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REGIME SHIFT IN MONSOON RAINFALL OF BANGLADESH: A SEQUENTIAL DATA PROCESSING APPROACH

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Abstract: As the economy and livelihoods of Bangladesh heavily depends on agriculture, any changes in monsoon rainfall have severe implications for the country. There is a growing concern on monsoon rainfall pattern change in Bangladesh in recent years like other parts of Indian summer monsoon region. A study has been carried out in this paper to analyze the monsoon rainfall time series of Bangladesh to decipher if there any shift in monsoon rainfall regime of Bangladesh. Sixty four years rainfall data recorded at twenty-nine locations distributed over Bangladesh were analyzed using a sequential regime shift detection method for this purpose. The proposed method employed Student's t-test to detect difference between two subsequent regimes with a cut-off length of one to determine the regime shift. The result shows that monsoon rainfall has increased, mostly in recent years in many locations of Bangladesh. Though increased monsoon rainfall will be helpful for rain-fed agriculture in Bangladesh, at the same time it will also cause more frequent floods, urban water logging, water-borne diseases, etc.

Keywords: *Rainfall shifting, sequential data processing, monsoon, climate change*

1.0 Introduction

The Asian summer monsoon has complicated spatial and temporal structures (Lau, 1992; Tian and Yasunari, 1998; Qian and Lee, 2000, Sandeep *et al*., 2014). It has been reported that Asian monsoon rainfall regime has undergone an obvious abrupt shift or jump in the mid- and late 1970s (Weng *et al*., 1999). This regime shift is in good coincidence with a significant abrupt climate change or jump which has been extensively observed in other regions over the world (Berkelhammer *et al*., 2012; Sabeerali *et al*., 2012). Wu *et al*. (2005) reported that the Indian summer monsoon circulation has undergone two weakening processes in the last 50 years, with the first one occurring in the mid-1960s and the second one in the late 1970s. Several other studies have also indicated that the Asian summer monsoon has become weaker after the end of the 1970s (Huijung, 2001; Suhas *et al*., 2008; Ding *et al*., 2010; Sabeerali *et al*., 2012). Number of studies has been carried out to understand the regime shifts in different parts of Indian subcontinents

(Suhas *et al*., 2008; Chang *et al*., 2010; Ding *et al*., 2010; Sabeerali *et al*., 2012). It has been reported that the annual mean rainfall in Sri Lanka is practically trendless; positive trends in February and negative trends in June have been reported (Chandrapala and Fernando, 1995). In India, long-term time series of summer monsoon rainfall have no discernible trends, but decadal departures are found above and below the long-time average alternatively for three consecutive decades (Kothyari and Singh, 1996). Recent decades have exhibited an increase in extreme rainfall events over northwest India during the summer monsoon (Singh and Sontakke, 2002). Moreover, the number of rainy days during the monsoon along east coastal stations has declined in the past decade. A long-term decreasing trend in rainfall in Thailand has been reported (OEPP, 1996). In Bangladesh, decadal departures were below long term averages until 1960; thereafter, they have been much above normal (Mirza and Dixit, 1997). The previous studies indicate a change in Asian monsoon rainfall in some parts of the region.

Precipitation is one of the most important factors for the livelihood of the population of Bangladesh where the economy strongly based on agricultural. About 80% people of Bangladesh live in rural area and directly or indirectly depend on agriculture (Shahid, 2011b). The irregularity of rainfall and associated extreme events may affect ecosystems, productivity of land, agriculture, food security, water availability and quality, health, and livelihood of the common people of Bangladesh. Therefore, a better understanding of precipitation variations has important implications for the economy and society of Bangladesh. There are limited studies on rainfall regime shift events in Bangladesh. For example, Ahmed (1989) studied the probabilistic estimates of rainfall extremes in Bangladesh during the pre-monsoon season. Karmakar and Khatun (1995) repeated a similar study for the southwest monsoon season. However, both the studies were concentrated only on maximum rainfall events for a limited time period. Palmer and Raisanen (2002) estimated that the probability of total boreal summer precipitation for the Asian monsoon region exceeding two standard deviations above normal, with implications for flooding in Bangladesh. May (2004) predict an increase in intensity of heavy rainfall events in northeast India as well as in Bangladesh through the simulation of variability and extremes of daily rainfall during the Indian summer monsoon.

