.

Spatial and temporal variability of seasonal rainfall and mean temperature over different region of Bangladesh

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Key findings:

(i) The seasonal variation for both maximum and minimum temperature is small. In winter there exists a north-south temperature gradient which reverses during summer (pre-monsoon and monsoon).

(ii) The seasonal variation for the rainfall is extremely large. In winter there exists a south-north precipitation gradient which reverses during the other seasons.

(iii) Overall we found a positive trend in the rainfall, especially large during the summer monsoon and in the southern zone.

(iv) The northwest area is characterized by decreasing rainfall values both in winter and summer.

(v) Trend in the south zone (Coastal) is higher than other zone of the country.

(vi) The regional analysis identified two regions in Bangladesh, which behave differently, i.e. the Hilly region in the southeast and the northwest area.

(vii) Difference between mean maximum temperature and mean minimum temperature (**ΔT)** T is increasing in the Southern Zone.

(viii) Overall the temperature of whole of the country is increasing (the rate of max temp is 0.028°/year)) concurrent with the global temperature increase.

Abstract

Bangladesh is a small country of South Asia which is considered as one of the most vulnerable countries in the world to climate change and it is affected by severe weather and climate events. In this paper, the climatic change and variability over Bangladesh has been studied. The time series analysis was applied to investigate the variability and trend over three zone [(Northern (North West & North East), Middle and Southern (Coastal, Island, Hilly)] of Bangladesh. The study was based upon the regional differences of climatic trends for the country and tested it for each region against other regions via a t-test. Result suggest that as a topical country, there is small temperature variation in Bangladesh. But there is regional variation between northwest and south zone. In winter there exists a north-south temperature gradient which reverses during summer (pre-monsoon and monsoon). There is an extreme large seasonal variation from winter- to summer- monsoon in Bangladesh. In all seasons the difference of maximum and minimum temperature is higher in the north zone than in the south zone. A remarkable correlation was discovered between this temperature range and the rainfall occurrence. All seasons the mean maximum temperature is increasing except in winter for the northwest and middle zone (-0.004 °C/year and –0.0069 °C/year). Hilly region is showing highest increasing rates of mean maximum Temperature in all season (+0.0754 °C/ year in winter, +0.0635 °C/year in Pre monsoon, +0.0554 °C/ year in monsoon, +0.0679 °C/year in Post monsoon); Where as in all season mean minimum temperature is decreasing only hilly region. Overall the temperature is increasing in whole of the country. We also find a positive trend in the rainfall, especially large during the summer monsoon and in the southern zone (in Hilly region, increasing rate of rainfall +17.784 mm/year). The northwest area on the contrary is characterized by decreasing rainfall values both in winter and summer. So we can conclude that the northwest is clearly becoming more arid. May be this is enhanced by the large scale deforestation processes going on.

[Key words: Pre monsoon, Summer monsoon, Post monsoon, Maximum temperature, Minimum temperature, Precipitation]

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1. Introduction:

Climate change is the one of the major alarm for the earth. “While most climate scientist agree that global temperature are rising and will continue to rise with so-called greenhouse warming there is much less agreement on how such changes will affect particular region of the globe” (Brammer, 2004). IPCC AR5 report shows a linear trend of 0.85°C from 1880 to 2012 (IPCC, 2013). The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest dataset available (IPCC, 2013). The IPCC Fourth Assessment Report for South Asia shows that warming is likely to be above the global mean (IPCC, 2014). Rainfall in the summer season is likely to increase and it is very likely that there will be an increase in the frequency of intense precipitation events in parts of South Asia (IPCC, 2014). MMD-IPCC FAR Scenario A1B

models show a median increase of 3.3°C in annual mean temperature and 11% precipitation median increase by the end of the 21st century in South Asia (Christensen *et al.,* 2007). The IPCC Special Report on the Regional Impacts of Climate Change (2007) indicated that Bangladesh will experience 5–6 % increase in precipitation by 2030 (Shahid, 2011).

The climate of Bangladesh is dominated by the Southwest monsoon. Southwest monsoon season shows considerable year-to-year rainfall variability over South Asia (Asian Development Bank, 2014). Current climatic projection suggest that temperature could increase by 1.1-1.25°C in the monsoon and by 1.25-1.5 °C in the dry season and monsoon rainfall could increase by 10-15 percent by 2030 and dry season rainfall by 5-10 percent in and around Bangladesh (Brammer, 2000, 2004). Such a changes could increase the frequent and severity of floods and keep some basin land wet longer into dry season than occur at present (Brammer, 2000, 2004). Changes to precipitation and temperature are expected to result in severe droughts and strong flooding in different parts of Bangladesh. It could be made more severe as the Himalaya's glaciers are melting; they feed seven rivers in this region, among which are the two big rivers Ganga and Brahmaputra, which lead into the Bay of Bengal through Bangladesh. Year to year variability of summer monsoon season influences agricultural activities, river drainage systems and hydrological behaviour all of which, in turn, influences the life and economy of the country (Johnson, 1982; Ahmed and Karmakar, 1993; Ahmed and Kim, 2003). According to the IPCC fifth assessment report, the loss of life and property associated with floods is highest in India and Bangladesh (IPCC, 2014). Thus, it is important to describe and distinguish the regional and seasonal climatic variability and climate change of Bangladesh. Therefore, this research aim to assess the present status of several climate changes. At the same time comprehensive environmental management plans can be made by using the data and results (Sarker, 2009).

There were a high number of research had been conducted on climatic event in Bangladesh. The variability of annual rainfall (Shamsuddin and Ahmed, 1974), extreme climatic even (Ahmed, 1989), variability of arrival and withdrawal date of the summer monsoon period (Ahmed and Karmakar,

1993; Ahmed and Kim, 2003), temperature and rainfall trend (Ericksen, Ahmad and Chowdhury, 1997; Karmakar and Shrestha, 2000), intra-annual and inter-annual variation of rainfall over different regions of Bangladesh (Debsarma, 2003), were vital work. A comparison of study of three individual metrological station such as Rajshahi (Northwest), Cox.sBazar (Coastal) and Sylhet (Northeast) conducted by Ahmed and Kim, 2004). They mentioned frequency of consecutive rain day of various duration. They found, in wettest monsoon season, Northwest (Rajshahi) region have fewer consecutive rain day 8-10 days than coastal 25-30 days (Cox's Bazar). Whereas, during driest monsoon season, the consecutive rainfall day range from 3-6 days in Northwest (Rajshahi) and 5-7 in coastal (Cox's Bazar). Asian Development Bank, (1994) suggested that rainfall for the nation as whole has slightly increased over time between 1951 and 1991 (the rate of increase is 0.19% per year) (Asian Development Bank, 1994). Mirza *et al.*, (1998) showed that precipitation over all the GBM basins of Bangladesh have been increasing over a period of 31 years. Lutz *et al.*, (2016) examined extreme event consider Ganges and Brahmaputra river basins, (that include Bangladesh as a study area as well), using mean air temperature, precipitation and ETCCDI indices between current scenario (1971–2000) and future (2071-2100). This indices includes R99pTOT [precipitation due to extremely wet days (>99th percentile)], Consecutive dry days (CDD), Warm spell duration index (WSDI), Cold spell duration index (CSDI). Similarly (Shahid, 2011) investigated trend in extreme rainfall using index with more indicator. He found CDD decreasing in Bangladesh. There are few studies projected temperature (Ramamasy and Baas, 2007; Immerzeel, 2008; Gosling *et al.*, 2011) and precipitation (May, 2004; Immerzeel, 2008; Gosling *et al.*, 2011) increases in future.

Before this study, none of the research has been considered to -combined temporal-spatial and variation of temperature and rainfall at seasonal and annual timescale over different regions or for the entire country. However, there are few studies examine spatiotemporal variation after this studies. Definitely, research to date, no studies have been investigated spatial and temporal variation of delta T (difference between maximum and minimum temperature) for at seasonal and annual timescale over different

regions and entire Bangladesh. In addition, very little focus given on seasonal timescale. Some studies focus on individual station rather regional basis. In addition, motive for spatial and at seasonal timescale variation poorly described. Furthermore, there is no previous study of comparison between different regions. Given the lack of work, a range of schemes such as spatial and temporal variation at seasonal and annual timescale of different region and tested the trends for each region against the trends for the other regions via a t-test has been explored in this study.

2. Location and physiographic setting of Bangladesh

Bangladesh is a small country of 145,452 km^2, extending from 20°45′ N to 26°40′ N, and from 88°05′ E to 92°40′ E (Salahuddin *et al.*, 2006). About 80% of the land surface is plain and most of the country lies below 10 meters elevation (Sarker, 2015) (see fig 1). It is bordered by the Assam Hills in the east, by the Meghalaya plateau in the north, with the lofty Himalayas lying beyond (Ahmed, 2003; Ahmed and Kim, 2003; Sarker, 2015). (Figure 1)

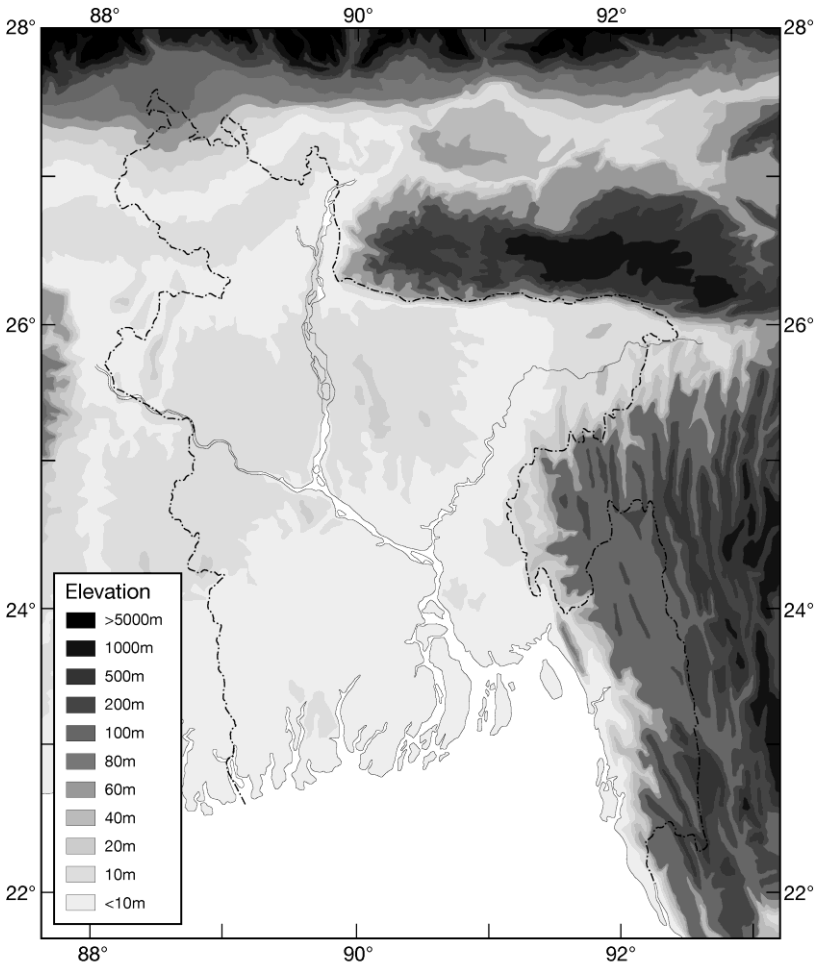


Figure 1 : Elevation map of Bangladesh. (Sources author PhD Thesis)

3. Methodology

3.1 Data source and data processing

Series of 23 years (1981-2003) monthly mean maximum temperature and minimum temperature and rainfall data for 23 stations were obtained from Bangladesh Metrological Department (BMD). There were a few missing data in the early eighties. This was overcome by filling in average values obtained by linear interpolation technique. Total missing data 1.88%. Value of each stations transformed to seasonal (e.g. winter) by calculating -average for both temperature (Tmax and Tmin) –summation for rainfall. Similarly seasonal value converted to regional value by calculating average value of selected stations for a region (as an example, average value of Rangpur, Dinajpur, Rajshahi, Bogra stations converted to Northwest region). Apart from the study of Tmax and Tmin the Temperature range ΔT,

defined as Tmax-Tmin, was also analyzed

3.2 Physio-climate of classified zone (as noted Sarker, 2009):

The country is split into three zone and six regions determined by the physiography of the country and its response to the general climatic patterns discussed below. (See fig 2, Table1).

