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INTERDEPENDENCE BETWEEN DRY DAYS AND TEMPERATURE OF SYLHET REGION: CORRELATION ANALYSIS

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Abstract: Climate change can have profound impact on weather conditions around the world such as heavy rainfall, drought, global warming and so on. Understanding and predicting these natural variations is now a key research challenge for disaster-prone country like Bangladesh. This study focuses on the north eastern part of Bangladesh which is a hilly region, plays an important role in the ecological balance of the country along with socio-economic development. Present study analyses the behavior of maximum temperature and dry days using different statistical tools. Pearson's correlation matrix and Man-Kendall's tau are used to correlate monthly dry days with monthly maximum temperature, and also their annual trend. A moderate correlation was found mostly in dry summer months. In addition, a positive trend was observed in Man Kendall's trend test of yearly temperature which might be an indication of global warming in this region.

Keywords: Dry days; temperature; climate change; correlation matrix; statistical analysis; Bangladesh

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INTRODUCTION

Bangladesh, a republic of South Asia, having area of 147 570 km^2 with a population of 142 316 000 (Population & Housing Census, 2011), is situated between the foothills of the Himalayas to the north and the Bay of Bengal to the south. Agriculture and related sectors, food security, and energy security of this country are crucially dependent on various natural factors involving the variability of rainfall and the pattern of extreme high or low temperature (Islam, 2003). The economy of Bangladesh is predominantly agricultural where about 80% of the total population lives in rural areas and 62% of them are directly and others are indirectly engaged in a wide range of agricultural activities. The agricultural sector contributes around 29% of the country's Gross Domestic Product (GDP) and generates employment for 63% of the total labor force (Ministry of Agriculture: Bangladesh, 2013). But this sector is already under pressure from increasing demands for food and the parallel problem of depletion of land and water resources caused by overuse and contamination.

Rainfall is the most important natural factor that determines the agricultural production. The variability of rainfall and the pattern of extreme high or low precipitation are very important for the agriculture as well as the economy of the country (Shahid, 2008). Another important climate factor is temperature and its variation influences agriculture (i.e., flowering and harvesting dates), power generation and some other sectors. Temperature plays an indispensable role in the development and growth of plants as a source of heat energy.

The populations of Bangladesh are chronically exposed and vulnerable to a range of natural hazards like droughts, tropical cyclones etc in the pre and post-monsoon seasons and floods in the monsoon season. The Intergovernmental Panel on Climate Change (IPCC) termed Bangladesh as one of the most vulnerable countries in the world due to climate change (Parry et al., 2007). Global circulation model (GCM) results predict an average temperature increase in Bangladesh due to climate change of 1.0ºC by 2030 and 1.4ºC by 2050. Though monsoon precipitation is likely to increase by 6.8% by 2050, the distribution pattern of precipitation during the growing season, high temperature with high rate of evapo-transpiration will create further stress on water sector conditions and a decline in agricultural production in the drought-prone areas (Selvaraju *et al.*, 2006).

Hydrological changes are the most significant impacts of climate change in Bangladesh. A study on climate change vulnerability based on certainty of impact, timing, severity of impacts and importance of the sector, ranked water resources as the greatest concern due to climate change in Bangladesh (Shahid, 2010). It has been predicted that due to climate change there will be a steady increase in temperature and rainfall of Bangladesh (Parry *et al.*, 2007).

Long-term climate variability is paramount for the estimation of its impact on human activities and for predicting the future challenges. Studies in different parts of the world indicate that global warming has altered the precipitation patterns and resulted in frequent extreme weather events such as floods, droughts, rainstorms etc (Schmidli & Frei, 2005; Zhang et al., 2008, 2009; Briffa *et al.*, 2009). Research works found that the world is warming 0.6 ± 0.2°C over last 100 years, as quoted by Folland *et al.* (2001), Meehl *et al.* (2004) and Nicholls & Collins (2006). There is strong evidence that most of the global warming over the past 50 years has been essentially contributed by the increase in greenhouse gas concentrations. In many parts of the world, the intensity and persistence of heat waves have been shown to be closely linked by dry conditions, often prolonged drought and soil moisture deficits, as shown by Seneviratne *et al.* (2006). Beniston (2013) also investigated the influence of observed dry summer days on daily maximum temperature (T_{max}) as well as a clustering of rainless days over 30 locations in Europe and found the influence of rainless days is discernible, with an average difference between mean summer T_{max} and T_{max} during rainless days is up to 1.5°C. In the present study, the correlation between dry days and temperature is trying to establish through statistical analysis and correlation matrix for the region of Bangladesh.

