Trend analysis and Changepoint Detection of Monthly, Seasonal and Annual Climatic Parameters in The Garo Hills of Northeast India

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Abstract

This study aims to estimate the change points, tendencies, trends existing between the estimated change points of weather parameters and to explore relationships with forest cover loss, and CO_2 emission in the Garo Hills region of Northeast India. The study is based on the secondary data of Precipitation, Maximum Temperature, Minimum Temperature, Relative Humidity, Tree cover loss, and CO_2 emission at Garo Hills for the period 1984–2019. Mann Kendal's and Sen's slopes were used for estimating the trend of monthly and seasonal weather parameters and the breakpoints were estimated using Pettitt's test. Further, we tried to establish a relationship between the variables under consideration using Pearson's correlation and regression analysis. The results suggest that the precipitation was on a decreasing trend during most of the months and seasons. Maximum temperature depicted an upward significant shift, while minimum temperature demonstrated a downward shift in all seasons post-2008. The relative humidity was on an increasing trend post-1999 in all seasons except monsoon. Regression analysis reveals that the relative humidity and maximum temperature contributed negatively to precipitation. The forest cover loss and CO_2 emission were positively correlated (r = + 0.58 and r = + 0.59) with the maximum temperature and negatively with the minimum temperature (r= -0.59 and r= -0.59). Results from this study will help the stakeholders to understand the temporal variability of weather factors and the effect of forest cover loss and CO_2 emission on weather change in the region, and to formulate climatic mitigation strategies in the region.

1. Introduction

Climate change is one of the major environmental challenges for mankind in the present world. India is also not out of the wave. The fluctuation in agricultural production and forest cover is the most conspicuous impact of climate change in India (Balasubramanian and Birundha, 2012 Nageswararao et al. 2018), besides some other challenges. India experienced intense weather conditions in recent years, which led to irregular rainfall, increased temperature affecting agricultural productivity, and eventually sluggish growth of the country's economy (Shah and Srivastava 2017). Thus, precise prediction of rainfall and temperature trends can play a crucial role in the conservation of natural resources and the nation's agricultural production for future economic growth and development.

According to the Intergovernmental Panel on Climate Change (IPCC2007), climate change is defined as any change in climate over time whether due to natural variability or because of human activity. Several studies have been done worldwide on trends and variability of weather parameters, mostly on rainfall and temperature. Analysis of climate variability for the past 60 years revealed a change in seasonal and annual rainfall distribution and increased temperature and wind velocities in different parts of the world (McElwain and Sweeney2003; Gumus et al. 2017; Kosanic et al.2019; Salvati et al.2019; Szwed et al. 2019; Tomczyk and Pluta 2019), which has also impact on potential evapotranspiration (Chaouche et al. 2010). The Glacio-meteorological condition at Chinese Taishan station, East Antarctica recorded a low temperature (-36°C), wind speed with moderately high, and normal ice flow, which has an impact on the southwest monsoon in southeast Asia (Tang et al. 2020). The IPCC (2007) reported that South-East Asia experienced an increase in temperature and rainfall variability. A declining trend in annual mean precipitation was noted in Northeast and North China, Northeast India, Russia, coastal belts, and arid plains of Pakistan, Indonesia, Philippines, and a few parts in Japan (Ahmad et al. 2015) and rising trend in the South-Eastern coast of China, Western China, Western coast of the Philippines, and Bangladesh (Bhuyan et al. 2018). In South Korea, a high amount of rainfall was experienced in the northern and southern parts, opposite to the south coastal part of South Korea (Azam et al.2018). Thus, trend analysis and prediction of water precipitation have become a vital component for sustainable agricultural management amidst the climate change perspective. It can help the field researchers and cultivators in agricultural water management (Feng et al. 2016).

The North-East (NE) region of India occupies an area of 0.26 million km², receives an average of 2450 mm rainfall, and Mawsynram in the Meghalaya state of this region receives the highest (11,500 mm) rainfall in the world (Das et al.2009). The agriculture in the Garo hills of Meghalaya (a state in NE India) heavily depends on rainwater and river sources. A variety of agriculture and horticulture crops like rice, maize, potato, rapeseed, mustard, areca nut, banana, pineapple, mandarin, vegetable crops, etc, are grown in this region. The rainfed area in the region spreads across 62.68 ('000) hectares and only 3.2 ('000) hectares under irrigation. The main source of irrigation is through canals, which cover almost 73% of the total irrigated area in the region (Agricoop 2014; Das et al. 2016). Increased forest cover loss and emission of CO_2 have enormously affected the region's climatic situation. According to global forest watch (2022), there is an increase of 78% in the loss of forest cover in the Garo Hills of the NE region during 2010–2020 compared to the previous decade (2001–2010), and the same trend was observed for the CO_2 emissions also. Recent studies indicated the relationship between the future water problems in the different parts of the world and forest cover loss (Bennet and

Barton 2018;Duku and Hein2021) and similarly maximum temperature and relative humidity (Georg von Arx et al.2012) with agricultural production (Lawrence2014).

The studies over the eastern and northeastern part of India (Arunachal Pradesh, Assam, Nagaland, Manipur, Meghalaya, Mizoram, Tripura, Sikkim, West Bengal, Orissa, and Chhattisgarh) on precipitation trend analysis stated evidence of change in rainfall in the past 95 years (Sathaye et al.2006; Kundu et al.2014). The temporal variability of seasonal and annual rainfall and temperature may affect the agricultural crop production in the hilly states of the NE region of the country (Patle and Libang2014; Lahiri et al.2017) and there is a decreasing trend of rainfall in Manipur, Tripura, and Assam (Das et al.2015). Studies suggest that agro-meteorological information from meteorological stations helps in better crop management and agricultural systems in Indian Himalayas (Basistha et al.2009; Choudhury et al.2012; Kumar et al.2017). The study conducted in Meghalaya indicated that the state receives an annual average rainfall of 2,267 mm and there was no incident of severe drought occurrences in the state during 1975–2010 (35 years), except in 2000 (Ray et al.2013). But Meghalaya experienced a decreasing trend (Ray et al.2014) and uneven distribution (Ray et al.2015) of annual rainfall. The West Garo Hills district, Meghalaya receives an average annual rainfall of 4851.5 mm with 113 average rainy days (1984–2007) and falls under the category of mild extremely wet agro-climatic region (Ray et al.2013). Since rainfed crops occupy the maximum cultivated area in the region, the study of its trends and their variability draws more attention. Recent surveys by the national statistical offices confirm that Meghalaya farmers earn more income than the other states in India (Krishi Jagran2021), which signifies the importance of agriculture in the state's economy. Similarly, changing the pattern of rainfall and temperature due to climate change might have some relation to the decreasing trend of forest cover and increased emission of CO_2 in the region.

