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Analysis of Trends and Variability of Monsoon Temperature and Precipitation of Nadia District of West Bengal

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Abstract: *Irregularities and variability of MeanR, MMax temp, and MMin temp are increasing during twentieth century (1901-2000) due to the changing climate. The present study attempts to find out variability, distribution, trends, and correlations of the variables over Nadia district from 1901-2002. This paper also focuses on temporal changing pattern of monsoon climate on smaller spatial scale. Comparatively monsoon has more reliable C.V. for rainfall (16.20%), maximum temperature (1.20%), and minimum temperature (1.41%) however; June records maximum C.V. for all three variables. Monsoon skewness is negative for minimum temperature but symmetrical for other two variables. Both parametric and non-parametric tests have been used for trend detection. For rainfall, June and August are showing declining trends. Statistically significant positive trends for temperature can be noticed in August. Statistically significant positive trend for mean minimum temperature is detected in monsoon. Increasing number of dry and wet years can be noticed in last few decades. But maximum and minimum temperatures of monsoon have been registered increasing frequency of warmer years in last 2 or 3 decades. The partial correlation coefficients among variables confirm very weak negative relationships. Overall, significant outcomes from the analysis highlight major concerning changes that to be managed with proper planning.*

Keywords: *Rainfall and temperature variability ; Statistical data analysis; Mann-Kendall test; Sen's slope; Positive trend; Partial correlation; Nadia district*

I. Introduction

Southwest Monsoon is the main feature in the climate of West Bengal, which normally stretches from July to the end of September. The state receives 73 to 80 percent of the normal annual rainfall. The South-eastern part of Gangetic West Bengal receives at about 1400 mm of rainfall in monsoon season. According to India Meteorological Department (IMD) the normal date of onset of monsoon over Gangatic West Bengal is the 7th June which normally withdraws by 10th October, resulting in a total span of this season of about 125 days. IMD (2013) reported an increasing trend of averaged monsoon season rainfall in West Bengal during 1950-2010 (State Level Climate Change Trends in India, 2013). It also observed a significantly increasing trend of mean maximum temperature and no trend of mean minimum temperature for monsoon season in West Bengal during 1951-2010. Mishra (2006) showed a number of complex factors for monsoon rainfall variability in West Bengal. IMD (2013) examined 60 years monthly trends of mean maximum temperature (MMax temp), mean minimum temperature (MMin temp), and mean monthly rainfall (MeanR) trends over states of India.

Air temperature and precipitation are principle elements of weather systems, so that examination of their behavior is important for understanding of climate variability because both are highly variable spatially and temporarily at different local, regional and global scales (Karabulut et. Al, 2008). According to the report of Intergovernmental Panel on Climate Change (IPCC, 2007) the seasonal, annual and spatial variation in precipitation trends were observed during past decades in all over Asia.

Rainfall and temperature are the two most important climatic variables that determine the spatial and temporal patterns of climate variability of a region, also provide useful information for planning of water resources, agricultural production etc (Abeysingha et al,2014 ; Jain et al,2012 ; Khavse et al, 2015 ; Banerjee et al,2010 ; Patra et al, 2011). Climatic variability can be described as the annual difference in values of specific climatic variables within averaging periods such as a 30 year period (Karabulut et al, 2008). Patra et al (2012) used the non parametric Mann-Kendall trend test to identify trends in Orissa, also to find out temporal variation in monthly seasonal and annual rainfall over the state during the period of 1871-2006.

Makuei et al (2013) analyzed trends in temperature and rainfall in three selected regions of Australia in two periods, 1907-1959 and 1960-2012. Banerjee et al (2010) investigated rainfall probability and climatic trend along with the agricultural, meteorological, and seasonal droughts using two weather station data i.e., Bankura and Canning. Cong and Brady (2012) used copula analysis to model the interdependence of rainfall and temperature in Scania, Sweden. IPCC (2007) reported the widespread increase in over the globe, especially it is greater at higher northern latitude and variation of rainfall due to climate change and suggested to focus on region and sector based adaptation and mitigation strategies.

All the studies mentioned above show the variability and trend analysis of temperature and rainfall over West Bengal, different parts of India and also in different parts of the world as well. In the present study temperature and rainfall interdependence has been analyzed along with their climatic trends, monthly and seasonal variability for monsoon season (June to September) over Nadia district of West Bengal, India.

II. Study Area and Data Description

Nadia district is a district of the state of West Bengal, in eastern India. It bonders Bangladesh to the East, North 24 Parganas and Hooghly districts to the South, Bardhaman to the West, and Murshidabad to the North.

Nadia district (3927 sq. km), a part of lower Indo-Gangetic Plain in West Bengal and lies between 22°52’30’’N to 24°05’40’’N latitude and 88°08’10’’E to 88°48’15’’E longitude in the alluvial plain of the lower Bhagirathi basin.