STUDY AREA AND DATA COLLECTION

North-eastern part of Bangladesh

Sylhet, the north-eastern division of Bangladesh, located on the banks of Surma River in the Barak Valley with latitude 24°53′52″N and longitude 91°52′17″E, has a population of 500 000, making it the fifth largest city in Bangladesh. Sylhet is also famed for its natural setting, amidst rainforests, waterfalls, hills and river valleys. The area covered by Sylhet division is 12 569 km², which is about 8% of the total land area of Bangladesh. Geologically, the region is complex having diverse sacrificial geomorphology, high topography of Plio-miocene age such as Khasi and Jaintia hills, and small hillocks along the border. Near the center there is a vast low laying flood plain, locally called Haors. Around 400 Haors and Beels (wet lands) occupied 4450 to 25 000 km^2 of this region which are big natural depressions and made the region quite different from the rest of the parts of Bangladesh.

The area around Sylhet is covered with terraces of tea gardens and tropical forests. The area has over 150 tea gardens, including three of the largest tea plantations in the world, both in terms of area and production. The climate of Sylhet is humid subtropical with a predominantly hot and humid summer and a relatively cool winter. The region is within the monsoon climatic zone, with annual average highest temperatures of 23°C (Aug–Oct) and average lowest temperature of 7°C (Jan). Nearly 80% of the annual average rainfall of 3334 mm occurs between May and September.

Sylhet region not only plays an important role in the socio-economic development of Bangladesh but also important for ecological balance of the country. Any change of the hydro-climatic pattern like irregularities of rainfall, delay in monsoon rainfall, drought, and extreme high or low temperature in this region will significantly affect the balance among these natural features. Therefore, a comprehensive understanding of these features is very important. This study focused on long-term temperature variability with dry days by utilizing daily rainfall and maximum temperature data over the period of 50 years (1961–2010). Monthly, yearly and seasonal variation of temperature was also analyzed to check for any significant changes which may lead to hamper the harmony of this region.

Data collection

Bangladesh Water Development Board (BWDB) divided the whole country into 35 regions, which is the principal source for all hydro-meteorological data in Bangladesh. This study considered Sylhet station as the study area (**Fig. 1**). From BWDB, 50 years rainfall data started from year 1961 to 2010 was collected and used for this study. Number of dry days was calculated from the collected data series.

Daily maximum, minimum and average temperature data starting from 1961 to 2010 were also collected from the Bangladesh Meteorological Department (BMD). Huge missing data was observed for daily minimum and daily average temperature record and become unusable for statistical analysis. However, daily maximum data seems useable, though the continuity of the data was slightly hampered by some missing records (less than 2%). Hence, daily maximum temperature is used for this study.

MATERIALS AND METHODS

Dry days

Indian Institute of Tropical Meteorology defined 'dry days' as continuous period with daily rainfall equal to or less than daily mean rainfall over the area of interest (Singh & Ranade, 2009). Indian Meteorological Department (IMD) also defined criteria to differentiate wet and dry events across the Indian subcontinent. According to IMD, a dry day is a day when rainfall is less than 2.5 mm (Dash *et al.*, 2009). In Australia a dry day is considered as a day when daily total rainfall is less than 0.2 mm. As 0.2 mm is quite a small amount of