4.1 Northern Zone:

North West Region: It is located near the foothills of the Himalayas and The contiguous plain of west Bengal and the Gangetic plain lies to its west. Relatively dry, shortest duration of the summer monsoon, least number of rain days and least amount of seasonal rainfall Temperature is higher in pre monsoon and coolest) in winter.

4.1.2 North East Region: It is located near the foothills of the Meghalaya Plateau (windward side) which add an orographic effect on the monsoon rainfall.

4.2 Middle Zone: It is central part of the country and consists of flat plains. High temperature and heavy rainfall is Characteristics of the zone.

4.3 Southern Zone: it is located near Bay of Bengal. This zone (southeast) is the entry and exit point of the Bay of Bengal Branch of the South Asian Monsoon (Spate and Learmonth, 1984; Ahmed and Karmakar, 1993; Ahmed and Kim, 2003). Relatively wet, longest duration of summer monsoon. High humidity, heavy rainfall and less temperature variation between day and night; are characteristics of Southern zone.

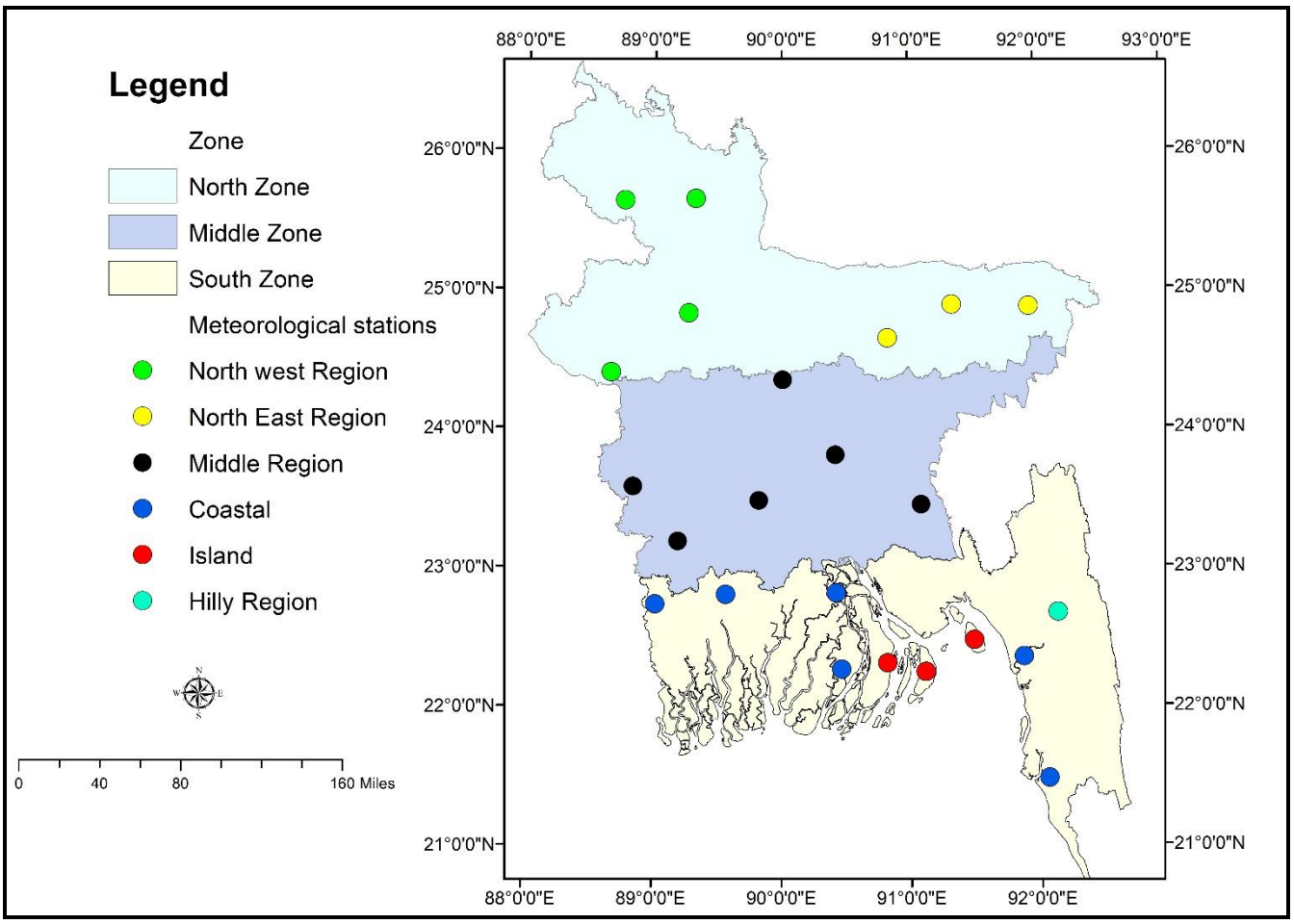


Figure 2: The Study area with 23 metrological station

Table 1: Distribution Meteorological stations in study area:

3 Zones	6 Regions	**23 Meteorological stations**	Number of Station Based on Zone
North	North West	Rangpur, Dinajpur, Rajshahi, Bogra	7
	North East	Mymensingh, Sylhet,Srimongal.	
Middle	Middle	Jessore, Chuadanga, Faridpur, Dhaka, Comilla, Tangail.	6
South	Coastal	Khulna, Satkhira, Patuakhali ,Barisal, Chittagong, Cox's Bazar.	10
	Island	Bhola,Hatiya,Sandwip	
	Hilly	Rangamati.	

3.3 Classification of Meteorological seasons:

Bangladesh is characterized by three distinct meteorological seasons with a relatively cool, sunny and dry season from November through February, a pre-monsoon hot season from March through May, the rainy summer monsoon (Rainy season) from June through mid-October and a short and mild autumn (Post-monsoon) season from mid-October to mid-November (Asian Development Bank, 1994; Ahmed, 2003, 2004; Rasheed, 2008; as noted by Sarker, 2009). Nevertheless, four season was recognised by (Brammer, 2000, 2004).

3.4 Statistical analysis

Using the familiar simple formula $Y=mx+b$, linear regression analysis was carried out with time (year) as an independent variable. The slope of the regression line indicates a per year increase or decrease in rainfall and temperature. The regional differences of climatic trends (mean TMAX and TMIN) for the country and tested it for each region against other regions conducted via a t-test. The statistical test will provide a p-value that bounded 0 and 1. The critical value (α) is tested at 95% (o.o5) confidence level. Finally, in this research, the seasonal mean maximum and minimum temperature and rainfall variation and trends are cartographically represented by iso-lines on maps, created by Arc View software.

4. Climate of Bangladesh

The climate of Bangladesh primarily influenced by the tropical summer and winter circulation, and partly by pre-monsoon and post-monsoon circulation. The southwest summer monsoon originates over the Indian Ocean and caries warm, moist, and unstable air. The winter monsoon originates over northwest India and carries cool and dry air. The seasonal variability of the climate of Bangladesh for the period 1981-2003 is given below.

In winter, two branches of the jet stream are anchored by the Himalayas, one to the north and the other to the south (Figure 3. (a)). The southern branch of the jet stream causes subsidence in the atmosphere in the north-western part of India and consequently, a centre of high pressure develops there, while low pressure develops over the relatively warmer Indian Ocean (Rafique Ahmed, 2004). As a result of this

pressure distribution, winds flow from the interior of India toward the Indian Ocean, in what is known as the winter monsoon circulation (Sarker, 2015).Since the wind in this season is characterized by the land-to-ocean flow, nearly dry conditions prevail during this season. January is the coldest month in Bangladesh. In this study it was found that mean maximum temperature in January varies from about 23.20 °C (Rangpur) to 26.88°C (Cox's bazaar) where is The mean minimum temperature in from 15.23 °C (Cox's bazaar) to 9.93°C (Srimongal) (Table 2). This season is very dry due to the effect of the wind flow from north India to the ocean. The average winter rainfall in Bangladesh is 48.86 mm (Table 2) or only 2% of the yearly total. ***The pre-monsoon*** season is the transition period when the northerly or north-westerly winds of the winter season gradually change to the southerly or southwesterly winds of the summer monsoon (Ahmed, 2003). During the early pre-monsoon season, a narrow zone of air-mass discontinuity lies over Bangladesh, which extends from the southwest corner to the northeast corner of the country (R. Ahmed, 2004). This line of discontinuity separates the warm moist air coming in from the Bay of Bengal and the hot dry air flowing from the interior of northern India. (Huq, 1974; Ahmed and Karmakar, 1993; Ahmed and Kim, 2003; Ahmed, 2004), resulting in high temperatures and the occurrence of thunderstorms and tornadoes (Sarker, 2015). April is the hottest month. The mean maximum temperature in April varies from about 30.04°C (Sandwip) to 35.92°C (Rajshahi) (Table 2) and mean minimum temperature varies from about 20.82 °C (Sylhet) to 24.49°C (Hatiyal) (Table 2). Rainfall in the pre-monsoon hot season (March-May) accounts for 21% of the total annual rainfall. The rain during this period is caused by convective storms (thunderstorms) or nor`western (locally called *Kalbaishakhi*) (Ahmed, 2003). The average total pre-monsoon rainfall in Bangladesh equals 526.35 mm. It varies from about 212.86 mm (Hatiya) to 1281.13 mm (Sandwip)

In summer monsoon

In the summer monsoon season a centre of low pressure develops over the western part of India because of the intense heating of the landmass, while high pressure develops over the relatively cooler Indian Ocean, and the Inter-Tropical Convergence Zone (ITCZ) of the North Indian Ocean moves to

the north (R. Ahmed, 2004) (Fig 3b). This flow pattern is known as the summer monsoon circulation.. Also the Equatorial low Pressure or Inter Tropical Convergence Zone (ITCZ) of North Indian Ocean progresses to the North. As the trough associated with the ITCZ moves to about 25°N over India at the height of the summer, the release of latent heat in the upper troposphere as well as the heating of the Tibetan Plateau causes a north south temperature and pressure gradient resulting in the development of an easterly jet stream at a height of about 150 hPa (15km) (Robinson et al., 1999). As the trough associated with the ITCZ moves to about 25°N over India at the height of the summer, the release of latent heat in the upper troposphere, as well as the heating of the Tibetan Plateau, causes a north-south temperature and pressure gradient and the development of an easterly jet stream at about 150 hPa (Robinson and Henderson-Seller, 1999). The summer monsoon flow enters Bangladesh in late May or early June, and continues to flow toward the centre of low pressure that lies over the western-central part of India. The temperature during this season is slightly lower than during the pre-monsoon season. June is the hottest month of this season. Heavy and prolonged rainfall characterizes the season, caused by tropical depressions that enter the country from the Bay of Bengal. June is the hottest month of this season. In June the mean maximum temperature varies from about 30.50°C (Sandwip) to 33.90°C (Chuadanga) (Table 2) and mean minimum temperature varies from about 24.45 °C (Sylhet) to 26.27°C (Satkhira) (Table 2). Heavy and prolonged rainfall characterize the season, caused by tropical depressions that enter the country from the Bay of Bengal. During this season the rainfall in the northwest and middle region is less than in other areas. The average total rainfall varies from about 750.26 mm (Rajshahi) to 2593.41 mm (Coxs' Bazar) (Table 2).

