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Rainfall Variability and Its Impact on Crop Agriculture in Southwest Region of Bangladesh

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Abstract

The amounts of annual rainfall in the southwestern part of Bangladesh are almost equal having very little spatial variation. Significant decreasing trend (Mann-Kendal) of annual rainfall over the region is found (-4.5 mm/year at Mongla, -9.14 mm/year at Jessore, -15.71 mm/year at Madaripur) except Khulna, Satkhira and Khepupara, where the trend is positive over the long period (1948-2014) but it exhibits a decreasing trend during the recent period i.e., after 1980s. It clearly indicates a gradual decrease of the amount of rainfall over southwestern part, which has become most prominent in the recent climatic period of 1981-2014. The trend is more intense at the upper southwestern part, i.e., places like Jessore and Madaripur. Annual rainfall deviates within the range -42.6% to +48.6% over the region. Most wide annual deviation is observed in Khulna from 48.6% to -35.5%. Like annual rainfall, seasonal rainfall also has anomalous behaviour over the region. Monsoon rainfall at maximum locations are syncline with annual trend, but at Khulna, Satkhira and Mongla though the annual trend is negative but the monsoon trend is positive, it clearly indicates, intensification of rainfall in monsoon period over the fore southwestern part. In pre-monsoon season, overall rainfall trend is significantly negative at maximum places (-8.49 mm/year at Jessore, -2.02 mm/year at Barisal, -7.80 mm/year at Madaripur) over the region except Khulna, satkhira and Khepupara. But in Khulna and Satkhira it is also significantly negative over recent climatic period.

Rainfall deviation is higher in seasonal scale than the annual scale. Among the seasons wider deviation is observed in winter (from -100.0% to +586%) and narrower in monsoon (from -43.0% to +62.1%). The coastal region of southwest Bangladesh has been facing various natural extremes like salinity intensification, drainage congestion, inundation, water logging etc. Anomalous behavior of rainfall in combination with these problems, affecting agricultural crop production in the upazilas under study. The problem is serious in Rabi season, where groundwater irrigation facility is limited for salinity problem. In these areas agriculture is totally dependent on surface water (irrigation canal), which becomes scarce during the month of January, February, March and rainfall is also becoming low in this time (supports by public opinion and rainfall trend analysis) imposing water shortage in crop field and as a result farmers have to incur yield reduction. In monsoon season problem is different. Drainage congestion is a major problem in this time. A little heavy rainfall causes inundation and water logged condition. Besides this problem, increasing trend of rainfall in monsoon is very likely to intensify the risk of inundation. And the farmers of the study area have already faced total damage of Aus crop due to flooding in some years with comparatively high rainfall or fallow due to water logged condition. Moreover, overall decreasing trend of rainfall is more likely to intensify the risks of salinization due to decreasing upstream flow as well as sedimentation on river bed and consequent poor drainage and water logging. This intensified environmental problem is further likely to intensify the detrimental effects on crop production. So, changing pattern of rainfall in combination with the local environmental stress is being imposed on risk of agricultural crop production over the study area. It is also occasionally responsible for crop failure over the study area. It is also likely to further intensify the risk for future time.

Keywords: Southwestern; Khulna; Sathkhira; Jessore; Khepupara

Introduction

Rainfall is one of the major climatic parameters and is also a major influencing factor for crop production [1]. Crop agriculture practices of a particular region are normally dependent on the precipitation pattern of that area. But now-a-days warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia [2].

IPCC estimated that changes in precipitation in a warming world will not be uniform. In many mid latitude and subtropical dry regions, mean precipitation will likely to decrease, while in many mid-latitude and tropical wet regions, mean precipitation will likely to increase. Besides, extreme precipitation events over wet tropical regions will very likely become more intense and more frequent as global mean surface temperature increases [2].

This change in precipitation, combined with increasing demand for food, would pose large risks to food security globally (high confidence). Moreover, it is projected to reduce renewable surface water and groundwater resources in most subtropical regions (robust evidence, high agreement), intensifying competition for water among ssectors.

Variability of Rainfall

Rainfall variability is the fluctuations of rainfall occurrence annually or seasonally above or below a long term normal value. Every year, in a specific time period the rainfall of a location can be different, either above or below normal, it is the variability [2], but round the year, the mean is not different.

The severity of impact of a climatic change depends on the specific physiographic setting of a particular area, i.e., the way, how the physiography interplay with the change and also the socio-economic and cultural strength of the people living there to act with it. The physiography of the southwest coastal region of Bangladesh is almost different from rest of the landmass of the country. It is a floodplain delta, having numerous beels, peat basins, swamps, rivers and canals. Elevation of the total landmass is very low and it is within 1 m above mean sea level [3].

The area covers 47,201 square kilometer land area, which is 32% of total landmass of the country [4]. Water area covers 370.4 square km (200 nautical miles) from the coastline including estuaries and the internal river water [5]. The landmass is very young and is also growing through erosion and accession activities of major rivers. A part of the coastal area, the Sundarbans, is a mangrove forest covering about 4,500 km^2, and the remaining part of the area is used for agriculture [1].

Bangladesh is considered as a one of the most disaster prone countries in the world [6]. Climate change is a major concern here. Climate change assumed to amplify existing risks and create new risks for natural and human systems.

But risks are unevenly distributed and are generally greater for disadvantaged people and communities in the country. The southwest region of Bangladesh is more vulnerable to climate change than other parts of the country due to high spatial and temporal climatic variability, extreme weather events, environmental stress, high population density, high incidence of poverty and social inequity, inadequate financial resources, and poor infrastructure [7]. So any adverse change is likely to influence tremendously the life and livelihood of people living here.

The impact of climate change on food production is of global concern, and also very important for Bangladesh. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion [8].

Bangladesh needs to increase the rice yield in order to meet the growing demand for food emanating from population growth. Irrigated rice or Boro is a potential area for increasing rice yield, which currently accounts for about 50% of the total rice production in the country [9]. However, change in hydrological cycle is a potential threat towards attaining this objective. It is therefore very important to understand the effect of rainfall variability on crop production NIDOS [10], in southwest coastal area to get a comprehensive knowledge on how rainfall variability is interplaying with coastal crop agriculture and its underlying risks.

Various studies have already been conducted to examine rainfall variability [11-13]. Some have also run GCM model to identify rainfall trend and to make future projections [8,14]. But most of these researches are either conducted over the whole country and generalizes overall feature not focusing on physiographic and environmental issues of coastal region or over a specific season or not considered the impact perceived at local level.

Some studies also conducted over southwest region focusing agriculture, climatic and hydrological problems like drought, salinity intrusion etc., [1,6,15,16] but not considered the rainfall variability interplay with crop agriculture. The present study aimed to analyze rainfall variability trend and its consequent impact on crop agriculture in the environmental condition of the southwest coastal region.

A deeper understanding of the characteristics and distribution pattern of rainfall will support water management, agricultural development and disaster management planning in Bangladesh in the context of global climate change in southwest region of the country (Tables 1-4).

Name of AEZS	Areal Coverage	Organic Matter Content	Fertility Level	Suitable Crops
High Ganges River Floodplain	It covers study area districts of Jessore, Satkhira and Khulna together with minor areas of Narail district	Low	Low	Kharif: B. Aus, T. Aman, T. Aus, Mungbean, Jute, Cotton. Rabi: Wheat, Mustard, Chickpea, Lentil, Boro rice
Lower Ganges River Floodplain	It covers Narail, North eastern part of Khulna, and Bagerhat and northern Barisal	Medium to high	Medium	Kharif: B. Aus, B. Aman, T. Aman, Jute, Kaon, GM. Rabi: Pulses, Wheat, Mustard, Linseed, Boro rice
Ganges Tidal Floodplain	All or most of the Barisal, Jhalakathi, Pirojpur, Patuakhali, Bagerhat, Khulna and Satkhira districts. Ti includes the Khulna and Bagerhat Sundarbans reserve forest	Medium to high	High	Kharif: B. Aus, T. Aman, Green manures. Rabi: Boro rice, Wheat, Mungbean, Grasspea, Cowpea, Chili
Gopalganj Khulna Beels	A number of separate basin areas in Madaripur, Gopalganj, Narail, Jessore, Bagerhat and Khulna districts	Medium to high	Medium	Kharif: T. Aman, T. Aus, Jute, Sesame, B. Aman. Rabi: Boro rice, Bean, Wheat, Grasspea

Table 1: Agro-ecological zones lied in the study area.

Station	Lat./Long.	Area Category	Period of Record	Record Length
Jessore	23.17°N 89.22°E	ICZ	1948-2014	67
Satkhira	22.68°N 89.07°E	ICZ	1948-2014	67
Khulna	22.80°N 89.58°E	ICZ	1948-2014	67
Madaripur	23.16°N 90.18°E	NCZ	1977-2014	38
Mongla	22.46°N 89.6°E	ECZ	1991-2014	24
Barisal	22.70°N 90.36°E	ICZ	1949-2014	66
Patuakhali	22.36°N 90.34°E	ECZ	1973-2014	42
Khepupara	21.98°N 90.22°E	ECZ	1974-2014	41
ICZ: Interior Coastal Zone; ECZ: Exposed Coastal Zone; NCZ: Non Coastal Zone				

Table 2: Location of rainfall records of BMD weather stations under study.

Station	Lat./Long.	Area Category	Period of Record	Record Length
Jessore	23.17°N 89.20°E	ICZ	1998-2014	17
Narail	23.13°N 89.50°E	ICZ	1998-2014	17
Gopalganj	23.20°N 89.80°E	ICZ	1998-2014	17
Madaripur	23.17°N 90.10°E	NCZ	1998-2014	17
Satkhira	22.35°N 89.08°E	ICZ	1998-2014	17
Khulna	22.35°N 89.30°E	ICZ	1998-2014	17
Bagerhat	22.06°N 89.08°E	ICZ	1998-2014	17
Barisal	22.80°N 90.37°E	ICZ	1998-2014	17
Jhalakathi	22.6431°N 90.20°E	ICZ	1998-2014	17
Pirojpur	22.58°N 89.97°E	ICZ	1998-2014	17
Patuakhali	22.354°N 90.3181°E	ECZ	1998-2014	17
Barguna	22.1508°N 90.1264°E	ECZ	1998-2014	17
Koyra	22.20°N 89.40°E	ECZ	1998-2014	17
Karamjol	22.43°N 89.6°E	ECZ	1998-2014	17
Pashurtala	22.244°N 89.443°E	ECZ	1998-2014	17
Arpangachia	22.313°N 89.461°E	ECZ	1998-2014	17
Sibsa Point	21.983°N 89.533°E	ECZ	1998-2014	17
Supati	22.057°N 89.818°E	ECZ	1998-2014	17

Table 3: Selected locations of TRMM rainfall records under study.