Regime shift known as an apparent shift in climatic conditions or marine community structure (Collie *et al*., 2004). The regime shift or discontinuity concept is rooted in the idea that sudden shifts in physical or biological variables are non-random and non-linear in origin (Noy-Meir 1975; Scheffer *et al*., 2001; Hsieh *et al*., 2005). In the present study, a sequential regime shift detection method is used to analyze the changing in monsoon rainfall of Bangladesh. Sixty four years (1948–2012) monthly rainfall data from twenty nine rain-gauges in different parts of Bangladesh are used for this purpose.

2.0 Climate of Bangladesh

Bangladesh geographically extends from 20°34′N to 26°38′N latitude and from 88°01′E to 92°41′E longitude has a tropical humid climate. The topography of the country is extremely flat except some parts in southeast region. The climate of Bangladesh is characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. Four distinct seasons can be recognized in Bangladesh from climatic point of view: (i) the dry winter season from November to February, (ii) the pre-monsoon hot summer season from March to May, (iii) the rainy monsoon season from June to October, and (iv) the post-monsoon season from October to November (Rashid, 1991). Rainfall in Bangladesh varies from 1598 mm in the west to 4197 mm in the east (Shahid and Khairulmaini, 2009). The monthly distribution of rainfall over the country is shown by a graph in Figure 1. The graph shows that the rainfall is very much seasonal in Bangladesh; more than 78% of rainfall occurs during monsoon. Spatial distribution of monsoon rainfall over Bangladesh is shown in Figure 2.

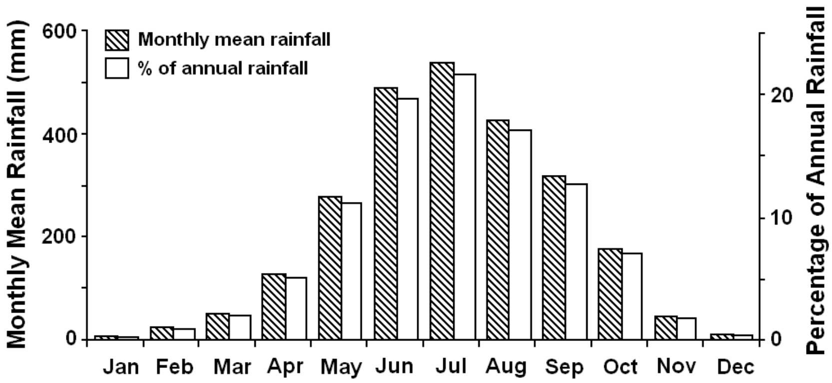


Figure 1: Monthly distribution of rainfall in Bangladesh

The moist air during monsoon enter Bangladesh from the Bay of Bengal with south-to-north trajectory and then turn toward the northwest and west being deflected by the Meghalaya Plateau. As these depressions move farther and farther inland, their moisture content decreases, resulting in decreasing rainfall toward the northwest and west of Bangladesh (Ahmed and Kim, 2003). On the other hand, the additional uplifting effect of the Meghalaya plateau increased the rainfall in northeast of Bangladesh.

3.0 Data and Methods

3.1 *Data and Sources*

The rainfall recorded at twenty-nine (29) stations distributed over Bangladesh was used in the present study. For this purpose daily records of rainfall for those stations were collected from Bangladesh Meteorological Department (MMD) .Location of rainfall stations used in this study is shown in Figure 3.