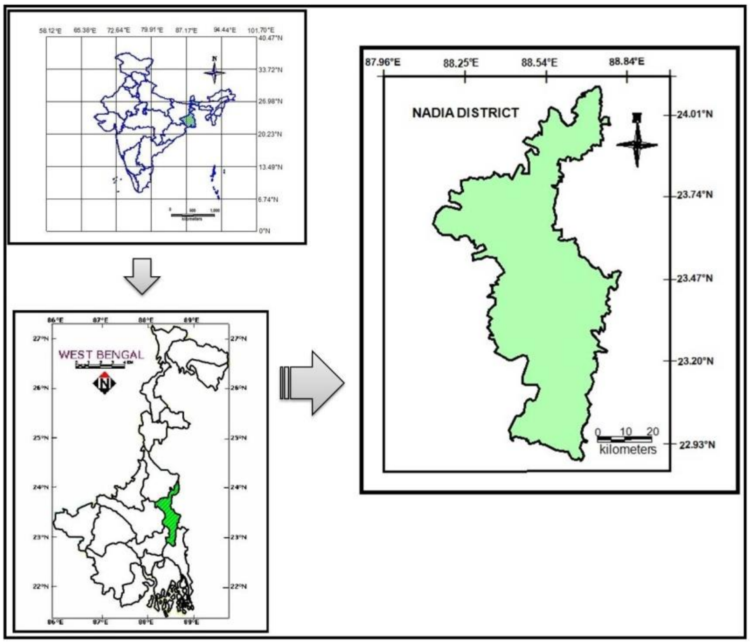

Fig. 1 Location map of Nadia District, West Bengal.

The climate of the area is characterized by oppressive hot summer, high humidity, mild winter with annual rainfall ranging from 1424 mm to 1635 mm, and mean daily minimum and maximum temperature ranges from 8°C to 12°C (in Winter) and 36°C to 41°C (in summer) respectively (M.V.Rao et al, 2015).

Average monsoon and kharif rainfall of Nadia district for the months of June, July, August, and September are 245.9 mm, 308.5 mm, 269.8mm, and 228.7 mm respectively (Mishra, 2006).

Mean monthly maximum temperature (MMax temp) in °C, mean minimum temp (MMin) in °C, and mean monthly rainfall (MeanR) in mm data over the study area were obtained from Indian Water Portal (www.indiawaterportal.org/met.data) for the period 1901-2002.

III. Methodology

Rainfall and temperature characteristics like mean, standard deviation (SD), and coefficient of variation were computed for monsoon season (June-September) and month wise, viz. June, July, August and September. Percentage contribution to monsoon season was computed for rainfall data.

Box plots of the observed mean monthly climate variables (MeanR, MMax temp, & MMin temp) for the calibration 1901-2002 period are used to depict some common measures of the distribution, variability, and relationships among the months for each climate variable.

5-year moving average was performed for monsoon season rainfall and temperature data to find long term trends.

Further linear trend was added as parametric test. Non parametric Mann-Kendall test was also performed with Sen’s slope estimation to confirm the significance of the observed trends.

Parametric tests assume that the random variable is normally distributed and homo-sedastic (homogeneous variance). Non-parametric tests make no assumption for probability distribution (Kumar &

Santosh, 2015). Trend analysis in statistics is used to determine the changing pattern of values of a random variable over some period of time.

3.1) Mann-Kendall Test:

The rank-based nonparametric Mann-Kendall (MK) test (Mann, 1945; Kendall,1975) has been widely used to assess the significance of monotonic trends in hydro-meteorological time series analysis such as temperature, rainfall and stream flow trend analysis (e.g. Addisu et al, 2015; Arora et al, 2005; Kahya & Kalayci, 2004; Khavse et al, 2015; Longobardi & Villani, 2009; Mishra & Gupta, 2015; Sahu & Khare, 2015; Zhang et al, 2001).

There are two advantages of using this test.

First, it is a non parametric test and does not require the data to be normally distributed, suiting perfectly to the present study.

Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series.

In the present study let x_1 , x_2, x_3, …. ,x_n represent n data points and the Mann-Kendall statistics (S) is defined as follows :

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k)$$

Where X_j are the sequential data values, n is the total number of data points in the set, and *sgn* (θ) being the sign functions is defined as

$$sgn(\theta) = \begin{Bmatrix} 1 \ \dots \ if\ \theta > 0 \\ 0 \ \dots \ if\ \theta = 0 \\ -1 \dots \ if\ \theta < 0 \end{Bmatrix}$$

If the variable constantly decreases downward then *S* is to be an indication of decreasing trend and the value *(S)* would be negative, whereas constantly increasing dataset shows a positive *(S)* value or increasing trend.

There is probably little important error involved in using the normal approximation for n>10, unless the ties are very extensive or very numerous (Kendall, 1975).

But number of data points (n) close to 10 may reduce the validity of the normal approximation when there are numerous tied values present in the time series. Thus, the variance is computed as

$$VAR(S) = {}^{1}/_{18}\left[n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5)\right]$$

Where, *t* denotes the extent to any known tie and *Σt* denotes the sum of all tied group having the same value in a data series.

The standardized test statistic *z* is given by :

$$Z = \begin{Bmatrix} \dfrac{s-1}{\sqrt{var(s)}} \ \dots \ if\ s > 0 \\ 0 \quad \dots \ if\ s = 0 \\ \dfrac{s+1}{\sqrt{var(s)}} \ \dots \ if\ s < 0 \end{Bmatrix}$$

If $|Z| < Z_{(1-\alpha/2)}$, then the null hypothesis H0 is accepted where α depicts the significance level. When $|Z| > Z_{(1-\alpha/2)}$, the alternative hypothesis, H1 is to be accepted. Significance level α is used for testing either an increasing or decreasing monotonic trend (a two-tailed test). $Z_{(1-\alpha/2)}$ is obtained from the standard normal cumulative distribution tables and represents the standard normal deviates. Instead of 0.01 level 0.05 significance level was considered in the present study as it is more conservative than the other.

