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Changing climate and its effect on rice yield in Meghalaya

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ABSTRACT

The change in precipitation pattern and temperature directly and indirectly affect the weather dependent agriculture sector. So, this paper assessed the effect of rainfall and temperature variability on the mean and variance of rice yield in Meghalaya by using Just & Pope model. The state received fairly good amount of rainfall during rice growing season but the minimum and maximum temperatures have increased during 1975-2007 Average monsoon maximum temperature has positive and significant effect on the mean yield of kharif rice. The significant effect of the squared term of monsoon minimum temperature, and the interaction term of monsoon minimum and monsoon maximum temperature implies their non-linear effect on the mean yield of kharif rice. The variance function reveals that the climatic parameters along with time trend are risk decreasing factors but only time trend is statistically significant.

1. Introduction

The crop yield is a function of different inputs *viz.* seed, nutrients, water, labour *etc.* Precipitation and temperature are the two important weather parameters which have direct bearing on agricultural production (Deachenes and Greenstone 2006). The studies on effect of climatic parameters on mean crop yield has taken centre stage in the regime of climate change; and is important for rainfed agriculture. Changes in precipitation and temperature have direct effect on crop water use and impact the crop yield (Birthal *et al.,* 2014; Grover and Upadhyay 2014). Rice yields are projected to decline by 5-12 % over India and China (Lin *et al.,* 2004) and by 4 % in overall Asia by the end of the century (Murdiyarso 2000). Saito *et al.* (2006) reported that rice yield is closely associated with the total amount of rainfall from June to August in northern Laos, since this period coincides with the rapid vegetative and early reproductive growth stages. They reported that if total rainfall from June to August was less than 610 mm the average yield of rice was 1.4 MT/ha, whereas if rainfall was greater than 690 mm the average yield increased to 2.5 MT/ha. Birthal *et al.* (2014) has studied the effect of temperature on crop yield in India during the period of 1969-2005 and found that rise in maximum temperature has a negative and significant effect on yields of kharif as well as rabi crops. On the other hand, a rise in minimum temperature has a significantly positive impact on yields of most crops. The opposing effects of rise in minimum and maximum temperatures suggest that temperature has a non-linear effect on the crop yields. Kumar *et al.* (2014) estimated that in India as a result of a 10% deficit in rainfall during 1980 to 2005, the yield of rice has declined by 6.3%, and also reported that 10% drought intensity would be responsible for the fall in production of rice by 10%. Meghalaya is an agrarian state in the north-eastern hill (NEH) region of India. The contribution of agriculture in state GDP is 18.06% (GoI 2015) and about 60% of the population is dependent on agriculture for livelihood. Rice is the staple food for the people and the primary cereal crop cultivated in the state with 108.27 thousand ha area under rice.

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The crop is cultivated primarily in rain-fed condition as the area under irrigation is only 22.66% as in 2011. Alike other states of the region Meghalaya also faces the challenge in terms of change in climatic parameters; specifically precipitation and temperature (Chakraborty *et al.,* 2017; Jain *et al.,* 2013). Rice being susceptible to climate change and events like droughts and floods (Karim *et al.,* 1996; Sarker *et al.,* 2014; Yu *et al.,* 2010,); any change in climatic parameters is expected to have negative effect on rice yield and in turn the household food availability. Hence, in this paper we have studied the trend in climatic parameters and their effect not only in mean yield but also on variance of yield of rice in Meghalaya. This kind of empirical study is lacking for the state.

2. Methodology

Data

Meghalaya situated in the North Eastern Indian Himalaya is one of the seven sister hill states which lies between $24^0 57$'N to $26^0 10$'N latitude and $89^0 46$'E to $92^0 52$'E longitudes. The elevation of the plateau ranges between 150 m to 1961 m above mean sea level (msl). The state receives very high rainfall and known as the "abode of clouds" aptly. Secondary data on daily rainfall (1975-2007) and daily temperature (1975-2009) were extracted from high resolution $1^0 \times 1^0$ daily gridded data obtained from India Meteorological Department (IMD), Pune for three stations *i.e.* 90.5^0E longitude and 25.5^0N latitude, 91.5^0E longitude and 25.5^0N latitude and 92.5^0E longitude and 25.5^0N latitude. The individual station data were used to arrive at state average. The secondary data on yield of rice was collected from the Directorate of Economics and Statistics, Government of Meghalaya to estimate the impact of rainfall on rice yield.