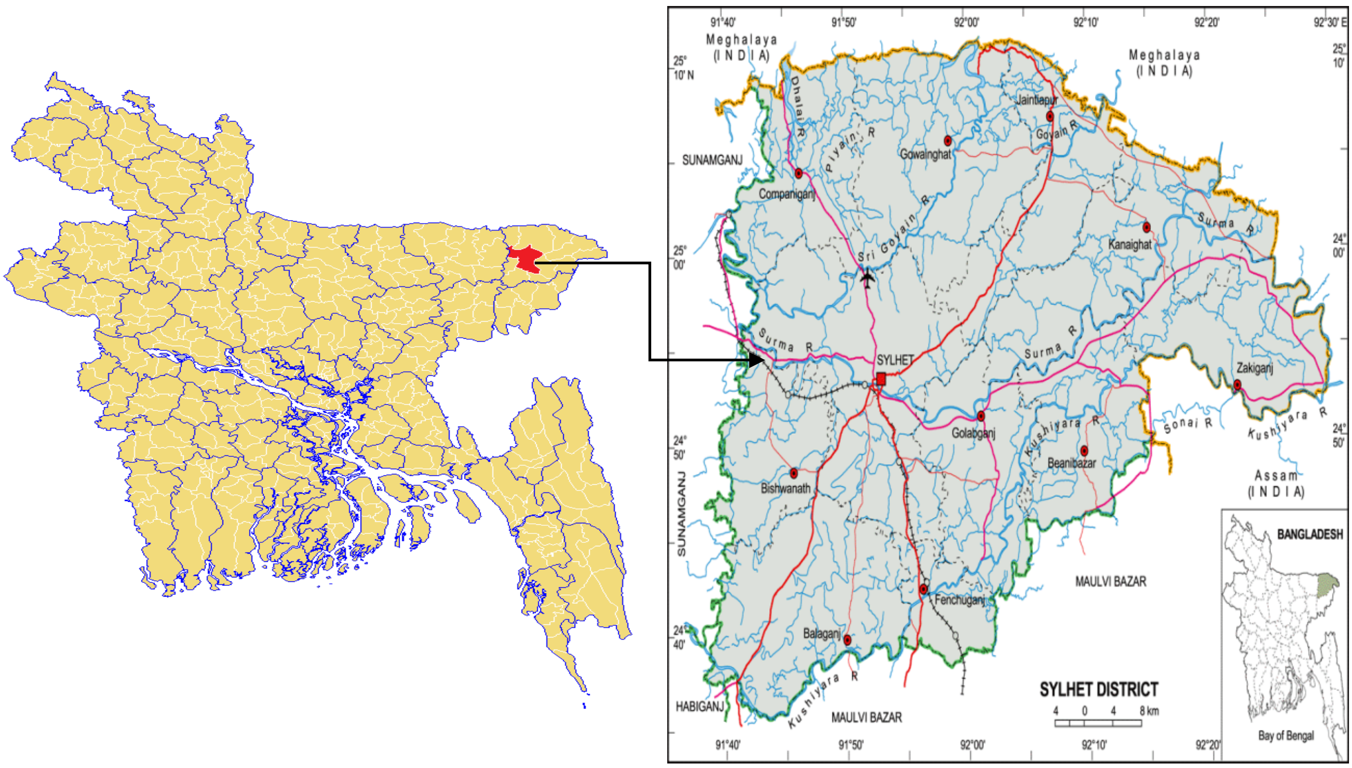


Fig.1 Map of Bangladesh with a close-up view which is showing the study region

rain, therefore recently less than 1 mm/day rainfall is considered as a dry day for some studies in Australia (Bureau of Meteorology, 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 rainfall less than or equal to 2.5 mm, similar definition is also considered by IMD.

Statistics tools

Statistical parameters are very important components to understand variability of a data set. This study used some useful measurements of variability involving Standard Deviation (σ), Average Absolute Deviation (AAD), Median Absolute Deviation (MAD), Skewness and Coefficient of Quartile Deviation (QD) which are widely used in the climate related studies. Definitions of those parameters are below:

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

$$AAD = (N-1)^{-1}\sum_{i=1}^{N}|X_i-\bar{X}| \quad (2)$$

$$AD = median\ (|x_i - median\ (x_i)|) \quad (3)$$

$$Skewness = \frac{\sum(Xi-\bar{X})^3}{(N-1)\sigma^3} \quad (4)$$

$$QD = \left(\frac{Q3-Q1}{Q3+Q1}\right) X\ 100 \quad (5)$$

where, N is the number of samples; X_i is the ith variable; $\overline{X}$ is the arithmetic mean; Q1, Q2 and Q3 are 1st, 2nd and 3rd quartile of a data series, respectively.

Inter-Quartile Range (IQR) also estimated using the available data series which provides rough approximation of the variability of data around their mean. The IQR is estimated as the 75% percentile of *sample* minus the 25% percentile.

Statistical analysis of dry days Monthly dry day’s distribution as shown in **Fig. 2(a)** reflects seasonal cycle during the study period. The number of dry days usually reaches to its minimum in July, whereas maximum values are observed in December and January. The variability of monthly dry days is relatively large from April to September. The statistical analyses (using above equations) of dry days are summarized in **Table 1**. Standard deviation, average absolute deviation, median absolute deviation and inter-quartile range express the variation in both the data set. Smaller value represents the data are closely spaced, whereas larger value denotes wide spreading. Estimated values of the calculated parameters are found relatively small for most of the months. The variability of data series was also checked using Fisher’s Skewness, **Eq. (4)**, to understand the degree to which the sample data deviates from the mean. Skewness becomes zero when a distribution is symmetric. Positive skewness value indicates clustering of data towards left of their mean whereas negative value indicates opposite. Estimated skewness are found either positive or negative, indicates normal distribution of the data series. Present study considered estimating coefficient of quartile deviation (QD) instead of coefficient of variation (CV), since for a skewed or grouped data set, the coefficient of quartile deviation is more useful than the CV. The calculated values of coefficient of quartile deviation are found to be satisfactory except for the month of June, July and August where the values are relatively high. High QD reflects low number of dry days during those monsoon months.

