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STATISTICAL ANALYSIS AND TRENDS OF DRY DAYS IN SYLHET REGION OF BANGLADESH

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Abstract: The rainfall distribution in Bangladesh is not uniform and reflecting topography. Hilly Sylhet region receives substantial rainfall every year compare to other regions of Bangladesh. Though Sylhet region is less vulnerable to drought but weather pattern is not constant and changing day by day. Hence as a part of drought analysis, behavior of dry days is important. This study focuses on dry days pattern and associated changes from daily records of last 54 years for Sylhet region. Monthly, yearly and seasonal variations of dry days were analyzed to check for major changes. In order to investigate extreme dry events, time history of monthly dry days data were transformed into frequency domain using the Fast Fourier Transform (FFT). Variability of dry days in time scale was also checked from filtered signals which is very useful for drought analysis, agricultural development and disaster management for the north-east region of Bangladesh.

Keywords: Dry days distribution; statistical behavior; linear trend; Fast Fourier Transform; Sylhet

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INTRODUCTION

Bangladesh is one of the most disaster-prone countries in the world (Ali, 1996). High spatial and temporal climatic variability, extreme weather events, high population density, high incidence of poverty and social inequity, poor institutional capacity, inadequate financial resources, and poor infrastructure have made Bangladesh highly vulnerable to natural disasters (Ahmed, 2004). The hydrological and climatic conditions of Bangladesh are characterized by huge rainfall in the wet monsoon and less rainfall in the dry months which are the major causes of floods as well as droughts. Due to the land use changes within the country as well as neighboring countries, Bangladesh has already shown an increased frequency of droughts in recent years (National Drought Mitigation Center, 2006).

Drought is a recurrent phenomenon in some parts of Bangladesh. Since her independence in 1971, Bangladesh has suffered from nine major droughts (Paul, 1998) in different part of the country. During last fifty years, Bangladesh suffered about twenty major and minor droughts which cause huge losses of crops as well as to perennial agricultural resources (Banglapedia, 2003). In addition of agriculture, power generation and industrial production also depends upon precipitation (Rafiuddin *et al.*, 2011). However, despite of the recurrent and devastating nature of droughts in Bangladesh, it has attracted far less scientific attention than floods or cyclones (Alexander, 1995; Brammer, 1987).

Due to the critical influence of large variability of precipitation or probability of dry-spell increase, analysis of dry days becomes very important for policy making efforts and for adopting mitigation to reduce drought impact in Bangladesh. Although a number of studies have been carried out on drought events in Bangladesh (i.e., Jabbar *et al.*, 1982; Ahmed and Bernard, 1989; Karim *et al.*, 1990; Jabbar, 1990; Ericksen *et al.*, 1993; Warproegic, 1996; Rasheed, 1998; Saleh *et al.*, 2000; Karim and Iqbal, 2001; Mazid *et al.*, 2005; Shahid and Behrawan, 2008 etc), only few of them focuses dry days and their variability particularly for the north-eastern part of Bangladesh.

Rafiuddin *et al.* (2011) analyzed the drought events from the monthly rainfall data (1961-1990) using Standardized Precipitation Index (SPI) over Bangladesh and found about 87 percent of the drought events occurred during their study period. The study disclosed that the frequency of moderate drought is high for all over the country. The study also found the central, northern and the south-western regions are the most severe drought prone area within the country. Keka *et al.* (2012) performed a drought analysis throughout Bangladesh to identify sectors that are highly affected and to understand adverse effects of drought on the agricultural sector as well as on other socio-economic sectors. Shahid and Behrawan (2008) characterized the spatial and temporal pattern of drought hazards, identified the vulnerability of various geographic populations to the impact of droughts and developed maps of drought risk zones for western part of Bangladesh. Karim *et al.* (1990) developed agricultural drought risk map of Bangladesh considering the cumulative effect of dry days, higher temperatures during pre-monsoon period and soil moisture availability. In addition, maps of winter and pre-monsoon drought prone areas was also prepared using agro-ecological zones database and land resources inventory map (Warproegic, 1996). Karim and Iqbal (2001) studied three different drought risk maps for winter, pre-monsoon, and monsoon seasons that defined drought risk classes as slight, moderate, severe, and very severe related to the yield losses of 15–20%, 20–35%, 35–45%, and 45–70% respectively for different crops.

Hence, the aim of present study was set as to understand the behavior of dry-spells (days) pattern and associated changes over time in the north-eastern part (Sylhet region) of Bangladesh. For this, statistical analyses of dry days were done to check their monthly, seasonally and yearly variations. In addition, to check extreme dry events, frequency analysis of monthly dry days was done using the Fast Fourier Transform (FFT). Moreover, this study tried to prepare signals for forecast which is very useful for drought analysis, agricultural development and disaster management for the north-east zone of Bangladesh.

