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Quantifying Trends of Historical Climatic Variables in the Jessore Region of Bangladesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

The aim of the study was to detect trends in salient key climate variables in the Jessore region of Bangladesh for the years 1985–2014, and the data was collected from the Bangladesh Meteorological Department (BMD). Annual rainfall, annual maximum temperature, and annual cloud coverage were analyzed using the non-parametric Mann-Kendall test, linear regression, and LOWESS curve to detect trends in the series. The rainfall and cloud coverage showed a decline trend at a rate of (4.50 mm/year; 45.02 mm/decade) and (0.045 octas/year; 0.45829 oktas/decade), respectively, whereas temperature manifested an increment trend (0.0285°C/year; 0.2854°C/decade), where cloud coverage was the only significant variable. The structural breakdown point was found using the graphical method and the Chow test, which showed in 2004 that both the series containing breakdown points and cloud coverage exhibit statistical significance.

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1 Introduction

Bangladesh is one of the most affected countries in the world in terms of climate change. The greater part of her territory is not elevated above sea level, and a large portion of the country is flooded on an annual basis. Natural calamities like floods, tsunamis, cyclones, storms, and droughts occur regularly due to climate change. That is why the study of climate-related variables is badly needed in Bangladesh.

"The temperature of the earth has increased by 0.3–1°C since the beginning of the 20th century as a consequence of increased CO2 in the atmosphere. Computer simulations of global temperature change show that if the CO2 concentration of the atmosphere doubles from its present-day value, then the global temperature would increase by 1.3–4 °C" [1]. Variables like temperature, rainfall, and cloud coverage are part and parcel of the atmosphere. If one of the variables is changed, surely other variables will be altered.

Bangladesh has already experienced, and generally we are facing, some of the impacts of climate change, such as summer becoming warmer, irregular monsoons, untimely rainfall, bulky amounts of rainfall during short periods causing landslides, small amounts of rainfall in dry periods, increased river flow during monsoons, monsoon floods, drought due to a shortage of potable water, extreme heat and extreme cold causing diarrhea, typhoid, malaria, cholera, dysentery, outbreaks of dengue, etc.

Research on climate variables for the Jessore region, such as rainfall, temperature, and cloud coverage, is not emphasized. A number of researchers have published papers regarding the trend of climate variables in the last 10 years such as Mann–Kendall trend detection for precipitation and temperature in Bangladesh [2]; Observed trends in climate extremes over Bangladesh from 1981 to 2010 [3]; *Trend analysis of major hydroclimatic variables in the Langat River basin, Malaysia.*[4]; A Trend Analysis of Temperature and Rainfall to Predict Climate Change for Northwestern Region of Bangladesh [5] and Trends of Climatic Variables (Rainfall and Temperature) at Sylhet, Bangladesh [6]. Detection of changes and trends in climatic variables in Bangladesh during 1988–2017 [7]; (Ali, 1999; Shahid, 2011). "Exploring the Behavior and Changing Trends of Rainfall and Temperature Using Statistical Computing Techniques Climate Change in Bangladesh" [8]. A Historical Analysis of Temperature and Rainfall Data [9]. "The variation of mean annual temperature over Bangladesh follows closely to that of the Northern Hemisphere land temperature: a warming trend during 1910-1940, a slight cooling trend until the mid -1970s, and resumed warming there after" [10]. For the period 1979-1991, 12 out of the 13 years were warmer than the reference period. Karmakar and Nessa [11] reported "on climate change's effects on natural disasters, the south-west monsoon, and the Bay of Bengal in Bangladesh. The mean annual temperature over Bangladesh has shown increasing tendency especially after 1961-1970". Chowdhury and Debsarma [12] observed "the increasing tendency of the lowest minimum temperature over Bangladesh". Ahmed & Karmakar [13] noted "arrival and withdrawal date of the summer monsoon in Bangladesh". Ferdous & Baten [14] explore "climatic variables of 50 years and their trends over Rajshshi and Rangpur division".

