CLIMATE VARIABILITY AND AGRICULTURAL PRODUCTIVITY IN UTTAR PRADESH, INDIA: EVIDENCE FROM PANEL STUDY

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The current study estimates rainfall, minimum & maximum temperature, irrigation, rural literacy, consumption of chemical fertilisers, pump set and tractors impact on the productivity of rice, wheat, sorghum, pearl millet, maize, finger millet, pigeon pea, chickpea, sugarcane, cotton, groundnut and barley during 1966 to 2015 by using feasible generalised least square method. Method is appropriate data sets containing cross-sectional dependence, serial correlation and heteroskedasticity. The FGLS empirical results indicate that the maximum temperature negatively associated with the yield of all twelve crops and irrigated area, rainfall, rural literacy, pump set, tractors, fertiliser consumption coefficients are positively associated with the yield of rice, wheat, sugarcane, finger millet, pearl millet. The marginal effect of rainfall shows that maize, barley and chickpea crops are adversely affected during 1966-2015. The maximum temperature increased from the threshold level of all the twelve study crops and adversely affected to Kharif crops, viz., sorghum, maize, finger millet, pigeon pea and groundnut by -187.70, -207.92, -108.50, -147.06 and -167.47 percent respectively. The projected results show the productivity of sorghum, maize, finger millet, pigeon pea and groundnut would be declined by -178.60, 181.92, -143.06, -111 and -179.36 percent by 2100.

INTRODUCTION

Among the causal factors of agricultural productivity, climatic factors, viz., rainfall and temperature, are most influencing factors, responsible for variability in the productivity of major cereals even in high-yield regions (Goswami et al. 2006; Deressa et al., 2009; Gupta et al., 2012 and Kumar et al., 2014). Variations in rainfall pattern, acceleration in day and night temperature, doubling in carbon di-oxide level, an increase in solar radiation, deceleration in average land size, unbalance use of artificial sub-additives (chemical pesticides and plant foods) are increasing degree of adverse climate change impact. The expected changes in climate, especially rainfall, are also marked by significant regional variation, with the Western Ghats, the central India and the Northeastern regions projected to receive more rainfall compared to the other parts of India by the end of this century (IMD, 2012). Further, an increase in intensity and frequency of extreme events such as droughts, floods and cyclones in coastal areas is also projected. All these changes are likely to have adverse impacts on India’s water resources, agriculture, forests and other ecosystems, coastal zones, energy and infrastructure and on human health (K.S. K. Kumar, 2010). An increase in population size putting the pressure on highly vulnerable and least adaptive capable marginalized farmers to increase the per hectare production to feed food demand (K.S. K. Kumar, 2010). In India, agricultural statistics claimed that arable land has declined from 0.48 hectares in 1950 to 0.15 hectares in 2000. It is likely to reduce further up to 0.08 hectares by the year 2020 (Mall et al., 2006). Sivakumar et al. (2005) claimed that the agriculture sector is potentially highly vulnerable to climate change because of degradation of the limited arable land. Further, the predicted increase in frequency and/or severity of extreme events coupled with any increase in the

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intensity of tropical cyclones could further exacerbate adverse impacts of climate change on the agricultural sector.

BACKGROUND OF THE STUDY AREA

The current study investigates climate variability and its impact on agricultural productivity in the most agriculturally diversified and populous state of India, viz., Uttar Pradesh. Uttar Pradesh has rich in terms of soil quality, water resources, and agricultural labourers. However, it is divided into four administrative zones (western, central, eastern and Bundelkhand) and nine agro-climatic zones[1]. These zones have heterogeneity terms of soil quality, climatic conditions, land, and population size and agriculture infrastructure (Figure 1). Among the agro-climatic zones, Bundelkhand zone is highly vulnerable, drier, with less fertile land and least water resources. On the other hand, western plain, south-western semi-arid, mid-western plain are highly productive, with fertile land and rich water resources. These features show diversity, complexity and heterogeneity in the agricultural productivity, inputs and environmental resources. Further, Uttar Pradesh is among the Indian states, benefited most from the Green Revolution implemented in early 1960s. The total cropped area under cereals especially in rice and wheat and non-food grain crops, i.e., sugarcane was increased by 10 percent up to mid-1980s (GoUP, 2013). However, stagnation in the cropped area growth of cereals, shift in gross sown are of food grain crops towards non-food grain crops, decline in an investment, shift in agricultural labour from agriculture to other sectors, decline in mean land size, rural to urban migration, high resources intensive farmers and increase in variability in the climatic factors, viz., rainfall, temperature has increased the degree of uncertainty about acute availability of food grains to massive increasing population after 1990s in Uttar Pradesh.