Statistical Analysis of Temperature Compared to dry days, monthly maximum temperature doesn’t depict a clear seasonality as can be seen from **Fig. 2(b)**.

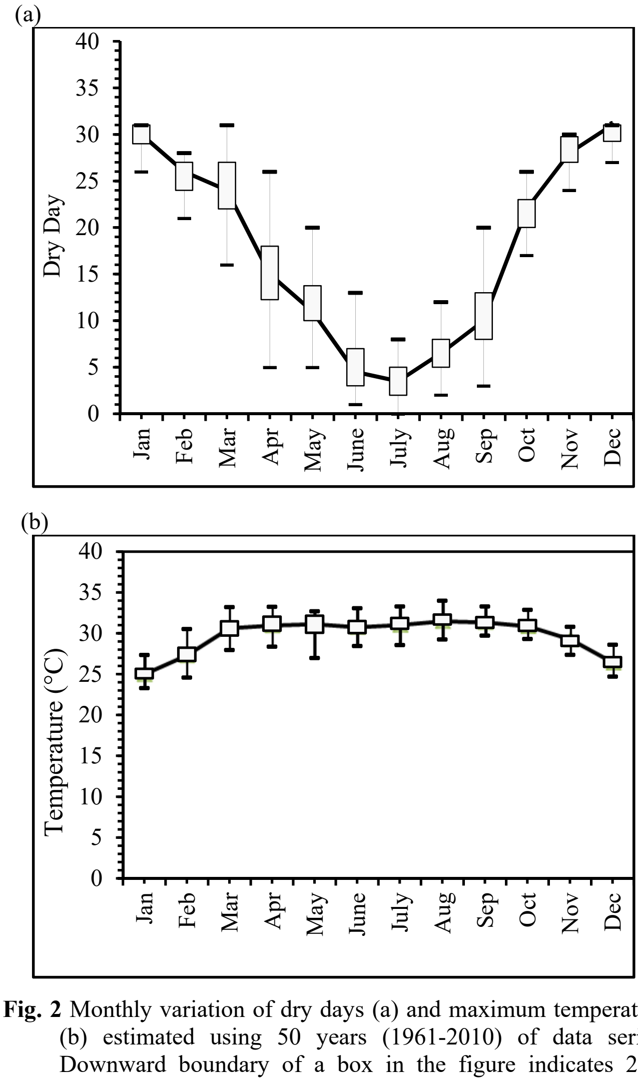


Fig. 2 Monthly variation of dry days (a) and maximum temperature (b) estimated using 50 years (1961-2010) of data series. Downward boundary of a box in the figure indicates 25th percentile and upward boundary indicates 75th percentile.

Maximum temperatures are found almost constant in most of the months in a year except winter (November to February). Estimated measures of variability are summarized in **Table 1**. Most of the statistical parameters are observed almost constant as the spreading of data are narrow.

Correlation Matrix

A correlation matrix describes relation among m variables where diagonal elements are equal to unity. It is a square symmetrical m x m matrix originates from the variance-covariance matrix. Both of these matrices contain similar information, but the correlation matrix makes it easier to relate variables with one another (Horn & Johnson, 1985). A correlation matrix for two variables can be estimated as following:

$$\text{Correlation matrix} = \begin{bmatrix} Pxx & Pxy \\ Pyx & Pyy \end{bmatrix} = \begin{bmatrix} 1 & Pxy \\ Pyx & 1 \end{bmatrix} \quad (6)$$

where Pxy an element of the correlation matrix which has the following form:

$$Pxy = \frac{SS_{xy}}{\sqrt{SS_{xx} * SS_{yy}}} \quad (7)$$

$$SSxx = \sum_{i \in S}(x_i - \bar{x})(x_i - \bar{x}) \quad (8)$$

$$SSxy = \sum_{i \in S}(x_i - \bar{x})(y_i - \bar{y}) \quad (9)$$

$SSxx$ is the sum of square of x variables with itself; whereas $SSxy$ is the sum of square of x variables with y. Sign of the correlation indicates whether both the variables are positively or negatively