2 Materials and Methods

2.1 Data AND variables

2.1.1 Data

The annual data of the climatic variables rainfall, temperature, and cloud coverage of the Jessore region for the period January 1985 to 2014 are used in this research, and the data were collected from the Bangladesh Meteorological Department (BMD). The data has been organized, and no missing value has been found. We have arranged, furnished, and tabulated the original raw data to pursue our objective of the study. The units of measurement of the considered variables are Celsius, mm, and octas respectively. Software like MS Office and the various R packages have been used to arrange this data set as time series data, and subsequent analysis has been conducted by R code.

2.1.2 Temperature

Temperature is an objective comparative measurement of whether something is hot or cold. Average maximum and minimum temperatures in winter are 29^0C and 11^0C, respectively, and 34^0C and 22^0 in summer over

Bangladesh (BBS, 2002). Bangladesh has a tropical monsoon-type climate, with a hot and rainy summer and a pronounced dry season in the cooler months. January is the coolest month of the year, with the temperature ranging from 13.5^0C to 26^0C, and April is the warmest month, with the temperature ranging from 33^0C and 36 36^0C.

2.1.3 Rainfall

Water that is condensed from the aqueous vapor in the atmosphere and falls in drops from the sky to the earth is called rain, and the total amount of rain that falls in a particular area within a certain time is called rainfall. The rainfall in Bangladesh varies seasonally and from place to place. About 70.6% of the country's average rainfall occurs in the monsoon season, and 18.8% occurs per monsoon season. The winter and post-monsoon contribute to 1.6 and 9.0% of annual rainfall, respectively. The area-weighted country average annual rainfall of Bangladesh is 2315.7 mm, and monsoon rainfall is 1635.4 mm, as obtained from the data of 57 years from 1948–2004.

2.1.4 Cloud Coverage

A visible collection of particles of water or ice suspended in the air, usually at an elevation above the earth's surface. In Bangladesh, the cloud cover has two opposing seasonal patterns, coinciding with the winter monsoon and the summer monsoon. As a result of the flow of cold, dry winds from the northwestern part of India during the winter season, the cloud cover is at a minimum. On average, the cloud cover in this season is about 10%, almost all over the country. With the progression of the season, the cloud cover increases, reaching 50–60% by the end of the pre-monsoon hot season. During the summer monsoon season, which is also the rainy season, the cloud cover is very widespread. In the months of July and August, which are the middle of the rainy season, the cloud cover varies from 75 to 90% all over the country. However, it is more extensive in the southern and eastern parts (90%) than in the northwestern part (75%). After the withdrawal of the summer monsoon, the cloud cover decreases rapidly, dropping to 25% in the northern and western parts and 40–50% in the southern and eastern parts.

2.2 Trend detecting tools

2.2.1 LOWESS curve

A very popular technique for curve fitting complicated data sets is called LOWESS (Locally Weighted Smoothing Scatter Plots). LOWESS, originally proposed by Cleveland [15] and further developed by Cleveland and Devlin [16], specifically denotes a method that is known as locally weighted scatter plot Smoothing. In LOWESS, the data is modeled locally by a polynomial-weighted least squares regression, with the weights giving more importance to the local data points. This method of approximating data sets is called locally weighted polynomial regression.

2.2.2 The LOWESS method

The Lowess method requires the use of a weighted least squares linear regression fit. For this weighted fit, the data points each have associated with them a weight, so you are given a set of points and weights. The difference between weighted least squares and regular least squares is that the function that is minimized as

$$F(\alpha_1, \alpha_2, \dots, \alpha_N) = \sum_{i=1}^{N} w_i \left(\frac{y_i - f(t_i;\ \alpha_1, \alpha_2, \dots, \alpha_M)}{\sigma_i} \right)^2$$

The lowess fit is calculated at each data point in the data set. At each point, a local polynomial is fitted to a local region of the data using linear least squares regression. The method has two inputs: the smoothing parameter (usually between 0 and 1) and the degree of the local polynomial (usually 1 or 2).

Let’s work out how Lowess fits into the data points.