The post-monsoon (autumn) represents a transitional period (R. Ahmed, 2004) similar to the pre-monsoon. The temperature remains mild during this season and it is more comfortable due to less moisture in the air. The mean maximum temperature varies from 30.14°C (Rangpur) to 31.78°C (Jessore) and the mean minimum temperature varies from 21.30°C (Dinajpur) to 25.46°C (Hatiya) (Table 2). This season is comfortable as there is less moisture in the air. The average total post

monsoon rainfall in Bangladesh is 538.95 mm (21.8%) and it varies from 331.38 mm (Sandwip) to 806.78 mm (Sylhet) (Table 2)

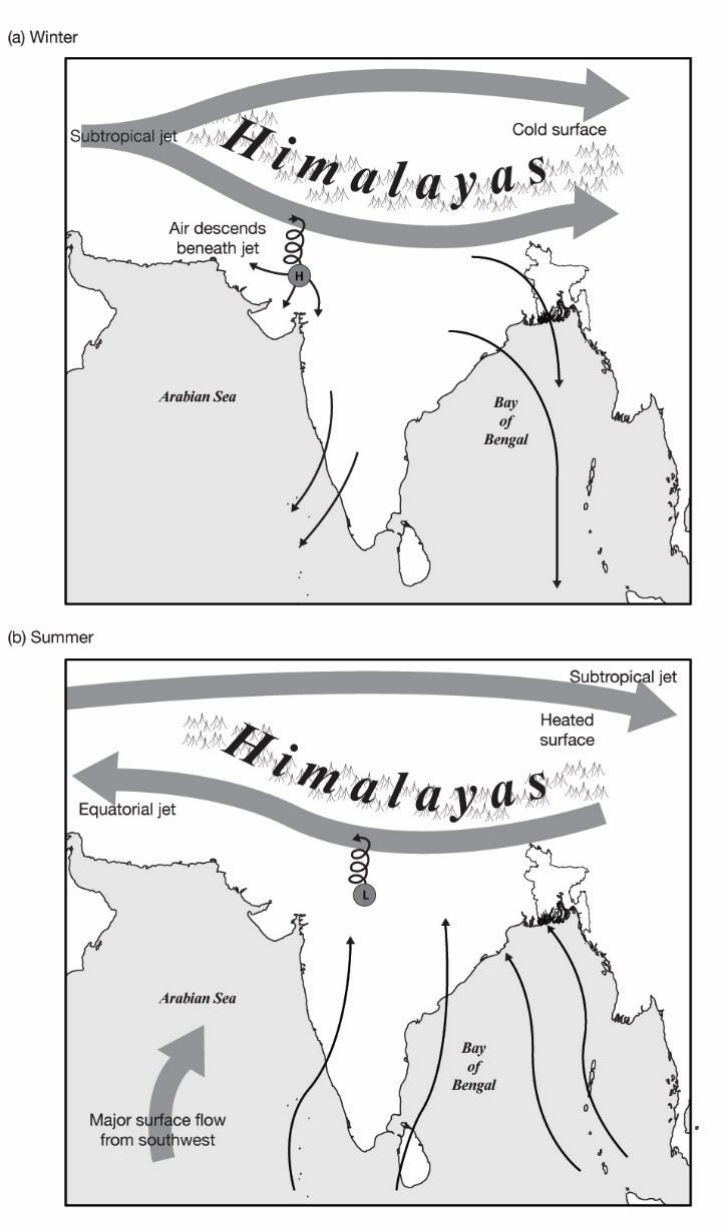


Figure 3: The airflow patterns over southern Southern Asia in (a) winter and (b) summer (Sources author PhD Thesis)

Table 2. Mean Minimum, Maximum Temperature and Rainfall for the period 1981-2003

Zones	Regions	Stations	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)
North	Northwest	Rangpur	12.12	24.94	65	20.32	31.28	421.06	25.78	31.82	1346.14	21.62	30.14	587.27	19.85	29.54	2512.57
		Dinajpur	11.63	24.97	60	23.23	32.1	302.24	25.53	32.17	1176.48	21.3	30.43	564.75	20.37	29.92	2079.73
		Rajshahi	11.96	25.83	37.09	21.38	34.64	227.7	25.89	32.8	825.91	21.97	31.3	470.13	20.19	31.14	1560.83
		Bogra	13.14	26.18	44.98	21.48	32.48	212.86	26.04	32.28	1427.63	22.33	31.32	490.9	20.64	30.56	2176.37
	Northeast	Mymensing	13.23	25.88	38.65	21.33	31.32	526.57	25.91	31.33	1184.21	22.3	30.67	588.43	20.58	29.8	2337.86
		Sylhet	13.8	26.28	59.91	20.56	30.7	1091.97	24.84	31.48	2250.26	21.86	30.7	806.78	20.16	29.79	4208.92
		Srimongal	11.46	26.48	55.81	20.48	32.09	738.11	24.98	32.19	1099.26	21.13	30.89	508.08	19.41	30.41	2401.26
Middle	Middle	Jessore	12.88	26.9	54.38	22.58	34.62	318.44	25.94	32.77	917.21	22.09	31.78	404.47	21.42	31.52	489.19
		Chuadanga	12.43	26.27	46.55	22.39	34.91	229.53	26.15	33.2	754.13	22.37	31.66	446.85	20.73	31.51	530.76
		Faridpur	13.68	26	49.95	22.2	33.32	451.38	25.84	31.77	945	22.99	30.79	451.04	21.06	30.47	533.35
		Dhaka	14.42	26.6	44.64	22.87	33.01	537.39	26.24	31.96	987.37	22.95	31.15	522.34	21.53	30.68	605.7
		Tangail	13.46	25.64	49.24	21.98	32.67	464.06	25.39	32.01	885.94	22.28	30.91	461.56	20.68	30.31	135.86
		Comilla	12.94	26.48	45.81	21.6	31.76	536.46	25.94	31.47	1085.41	22.61	30.99	418.12	20.65	30.17	499.93
South	Coastal	Khulna	13.58	26.88	62.98	22.99	33.93	333.51	26.08	32.29	984.7	22.99	31.4	535.31	21.92	31.13	619.76
		Satkhira	13.56	27.15	56.6	23.31	34.37	301.73	26.18	32.58	1246.51	22.51	31.59	455.43	21.94	31.42	540.39
		Patuakhali	15.12	26.86	40.86	23.43	32.68	429.12	25.98	31.09	1636.78	23.37	30.78	588.7	22.43	30.35	672.27
		Barishal	14.17	26.81	43.82	23.25	32.89	403.52	25.92	31.37	1206.98	22.93	30.97	479.7	21.48	30.51	562.66
		Chittagong	15.19	27.18	47.37	22.82	31.64	526.91	25.25	31.36	1859.12	23.12	31.16	503.68	21.49	30.34	586.67
		Cox's Bazer	16.48	27.89	45.44	23.35	32.11	462.21	25.21	30.61	2593.41	23.46	31.15	715.31	22.04	30.44	798.94
	Island	Bhola	14.17	26.9	46.26	23.25	32.41	414.47	25.92	31.09	1323.32	22.93	30.95	490.91	22.06	30.34	574.25
		Hatiya	16.92	26.69	29.36	20.54	30.08	454.76	25.28	30.82	1898.48	25.07	30.65	684.25	21.75	29.56	766.2
		Sandwip	15.95	26.14	70	23.86	30.41	1281.13	25.59	30.23	1902.26	23.56	30.32	331.38	22.15	29.28	413.13
	Hilly	Rangamati	14.51	26.82	46.92	21.85	32.59	564.84	24.71	31.34	1474.58	22.57	30.86	593.43	20.8	30.4	675.49
Bangladesh			13.5	26	40	21	31.5	500	24	31	1400	23	30.4	550	20.5	29.73	630.63

5. Result and Discussion

5.1 Seasonal variation

5.1.1 Seasonal variation of Temperature:

Winter is the coldest and pre-monsoon is the hottest season in this country. All regions of the country show their highest mean maximum temperature in pre-monsoon except the northeast region (31.37°C in pre monsoon and 31.66° C in monsoon) while the highest mean minimum temperature occurs during the summer monsoon (Figure 4 and table 3). This is because the atmospheric moisture content and cloud cover are the highest during the summer monsoon season. At night they absorb the outgoing long wave radiation very efficiently, and thereby they trap the heat at night. As a result, in the summer monsoon, the minimum temperature is slightly higher than expected (Ahmed, 2005; Sarker, 2005). An analogue explanation holds to explain the high maxima in the pre-monsoon dry period.

In winter mean maximum temperature is slightly lower in the north zone (25.48 °C in northwest region) and higher in south zone of the country (27.13 °C mean maximum temperature in coastal region). [(Figure 4 & 5(A) Table 3)]. The northwest region is clearly the coolest region of the country. This is certainly due to the advection of cold continental air that enters the country from the northwest and being farthest north, the angle of the sun is also smaller than in any other region in winter. In addition the proximity of the Himalaya's contributed to the relatively lower maximum temperatures than in any other region (Ahmed, 2005).. The mean minimum temperature of the northwest region also shows lower values than in any other region of the country (12.21°C Table 3), because atmospheric moisture content in this region is generally low. Due to the high moisture content of the atmosphere over the Island region and the coast, these areas show highest mean minimum temperature values of 15.68°C and 14.68°C (Table 3).