STUDY AREA AND COLLECTION OF DATA

North-eastern part of Bangladesh

Bangladesh weather board divided the country into four regions: (a) north-west, (b) south-west, (c) south-east and (d) north-east region based on the hydrological characteristics of these regions. Sylhet, the north-eastern division of Bangladesh located at 240°53′ latitude and 910°52′E longitudes, having population of 3 404 000 is one of the most picturesque and archeologically rich regions in South Asia. Its growing economy has become a part of the attractions of the country, as landscapes are filled with fragrant orange and pineapple gardens and breathtaking tea plantations. Over 150 tea gardens, including three of the largest tea garden in the world both in terms of area and production are located here. In addition, for miles around one can see the gardens of pineapple, rubber and lemon plantations on the hill slopes, dense bamboo and cane bushes on the hills and land. Cultivation of Aman crop in the greater Sylhet region also contributes in country's total rice production. Besides Boro, Aus and deep-water rice (floating rice) are also cultivated in Sylhet region [International Rice Research Institute (IRRI)].

The Sylhet valley is formed by a beautiful pair of rivers named the Surma and the Kushiara, both of which are fed by innumerable hill streams from the north and the south. The valley has a good number of (around 400) Haors, Beels (wet land) of 4450 to 25 000 km² which are big natural depressions. During winter season these Haors become vast stretches of green land, but in rainy season they turn into turbulent seas. These Haors provide a sanctuary to the millions of migratory birds who fly from Siberia across the Himalayas to avoid the severe cold there (Banglapedia-2003). Any change of the hydro-climatic pattern like irregularities of rainfall, delay in monsoon rainfall, drought etc in this region will significantly affect the balance among these natural features and also other parts of the country. Hence, a comprehensive understanding of the dry days pattern is greatly needed.

Data collection

Bangladesh Water Development Board (BWDB) is the main organization responsible for collecting all hydro-meteorological data of Bangladesh with a wide network of rainfall stations distributed throughout the country (35 rain gauge stations). For this study, rainfall data of 54 years started from 1957 was collected from their record. Number of dry days was calculated from the collected daily data records.

The daily record seems very helpful, though the continuity of the data was slightly hampered by some missing records . Missing data was calculated by the method of interpolation. Time series of accumulated monthly dry days variation during the study period is shown in **Fig. 1**, which looks smooth. Noisy data were found in the year 1996 that may occur due to faulty recording. No severe mischief was observed due to the interpolation of missing records.

METHODOLOGY

Dry day

Indian Institute of Tropical Meteorology defined dry days as continuous period with daily rainfall equal to or less than daily mean rainfall of climatological monsoon period over the area of interest (Singh and Ranade, 2009). Indian Meteorological Department (IMD) also defined criteria to differentiate wet and dry events across the Indian subcontinent. According to IMD, dry day is a day when rainfall is less than 2.5 mm in that day (Dash *et al.*, 2009). However, criteria for dry events depend on many factors such as geological position, weather pattern and so on. For example, in Australia a dry day is considered as a day when daily total rainfall is less than or equal to 0.2 mm, recently less than or equal to 1 mm/day rainfall is also considered as a dry day for some studies in Australia. To identify dry spells across China, Bai *et al.* (2007) used a rainfall magnitude less than 0.1 mm/day. Considering geographical location, this study considered dry day as a day of having total rainfall less than or equal to 2.5 mm.

Statistical analysis

Statistical parameters are very important components to understand the variation of a particular data set. For statistical analysis of the dry days, this study used some important measurements of variability i.e., standard deviation (*SD*), standard error (*SE*) and coefficient of variability (*CV*) as defined below:

$$SD = [(N-1)^{-1} \sum_{i=1}^{N} (X_i - \overline{X})^2]^{1/2} \quad (1)$$

$$SE = [(\sqrt{N} - 1)^{-1} SD] \quad (2)$$

$$CV = SD / \overline{X} \quad (3)$$

where, N is the total number of samples, X is the number of dry days, $\overline{X}$ is the arithmetic mean for N years.

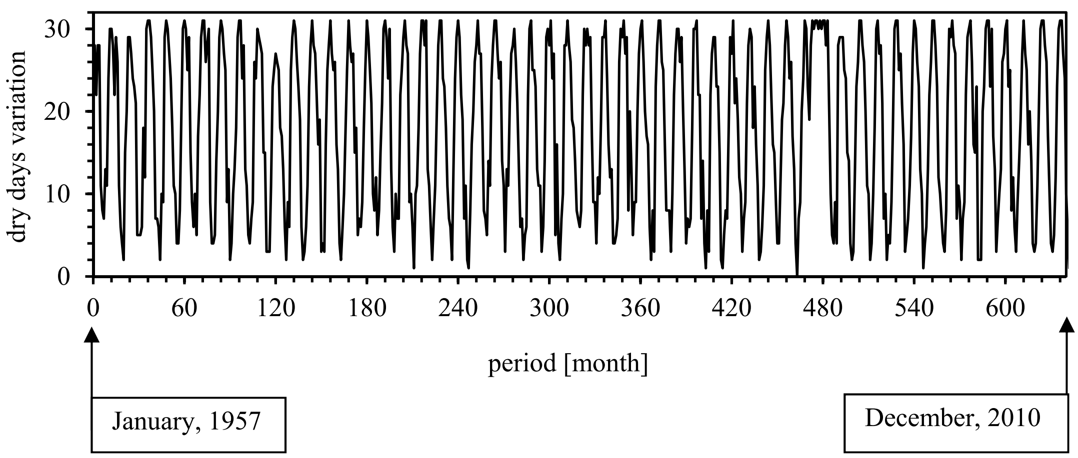


Fig. 1 Time history of monthly dry days.