NEED OF THE STUDY

The current study is different from the previous studies (Kumar et al., 2015; Birthal et al., 2014 and Gupta et al., 2012) with the following objectives. First, district level panel analysis in Uttar Pradesh on major & minor food and non-food grain crops, especially pulses is limited in the literature. Basically, previous studies covered four to five crops, but present study has taken twelve crops which are not studied earlier[2]. Second, the present study covered all four administratively divided regions viz., Western, Central, Eastern and Bundelkhand and nine agro-climatic zone to capture climate change impact. Third, study period during 1966-2015 which is relatively larger. Fourth, the present study uses FGLS model for regression estimation. Model is the most appropriate to control, serial correlation, autocorrelation, heteroskedasticity and multi-colinearity issues (Kumar et al., 2015; Birthal et al., 2014 and Gupta et al., 2012). The main objective of the present study to examine climate change impact on the study crops in the Uttar Pradesh and forecast future trends of productivity with the help of IPCC (2001b) predictions about rainfall and temperature.

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[1] Bhabhar and Tarai, Bundelkhand, Central, Eastern Plain, Mid-Western Plain, North Easter Plain, South western Semi-Arid, Vindhyanchal, Western Plain.

[2] Rice, Wheat, Sorghum, Pearl millet, Maize, Finger millet, Barley, Chickpea, Pigeon pea, Groundnut, Sugarcane and Cotton.

SOURCES OF DATA

The study employed non-climatic and climatic variable to assess their influence on major crop yield and its variability. Irrigated area, rural literacy, fertilisers consumption, number of pump sets, number of tractors and sown area is considered as non-climatic factors and annual minimum & maximum temperature, and annual rainfall are considered as climatic factors responsible for crop productivity. Mean yield of crops per hectare is considered dependent variable. For this estimation our district- wise panel data of 46 major crops growing districts of the Uttar Pradesh were limited and includes 50 years during 1966-2015. Because in India, a district is the lowest unit of these type of datasets. Further, data has been collected from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for irrigated area, annual rainfall, rural literacy, number of tractors, fertilisers consumption and number of pump sets. Minimum & maximum temperatures data has been collected from Indian Meteorological Department (IMD), India Water Portal and various volumes of statistical dairy of Uttar Pradesh. Both interpolation and extrapolation are done to bridge the gap if the missing values in time series.

METHODS OF ESTIMATION

There are broadly three methods, viz., (i) Production function or bio-physical crop modeling method or agronomist method, (ii) Ricardian method or hedonic method or cross section model and, (iii) Panel data method available to capture climate change impact on crop productivity. The impact assessment of climatic factors in agriculture has been traditionally estimated by numerous researchers with the help of the production function method to capture agricultural loss (Adams, R. 1989; Adams, R. et al., 1998; Rosenberg, 1992; Rozenzweig, Cynthia and Parry, Martin L., 1994). Further, the more sophisticated crop model was incorporated for certain adaptations to climate change, such as shifts in planting dates, increased irrigation, and changes in crop varieties (Parry, M.L. et al, 1999). However, this method suffers from the problems. First, the prediction of how the future farmers would behave though adaptability was assumed under this method. Second, Production function method normally overestimates the damages from climate change due to the fact that cannot take into account the substitution of crops or adaptability of crops or emergence of new crops; it simply estimates the decline of productivity due to the increase in temperature or the enrichment of CO_2 or climatic factors (Mendelsohn et. al., 1994). Third, this method estimates the effect of weather on the yields of specific crops that are purged of bias due to the determinants of agricultural output that are beyond farmers' control, e.g., soil quality (Deschenes and Greenstone, 2007).