Table 1. Monthly variation of different statistical parameters i.e., Mean (M), Median Absolute Deviation (MAD), Standard Deviation (SD), Inter-Quartile Range (IQR), Average Absolute Deviation (AAD), Skewness (SK) and Coefficient of Quartile Deviation (QD) estimated for dry days (upper table) and for maximum temperature (lower table)

Observed values							
Month	Statistical Parameters						
	M	MAD	σ	IQR	AAD	SK	QD
Jan	29.88	1.00	1.36	2	1.12	-1.08	3.33
Feb	25.48	1.50	1.97	3	1.64	-0.43	5.88
March	24.18	3.00	4.06	5	3.27	-0.40	10.20
April	14.74	3.00	4.56	5.75	3.64	-0.25	19.00
May	11.68	2.00	3.24	3.75	2.53	0.31	15.78
June	5.40	1.50	3.06	4	2.49	0.69	40.00
July	3.70	1.50	1.89	3	1.50	0.55	42.80
Aug	6.48	1.50	2.54	3	2.08	0.02	23.01
Sep	10.46	2.00	3.66	5	2.80	0.37	23.80
Oct	21.44	2.00	2.50	3	2.10	0.04	6.97
Nov	28.04	1.00	1.76	2.75	1.44	-0.67	4.84
Dec	30.18	0.00	1.19	1.75	0.98	-1.27	2.90

Estimated values							
Month	Statistical Parameters						
	M	MAD	σ	IQR	AAD	SK	QD
Jan	25.22	0.60	1.21	1.22	0.89	1.23	2.28
Feb	27.48	0.88	1.45	1.83	1.12	0.66	2.97
March	30.65	0.89	1.33	1.73	1.10	0.14	2.83
April	30.88	1.05	1.45	1.86	1.15	-0.56	2.75
May	30.92	1.06	1.32	2.10	1.10	-0.63	3.38
June	30.78	0.76	1.04	1.49	0.85	-0.07	2.41
July	31.12	0.57	1.05	1.34	0.79	-0.13	2.16
Aug	31.61	0.71	1.07	1.21	0.86	-0.17	1.91
Sep	31.40	0.67	1.00	1.31	0.83	0.22	2.1
Oct	30.94	0.67	0.93	1.32	0.75	0.24	2.15
Nov	29.14	0.69	0.83	1.22	0.69	-0.24	2.11
Dec	26.54	0.64	0.91	1.23	0.74	0.51	2.25

Table 2. Value of Pearson's correlation matrix indicating strength and association between variables (Horn & Johnson, 1985)

Absolute Value	Interpretation	Meaning: How much of the Variance in 'y' is explained by Variance in 'x'
1.00	Perfect	All
0.80-0.99	Strong	Nearly all
0.50-0.79	Moderate	Definitely few but not all
0.30-0.49	Weak	Few of them
0.00-0.29	Possible	Probably none; any connection is more likely random

related whereas the absolute value (difference from 0 without regard to sign) indicates the strength of relationship between the variables (**Table 2**).

To determine statistical significance of an observed outcome, there are two important numbers. First one is called the p-value of test statistic and the other one is the level of significance, also known as alpha (α). Alpha indicates how extreme the results are which must be in order to reject the null hypothesis of a significance test. The value of alpha is associated to the confidence level of the test. Although in theory and practice different values can be used for alpha, but the standard one is 0.05. This study used 0.05 as the experimental value. A p-value is a probability and explains how extreme a statistic is for an experimental data. To determine the statistical significance of the observed outcome it's important to compare the values of alpha and the p -value. There are two possibilities that emerge:

- The p-value is less than or equal to alpha (p-value ≤ α): reject the null hypothesis which means the experimental result is statistically significant.
- The p-value is greater than alpha (p-value > α): accept null hypothesis which means the experimental result is not statistically significant.

Estimated correlation matrix between monthly maximum temperature and dry days are shown in **Fig. 3** and summarized in **Table 3**, where for better understanding, matrix value of respective months are shown only. From monthly variation of dry days, weak correlation is observed in most of the months except March, April and May; whereas moderate correlation was found between monthly maximum temperatures and dry days. Moderate correlation indicates weak change of monthly maximum temperature which can be explained by change of the monthly dry days.

