Seasonal variation of radiation (Cal/cm².min) in different regions of Bangladesh in 2010

The seasonal variation of radiation for different regions of Bangladesh for the 2006 & 2008 are shown in Fig 4(c) & 4(d). In Fig. 4(c) data for the Eastern Hill region were not available so the work was done for rest of the 7 regions. The figure shows that Spring gives the maximum radiation for all regions of Bangladesh. Also Winter gives the minimum radiation for all regions except for South Central & South West regions where Autumn & Summer shows minimum radiation respectively for all the regions of Bangladesh for 2006. In Fig. 4(d) data for the Eastern Hill region were not available so the work was done for rest of the 7 regions. The figure indicates that Spring gives the maximum radiation for all regions of Bangladesh for 2008. Also Winter gives minimum radiation for all regions of Bangladesh except for South West region where Autumn gives minimum radiation.

The seasonal variations of radiation for different regions of Bangladesh for the year 2010 are shown in Fig 4(e). For the Eastern Hill region data were not available so the work was done for rest of the 7 regions. It is clear that, Spring is the season which gives maximum radiation for all the regions of Bangladesh apart from North East region where Summer gives the maximum radiation. Also Winter is the season which gives the minimum radiation for all regions of Bangladesh except for South Central region where Autumn gives minimum radiation for the year 2010.

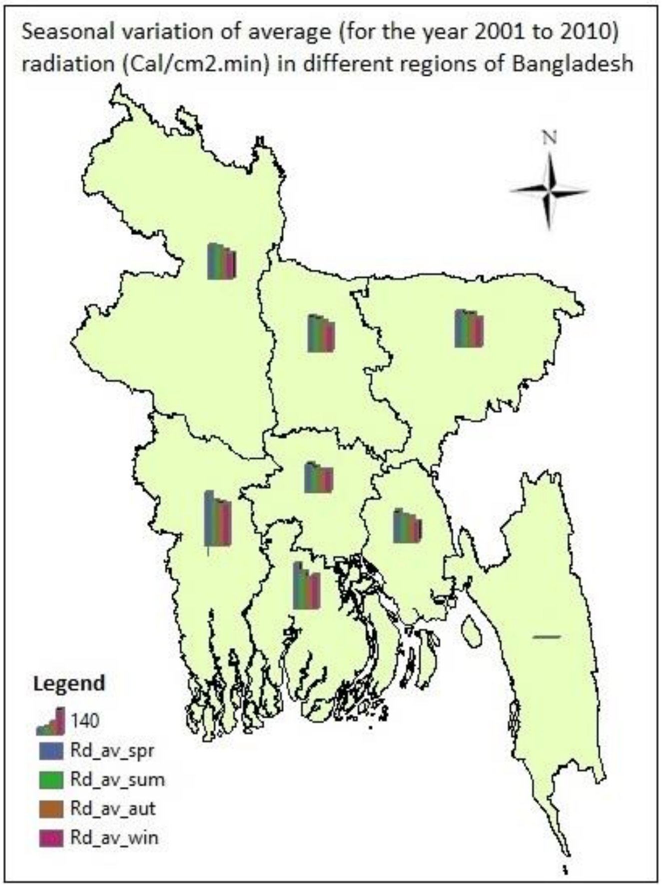
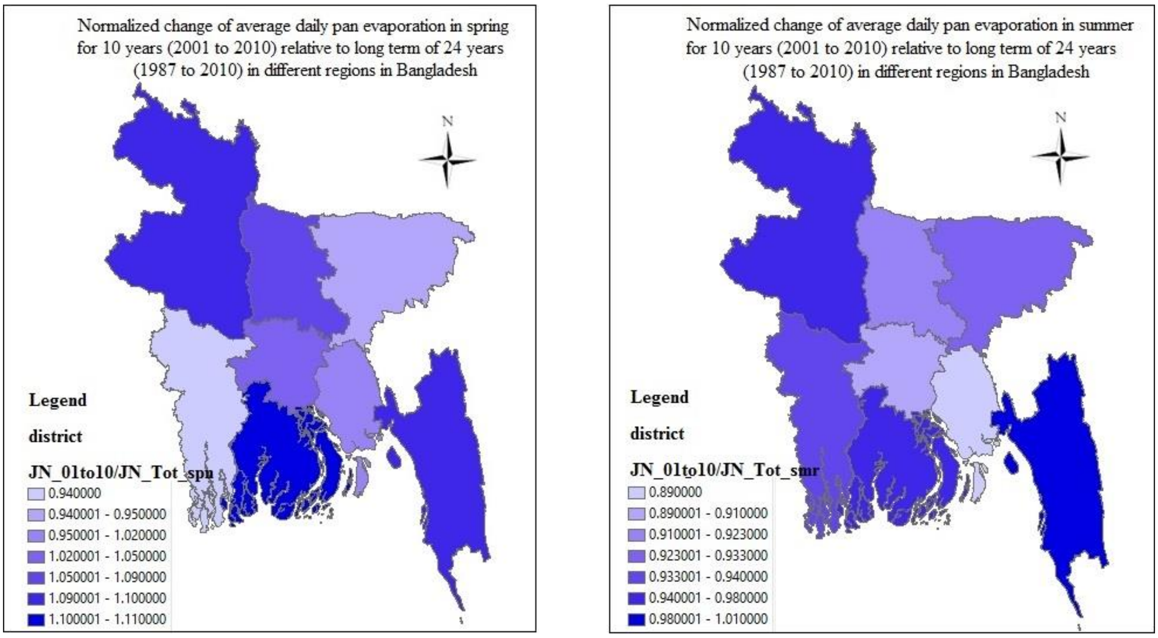