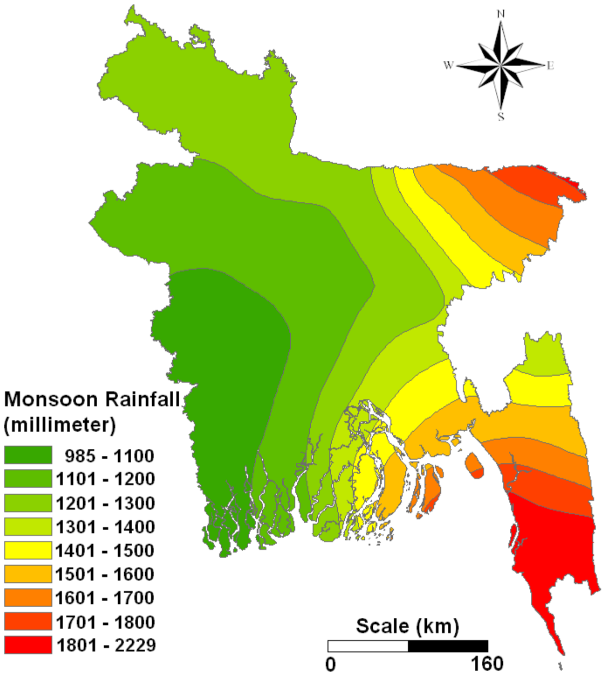


Figure 2: Spatial distribution of monsoon rainfall over Bangladesh

3.2 *Methodology*

Sequential data processing technique is an efficient method to detect regime shift (Rodionov, 2004). In the present study, sequential data processing technique is employed to understand the shift in monsoon precipitation regime in Bangladesh. In sequential analysis, a test is performed to determine the validity of the null hypothesis H_0 or the existence of a regime shift Rodionov (2004). There are three possible outcomes of the test: accept H_0, reject H_0, or keep testing.

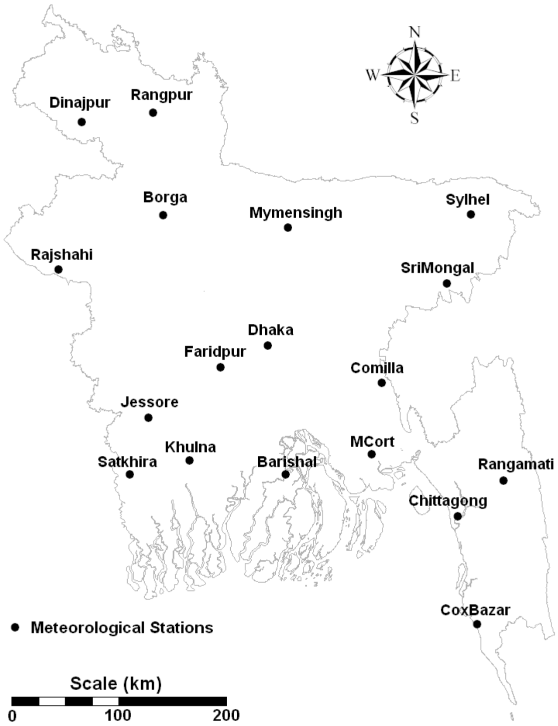


Figure 3: Location of rain gauges in Bangladesh used in the present study

The difference between the mean values of two subsequent regimes, R1 and R2 is statistically significant when calculated Student's t-test statistics is more than critical table value:

$$diff = t\sqrt{2\sigma_1^2/l} \qquad (1)$$

Where t is the value of t-distribution with 2l - 2 degrees of freedom at the given probability level p.
it is assumed that the variances for both regimes are the same and equal to the average variance σ_1^2 of the time series of variable X. The mean, $\bar{x}_{R1}$ of the initial l values of variable X is calculated as an estimate for regime, R1. The levels that should be reached in the subsequent l years to qualify a shift to regime, R2 is

$$\bar{x}'_{R2} = \bar{x}_{R1} \pm diff \qquad (2)$$

For each new value starting from first year, it is checked whether it is within the range of $\bar{x}_{R1} \pm diff$ or not. If the new value does not exceed the $\bar{x}_{R1} \pm diff$ range, it is assumed that the current regime has not changed. In this case, the mean of regime, R1is recalculated by including the next value the time series of X. However, if the new value exceeds the range, then the year is considered as a possible start point of the new regime, R2.

After detection of shift point, the null hypothesis of a regime shift is statistically tested by estimating the regime shift index (RSI) which represents a cumulative sum of the normalized anomalies (Rodionov, 2004):

$$RSI_{i.j} = \sum_{i=j}^{j+m} \frac{x_i^*}{l\sigma 1}, m = 0,1,2 \ldots \ldots, l - 1. \qquad (3)$$

Here $x_i^* = x_1 - \overline{x}'_{R2}$, if the shift is up, or $x_i^* = \overline{x}'_{R2} - x_1$ if the shift is down. If at any time from $i = j + 1$ to $i = j + l - 1$ the RSI value turns negative, it means that the test for a regime shift at year j failed. On the other hand, the positive value of RSI means that the regime shift at year j is significant at the probability level *p*. Then actual mean value for the new regime $\overline{x}'_{R2}$ is calculated. Details of the method can be found in (Rodionov, 2004).