These are useful measures of variability and widely used in the climatological studies. The measures of variability of dry days at Sylhet station for all the months from 1957 to 2010 are presented in **Table 1**. The minimum dry day occurred in the month of July, while the maximum value found almost in all other months. The maximum mean monthly dry days occurred during winter months (December and January). Coefficient of Variability (*CV*) is minimum in winter months and increases in monsoon period, while the highest values of *CV* occur in the month of July which is in line with expectation. Standard Deviation (*SD*) shows the variation in data set. Smaller value represents the data is close together, whereas larger value denotes wide spreading of data set. Observed standard deviation was relatively small during winter period (**Table 1**) compared to monsoon period which indicates the spreading of data set. Standard Error (*SE*) represents the amount of sampling error associated during sampling process. Value of *SE* for all month was less than 1 which indicates the samples were taken for this study was relatively large, however, value of error can be reduced by increasing its size.

Aridity Index

To understand the climate condition and associated vegetation condition of the study region Aridity Index (*AI*) was calculated using De Martonne's equation as shown below (**Eq. 4**). Vegetation of a region can eventually classify broadly based on the index with the help of **Table 2**.

$$AI = P/[t_m + 10] \quad (4)$$

where P is rainfall average and t_m is mean average.

Frequency analysis

To check the frequency structure of the dry days variation, Fourier transform was used which is a very useful mathematical tool that transforms one function into another. When the original function is in time domain, this tool transforms it into frequency domain and vice versa. A Fast Fourier Transform (FFT) is an efficient algorithm to complete the Fourier transform. Present study transformed a sequence of number in time domain into a frequency domain and then inverse Fourier transform was performed using the following equations.

Table 1. Monthly variation of different statistical parameters (i.e., maximum, minimum, mean, standard deviation, standard error and coefficient of variability) estimated from dry days record of 54 years (1957−2010) covering Sylhet region

Month	Max	Min	Mean	*SD*	*SE*	*CV*
January	31	25	29.7	1.56	0.213	5.3%
February	29	18	25.3	2.26	0.308	8.9%
March	31	16	24.3	3.99	0.543	16.4%
April	30	5	15.8	5.66	0.769	35.8%
May	31	2	11.8	4.68	0.637	39.4%
June	30	1	5.91	4.46	0.508	75.38%
July	31	0	4.48	4.25	0.578	94.8%
August	31	2	6.96	4.46	0.607	64.1%
September	30	3	11.11	4.52	0.615	40.7%
October	31	9	21.56	3.80	0.517	17.6%
November	30	24	28.20	1.75	0.238	6.2%
December	31	27	30.18	1.16	0.159	3.9%

Table 2. Type of vegetation (from desert to dense) based on Aridity Index (after Subramanya, 2005)

Aridity Index (AI)	Vegetation Type
Less than 5	Desert
5−10	Dry steppe
10−20	Prairie
20−30	Transition between grassland and forest
30−60	Forest (Less vegetation)
60−100	Moderate vegetation
More than 100	More vegetation

$$X_K = \sum_{n=0}^{N-1} X_n e^{-\frac{2\pi i}{N}Kn} \quad , K = 0, 1, 2, \dots\dots\dots, N-1 \qquad (5)$$

$$X_n = \frac{1}{N}\sum_{K=0}^{N-1} X_K e^{-\frac{2\pi i}{N}Kn} \quad , n = 0, 1, 2, \dots\dots\dots, N-1 \quad (6)$$

where X_K = variables in frequency domain; X_n = variables in time domain; N = total no of data records.

ANALYSIS AND DISCUSSION

The variability of dry day in Sylhet region and their frequency distribution were analyzed from the collected daily records and discussed in the following sections.

Linear regression

Scatter plot with linear regression of monthly dry days were plotted for the year 1957 to 2010 as shown in **Fig. 2** and this trend is summarized in **Table 3**. Number of monthly dry days for each year was estimated and used for the scatter plot. It was found that, the month January, May and October experienced weak positive trend while some other months i.e., March, April, June, July and September showed a weak negative trend as illustrated in **Table 3**. Moreover, a moderately constant trend was found in August and November whereas the trend of February and December remained almost stable. Hence, the dry days pattern is not changing significantly, instead a gradual variation is observed. Positive trend in winter months are indicating the dry periods are getting even drier.

Number of dry day for each season was also estimated from available data series and with their linear trend to understand the seasonal behavior. The corresponding graphs are shown in **Fig. 3** and trend is summarized in **Table 3**. The seasonal trend is slightly positive in post-monsoon and winter periods whereas summer shows a little decreasing trend. A moderately stable condition is found in monsoon season. Hence, the number of dry days and its distribution is not changing significantly rather slowly or steadily which can also be observed from the seasonal scatter diagrams.