Further, numerous studies were undertaken either on structural or on spatial analogue method, but they were described substantially for adaptation to offset the negative effects of climate change (Mendelsohn et. al., 1994; Adams et al., 1998b; Mendelsohn et. al., 2001, 2006 &10). This method is similar to the hedonic price method, as all other factors remaining constant, regional differences in climatic values or productivity are explained by the differences in climatic factors. This method is more advantageous in many ways than production function method as it captures the present land value over future streams of profits by using the discount rate, and regional differences in land values or productivity; it accounts for the full range of farmers' adaptations, and it neutralizes (lowers) the impacts more than biophysical crop modeling. Though, Ricardian method has the potential for addressing the adaptation satisfactorily, yet the issues concerning the cost of adaptation are not completely addressed and fail to capture the impacts fully in various ways. First, it fails to capture the effect of unobservable farms and farmers' characteristics on farm income that may be correlated with climate change. Second, a cross section or a repeated cross section is often misleading or mis-specified and lead to bias in estimates (Guiteras, R., 2007). Third, it does not account for the effects of factors that do not vary across space and time (Deschenes and Greenstone, 2007). Four, the constant relative price assumption used in this approach could bias the estimates (Cline, 1996).

Furthermore, panel data method has been use in recent years (Deschenes and Greenstone, 2007; Birthal, P.S. et al., 2014 and Kumar et al., 2014), as it enables us to capture the effects of time-invariant variables, weather variables rather than the normal climate and short- term effects of adaptation on productivity. The panel data method is the latest one and has more advantageous in numerous ways than the previous methods (present study uses). First, the dependent variable, i.e., land value or net revenue or gross revenue per hectare is an annual measure rather than an average of cross sections as in the case of Ricardian analysis. Second, it is possible to capture the effects of time invariant variables, like soils, and elevations in the panel data. Third, the independent variables of interest are the functions of monthly or yearly realised weather variables rather than the normal climate. Four, it is possible to accommodate the short term effects of adaptations, i.e., year to year fluctuations of temperature and precipitation on production or agricultural profits. Therefore, we found that the cross-sectional panel estimation method is most appropriate for the current study and datasets we collected. It is capable to capture existing adaptation, viz., use of pump sets and tractors as a technological tools, and rural literacy and use of chemical fertilisers.

FORMULATION OF MODELS

The present study uses simple Cobb-Douglas production function (Panel data method) by incorporating proxy for independent variables as determinants of crop productivity in Uttar Pradesh. Because, the present study uses panel data, therefore, it is necessary to check all possible errors in the data will occur viz., unit root, cross-sectional dependence, heteroskedasticity and serial correlation, etc. (appendix A & B) and it is found that data sets contain cross-sectional dependence, heteroskedasticity, and serial correlation. Therefore, simple OLS model is not appropriate. Therefore, the present study is uses Feasible Generalized Least Square (FGLS) in three stages;

First, the regression coefficient of major crops yield function $[f(X_{it,}\beta)]$ is estimated by ordinary least square (OLS) estimation. Cabas et al., (2010) and Kumar at al., (2015) also experimented similar process to assess the influence of climatic and non- climatic variables on various crops and yield variance. The functional form of the model is given as follows.

$(P)_{it} = f\{(SA)_{it}, (IA)_{it}, (ARF)_{it}, (Mintemp)_{it}, (Maxtemp)_{it}, (Rurallit)_{it}, (Tractors)_{it}, (Fertilizers)_{it}, (Pumpset)_{it}, \}$.............(1)

Where, P is the aggregate production of the respective crop, i is state and t is the time period. Subsequently, SA is sown area, IA is irrigated area, ARF is annual rainfall, Mintemp is minimum temperature, Maxtemp is Maximum temperature, Rurallit is total rural literacy, Tractors is number of tractors, Fertilizers is fertilizer consumption and Pumpset is total pump sets used for irrigation .

Further, dividing by SA, equation (1) could be written in yield terms that indicate the production on per hectare basis (land productivity) as:

$(P/SA)_{it} = f\{(IA)_{it}, (ARF)_{it}, (Mintemp)_{it}, (Maxtemp)_{it}, (Rurallit)_{it}, (Tractors)_{it}, (Fertilizers)_{it}, (Pumpset)_{it},\}$.............(2).