4.0 Results and Discussion

This study analyzed the regime shift of monsoon rainfall of Bangladesh over the time period 1948–2012. Figures 4, 5 and 6 show the monsoon rainfall regimes along with the time series of monsoon rainfall in different stations of Bangladesh. The results show that overall there was an increase in monsoon rainfall in 1970s and 1980s, followed by a decrease, at a higher rate in the end of the study period. In particular, the rainfall amount during monsoon season was dramatically shifted downward at 20 stations (Figure 4) namely, Barishal, Bhola, Bogra, Chadpur, Cox's Bazar, Dhaka, Faridpur, Feni, Hatiya, Ishurdi, Jessore, Khepupara, Khulna, M. Court, Madaripur, Mymensingh, Patuakhali, Rajshahi, Rangpur and Satkhira. At the same time, it was increased significantly at 7 stations (Figure 5) namely, Chittagong, Comilla, Dinajpur, Rangamati, Sandwip, Srimongal and Teknaf. The monsoon rainfall patterns in the rest 2 stations (Sitakunda and Sylhet) were not remarkably changed (Figure 6). Changes in the monsoon regime at different stations of Bangladesh are summarized in Table 1.

The table shows that a remarkable difference has been found between the periods before and after the transition years. For example, the average rainfall at Rajshahi station (Figure 4(h)) during 1948–1965 was about 1200 mm. But rainfall regime in the station was changed three times, in the years 1965, 1987 and 2008, and reduced to 800 mm. On the other hand, the average monsoon rainfall at Chittagong station was about 1700 mm for the period 1948–2008, but it increased by 700 mm in the year 2008. On average, an increase of rainfall by 400-900 mm was observed at 7 stations during the time period

1948-2012, and on average an decrease of rainfall by 200-700 mm was observed at 20 stations.

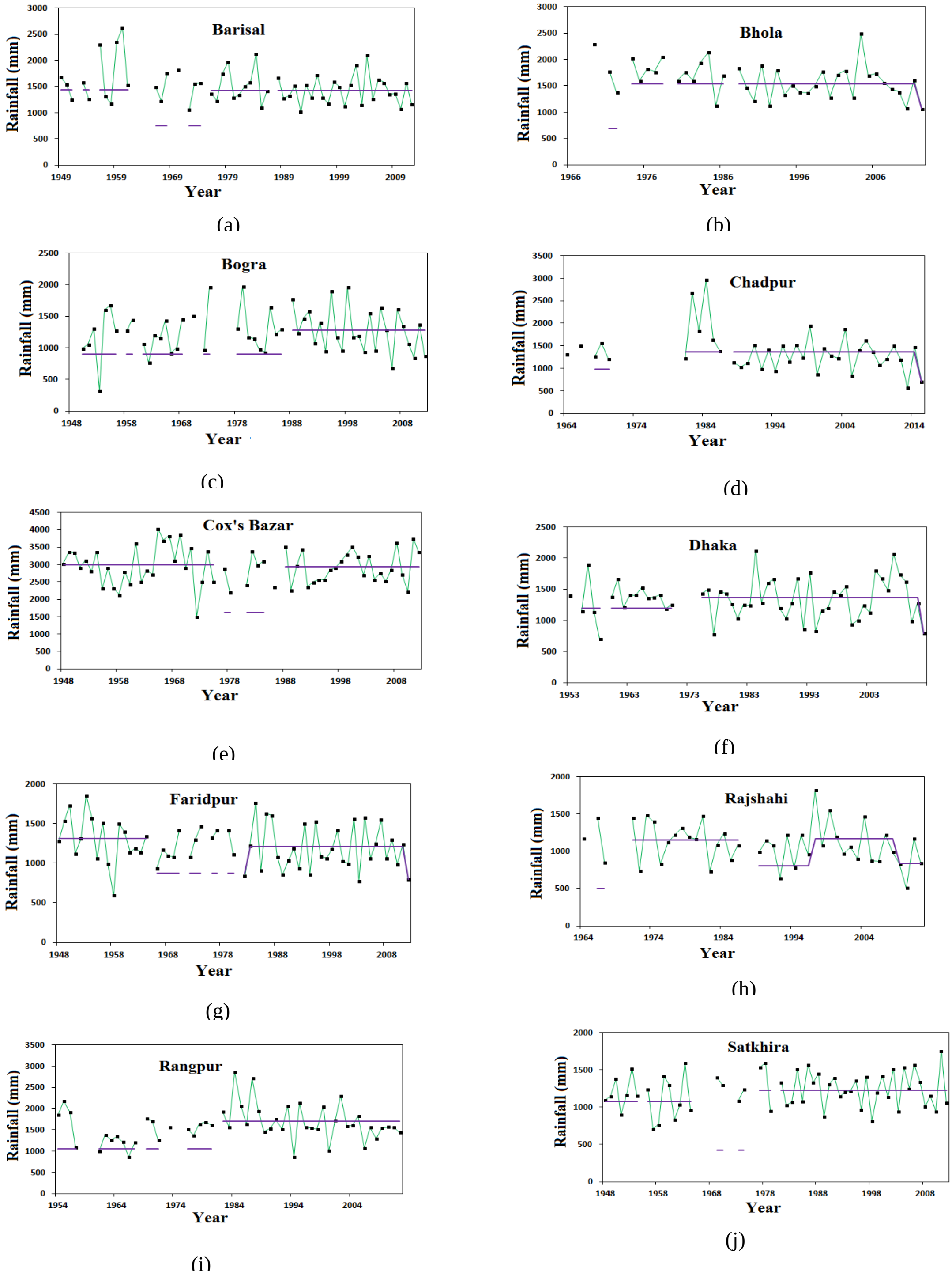
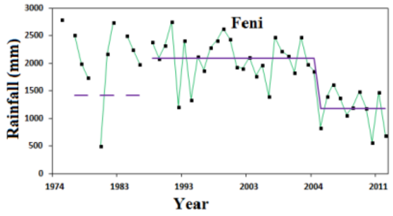