The variability of weather parameters in West Garo Hills was investigated by various researchers, but the research was limited to trend analysis for a data set. There are also very limited studies in change point detection in the Garo hills region. Moreover, there is no study on the trend between the estimated change points, and the relationship between weather parameters, forest loss, and CO_2 emission. Therefore, it is very imperative to estimate the trends between the estimated breakpoints in time series data. The prime objective of this paper is to estimate the change points, tendencies, trends existing between the estimated change points in weather parameters, and to explore the relationships between the weather parameters with forest cover loss, and CO_2 emission in the region. The findings of this paper would be extremely helpful to understand the uncertainties from different dimensions and provide a complete overview of climate change for improvement in the management of agriculture and allied, water-related activities and designing of upcoming climate scenarios in the region.

2. Materials And Methods

2.1 Study Area and Data used:

The West Garo Hills district is situated at (25.567938^{o} N, 90.224464^{o}E) and is the second most populated district after the state capital in the Meghalaya state of India. The study domain is depicted in Fig. 1. coordinate. The Government of Meghalaya has set up its meteorological observatory as Agricultural Research Station from the Department of Agriculture at Sangsanggre in the West Garo Hills district, which aims to collect real-time data. The parameters like rainfall (mm), maximum temperature (Degree Celsius), minimum temperature (Degree Celsius), and daily relative humidity (%) data are recorded. The present study is based on the secondary data collected for a period of 36 years (1984–2019).The time-series data of forest cover loss and CO_2emission for the West Garo Hills were obtained from Global Forest Watch Open Data Portal (http://data.globalforestwatch.org/) for the period 2001–2020 which is an open portal for various climatic and greenhouse gasses emission information. The data has been analyzed for monthly and seasonal scale variations, and the seasons are Monsoon: May-September (MJJAS), Post monsoon: October-November (ON), Winter: December-February (DJF),and Pre-monsoon months are March-April (MA) (Meghalaya Tourism, https://www.meghalayatourism.in/about-meghalaya/seasons-and-climate/, 2022). The missing data points in the data series were replaced with the average of the corresponding variable.

2.2 Analysis Procedure:

The time-series data were analyzed with an objective of (1) long-term analysis for estimating the monthly and seasonal trends, (2) identification of breakpoints, and (3) trend of weather parameters before and after breakpoints. (4) To identify the variables which affect the regional precipitation and quantitative relationship between weather parameters and forest cover loss and regional CO_2

emission. The analysis was carried out separately for monthly, seasonal, and annual scale variations in weather parameters. Firstly, the data were summarized by using descriptive measures, and for the trend estimation Mann Kendal (Kendal1974), Sen's Slope test (Sen1968) have been used. The change point was estimated by using Pettit's test (Pettit1979) for monthly and seasonal weather parameters in the region. The existing relationship between weather parameters, forest cover loss, and CO_2 emission was analyzed by using the correlation and regression technique. The data was also tested for autocorrelation by using Modified Mann Kendal's test, given by Hamed and Rao (1998).

2.2.1.Trend Analysis:

The Monthly and Seasonal time series data of different weather parameters were analyzed by using non-parametric Mann Kendal's Z and Sen's slope Q to identify the existing trend.

2.2.2. Mann-Kendal's Z:

The Mann-Kendall test is mainly used to test whether univariate time series data has a monotonic trend (Upward or Downward) or not. It assumes in the data that there should not be any autocorrelation. This is the most commonly used non-parametric trend estimation method by many researchers (Jain and Kumar2012; Jain et al.2013; Kundu et al. 2014; Laskar, et al.2014; Oza and Kishtawal2014; Das et al.2015; Ganguly et al.2015; Kumar et al.2016; Radhakrishnan et al.2017; Sharma and Singh2017; Waghaye et al.2018; Mandal et al.2019; Panda and Sahu2019; Swain et al.2019), dealing with climate change (Gumus et al. 2017). More importantly, trend estimation has also been used for proper agricultural planning (Ojo and Ilunga 2018).

The hypothesis under this test is as follows.

H_0 = No trend

H_1 = There exists a trend (Upward or Downward)

The test statistic is given by

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

Where $x_j$and x_i sequential data values. The variance of S is given as follows

$$Var = \frac{1}{18}\left[n\left(n-1\right)\left(2n+5\right) - \sum_{t} f_t\left(f_t - 1\right)\left(2f_t + 5\right)\right]$$

Where t-varies over a set of tied ranks and f_t is the frequency that rank t appears and the test statistic will be

$$z = \{\frac{(s-1)}{se}, S > 00, S = 0\,(s+1)\,S < 0/se,$$

Where se = Standard deviation: if there is no monotonic trend.

2.2.3 Sen's slope Q:

Sen's slope is used to estimate the magnitude of the trend, and researchers dealing with climate change were mostly using this test. Mann Kendal's test and Sen's slope are used together in estimating the trend in the data series. The Mann-Kendall test and Sen's slope were used for trend analysis in Eastern Mississippi by (Feng et al.2016). Spatiotemporal trend analysis of precipitation for a period of (1940–2013) in Senegal was analyzed using the Mann-Kendall test and Sen's slope estimator (Diop et al., 2016). The magnitude of the trend estimated using Sen's Slope Q is based on the median values of variables (X_{ij}). The test statistics are given by

$$Q = \{Z_{\frac{(N+1)}{2}} WhereNisodd \frac{1}{2}\left(Z_{N/2} + Z_{\frac{(N+2)}{2}}\right) WhereNiseven$$

A positive Q value indicates an upward trend and Negative represents downward trend

2.2. 4 Pettit's test:

Pettit's test (Pettit1979) is used to test for a shift in the central tendency of a time series. Many studies have been conducted by different investigators throughout the world in change point detection of weather variables by using Pettit's test. In northern Tamil Nadu, change points were estimated for maximum and minimum temperatures using Pettit's test (Palaniswami and Muthiah2018). Sharma and Singh (2017) studied change points in annual precipitation, and Basistha et al. (2009) observed changes in annual and seasonal precipitation over Indian Himalayas. Other studies also mentioned Pettit's test in detecting change points (Zarenistanak et al.2014; Pingale et al.2016; Adeyeri et al.2017; Nageswararao et al.2019; Bannayan et al.2020; Kocsis et al.2020; Praveen et al.2020).