3.2) Sen's Slope Estimator:

If a linear trend is present, the magnitude of trend can be estimated by using a simple non-parametric procedure developed by P.K. Sen (1968). Sen's method proceeds by calculating the slope (Qi) of N data pairs.

$$Qi = \frac{X_j - X_k}{j - k} \quad for\ i = 1,2,\dots,N$$

Where, X_j and X_k are data values at times j and k (j>k), respectively. The median of these N values of Qi is Sen's estimator of slope.
Sen's estimator of slope (Qi) is computed as

$$Q_{median} = Q_{(N+1)/2} \quad \dots if\ N\ is\ odd$$
$$Q_{median} = \left[Q_{\left(N/_2\right)} + Q_{(N+2)/_2}\right]/2 \quad \dots if\ N\ is\ even$$

The measured value of Q_{median} is tested by a two-sided test at the 100(1-α)% confidence by the non-parametric test.

3.3) Regression Analysis:

Simple linear regression model was adopted to show long-term monthly and seasonal trends in rainfall and temperature for a period of 100 years (1901-2002).

3.4) Partial Multiple Correlations:

In this present study partial multiple correlation method is used to measure the correlation between two variables, say X1 (dependent) and X2 (independent) among a group of variables, e.g., X1, X2, X3, … ,Xp. The effects of other independent variables, X3, X4, … ,Xp would be eliminated to determine the correlation betweenX1 and X2 (Gun et al, vol. 1, 2014).

The partial correlation coefficient (r_p) for dependence of X1 on a group of independent variables, e.g., X2 and X3 can be computed as follows.
r_p of X1 and X2, eliminating the effect of X3, is

$$r_{12.3} = \frac{r_{12} - r_{13}r_{23}}{\sqrt{1 - r_{13}^2}\sqrt{1 - r_{23}^2}}$$

r_p of X1 and X3, eliminating the effect of X2, is

$$r_{13.2} = \frac{r_{13} - r_{12}r_{23}}{\sqrt{1 - r_{12}^2}\sqrt{1 - r_{23}^2}}$$

IV. Results and Discussion

4.1) Rainfall and Temperature Characteristics of Nadia:

Rainfall and temperature characteristics of Nadia for the period of 1901-2002 are presented in Table 1. The mean monsoon rainfall over Nadia district is 1100.54 mm with a standard deviation (σ) of 178.26 mm. the coefficient of variation (CV) of monsoon rainfall is 16.20% indicating low variation. August contributes 29.86% of the monsoon rainfall in Nadia; whereas rainfall in September is least (20.96%).

The MMax temp and th MMin temp of monsoon season are 33.09°C and 25.72°C respectively. Standard deviation (σ) of MMax temp for monsoon is 0.40°C with a CV of 1.20% whereas highest σ (1.02°C) and CV (2.93%) are observed in the month of June, with highest temperature (34.83°C) in the whole season. For MMin temp in monsoon the σ and CV are 0.36°C and 1.41% respectively. It is lowest in September (25.47°C) with a σ of 0.42°C and CV of 1.65%.

Table 1 MeanR, MMax temp, and MMin temp characteristics of Nadia District (1901-2002)

PARAMETER	MONTH/SEASON	MEAN (mm)	STANDARD DEVIATION (σ)	COEFFICIENT OF VARIATION(%)	% CONTRIBUTION TO MONSOON
RAINFALL (MM)	JUNE	240.86	102.65	42.62	21.89
	JULY	300.41	88.31	29.40	27.30
	AUGUST	328.61	79.51	24.20	29.86
	SEPTEMBER	230.67	89.57	38.83	20.96
	MONSOON	1100.54	178.26	16.20	100
MEAN MAX TEMP (°C)	JUNE	34.84	1.02	2.93	
	JULY	32.75	0.51	1.56	
	AUGUST	32.14	0.48	1.49	
	SEPTEMBER	32.62	0.42	1.30	
	MONSOON	33.09	0.40	1.20	

MEAN MIN TEMP (°C)	JUNE	26.12	0.80	3.04	
	JULY	25.66	0.46	1.79	
	AUGUST	25.63	0.44	1.72	
	SEPTEMBER	25.47	0.42	1.65	
	MONSOON	25.72	0.36	1.41	

The box-and-whisker plots for MeanR, MMax temp, and MMin temperature split the dataset into quartiles. The inter quartile range (IQR) is the length of the box (Q3-Q1). Given that the medians for the four months and the monsoon are different from one another.