Figure 4: Regime shift (down) of monsoon rainfall of Bangladesh



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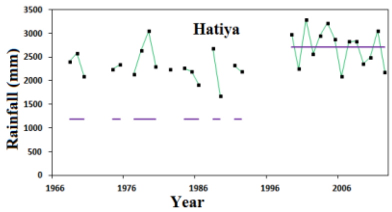

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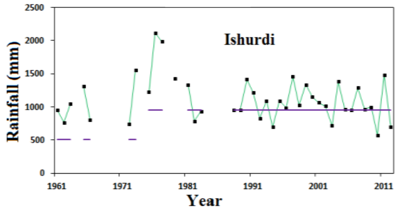

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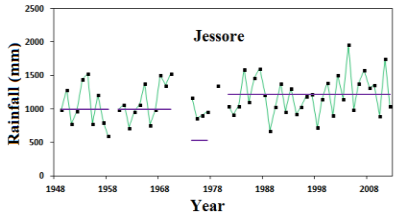

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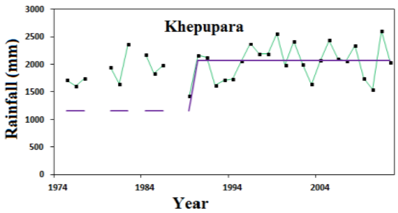

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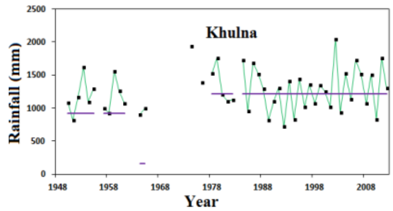

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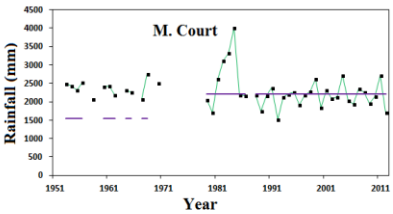

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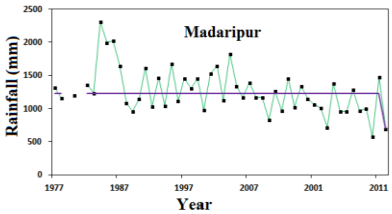

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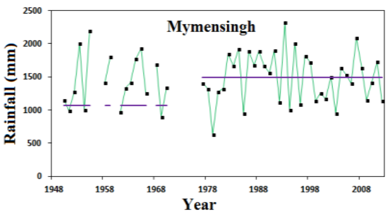

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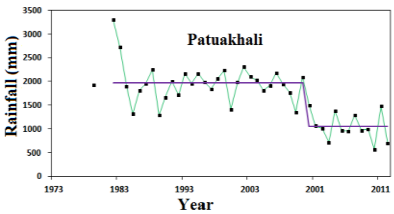


(t)