H_0-hypothesis = No change is tested

H -hypothesis = Change occurred

The test is given by following statistical formula,

$$U_k = 2\sum_{i=1}^{k} r_i - k\,(n+1)\,k = 1,\ldots,n$$

The test statistics is the maximum of the absolute value of the vector:

$$\hat{\text{U}} = max|U_k|$$

The probable change point K is located where Û has its maximum. The approximate probability for a two-sided test is calculated according to

$$p = 2exp^{-6K\ /(T\ +T^2)}$$

2.2.5. Regression and Pearson's Correlation Analysis:

Regression analysis is a common method of estimating the dependency of one variable on the other variable (Boscardin2010; Jain et al.2016; Edelman et al.2017; Kang and Zhao2020). In the present study, the functional relationship of precipitation on temperature and relative humidity was explained. The linear equation in the form of $Y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots\ldots + e_{ij}$ was fitted to the data. Where, Y represents the response variable and x explanatory variable, and their effects were tested using analysis of variance technique (ANOVA). Correlation analysis (r) is applied to continuous data to estimate the extent of the linear relationship between the variables. Correlation analysis has been used extensively by researchers to estimate the relationship between weather parameters with diseases (Chawdhury et al. 2018; Pahuja et al. 2021; Zec et al. 2021, Majumdar and Ray 2021), regional meteorological parameters (Mayilvaganan and Vanitha 2015; He et al. 2015). The data analysis has been carried out using R software (RCore Team 2020) and XLstat 2022 version.

3. Results And Discussion

Long-term analysis of weather data from 1984 to 2019 indicated that the West Garo Hills district receives an average annual precipitation of 3848.85 mm (Table 1). The district receives the major portion of rainfall during the monsoon period (Average – 3205.53 mm), followed by summer (311.47 mm) and post-monsoon (292.36 mm) seasons. Winter precipitation in the district was highly inconsistent (CV- 79%), followed by post-monsoon (67%) and summer (62%). Mainly during November to February, the precipitation was highly scattered, and the region had received significant unusual rainfall over the years.

The maximum temperature in the region was consistent over the years. The region experienced higher maximum temperature during the monsoon season, varying between 27˚C to 39˚C (Table S1). During Julymonth, the region has experienced warm weather over the year and recorded a maximum temperature of 42^0C. Minimum temperature found less peaked in almost all the year, and during the winter season, it was inconsistent compared to other seasons. The average minimum temperature in the region ranges from 14°C to 21.62°C and the minimum temperature recorded was 7^oC during the winter season. Relative humidity was consistent during the monsoon season compared to other seasons. The average relative humidity ranges from 60–75% over the years, and the highest humidity on the seasonal scale I recorded during the monsoon season was 89% (Table.S1).

3.1 Trend Analysis:

From Table 1, the trend of precipitation was negative in the major portion of the year except for April. The magnitude of the trend was much higher in July (Z= -3.418) followed by September (Z= -2.629) and May (Z= -1.893). The average precipitation continued to decrease from the onset of monsoon in the region over the years. The trend of the precipitation was negatively significant ($p < 0.05$) during the major portion of rainy months and seasons (May, July, and September). It was clear that the precipitation in the region was on decreasing trend over the years. The seasonal precipitation decreased considerably during the winter season (Z= -3.406), followed by annual (Z= -3.446) and post-monsoon season (Z= -3.691). It was confirmed from box-whisker plots (Fig. 2a-b), which were plotted using Mann Kendal's Z values of complete-time series (1984–2019) and trend values before and after change points. The results from the table showed that the maximum temperature was increasing in most of the months. The magnitude of the trend was high in January (Z = 1.296), followed by July (Z = 1.050), while in other months, the magnitude was below 1. The trend of maximum temperature in the region was insignificant all the months and seasons, but the trend was found positive. It was clear from the box whisker plots (Fig. 2c-d) that the maximum temperature was on the increasing trend in the winter season (Z = 0.94) followed by annual, summer, post-monsoon, and monsoon seasons. The minimum temperature in the region displayed a declining trend for all months as well as seasons. The decreasing trend of minimum temperature was significantly ($p < 0.05$) high during July (Z=-4.255) followed by June (Z=-3.944), August, September, and March, and in the rest of the months the Sen's slope was under 3. The trend of the minimum temperature during the monsoon recorded the highest declining trend compared to other seasons (Fig. 2e-f).

The relative humidity (RH) in the region was found positive and significant. There exists an increase in the summer relative humidity which was highest (Z = 6.158) among seasons and found significant at $p < 0.05$ significance level. Overall annual RH was on an increasing trend annually, which was confirmed by the box-whisker plots (Fig. 2g-h). It was clear from the table and the box-whisker plots that the precipitation decreased over the years across seasons and months. The annual trend showed negatively significant (Z= -3.446) during monsoon and in the winters though the trend was found negative in the summer and post-monsoon but found non-significant. The maximum temperature during the season was found to be positive and non-significant, whereas the minimum temperature trend was decreasing over the seasons, and the magnitude was found high during the monsoon. The relative humidity was significantly high (Z = 6.158, $p < 0.05$) mainly during the summer, followed by winter (Z = 5.448, $p < 0.05$) and annual (Z = 5.434, $p < 0.05$).

Table 1: Monthly and seasonal trend analysis weather parameters for West Garo Hills of Meghalaya.

Season	Rainfall (mm)	Max Temperature (^{0}C)	Min Temperature (^{0}C)	Relative Humidity (%)
Annual	**-3.446**	0.926	**-3.514**	**5.434**
Summer	-0.04	0.626	**-3.639**	**6.158**
Monsoon	**-3.691**	0.204	**-4.032**	1.348
Post Monsoon	-1.266	0.367	**-2.808**	**2.874**
Winter	**-3.406**	0.940	**-2.152**	**5.448**
Jan	-1.573	1.296	**-2.644**	**5.395**
Feb	-1.323	0.561	**-1.976**	**5.313**
Mar	-0.94	0.805	**-3.3**	**5.735**
Apr	0.34	0.122	**-3.029**	**5.616**
May	**-1.893**	-0.068	**-3.275**	**4.228**
Jun	-1.702	0.627	**-3.944**	1.553
Jul	**-3.418**	1.05	**-4.255**	0.054
Aug	-1.675	0.00	**-3.857**	0.422
Sep	**-2.629**	0.722	**-3.313**	-0.626
Oct	-0.599	0.559	**-2.741**	0.914
Nov	-0.833	0.19	**-2.389**	**4.061**
Dec	-1.043	-0.383	-0.885	**4.55**
Values in the table are Mann Kendals Z values, Bold Values showing significance at 0.05 level.				