After applying a C-D model, equation (2) will take the following specification:

$Log(P)_{it} = \beta_0 + \beta_1 log(IA)_{it} + \beta_2 log(ARF)_{it} + \beta_3 log(Mintemp)_{it} + \beta_4 log(Maxtemp)_{it} + \beta_5 log(Rurallit)_{it} + \beta_6 log(Tractors)_{it} + \beta_7 log(Fertilizers)_{it} + \beta_8 log(Pumpset)_{it} + U_{it}$.....................(3)

Where, β_0 is a constant coefficient that is known as Total factor productivity and assumes that the production function is constant returns to scale and a linear production function with homogeneous degree one. U_{it} is white noise error term with zero mean and constant variance and β_1 to β_8 are estimated regression coefficients for respective variables under the C-D model.

RESULTS & DISCUSSION

Table 1 reveals mean and standard deviation of the crop productivity. Table 1 indicates that sugarcane has the highest productivity and sorghum and cotton have lowest among the study crops. Further, in the food grain crops, wheat on top and sorghum on the bottom, i.e., 2.05 & 0.85 ton per hectare, whereas, in the non-food grain crops, sugarcane on top and cotton on the bottom, i.e., 4.50 & 0.85. Furthermore, annual rainfall has recorded 933.42 millimetres. This is higher from long range average, estimated by the Indian Meteorological Department of India (887 millimetres). Mean minimum and the maximum temperatures are varying between 18.99 to 32.33 ^{O}C. Table 1 also indicates that farmers have 7.92 & 43.07 numbers of tractors and pump sets per thousand hectare land. The use of total fertilisers per thousand hectares was 4.33 tones.

Table- 1

Yield of Major Crops & Environmental Factors during 1966-2015 in Uttar Pradesh

Name of Variable	Unit	Mean	Standard Deviation
Rice	Ton/Hectare	1.46	0.65
Wheat	Ton/Hectare	2.05	0.77
Sorghum	Ton/Hectare	0.85	0.47
Pearl Millet	Ton/Hectare	0.97	0.46
Maize	Ton/Hectare	1.06	0.49
Finger millet	Ton/Hectare	0.91	0.24
Barley	Ton/Hectare	1.51	0.70
Chickpea	Ton/Hectare	0.86	0.26
Pigeon pea	Ton/Hectare	1.07	0.53
Groundnut	Ton/Hectare	1.07	2.00
Sugarcane	Ton/Hectare	4.50	1.10
Cotton	Ton/Hectare	0.85	1.10
Annual Rainfall	Millimeter	933.42	395.22
Maximum Temperature	Degree Centigrade	32.33	0.615
Minimum Temperature	Degree Centigrade	18.99	0.612
Tractors	Nos./'000'Hectare	7.92	7.41
Fertilizer Consumption	Ton/'000'Hectare	4.33	36.71
Pump Sets	Nos./ '000'Hectare	43.07	30.50

Source: Estimated from ICRISAT database

Table 2 reveals district year fixed effects. Irrigated area is positively associated with the yield of rice, wheat, pearl millet, maize, barley, pigeon pea and sugarcane in one hand and on the other hand, negatively associated with sorghum, finger millet, groundnut and cotton. It means increase in irrigated area leads to increase the yield of rice, pearl millet, maize, barley, pigeon pea and sugarcane and reduce the yield of sorghum, finger millet, groundnut and cotton. Further, annual rainfall is positively associated with rice, wheat, sorghum, pearl millet, maize, pigeon pea, groundnut, sugarcane and cotton on one hand and on the other hand, barley, finger millet and chickpea negatively associated. Furthermore, the minimum temperature is positively associated and maximum temperature negatively associated with the yield of all study crops. In contrast, rural literacy positively associated with the yield of rice, wheat, sorghum, pearl millet, maize, barley, finger millet, chickpea, groundnut, sugarcane and cotton. Only pigeon pea is negatively associated with rural literacy. Moreover, the tractor is taken as a technological factor and theoretically positive associated claimed by the many researchers (Kumar et al., 2015 and Birthal et al., 2014). It is confirmed by the present study. Means increase in a number of tractors per thousand hectare leads to increase the yield of rice, wheat, sorghum, maize, barley, finger millet, chickpea, pigeon pea, groundnut, sugarcane and cotton. Only pearl millet yield negatively associated with tractors. The uses of chemical fertilisers has boosted the crop yield. It is observed in the FGLS regression results (Table 2) that yield of rice, wheat, sorghum, pearl millet, barley, finger millet, chickpea and sugarcane positively associated in one hand and on the other hand, the yield of maize, pigeon pea, groundnut and cotton negatively associated. Means increase in fertiliser consumption leads to increase the yield of rice, wheat, sorghum, pearl millet, barley, finger millet, chickpea and sugarcane. Moreover, pump sets (diesel & electric) are an insured availability of water when rainfall is not sufficient to feed water requirement for the respective crop. Further, it is observed that pump set is positively associated with the yield of rice, wheat, sorghum, pearl millet, barley, finger millet, chickpea, pigeon pea, groundnut, sugarcane and cotton and negatively associated with the yield of maize (Table 2).

