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# Climate change effects on crop yields are evident in North Eastern hills states of India

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ABSTRACT

This paper is an attempt to understand the change in climatic factors in the North Eastern (NE) hill region of India and its effect on mean and variability in crop yields using Just and Pope Model. The analysis of gridded climate data revealed that Nagaland registered significant decline (16.72 mm/annum) in monsoon rainfall whereas the decline was insignificant in three other NE hill states during 1975-2007. The monsoon maximum as well as minimum temperatures increased with the increase being higher for the latter (0.05$^0$C/annum in Arunachal Pradesh). The effects of monsoon maximum temperature and monsoon rainfall on mean yield of maize are negative. Monsoon rainfall also has negative effect on mean yield of potato. The technological progress has shown the evidence of offsetting the gradual part of climate change in case of rice and maize ($p<0.01$) but for wheat, potato and ginger it was not true. Monsoon rainfall and monsoon maximum temperature found to be risk increasing whereas monsoon minimum temperature a risk decreasing factor for most of the crops under study. Hence, the study suggests development of new varieties with higher yields and resilience to climatic stress by the research institutes.

## 1. Introduction

Rainfed agriculture is expected to be hit most by the changing climate. This consequently has the potential to negatively affect economy of the agrarian countries and the make the poor farmers vulnerable to climatic change (Mongi *et al.*, 2010) in absence of planned adaptation measures. Globally, a number of studies tried to capture the impact of climate change on agricultural production and productivity (Kurukulasuriya and Rosenthal, 2003; Carraro and Sgobbi, 2008; Kameyama *et al.*, 2008). Researchers have found that production of major cereal crops viz., rice, maize and wheat in the past few decades has declined in many parts of Asia due to increasing water stress arising partly from increasing temperature, increasing frequency of El Nino and reduction in the number of rainy days (Wijeratne, 1996; Aggarwal *et al.*, 2000; Jin *et al.*, 2001; Fischer *et al.*, 2002; Tao *et al.*, 2003; Tao *et al.*, 2004). Fischer *et al.,* 2002) indicated that substantial losses are likely to occur in rainfed wheat areas of South and South-East Asia. Faisal and Parveen, 2004 predicted the decline in rice by 8% and wheat production by 32% in Bangladesh, by the year 2050. A 2$^0$C increase in mean air temperature could decrease rain-fed rice yield by 5 to 12% in China (Lin *et al.*, 2004).

Most of the researchers studied the effect of climate variables on mean yield but fluctuation in crop yields is also important because agricultural production is very sensitive to changes in precipitation and temperature. This aspect has been studied only to a much lesser extent (Bindi *et al.*, 1996; Mearns *et al.*, 1997). Chen *et al.*, 2004 and Isik and Devadoss, 2006 have used Just-Pope, 1978 production functional form to simultaneously estimate the mean and variability in crop

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productivity. Isik and Devadoss, 2006 reported that climate change will have modest effects on the mean crop yields, but will significantly reduce the variance and covariance for the crops viz., wheat, barley, potato and sugar beets in Idaho, USA. Ranganathan, 2009 found that precipitation and temperature have varying effect on productivity and variability of crops in Tamil Nadu.

The hills of India are well known for its biodiversity but at the same time the hill eco-system is more fragile. The crop yields are much lesser than the national average; hence, the hill agriculture becomes more vulnerable to the changes in climatic parameters. In the North-Eastern (NE) region, the number of rainy days is likely to decrease by 1–10 days and the intensity of rainfall in the region is likely to increase by 1–6 mm/day (INCCA, 2010). The projected increase in these events will result into greater instability (seasonal/annual fluctuations) in food production and threaten the livelihood of the farmers (Mall *et al.*, 2006). Availability of food for the growing population will be a matter of concern under the climate change scenario in case of inadequate autonomous and planned adaptation measures. Hence, this paper tried to answer the questions viz., what are the changed observed in climatic factors viz., rainfall and temperature parameters in the NE hill region? How these changes in climatic factors impact the mean and variability in yields of major crops?