Annual dry days have been plotted with linear regression during the study period and depicted in **Fig. 4**. An almost complete dry year was found in the year of 1996 which may occur due to faulty recording of the rain gauge. The annual data doesn’t look scattered and the trend is almost constant. Hence, the total number of dry days in a year is not changing year to year.

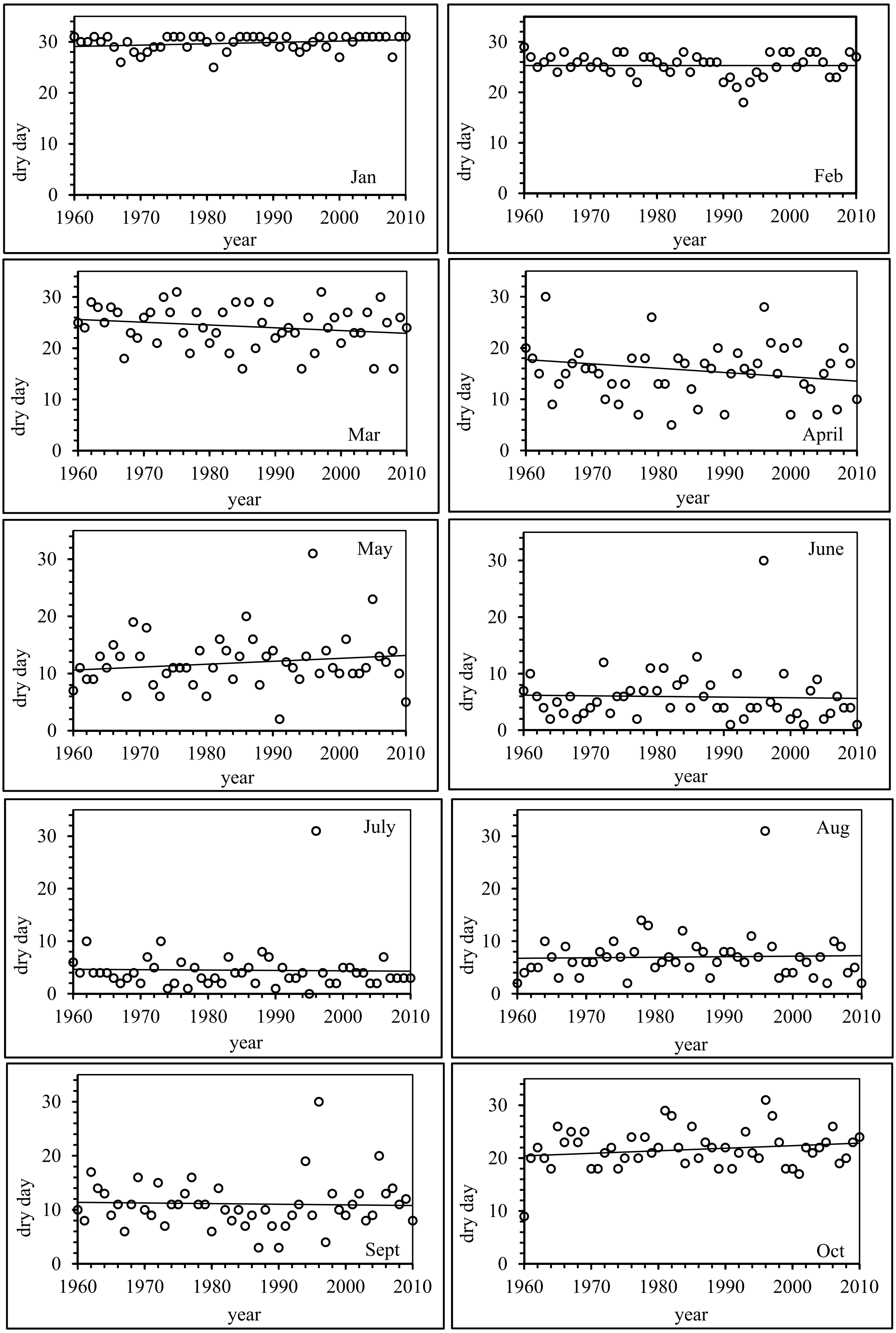
To understand the changing nature of dry days, number of dry days in five years interval for each month were also estimated during the study period starting from 1957 to 2010 and plotted with linear regression as shown in **Fig. 5**. The average value of dry days for a particular month during the five yearly slots is superimposed by empty bars in the same figure. The month January, May, June, July, August, October and November have a slight increasing trends whereas, the remaining months have decreasing trends. Minor or steady changing pattern of dry days can be observed from this analysis. Yearly average distribution of monthly dry days were estimated during the study period (1957–2010) and depicted in **Fig. 6**. The figure clearly indicates the dry and wet months in a year of the Sylhet region.

Spectral analysis of dry days

The Fast Fourier Transform (FFT) was used to analysis the temporal variations of monthly dry days data to check their frequency structure. A sequence of 512 months started from January, 1957 was used in the analysis and the dominating frequency corresponding to highest spectral density was determined. Monthly variation of dry days is shown in **Fig. 1**. Although few noisy data is observed in the monthly variation but the time series looks quite smooth with periodic variation.