Table 3. Seasonal Mean Minimum, Maximum, Difference of maximum & minimum (**ΔT)** Temperature and Rainfall (Average total per season)

Zone	Region	Winter				Pre monsoon				Monsoon				Post monsoon				Annual			
		Min Temp (°C)	Max Temp (°C)	**ΔT** (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	**ΔT** (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	**ΔT** (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	**ΔT** (°C)	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)	**ΔT** (°C)	Rainfall (mm)
North	**Northwest**	12.21	25.48	13.27	51.77	21.6	32.63	11.02	290.97	25.81	32.27	6.46	984.7	21.8	30.8	8.99	528.26	20.26	30.29	10.03	1855.69
	Northeast	12.83	26.22	13.39	51.46	20.79	31.37	10.58	785.55	25.24	31.66	6.42	1511.24	21.76	30.75	8.99	634.43	20.05	30	9.95	2982.68
Middle	**Middle zone**	13.3	26.31	13.01	48.43	22.27	33.38	11.11	422.88	25.92	32.2	6.28	943.7	22.55	31.21	8.66	450.73	21.01	30.78	9.76	1865.73
	Coastal	14.68	27.13	12.45	49.51	23.19	32.94	9.75	409.5	25.77	31.55	5.78	1587.92	23.07	31.18	8.11	546.36	21.88	30.7	8.81	2593.28
	Islands	15.68	26.58	10.9	48.54	22.55	30.97	8.42	716.79	25.6	30.71	5.12	1708.02	23.85	30.64	6.79	502.18	21.98	29.72	7.74	2975.53
South	**Hilly**	14.51	26.82	12.41	46.92	21.85	32.59	10.62	564.84	24.71	31.34	6.81	1474.58	22.57	30.86	7.84	593.43	20.8	30.4	9.41	2679.77
Bangladesh		13.78	26.35	12.57	49.44	21.97	32.3	10.25	531.75	25.45	31.59	6.15	1368.36	22.64	31	8.23	542.56	20.97	30.31	9.29	2492.11

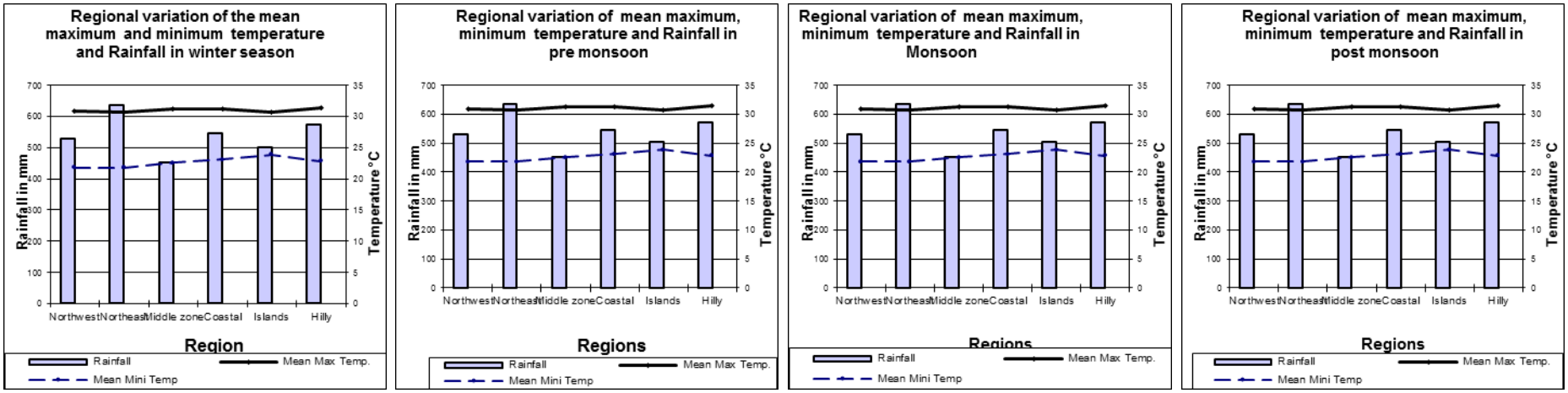


Fig. 4. Regional variation of the mean maximum and minimum temperature and Rainfall in different season

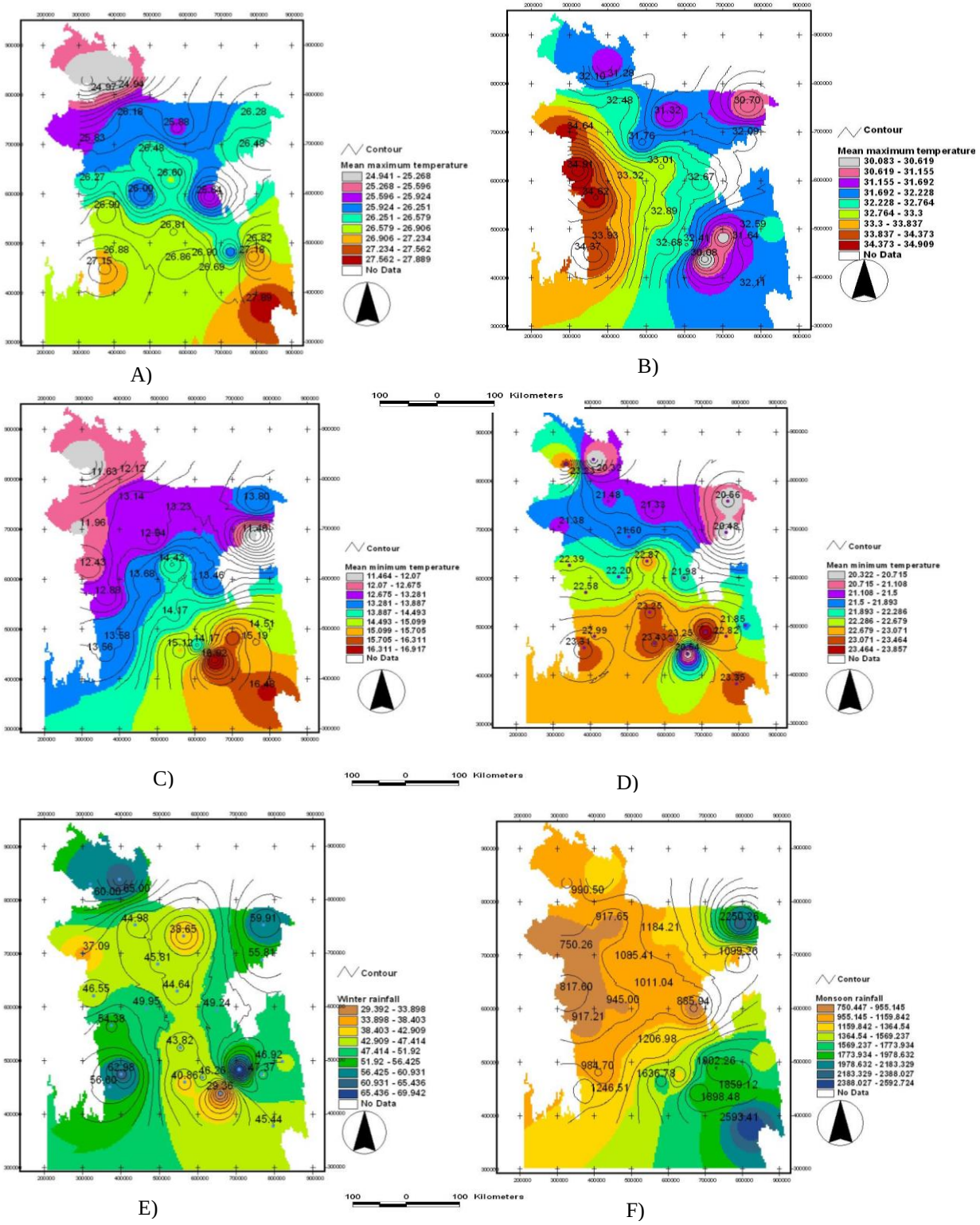


Fig. 5. The mean maximum Temperature in (A) Winter (B) Pre monsoon; the mean minimum Temperature in (C) Winter (D) Pre monsoon; The average total rainfall in (E) Winter (F) Monsoon

In the Pre-monsoon and monsoon seasons The mean maximum temperature, is highest in the middle zone (33.38 °C in figure 4, 5.(B) & Table 3)]. There are several reasons for this reversal in regional temperature gradient as compared tot the winter season : (a) during the pre monsoon season, the sun is nearly vertical over this zone, (b) coastal regions and islands are slightly cooler due to the maritime effect, (c) hilly regions are slightly cooler because of the elevation, and (d) the northern regions are slightly cooler because the sun shines at a smaller angle over the northern regions resulting in lesser intensity of the sun over these (Ahmed, 2005).

Temperature during the ***summer monsoon*** season is generally lower than the temperature during the pre-monsoon season. Widespread cloud cover during the monsoon season reduces the insulation which, in turn, causes the temperature to be lower than expected for the season (Ahmed, 2005; Sarker, 2005). In the pre-monsoon, the coastal region shows the highest mean minimum temperature (23.19°C) while the northern regions show lower mean minimum temperature values of 20.79 °C in (Figure 4, & Table 3)] in the northeast and 21.6 in the northwest region. This indicates that the mean minimum temperature increases from the north region to the coastal areas. In monsoon season mean maximum temperature in the northwest region shows the highest value of 32.27°C while the islands area show the lowest value of 30.71°C. It indicates that the mean maximum temperature decreases from the northwest region to the south zone (Coastal, island and hilly regions). Compared to other regions, the northwest region has the least widespread cloud cover during the summer monsoon season. So, under less cloud cover, insulation is relatively high which causes the maximum temperature in northwest region to be higher than any other region. In this season the middle zone shows higher mean minimum temperatures (25.92°C) than the other regions (Figure 4 and Table 3)

In Post monsoon the mean maximum temperature in the middle zone and coastal area is slightly higher (31.21°C and 31.18°C in coastal) than in the north zone (30.75 °C in northeast and 30.80°C in northwest region) (Figure 4 and Table 3). During the post monsoon period a branch of the mid latitude western jet stream settles south of the Himalayan's. It enters into Bangladesh through the northwest

corner of the country. For this reason the northern zone is cooler than the middle and coastal region these (Ahmed, 2005).

5.1.2 Seasonal variation of Rainfall

Rainfall is most important phenomena for the country as it is an agro based country and economy of the country depend on agriculture. There is an extreme large seasonal variation from winter- to summer-monsoon in Bangladesh as wind blows from different direction for winter and summer. In monsoon rainfall varies from 943.7 mm to 1708.02 mm. The Seasonal rainfall variation of all regions are given in the figure 4 and 6.

In winter rainfall varies from 46.92 mm to 51.77 mm. The northwest region is showing higher winter rainfall than any other region of the country (Figure 4, Fig 5(E) and Table 3).In this season the remnants of the Mediterranean disturbances enter the sub-continent through the north western corner of the sub-continent. These weather disturbances travel from west to east along the foothills of the Himalayas, causing precipitation along their travel path. Some of these disturbances reach the north western region of Bangladesh. That is why the northwest region of Bangladesh receives more winter rainfall than any other regions in the country.