## 2. Methodology Data

Data on climatic variables *viz.,* rainfall and temperature ($1^0$ X $1^0$) were retrieved from India Meteorological Department (IMD) gridded data at state level for the period of 1975-2007 and 1975-2009, respectively. The crop yield data at state level were collected from the State Agricultural Departments and the publications of Directorate of Economics and Statistics (GoI 2011, GoMa, 2013, GoMb 2013, GoMz 2013, GoN 2010, GoS 2007).

***Analytical Techniques***

*Just-Pope Model*: This stochastic production function as given by Just and Pope (1978) is following.

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

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

$X$ is a vector of explanatory variables

$\omega$ is the stochastic term with mean zero and variance 1

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The error term) $\omega h\,(X;\ \delta)^{0.5}$ in equation (i) shows that Just-Pope model has heteroskedastic error terms. From equation (i), the expected productivity of crop is given by $E(y) = f(X; \beta)$ and crop variability is given by $V\,(y) = h(X; \beta)$. Hence, by $E(y) = f(X; \beta)$ and $V(y) = h(X; \beta)$ are called mean and variance functions, respectively. 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, $= \delta h/\delta x > 0$, it indicates that the corresponding input variable x is risk increasing, if $h_x < 0$ it implies risk decreasing. Thus, by employing Just-Pope production function, not only the mean yield but also yield variability and effect of an input variable on risk can also be simultaneously estimated.

*Estimation of the function:* Estimation of the above production function can be considered as estimation with heteroskedastic errors as in the following equation.

$$y = f(X; \beta) + u \qquad \text{.... (ii)}$$

Where, u = $\omega h\,(X;\ \delta)^{0.5}$ with $E(U) = 0$ and $Var(u) = hf(X; \beta)$

Maximum likelihood estimation (MLE) technique has been applied to estimate the mean and variance functions of the Just-Pope production function and the model was estimated using GRETL 1.10.1.

## 3. Results and Discussion

The climatic parameters for the study area are presented in Table 1. Sikkim received highest mean monsoon rainfall of 2128.4 mm among the seven NEH states of India during the study period of 1975-2013. Sikkim was followed by Mizoram, and Meghalaya. The lowest mean monsoon rainfall was observed in Manipur, followed by Tripura. The monsoon rainfalls were highly erratic in Tripura, Meghalaya

### Change in rainfall and temperatures in the study area

**Table 1. Mean, CV and trend of the climatic variables across different states of NEH**

| Parameters | Sikkim | Arunachal Pradesh | Meghalaya | Manipur | Nagaland | Tripura | Mizoram |
|---|---|---|---|---|---|---|---|
| Monsoon Rainfall | | | | | | | |
| Mean (mm)# | 2128.4 (80.46) | 1475.1 (66.62) | 1614.8 (69.3) | 969.1 (62.87) | 1496.6 (67.90) | 1394.7 (62.28) | 1594.4 (62.77) |
| CV (%) | 25.3 | 11.8 | 29.8 | 12.7 | 20.0 | 32.0 | 28.6 |
| Trend | 1.96 | -4.99 | 13.57 | 1.25 | -16.72*** | -13.01 | -12.58 |
| P | 0.85 | 0.12 | 0.12 | 0.59 | 0.00 | 0.11 | 0.13 |
| Monsoon minimum temperature | | | | | | | |
| Mean ($^0$C) | 21.6 | 24.4 | 23.4 | 23.3 | 24.4 | 22.9 | 23.0 |
| CV (%) | 2.7 | 4.1 | 1.9 | 1.5 | 1.3 | 1.9 | 1.5 |
| trend$ | 0.04*** | 0.05*** | 0.03*** | 0.01** | 0.02*** | 0.03*** | 0.02*** |
| P | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| Monsoon maximum temperature | | | | | | | |
| Mean ($^0$C) | 29.1 | 31.5 | 30.5 | 30.7 | 32.1 | 30.3 | 30.2 |
| CV (%) | 1.4 | 1.4 | 1.4 | 1.3 | 1.4 | 1.2 | 1.2 |
| trend$ | 0.01 | 0.02*** | 0.02*** | 0.03*** | 0.02*** | 0.01 | 0.01** |
| P | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.02 |