Normality Test

Normal Quantile-Quantile (QQ) plot: It's a visual check in which a scatter diagram of two sets of quantiles *i.e.* the theoretical or normal quantile and sample quantile are plotted against each other. Hence if the distribution is normal the sample quantiles will be around the normal quantile *i.e.* the diagonal straight line.

Jarque Bera (JB) test of normality test: At first the residuals are calculated using ordinary least squares (OLS); and then skewness and kurtosis is calculated. The test statistics is as follows:

$$JB = n\left[\frac{S^2}{6} + \frac{(K-3)^2}{24}\right] \qquad \text{.......(1)}$$

Where n = sample size, S = skewness coefficient, K = kurtosis coefficient. The null hypothesis is the residuals area normally distributed. In that case S = 0, K = 0 and JB = 0. (Gujarati, 2003)

Trend analysis

The parametric tests are robust than non-parametric tests but non-parametric tests are useful when the variables do not follow normal distribution. Hence, we have calculated trends for yield and all the climatic variables using linear regression equations (parametric) as well as monotonic trends using Sen's slope (non-parametric).

Linear regression equation: The simple linear regression model used is as follows:

$$Y_i = \beta_1 + \beta_2 Time \qquad \text{......(2)}$$

Where Yi is regressand, β_1 is the intercept and β_2 is the slope coefficient. The parameters are estimated using ordinary least squares (OLS) technique and tested for their significance using corresponding probability (p) values.

Sen's slope and Man-Kendall test

Sen's slope estimates the magnitude of trend (Sen, 1968) which is used by a number of researchers in hydro-meteorological studies (Yue and Hashino, 2003; Partal and Kahya, 2006 ; Jhajaria and Singh, 2010; Jain *et al.,* 2013; Chakraborty *et al.,* 2014). In this method at first a set of monotonic slope is calculated as

$$T_i = \frac{x_j - x_k}{j-k} \; for \; i = 1 \ldots\ldots N \qquad \text{.......(3)}$$

where x_j and x_k are data values at time j and k ($j > k$), respectively. The median of these N values of T_i is Sen's estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} \; ; N \; is \; odd \\ 1/2\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right); N \; is \; even \end{cases} \qquad \text{.......(4)}$$

The significance of Sen's slope estimates are tested using Mann Kendal (MK) Z statistic (Mann,1945; Kendall,1970). The statistics (S) is defined as (Salas, 1993) follows:

$$S = \sum_{i=1}^{N-1} \sum_{i+1}^{N} sign(x_j - x_i) \qquad \text{.........(5)}$$

Where, N is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of sign(θ) is computed as follows:

$$\text{sign}(\theta) = \begin{cases} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{cases} \qquad \text{..........(6)}$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered.

The standard normal deviate (Z-statistics) is computed as follows:

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{s+1}{\sqrt{var(s)}} \text{ if } S < 0 \end{cases} \quad \text{......... (7)}$$

Where, $var\,(s) = \frac{1}{18}\{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t+5)\}$

If the computed value of $|Z| > z_{\alpha/2}$, the null hypothesis (H_0) is rejected at α level of significance in a two-sided test.

Effect of climatic variability on rice yield: Just-Pope model

Just-Pope stochastic production function was employed to estimate the effect of climatic variability not only on the mean yield but also yield variability by many researchers across the globe (Tveteras, 1999; Chen *et al.,* 2004; Isik and Devadoss, 2006; Kim and Pang, 2009). The Cobb–Douglas and linear–quadratic forms are consistent with the Just and Pope postulates (Kim and Pang, 2009; Tveteras, 2000). The function is as follows

$$y = f(X;\beta) + \omega h\,(X;\delta)^{0.5} \quad \text{.... (i)}$$

Where,

y is the productivity (production per hectare) of *kharif* rice

X is a vector of explanatory variables

ω is the stochastic term with mean zero and variance 1

β and δ are the production function parameters to be estimated using historical data

(Just and Pope 1978)

From equation (i), the expected productivity of crop is given by $E(y) = f(X;\beta)$ and crop variability is given by $V(y) = h(X;\beta)$. The derivatives of the variance function $h(X;\beta)$ w.r.t. the input variables, *viz.* precipitation and temperature can be used to identify whether a climate variable increases or decreases crop variability. So if, $h_x = \delta h/\delta x > 0$, it indicates that the corresponding input variable x is risk increasing, if $h_x < 0$ it implies risk decreasing.