First, we need the weights for the neighboring data points. Here is how these weights can be calculated: The user supplies two parameters: a smoothing parameter and the degree of the local polynomial that is to be fitted to the data.

Then, the following distances are calculated:

$$d_i = (t_k - t_i)\,, i = 1, 2, \dots, N$$

which are sorted into ascending order.

The quantity q is calculated,

$$q = \max\,(Truncated(\alpha N), 1).$$

This is used to calculate the distance scale

$$D = \begin{cases} d_q & , \quad \alpha \leq 1 \\ \alpha d_N & , \alpha > 1 \end{cases}$$

The weight function for the data points is defined as

$$T(u) = \begin{cases} (1 - |\mathrm{u}|^3)^3 & |\mathrm{u}| \leq 1 \\ 0 & |\mathrm{u}| \geq 1 \end{cases}$$

The weights for the data points are then given by

$$w_i = T\left(\frac{t_i}{D}\right)$$

Once the weights have been found, the weighted polynomial fit on the points $(t_i\,,\,y_i)$ with weights w_i is performed. This fit function is then used to determine the lowess fit at t_k.

This entire procedure is repeated for each data point $(t_k\,,\,y_k)$, $k = 1, 2, \dots, N$. The effect of the weight function is to make LOWESS a local polynomial fit, taking into account the neighboring points of the point (t_k,y_k). Typically, the smoothing makes only a few neighboring points contribute; the weights for points far away from (t_k,y_k) are going to be zero.

2.2.3 Mann-Kendall trend test

A non-parametric test for monotonic trend detection is known as the Mann-Kendall test. A monotonic trend can be either an upward trend or a downward trend. In the Mann-Kendall test [17] (Kendall, 1975), the data are evaluated as an ordered time series. Each data point is compared to all subsequent data points. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (e.g., no trend) [18-21]. If data from a later time period is higher than data from an earlier time period, S is incremented by 1. On the other hand, if the data from a later time period is lower than the data sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.If $x_1, x_2, \dots, x_i$ represent *n* data points where x_i represents the data point at time *j*, then *S* is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

Where,

$$sign(x_j - x_k) = \begin{cases} 1 if\,(x_j - x_k) > 0 \\ 0 if\,(x_j - x_k) = 0 \\ -1 if\,(x_j - x_k) < 0 \end{cases}$$

The probability associated with S and the sample size, n, are then computed to statistically quantify the significance of the trend [22-25].

Mann-Kendall statistics computed as follows

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 if S = 0 \\ \frac{S-1}{\sqrt{VAR(S)}} if S < 0 \end{cases}$$

In Mann-Kendall trend test assume that under following hypothesis.

H_0 : There is no trend in entire data set

H_1 : There is a monotonic trend in the data set (upward or downward)