3.2. Change Point Detection:

Pettit's test was administered in a two-tailed test to identify a change point or shift in the mean weather parameters, and the null hypothesis was tested at a significance level < 0.05. The weather parameters are changing due to plenty of human activities on the forest like, exploitation of forest for livelihood, shifting cultivation, which is still prominent in the region, in turn causing climatic uncertainties across the state (Roy and Sanjay 2000; Surma et al. 2015; Riahtam et al. 2018). The shift in the normal climatic situation was posing frequent environmental problems. The seasonal shift in the rainfall, maximum temperature, minimum temperature, relative humidity was detected by using Pettit's test. The results are presented in Table 2. It is clear from the results that the rainfall showed a downward shift in the year 1996, which was highly significant ($p < 0.001$) in the case of annual rainfall (Fig. 3). Two more downward shifts were noticed during the monsoon and winter seasons in 1997 (Fig. 3). In July (2009) and September (1996), there has been a significant ($p < 0.01$) downward shift. The change point detection plots are provided separately for each month in the supplementary Fig.S2, S3, and S4. The maximum temperature in the region exhibited an upward shift for the seasonal data, and the year 2010 was responsible for the change. Even in the case of monthly data, 2010 was critical for June ($p = 0.012$), July ($p = 0.017$), and September ($p = 0.014$) to November ($p = 0.015$), which caused an upward change in the mean maximum temperature in the region. It was clear from the following figures (Fig. 3) that the maximum temperature across seasons was increasing significantly.

The minimum temperature witnessed a downward shift in the years 2008 and 2010 (Fig. 3). The shift was statistically demonstrated for the seasonal data (Annual: $p = 0.001$), (Monsoon: $p = 0.001$), (Summer: $p = 0.003$), (post-monsoon: $p = 0.004$) and (Winter: $p = 0.020$). On the other hand, the years 2008, 2009, and 2010 were accountable for the significant downward shift in the monthly mean minimum temperature excluding December month. The upward change in relative humidity was reflected over the years and seasons (Fig. 3). For the seasonal data, a significant change point was estimated in the year 1999 for annual ($p < 0.001$), summer ($p < 0.001$), and post-monsoon season ($p = 0.043$). Whereas for the winter season, the significant ($p < 0.001$) change has detected in 2001. There exists a significant upward shift in the years 2000 (January), 2001 (February, March, April, May, December), and 2005 (November). It can be summarized that the mean precipitation and minimum temperature displayed a downward shift, whereas the mean maximum temperature and relative humidity demonstrated a significant upward shift. The shift has been detected, and statistically demonstrated in early 2000 for precipitation, maximum temperature, and minimum temperature late 2000, and relative humidity, it was detected in early 2001. Results from Table.S2 demonstrated a statistically significant decreasing trend in the annual precipitation (-92.848 mm to -25.56 mm per year), in the monsoon (-86.109 mm to -24.178 mm per year) and the winter season (-2.604 mm to -0.608mm per year). Whereas the summer and post-monsoon precipitations were not demonstrated a statistically significant trend. The maximum temperature in the region was not significant, but there is a possibility that the temperature could be up by 0.11°C across the season. The minimum temperature in the region exhibited decreasing trend across the season. The annual minimum temperature was on decreasing trend of about 0.096°C to 0.23°C, 0.099°C to 0.274°C in summer, 0.137°C to 0.270°C in monsoon, 0.40°C to 0.198°C in post-monsoon, and about 0.152°C to 0.254°C per year during the winter season. The tendencies were statistically significant. The relative humidity showed an increasing trend in the region, and the trend was statistically significant at a 95% significance level. The annual relative humidity was increased by 0.317 percent to 0.473 percent, 0.546 percent to 0.798 percent in summer, which was high, 0.2 percent to 0.35 percent in post-monsoon and winter there was an increase of 0.5 percent to 0.78 percent per year while the trend of relative humidity in the monsoon was not significant.

Table 2
Change point detection using Pettit's test for monthly and seasonal weather parameters

Season	Rainfall			Max Temperature			Min Temperature			Relative Humidity		
	Year	*p-value*	Shift	Year	*p-value*	Shift	Year	*p-value*	Shift	Year	*p-value*	Shift
Annual	1996	**0.001**	Downward	2010	**0.003**	Upward	2010	**0.001**	Downward	1999	**< 0.001**	Upward
Summer	1986	0.999	-	2010	**0.051**	Upward	2010	**0.003**	Downward	2000	**< 0.001**	Upward
Monson	1997	**0.001**	Downward	2010	**0.026**	Upward	2008	**0.001**	Downward	1999	0.211	
Post Monson	2007	0.330	-	2010	**0.018**	Upward	2010	**0.004**	Downward	1999	**0.043**	Upward
Winter	1997	**0.010**	Downward	2010	**0.039**	Upward	2010	**0.020**	Downward	2001	**< 0.001**	Upward
Jan	2002	0.301	-	2010	**0.049**	Upward	2009	**0.053**	Downward	2000	**< 0.001**	Upward
Feb	2007	0.544	-	2010	0.371	-	2010	**0.014**	Downward	2001	**< 0.001**	Upward
Mar	1995	0.775	-	2010	0.218	-	2010	**0.022**	Downward	2001	**< 0.001**	Upward
Apr	1999	1.000	-	2010	0.091	-	2009	**0.004**	Downward	2001	**< 0.001**	Upward
May	1994	0.106	-	2010	0.133	-	2009	**0.009**	Downward	2001	**< 0.001**	Upward
Jun	1997	0.160	-	2010	**0.012**	Upward	2009	**0.003**	Downward	1999	0.115	-
Jul	2009	**0.016**	Downward	2010	**0.017**	Upward	2008	**0.001**	Downward	1990	0.989	-
Aug	1999	0.095	-	2010	0.061		2008	**0.002**	Downward	1997	1.000	-
Sep	1996	**0.010**	Downward	2010	**0.014**	Upward	2010	**0.002**	Downward	2008	0.586	-
Oct	2007	0.844	-	2010	**0.024**	Upward	2008	**0.004**	Downward	1997	0.844	-
Nov	1995	0.416	-	2010	**0.015**	Upward	2010	**0.036**	Downward	2005	**0.002**	Upward
Dec	1997	1.000	-	1989	0.074	-	2009	0.350	-	2001	**< 0.001**	Upward