Table 3. Summary of linear regression for both monthly and seasonal variation of dry days in the Sylhet region

Month	Trend pattern	Season	Trend pattern
November	Moderately, constant	Winter	Weak, positive
December	Strong, constant		
January	Weak, positive		
February	Strong, constant		
March	Weak, negative	Summer	Weak, negative
April	Weak, negative		
May	Weak, positive		
June	Weak, negative	Monsoon	Moderately, constant
July	Weak, negative		
August	Moderately, constant		
September	Weak, negative	Post-monsoon	Weak, positive
October	Weak, positive		


Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
dry day
year
0
10
20
30
1960
1970
1980
1990
2000
2010

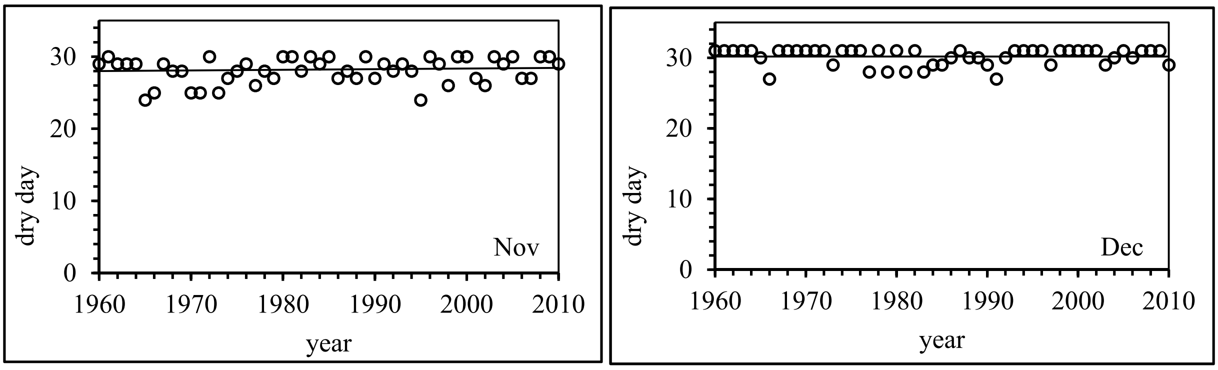


Fig. 2 Dry days distribution of each month with their linear trends considering data length of last 54 years (1957 – 2010).

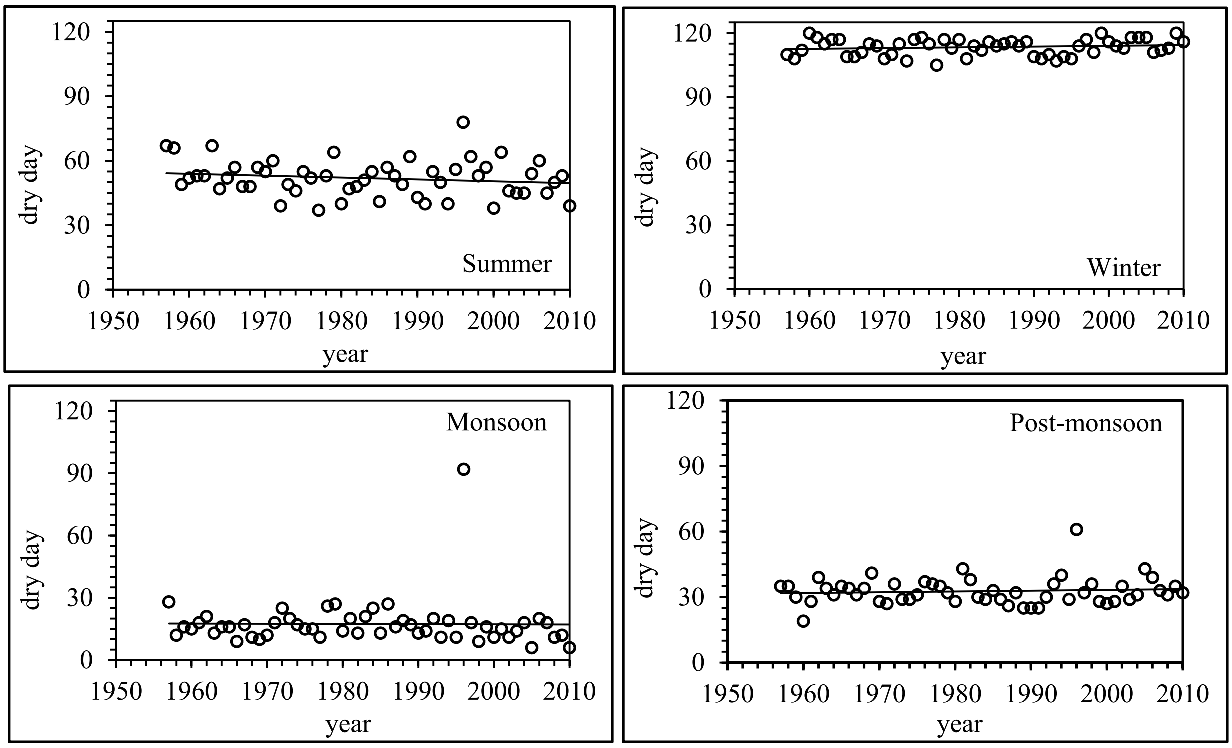


Fig. 3 Seasonal variation of dry days with their linear trend at Sylhet station.