Figure 4 (cont'): Regime shift (down) of monsoon rainfall of Bangladesh

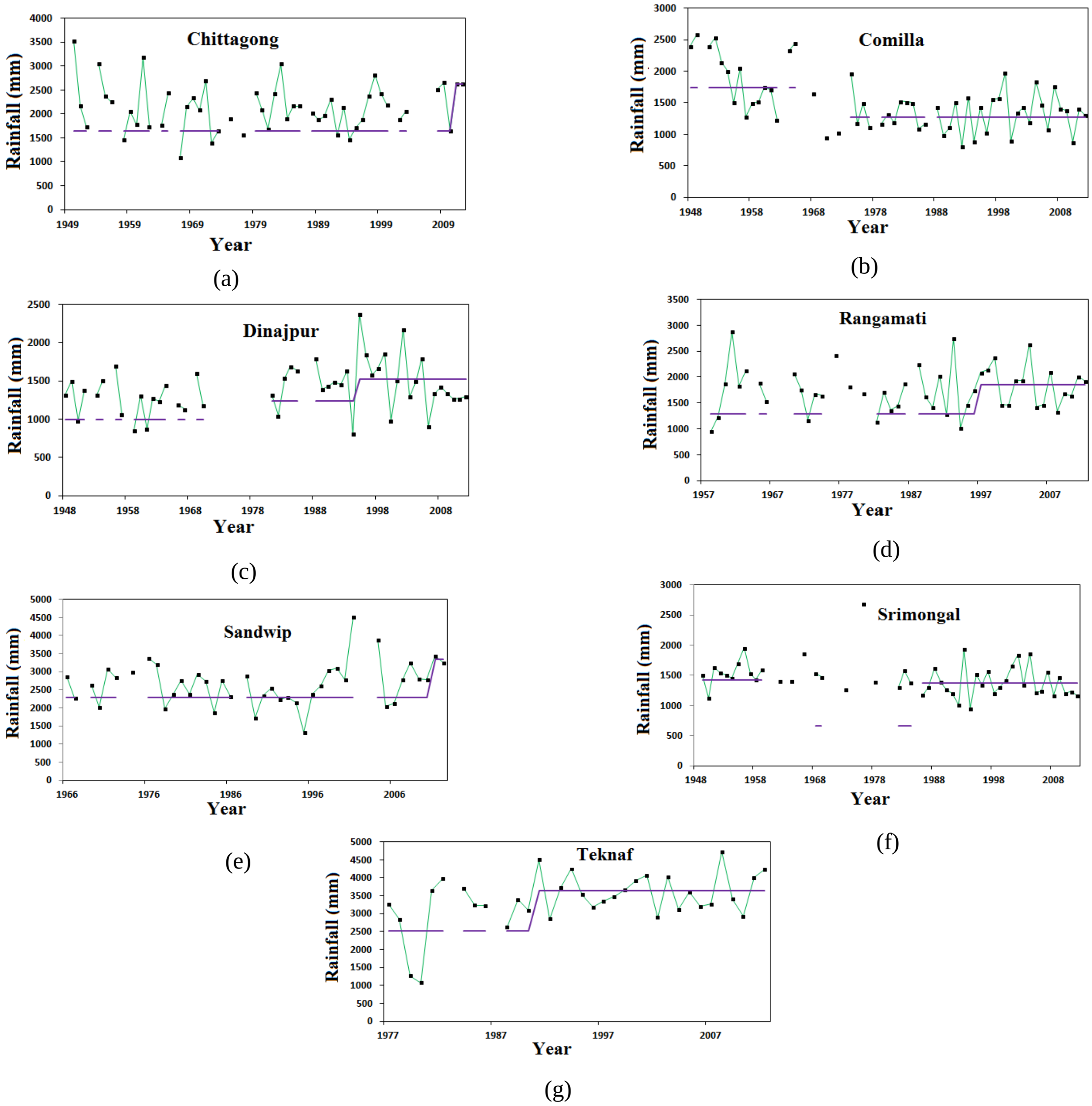
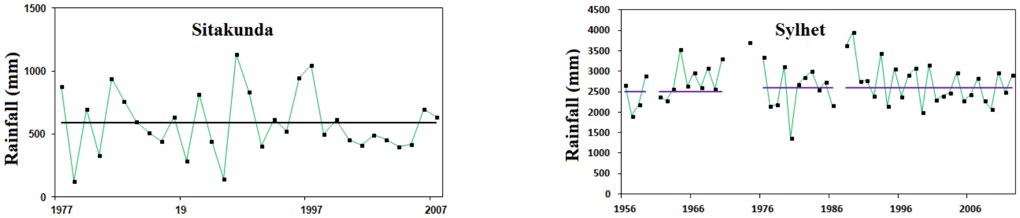


Figure 5: Regime shift (up) of monsoon rainfall of Bangladesh

The study indicates that the monsoon rainfall has significantly decreased mostly in the East part and increased in the northern part of Bangladesh. Thunderstorms during monsoon are responsible to produce widespread and heavy rainfall in Bangladesh. The amount of rainfall depends upon the supply of moist air from the Bay of Bengal.