Moreover, based on the adjectives, this study divided a year into four seasons usually used in Bangladesh, i.e., winter (November, December, January and February), summer (March, April and May), monsoon (June, July, and August) and post-monsoon (September and October). Seasonal change of temperature due to respective dry days change are also analyzed using Pearson's correlation matrix as shown in **Fig. 4** and summarized in **Table 3**. Summarized value indicates a moderate relationship exists in summer season while weak or no correlations were found in other seasons.

Mann-Kendall's trend test

Mann-Kendall test (Mann, 1945; Kendall, 1975) is commonly used to assess the statistical significance of a trend. This test analyzes the sign of difference between 'later-measured' data and 'earlier-measured' data. Each later-measured data is compared to all data measured earlier; resulting in a total of n(n – 1)/2 possible pairs of data, where n is the total number of observations. The test statistic, S (score) is then computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \quad (10)$$

where, $sign(y_j - y_i)$ is equal to +1, 0 or -1. A positive value of S indicates an 'upward trend' whereas a negative value indicates 'downward trend'. If S is a large positive number which indicates later-measured values tend to be larger than earlier values with an upward trend. Alternatively if S is a large negative number, then later values tend to be smaller than earlier values with a downward trend and small value of S indicates no trend.

The test statistic τ (Kendall's tau) is used to measure the association between two measured quantities and computed as:

For large samples (if $n > 8$), S is normally distributed with mean zero and variance is

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (11)$$

Therefore, the test statistic Z is calculated as

$$Z = \begin{cases} \frac{(S-1)}{\sqrt{var(S)}} if S > 0 \\ 0, if S = 0 \\ \frac{(S+1)}{\sqrt{var(S)}} if S < 0 \end{cases} \quad (12)$$

where, Z follows standard normal distribution with mean zero and variance unity. A positive value of test statistic indicates a positive association, a negative value of test statistic indicates negative association and test statistic equal zero means no association. The null