As the equation (i) has heteroskedastic errors; Feasible Generalized Least Squares (FGLS) technique has been applied to estimate the mean and variance functions and the model was estimated using GRETL 1.10.1. The essential steps for estimating the Just-Pope production function using FGLS are as follows:

i. Estimate the mean function by running OLS regression of y (yield of crop per ha) on f (X; β)
ii. Compute the residuals u_{it}
iii. Regress natural logarithm of u_{it}^2, *i.e.* log (u_{it}^2) on log (h(X;δ)) and get the predicted values of log (u_{it}^2) in the second regression.
iv. Obtain the antilogarithms of the predictions obtained in Step 3. They are consistent estimates of the variances.
v. Re-estimate the original mean function f (X; β) by Weighted Least Squares (WLS) with inverse of variances (obtained in step 4) as weights.

$$yh^{-1/2} = f(X;\beta)h^{-\frac{1}{2}}(X;\delta) + uh^{-\frac{1}{2}}(X;\delta) \quad \text{.... (ii)}$$

The variables used in the Just and Pope model and their functional forms are as below:

Variables	Functional form	
	Mean function	Variance function
Dependent : *Kharif* yield (1975-2007)		
Explanatory		
Time Monsoon rainfall (MRain) in mm Monsoon maximum temperature (MaxT) in ^{0}C Monsoon minimum temperature (MinT) in ^{0}C	Time, MRain, MaxT, MinT, squared MaxT, squared MinT, squared MRain, MaxT*MinT, MaxT*MRain, MinT*MRain.	Time, MRain, MaxT, MinT

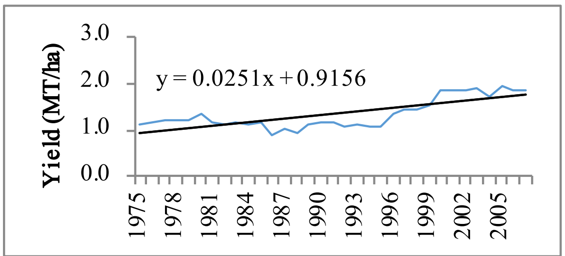
3. Results and Discussion

Descriptive statistics of the variables

Table 1. Descriptive statistics for yield and climatic variables

Variables	Average	Extreme value		CV
		Minimum	Maximum	(%)
Yield (MT/ha)	1.34	0.90	1.96	24.01
MRain (mm)	1614.78	957.80	3330.93	29.80
MinT (^{0}C)	23.37	22.77	24.69	0.43
MaxT (^{0}C)	30.44	29.82	31.64	1.32
& * represents p<0.05 and p<0.01, respectively				

Figure 1. Trend in *kharif* rice yield in Meghalaya



The *kharif* rice yield has increased from 1.13 MT/ha in 1975 to 1.83 MT/ha in 2007 (Figure 1). The estimated annual trend growth of yield, calculated using LOGEST function in excel, is 1.73%. This increase can be attributed to technological interventions in terms of high yielding varieties, irrigation and fertilizer application. The highest yield of 1.96 MT/ha was registered in 2005 which was high rainfall year whereas, the lowest yield of 1.73 MT/ha in 1986. The instability in yield was very high during 1975-2007 which can be observed in Figure 1 and is evident from the high value of estimated coefficient of variation (CV) for the yield (Table 1). Similarly, the inter year variations in monsoon rainfall was very high (CV=30%) during the study period. The average monsoon rainfall was 1615 mm which is about 69% of the total annual rainfall in Meghalaya during the period 1975-2007. The state received highest monsoon rainfall of 3331 mm in 2005 and it was followed by minimum monsoon rainfall of 958 mm in the very next year *i.e.* 2006. The average MinT and MaxT were 23.37^{0}C and 30.44^{0}C, respectively during 1975-2007 (Table 1). The inter year variation in MaxT was relatively higher than MinT in the state.

Trend in variables

The parametric trends in Yield, MRain, MinT and MaxT are presented in Figure 1 to Figure 4 which depicts positive linear trends for all these variables. The normality of the variables is checked first visualizing the Normal Q-Q plot and further confirming it by applying Jarque Bera (JB) test of normality. The Normal Q-Q plot reveals that the residuals are around the diagonal line for all the variables except MaxT. Similarly, the JB statistics are also significant for all the variables except MaxT. Hence, it is concluded that only MaxT follows normal distribution (Figure 5 and Table 2).