Rainfall Variability over Southwestern Part of Bangladesh

The observed annual rainfall over southwestern part of Bangladesh varies from location to location. It is the lowest of 1607.8 mm (at Satkhira) and the highest of 2608.7 mm (at Patuakhali). The standard deviation of annual rainfall over this region varies from 334.0 to 586.3 mm. The mean annual rainfall of each of the location under study and their standard deviations are given in Figure 1. TRMM rainfall at each of district headquarters as well as some selected locations of southwestern part of Bangladesh exhibits almost similar scenario. From TRMM data it is found that the mean annual rainfall varies between from 1680.3 to 2467.3 mm during the study period of 1998-2014.

The highest amount of rainfall is observed at Patuakhali but the lowest is at Jessore. The mean annual rainfall was higher over the eastern part and lower over western part of the region. The standard deviation of rainfall was maximum at Supati but it is lowest at Jessore. Long periodic (1948-2014) annual rainfall of the Jessore, Satkhira, Khulna and Barisal indicates that the rainfall variability is high at these locations as it is found for the recent climate period (1981-2014). Accordingly, the mean rainfall for long period over Jessore, Satkhira, Khulna and Barisal are 2157.2, 1705.3, 1751.9 and 2115.6 mm respectively and their STDs are 457.4, 308.8, 368.1 and 426.0 mm respectively.

The mean and STDs of the rainfall of long and short period of these stations fluctuates slightly that is the indication of the similar annual rainfall variability over this region (Figure 2).
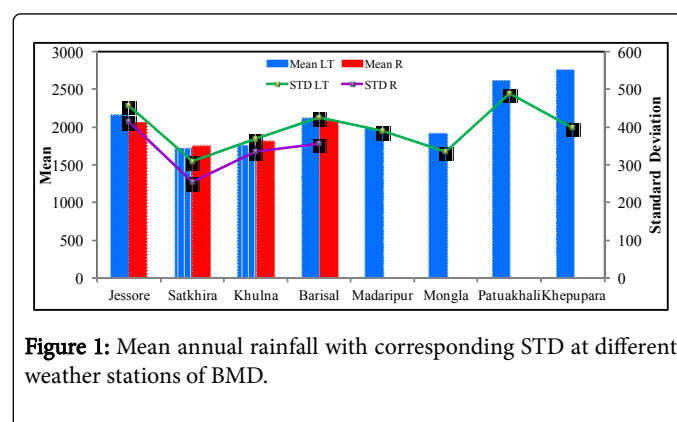

Figure 1: Mean annual rainfall with corresponding STD at different weather stations of BMD.

Description	Total cultivable area (ha)	Saline Area	Area of each salinity class (dS/m)				
			S1 (2.0-4.0)	S2 (4.1-8.0)	S3 (8.1-12.0)	S4 (12.1-16.0)	S5 (>16.0)
Non-saline with very slightly saline	4,25,490	1,15,370 (27%)	82,260 (72%)	31,590 (27%)	1,520 (1%)	0	0
Very slightly saline with slightly saline	4,20,420	3,09,190 (73%)	1,70,380 (55%)	1,10,390 (35%)	29,420 (10%)	0	0
Slightly saline with moderately saline	2,57,270	2,40,220 (93%)	35,490 (15%)	1,13,890 (47%)	61,240 (26%)	25,870 (11%)	2,650 (1%)
Moderately saline with strongly saline	1,98,890	1,98,890 (100%)	1,630 (1%)	36,060 (18%)	73,400 (37%)	55,130 (28%)	32,750 (16%)

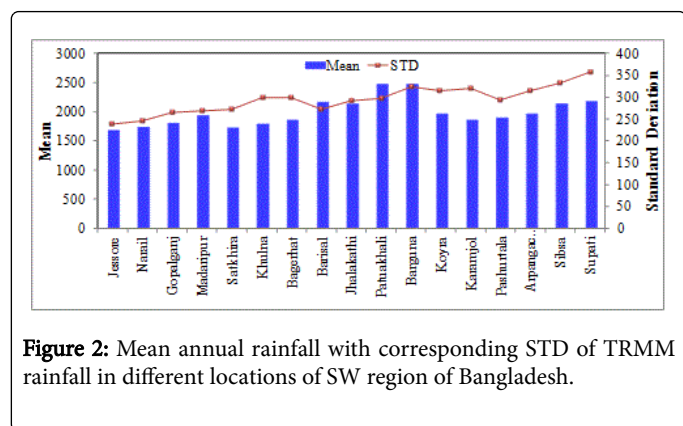**Table 4:** Salinity affected areas in the coastal regions of Bangladesh.

Figure 2: Mean annual rainfall with corresponding STD of TRMM rainfall in different locations of SW region of Bangladesh.

Analysis also reveals that the higher amounts of rainfall are recorded in the monsoon months with the maximum in July followed by June or August (Figure 3). Accordingly, about 69.1, 71.3, 70.9, 69.8, 67.8, 71.9, 74.0 and 72.9% rainfall are recorded in monsoon, about 23.0, 15.3, 17.1, 16.9, 21.3, 15.0, 15.4 and 14.5% in pre-monsoon, about 9.6, 9.7, 9.5, 10.6, 9.6, 11.1, 9.6 and 11.5% in post-monsoon and about 1.7, 3.8, 2.2, 1.7, 1.8, 2.0, 1.3 and 1.3% in Patuakhali and Khepupara. The mean monthly, seasonal and annual rainfall and their STDs of the stations are under study is given in Figures 1, 3 and 4 and in Tables 5 and 6. Winter season respectively in Jessore, Satkhira, Khulna, Barisal, Madaripur, Mongla, Mean seasonal rainfall is highest in Monsoon and lowest in winter. Long term mean monsoon rainfall varies between 1228.6 mm to 2001.4 mm (Figure 4). Highest value was observed in Khepupara and lowest at Satkhira. It deviates within the range 135.0 mm to 388.3 mm (Table 1). Mean Pre-monsoon rainfall was found within 271.0 mm (Satkhira) to 519.5 mm (Jessore) range. Mean Post-monsoon rainfall was within 165.8 mm (Khulna) to 314.9 mm (Khepupara). Mean winter rainfall was observed within a very short range of 34.0 mm (Madaripur) to 50.4 mm (Khulna). In most of the cases STD value becomes lower in recent climatic period reveals decline of in fluctuation in rainfall amount (Figure 4).
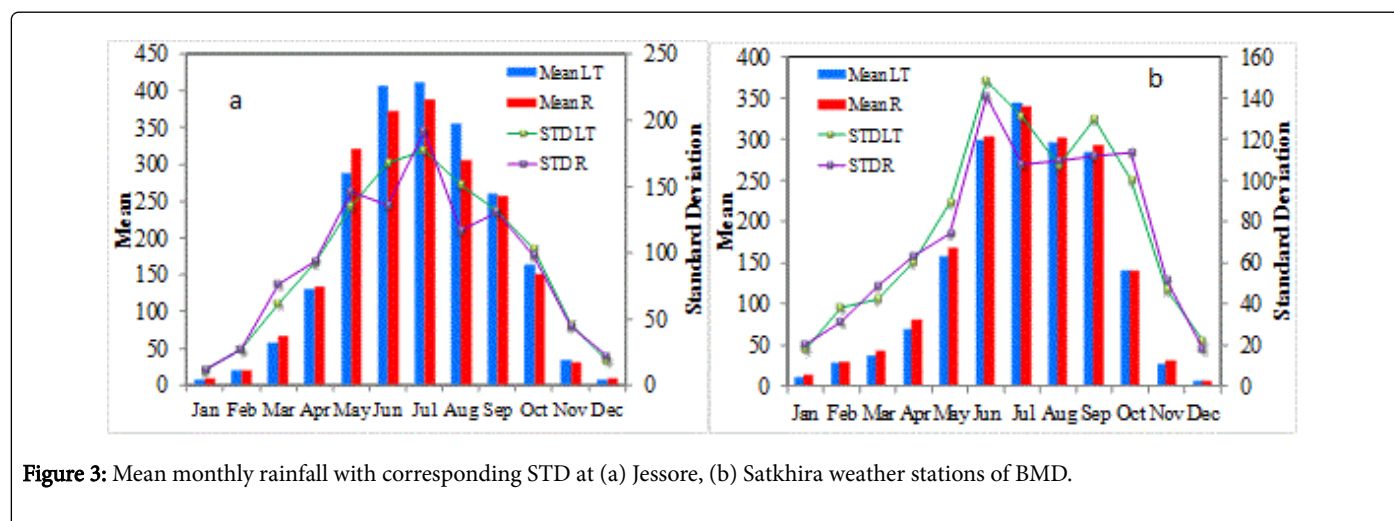