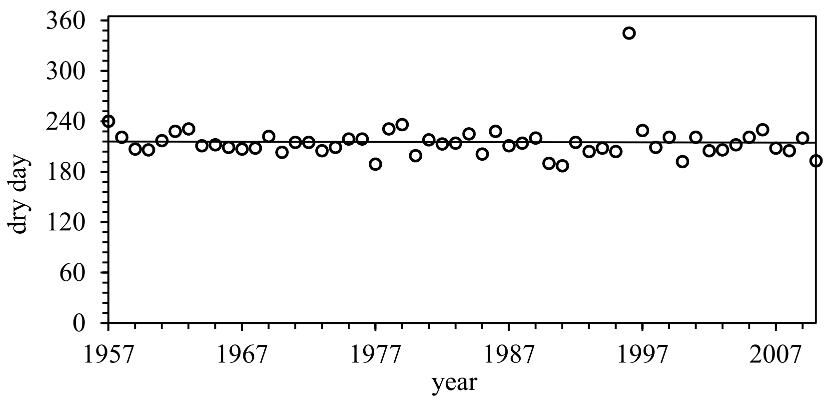
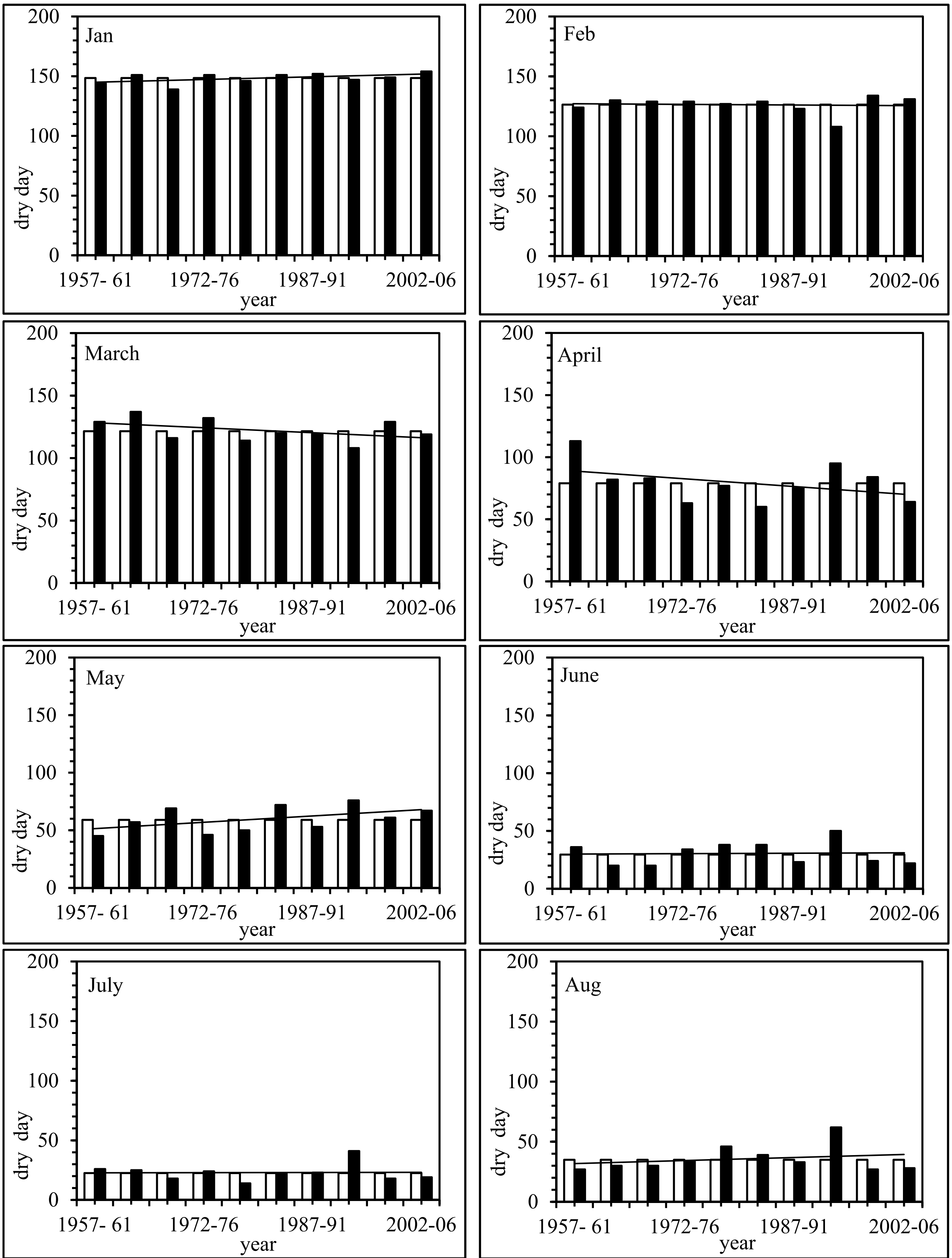


Fig. 4 Variation of annual dry days at Sylhet station for 1957 – 2010.