In pre monsoon rainfall varies from 290.97 mm in the northwest region to 785.55 mm in the northeast region (table 3) in this season. Sandwip and Sylhet receive rainfall values of 1281.13 and 1091.97 mm (Table 2). The middle zone shows less rainfall. (Figure 4)

In monsoon seasons, all the regions of the country receive heavy rainfall. As "during monsoon the surface wind blows from the southwest direction and carries a lot of moisture from the Bay of Bengal and North Indian Ocean. This causes a lot of precipitation over Bangladesh and adjoining countries. High orographic precipitation occurs over the northern hills and mountain slopes in the territories of Indi, Nepal and Bhutan. The upstream regions over Meghalaya and Assam get very high amount of precipitation, Cherrapunji which received world's highest annual precipitation 11387 mm lies over the hilly region close to Bangladesh border" (Quadir *et al.*, 2003, p. 168) for which the Sylhet, the one of

weather station of northeast receives highest monsoon rainfall (2250.26 mm) in the country. (Table 2) and northeast receive 1511.24 mm where south zone receive (Islands 17.08.02 mm, Coastal 1587.92 mm and hilly 1474.58 mm) higher rainfall than other zone. In addition the periods of consecutive rain days range is higher in Northeast and southeast than other regions. Ahmed and Kim, (2003) has shown very long episodes of consecutive rain days in the northeast (Sylhet) are due to the additional effect of orographic uplift on the rainfall provided by the Meghalaya Plateau. Similarly, very long episodes of consecutive rain days in the coastal southeast (Cox's Bazar) are due to the additional effect of orographic uplift on the rainfall provided by the coastal hills. From the table 3 and Figure 5.(F), we can conclude that the northeastern and southeaster part of Bangladesh gets the highest precipitation and the north western and south-western part is relatively dry.

In post monsoon rainfall is less than the monsoon rainfall. In this season highest rainfall occurs in Sylhet (806.78 mm). The Northeast region receives rainfall amount of 634.43 mm. and the middle region receives 450.73 mm (Figure 4 & table 3.). The rainfall amount of the season is slightly enhanced in the northeast region than other region (Same as orographic effect).

5.2 Relation between Maximum-Minimum Temperature Difference and Rainfall:

A remarkable correlation was discovered between this temperature range and the rainfall occurrence (Fig 6). In summer-monsoon, the difference of temperature (ΔT) is lower than any other season while rainfall is higher than any other season, in all regions of the country. It indicates a negative correlation between ΔT and the rainfall. Again in monsoon, island and coastal region (south zone) is showing ΔT value (lowest ΔT value is 5.12°C in islands). Table 3, reveals the variation of ΔT over different region and the value is decreasing from the north to the south while at the same way the rainfall increases from northwest to the south (Figure: 7) as south zone located in coastal area and humidity of that zone is higher.

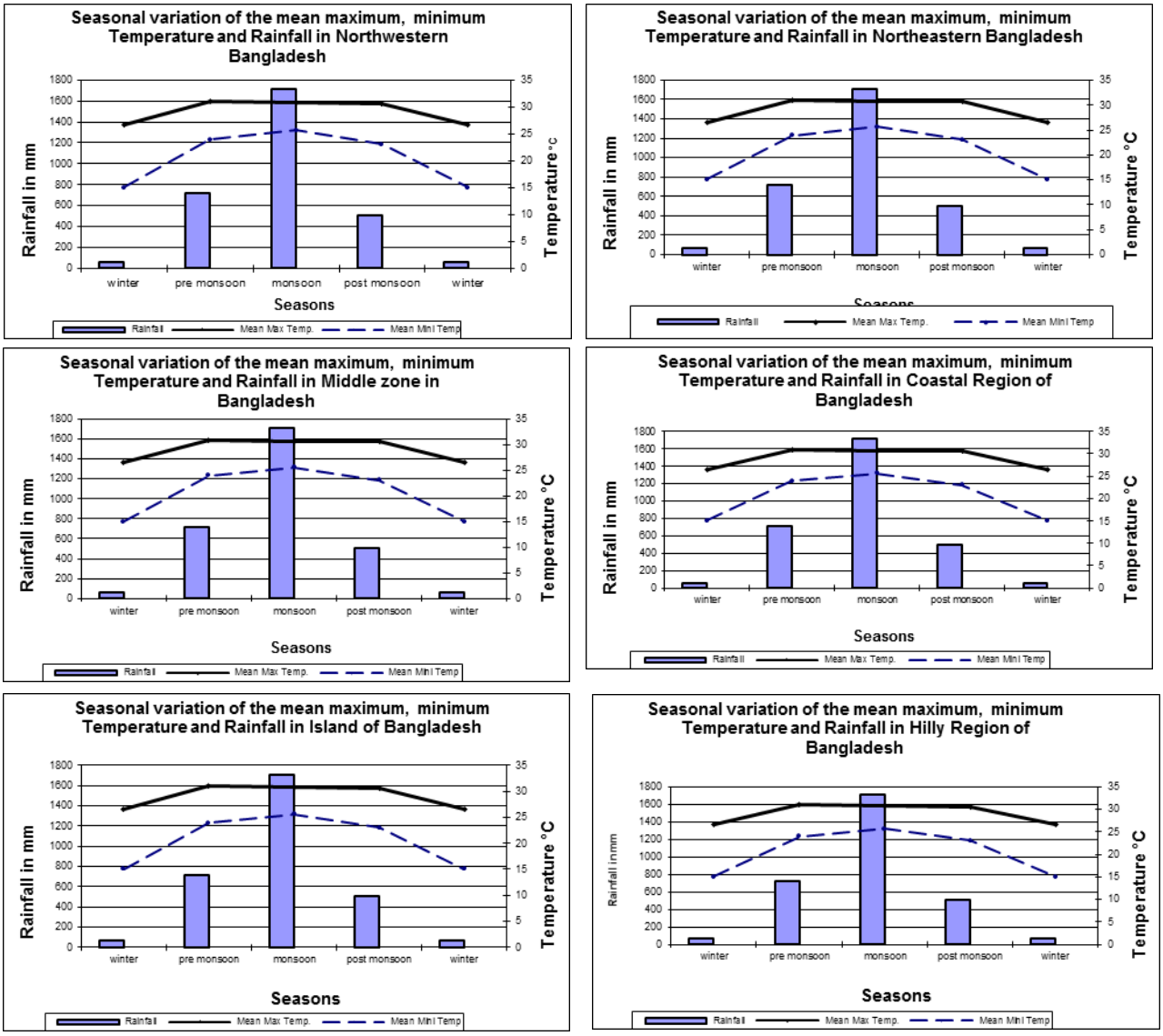


Fig. 6. Seasonal variation of the mean max, min Temperature and Rainfall in different region

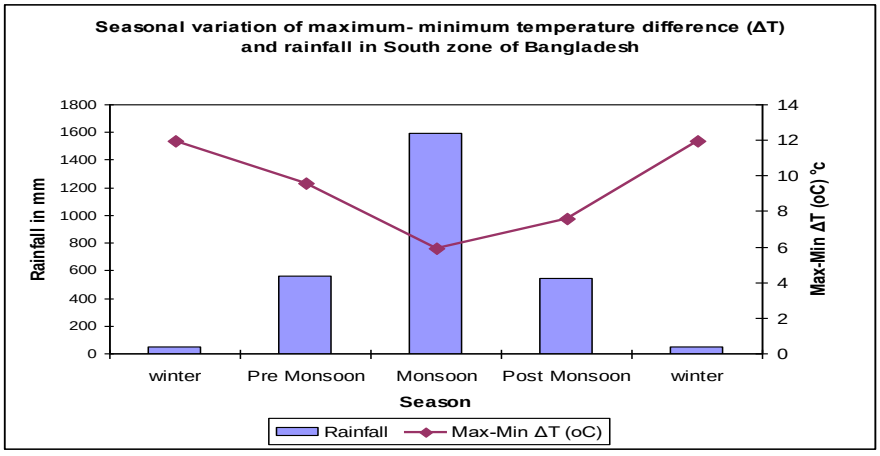


Fig. 7. Seasonal variation of the difference of mean Max & Min temperature and rainfall in south zone.

5.3 Time Series Analysis

5.3.1 Trend of Temperature

To investigate the temporal variability and trends over different region of Bangladesh, the time series plot and regression analysis has been applied (Appendix fig A-D). Table 4 & 5 and figure 8, and 9 show that in all seasons the mean maximum temperature is increasing except in winter for the northwest and middle zone and mean minimum temperature is increasing as well except hilly region for all season.

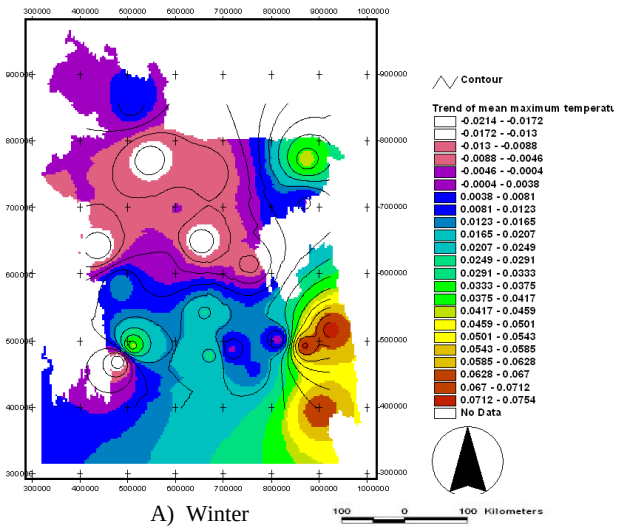
In winter, the mean maximum temperature is rising by 0.0754°C/year (Hilly region) to 0.0076°C/year (islands regions). The northwest and middle zone are showing decreasing rates of -0.0004 °C/year and -0.0069 °C/year [Table 4 and Figure 8 (A)]. The mean minimum temperature is increasing in northwest region with rate of +0.0281°C/year while the middle zone and coastal region are showing very small increasing rates. The northeast, island and hilly region are showing deceasing rates [(Table 5 and figure 9(A)].

In the pre-monsoon period, mean maximum temperature is rising from +0.0034°C/year (middle zone) to +0.064°C/year (Hilly region) [(Table 4 and figure 8 (B)].. The mean minimum temperature is increasing in most regions except island and hilly region, where the mean minimum temperature are decreasing with the rate of -0.006°C/ year and -0.047°C/ year [(Table 5 and figure 9(B)].

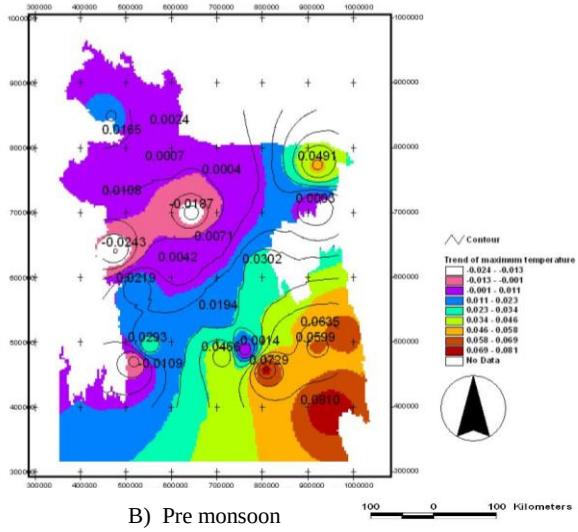
In the monsoon period, mean maximum temperature is rising from +0.0167 °C/year (northeast region) to +0.056°C/year (Hilly region) [(Table 4 and figure 8(C)].. Like pre monsoon, the mean minimum temperature at island and hilly region are decreasing with values of -0.004 °C/year and -0.003 °C/ year [(Table 5 and figure 9(C)].