Fig : 4 (f) : Seasonal variation of average (for the year 2001 to 2010) radiation (Cal/cm².min) in different regions of Bangladesh.

In Fig. 4(f), we can see the seasonal variation of average radiation in different regions for the year 2001 to 2010. The data of Eastern Hill regions were not available. So for that the work was done for only rest of the 7 regions. The figure shows that Spring is the season which gives the maximum radiation for the year 2001 to 2010. Also from the figure Winter is the season which shows minimum radiation for all regions except South Central region where Autumn gives minimum radiation for the year 2001 to 2010.

3.4 Trend analysis of pan evaporation

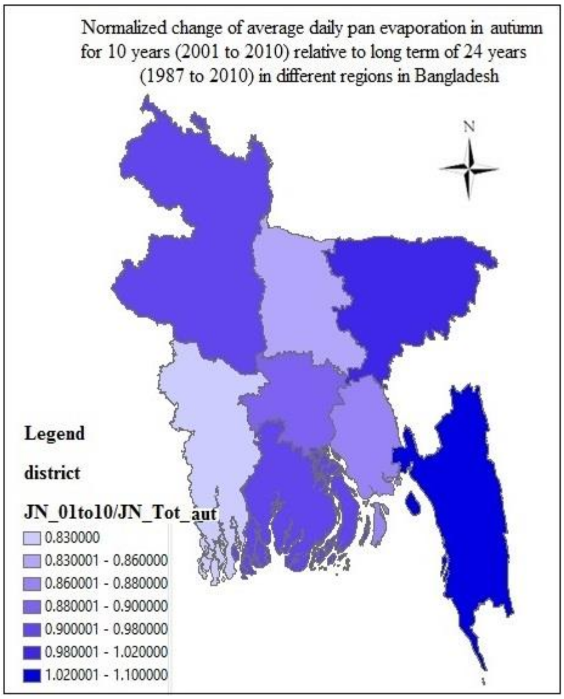


(a) (b)

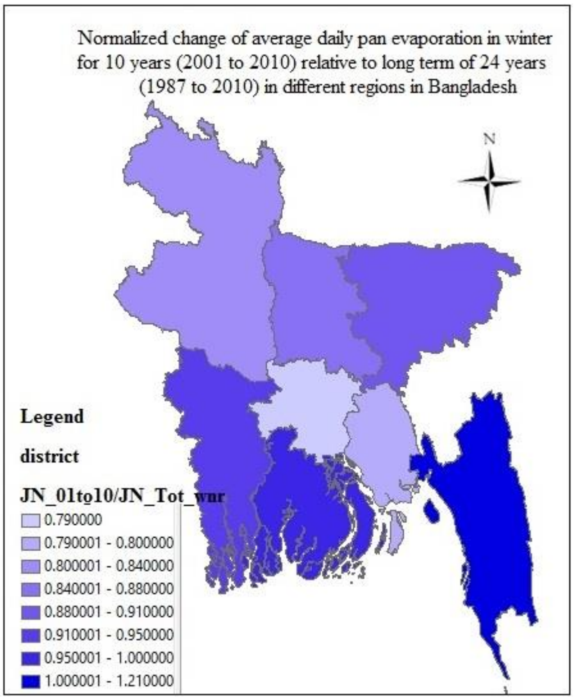
Fig : 5 : Normalized change of average daily pan evaporation in spring (a) and summer (b) for 10 years (2001 to 2010) relative to long term of 24 years (1987 to 2010) in different regions in Bangladesh