3 Results and Discussion

3.1 Graphical visualization

3.1.1 Lowess curve, trend line, and time series plot for rainfall

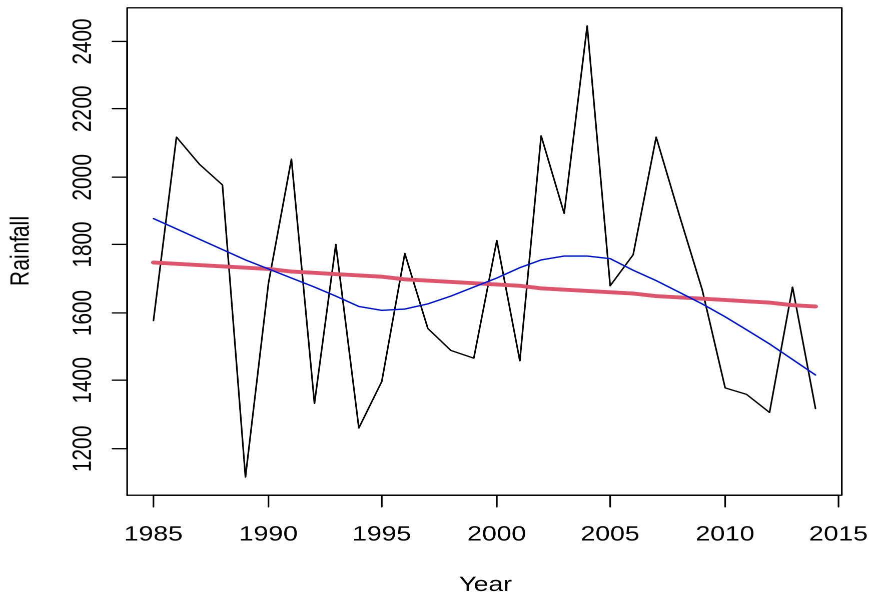

Fig. 1. Lowess curve for Rainfall

Comments: From the aforementioned graph, it can be seen that the monthly rainfall is monotonically falling from 1985 to 1995; it then slightly increases from 1996 to 2004; and finally, it decreases monotonically from 2005 to 2014. Therefore, it may be concluded that rainfall throughout our research period has been progressively declining.

3.1.2 Lowess curve, trend line, and time series plot of temperature

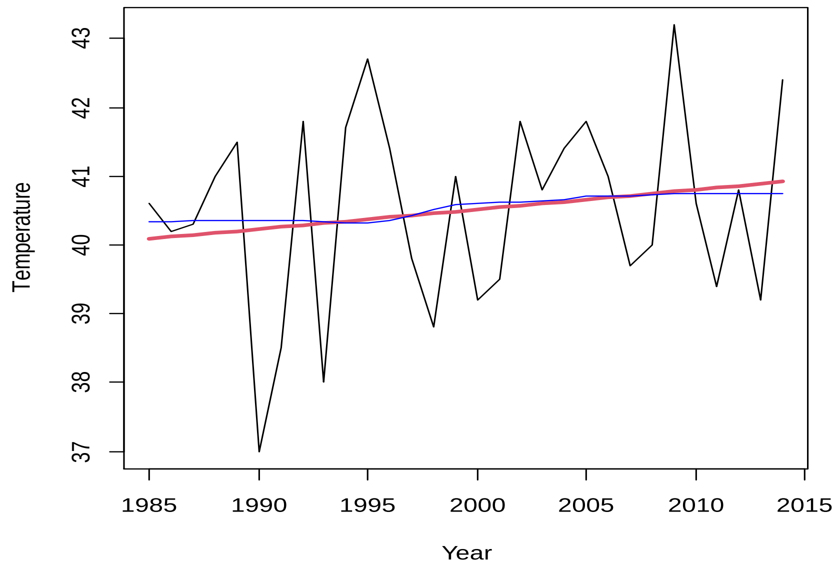

Fig. 2. Lowess curve for annual maximum Temperature

Comments: It is obvious from the above graph that over the study period, maximum temperature is increasing gradually.