Note: #Figures in parenthesis indicate per cent to total and $ Figures in parenthesis indicate p values
** & *** indicates p< 0.05 and p<0.01, respectively

and Mizoram which was evident from the high CV values (> 28%) whereas inter year variations in rainfall was lowest in Arunachal Pradesh (11.8%). The trends in monsoon rainfall are positive for Meghalaya, Sikkim and Manipur whereas negative for Arunachal Pradesh, Tripura and Mizoram but these trends are insignificant, except in case of Nagaland where the negative trend is significant (p<0.01). The temperature data reveal that Sikkim was the coolest and Nagaland was the hottest state during the study period. The inter year variations in monsoon minimum temperature was highest in Arunachal Pradesh (4.1%), followed by Sikkim (2.7%). All the NEH states experienced increase in monsoon minimum temperature during the period of 1975-2009 and the trends are strongly significant (p<0.01). Similarly, the trends for monsoon maximum temperatures are positive for all the states and significant, except Sikkim and Tripura. The annual increment in mean monsoon minimum temperature was as high as 0.05$^0$C in Arunachal Pradesh, 0.04$^0$C in Sikkim, 0.03$^0$C in Meghalaya and Tripura. The annual increment for mean monsoon maximum temperature ranged in between 0.01$^0$C to 0.02$^0$C.

### *Productivity of different crops in NE hill states*

The mean yields of rice, maize, wheat, potato and ginger were estimated to be 1444.0 kg/ha, 1571.4 kg/ha, 1742.6 kg/ha, 8163.1 kg/ha and 5146.3 kg/ha respectively in the NE hill region of India. Manipur ranked first in terms of mean yield of rice (2015.0 kg/ha) and maize (2347.6 kg/ha) crop. The mean yield of wheat (2006.6 kg/ha) and ginger (9887.6 kg/ha) was highest in Nagaland whereas mean potato yield (17473.0 kg/ha) was highest in Tripura. Tripura also ranked second in mean yield for rice (1909.1 kg/ha) and wheat. The second highest yields for maize, potato and ginger were recorded in Mizoram, Meghalaya and Arunachal Pradesh, respectively. Manipur and Tripura were the forerunners in terms of yield for most of the crops under study, with exception of maize for Tripura and ginger for Manipur. The mean yields for most of the crops in Sikkim and AR were significantly lower than Manipur and Tripura (Table 2).

The standard deviation (SD) values reveal that the inter year variability were significantly higher for cash crops like ginger and potato than the food grain crops in the study area. The instabilities for different crops were higher for the states where yields were comparatively higher and lower in low yielding states. The inter year variability in rice yield was comparatively higher in Mizoram and Tripura than in Arunachal Pradesh and Meghalaya. The variability in maize yield was found to be highest in Manipur whereas, it was lowest in Arunachal Pradesh. The instabilities in case of yields of wheat, potato and ginger crops were highest in Nagaland.