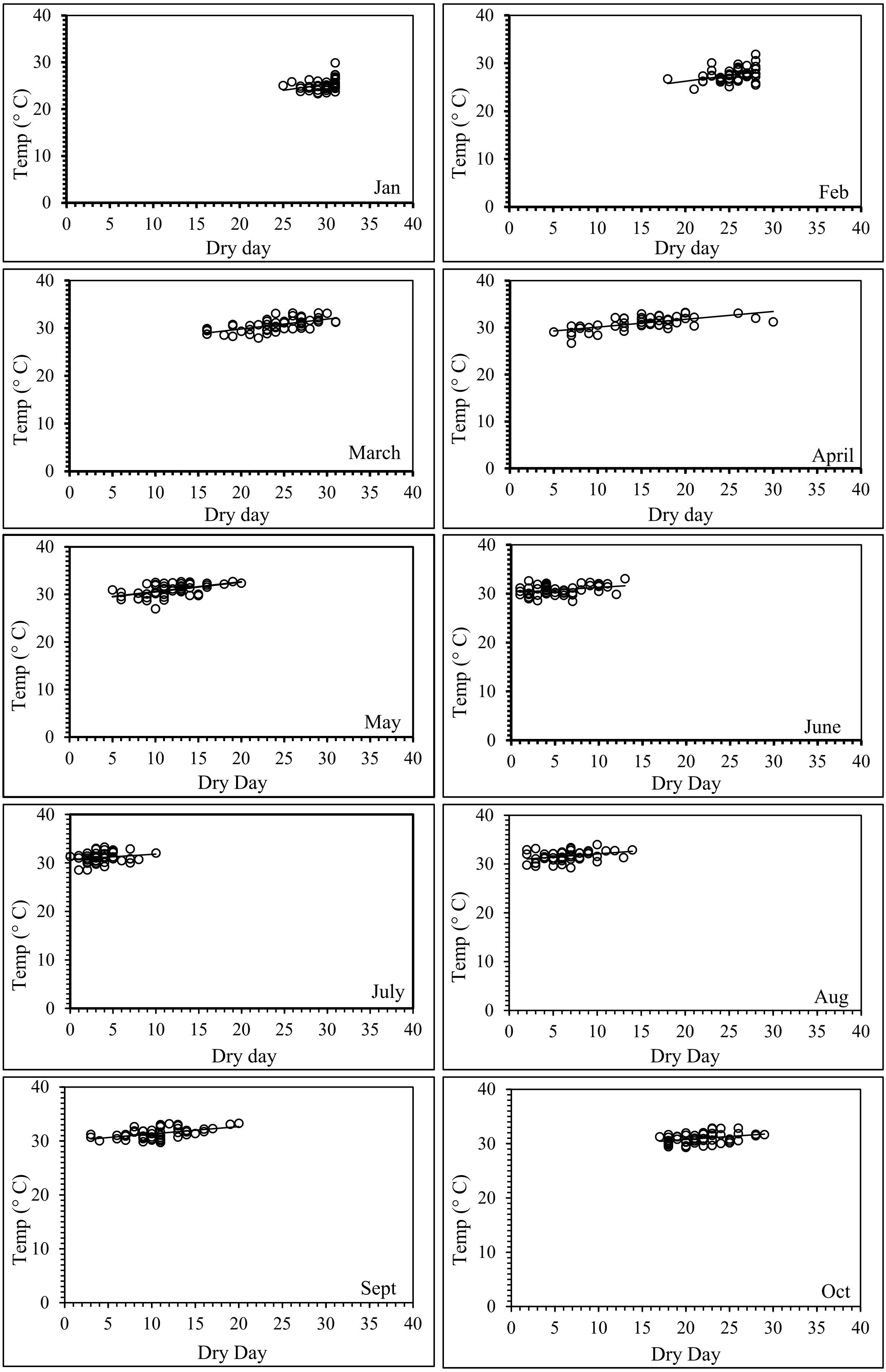
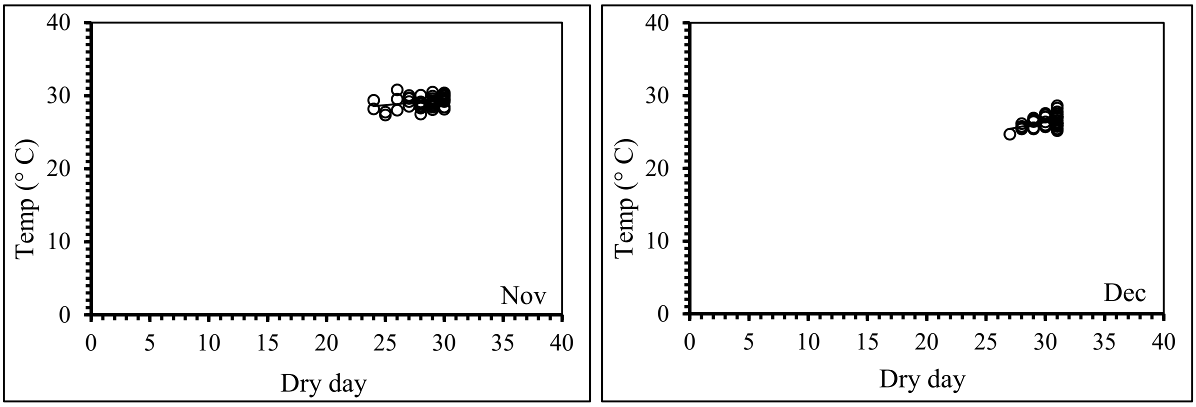


Fig. 3 Correlation between maximum temperature and dry days for every month during the study period (1961-2010).



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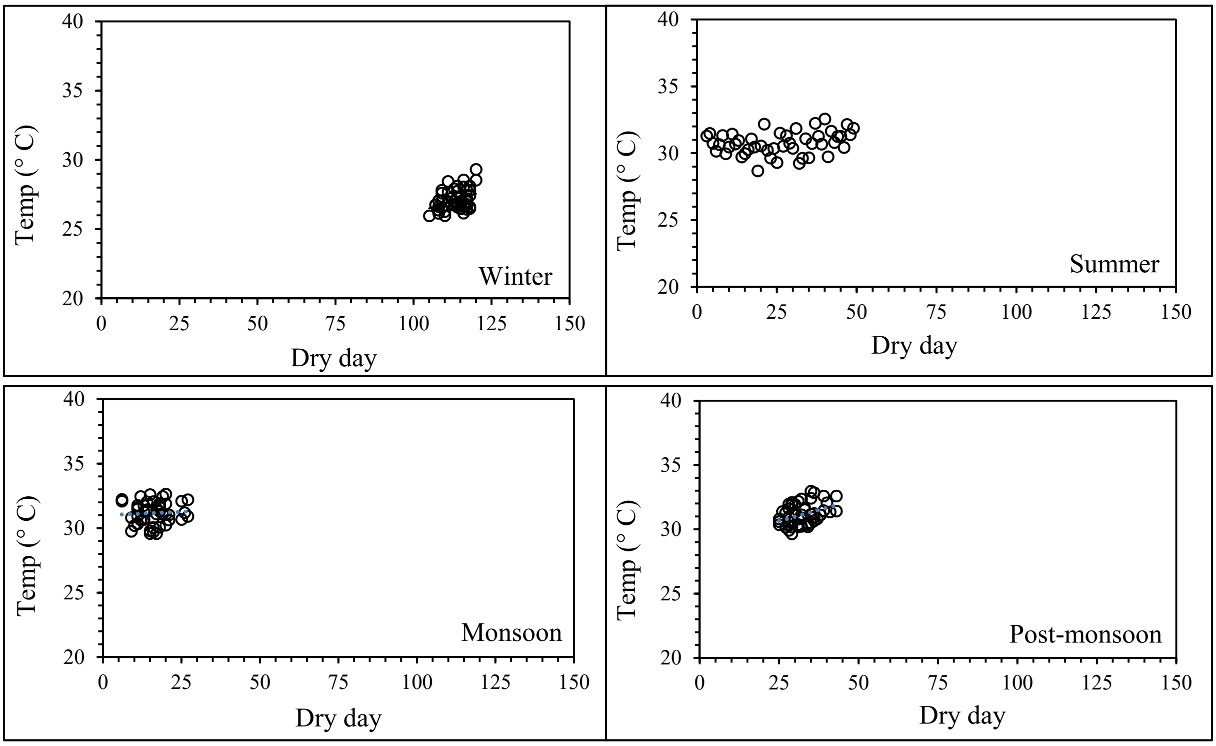