Bold values are significant at p < 0.05

3.3. Trends in monthly and seasonal weather parameters before and after the breakpoint year:

The data points before the change point detected and data points after the change point were analyzed in two separate parts from the perspective of the monotonic trend. The trend was detected by using Mann Kendal's test at a 5% level of significance. Results from Table 3 revealed that there was no significant trend observed before and after the breakpoint detected for annual and monthly scale precipitation except June month. The trend of precipitation was negative after the change point in most of the months as well as seasons. It gives the clear-cut indication that the amount of precipitation was declining across months and seasons over the years. The mean maximum temperature showed a significant negative trend before the change point in most of the seasons and months. Temperature gained a significant upward shift in the annual data and winter. A positive significant trend was observed during the winter months in January, December, and during monsoon month in July (2.645, $p < 0.05$) the shift was statistically significant but during June (1.722) and August (1.605) the trend was positive, but it was not statistically significant. After the year 2010, the mean temperature was significantly ($p < 0.05$) increasing causing the overall temperature in the region. A significant decrease in the minimum temperature was observed after the change point. Especially during the monsoon season, the mean minimum temperature decreased significantly. The region has experienced an increase in the mean relative humidity before and after the change point, and it has been observed that the mean relative humidity during the summer increased significantly after the change point, there was an increase in the mean humidity during annual (Z:-1.936), summer (Z:2.955, $p < 0.05$), winter season(Z:1.363) and during monsoon season the relative humidity showed a negative trend (-1.396) but it wasn't statistically significant. It was clear that the mean precipitation and minimum temperature were decreasing after the change point, while the mean maximum temperature and relative humidity were increasing trend after the change point.

Table 3
Mann Kendal's Trend in detected change points for monthly and seasonal weather parameters

Season	Rainfall		Max Temperature		Min Temperature		Relative Humidity	
	Before Change Point	**After Change point**	**Before Change Point**	**After Change point**	**Before Change Point**	**After Change point**	**Before Change Point**	**After Change point**
Annual	1.64	-1.21	**-3.75**	**2.51**	-0.667	1.46	1.936	1.84
Summer	0.00	-0.852	**-2.35**	-0.94	-0.667	-0.96	1.84	**2.955**
Monsoon	0.76	-0.90	**-3.879**	1.70	-0.770	**-1.952**	0.405	-1.396
Post Monsoon	0.42	0.48	**-3.669**	1.06	0.416	-0.861	1.125	0.324
Winter	0.32	-0.823	**-2.64**	**2.09**	0.14	**2.424**	1.478	1.363
Jan	0.676	-0.823	**-2.085**	**2.583**	-0.992	1.803	1.853	1.156
Feb	0.00	-0.314	-1.585	0.236	1.021	0.215	1.593	**1.933**
Mar	0.068	0.347	-1.105	**-1.967**	-0.980	-0.533	**2.615**	**2.160**
Apr	0.135	-1.589	**-3.023**	0.00	0.264	-1.396	**2.696**	1.444
May	1.0.89	-0.023	**-3.211**	0.126	-0.462	-1.122	1.216	0.947
June	**2.956**	-1.071	**-3.545**	1.722	-1.013	-1.396	0.495	-1.528
July	-1.013	-0.715	**-2.940**	**2.645**	-1.238	-1.684	1.501	1.277
Aug	1.845	-0.292	**-3.774**	1.605	-0.817	-1.188	0.00	-1.044
Sep	-0.061	0.317	**-3.211**	1.076	0.020	-1.763	0.700	1.566
Oct	0.719	0.480	**-3.170**	0.695	-**2.005**	-1.583	0.270	-0.425
Nov	0.691	0.995	**-3.964**	0.861	0.208	-0.757	1.720	0.110
Dec	-0.833	0.366	-0.375	**2.427**	0.771	1.373	0.00	1.365

Bold values are significant at $p < 0.05$

3.4. Relationships of weather parameters with forest cover loss, and CO_2 emission:

Table S3 indicates the relationship among different weather parameters. The results showed that the maximum temperature and relative humidity were affecting the regional precipitation negatively. The relative humidity significantly contributed about 88% (p = 0.005) variations in the precipitation while maximum temperature contributed about 4% variations (Fig. 4b). The same has been indicated using the correlation matrix in Fig. 4a. Figure 4c indicates the relationship between CO_2 emission and forest cover loss in the Garo Hills region from 2001 to 2020 and it is clear from the figure that there was a perfect positive correlation between the parameters. Figure 4d presents the correlation between weather parameters and forest cover loss, and CO_2 emission. It was found that the precipitation was associated negatively with CO_2 emission and tree forest cover loss, Maximum Temperature (r= -0.56**), Relative Humidity during 2001–2019. The Maximum Temperature was positive and significantly correlated with Co2 emission (r = +

0.59**) and forest cover loss (r = + 0.58**) while the minimum temperature was associated negatively with the CO_2 emission and forest cover loss.

4. Discussion

The precipitation in the region was on a decreasing trend. A negative trend was observed during monsoon months, and there was a significant downward trend in the seasonal precipitation (IMD Report2020;Marak et al. 2020). Long-term trend analysis of precipitation was having a negative trend in most of the months and seasons (Jain et al. 2012). But the data were analyzed from the change point perspective, it yielded positive tendencies before the actual change point and negative tendencies after the change point. The trends of precipitation before (Annual; μ1 = 4832 mm, Monsoon; μ1 = 4085 mm, Winter; μ1 = 61.704 mm) and after the change point (Annual; μ2 = 3293 mm, Monsoon; μ2 = 2646 mm, Winter; μ2 = 25.345mm) were not clear though it showed negative tendencies (Jain et al. 2012; Praveen et al.2020; Sangma et al.2020; Kuttipurath et al.2021) the shift in the rainfall was found significant during Annual, Monsoon and Winter season data. There was a decrease in the annual precipitation in the range of -92.848 mm to-25.56 mm/year, which was mainly attributed to a significant decrease in monsoon precipitation (-86.109 mm to -24.178 mm/Year). There was no autocorrelation found for the precipitation data when it was tested by using modified Mann Kendal's test given by Hameed and Rao test (Hamed and Rao 1998). Marak et al. (2020) found that Umiam and Umtru watershed areas are dominated by the increasing trend of post-monsoon rainfall. But in our study, we found a non-significant negative trend and it might be due to regional variations. In the case of maximum temperature, no clear trend was observed during 1984–2019, but the trend was positive across seasons and months except May and December. The maximum temperature and relative humidity were the key factors in affecting the rainfall negatively over the years (Romeo and Godcares2017). Out of two, relative humidity was found to be a highly influential variable that significantly decreased the amount of rainfall in the region.