The frequency spectrum was estimated using **Eq. 5** and displayed in **Fig. 7**, which was normalized between 0 and 1. The peak frequency fp of 0.083984 month^{-1} (11.91 month) is found from the spectra, which speculates almost every year there is a major dry event (11.91 month < 12 month). However, the peak frequency occurred slightly less than 12 month indicates the major dry events are occurring earlier to some extent in a year compare to the previous year. Climate change might be the reason of minor shifting, but without further analysis it is not possible to conclude at this stage. The frequency structure is not showing any power in its higher frequency zone.

Monthly dry days variation was filtered through a band pass filter (0.08 to 0.088 month^{-1}) and compared with the original monthly variation and displayed in **Fig. 8**. Both the data series was normalized between 0 and 1 by the difference of the maximum and minimum values. The figure shows that the filtered signal follows reasonably well with the passage of major dry events. The filtered signal can be used for prediction of major events such as drought by extrapolating the series.



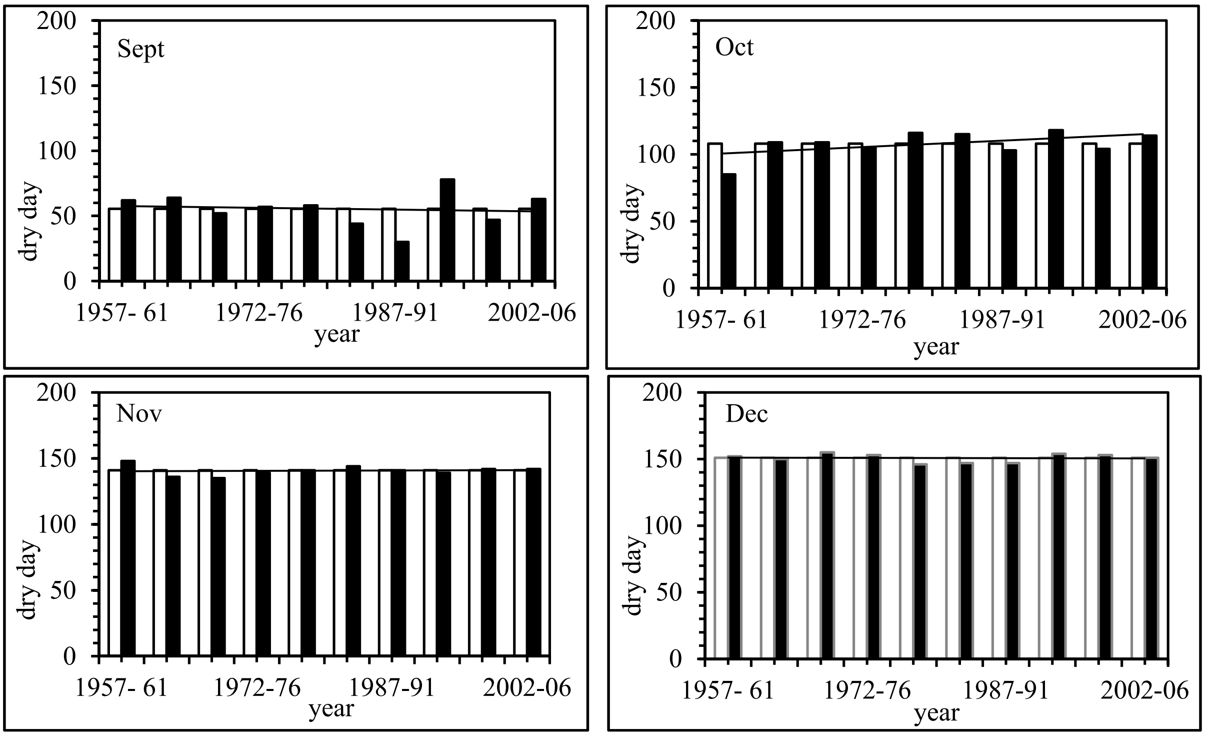


Fig. 5 Five yearly dry days variations of every month with their linear trend. Solid vertical bars indicate dry days whereas empty bars denote average values during the corresponding periods.

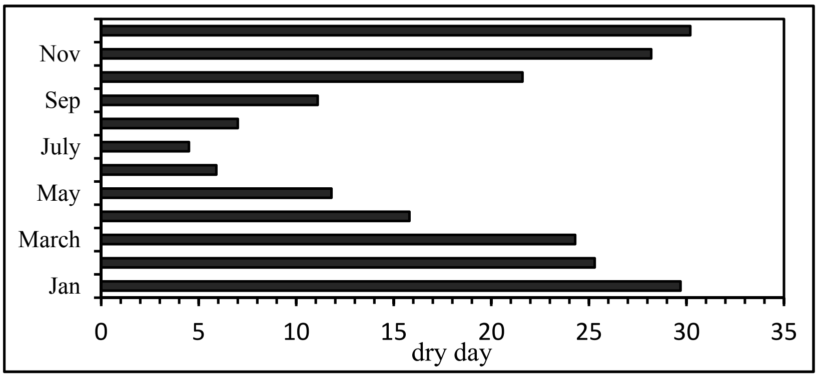


Fig. 6 Monthly average dry days distribution at Sylhet station estimated considering last 54 years data (1957–2010).