What about previous studies claimed about relationship between yield of crops and climatic factors viz., rainfall and temperature? Studies indicated that surface warming accelerated in India at the end of the 20th century, with minimum temperature rising 0.025^0C per year during 1981-1990 and 0.056^0C per year during 1991-2000. India’s land surface also became dimmer, with surface solar radiation falling by about 5 percent during 1981- 2004 (Kumari et al., 2007). These changes are not just changes in the monsoon, could contribute to any residual reductions in yield that are detected after controlling for changes in technology. Further, Wheat productivity observed that in north India states such as Uttar Pradesh, Punjab, Haryana, Uttarakhand and Himachal Pradesh is affected by increasing trends of temperature (Samuel C., 2007). Moreover, an increase 0.05^0C in winter temperature would reduce wheat crop duration of seven days and reduced yield by 0.45 per hectare (Sinha and Swaminathan, 1991). Further, it is estimated that mean temperature over the wheat growing regions of northern India were high by 1.7^0C over the period of 15 days (January 16 to February 1). The actual temperature rise was of the order of 2.4 to 4^0C in the major producing States, Viz., Punjab and Haryana during 1991 to 2000 (Singh and Sonatakke, 2002). In addition, (Guiteras R. 2007) predicted that an increase in temperature to medium- term (2010-2039) yields, reduce by 4.5 to 9 percent, depending on the magnitude and distribution of warming. The study predicted that the impact of long- term climate change (2070-2099) is even more detrimental with predicted yields falling by 25 percent or more. Because these large changes in long- run temperatures will develop over many decades, farmers will have time to adapt their practices to the new climate, likely lessening the negative impacts.

Moreover, wheat and rice are major food crops in the Asian as well as India. Agricultural productivity in tropical Asia is sensitive not only to temperature, but also to changes in the nature and characteristic of monsoon. Simulations of the impacts of climate change using crop simulation model show that crop yield decreases due to climate change could have serious impacts on food security in tropical Asia. Climate change is likely to cause environmental and social stress in many of Asia's range lands and dry lands. In the arid and semi- arid tropics of Africa, which are already having difficulty coping with environmental stress, climate change resulting increased frequencies of drought poses the greatest risk to agriculture. Impacts were described as those related to projected temperature increases, the possible consequences to water balance of the combination of enhanced temperature and changes in precipitation and sensitivity of different crops/ cropping systems to projected changes (Sivakumar et al., 2005). Moreover, agriculture and water resources are most affected through the impact of extreme temperatures (excess heat, frost) and the change in rainfall (drought, flooding).