The spatial distribution of normalized change of average daily pan evaporation in Spring for 10 years (2001 to 2010) relative to long term daily pan evaporation of 24 years (1987 to 2010) are plotted in Fig. 5 (a) In this figure, light blue indicates decreased evaporation zone and dark blue indicates increased evaporation zone. As seen in the figure, in the last ten years, average daily pan evaporation in Spring is found to be increased for all the regions except North East and South West region where decreasing trends were observed. South Central region has the increasing evaporation trend and South West region has the decreasing evaporation trend in the last 10 years for Spring in Bangladesh.

The spatial distribution of normalized change of average daily pan evaporation in Summer for 10 years (2001 to 2010) relative to long term daily pan evaporation of 24 years (1987 to 2010) are plotted in Fig. 5 (b) In this figure, light blue indicates decreased evaporation zone and dark blue indicates increased evaporation zone. As seen in figure, in the last ten years, average daily pan evaporation in Summer is found to be decreased for all the regions except for Eastern Hill region where increasing trends were observed. South East region has the decreasing pan evaporation trend and Eastern Hill region has the increasing pan evaporation trend in the last10 years for Summer in Bangladesh.



(c)



(d)

Fig : 5 : Normalized change of average daily pan evaporation in autumn (c) and winter (d) for 10 years (2001 to 2010) relative to long term of 24 years (1987 to 2010) in different regions in Bangladesh.

The spatial distribution of normalized change of average daily pan evaporation in Autumn for 10 years (2001 to 2010) relative to long term daily pan evaporation of 24 years (1987 to 2010) are plotted in Fig. 5 (c) and 5 (d). In this figure, light blue indicates decreased evaporation zone and dark blue indicates increased evaporation zone. As seen in figure, in the last 10 years, average daily pan evaporation in Autumn is found to be decreased for all regions except for North East and Eastern Hill region where increasing trends were observed. South West region has the decreasing pan evaporation trend and Eastern Hill region has the increasing trend in the last 10 years for Autumn in Bangladesh.

The spatial distribution of normalized change of average daily pan evaporation in Winter for 10 years (2001 to 2010) relative to long term daily pan evaporation of 24 years (1987 to 2010) are plotted in Fig. 6. In this figure, light blue indicates decreased evaporation zone and dark blue indicates increased evaporation zone. As seen in figure, in the last 10 years, average daily pan evaporation in Winter is also found to be decreased for all the regions except Eastern Hill region where increasing trends were noticed. Central region has the decreasing pan evaporation trend and Eastern Hill region has the increasing trend in the last 10 years for Winter in Bangladesh.

Fig : 6 : Trend analysis of average daily pan evaporation in spring in different regions (1987-2010)

To facilitate the trend analysis of pan evaporation, the average daily pan evaporation in spring for the period of 1987 to 2010 has been plotted for different regions in fig. 6. “2 year moving average curve” is adopted to overcome the effect of any missing data. The trend of average daily pan evaporation has been analyzed assuming a linear variation and similar results like normalized change distribution from Fig. 5 were found. It is observed, like Fig. 5, the trend analysis curves in Fig. 6 also show a general lowering of pan evaporation in all regions except North West, South Central and North East regions where an increasing trend was observed. Among the all regions most insignificant changes in pan evaporation was observed in North East (changing gradient 0.022, see Fig. 6-c) and Eastern Hill region (changing gradient 0.035, see Fig. 6-h). On other hand, most significant changes in pan evaporation was observed in North West region (changing gradient 0.408, see Fig. 6-a).

Fig : 7 : Trend analysis of average daily pan evaporation in summer in different regions (1987-2010)

To facilitate the trend analysis of pan evaporation, the average daily pan evaporation in summer for the period of 1987 to 2010 has been plotted for different regions in fig. 7. “2 year moving average curve” is adopted to overcome the effect of any missing data. The trend of average daily pan evaporation has been analyzed assuming a linear variation and similar results like normalized change distribution from Fig. 5 were found. It is observed, like Fig. 5, the trend analysis curves in Fig. 7 show a general lowering of pan evaporation in all regions except North West, South Central & Eastern Hill region of Bangladesh where an increasing trend were observed. Among the all regions most insignificant changes in pan evaporation was observed in South central zone (changing gradient 0.038, see Fig. 7-e). On other hand, most significant changes in pan evaporation was observed in Central region (changing gradient 0.337, see Fig. 7-g).