Figure 3: Mean monthly rainfall with corresponding STD at (a) Jessore, (b) Satkhira weather stations of BMD.
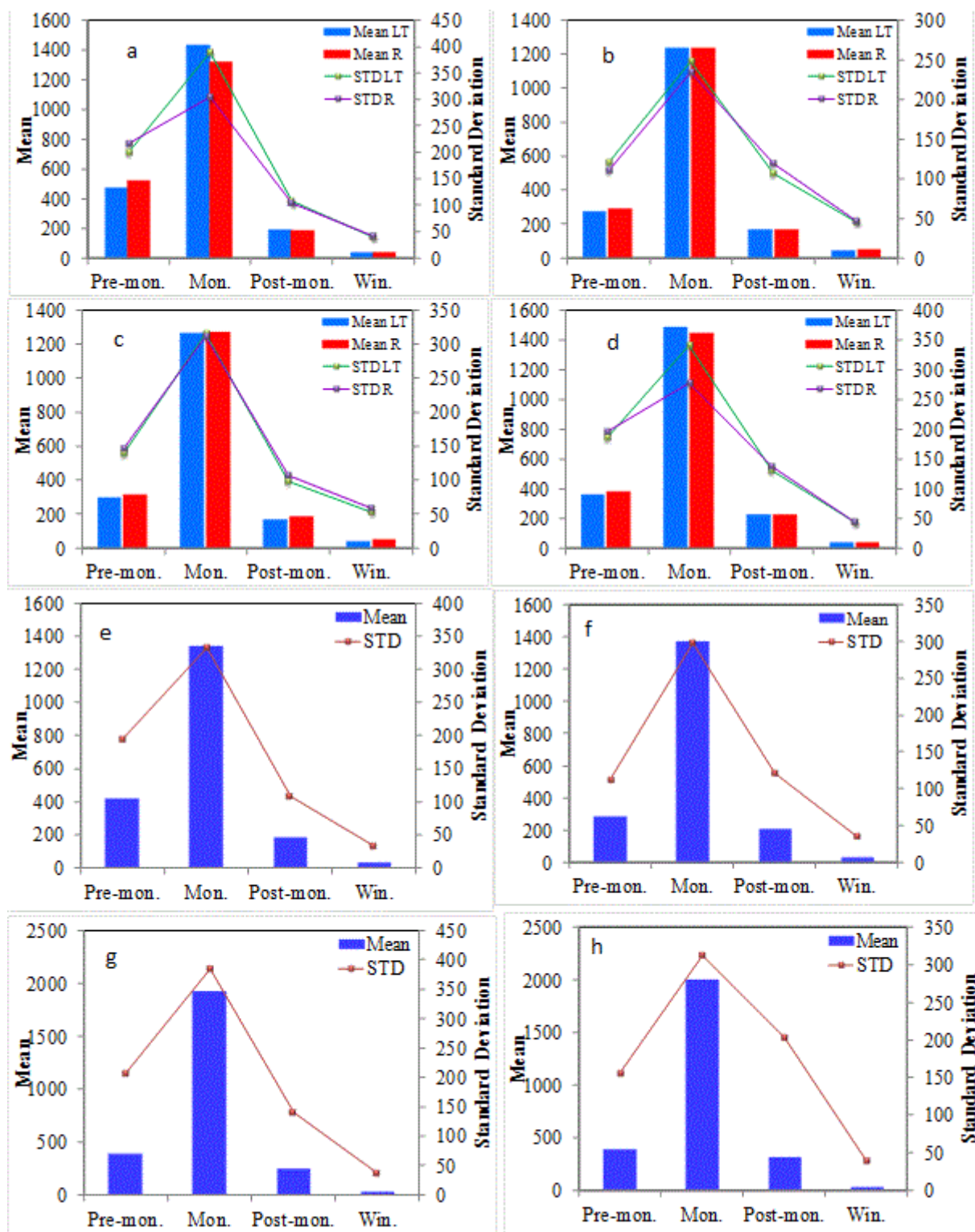
Figure 4: Mean seasonal rainfall with corresponding STD at (a) Jessore, (b) Satkhira, (c) Khulna, (d) Barisal, (e) Madaripur, (f) Mongla, (g) Patuakhali and (h) Khepupara weather stations of BMD.

Time Period		Jessore	Satkhira	Khulna	Barisal	Madaripur (1977-2014)	Mongla (1991-2014)	Patuakhali (1973-2014)	Khepupara (1974-2014)
Jan	1948-14	7.7	10.6	11	9.5	8	12.8	7.7	8.2
	1981-14	8.4	14	14.9	10.8				
Feb	1948-14	20	27.6	23.5	19.3	23.1	22.8	21.2	20.4
	1981-14	19.6	29	30.2	20.9				
Mar	1948-14	57.2	36.2	42.9	49.9	49.7	41.5	37.5	43.1
	1981-14	66.6	42.4	49	55.1				
Apr	1948-14	130.4	68.2	74.8	94.2	120.9	54.7	100.9	88.3
	1981-14	133.5	79.6	75.4	103.2				
May	1948-14	286.3	156.2	181.4	213.5	148.2	190.9	262.2	265.8
	1981-14	319.3	167.3	188.1	217				
Jun	1948-14	404.4	297.3	335.5	409.5	374.2	340.7	535.3	509.9
	1981-14	371.3	302.1	330.5	397.9				
Jul	1948-14	409	342.6	351	412.8	381.7	373.8	560.3	637.3
	1981-14	386.4	337.4	336.8	408				
Aug	1948-14	353	293.6	291.3	353.5	319.6	331.7	450.8	467.2
	1981-14	303.3	299.9	315.1	350.3				
Sep	1948-14	258.4	282	264.4	300.6	259.7	326	382.2	385.8
	1981-14	255.9	291	287.5	281.5				
Oct	1948-14	162.6	139.7	138.4	187.4	158.7	175.1	200.2	263.6
	1981-14	150.6	139	147.2	186				
Nov	1948-14	34.1	26.4	27.2	37.5	30.3	36	51.4	51.3
	1981-14	31.1	30.5	35	43.5				
Dec	1948-14	6.9	6.6	3.7	8	4.1	2.7	5	6.6
	1981-14	8.8	6.6	5.8	6.4				
Pre.	1948-14	474.1	271	297.8	359.6	418.7	287.1	394	397.2
	1981-14	519.5	289.2	312.4	375.3				
Mon.	1948-14	1428.5	1228.6	1262.5	1479.2	1339.3	1372.2	1922.8	2001.4
	1981-14	1311.2	1230.3	1268	1437.7				
Post.	1948-14	192.6	166.4	165.8	224.8	189	211.2	251.5	314.9
	1981-14	181.7	169.6	182.2	221.4				
Win.	1948-14	35.4	42.6	38.3	37.9	34	37.3	34.4	36.2
	1981-14	36.9	49	50.4	37.2				
Ann.	1948-14	2157.2	1705.3	1751.9	2115.6	1969.8	1908.6	2607.8	2745.2
	1981-14	2053.2	1738.7	1805.4	2072.5				

Table 5: Mean monthly, seasonal and annual rainfall at different BMD weather station.

Time Period		Jessore	Satkhira	Khulna	Barisal	Madaripur (1977-2014)	Mongla (1991-2014)	Patuakhali (1973-2014)	Khepupara (1974-2014)
Jan	1948-14	11.5	17.5	20.9	21.4	14.9	16.5	13.6	17.1
	1981-14	11.3	20.2	22.6	22.4				
Feb	1948-14	26.6	37.8	40.4	25	24	27.8	30.4	31
	1981-14	26.6	31.3	42	26.4				
Mar	1948-14	61.7	41.8	62	66.5	57.7	60.9	57	71.2
	1981-14	76.2	48.5	70.1	73.3				
Apr	1948-14	92.8	60.3	70.9	79	95.3	44.3	91.6	71.1
	1981-14	93.1	63.1	66.1	83.3				
May	1948-14	134.5	88.9	87.9	124.6	141.1	84.2	175.3	142.7
	1981-14	145.9	74.1	83.8	125.2				
Jun	1948-14	167.5	148.4	149.4	180	170.9	159.3	266.6	201.4
	1981-14	135.6	140.6	165.5	188.7				
Jul	1948-14	177.2	130.6	138	136	127.8	99.7	155.9	189.8
	1981-14	192.1	107.4	108.6	122.8				
Aug	1948-14	151.2	107	130	143.1	132	111.3	171.1	182.9
	1981-14	117.1	109	124.7	133.6				
Sep	1948-14	131.1	129.6	157.4	167.9	149.9	134	179.4	161.7
	1981-14	130.6	111.4	161.8	169.2				
Oct	1948-14	130	99.8	92	117.7	103.8	105.2	129.5	175.2
	1981-14	98	113.3	104.1	127.4				
Nov	1948-14	46.4	46.6	47.8	58.4	42.2	63.8	71.4	96.3
	1981-14	44.4	51.5	54.7	69.5				
Dec	1948-14	18.5	21.6	10.8	26	9	6.6	12.2	13.3
	1981-14	21.9	18.1	14	12.4				
Pre	1948-14	199.9	120.8	138.6	185.3	194.4	111.2	205.9	155.5
	1981-14	216.4	110.1	146.7	196.3				
Mon	1948-14	388.3	248.4	135	340	333.6	298.2	385	312.9
	1981-14	304	233.7	311	276.8				
Post	1948-14	107.5	106.8	97.8	129.7	108.4	120.8	140.5	203.3
	1981-14	104.3	119.5	106.7	137.6				
Win	1948-14	39.1	45.3	52.4	43.5	32	35	35.9	38.3
	1981-14	41.6	47	58.3	43				
Ann	1948-14	457.4	308.8	368.1	426	388.9	334	488.2	397.9
	1981-14	416.1	254.6	334.4	355.9				

Table 6: Standard deviation of monthly, seasonal and annual rainfall at different BMD weather stations.

Rainfall Occurrence Trend over Southwest in Bangladesh

Annual rainfall trend over the southwestern part of Bangladesh and their magnitudes are calculated using Mann-Kendal Tests, Sen's slope estimator and simple linear regression analysis (Least squares).

The annual trend from these three different tests indicates similar results. Predominantly negative trends of annual rainfall are found over the region except Khulna, Satkhira and Khepupara where, trends are going positive with a magnitude of 5.36 mm/year (at 95% confidence level, 1948-2014), 1.15 mm/year (1948-2014) and 12.67 mm/year (at 90% confidence level, 1974-2014) respectively (Figures 5i and 5ii).

The highest significant negative trend is observed at Madaripure (at 99% confidence level) with a magnitude of 15.71 mm/year over the period 1977-2014. In case of Mongla Mann-Kendal test indicates no significant trend in annual rainfall but a negative Sen's slope (4.74 mm/year) (Table 6).