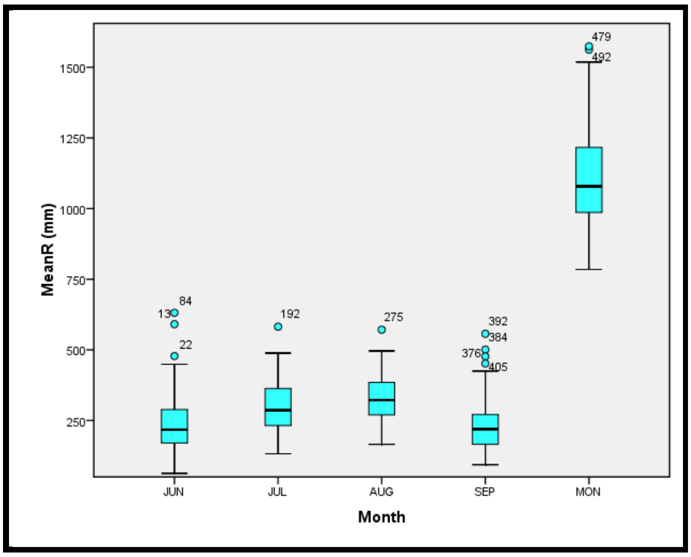

Fig. 2 Box plots of the MeanR (mm) for Nadia for calibration 1901-2002 period. The boxes correspond to the IQR, the band in the middle of each box to the median value, and the whisker to the 1.5 X IQR. The circles represent outliers.

In Mean R (in mm) data points lie outside back whiskers, termed as 'outliers' are clustered maximum for June and September.

MMax temp and MMin temp (in °C) datasets have outliers for maximum cases (be Q1-1.5XIQR or above Q3+1.5XIQR). Considering shape and pattern of the datasets for MeanR, months of Jun, Jul, Aug and monsoon are skewed right, while Sep depicts symmetrical distribution.

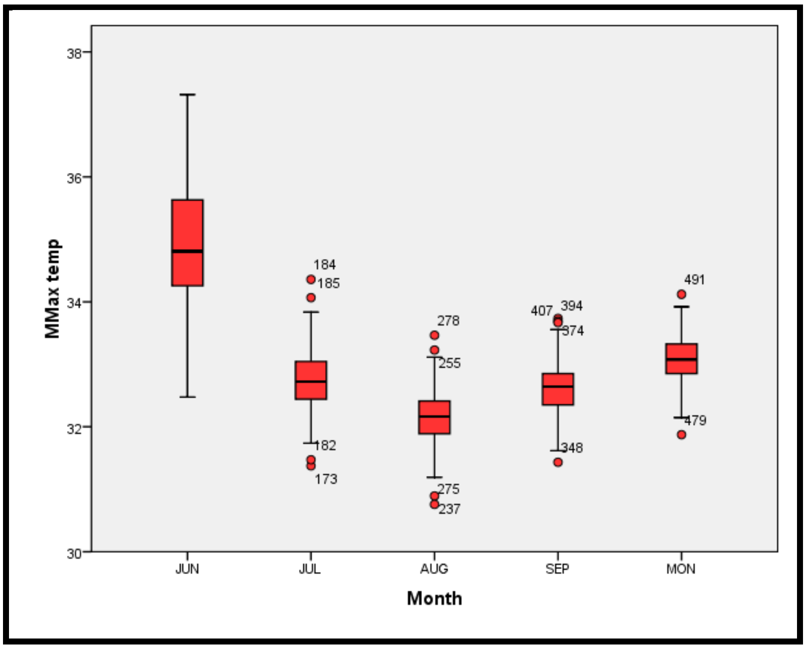

Fig. 3 Box plots of MMax temp (in °C) for Nadia for the period of 1901-2002

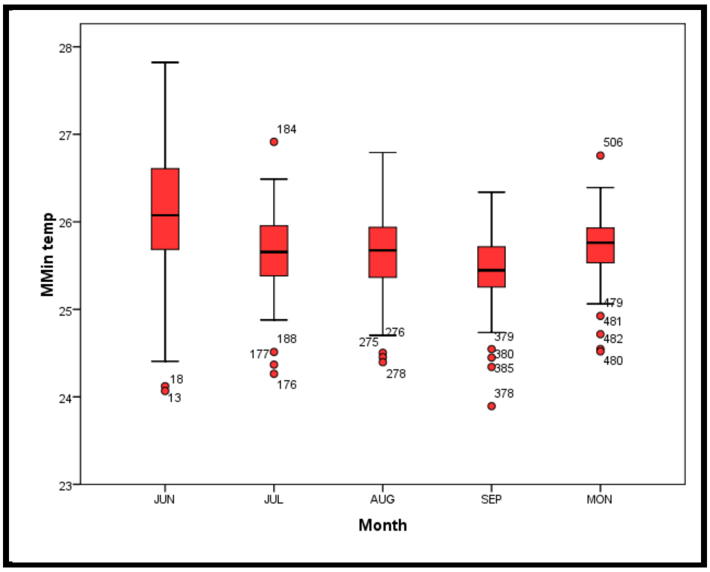

Fig. 4 Box plots of MMin temp (in °C) for Nadia for the period of 1901-2002

MMax temp (in °C) datasets show symmetric for Jul and Aug months, while Jun and Sep positive and negative skewness respectively. MMin temp (in °C) datasets shownegative skewness for Aug and monsoon, but it is positive Sep. Jun and Jul have symmetric distribution.

4.2) Seasonal Trend for Monsoon (Jun-Sep):

The results of the both parametric and non-parametric test obtained from analyzing rainfall and temperature dataset for monsoon and months of the season are summarized in Table. 2.