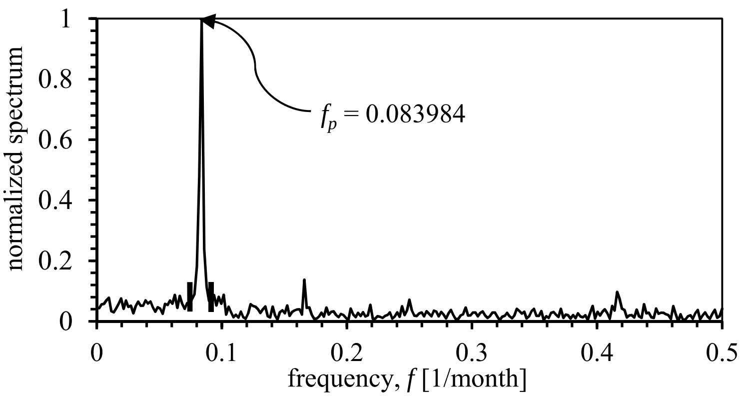


Fig. 7 Normalized spectra estimated from monthly dry days variation. Small vertical bars indicate the frequency range used for filtering.

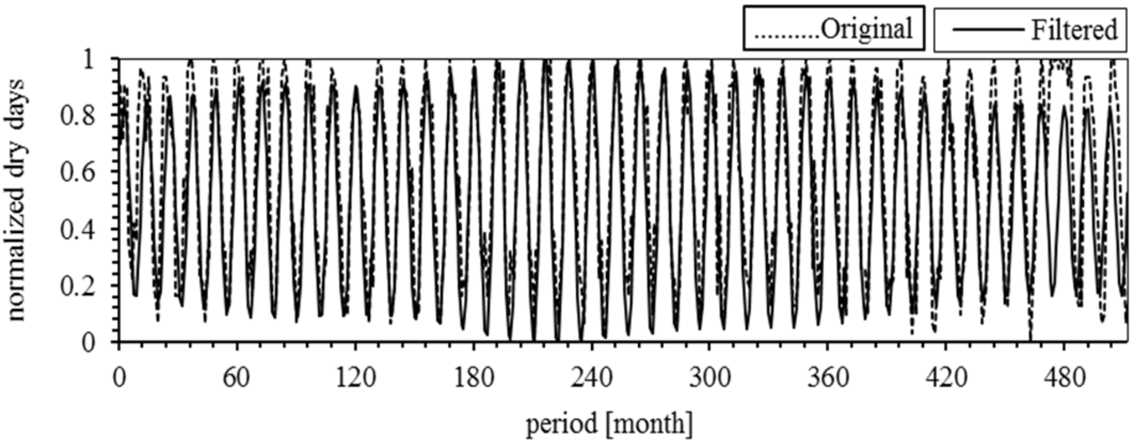


Fig. 8 Comparison between original monthly dry days variation and filtered (with a band pass filter 0.08 to 0.088 month^{-1}) variation. Both the data series were normalized between 0 and 1 by the difference of the maximum and minimum values.

Climatic classification

Climatic classification of Sylhet region was also performed by estimating the Aridity Index as discussed in section 3.3. The average annual precipitation was measured from the rainfall record of last 50 years (1961~2010). For missing data estimation, rainfall data of each day of a corresponding month in the data series were summed and then divided by the total number of available rainy days within that month. The obtained amount of rainfall was then multiplied by the actual number of days of the corresponding month, results rainfall for that particular month.

Rainfall magnitude of each day of a corresponding year was obtained in mm from the available data record. Annual mean precipitation was then estimated from the record. Mean annual temperature was collected from the Bangladesh Meteorological Department (BMD). Aridity Index was then calculated using **Eq. 4** and compared with the standard values as shown in **Table 2**. The estimated value is 101.02 (> 100) represents the climatic condition of the Sylhet region is "More Vegetation" type which indicates less vulnerable to drought and suitable for agricultural practices.

CONCLUSION

Rainfall data of the north-eastern part (Sylhet region) of Bangladesh were analyzed using statistical methods to understand the dry days and their changes over time. The dry days pattern are not changing significantly instead of a gradual variation is found from the monthly distribution. Yearly and seasonal variations are found almost constant. Temporal variation of monthly dry days data was analyzed with the Fast Fourier Transform. Peak frequency observed from the spectra is slightly less than 12 months indicating that almost every year there is a peak dry event and the major dry events are slightly earlier in a year compare to the previous year. The variability of dry day pattern in time scale was also estimated from filtered signals, which might be very useful for drought analysis, agricultural development and disaster management for Bangladesh. Moreover, Aridity Index was checked for climatic classification of the study area. The estimated index represents the climatic condition is less vulnerable to drought and suitable for agricultural practices.

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