Fig : 8 : Trend analysis of average daily pan evaporation in autumn in different regions (1987-2010)

To facilitate the trend analysis of pan evaporation, the average daily pan evaporation in autumn for the period of 1987 to 2010 has been plotted for different regions in fig. 8. “2 year moving average curve” is adopted to overcome the effect of any missing data. The trend of average daily pan evaporation has been analyzed assuming a linear variation and similar results like normalized change distribution from Fig. 5 were found. It is observed, like Fig. 5, the trend analysis curves in Fig. 8 also show a general lowering of pan evaporation in all regions except North East and Eastern Hill region where an increasing trend were observed. Among the all regions most insignificant changes in pan evaporation was observed in North East (changing gradient 0.042, see Fig. 6-c). On other hand, most significant changes in pan evaporation was observed in South east region (changing gradient 0.389, see Fig. 6-f).

Fig : 9 : Trend analysis of average daily pan evaporation in winter in different regions (1987-2010)

To facilitate the trend analysis of pan evaporation, the average daily pan evaporation in winter for the period of 1987 to 2010 has been plotted for different regions in fig. 9. “2 year moving average curve” is adopted to overcome the effect of any missing data. The trend of average daily pan evaporation has been analyzed assuming a linear variation and similar results like normalized change distribution from Fig. 5 were found. It is observed, like Fig. 5, the trend analysis curves in Fig. 9 show a general lowering of pan evaporation in all regions except Eastern Hill region of Bangladesh where an increasing trend were observed. Among the all regions most insignificant changes in pan evaporation was observed in South Central (changing gradient 0.042, see Fig. 6-e). On other hand, most significant changes in pan evaporation was observed in North West region (changing gradient 0.52, see Fig. 6-a).

3.5 Spatial distribution of seasonal variation of daily pan evaporation

The spatial distributions of mean seasonal pan evaporation for the year 2010 are plotted in Fig 10(a). In the figure, light blue indicates lower evaporation zone & dark blue indicates higher evaporation zone. In Spring as seen in figure, higher values are found in Northern and some part of Southern regions of Bangladesh. Also lower values are found in some part of Northern and Eastern regions of Bangladesh. The maximum value was found in North Central region of Bangladesh and the minimum value was found in North West region of Bangladesh.

The spatial distributions of mean seasonal pan evaporation for the year 2010 are plotted in Fig 10(b). In the figure, light blue indicates lower evaporation zone & dark blue indicates higher evaporation zone. In Summer as seen in figure, higher values were found in Eastern and Southern regions of Bangladesh. Also the lower values were found in Eastern part of Bangladesh. The maximum value was found in South East region of Bangladesh and minimum value was found in Eastern Hill region of Bangladesh.

The spatial distributions of mean seasonal pan evaporation for the year 2010 are plotted in Fig 10(c). In the figure, light blue indicates lower evaporation zone & dark blue indicates higher evaporation zone. In Autumn, as seen in figure, higher values are found in Northern and Eastern regions and lower values are found in Eastern region of Bangladesh. The maximum value was found in South East region of Bangladesh and the minimum value was found in Eastern Hill region of Bangladesh.

The spatial distributions of mean seasonal pan evaporation for the year 2010 are plotted in Fig 10(d). In the figure, light blue indicates lower evaporation zone & dark blue indicates higher evaporation zone. In Winter as seen in figure, the spatial distribution changes to a different pattern where the higher values were found in Eastern and some part of Northern regions of Bangladesh. Also lower values were found in Northern part of Bangladesh. The maximum value was found in North Central region and minimum value was found in North West region of Bangladesh.