Although in Khulna and Satkhira trends are positive over long period (1948-2014), but it turned to negative over recent climatic period (1981-2014) with a magnitude of 1.43 mm/year to 4.08 mm/year respectively (Figure 6).
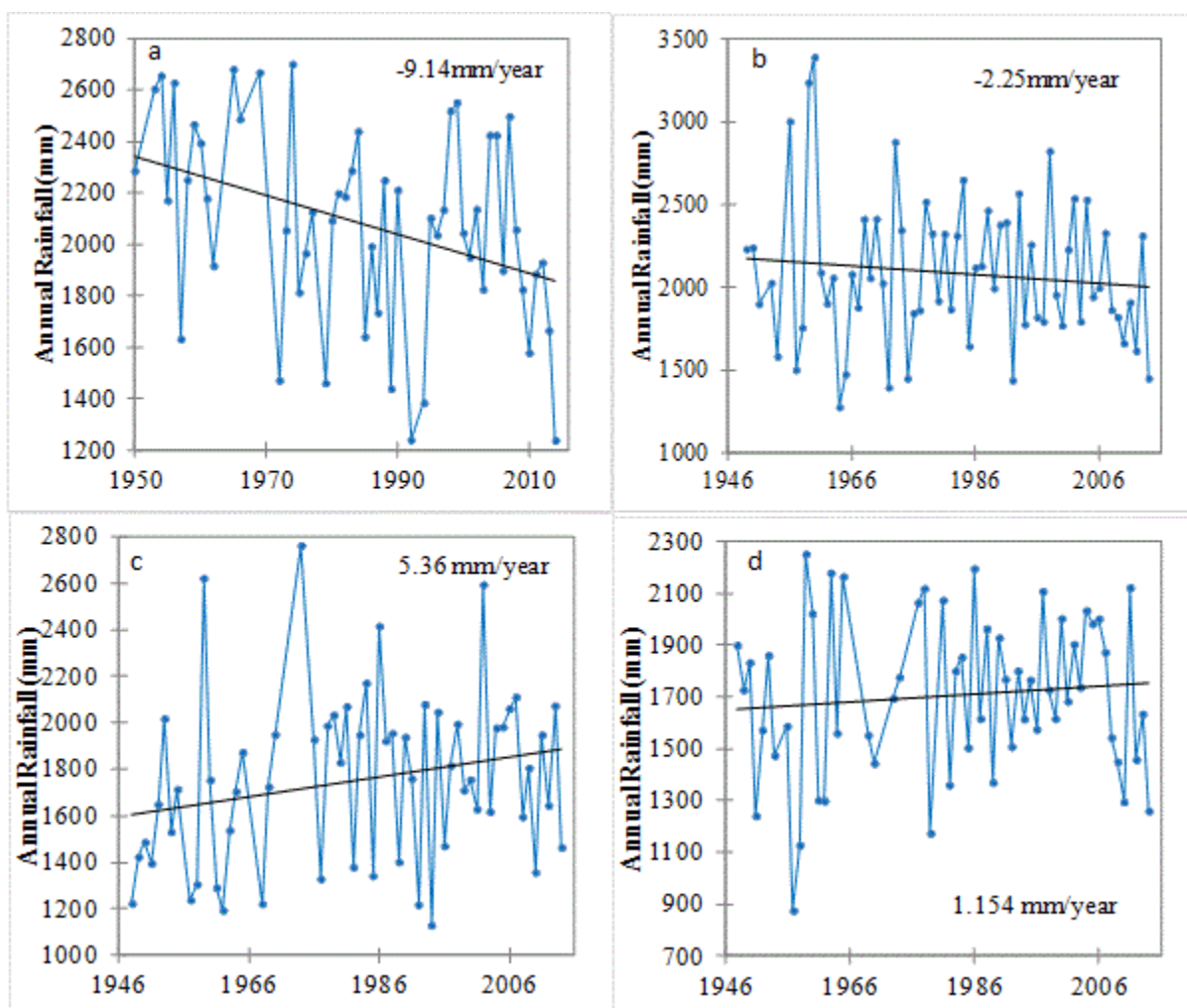

Figure 5i: Annual Rainfall Trend (Mann-Kendal & Sen's Slope) at (a) Jessore, (b) Barisal, (c) Khulna and (d) Satkhira weather stations of BMD.
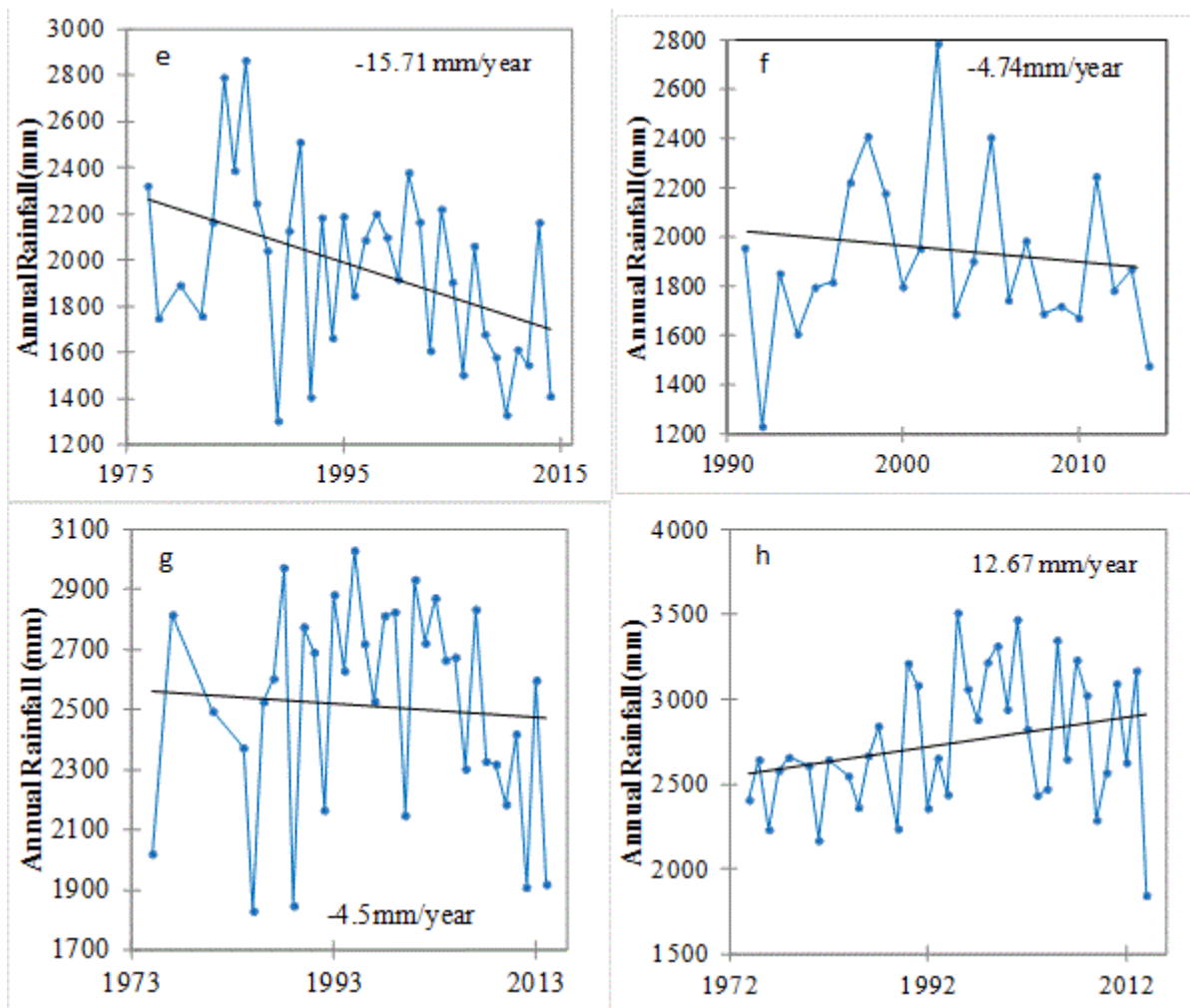
Figure 5ii: Annual Rainfall Trend (Mann-Kendal & Sen's Slope) at (e) Madaripur, (f) Mongla, (g) Patuakhali and (h) Khepupara weather stations of BMD.

Mann-Kendal and Sen's slope tests are also applied over the annual rainfall time series of TRMM records of different study points. Significant negative trends are observed at Gopalganj, Madaripur, Barisal, Jhalakathi, Patuakhali, Barguna and Sibsa point. While other places negative slopping with no significance.

For the month of January, February, March, November and December no significant trend (Mann-Kendal) is observed for maximum cases. While for rest of the months significant trend is found for maximum cases. In these months at Khulna, Satkhira and Khepupara trends are observed positive (i.e., increase) for maximum cases but in other stations significant negative trends are found for maximum cases.

Trends in seasonal rainfall also varied over the study area. In Pre-monsoon season highest negative trend is observed at Madaripure

(6.91 mm/year, at 99% confidence level), and positive at Satkhira (1.46 mm/year, at 99% confidence level). But in Monsoon highest negative trend is observed at Jessore (10.49 mm/year, at 99% confidence level) and positive at Khepupara (4.85 mm/year, at 99% confidence level). In Post-monsoon trends turned positive for maximum cases, but only significantly negative at Jessore. And in winter significant negative trends are present at Madaripur, Mongla and Patuakhali but positive over Khulna and Satkhira (Table 7).

Station wise linear regression analysis of monthly, seasonal and annual rainfall is under study and negative trends are observed for maximum cases. In Khulna annual trend is positive over long term period but becomes negative over the recent climatic period. Monthly and seasonal trends are anomalous but predominantly negative for maximum cases (Table 8).
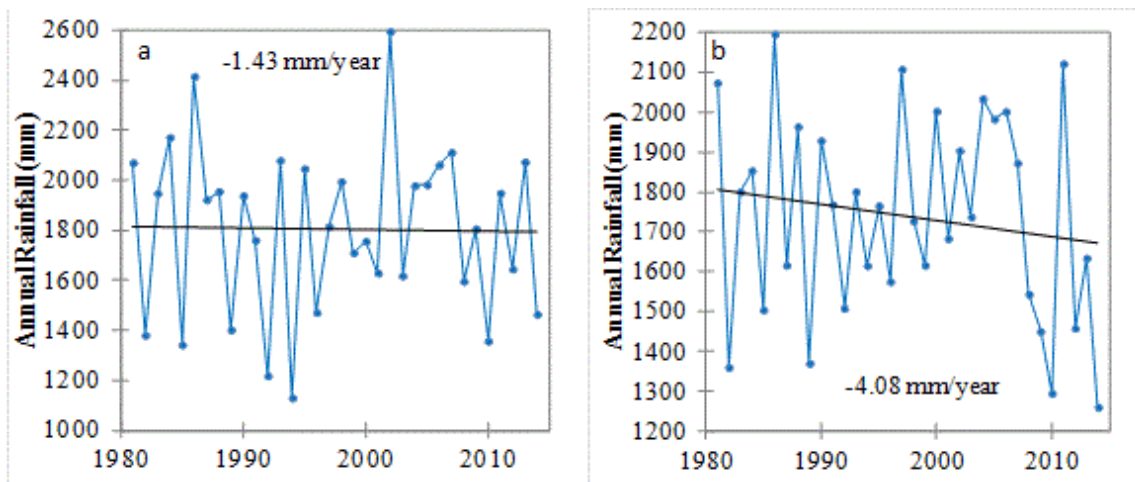
Figure 6: Annual rainfall trend over recent climatic period (1981-2014) at (a) Khulna and (b) Satkhira.