Table 2

Cross-Sectional Time Series FGLS Regression Results

Variables	**GLS**	**GLS**	**GLS**	**GLS**	**GLS**	**GLS**
Number of Observation	1861	1865	1842	1846	1854	1865
Wald chi2	2425.08	4364.81	603.07	847.55	1119.93	2093.69
Prob> chi2	0.000	0.000	0.000	0.000	0.000	0.000
Crops	Rice	Wheat	Sorghum	Pearl millet	Maize	Barley
Log of Irrigated area	0.104* (0.004)	0.0301* (0.009)	-0.119* (0.008)	0.006^{NS} (0.005)	0.019* (0.005)	0.039* (0.004)
Log of Annual Rainfall	0.015^{NS} (0.019)	0.011^{NS} (0.011)	0.131* (0.026)	0.104* (0.024)	0.004^{NS} (0.024)	-0.040* (0.017)
Log of Minimum Temperature	2.051* (0.470)	1.687* (.284)	2.312* (0.661)	0.769*** (0.612)	4.813* (0.620)	1.786* (0.419)
Log of Maximum Temperature	-1.311* (0.722)	-1.734* (0.435)	-4.935* (0.976)	-2.458* (0.903)	-6.817* (0.923)	-2.092* (0.643)
Log of Rural Literacy	0.087* (0.014)	0.093* (0.010)	0.165* (0.019)	0.185* (0.018)	0.180* (.019)	0.187* (0.013)
Log of Tractors	0.067* (0.013)	0.0994* (.008)	0.049* (0.018)	-0.011^{NS} (0.016)	0.241* (0.016)	0.109* (0.012)
Log of Fertiliser Consumption	0.112* (0.017)	0.117* (.010)	0.035* (0.024)	0.166* (0.022)	-0.002^{NS} (0.023)	0.078* (0.015)
Log of Pump Set	0.075* (0.019)	0.062* (0.011)	0.008* (0.026)	0.015^{NS} (0.024)	-0.062* (0.025)	0.033* (0.0172)
Constant	-0.709^{NS} (1.662)	-2.778* (1.013)	-13.404* (2.264)	-14.572* (2.068)	-10.88* (2.151)	-3.710* (1.487)

Source: Estimated from ICRISAT database, the *, **, *** and **** indicate 1, 5, 10 and 20 percent level of significance. The values in the brackets are standard error.

MARGINAL EFFECT

The FGLS panel regression coefficient results are estimated from 46 district of Uttar Pradesh. These districts have huge heterogeneity in yield, temperature, rainfall. Therefore, present study estimates marginal effect of rainfall, minimum and maximum temperatures on yield of respective crop by using equation (4).

Table 2 (contd.)

Cross-Sectional Time Series FGLS Regression Results

Variables	**GLS**	**GLS**	**GLS**	**GLS**	**GLS**	**GLS**
Number of Observation	1861	1864	1842	1854	1864	1857
Wald chi2	1197.75	4868.16	156.51	86.33	1305.01	1479.77
Prob> chi2	0.000	0.000	0.000	0.000	0.000	0.000
Crops	Finger Millet	Chickpea	Pigeon pea	Groundnut	Sugarcane	Cotton
Log of Irrigated area	-1.069* (0.037)	-0.049^{NS} (0.002)	0.005^{NS} (0.005)	-0.029* (0.009)	0.155* (0.012)	-0.343* (0.012)
Log of Annual Rainfall	-0.098* (0.015)	-0.015* (0.013)	0.037***** (0.025)	0.122* (0.027)	0.116* (0.045)	0.061* (0.048)
Log of Minimum Temperature	1.198* (0.383)	1.658* (0.318)	3.902* (0.638)	1.709* (0.668)	3.466* (1.115)	7.547* (1.156)
Log of Maximum Temperature	-3.054* (0.581)	-1.297* (0.489)	-3.912* (0.947)	-5.377* (1.016)	-4.894* (1.704)	-12.116* (1.786)
Log of Rural Literate	0.086* (0.012)	0.133* (0.009)	-0.025**** (0.019)	0.096* (0.020)	0.132* (0.035)	0.637* (.035)
Log of Tractors	0.011^{NS} (0.010)	0.119* (0.008)	0.015^{NS} (0.018)	0.059* (0.018)	0.334* (0.031)	0.053* (0.032)
Log of Fertiliser Consumption	0.060* (0.014)	0.086* (0.012)	-0.122* (0.023)	-0.034* (0.025)	0.304* (0.043)	-0.459* (0.044)
Log of Pump Set	0.036* (0.015)	0.061* (0.013)	0.065* (0.025)	0.077* (0.027)	0.018^{NS} (0.045)	0.083* (0.047)
Constant	-9.167* (1.368)	-1.154^{NS} (1.136)	-1.154^{NS} (2.189)	12.108* (2.343)	-6.206*** (4.037)	18.009* (4.249)

Source: Estimated from ICRISAT database, the *, **, *** and **** indicate 1, 5, 10 and 20 percent level of significance. The values in the brackets are standard error.

$$\Delta y = \left\{ \left(\frac{\delta y}{\delta ARF} \right) \times \Delta\, ARF + \left(\frac{\delta y}{\delta AAMAXT} \right) \times \Delta AAMAXT + \left(\frac{\delta y}{\delta AAMINT} \right) \times \Delta AAMINT \right\} \quad \ldots\ldots\ldots\ldots\ldots(4)$$

Where, $E\left[\frac{dy}{dx}\right]$ is marginal effect of minimum & maximum temperature and rainfall on the crop productivity, Y is coefficient value, $\Delta\, ARF$ is annual rainfall, $\Delta AMAXT$ is maximum temperature, $\Delta AAMINT$ is minimum temperature, and Δy is mean productivity of the crop.