### Productivity of different crops in NE hill states

**Table 2.** Mean and SD of the crop yields across different states of NEH

| Crops | Sikkim | Arunachal Pradesh | Meghalaya | Manipur | Nagaland | Tripura | Mizoram | NE hill |
|---|---|---|---|---|---|---|---|---|
| 1. Rice (1981-2007) | | | | | | | | |
| Mean (kg/ha) | 1316.4 | 1142.9 | 1155.1 | 2015.0 | 1249.0 | 1909.1 | 1320.6 | 1444.0 |
| SD | 311.2 | 144.0 | 108.8 | 370.8 | 315.2 | 407.3 | 486.2 | 306.2 |
| 2. Maize (1994-2007) | | | | | | | | |
| Mean (kg/ha) | 1450.3 | 1385.7 | 1438.9 | 2347.6 | 1456.2 | 925.5 | 1995.4 | 1571.4 |
| SD | 92.0 | 51.0 | 90.2 | 712.1 | 344.4 | 92.9 | 181.8 | 223.5 |
| 3. Wheat (1991-2007) | | | | | | | | |
| Mean (kg/ha) | 1487.4 | 1542.1 | 1622.3 | NA | 2006.6 | 1941.0 | 1856.4 | 1742.6 |
| SD | 283.49 | 211.1 | 196.18 | NA | 788.2 | 80.0 | 487.9 | 341.1 |
| 4. Potato (1996-2007) | | | | | | | | |
| Mean (kg/ha) | 4461.7 | 7120.4 | 8995.2 | 5425.7 | 9031.4 | 17473.0 | 4634.1 | 8163.1 |
| SD | 209.7 | 488.5 | 873.1 | 670.3 | 1719.1 | 1682.1 | 1716.3 | 1051.3 |
| 5. Ginger (1996-2007) | | | | | | | | |
| Mean (kg/ha) | 3384.5 | 7441.8 | 5670.9 | 1607.3 | 9887.6 | 2186.9 | 5845.2 | 5146.3 |
| SD | 2208.2 | 365.6 | 401.2 | 165.4 | 3570.9 | 953.9 | 798.8 | 1209.1 |

### *Impact on crop yield*

Just and Pope Model was applied on panel data constructed from time series of seven states to assess the impact of climatic variable on mean yield and yield variability of major crops in NEH states. Annual yield was used as dependent variable in the model. Monsoon rainfall, monsoon minimum and maximum temperatures, time as trend and state dummy were included as explanatory variables in the model. The coefficients were estimated using Maximum Likelihood (ML) technique. The data pertain to different period for different crops based upon the availability. Various functional forms of mean function and variance function were used and the best fit is selected based upon the logical (sign and magnitude of coefficients) and econometric criteria *i.e.,* least Akaike criterion (AIC). The coefficients, their standard errors (SE) and probability (p) values of selected best functional forms of Just and Pope Model are presented in Table 3.

*Impact on rice yield:* The quadratic model with dependent variable in log form and the variance function in linear form is found to be the best model. Only the time trend variable is significant ($p<0.01$) in the mean function which implies that technological progress, in the form of improved varieties, better agronomic practices and plant protection measures, has positive influence on rice yield which is evident from increased rice yield in the region over the study period. None of the climatic factors have significant influence on the mean yield of rice in the region. The mean yields of rice in Manipur and Tripura are statistically different from the other states. But in variance function, time trend and monsoon rainfall found to be positive and strongly significant ($p<0.01$) whereas, monsoon minimum temperature is negative and weekly significant ($p<0.10$) which means that, time and monsoon rainfall are the variance increasing factors whereas, monsoon minimum temperature is variance decreasing factor. The variability in rice yield is increasing over the years and increase in monsoon rainfall is expected to increase the variability in rice yield.

*Impact on maize yield:* The double log model with the variance function in linear form has turned out to be the best model. The time trend variable is significant ($p<0.01$) in the mean function which implies that technological progress has positive influence on maize yield. Rainfall ($p<0.01$) and monsoon maximum temperature ($p<0.10$) have significant negative influence on mean yield of maize. As the area receives high annual rainfall the increase in rainfall is expected to decrease the mean yield of maize. Similarly, the increasing temperature especially during the maturity period will hamper the grain filling in maize. The yields of maize of the different states are significantly different from the yield of maize in Manipur and Mizoram. In variance function, monsoon minimum temperature and monsoon rainfall are found to be negative and strongly significant ($p<0.01$) whereas, maximum temperature is positive and significant ($p<0.01$) which implies that monsoon minimum temperature and monsoon rainfall are the variance decreasing factors whereas, monsoon maximum temperature is a variance increasing factor. If the