Time Period	Jessore	Satkhira	Khulna	Barisal	Madaripur	Mongla	Patuakhali	Khepupara
Jan	-	-	-	-	-	-0.24***	-	-
Feb	-	-	0.05**	-	-0.55***	-1.18***	-	-
Mar	-0.178	0.06	-	0.02	-0.52**	-1.06***	-	-
Apr	-0.86***	0.15	-0.39**	0.06	-3.73***	-1.33***	-2.42***	-1.06**
May	0.63**	1.25***	0.68***	-0.06	-3.29***	2.26**	-1.48	0.673
Jun	-3.02***	0.02	-1***	-1.01***	-2.64**	-4.38***	-4.89***	-0.495
Jul	-3.91***	0.14	0.273	-0.22	-3.16***	2.81**	-0.18	0.919
Aug	-2.95***	-0.17	1.8***	-0.26	-2.52***	-0.65	-1.6*	-0.722
Sep	-1.11**	1.14***	2.33***	-0.5*	-0.02	2.44	-0.31	3.72***
Oct	-0.86**	-0.25	0.71***	-0.84**	1.53***	1.51*	4.5***	4.86***
Nov	-	-	-	-	-	-0.09*	-1.13***	-
Dec	-	-	-	-	-	-	-	-
Pre	-0.34	1.46***	0.143	0.293	-6.91***	-3.53	-4.66***	-0.58
Mon	-8.49***	0.77	3.69***	-2.02***	-7.80**	0.06	-3.6	4.85***
Post	-0.99**	-	1.15***	-0.469	1.95***	0.2	2.08***	4.44***
Win	0.05	0.39***	0.33***	-	-0.81***	-1.27***	-0.37**	0.11
Ann.	-9.14***	1.15	5.36**	-3.67	-15.71***	-4.734	-4.5*	12.67*

***Significant at 99% confidence level; **Significant at 95% confidence level; *Significant at 90% confidence level.

Table 7: Mann-Kendal trend test results over the study area.

Time Period		Jessore	Satkhira	Khulna	Barisal	Madaripur (1977-2014)	Mongla (1991-2014)	Patuakhali (1973-2014)	Khepupara (1974-2014)
Jan	1948-14	0.01	0.13	0.14	-0.01	-0.19	-0.32	-0.08	0.16
	1981-14	-0.05	-0.18	-0.23	-0.12				
Feb	1948-14	-0.26	0.11	0.28	0.01	-0.69	-1.56	-0.02	-0.01
	1981-14	-0.27	-0.569	-0.803	-0.61				
Mar	1948-14	0.14	0.27	0.13	-0.02	-1.21	-2.82	0.01	-0.55
	1981-14	-1.40	-0.31	-1.21	-0.95				
Apr	1948-14	-1.39	0.11	-0.75	0.04	-4.32	-1.59	-3.02	-1.40
	1981-14	-4.36	-2.51	-3.89	-3.64				
May	1948-14	0.60	0.68	0.73	0.06	-1.50	2.05	-2.92	2.34
	1981-14	-2.49	1.45	-0.06	-0.32				
Jun	1948-14	-4.02	-0.43	-0.45	-1.69	-3.76	-3.89	-4.96	-0.30
	1981-14	1.84	-2.48	-2.73	-3.22				
Jul	1948-14	-3.84	0.15	-0.16	-0.71	-2.91	3.02	-0.62	1.29
	1981-14	-1.74	0.02	2.06	-0.86				
Aug	1948-14	-3.15	0.19	2.03	-0.77	-3.39	1.05	-2.42	-0.35
	1981-14	-1.28	-0.8	0.39	-3.54				
Sep	1948-14	-1.04	0.81	2.24	-0.31	0.77	2.67	-1.26	3.26
	1981-14	0.41	0.57	3.94	2.77				
Oct	1948-14	-1.26	0.20	0.78	-0.54	1.57	1.75	4.23	4.17
	1981-14	1.03	1.55	1.54	1.18				
Nov	1948-14	-0.44	0.04	0.22	0.22	-0.11	-1.35	-2.39	-0.50
	1981-14	-0.49	-0.37	-0.57	-1.22				
Dec	1948-14	0.04	-0.03	0.05	-0.04	-0.16	0.07	-0.38	-0.08
	1981-14	-0.40	-0.47	-0.43	-0.26				
Pre	1948-14	-0.79	1.21	0.25	0.83	-7.03	-2.36	-6.76	0.38
	1981-14	-8.24	-1.36	-5.17	-4.71				
Mon	1948-14	-12.05	1.32	4.10	-3.83	-10.41	2.847	-3.24	4.32
	1981-14	-0.77	-2.69	5.02	-5.76				
Post	1948-14	-1.70	0.29	1.02	-0.43	1.49	0.40	1.84	3.67
	1981-14	0.54	1.18	0.97	-0.09				
Win	1948-14	0.05	0.53	0.65	-0.25	-0.90	-1.75	-0.42	0.05
	1981-14	-0.73	-1.14	-1.46	-0.92				
Ann	1948-14	-7.31	-0.06	6.41	-2.70	-12.94	-0.92	-3.00	8.86
	1981-14	-9.18	0.03	-0.64	-10.48				

Table 8: Linear regression trend values of monthly, seasonal, and annual rainfall.
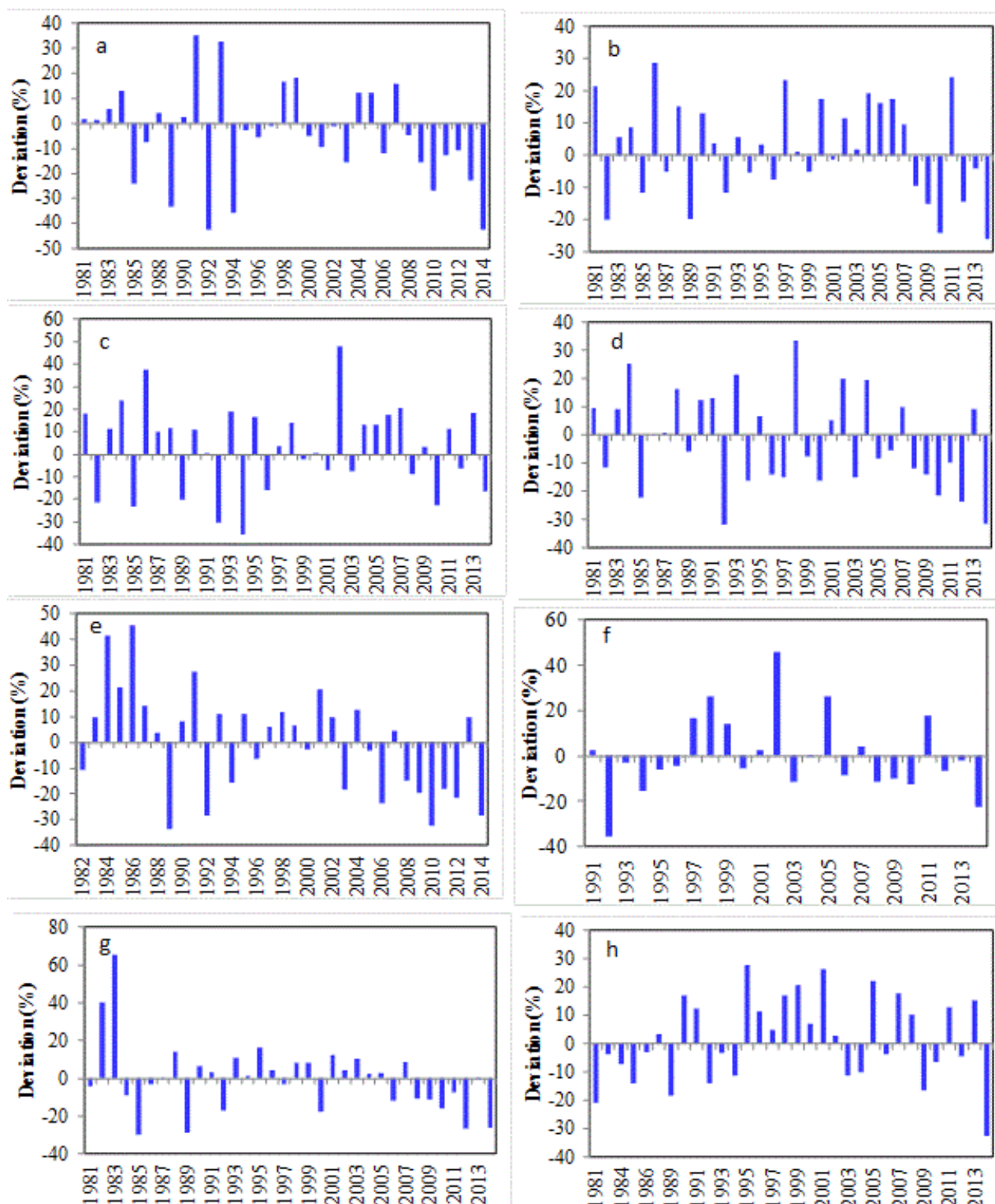
Figure 7: Annual rainfall deviation (%) in recent period at (a) Jessore, (b) Satkhira, (c) Khulna, (d) Barisal, (e) Madaripur, (f) Mongla (1991-2014), (g) Patuakhali and (h) Khepupara weather stations of BMD.

Deviation of Rainfall in Recent Period

Rainfall in the southwestern part of Bangladesh is very much variable in nature. In recent time annual rainfall varies within a range of 48.1% to -42.6%. Most wide annual deviation is observed in Khulna from 48.6% to -35.5%, and most narrow deviation is found in Satkhira, from 28.7% to -26.1% (Figures 6 and 7).

Rainfall deviation is wider in seasonal scale than annual scale. It is observed lowest in monsoon and highest in winter, i.e., rainfall is most consistent in monsoon and most variable in winter. In monsoon positive deviation is found as high as 72.0% in Madaripur and negative deviation as low as -43.0% in Khulna.

In pre-monsoon it is found within 216.5% (Patuakhali) to -71.6% (Barisal), and in post-monsoon within 181.9% (Satkhira) to -100.0% (Jessore & Mongla), and in winter within 586.0% (Khulna) to -100.0% (all station) (Table 9).

Station	Deviation Category	Pre-monsoon	Monsoon	Post-monsoon	Winter	Annual
Jessore	Highest (%)	114	40.3	88	399.6	35.1
	Lowest (%)	-66.2	-42.9	-100	-100	-42.6
Satkhira	Highest (%)	117.3	40.7	181.9	278.1	28.7
	Lowest (%)	-51.7	-33.5	-95.2	-100	-26.1
Khulna	Highest (%)	173.7	61.4	152.7	586	48.1
	Lowest (%)	-61	-43	-94.6	-100	-35.5
Barisal	Highest (%)	142.5	43.3	145.1	465.1	33.4
	Lowest (%)	-71.6	-30.7	-95.1	-100	-32
Madaripur	Highest (%)	94.4	72	121.2	285.6	45.4
	Lowest (%)	-54.9	-40	-91	-100	-33.8
Mongla	Highest (%)	67.2	62.1	97.9	216.3	46
	Lowest (%)	-57.5	-31.7	-100	-100	-35.5
Patuakhali	Highest (%)	216.5	71.9	119.5	251.8	39.4
	Lowest (%)	-68.3	-32.3	-92.8	-100	-29.8
Khepupara	Highest (%)	100.4	28.7	160.4	388.9	27.9
	Lowest (%)	-57.7	-28.8	-93.3	-100	-32.8

Table 9: Seasonal and annual extreme rainfall deviation (%) in recent time.