Table 3 indicates that most of the study crops adverse effect through variability in rainfall and temperature. Increase in maximum temperature reduced yield of rice, wheat, sorghum, pearl millet, maize, finger millet, barley, chickpea, pigeon pea, groundnut and sorghum by 2.11, 11.59, 132.41, 73.78, 121.60, 86.04, 22.96, 12.56, 12.56, 77, 129.44 and 19.93 percent during (1966-2015) respectively. The current study reconfirms that Indian agriculture system highly vulnerable from the climate change impact.

PROJECTED EFFECT

Study also estimates future scenarios of the yield with increase in rainfall, minimum and maximum temperatures. The effects of climate change on crop yields have been projected for four-time slices, viz., 2040, 2060, 2080 and 2100 by using equation (5).

$$\Delta y = \left\{\left(\frac{\delta y}{\delta \mathrm{ARF}}\right) \times \Delta\, ARF + \left(\frac{\delta y}{\delta \mathrm{AAMAXT}}\right) \times \Delta AAMAXT + \left(\frac{\delta y}{\delta \mathrm{AAMINT}}\right) \times \Delta AAMINT\right\} \ldots\ldots (5)$$

Where, Δy is change in crop productivity; $\Delta\, ARF$ is increase in annual actual rainfall; $\Delta AAMAXT$ is increase in annual average maximum temperature and $\Delta AAMINT$ is increase in annual average minimum temperature in different scenarios. $\left(\frac{\delta y}{\delta \mathrm{ARF}}\right), \left(\frac{\delta y}{\delta \mathrm{AAMAXT}}\right)$ *and* $\left(\frac{\delta y}{\delta \mathrm{AAMINT}}\right)$ are estimated by model equations (Gupta et al., 2012, pp. 10-18).

Table 3

Marginal effect of Rainfall, Minimum & maximum Temperature (1966-2015)

Name of the Crops	Rainfall	Minimum Temperature	Maximum Temperature	Total (1966-2015)
Rice	0.24	26.68	-29.03	-2.11
Wheat	0.13	15.63	-27.35	-11.59
Sorghum	3.64	51.65	-187.70	-132.41
Pearl Millet	2.53	17.18	-93.49	-73.78
Maize	0.09	86.23	-207.92	-121.60
Finger millet	-2.54	25.00	-108.50	-86.04
Barley	-0.63	22.46	-44.79	-22.96
Chickpea	-0.41	36.61	-48.76	-12.56
Pigeon pea	0.82	69.25	-147.06	-77.00
Groundnut	2.69	30.33	-162.47	-129.44
Sugarcane	0.61	14.63	-35.16	-19.93
Cotton	1.70	-168.61	460.84	293.92

Source: Estimated from ICRISAT database

Table 4

Projected Results for 2040, 2060, 2080 and 2100

Name of the Crop	**2040**	**2060**	**2080**	**2100**
Rice	0.38	-0.55	-0.90	-1.83
Wheat	-2.42	-8.16	-10.96	-16.69
Sorghum	-19.45	-83.84	-114.21	-178.60
Pearl Millet	-8.95	-44.57	-61.12	-96.74
Maize	-30.07	-90.82	-121.16	-181.92
Finger millet	-31.05	-75.34	-98.76	-143.06
Barley	-8.09	-19.88	-26.08	-37.87
Chickpea	-4.68	-11.17	-14.62	-21.10
Pigeon pea	-16.19	-54.28	-72.91	-111.00
Groundnut	-22.26	-85.64	-115.98	-179.35
Sugarcane	-2.70	-12.36	-16.88	-26.54
Cotton	79.84	227.65	302.40	450.21

Source: Estimated from ICRISAT database

Table 4 indicates that yield of sorghum and maize highly sensitive among the cereals. End of this century (2100), if rainfall, minimum & maximum temperature increase up to 7 m.m. and 1.5^{O}C, the yield of sorghum and maize would be reduced by 178.60 and 181.92 percent from the current level. Sugarcane and cotton are also important crops in the non-food category. If similar projection about rainfall and temperatures to be continued then, an end of this century (2100), sugarcane yield would be reduced by 26.54 percent. Interestingly, the cotton yield would be increased by 450.21 percent.