Figure 2. Trend in monsoon rainfall in Meghalaya

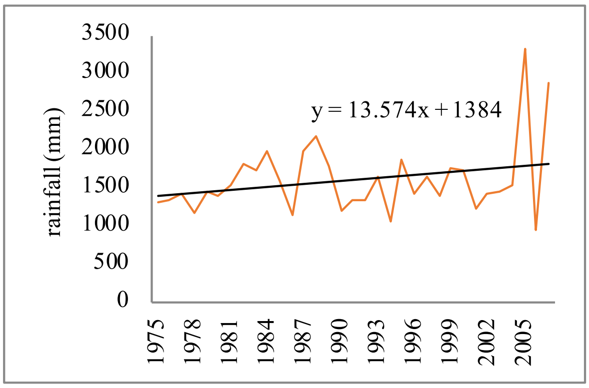


Figure 3. Trend in monsoon minimum temperature in Meghalaya

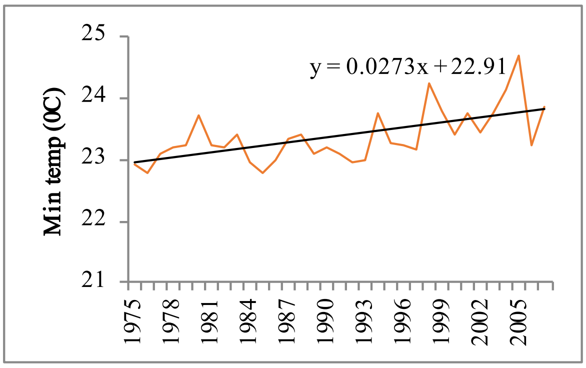