In the post monsoon period, it was found that in all regions the mean maximum temperature is increasing with a rate varying from +0.029°C/ year (Island) to +0.068 °C/year (Hilly) [(Table 4 and figure 8(D)]. The mean minimum temperature is decreasing only in the hilly region with a rate of -0.04°C/ year [(Table 5 and figure 9(D)].

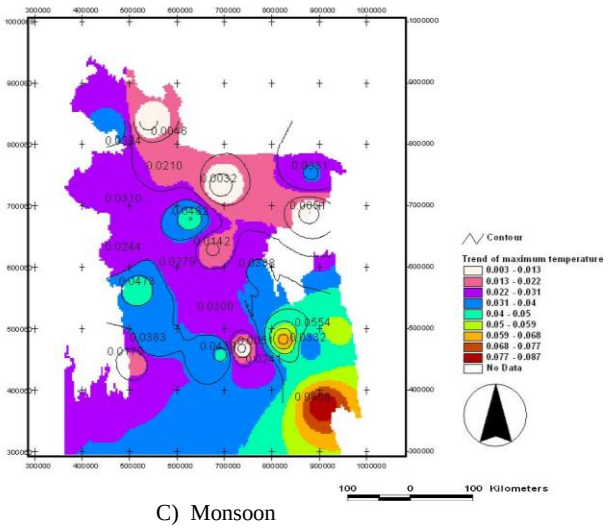
From the above calculation we can conclude that overall the temperature is increasing over the whole country (the rate of max temp is +0.028°/year) concurrent with the global temperature increase. From the table 3 and 4, it is clear that the increasing rate of mean maximum temperature is higher in southern zone than in the other zones. It may be caused by increasing of sea surface temperature. (Josheph, 1995) shown increase of SST (Sea Surface temperature) using data for the Bay of Bengal over the period 1951-1987 (See also (Ali, 2003)), but why this should affect in the first place the maximum temperatures is not clear.



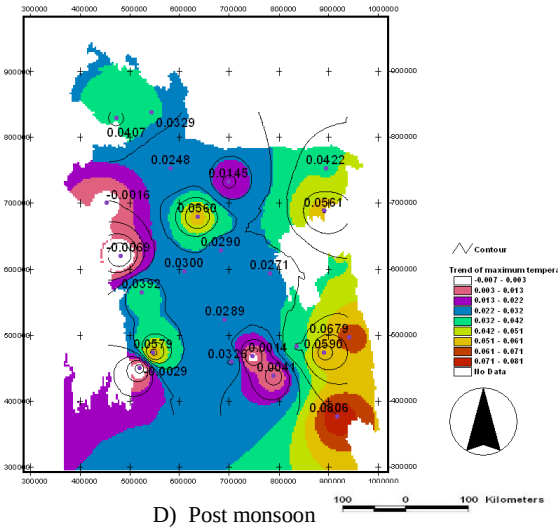
A) Winter



B) Pre monsoon



C) Monsoon



D) Post monsoon

Fig. 8. The mean maximum Temperature trend in (A) Winter (B) Pre monsoon (C) Monsoon (D) Post monsoon

Table 4. Mean maximum temperature trends (°C/year)

Regions	Winter	Pre monsoon	Monsoon	Post monsoon
Northwest	*-0.0004*	*+0.008*	*+0.024*	*+0.025*
Northeast	*+0.013*	*+0.017*	*+0.017*	*+0.032*
Middle zone	*-0.007*	*+0.003*	*+0.031*	*+0.031*
Coastal	*+0.036*	*+0.038*	*+0.043*	*+0.047*
Islands	*+0.008*	*+0.049*	*+0.026*	*+0.018*
Hilly	*+0.075*	*+0.066*	*+0.055*	*+0.068*

Table 5. Mean minimum temperature trends (°C/year)

Regions	Winter	Pre monsoon	Monsoon	Post monsoon
Northwest	*+0.028*	*+0.048*	*+0.035*	*+0.06*
Northeast	*-0.013*	*+0.023*	*+0.014*	*+0.047*
Middle zone	*+0.002*	*+0.010*	*+0.002*	*+0.0169*
Coastal	*+0.001*	*+0.009*	*+0.011*	*+0.0315*
Islands	*-0.037*	*-0.006*	*-0.004*	*+0.0006*
Hilly	*-0.044*	*-0.045*	*-0.003*	*-0.0411*

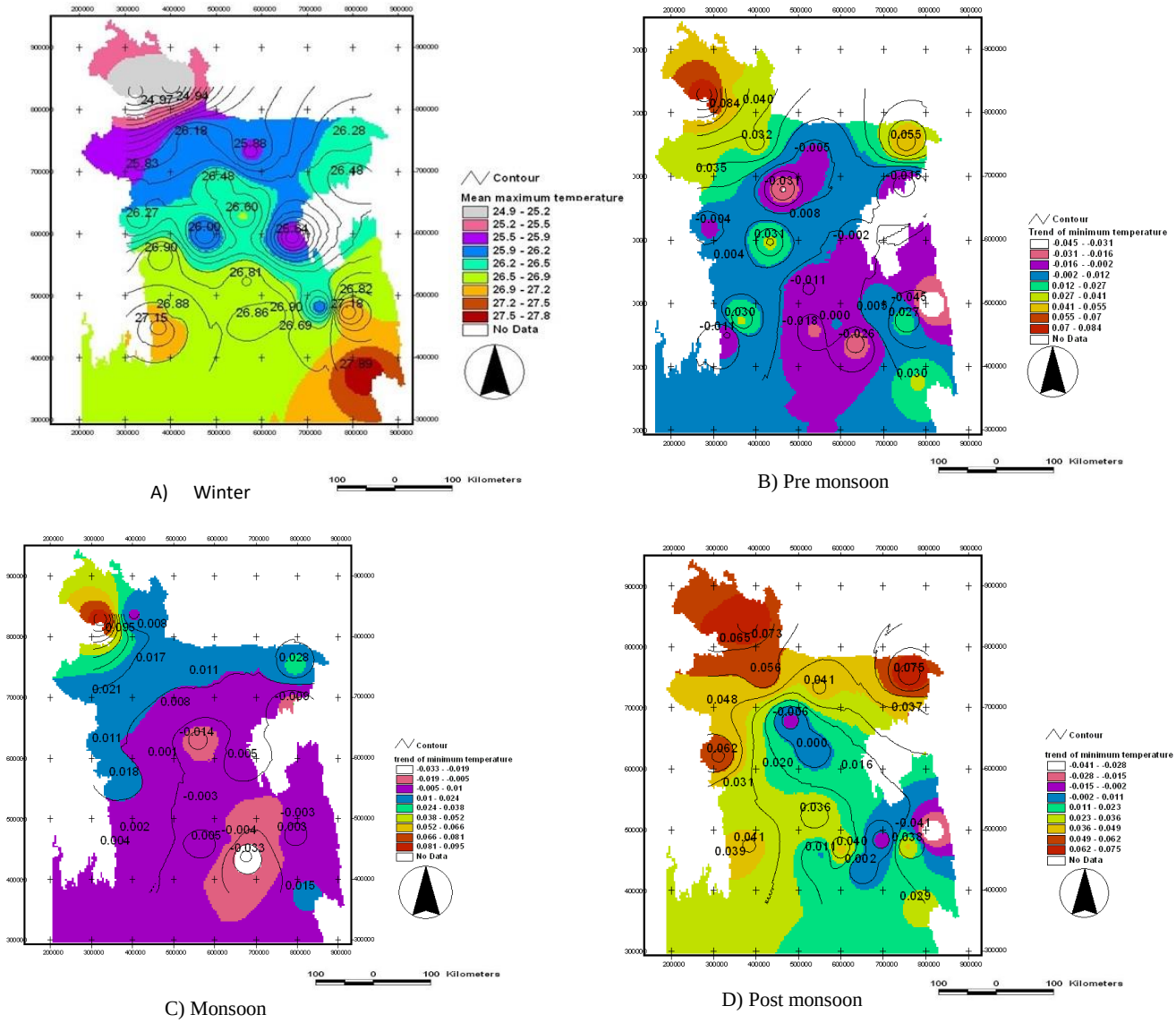


Fig. 9. The mean minimum Temperature trend in (A) Winter (B) Pre monsoon (C) Monsoon (D) Post monsoon

5.3.2 Trend of Precipitation

Several studies have indicated that during the recent decade the precipitation of Bangladesh has been increasing (as noted by (Quadir *et al.*, 2003)) (Fig 10). Restricting ourselves to the two extreme seasons (winter and summer-monsoon) I found that the precipitation trends in the monsoon season are positive in all the regions of the country except the northwest region (-3.06 mm/ year) . The Hilly region shows the highest increase in rainfall (+17.78 mm/ year). (Table 6, and Figure 11). But in winter, precipitation shows a decreasing trend in all the regions except the islands and hilly region. The

increasing rate of precipitation for the island has been found as +0.016 mm/ year. Hilly region shows 0.93mm/ year. (Table 6, and Figure 11).

So we can conclude that in the monsoon period the rainfall is increasing in all regions except in the northwest region. The northwest is clearly becoming more arid. May be this is enhanced by the large scale deforestation processes going on.