**Table 3.** Estimated Just and Pope Model for major crops in NE hill states

| Crop | Rice | | | Maize | | | Wheat | | | Potato | | | Ginger | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dependent variable: | Ln (Yield) | | | Ln (Yield) | | | Ln (Yield) | | | Ln (Yield) | | | Ln (Yield) | | |
| Variables | B | SE | P | B | SE | P | b | SE | P | b | SE | P | b | SE | P |
| Mean function | Ln_yield | | | LnY-LnX | | | LnY-LnX | | | LnY-LinX | | | LnY-LnX | | |
| const | 5.066 | 32.283 | 0.875 | 13.344 | 2.617 | 0.000*** | 2.421 | 5.799 | 0.676 | 7.300 | 2.076 | 0.000*** | −0.834 | 10.313 | 0.936 |
| Time | 0.019 | 0.003 | 0.000*** | 0.012 | 0.003 | 0.000*** | −0.004 | 0.008 | 0.616 | −0.005 | 0.010 | 0.619 | −0.003 | 0.017 | 0.850 |
| MaxT | −0.848 | 2.329 | 0.716 | −1.574 | 0.880 | 0.074* | 2.045 | 1.877 | 0.276 | 0.056 | 0.090 | 0.532 | 2.089 | 3.801 | 0.583 |
| MinT | 1.645 | 1.047 | 0.116 | 0.083 | 0.254 | 0.745 | −0.114 | 1.362 | 0.933 | −0.008 | 0.099 | 0.936 | 1.254 | 2.752 | 0.649 |
| RainT | −0.001 | 0.002 | 0.801 | −0.112 | 0.029 | 0.000*** | −0.168 | 0.170 | 0.321 | −0.000 | 0.000 | 0.063* | −0.153 | 0.284 | 0.590 |
| MaxT2 | 0.025 | 0.046 | 0.584 | | | | | | | | | | | | |
| MinT 2 | −0.009 | 0.025 | 0.716 | | | | | | | | | | | | |
| RainT2 | 0.000 | 0.000 | 0.527 | | | | | | | | | | | | |
| MaxTMinT | −0.041 | 0.039 | 0.304 | | | | | | | | | | | | |
| MaxTRain | 0.000 | 0.000 | 0.478 | | | | | | | | | | | | |
| MinTRain | −0.000 | 0.000 | 0.333 | | | | | | | | | | | | |
| Sikkim | 0.018 | 0.156 | 0.911 | −0.387 | 0.053 | 0.000*** | −0.091 | 0.156 | 0.561 | 0.072 | 0.206 | 0.728 | 0.015 | 0.313 | 0.961 |
| AP | −0.015 | 0.064 | 0.817 | −0.355 | 0.039 | 0.000*** | −0.296 | 0.130 | 0.022*** | 0.398 | 0.160 | 0.013** | 0.203 | 0.195 | 0.298 |
| Meghalaya | 0.001 | 0.051 | 0.989 | −0.314 | 0.030 | 0.000*** | −0.253 | 0.124 | 0.041*** | 0.685 | 0.149 | 0.000*** | −0.001 | 0.210 | 0.995 |
| Manipur | 0.420 | 0.063 | 0.000*** | −0.024 | 0.058 | 0.679 | | | | 0.046 | 0.134 | 0.729 | −1.329 | 0.140 | 0.000*** |
| Nagaland | −0.017 | 0.088 | 0.848 | −0.272 | 0.052 | 0.000*** | −0.285 | 0.113 | 0.011*** | 0.535 | 0.120 | 0.000*** | 0.384 | 0.166 | 0.021** |
| Tripura | 0.371 | 0.074 | 0.000*** | −0.763 | 0.032 | 0.000*** | −0.074 | 0.102 | 0.466 | 1.302 | 0.114 | 0.000*** | −1.027 | 0.186 | 0.000*** |
| Variance function | Linear | | | Linear | | | Ln | | | Ln | | | Linear | | |
| const | −10.562 | 5.525 | 0.056* | −21.097 | 7.194 | 0.003*** | −124.692 | 32.473 | 0.000*** | −20.960 | 33.624 | 0.533 | 11.305 | 7.699 | 0.142 |
| Time | 0.070 | 0.011 | 0.000*** | 0.063 | 0.042 | 0.134 | 0.088 | 0.019 | 0.000*** | −0.004 | 0.077 | 0.961 | 0.035 | 0.059 | 0.560 |
| MaxT | 0.459 | 0.279 | 0.100 | 1.658 | 0.413 | 0.000*** | 18.384 | 10.201 | 0.072* | 5.141 | 12.443 | 0.680 | 0.742 | 0.428 | 0.083* |
| MinT | −0.461 | 0.255 | 0.070* | −1.552 | 0.426 | 0.000*** | 10.605 | 6.975 | 0.128 | −4.277 | 8.570 | 0.618 | −1.996 | 0.470 | 0.000*** |
| Rain | 0.001 | 0.000 | 0.001*** | −0.001 | 0.000 | 0.001*** | 3.787 | 0.849 | 0.000*** | 1.670 | 0.947 | 0.078* | 0.001 | 0.000 | 0.097* |
| Akaike criterion | −40.514 | | | −137.510 | | | 52.669 | | | 59.531 | | | −25.271 | | |