Trend of 99th Percentile of Seasonal and Annual Rainfall

Trend of 99th percentile of seasonal and annual rainfall in southwestern part of the country is under study. The annual 99th percentile is on a negative trend over Jessore, Barisal, Madaripur and Patuakhali, but positive over Satkhira, Khulna, Mongla and Khepupara.

Highest significant positive trend is observed at Mongla (0.79) at 90% confidence level, while highest negative magnitude is observed at Madaripur (-0.32) (Figures 8i and 8ii).

In pre-monsoon season the trend is negative at maximum stations except Barisal. In case of Khulna and Satkhira it is positive over long period but becomes negative over recent period. In this season highest significant negative magnitude (-0.61) is observed at Madaripur at 95% confidence level. In monsoon trend direction is almost synclined with the annual except Satkhira, where annual trend is positive but becomes negative in monsoon.

In this season highest negative magnitude is observed at Patuakhali (-0.68) and positive at Mongla (0.40) (Table 10).
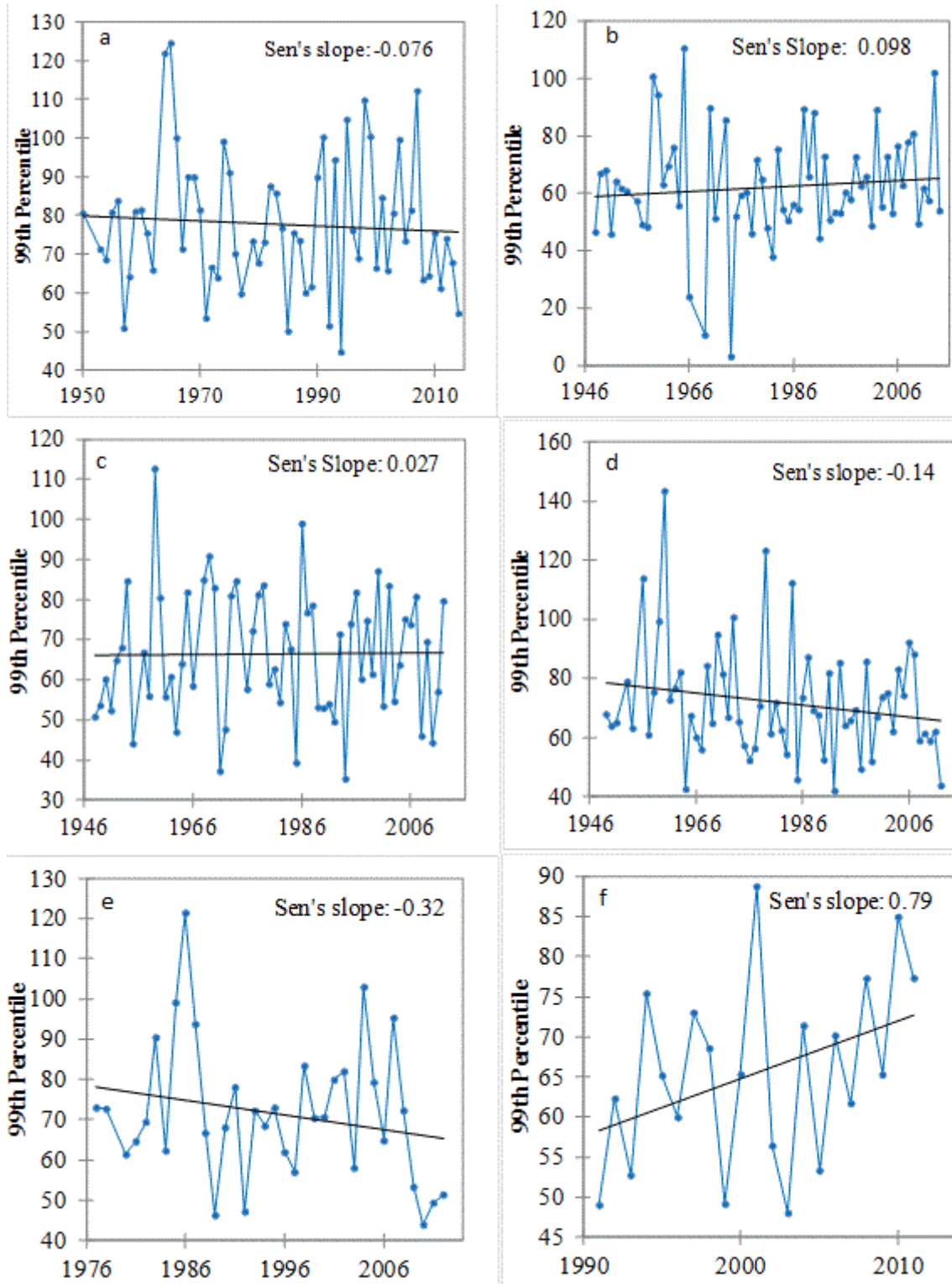
Figure 8i: Trend of 99th Percentile of annual rainfall at (a) Jessore, (b) Satkhira, (c) Khulna, (d) Barisal, (e) Madaripur and (f) Mongla weather stations of BMD.
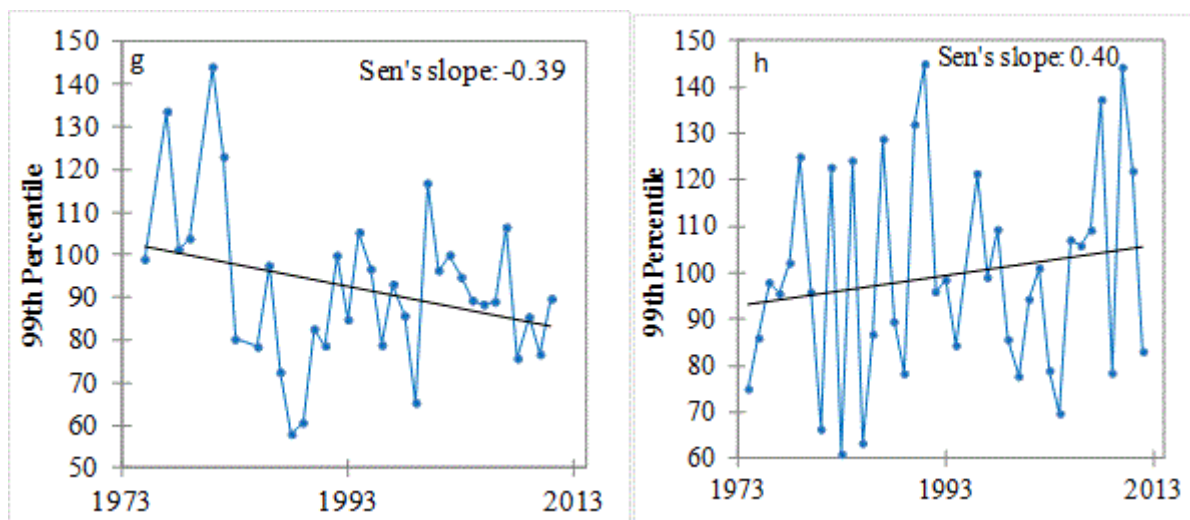
Figure 8ii: Trend of 99th Percentile of annual rainfall at (g) Patuakhali and (h) Khepupara weather stations of BMD.

Station	Time Range	Pre-monsoon	Monsoon	Annual
Jessore	1948-2014	-0.18	-0.61	-0.08
	1981-2014	-0.71	-0.07	-0.22
Satkhira	1948-2014	0.11	-0.67	0.10
	1981-2014	-0.10	-0.19	0.41[*]
Khulna	1948-2014	0.04	0.01	0.03
	1981-2014	-0.55	0.37	0.41
Barisal	1948-2014	0.05	-0.19	-0.14
	1981-2014	0.07	-0.49	-0.14
Madaripur	1977-2014	-0.61[**]	-0.32	-0.32
Mongla	1991-2014	-0.23	0.40	0.79[*]
Patuakhali	1973-2014	-0.39	-0.68	-0.39
Khepupara	1974-2014	-0.20	0.08	0.40

[**]Significant at 95% confidence level; [*]Significant at 90% confidence level.

Table 10: Mann-Kendal and Sen's slope test result of 99th percentile of seasonal and annual rainfall at different BMD stations.