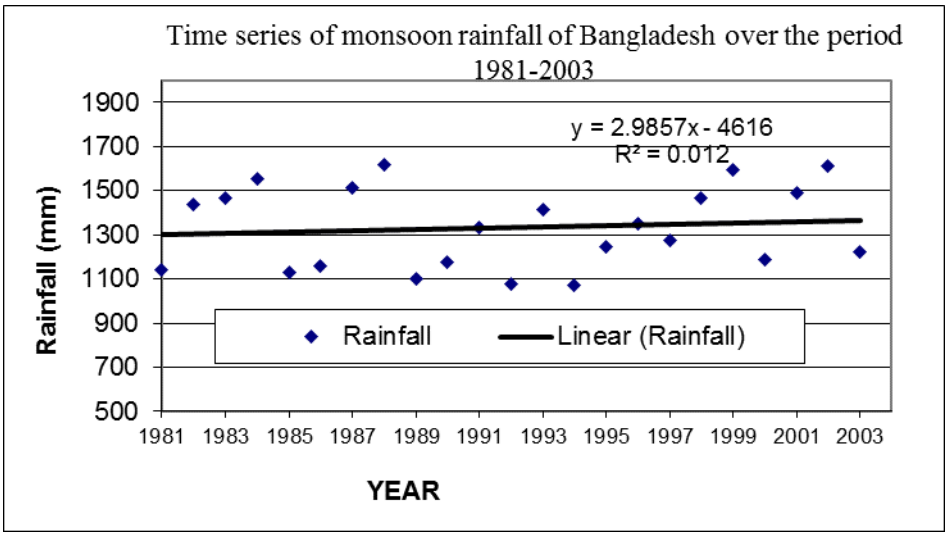
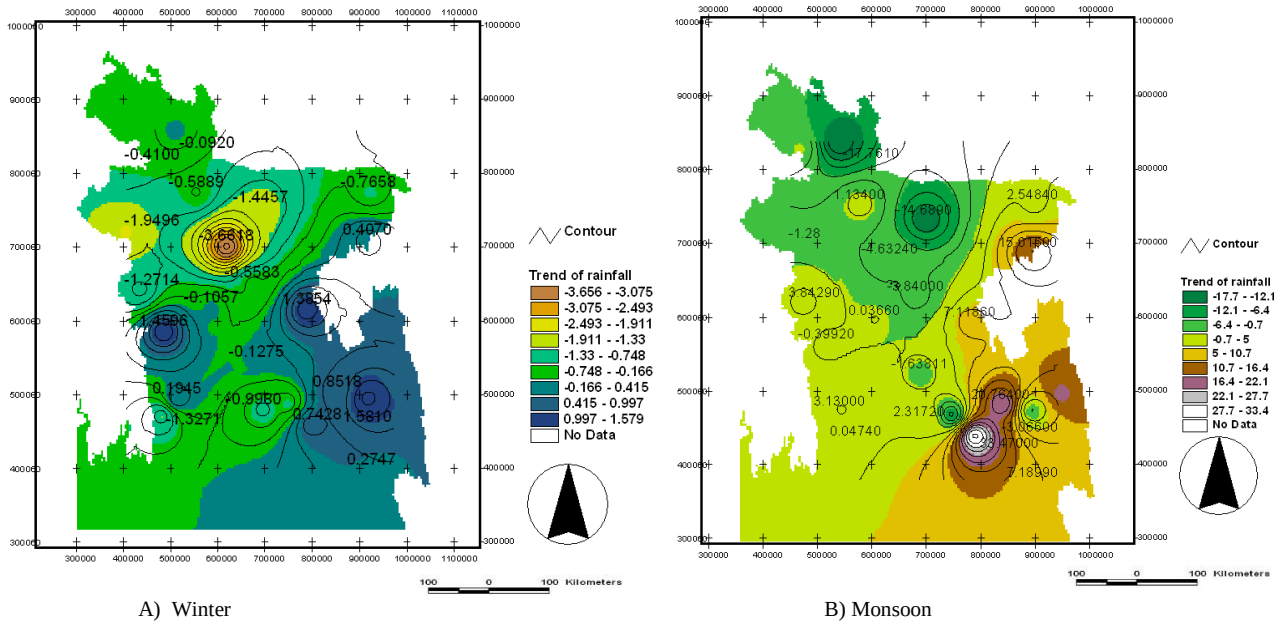


Fig. 10. Time series of monsoon rainfall of Bangladesh over the period 1981-2003



A) Winter B) Monsoon

Fig. 11. The Rainfall trend in (A) Winter (B) Monsoon

Table 6. Rainfall trends in mm/year

Regions	Winter	Monsoon
Northwest	*-1.0109*	*-3.057*
Northeast	*-0.833*	*+0.096*
Middle zone	*-0.734*	*+0.727*
Coastal	*-0.131*	*+3.827*
Islands	*+0.161*	*+12.183*
Hilly	*+0.932*	*+17.784*

5.4 Regional differences:

As the emphasis in this research was laid upon the regional differences of the climatic trends for Bangladesh, we present maps (Figure 8 & 9) displaying the trends and tested the trends for each region against the trends for the other regions (t-test). The t-test was only carried out for the maximum and minimum temperatures and the results shown in table 7. From this table we can see that essentially the Hilly region and the northwest region stand out as separate regions from the overall Bangladesh area: the Hilly region as a region with an exceptional large increase in maximum temperature and decrease in minimum temperature. The northwest region with a very small increase in maximum temperature and a comparative large increase in minimum temperature.

Table 7: Statistical t-test.

Maximum temperature						
Region	Northwest	Northeast	Middle zone	Coastal	Islands	Hilly
Northwest	I	I	I	S	I	S
Northeast	I	I	I	S	I	S
Middle zone	I	I	I	I	I	S
Coastal	S	S	I	I	I	S
islands	I	I	I	I	I	S
Hilly	S	S	S	S	S	I
Minimum temperature						
Region	Northwest	Northeast	Middle zone	Coastal	islands	Hilly
Northwest	I	I	S	S	S	S
Northeast	I	I	I	I	I	S
Middle zone	S	I	I	I	I	S
Coastal	S	I	I	I	I	S
islands	S	I	I	I	I	S
Hilly	S	S	S	S	I	I
Insignificant = I Significant = S						

6. Conclusion:

In this research, the recent climatic variability and trend of temperature and precipitation over Bangladesh have been studied. The conclusion of this study can be summarized as follows:

(ix) The seasonal variation for both maximum and minimum temperature is rather small. In winter there exists a north-south temperature gradient which reverses during summer (pre-monsoon and monsoon).

(x) The seasonal variation for the rainfall is extremely large. In winter there exists a south-north precipitation gradient which reverses during the other seasons.

(xi) In all seasons the difference of maximum and minimum temperature is higher in the north zone than in the south zone. We discovered a remarkable correlation between this temperature range and the rainfall occurrence.

(xii) Overall we find a positive trend in the rainfall, especially large during the summer monsoon and in the southern zone. The northwest area on the contrary is characterized by decreasing rainfall values both in winter and summer. Thus there appears to be an increasing contrast between the summer and winter monsoon.

(xiii) The maximum temperature shows a remarkable increasing trend especially in winter. The minimum temperature on the other hand shows an overall decreasing trend except in the north. This results in a conspicuous increasing trend for the temperature range (Maximum – minimum). Overall the temperature of whole of the country is increasing as same as global temperature is increasing. It was found in this study that trend in the south zone is higher than other zone of the country. It may be caused by increasing of sea surface temperature. Global warming would result in an increase in sea surface temperatures as a result of which changes in the frequency, intensity or tracks in cyclones hitting the coastal zones may take place. So "an increasing in SST will lead to higher storm surges and higher risk of coastal disaster in low coastal areas particularly of Bangladesh" (Ali, 2003, p. 134).

(xiv) The regional analysis identified two regions in Bangladesh which behave differently, i.e. the Hilly region in the southeast and the northwest area. The northwest area is clearly under the influence of processes more typical for middle latitudes, while in the hilly region orographic and coastal processes might be at work.

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Appendix:

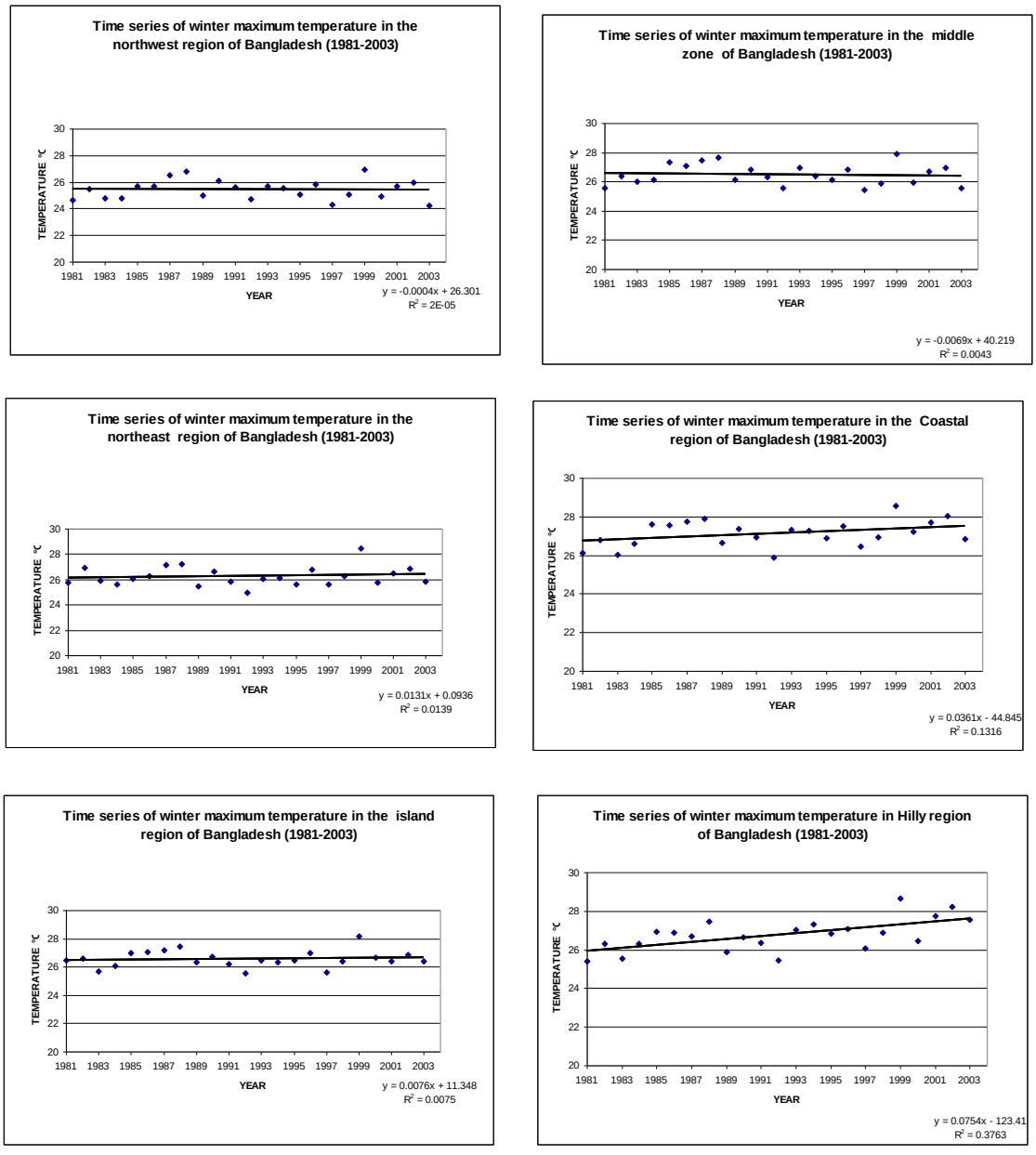


Figure A: Time series of winter mean maximum temperature.