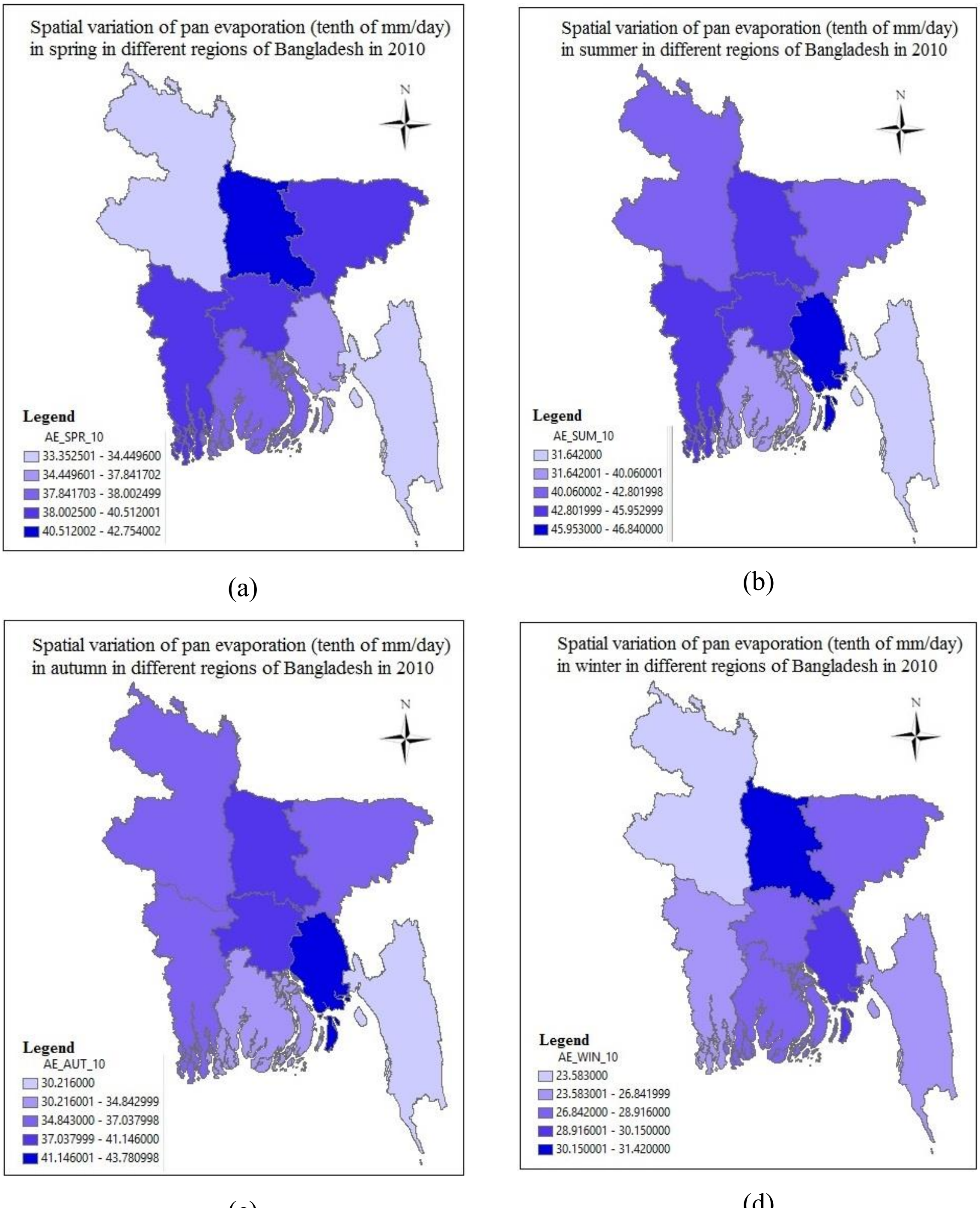


Fig : 10 : Spatial variation of pan evaporation (tenth of mm/day) in different regions of Bangladesh in 2010.

Chapter 4

CONCLUSIONS

This study contains the analytical discussion of the nature and possible trend of pan evaporation with related climatological factors in different regions all over the Bangladesh. Seasonal variation of daily pan evaporation is analyzed and almost all over the regions, highest and lowest evaporation are found in Spring (February to April) and Winter (November to January) respectively. Only exception is North Central region where Summer (May to July) and Autumn (August to October) are found the seasons of highest daily pan evaporation and Winter is found the season of lowest daily pan evaporation.

The spatial distribution of seasonal variation of pan evaporation along with radiation and humidity was analyzed and radiation was found the major controlling factor for evaporation.

From the trend analysis of pan evaporation, evidence of climate change impact on pan evaporation in Bangladesh is apparent and it can be expected that that rate of change of average daily pan evaporation in Bangladesh will continue in future years as a result of ongoing climate change.

The most important factor that can be mentioned under the social benefit issue is that, this study can contribute in approximation of future hydro meteorological water balance, which is one of the primary benefits of using Geographic Information System. These analytical results may vary provided with extensive analysis of evaporation data including the missing and historical data.

The trend analysis of radiation could not be analyzed like evaporation and humidity due to lack of data. The trend analysis of radiation and wind speed change should be studied in order to better explain the outcome of this research.

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