Trend of Seasonal and Annual Heavy Rainfall Days

Trend is also studied on seasonal and annual heavy rain days over the study area. Only significant negative trends are observed in Jessore (at 99% confidence level) and Madaripur (90% confidence level) over pre-monsoon, monsoon and annual time period (Tables 10 and 11). In other stations in pre-monsoon and monsoon season no trends are observed. On annual scale slight positive trend is observed in Khulna and slight negative in Barisal and Patuakhali (Figures 9i and 9ii).
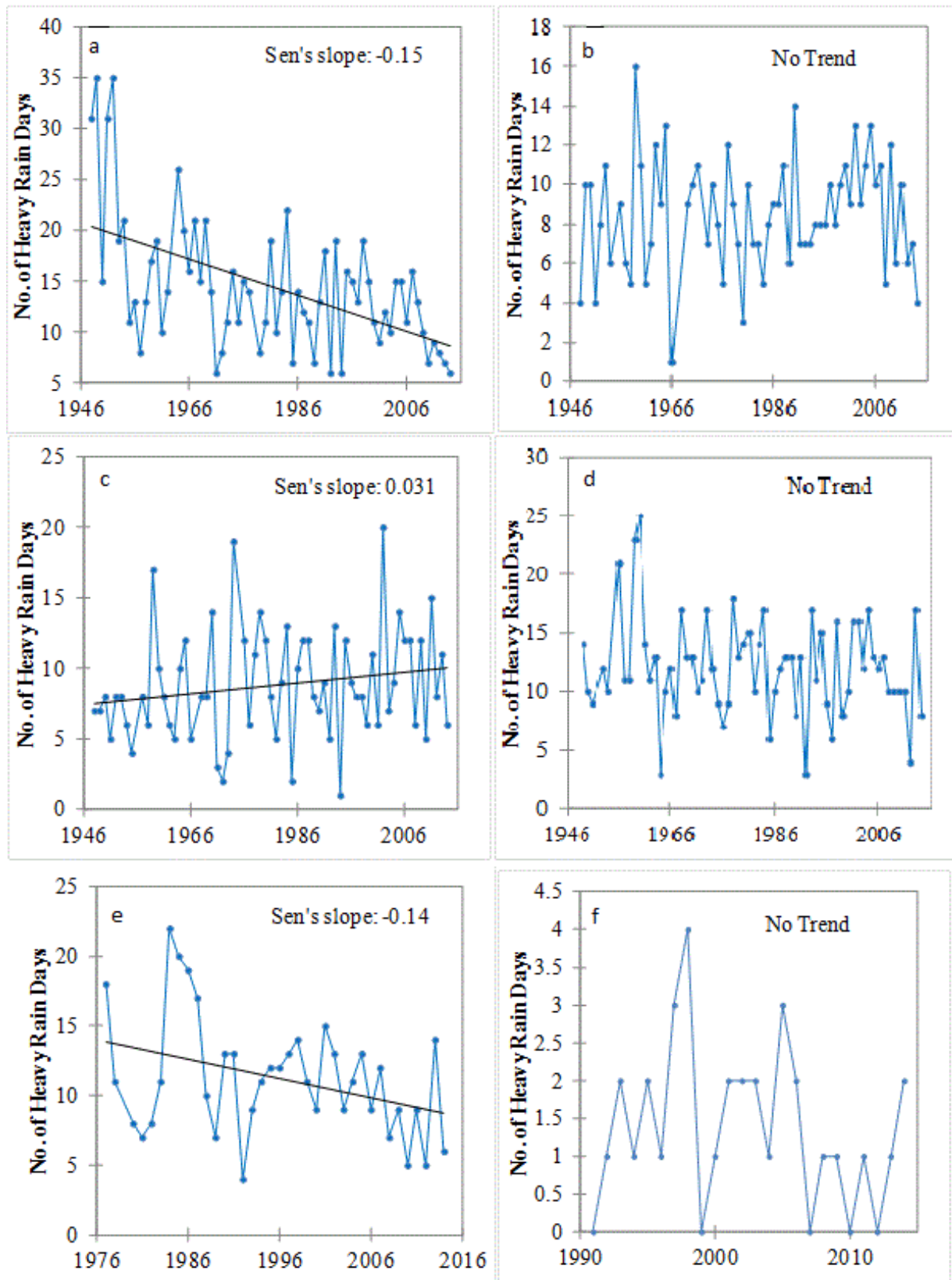
Figure 9i: Trend of annual heavy rain days at (a) Jessore, (b) Satkhira, (c) Khulna, (d) Barisal, (e) Madaripur and (f) Mongla weather stations of BMD.
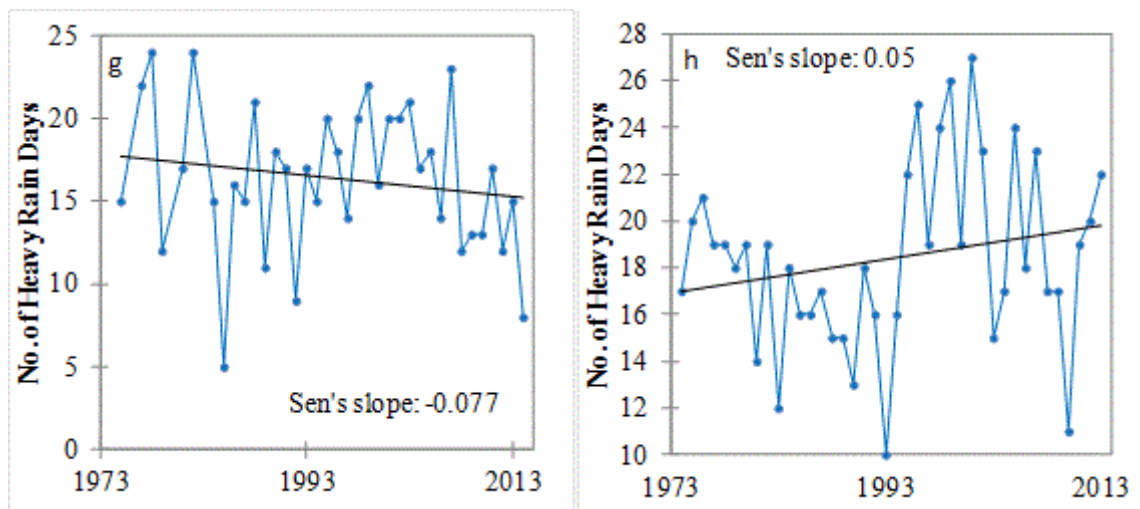
Figure 9ii: Trend of annual heavy rain days at (g) Patuakhali and (h) Khepupara weather stations of BMD.

Station	Time Range	Annual	Pre-monsoon	Monsoon
Jessore	1948-2014	-0.15[***]	-0.12[***]	-0.12[***]
Satkhira	1948-2014	0	0	0
Khulna	1948-2014	0.031	0	0.018
Barisal	1948-2014	-0.023	0	0
Madaripue	1977-2014	-0.14[*]	-0.059[*]	-0.066[*]
Mongla	1991-2014	0	0	-0.063
Patuakhali	1973-2014	-0.077	0	0
Khepupara	1974-2014	0.05	0	0
[***]Significant at 99% confidence level; [*]Significant at 90% confidence level.				

Table 11: Mann-Kendal and Sen's slope test result of seasonal and annual heavy rain days at different BMD stations.

Overall Rainfall Scenario over the Southwest Region

Statistical analysis of rainfall variability over the southwestern part of Bangladesh exhibits an overall decreasing scenario, except the Khepupara station which lies in the exposed coastal zone while other stations lies in the interior part. At Khulna and Satkhira, though the rainfall trend is found positive over the long term period but turned into negative (-4.08 mm/year at Khulna and -1.43 mm/year at Satkhira) in recent climatic period. It clearly represents a major turning point in rainfall variability in recent times after 1980s. Magnitude of decreasing trend is highest in the most upper part of southwest region like places in Jessore (-9.4 mm/year at 99% confidence lever) and Madaripur (-15.71 mm/year at 99% confidence level) (Table 3). Besides, some other specific seasonal specialties are also observed. In pre-monsoon period over the places of Khulna, Satkhira and Barisal rainfall trends are positive, but shifted to a negative slopping after 1980s. While in other places of Mongla, Madaripur, and Patuakhali, recent (1981-2014) pre-monsoon trends are significantly negative except the exterior coastal station of Khepupara. Earlier longer term scenarios are not possible to assess here due to non-availability of long term records. But in monsoon season, rainfall trend is almost similar to annual trend except Khulna, Satkhira and Mongla stations, where though the annual trend is negative but monsoon trend is positive. It indicates monsoon rain intensification in fore southwestern part of the region. In winter season, a major turning point in trend is also prominent. Stations having long term record, e.g. Jessore, Khulna, Satkhira exhibit an increasing trend over long term period but turned to a decreasing one after 1980s (Table 3). Other young stations also exhibit negative trends except Khepupara. It represents a major change in recent climatic condition.

TRMM satellites records also represent significant negative trends (Table 2) with higher magnitudes over recent (1998-2014) times. Annual 99th percentile trend in most of the cases is synclined with the trend of annual rainfall, except Mongla, where rainfall is going on a decreasing trend but 99th percentile is on an increasing trend, i.e., extreme rainfall events are intensifying. In case of Khulna and Satkhira

annual rainfall trend is positive over long period (1948-2014) but turned into negative over recent (1981-2014) period. But 99th percentile of these two stations is positive over long period and recent period. Moreover the magnitude is further intensified from 0.10 to 0.41 in Satkhira and 0.03 to 0.42 in Khulna. It reveals that extreme rainfall events are intensifying over Khulna and Satkhira in recent time.

Impact of present rainfall trend on crop agriculture in the study area

The present research identified that the crop agriculture in the study area is greatly influenced by the rainfall pattern as well as the local hydrologic and geomorphic characteristics. The local environmental stress together with rainfall anomaly and changing pattern continues to build up a severe threat to crop agricultural practices.

Impact of monsoon rainfall variability on crop agriculture: As the study area is a part of floodplain delta, there is always a risk of flooding. Most of the land of the study area is between medium high to medium low and thus are flooded to different degrees, from less than 90 cm to more than 180 cm. But it was not a major concern at earlier times. But the current problem is becoming worse is the poor drainage condition (opinion of local people), due to siltation on river bed. It has made rivers lower capacitate to drain water, and thus a little heavy rainfall causes serious flooding condition. And it is becoming intensive day by day. In the current year 2015 rainfall was comparatively higher that has caused severe flooding and crop damage. If we focus on the monsoon rainfall trend (Figure 10) over Khulna district, it has started to increase recently. It is intensifying the risk of similar crop damage. And day by day if the drainage condition becomes poorer and monsoon rain intensified will impose tremendous risk to monsoon season crop cultivation.
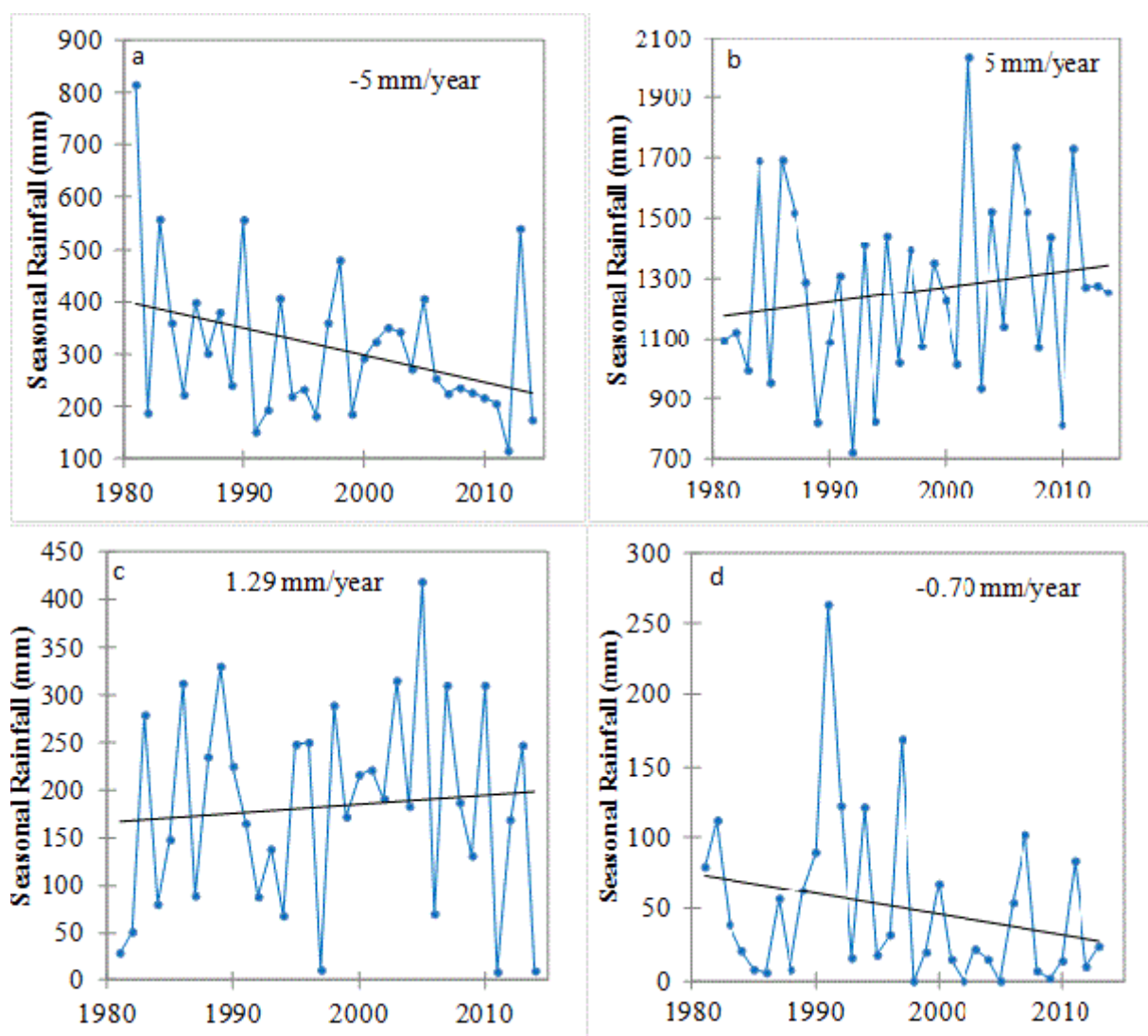