*, ** & *** indicates p<0.10, p<0.05 & p<0.01, respectively

monsoon rainfall increases, the variability in maize yield will decrease. Similarly, increase in monsoon minimum temperature will decrease the yield variability of maize. The monsoon maximum temperature is risk increasing factor which implies that with increase in monsoon maximum temperature variability in yield of maize will also increase.

*Impact on wheat yield:* The double log model with the variance function in logarithmic form is found to be the best model. None of the climatic variable found to be significant in mean function. The yields of wheat in Arunachal Pradesh, Meghalaya and Nagaland are significantly different from the yield of wheat in other states of NEH. In variance function, time and monsoon rainfall turned out to be strongly risk increasing factors and maximum temperature is marginally risk increasing factor. With each increasing year the variability in wheat yield is increasing. Increase in monsoon rainfall and monsoon maximum temperature is also expected to increase the variability in wheat yield.

*Impact on potato yield:* The log-lin model with the variance function in logarithmic form is turned out to be the best model. Only monsoon rainfall has negative but week ($p<0.10$) influence on potato yield. Similarly, monsoon rainfall is the factor which increased the variability in potato yield but the impact is marginal ($P<0.10$). The yields of potato in Arunachal Pradesh, Meghalaya, Nagaland and Tripura are significantly different from the yield of potato in Sikkim, Manipur and Mizoram.

*Impact on ginger yield:* The double log model with the variance function in linear form is the best model. None of the climatic variable found to be significant in mean function. The yields of ginger in Manipur, Nagaland and Tripura are significantly different from the yield of ginger in other states. In variance function, monsoon maximum temperature and monsoon rainfall turned out to be marginally risk increasing factors ($p<0.10$). Increase in monsoon maximum temperature and rainfall is expected to increase the variability in ginger yield. Monsoon minimum temperature is found to be strong risk reducing factor which implies that if the monsoon minimum temperature increases the variability in ginger yield will decrease.

## 4. Conclusions

The analysis of climatic data revealed that the rainfall was erratic in nature in the NE hill region. Many of the NE states registered decline in quantum of rainfall in monsoon season. The monsoon maximum and minimum temperatures increased with the increase being higher for the latter during the study period. The effect of monsoon maximum temperature on mean yield of maize is negative but week in the region. Monsoon rainfall has strong negative effect on mean yield of maize but the negative effect is week in case of potato. The technological progress has shown the evidence of offsetting the gradual part of climate change in case of rice and maize but for wheat, potato and ginger it was not true. As potato and ginger are the important cash crops of this region the breeders may develop new verities with the characteristics of higher yield and resilience to climatic stress, and at the same time suitable to local land situation. The agronomists and soil scientists together may come out with better agronomic management practices to lessen the yield loss during these stress periods.

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