(a) (b)

Figure 6: Regime shift (no change) of monsoon rainfall of Bangladesh

Table 1: Changes in the monsoon regime at different stations of Bangladesh

Station name	Year of regime shift	Before shift rainfall (mm)	After shift rainfall (mm)	Remark
Feni	1988,2004	2000	1500	down
Ishurdi	1974	900	500	down
Khepupara	1991	2000	1000	down
M. Court	1969,1980	2500	1500	down
Mymensingh	1970,1975	1600	1000	down
Hatiya	1995	2700	1000	down
Jessore	1970,1979	1300	1000	down
Khulna	165,1978	1200	1000	down
Madaripur	2011	1000	700	down
Patuakhali	2000	1700	1000	down
Barishal	1965, 1971	1500	800	down
Bogra	1987	1300	800	down
Chittagong	2008	1700	2400	up
Cox’s Bazar	1976,1985	3000	1400	down
Dinajpur	1970,1990	1000	1500	up
Bhola	2009	1400	900	down
Chadpur	1968,2010	1400	700	down
Comilla	1968	1200	1700	up
Dhaka	1972,2004	1300	1200	down
Faridpur	1962,1978	1300	800	down
Rajshahi	1965,1987,2008	1200	800	down
Rangpur	1982	1700	1100	down
Satkhira	1965,1978	1200	1400	up
Srimongal	1968,1982	1300	700	down
Rangamati	1998	1300	1700	up
Sandwip	2010	2300	3200	up
Sitakunda	-	-	-	No change
Syhet	-	-	-	No change
Teknaf	1990	2500	3200	up

Atmospheric moisture amounts have been observed to be increasing after about 1973 (Ross and Elliott, 2001). As the increased moisture content of the atmosphere favours stronger rainfall events (Trenberth, 1998), it can be remarked that increased monsoon rainfall in northern parts of Bangladesh might be due to the increase of atmospheric moisture in recent years (Shahid, 2011b). The strong increase of rainfall has been observed in Chittagong station situated in southeast hill region of Bangladesh. The region experienced a number of landslides in the recent years (Shahid, 2011a; Rahman, 2012). Significant increase of heavy rainfall events may trigger more landslides in the region in future.

Increasing trends of heavy precipitation during monsoon might also cause a number of negative impacts on public health in Bangladesh (Shahid, 2010). Many diseases of Bangladesh have direct relation with rainfall pattern. Hashizume *et al*. (2007) found that the number of non-cholera diarrhoea cases in Dhaka increases both above and below a threshold level with high and low rainfall. Outbreaks of water-borne diarrheal diseases caused by parasites, like *Giardia* and *Cryptosporidium*, are associated with heavy rainfall events (McMichael, 2006), therefore likely to become more frequent in Bangladesh with the increase of heavy precipitation events. Runoff related to increased heavy precipitation events may cause increase of river water levels and flash flood. Water logging in urban areas as well as in northwest coastal zone of Bangladesh might be frequent phenomena. This might cause an increase of rotavirus diarrhoea in Bangladesh as it is directly associated with river level (Hashizume *et al*., 2007).

5.0 Conclusions

A sequential regime shift detection method has been applied over long-term rainfall data recorded at twenty-nine locations distributed over Bangladesh to decipher the changes in monsoon rainfall regime in Bangladesh. The study reveals an increase in monsoon rainfall in Bangladesh in 1970s and 1980s followed by an abrupt decrease in recent years. The downward shift of monsoon rainfall in recent years is found to be very drastic at 40% stations of the country. As monsoon is an important factor in the economy and people’s livelihood, it might have severe consequences in Bangladesh. Therefore, it is required to apply other robust mathematical and statistical methods to confirm the changes in monsoon regime of Bangladesh. It is expected that the study will help to initiate more studies in this regard.

6.0 Acknowledgements

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