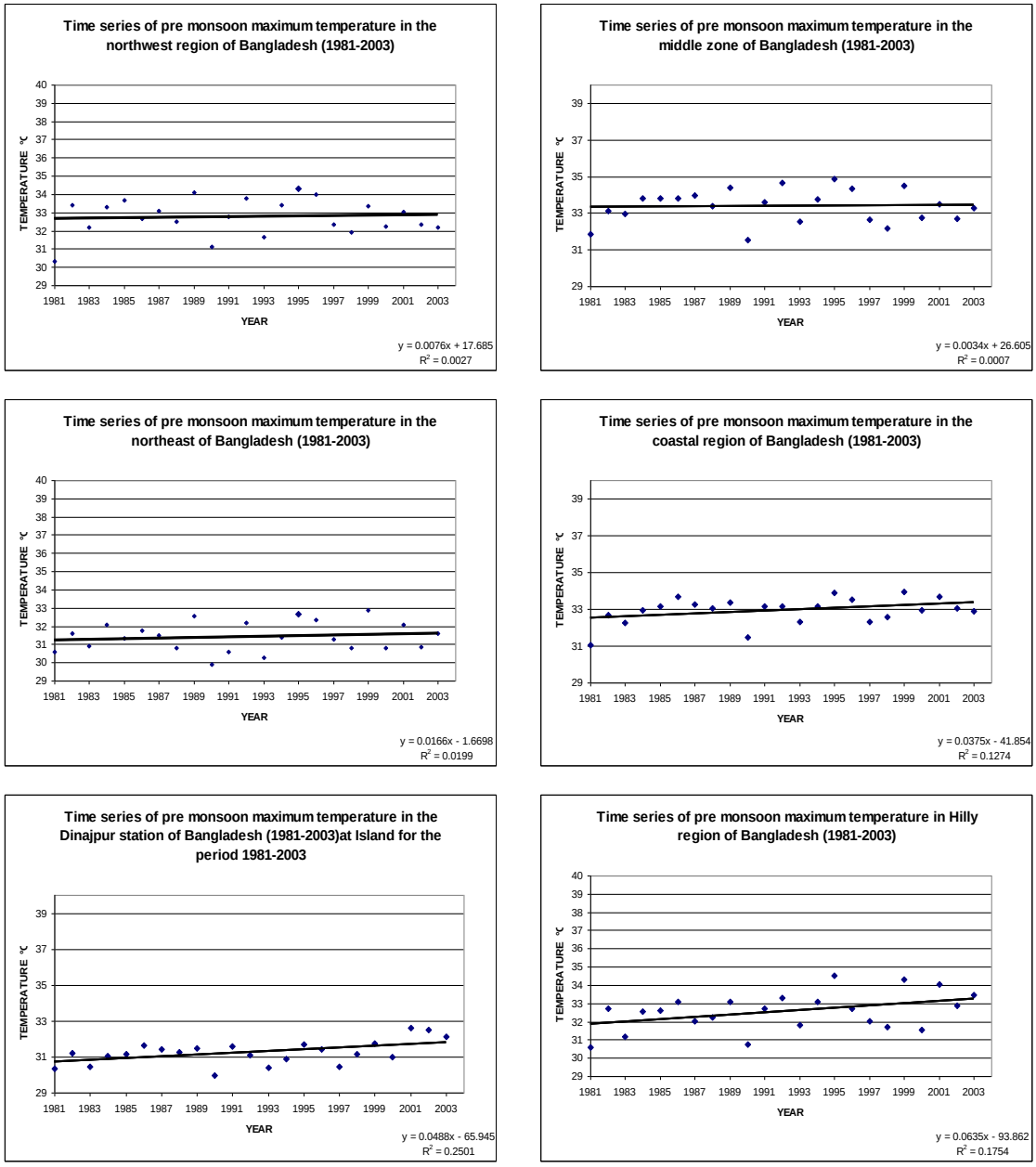


Figure B: Time series of pre monsoon mean maximum temperature.

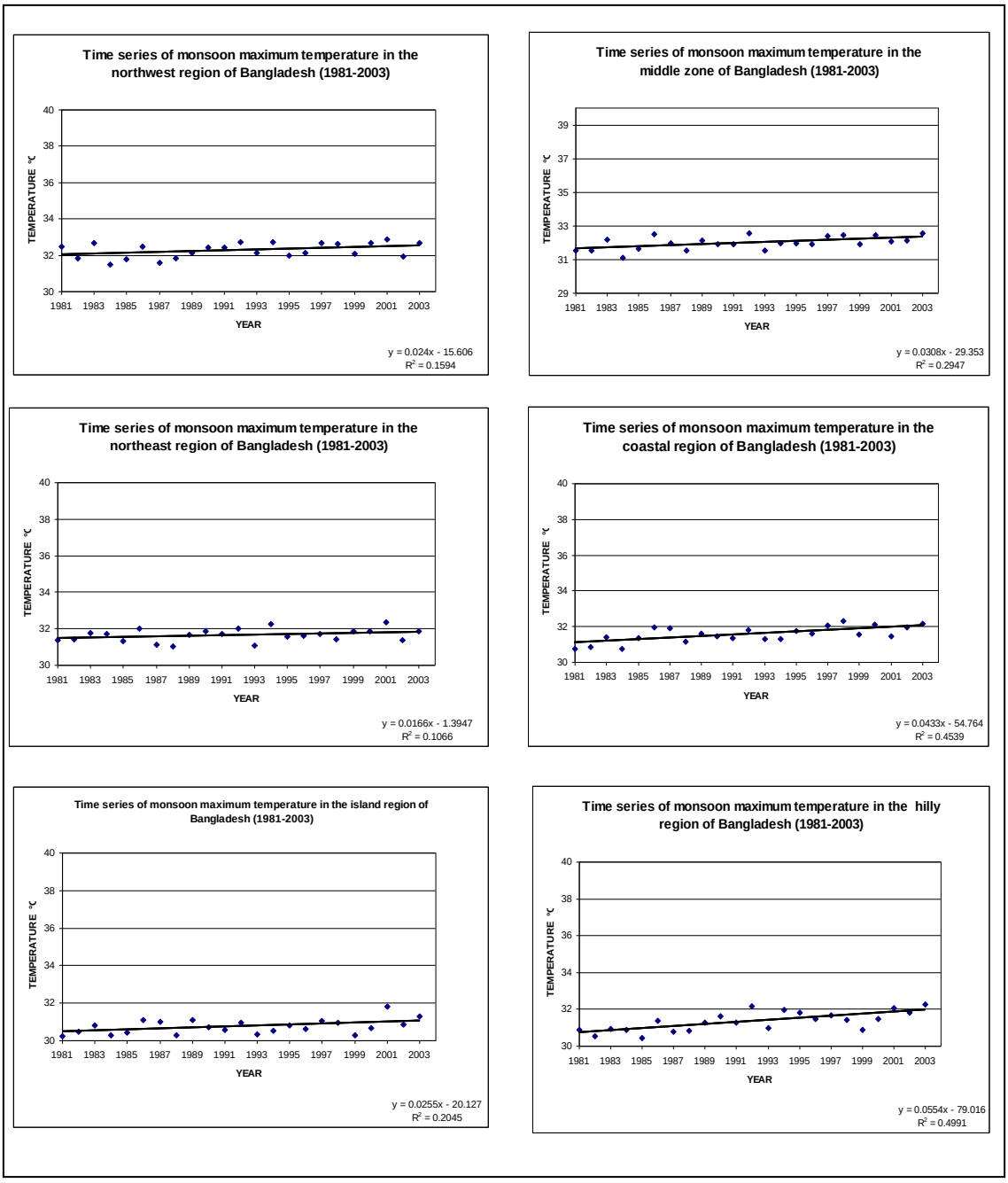
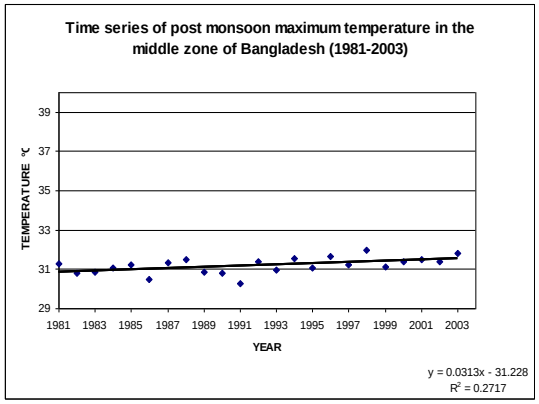
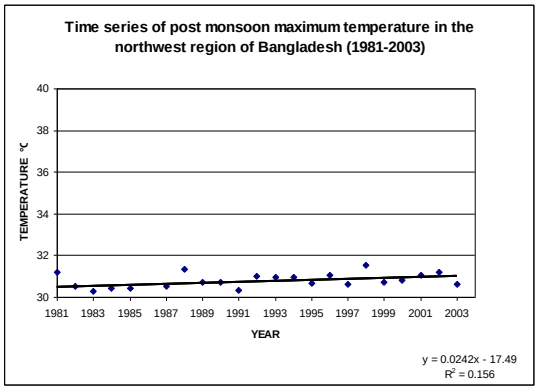
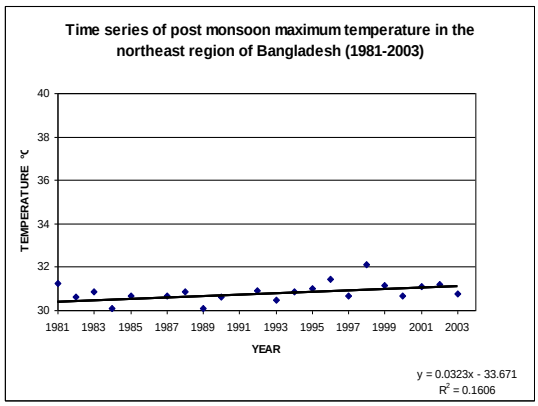
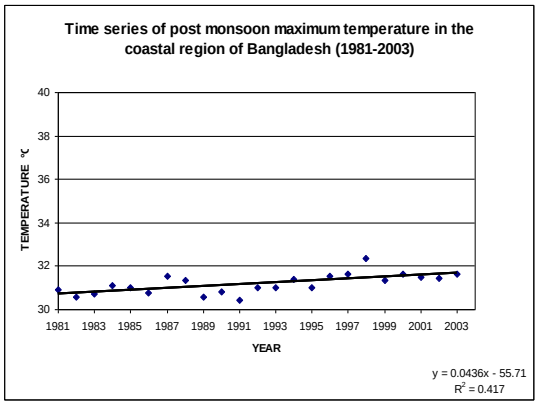


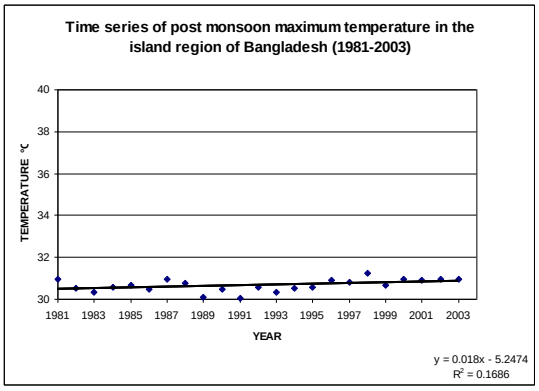
Figure C: Time series of monsoon mean maximum temperature.











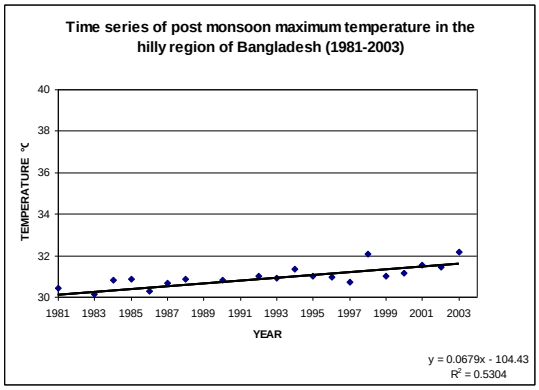


Figure D: Time series of post monsoon mean maximum temperature.