3.1.3 Lowess curve, trend line, and time series plot for cloud coverage

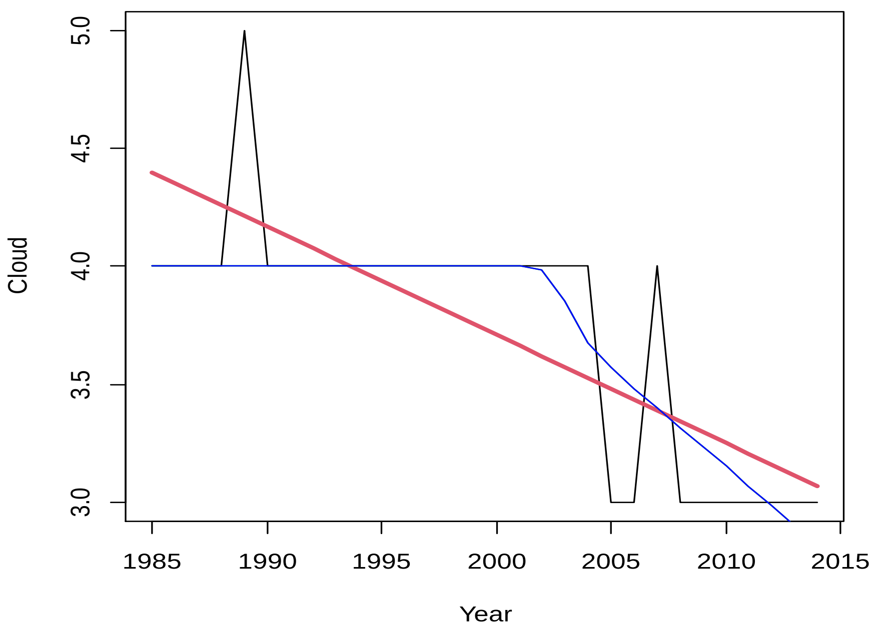

Fig.3. Lowess curve for Cloud coverage

Comments: We observed from the graph that the yearly mean cloud coverage has been decreasing throughout the period, but the breakdown point in 2004 which is visible.

3.1.4 Breakdown point of rainfall

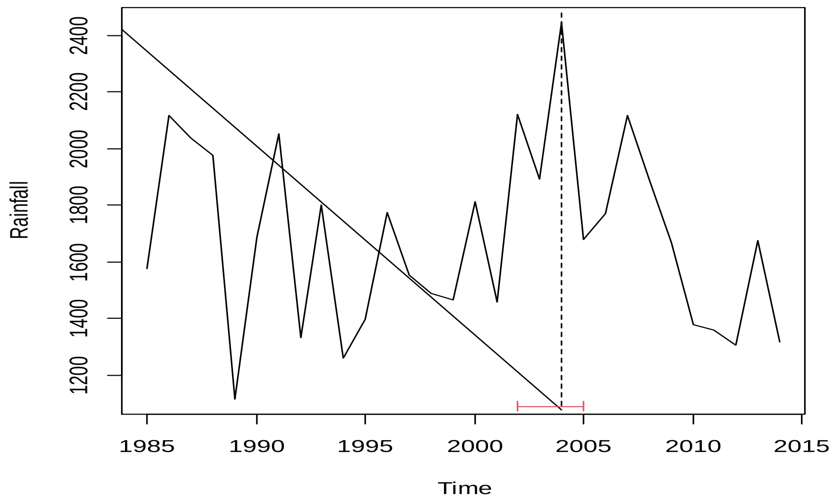

Fig.4 Detection of breakdown point of rainfall

Comments: We see that there is a breakdown point in the yearly rainfall series for the year 2005. So, there are two patterns in the series, such as 1985–2004 and 2005–2014.

3.1.5 Breakdown point for cloud coverage

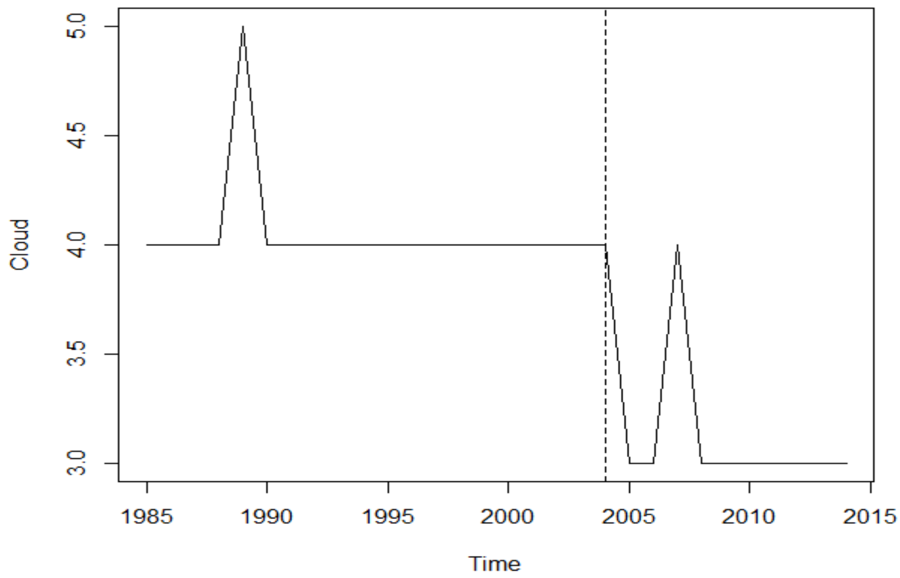

Fig. 5 Detection of breakdown point of cloud coverage

Comment: We see that cloud coverage is suffered from structural break in the year 2004. So, there are two different pattern of the series like 1985 to 2004 and 2005 to 2014.