Figure 4. Trend in monsoon maximum temperature in Meghalaya

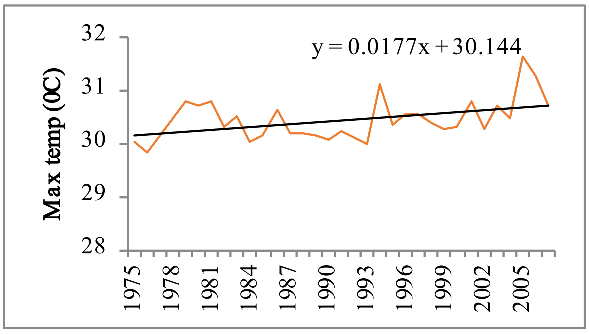
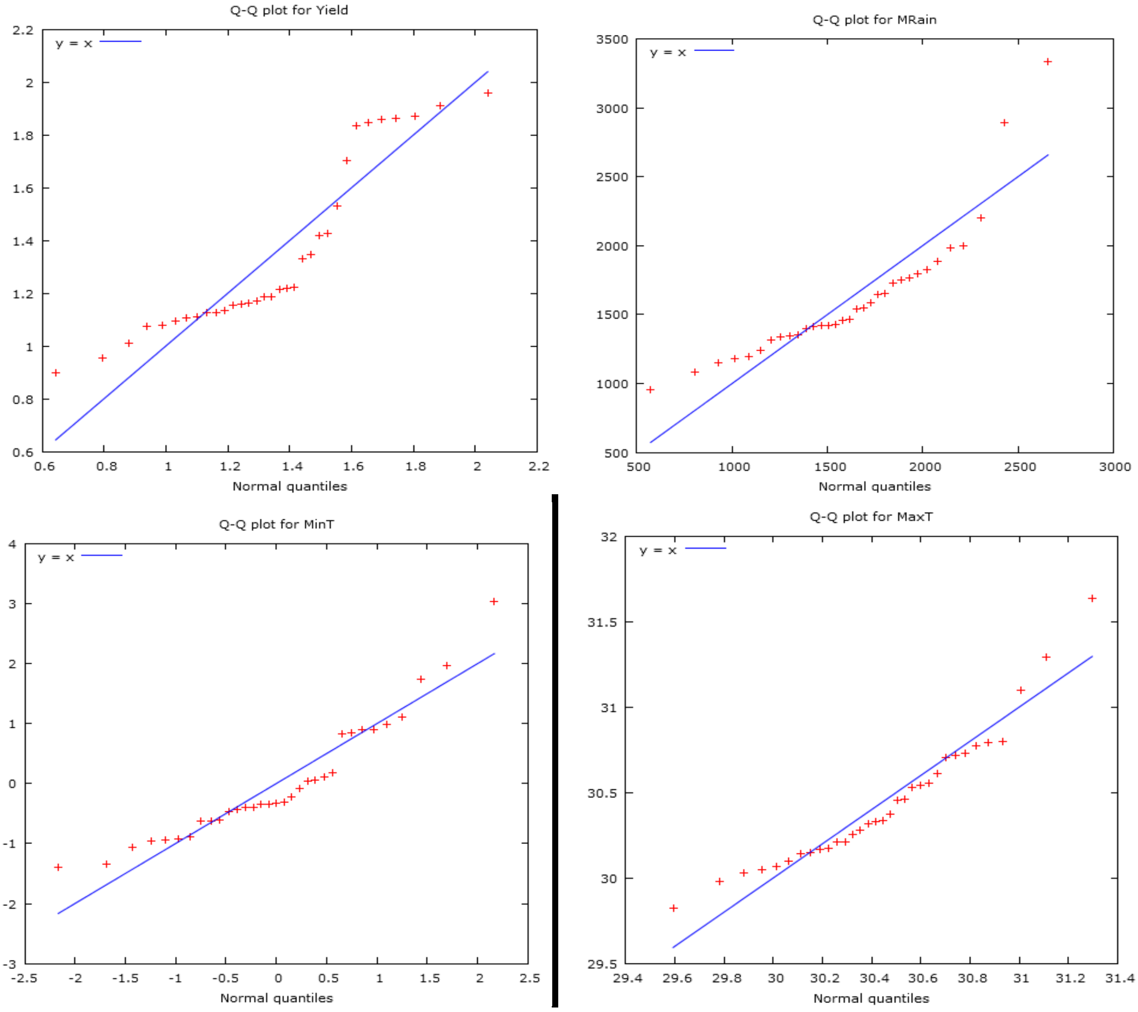
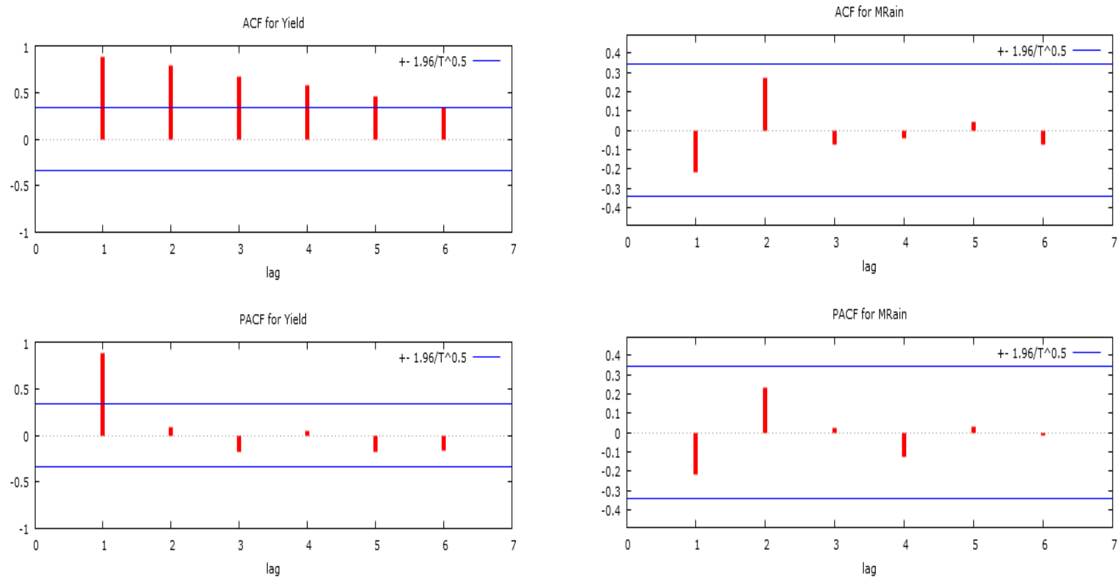