Maximum temperature in recent times showed a positive trend in the region across seasons (Jhajharia and Singh 2011). The long-term analysis of temperature yielded a non-significant trend, but when the data is analyzed with a change point perspective, a clear trend of recent times was visible. There was a significant rise in the maximum temperature after the change was detected for annual (μ1 = 29.50^{o}C, μ2 = 32.75^{o}C), monsoon (up by approx. 4^{o}C), post-monsoon (by 3°C), and winter season (2.7°C) (Jain et al.2012), whereas the minimum temperature exhibited a significant negative trend. The shift in the temperature in the region was observed during 2010 for seasonal and monthly temperatures. These results were contradictory to Chakraborty et al. (2017), where the shift in the temperature was identified during early 2000. Long-term analysis of relative humidity showed increasing tendencies across seasons except for the monsoon (Rohit et al. 2019). The significant shifts in the relative humidity were found in early 2000, except for the winter season, which was in 2001.

The above results show evidence of climate change in the region. Activities in the region viz., practicing of *Jhum* cultivation (slash and burn cultivation), leading to increased greenhouse gasses emissions (Deka, et al.2009; Lahiri and Das 2010; Prabha et al. 2017;Kurien et al.2019) in the region were also the reasons for the change in climate in the Meghalaya (Maisnam et al., 2016). In Meghalaya, the area under *Jhum* was high in Garo hills compared to other regions of the state (Hazarika 2013). Change in forest cover (in the region received extreme disturbance (Hazarika 2013), and dependency of the region on forest resources would pose serious concern on climate change (Yadav and Sarma 2013). The agricultural activity including *Jhum* in the region starts in the early summer season and due to decreased forest cover, we could observe an increase in the temperature and humidity, which indirectly affects the rainfall negatively. It was evident from the results that the relative humidity and its effect on precipitation were negatively significant from 1984 to 2019, whereas the correlation studied from 2001 to 2019 was not found significant. Though the maximum temperature was non-significant from 1984 to 2019, after shifts detected during 2010 it showed a significant positive correlation with the forest cover and CO_2 emission, and these parameters were negatively correlated with the precipitation. There was a significant increase in the maximum temperature during post-2010 due to increasing forest cover loss and increased CO_2 emission in the region. The forest cover loss and the CO_2 emission in the region increased by 78 percent during 2010–2020 compared to 2001–2010. The results of change point detection, tendencies in weather parameters helped to identify the cardinal points in temporal variability of climate change impact in the region in the form of forest cover loss and emission of CO_2, which would be extremely important to formulate strategies to contain future climatic catastrophe in the Garo Hills region of Northeast India.

5. Summary And Conclusions

Climate change is apparent in most of the regions in the country. The Garo hill region is one of the prominent regions in the state of Meghalaya in terms of agricultural production and diversity. Forest also plays an important role in the livelihoods of the people in the region. The region experienced a wide range of climate change over the decades, which includes increased loss of forest cover, emission of greenhouse gasses, decreased precipitation, minimum temperature, increased maximum temperature, and relative humidity. It was clear from this study that the rainfall was on decreasing trend in the region during post-2000, whereas the temperature was on increasing trend after the change point except in the summer season (during 2010) and the relative humidity on an increasing trend (except during monsoon) before and after the change points post-1999. The increased forest cover loss and CO_2 emission in the region significantly contributed to the increase of maximum temperature, which needs immediate attention. The results of change point detection, tendencies in weather parameters helped to identify the cardinal points in temporal variability of climate change impact in the region in the form of forest cover loss and emission of CO_2, which would be extremely important to formulate strategies to contain future climatic catastrophe in the Garo Hills region of Northeast India. Therefore, collective efforts of the stakeholders through a community-based approach would be needed to change the region's climatic problems. Increasing forest cover through scientific climate-resilient agricultural management and scientific management and interventions especially for *Jhumming*, in the region, is tremendously critical, which will indirectly act as a carbon sink to conserve the region's environmental problems.

Declarations

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Data Availability: Time series data of weather parameters were collected from the agriculture research station, Govt. of Meghalaya at Sangsanggre, Tura, West Garo Hills of Meghalaya. The data is available on request from the Department. The data on tree cover loss and CO_2 emission in the West Garo Hills region is retrieved fromhttp://data.globalforestwatch.org/ which is available on the portal.

Code availability: On request.

Author Contribution:

Dr. Pavan Kumar ST: Conceptualization, Methodology, Data curation, Software, Formal analysis, Investigation, Writing original draft, review & editing, Visualization, Overall supervision. **Dr. Biswajit Lahiri:** Conceptualization, Supervision, Validation, Writing-Review, Discussion. **Dr. Murali Nageshwara Rao Malasala**: Review and Editing, Supervision. **Dr. Silkame N Sangma**: Writing Review of Literature, Collection of Data