Table 2 Trend statistics of MeanR, MMax temp and MMin temp for Nadia (1901-2002)

PARAMETER	MONTH/SEASON	NUMBER OF DATA POINTS (n)	TREND DETECTION								TREND (95 % significant level)
			SLOPE	t-STAT	SIGNIFICANCE	p-VALUE	MK STAT (S)	Z TEST	PROB.	SEN'S SLOPE (Q)	
RAINFALL (MM)	JUN	102	-0.273	-0.791	0.431	0.648	-159	-0.463	0.322	-0.131	No
	JUL	102	0.126	0.423	0.673	0.703	133	0.382	0.649	0.109	No
	AUG	102	-0.169	-0.630	0.530	0.502	-233	-0.677	0.249	-0.225	No
	SEP	102	0.640	2.163	0.033	0.105	561	1.619	0.947	0.472	No
	MONSOON	102	0.323	0.538	0.592	0.808	85	0.243	0.596	0.155	No
MEAN MAX TEMP (°C)	JUN	102	0.002	0.559	0.550	0.466	253	0.729	0.767	0.003	No
	JUL	102	0	0.254	0.800	0.831	-75	-0.220	0.413	-0.0004	No
	AUG	102	0.004	2.605	0.011	0.022	792	2.287	0.989	0.0006	Positive
	SEP	102	0.001	0.902	0.369	0.696	136	0.390	0.652	0.0006	No
	MONSOON	102	0.002	1.481	0.142	0.185	459	1.324	0.907	0.002	No

MEAN MIN TEMP (°C)	JUN	102	0.001	0.494	0.622	0.731	120	0.344	0.635	0.001	No
	JUL	102	0.002	1.384	0.169	0.069	629	1.816	0.965	0.003	No
	AUG	102	0.004	2.638	0.01	0.003	1028	2.969	0.999	0.004	Positive
	SEP	102	0.001	1.025	0.308	0.146	504	1.454	0.927	0.002	No
	MONSOON	102	0.002	1.809	0.073	0.021	802	2.316	0.990	0.003	Positive

4.2.1) Rainfall Trend in Monsoon:

The non-parametric MK test for mean monsoon rainfall over Nadia district revealed a long term statistically insignificant positive trend where the magnitude is +0.16 mm/year. Z test also confirms statistically insignificant increasing trend. The 5-year moving average of monsoon rainfall is showing a sharp increasing trend during 1935 to 1941 and 1963 to 1971.

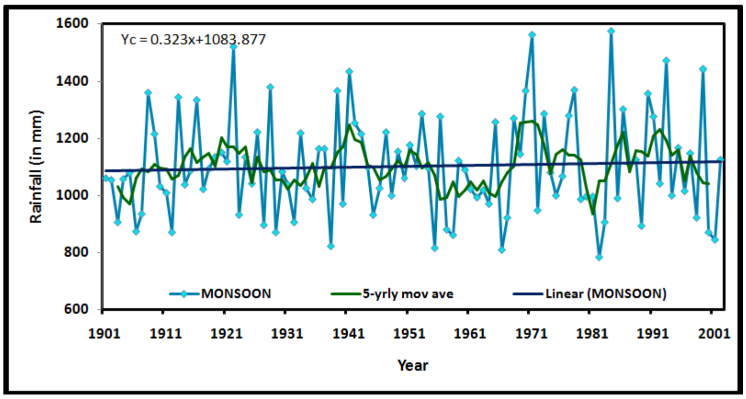

Fig. 5 Monsoon rainfall (mm) trend over Nadia (1901-2002). A linear trend with moving average.

Linear regression trend for monsoon is showing an overall increasing trend with a magnitude of +0.32 mm/year.

4.2.) Maximum Temperature Trend in Monsoon:

Non-parametric test for MMax temp is showing a statistically insignificant increasing trend with an increasing rate of +0.002°C/year. The monsoon maximum temperature has a high increasing trend from 1936 to 1950.

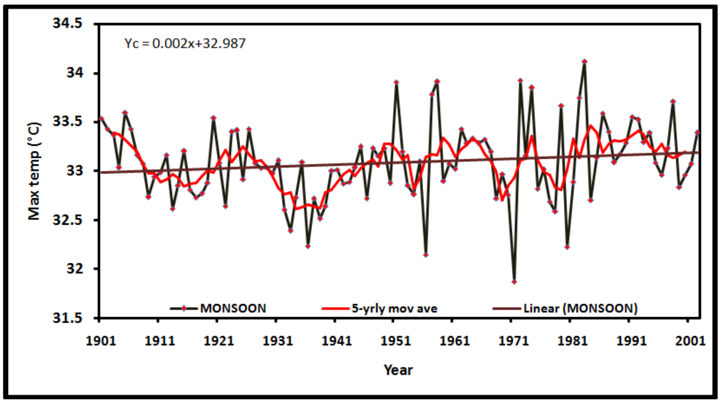

Fig. 6 Monsoon max temp (°C) trend over Nadia (1901-2002). A linear trend with moving average.

Linear trend also confirms an increasing trend (+0.002°C/year each).

4.2.3) Minimum Temperature Trend in Monsoon:

Non-parametric test for mean monthly minimum temperature is revealing a statistically significant increasing trend with a magnitude of +0.003°C/year. A high increase in MMin temp is noticeable from fig 7 during 1924-1932.