Figure 5. Q-Q plot for Yield, MRain, MinT and MaxT

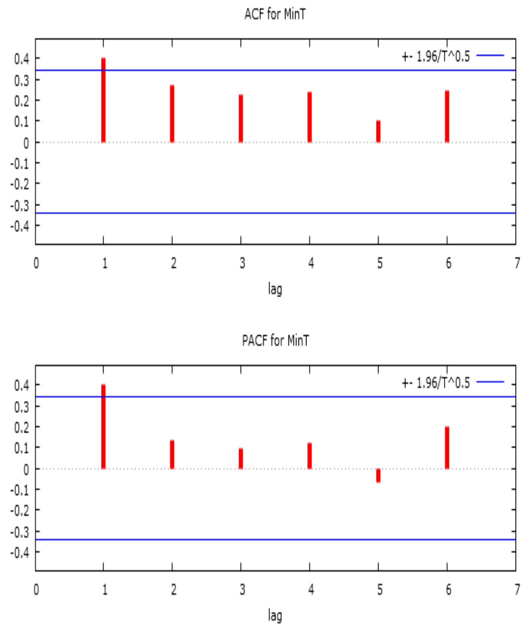


Annexure I

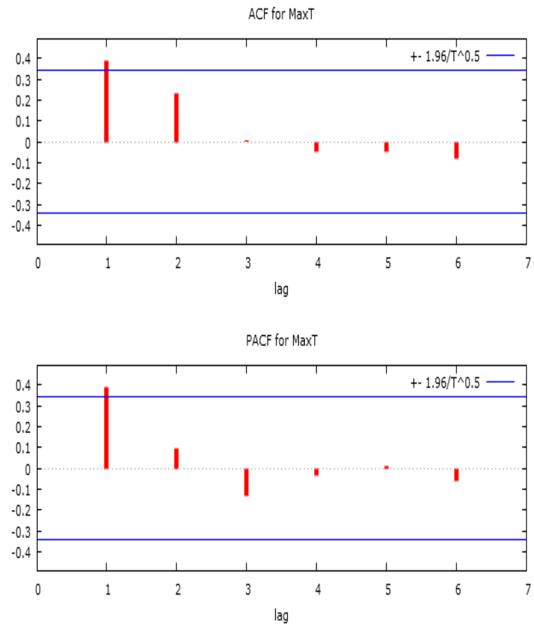
Correlogram for yield, MRain, MinT and MaxT



(a) Yield (b) MRain



(a) MinT



(b) MaxT

Table 2. Normality test and estimated trend coefficients of the yield and climatic variables

Variables	Normality test		Parametric (linear)	Non-parametric (monotonic)	
	Jarque Berra (B)	P value	slope coefficient	Men Kendall's Z statistic	Sen's slope estimate
Yield (MT/ha)	4.32**	0.01	0.03***	2.93**	0.03
MRain (mm)	43.23***	<0.01	13.57	1.84	0.04
MinT (^{0}C)	8.18**	0.02	0.03 ***	2.92**	0.03
MaxT (^{0}C)	8.25	0.12	0.02 **	1.38	0.05

& * represents p<0.05 and p<0.01, respectively

The positive monotonic trend is significant for yield (p<0.05) and the yearly increment is 0.03MT/ha. Though the MRain shows increasing linear monotonic trend but it is statistically insignificant. Similar finding was reported by Das *et al.* (2015) who observed positive but insignificant trend in monsoon rainfalls during 1960-2010 at Cherrapunjee and Shillong in Meghalaya. Chakraborty *et al.* (2017) reported negative trend in monsoon rainfall for Umiam in Meghalaya is insignificant, which is similar to the findings of Jain *et al.* (2013) for Assam & Meghalaya sub-division for the period of 1871-2008.

The MinT and MaxT have shown significant positive monotonic (p<0.05) and positive linear (p<0.05) trend. The average monsoon minimum and maximum temperature have increased by 0.30C/decade and 0.020C/decade, respectively Table 2 and Figure 4). Chakraborty *et al.* (2014) analysed the monthly, seasonal as well as the annual trends in mean air temperature over seven different places situated at various hills of north eastern India. They reported a dissimilar pattern of changes among the stations; places *viz.* Basar in Arunachal Pradesh, Imphal in Manipur and Gangtok in Sikkim where the mean temperature was lower, *i.e.* those places which are climatologically cooler, the increase in temperature is significant. Jain *et al.* (2013) also observed increasing trend in temperature in Assam & Meghalaya subdivision. Similarly, Jhajharia and Singh (2010) reported increase temperature trend in Assam which is different in physiography.