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Figures

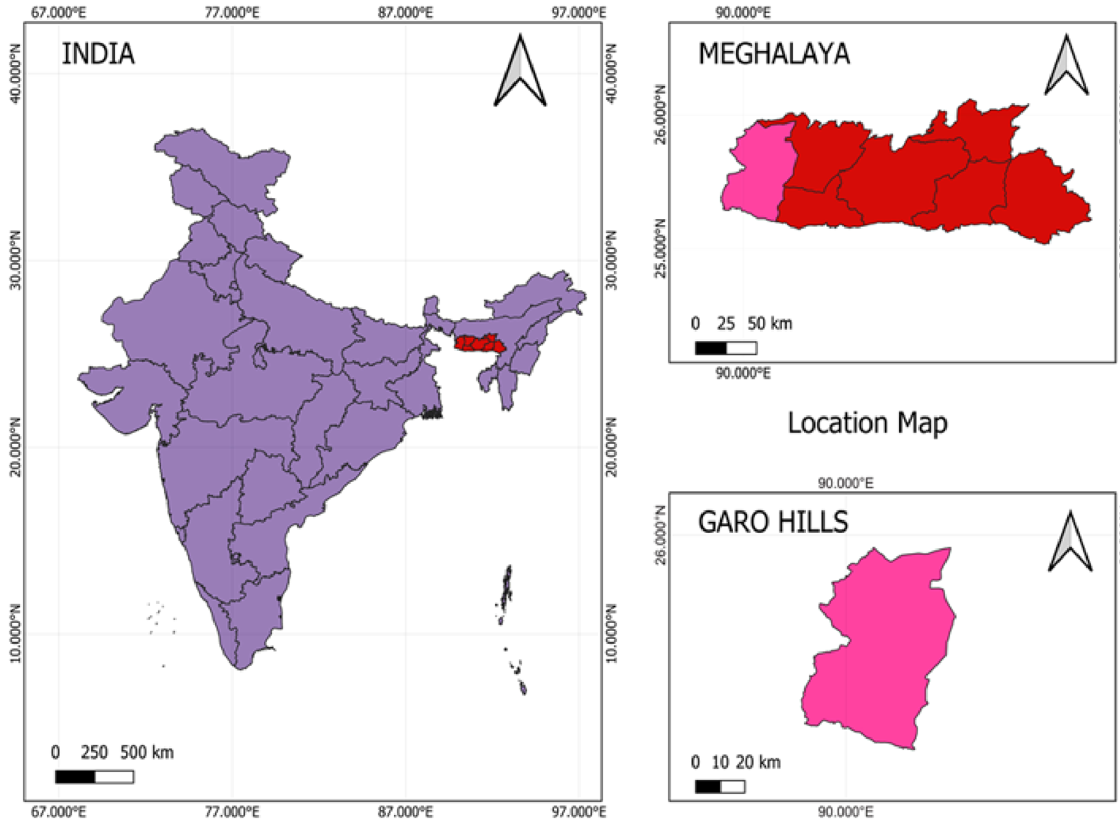

Figure 1

The study location Garo Hills.

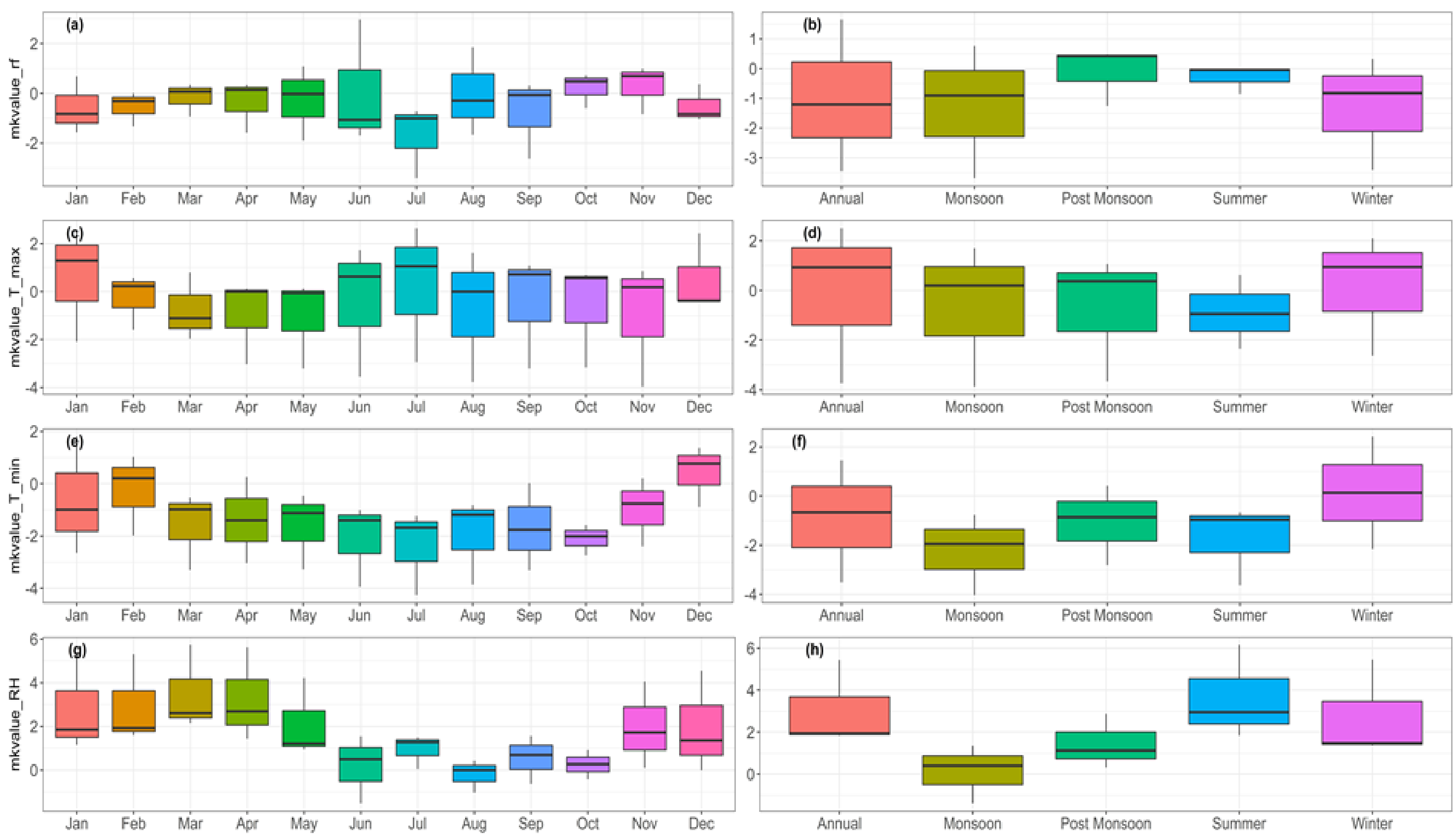

Figure 2

Trend of seasonal and monthly rainfall (a-b), Maximum Temperature (c-d), Minimum Temperature (e-f), and Relative Humidity (g-h) at Garo Hills for the period (1984-2019).