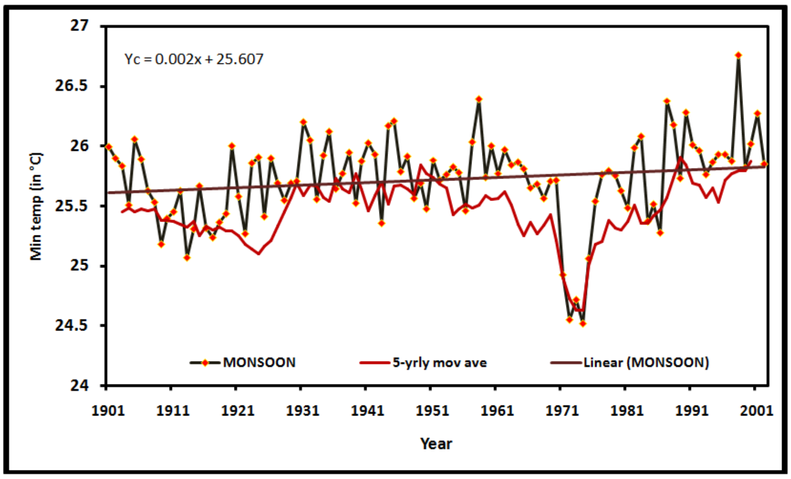

Fig. 7 Monsoon min temp (°C) trend over Nadia (1901-2002). A linear trend with moving average.

Linear trend has as overall increasing trend of +0.002°C/year.

4.3) Monthly Trends:

Monthly rainfall and temperature trends were analyzed for monsoon months (Jun-Sep) individually using both parametric and non-parametric tests.

4.3.1) Rainfall Trends:

The mean rainfall during June and August shows statistically insignificant negative trend (95% significant level) with the changing rates of -0.131mm/year and -0.225mm/year respectively. July and September have insignificant positive trend (95% sig level) with the rate of +0.109mm/year and 0.472mm/year respectively.

4.3.2) Maximum Temperature Trend:

Statistically insignificant positive trend can be noticed (Table 2) in the months of June and September, whereas in July a negative insignificant trend is present.

Statistically significant positive trend (95% confidence level) observed in August (+0.0006°C/year each).

4.3.3) Minimum Temperature Trend:

June, July, and September reveal statistically insignificant positive trends, whereas August shows an increasing trend (+0.004°C/year each) which is significant at 95% confidence level.

Overall results disclose statistically significant increasing trends of mean maximum and mean minimum temperature in the month of August which indicates a positive trend of mean temperature.

4.4) Decadal, Monthly and Seasonal Behavior:

Decadal and monsoon climate variables (MeanR, MMax temp,and MMin temp) data analysis are performed to find out the changing natures of the variables from normal over the time period.

Table 3, 4, and 5 consist of decade wise percentage changes in monthly and seasonal MeanR, MMax temp, and MMin temp from normal values with the frequencies of excess and deficit rainfall years (for rainfall); increase and decrease years (for temperature).

Positive departure of one standard deviation from mean is considered as wet year (rainfall), or warmer year (temp), whereas negative departure of one standard deviation from mean is a dry year (rainfall), or cooler year (temp).