3.2 Quantitive method

3.2.1 Detecting structural breaks

Table 1. Detecting Structural Breakdown point with Cho-test.

Variables	Corresponding to breakdates	Chow test
Rainfall	2004	inadmissible
Temperature	Nill	Nill
Cloud	2004	p-value = 0.0242 Significant

Comments: In temperature series, there is no breakdown point**.** Since amount of rainfall and cloud coverage are positively correlated, that is why, same breakdown point has happened in 2004 for the series of rainfall and cloud coverage which was expected.

3.2.2 Mann-Kendall trend test

Table 2. Mann-Kendall trend test for the selected variables

Variable	Tau (τ)-statistics	Two-sided p-value	Decision Rule
Rainfall	-0.131	0.315	insignificant
Temperature	0.0814	0.54339	insignificant
Cloud coverage	-0.653	0.000018	significant

Comments: The tau statistic shows that the monthly rainfall level has been declining for the whole time. However, the Mann-Kendall test's p-value is greater than 0.05, which suggests that there is a statistically insignificant decrease trend in the rainfall levels. The test statistic indicates that there is a positive trend in the monthly maximum temperature. As it is seen that the Mann-Kendall test's p-value is less than the level of significance (0.05), it may be concluded that there is a statistically insignificant upward trend in temperature. The test statistic indicates that there is a negative trend in the cloud overage. As it is seen that the Mann-Kendall test's p-value is less than the level of significance, it may be concluded that there is a statistically significant downward trend in monthly cloud coverage.

Table 3. Quantifying trend with linear regression

Series	Regression Line	A decade trend
Temperature	$\hat{Y} = 40.06092 + 0.0285\hat{X}$	0.2854 °C
Rainfall	$\hat{Y} = 1754.016 - 4.502\ \hat{X}$	-45.02 mm
Cloud Coverage	$\hat{Y} = 4.44367 - 0.045\ \hat{X}$	-0.45829 oktas

Table 4. Correlation matrix of study variables

	Rainfall	Temperature	Cloud Coverage
Rainfall	1.000	-0.184	0.113
Temperature	-0.184	1.000	-0.134
Cloud Coverage	0.113	-0.134	1.000

Comments: We see that there is opposite relation between temperature and rainfall and temperature and cloud coverage but positive relation between rainfall and cloud coverage.

4 Conclusion

This study was conducted to evaluate the trends of three meteorological variables in the country's Jessore region from 1985 to 2014. The LOWESS curves show that there is an upward trend in annual maximum temperature but a diminishing trend for annual rainfall and annual cloud coverage, respectively. The Mann-Kendal trend test quantifies the trend of rainfall, which supports the declining character of rainfall for the research period in the region. A similar decreasing trend has been traced for annual cloud coverage over the time span. On the other hand, an increasing trend of 0.0285 was found for the annual maximum temperature. There is one breakdown point found for each of the series of rainfall and cloud coverage in the same year, 2004. But the Chow test suggests that only cloud coverage's breakdown point is significant. The Mann-Kendall test indicates an insignificant decreasing trend for rainfall, an insignificant upward trend for temperature, and a significant decreasing trend for cloud coverage. Linear regression trend analysis shows that rainfall and cloud coverage are decreasing by 4.50 mm and 0.045 octas annually. The correlation matrix tells us that cloud and amount of rainfall are positively correlated, which also supports the breakdown point year in 2004, but temperature and remaining variables are negatively correlated. In one word, it can be said that the usual pattern of the study variables has been altering gradually, which may be alarming signs for the climatic component of the study region.

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Competing Interests

Authors have declared that no competing interests exist.

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