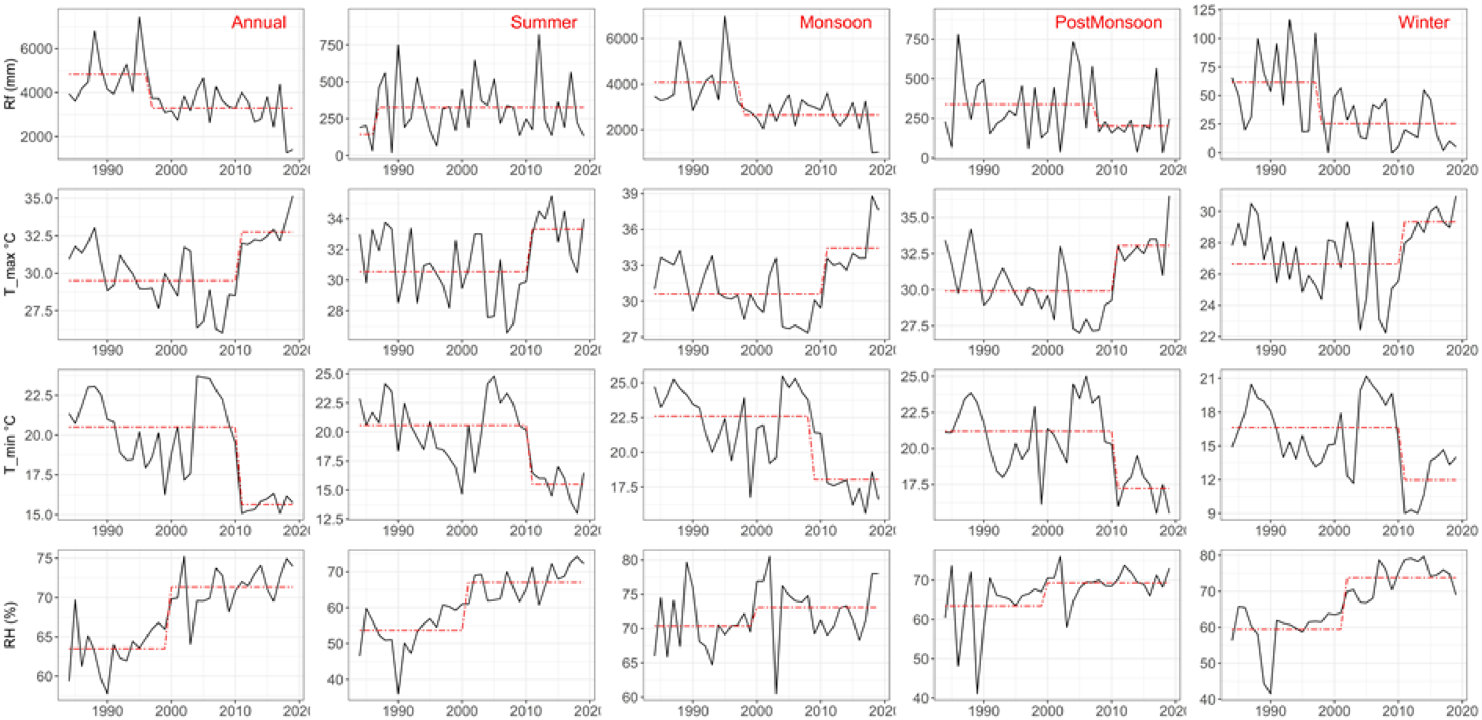

Figure 3

Change point detection for rainfall (Row 1), Maximum Temperature (Row 2), Minimum Temperature (Row 3) and Relative Humidity (Row 4) on Annual (Column 1), Summer (Column 2), Monsoon (Column 3), Post Monsoon (Column 4) and Winter (Column 4) at Garo Hills for the period (1984-2019).

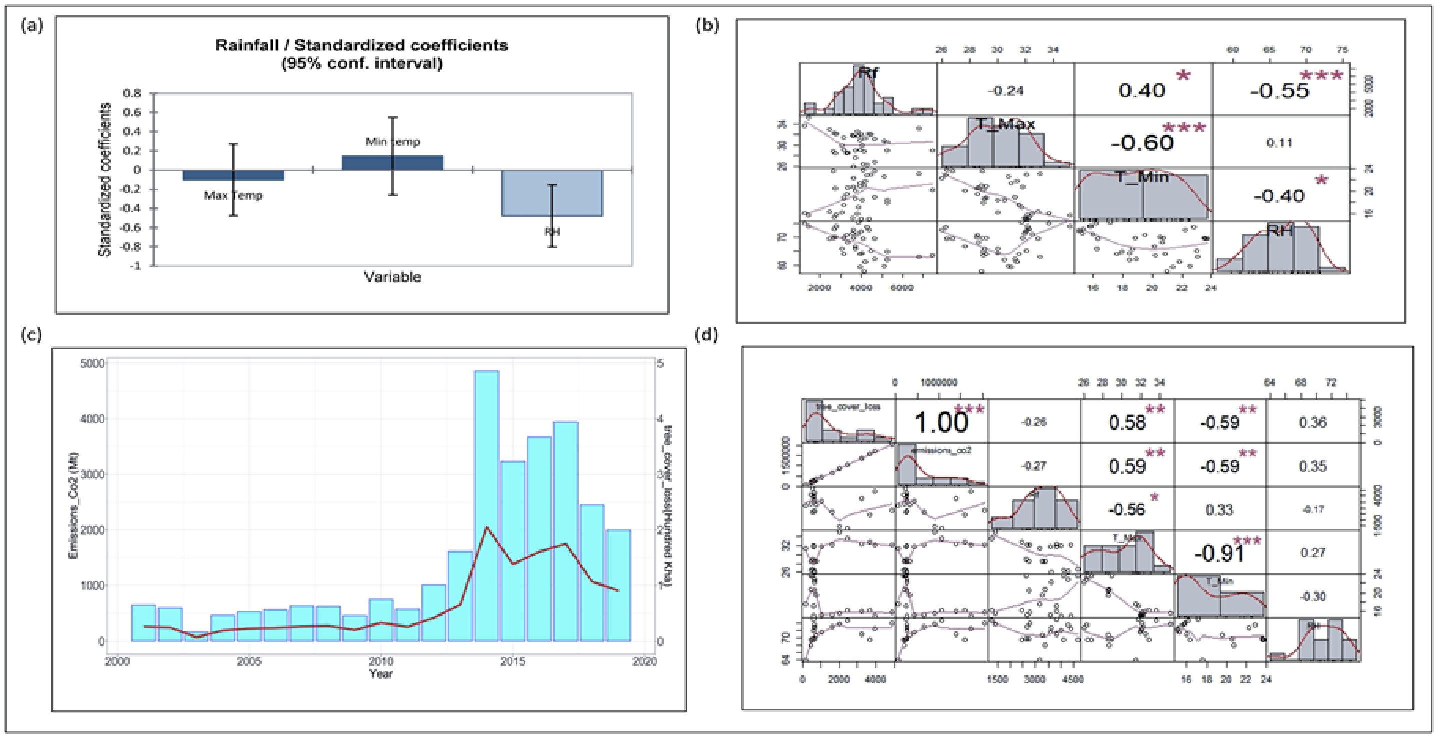

Figure 4

(a) correlogram for weather parameters for the period 1984-2019, (b) Variable contribution towards rainfall at 95% confidence level, (c) Yearly CO2 emissions and tree cover loss in West Garo Hills of Meghalaya for the period 2001-2020, and (d) Correlogram for weather parameters, tree cover loss, CO2 emission in the region for the period 2001 to 2019.

Supplementary Files

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- SupplementaryFile02.03.2022.docx