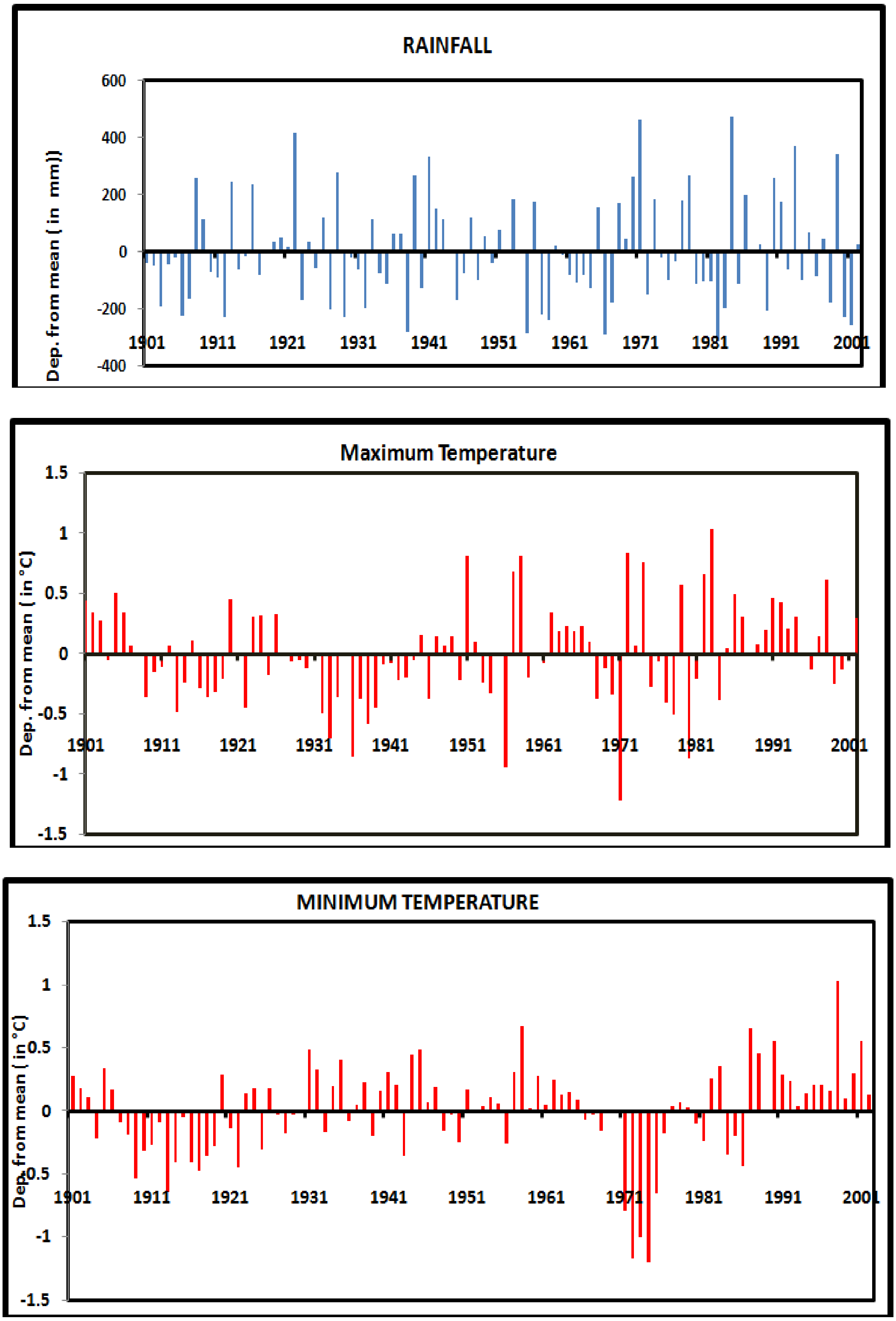

Fig. 8 Rainfall and Temperature deviations from mean over Nadia district, W.B. (1901-2002)

4.4.1) MeanR Analysis:

In monsoon, during 1971-1980 there are total four wet years with no dry years and the decadal mean is about +5.14% higher than the normal. While during the same period of time Jun, Jul, Aug, and Sep are accounted for two, one, three and one dry years respectively. Negative departures of -3.76% and -0.27% from normal can be observed for the months of Jun, and Aug which have more numbers of dry years than the wet. This season experiences dry decades during 1901-1910, 1931-1940, 1951-1960, 1961-1970, and 1991-2002.

Table 3 Decadal mean (% change from normal), frequency of excess and deficit rainfall years over Nadia (1901-2002)

DECADE	RAINFALL (MM)														
	JUNE			JULY			AUGUST			SEPTEMBER			MONSOON		
	DECADAL MEAN	EXCESS	DEFICIT	DECADAL MEAN	EXCESS	DEFICIT	DECADAL MEAN	EXCESS	DEFICIT	DECADAL MEAN	EXCESS	DEFICIT	DECADAL MEAN	EXCESS	DEFICIT
1901-1910	-0.00715	2	1	1.20108	3	3	-5.17953	1	1	-13.42184	0	1	-4.03341	1	2
1911-1920	21.73795	3	1	-11.53352	1	2	7.80413	1	0	-15.82434	1	3	0.62271	2	1
1921-1930	4.17125	2	1	13.40444	4	0	1.88263	2	3	-16.59411	1	1	1.65589	2	2
1931-1940	-5.07040	0	0	-13.25096	0	3	-0.98770	2	2	8.60203	1	1	-3.21866	1	2
1941-1950	-3.06286	2	1	0.45938	1	1	9.34860	2	0	6.09704	2	0	3.52436	1	0
1951-1960	-12.11301	1	2	4.57075	3	1	-5.15062	0	2	0.78620	1	1	-2.77645	1	3
1961-1970	-1.22767	1	1	-8.47668	1	3	0.32411	2	2	1.49345	1	1	-2.17270	1	2
1971-1980	-3.76208	1	2	12.82149	4	1	-0.26738	2	3	12.13321	2	1	5.13968	4	0
1981-1990	2.48474	1	1	8.34049	1	1	-12.75992	0	4	5.77832	1	1	0.22160	3	3
1991-2002	-2.62563	1	1	-6.28040	1	3	4.15472	3	3	9.12501	3	3	0.86416	2	3

This season has equal number of excess (18) and deficit (18) years from 1901-2002. During 1931-1940, there is no excess or deficit year for the month of June. Comparing to the other months June has more excess years (14) and the difference of excess and deficit (11) is also the maximum, indicating maximum water surplus month in the whole season.

4.4.2) MMax Temp Analysis:

During 1981-2002, this season has experienced six warmer years but no cooler years with a decadal mean of +0.58% higher than the normal MMax temp. Other warmer decades are 1901-1910, and 1951-1960 with a change percentage of 0.49% and 0.22% respectively. 1941-1950 and 1961-1970 have recorded normal with no increase or decrease year.