Figure 10: Seasonal Rainfall trend (a) pre-monsoon, (b) monsoon, (c) post-monsoon and (d) winter over Khulna district in recent climatic period (1981-2014).
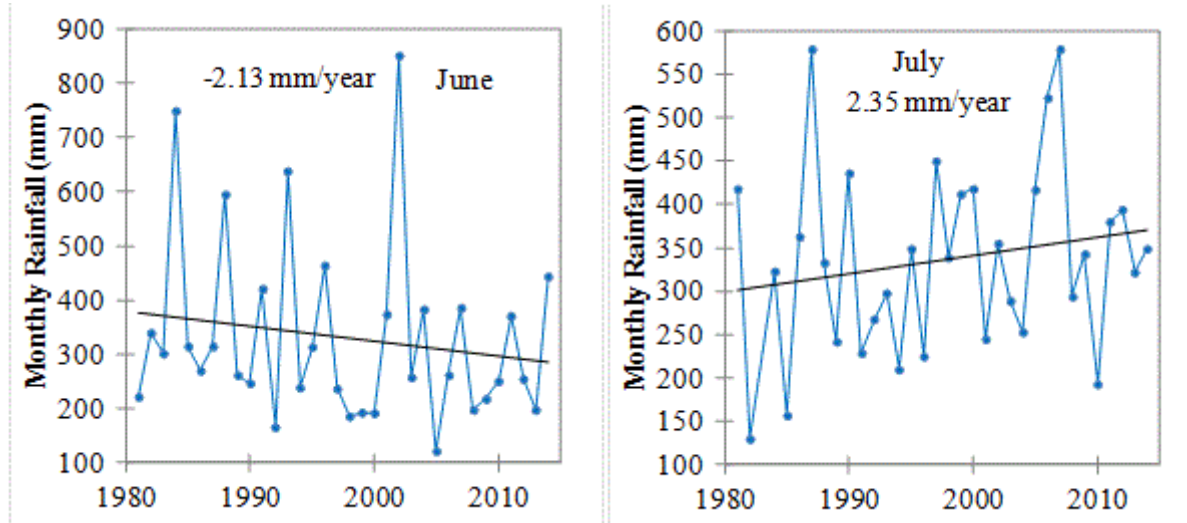
Figure 11: Monthly (June and July) rainfall trend over Khulna district in recent climatic period.

Local people of the study area also opined the observation of anomalous timing of monsoonal onset. Monthly rainfall trend (both Mann-Kendal and linear regression) over the month of June reveals a significant decreasing trend while overall monsoonal rainfall is increasing. Besides, rainfall trend over July is increasing, which represents a delayed onset of monsoon. In case of delayed monsoonal onset, transplantation of aman rice becomes delayed, and farmers have to incur yield loss. Delayed monsoon together with poor drainage and subsequent delayed water recession made loss of land for Boro cultivation. Post-monsoon rainfall also following a increasing trend (Figure 11). In addition to increased post-monsoonal rainfall, the area is under high risk of intense water logging condition.

Impact of winter and Pre-monsoon Rainfall Anomaly

Salinity intensification is a major problem in the study area. Salinity is increasing northward at a high rate. About 0.17 million hactares of new land has been affected by various degrees of soil salinity within 1973-2000 [17]. It is may be due to various reasons like fresh river water withdrawal from upstream, introduction of brackish water shrimp cultivation, faulty management of sluice gates, regular tidal water flooding in unpoldered area, capillary upward movement of soluble salts due to presence of high saline ground water table at shallower depth etc. According to the classification of SRDI the study area lies within slightly saline to highly saline group.

Salinity Status of the Southwest Region

Tidal flooding through a network of tidal creeks and drainage channels connected to the main river system inundates the soil and impregnates them with soluble salts thereby rendering both the top and subsoil saline. Saline water intrusion is highly seasonal. It is at its minimum during the monsoon (June-October) when the main rivers discharge about 80% of the annual fresh water flow. In dry season months, the saline front begins to penetrate inland, and affects the area with sharp rise from 10% in the monsoon to over 40%. The salts enter the soil by flooding with saline river water or by seepage from the rivers, and the salts become concentrated in the surface layers through evaporation. The saline river water may also cause an increase in salinity of the ground water and make it unsuitable for irrigation. 70% of the 2.35 million hectares within the Khulna and Barisal Divisions is affected by different degree of soil salinity [1]. The decrease in water flow to the Gorai distributaries during the dry season has accentuated the surface water salinity in the southwest region. 1,98,890 ha of cultivable land in the coastal area is under moderately saline with strongly saline class developed by SRDI, where the soil of maximum land (37%) contains high Electrical Conductivity (EC) value of 8.1-12.0 dS/m (Table 3). However 16% land under this class contains extreme EC value of >16.0 dS/m, those are highly detrimental for crop growth.

Conclusion

According to the analysis the following conclusions can be drawn

Amounts of annual rainfall in the southwestern part of Bangladesh are almost equal having very little spatial variation. Significant decreasing trend (Mann-Kendal) of annual rainfall over the region is found (-4.5 mm/year at Mongla, -9.14 mm/year at Jessore, -15.71 mm/year at Madaripur) except Khulna, Satkhira and Khepupara, where the trend is positive over the long period (1948-2014) but it exhibits a decreasing trend during the recent period i.e., after 1980s. It clearly indicates a gradual decrease of the amount of rainfall over southwestern part, which has become most prominent in the recent climatic period of 1981-2014. The trend is more intense at the upper southwestern part, i.e., places like Jessore and Madaripur. Annual rainfall deviates within the range -42.6% to +48.6% over the region. Most wide annual deviation is observed in Khulna from 48.6% to -35.5%.

Like annual rainfall, seasonal rainfall also has anomalous behaviour over the region. Monsoon rainfall at maximum locations are syncline with annual trend, but at Khulna, Satkhira and Mongla though the annual trend is negative but the monsoon trend is positive, it clearly indicates, intensification of rainfall in monsoon period over the fore

southwestern part. In pre-monsoon season, overall rainfall trend is significantly negative at maximum places (-8.49 mm/year at Jessore, -2.02 mm/year at Barisal, -7.80 mm/year at Madaripur) over the region except Khulna, satkhira and Khepupara. But in Khulna and Satkhira it is also significantly negative over recent climatic period. Rainfall deviation is higher in seasonal scale than the annual scale. Among the seasons wider deviation is observed in winter (from -100.0% to +586%) and narrower in monsoon (from -43.0% to +62.1%).

The coastal region of southwest Bangladesh has been facing various natural extremes like salinity intensification, drainage congestion, inundation, water logging etc. Anomalous behavior of rainfall in combination with these problems, affecting agricultural crop production in the upazilas under study. The problem is serious in Rabi season, where groundwater irrigation facility is limited for salinity problem. In these areas agriculture is totally dependent on surface water (irrigation canal), which becomes scarce during the month of January, February, March and rainfall is also becoming low in this time (supports by public opinion and rainfall trend analysis) imposing water shortage in crop field and as a result farmers have to incur yield reduction. In monsoon season problem is different. Drainage congestion is a major problem in this time. A little heavy rainfall causes inundation and water logged condition. Besides this problem, increasing trend of rainfall in monsoon is very likely to intensify the risk of inundation. And the farmers of the study area have already faced total damage of Aus crop due to flooding in some years with comparatively high rainfall or fallow due to water logged condition.

Moreover, overall decreasing trend of rainfall is more likely to intensify the risks of salinization due to decreasing upstream flow as well as sedimentation on river bed and consequent poor drainage and water logging. This intensified environmental problem is further likely to intensify the detrimental effects on crop production.

So, changing pattern of rainfall in combination with the local environmental stress is being imposed on risk of agricultural crop production over the study area. It is also occasionally responsible for crop failure over the study area. It is also likely to further intensify the risk for future time.

Salinity status of the southwest region

Tidal flooding through a network of tidal creeks and drainage channels connected to the main river system inundates the soil and impregnates them with soluble salts thereby rendering both the top and subsoil saline. Saline water intrusion is highly seasonal. It is at its minimum during the monsoon (June-October) when the main rivers discharge about 80% of the annual fresh water flow. In dry season months, the saline front begins to penetrate inland, and affects the area with sharp rise from 10% in the monsoon to over 40%. The salts enter the soil by flooding with saline river water or by seepage from the rivers, and the salts become concentrated in the surface layers through evaporation. The saline river water may also cause an increase in salinity of the ground water and make it unsuitable for irrigation. 70% of the 2.35 million hectares within the Khulna and Barisal Divisions is affected by different degree of soil salinity [1]. The decrease in water

flow to the Gorai distributaries during the dry season has accentuated the surface water salinity in the southwest region. 1,98,890 ha of cultivable land in the coastal area is under moderately saline with strongly saline class developed by SRDI, where the soil of maximum land (37%) contains high Electrical Conductivity (EC) value of 8.1-12.0 dS/m (Table 3). However 16% land under this class contains extreme EC value of >16.0 dS/m, those are highly detrimental for crop growth.

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