Relationship between yield and climatic variables

Table 3. Zero order correlation coefficients among the variables

Variables	Yield	MRain	MinT	MaxT
Yield	1.00			
MRain	0.22	1.00		
MinT	0.62***	0.44**	1.00	
MaxT	0.51**	0.20	0.61***	1.00
	d_Yield	MRain	d_MinT	d_MaxT
d_Yield	1.00			
MRain	0.31	1.00		
d_MinT	0.18	-0.04	1.00	
d_MaxT	0.02	0.21	0.23	1.00

& * represents $p<0.05$ and $p<0.01$, respectively

Note d_Yield, d_MinT and d_MaxT are the first difference forms

Table 4. Stationarity of different the variables: ADF test

Variables	Model	tau	P
Yield	with constant	-0.65	0.85
	with constant and trend	-1.75	0.71
MRain	with constant	-6.42	<0.01
	with constant and trend	-6.81	<0.01
MinT	with constant	0.84	0.99
	with constant and trend	-1.14	0.92
MaxT	with constant	-3.65	0.01
	with constant and trend	-4.06	0.02

The zero order correlation coefficients among the variables were calculated and presented in Table 3. The MinT and MaxT are positively correlated ($p<0.01$). The years with higher minimum temperature received significant ($p<0.01$) higher monsoon rainfall in the state. The MaxT ($p<0.05$) and MinT ($p<0.01$) are significantly correlated with *kharif* rice yield (Table 3). Then, the stionarity for all the variables was checked using correlogram (see Annex I) and further applying Augmented Dickey-Fuller (ADF) test. It is found that all the variables, except yield of rice, were non-stationary in nature (Table 4). Hence, they were made stationary by taking the first difference of each series. But when the simple correlation coefficients were calculated using the stationary variables it revealed no significant linear association among them (Table 3).

Effect on mean and variance in rice yield

The variables of Just and Pope Model are assumed to be stationary (Chen *et al.,* 2004) as non-stationary series may lead to spurious results (Chen and Chang 2005). Hence, we used the original series of MinT which is stationary and first differenced form of Yield, MRain and MaxT. The coefficient of Just and Pope Model reveals that maximum temperature has a positive and significant effect on the mean yield of

Table 5. Estimated coefficients of Just and Pope model

Variables	Coefficient		p-value
Mean function			
Constant	-0.30		0.640
Time	<-0.01		0.882
MaxT	0.24**		0.050
MinT	0.12		0.717
MRain	<0.01		0.708
Squared MaxT	0.51		0.165
Squared MinT	0.15**		0.043
Squared MRain	<-0.01		0.836
MaxT*MinT	-0.99**		0.042
MaxT*MRain	0.99		0.199
MinT*MRain	<-0.01		0.178
Variance function			
Constant	-3.52		0.076
MRain	<-0.01		0.54
MaxT	-0.34		0.802
MinT	-0.64		0.616
Time	-0.03**		0.032
F value (10,21)	12.48***		<-0.01
Akaike criterion	186.06		

& * represents $p<0.05$ and $p<0.01$, respectively *kharif* rice in Meghalaya (Table 5). The significant effect of the squared term of monsoon minimum temperature, and the interaction term of monsoon minimum and monsoon maximum temperature implies their non-linear effect on the mean yield of *kharif* rice. The optimum temperature for rice cultivation is about 25-33^{0}C though it varies across different stages (Yoshida 1978) (see Annex II). The long term average temperature was 26.91^{0}C in Meghalaya during the study period; hence the increasing temperature has positive effect on mean yield. The variance function too reveals that the climatic parameters along with time trend are risk decreasing factors but only time trend is statistically significant ($p<0.05$). This means technological progress had played positive role in reducing the variance in yield of rice. This finding is in line of the finding of Sarker *et al.* (2014) who found that mean minimum temperature is a risk decreasing factor for Aus and Aman rice in Bangladesh.

4. Conclusions

The monsoon rainfall in Meghalaya showed increasing but insignificant trend during the period of 1975-2007. The linear trends for minimum and maximum temperatures are positive and significant. Monsoon maximum temperature has positive and significant effect on the mean yield of kharif rice. Time is risk decreasing factor for rice yield in Meghalaya. Hence, the study does not find significant negative effect of climatic variables on rice yield in Meghalaya as the average rainfall is sufficient and though the temperature is increasing but not crossed the critical limit to become detrimental to rice yield in the state.

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