Table 4 Decadal mean (% change from normal), frequency of increase and decrease MMax temp years over Nadia (1901-2002)

DECADE	MEAN MONTHLY MAXIMUM TEMP (^{0}C)														
	JUNE			JULY			AUGUST			SEPTEMBER			MONSOON		
	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE
1901-1910	0.42056	1	1	0.39016	1	0	0.33991	1	1	0.56430	0	0	0.42888	2	0
1911-1920	-1.89537	1	2	0.55991	1	0	-0.07075	1	0	-0.10022	0	0	-0.40214	1	1
1921-1930	0.70592	2	1	-0.19052	0	0	-0.34547	0	0	-0.07692	1	2	0.03577	0	1
1931-1940	-0.87018	1	2	-0.93211	0	2	-1.88425	0	5	-1.01303	0	3	-1.16698	0	5
1941-1950	0.78056	1	0	-0.37554	1	2	-0.58689	1	2	-0.63049	0	1	-0.18545	0	0
1951-1960	0.52620	2	2	-0.35172	2	3	0.36760	2	0	0.33809	3	1	0.22405	3	1
1961-1970	0.19720	2	1	0.23934	2	2	-0.10311	0	3	0.16491	1	1	0.12673	0	0
1971-1980	-0.79956	3	4	-0.51628	2	4	0.39218	3	2	-0.33624	2	3	-0.32583	3	4
1981-1990	0.58161	1	2	0.68386	2	1	0.89183	2	0	0.56951	2	0	0.67927	3	0
1991-2002	0.29419	1	1	0.41076	4	1	0.83246	4	1	0.43342	3	2	0.48808	3	0

Significantly negative departure can be observed during 1931-1940 when the season has five cooler years with no increase year. During this period increase year and decrease year ratios for Jun, Jul, Aug, and Sep are 1:2, NIL:2, NIL:5, and NIL:3 respectively. Frequency of increase years (15) is more than the decease years (12), indicating rise in MMAx temp.

4.4.3) MMin Temp Analysis:

From 1901 to 1930 the season has observed total six decreasing years with a combined decadal mean of -0.48% from the normal MMin temp. During 1931-1960, the number of increasing years is five while decreasing year is NIL for monsoon.

Table 5 Decadal mean (% change from normal), frequency of increase and decrease MMin temp years over Nadia (1901-2002)

	MEAN MONTHLY MINIMUM TEMP(^{0}C)														
	JUNE			JULY			AUGUST			SEPTEMBER			MONSOON		
DECADE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE	DECADAL MEAN	INCREASE	DECREASE
1901-1910	-0.02351	1	1	-0.03753	1	1	-0.34993	0	1	-0.02292	0	0	-0.10819	0	1
1911-1920	-3.11397	1	6	0.22166	1	0	-0.71667	0	1	-0.57266	0	1	-1.05574	0	4
1921-1930	0.97141	3	2	-0.66311	0	2	-0.67142	0	0	-0.68261	0	2	-0.25497	0	1
1931-1940	1.06252	2	1	0.19633	1	0	0.26064	2	1	0.66660	1	0	0.54871	2	0
1941-1950	1.34887	2	0	-0.44172	0	1	-0.20519	1	2	0.71018	3	1	0.35702	2	0
1951-1960	1.02615	2	1	-0.14394	1	1	0.82908	2	0	0.43924	1	0	0.53996	1	0
1961-1970	0.62114	2	1	0.16397	1	1	-0.02806	0	1	-0.17175	1	2	0.14910	0	0
1971-1980	-2.75527	0	5	-1.22243	1	4	-1.90507	2	7	-1.80291	1	4	-1.92542	0	5
1981-1990	0.38418	1	0	-0.07378	2	3	1.08034	3	1	0.30259	3	2	0.42322	3	1
1991-2002	0.39872	1	0	1.66713	7	0	1.42191	4	0	0.94520	3	0	1.10525	2	0

From 1971-1980, frequency of decrease years is maximum i.e., 5 with a decadal mean of -1.93% for monsoon. Monsoon records more decrease years (12) than increase years (10) in total.

4.5) Partial Multiple Correlation Analysis:

An attempt is made to calculate the partial correlation coefficient of monsoon rainfall (X_1) and MMax temp (X_2) eliminating the effect of MMin temp (X_3) and vice versa.

Table 6 Parial Multiple Correlation among MeanR, MMax temp, MMin temp

CONTROL VARIABLES			MeanR	MMax Temp (X2)
MMin Temp (X3)	MeanR (X1)	CORRELATION	1	-0.31626039
		SIGNIFICANCE (2-TAILED)		0.001
		df	0	99
	MMax Temp (X2)	CORRELATION	-0.31626039	1
		SIGNIFICANCE (2-TAILED)	0.001	
		df	99	0

The result shows weak negative relations in both cases. Between X_1 and X_2 correlation coefficient (**$r_{12.3}$**) is -0.3016 whereas **$r_{13.2}$** of X_1 and X_3 is -0.192.

V. Conclusions

Analysis of distribution and variability of climate variables for Nadia district of West Bengal showed range of SD and C.V. are from 79 mm to 178 mm and from 16% to 43% respectively. SD and C.V. of mean rainfall, mean maximum and minimum temperatures are maximums in June, which indicate high irregularities over the time period (1901-2002). August (27.3%) and September (29.9%) contribute maximum rainfall to the season. Monsoon (Jun-Sep) rainfall and temperatures analysis for 102 years (1901-2002) revealed insignificant positive trends for mean rainfall and mean maximum temperature, whereas the trend is statistically significant positive for mean minimum temperature at 95% level. The results reveal many important changing nature of the variables; such as increasing trends of variables, high variability in the time of starting season, alternative positive and negative trends of the rainfall, equal number of excess and deficit years, increasing years of maximum and minimum temperature in last few decades, weak seasonal dependence of rainfall on maximum and minimum temperatures etc. These discussions showed the real changes of trends and variability, which would be significant for proper agricultural planning and water resource management over Nadia district of West Bengal.

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