CONCLUSION

It is confirmed by the current study, agriculture in the arid and semi-arid region is highly vulnerable. The maximum temperature reached the threshold level of all study crops and adversely affected during 1966-2015. Variability in day and night temperature, increase the degree of vulnerability among the study crops. Further, variability in rainfall adds an additional layer of risk and uncertainty to an agriculture system in Uttar Pradesh. Empirical results show that rainfall and minimum temperature still below to a threshold level and positively associated with the productivity of rice, wheat, sorghum, pearl millet, maize, pigeon pea, groundnut, sugarcane and cotton. Further, the increase in the irrigated area reduces the degree of vulnerability as a planned adaptation strategy. Use of chemical fertilisers, pump sets, tractors and increase in the rural literacy rate, adaptation area moderated potential impacts of climate variability. However, projected results, based on future projection about rainfall and temperatures about South Asia, if no new adaptation strategies added shows all the study crops adversely affected.

POLICY PRESCRIPTION

Based on current study empirical findings, several policy suggestions can be given like policy makers need to provide more irrigation facilities. Crop productivity positively associated with irrigated area. It means that irrigated area is a crucial instrument to complete the irrigation requirement in cultivation. Here it can be concluded that more irrigation facilities in agriculture would be useful to increase the productivity of crops. Further, productivity would increase with the application of recommended fertilisers in agriculture. It can be justified that the productivity of a specific crop will increase with additional utilisation of fertilisers. More participation of the literate population in agricultural also could be an important factor to increase land productivity. Apart from these policy prescriptions, use of bio-fertilizers, simplification in institutional micro credit facilities, high yielding varieties of seeds and modern techniques to farmers; rural development; public spending on agriculture and investment in infrastructure.

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Appendix- A

Im-Pesaran-Shin Unit-Root Test for Stationary

Productivity	P-Value	Irrigated Area	P-value
Rice	0.010	Rice	0.000
Wheat	0.020	Wheat	0.000
Sorghum	0.000	Sorghum	0.010
Pearl Millet	0.020	Pearl Millet	0.030
Maize	0.000	Maize	0.000
Finger Millet	0.000	Finger Millet	0.010
Barley	0.010	Barley	0.050
Chickpea	0.000	Chickpea	0.000
Pigeon pea	0.000	Pigeon pea	0.010
Groundnut	0.010	Groundnut	0.000
Sugarcane	0.000	Sugarcane	0.020
Cotton	0.020	Cotton	0.000
Fertilizers	0.000		
Pump Set	0.020	Max Temperature	0.000
Rural Literacy	0.000	Min Temperature	0.010
Tractors	0.020	Annual Rainfall	0.010

Source: Estimated from CRISAT database by Authors

Appendix B

Hauseman Test, Pesaran CD Test, Wald Test and Wooldridge Test

Model Crop	Hausman Test for Random Effect Model	Pesaran CD test for Cross Sectional Dependence	Modified Wald test for Heteroskedasticity	Wooldridge test for Serial Correlation and Auto-correlation
	P- Value	P- Value	P- Value	P- Value
Rice	0.020	0.009	0.021	0.020
Wheat	0.025	0.003	0.000	0.023
Sorghum	0.021	0.000	0.010	0.000
Pearl Millet	0.000	0.004	0.000	0.014
Maize	0.000	0.000	0.009	0.000
Finger Millet	0.021	0.030	0.0023	0.029
Barley	0.000	0.000	0.050	0.031
Chickpea	0.022	0.021	0.000	0.000
Pigeon pea	0.030	0.000	0.022	0.045
Groundnut	0.010	0.020	0.000	0.000
Sugarcane	0.015	0.013	0.021	0.021
Cotton	0.020	0.012	0.010	0.000

Source: Estimated from CRISAT database by Authors