Fig.4 Seasonal distribution of maximum temperature and dry days during the study period (1961 – 2010) of Sylhet region.

Table 3. Summary of correlation matrix analysis for both monthly and seasonal variation of maximum temperature due to the change of corresponding dry days. Statistically significant values (p-value ≤ α) are denoted by bold font.

Month	Pearson's correlation value	Interpretation	Season	Pearson's correlation value	Interpretation
November	0.30	Weak	Winter	0.37	Weak
December	0.37	Weak			
January	0.33	Weak			
February	0.34	Weak			
March	0.59	Moderate	Summer	0.56	Moderate
April	0.63	Moderate			
May	0.51	Moderate			
June	0.31	Weak	Monsoon	0.10	Possible
July	0.17	Possible			
August	0.34	Weak			
September	0.44	Weak	Post-monsoon	0.40	Weak
October	0.33	Weak			

Table 4. Mann-Kendall's trend test for annual temperature and dry days variation. Statistically significant values (p-value ≤ α) are denoted as bold font.

Mann-Kendall's Trend Test			
Annual Maximum Temperature		Annual Dry Day	
Kendall's tau	0.513	Kendall's tau	-0.087
p-value	0.0001	p-value	0.379
Alpha (α)	0.05	Alpha (α)	0.05

hypothesis of no trend is rejected when S and *Z* are significantly different from zero.

Man Kendall's test evaluates whether a recorded data has increasing or decreasing tendency over time. Kendall's trend test is summarized for both annual maximum temperature and annual dry days in **Table 4**. A positive value of tau for maximum temperature was found from the analysis. As the computed *p*-value is lower than the significance level alpha (= 0.05), present study rejected the null hypothesis (H_0), and accepted the alternative hypothesis (H_a), while the risk to reject the null hypothesis H_0 is lower than 0.01%. Consequently it's clear that the observed Kendall's positive tau is statistically expectable and annual temperature is increasing with a slight upward trend over time which might be a signal of global warming in this region. In addition to temperature, Kendall's tau also calculated for annual dry days and found a negative value. Estimated p-value is found to be greater than the significance level alpha (= 0.05), and the risk to reject the null hypothesis (H_0) was 37.93%. As a result present study accepted null hypothesis, thus Kendall's tau became statistically insignificant.

CONCLUSION

Statistical analysis of dry days and temperature represents quite acceptable results except descriptive statistics for dry days during monsoon season. As major portion of rainfall occur during monsoon period might be a reason behind this fluctuation. Present study used correlation matrix to identify the correlation between monthly dry days and monthly maximum temperature. A weak correlation was found in almost all months except dry summer months i.e. March, April and May where moderate correlation was observed. Moreover, seasonal variation represented a moderate correlation during summer while a gradual or no relationships were found in other seasons. In addition present study also used Man Kendall's test to evaluate the behavior of annual dry days and annual maximum temperature.

A statistically significant positive trend was observed for yearly maximum temperature which might be a signal of global warming. On the other hand, the dry days pattern are not changing significantly instead of a slow/gradual variation is found from the Kendall's test.

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