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Measuring the productivity of food-grain crops in different climate change scenarios in India: An evidence from time series investigation

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This study assess the impact of climate change on productivity of food-grain crops in India. It used Cobb-Douglas production function model to investigate the climate change impact on food-grain productivity in India using time series, 1980-2010. In this study, food-grain production/hectare land is used as a dependent variable that is regressed with different socio-economic and climatic variables. Thereupon, it estimates the expected productivity of food-grain crops in different climate change scenarios. Empirical result based on Newey-West Standard Errors model shows that increase in maximum and minimum temperature, and change in rainfall pattern have a negative and significant impact on productivity of rice, arhar, bajra, jowar, wheat, ragi, gram and barley crops. Estimates also indicates that productivity of aforesaid crops are likely to be declined significantly by 2025, 2040, 2050, 2075 and 2100 in different climate change scenarios in India.Thus, it would be very serious concern for Indian farmers and policy makers to mitigate the negative consequences of climate change in food-grain crop farming and to meet food security in India. It provides several viable policy proposals to mitigate the negative impact of climate change in food-grain crops farming and to achieve sustainable food security in India in near future.

INTRODUCTION

Agricultural sector plays a significant role in several ways to maintain socio-economic and human development in several ways in larger agrarian economies (Kumar and Sharma, 2013b; Singh, 2017). Agriculture is a sole source to meet the food requirement of population, and it also creates job opportunities for large portion of population at global (Kumar and Sharma, 2013b; Kumar et al., 2014; Singh, 2017; Singh and Narayanan, 2018). Food security of a region directly reflects agricultural production activities (Ye et al., 2013; Kumar et al., 2015d; Singh et al., 2016; Singh et al., 2017a; Sharma and Singh, 2017; Singh, 2017; Kumar et al., 2017; Sharma and Singh, 2017; Singh and Issac, 2018; Singh, 2018a; Singh and Narayanan, 2018).Hence, sustainable food security depends upon agricultural developmental policies in larger agrarian economies (Singh et al., 2017a; Kumar et al., 2017). Also, agriculture is a crucial sector for poverty eradication and to maintain sustainable livelihood security of peoples in developing economies (Kumar and Sharma, 2013b; Kumar et al., 2016; Kumar et al., 2017; Singh, 2017; Sharma and Singh, 2017; Singh and Issac, 2018; Singh and Narayanan, 2018). Thus, this sector must be given high priorities in all economies of the world. However, at present agricultural sector is facing a lot of problems due to several reasons such as rising cost of cultivation, cost of inputs (fertilizer, pesticides, oil price, etc.), declining groundwater availability, declining average size of land holding, decreasing arable land due to over urbanization and industrialization and application of arable land in non-agricultural purpose, and climate change (Attri and Rathore, 2003; Zhai et al., 2009; Lee, 2009; Ayinde et al., 2011; Kumar and Sharma, 2013b; Ye et al., 2013; Kumar at al., 2016; Singh et al., 2016; Sharma and Singh, 2017; Singh, 2017; Singh et al., 2017b; Singh and Narayanan, 2018). As climatic factors may not be control by farmers, therefore among the other inputs of cultivation, climate change is a most significant factor to increase or decrease productivity of food-grain and cash crops (Gbetibouo and Hassan, 2005; Zhai et al., 2009; Lee, 2009; Fofana, 2011; Kumar and Sharma, 2014;

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Kumar et al., 2014; Birthal et al., 2014; Sharma and Singh, 2017; Singh, 2017; Singh and Narayanan, 2018). Crop choice depend upon climatic and geographical location, thus both the factors play a significant role to maintain agricultural production activities in a specific region. However, the impact of climatic change in agriculturalsector would be more sensitive in developing economies as compared to developed economies (Tobey et al., 1992; Gbetibouo and Hassan, 2005; Sathaye et al., 2006; Ye et al., 2013; Mahato, 2014; Mondal et al., 2015; Kumar et al., 2017; Singh, 2017; Singh et al., 2017a; Singh et al., 2018; Singh and Narayanan, 2018). As developing economies are located at lower latitude, thus agricultural production in these economies would be declined due to climate change (Gbetibouo and Hassan, 2005; Mendelsohn et al., 2006; Lee, 2009; Zhai et al., 2009; Masters et al., 2010; Fofana, 2011).

Wide range of studies empirically proved that climate change have a negative impact on agricultural productivity,and yield of food-grain and cash crops in India (Saseendran et al., 2000; Kumar and Parikh, 2001; Attri and Rathore, 2003; Kumar et al. (2004); Nandhini et al., 2006; Kalra et al., 2008; Kaul and Ram, 2009; Palanisami at al., 2010; Hariss et al., 2010; Kumar et al., 2011a; Kumar et al., 2011b; Geethalakshmi et al., 2011; Jha and Tripathi, 2011;Asha latha et al., 2012; Panda et al., 2012; Gupta et al., 2012; Bhattacharya and Panda, 2013; Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Mondal et al., 2014;Kumar et al., 2014; Birthal et al., 2014; Yadav et al., 2015; Mondal et al., 2015; Kumar et al., 2015a; Kumar et al., 2015b; Kumar et al., 2015c; Kumar at al., 2016; Singh et al., 2016; Kumar et al., 2017; Singh, 2017; Singh et al., 2017b; Singh et al., 2018; Singh and Narayanan, 2018). Aforementioned studies provide a significance evidence that agricultural sector is most sensitive to climate change. Most studies have provided an evidence that climate change is caused to decrease agricultural productivity or net revenue of food-grain and cash crops in different states/regions/districts of India. Most studies investigate the impact of climate change on agricultural productivity or net revenue specifically one to three food-grain and cash crops for a particular regions of India. In India, limited studies analysis the impact of climatic variation on productivity of food-grain crops at national level. Due to this drawback the present study assess the impact of climate change on productivity of food-grain crops (i.e., rice, arhar, bajra, jowar, wheat, ragi, gram and barley) in India using Cobb-Douglas production function model. It addresses following research questions with regards to climate change and productivity of food-grain crops in India:

- What is impact of climate change on productivity of food-grain crops in India?
- Which food-grain crops are most sensitive due to climate change in India?
- What would be the projected yield of food-grain crops due to climate change in India?
- How food security would be reflected due to variability in food-grain crops?
- How food security would be influenced due to variability in productivity of food-grain crops in India?
- How India can be achieved sustainable food security in near future?
- What must be appropriate policy suggestions to mitigate the negative impact of climate change in food-grain crop farming and to sustain food security in India?

Relevance to afore-mentioned research question, the present study is achieved following objectives:

- To measure the impact of climatic and non-climactic factors on productivity of food-grain crops in Kharif and Rabi crop seasons in India.
- To estimate the expected productivity of food-grain crops in different climate change scenarios by 2025, 2040, 2050, 2075 and 2100 in India.
- To provide the practical and viable policy implications to mitigate the adverse impact of climate change in food-grain crop farming in India.

EMPIRICAL REVIEW

In India, many studies have assessed the climate change impact on agricultural productivity. Empirical and descriptive studies deliver an indication that climate change is negatively affect the agricultural production and productivity (in term of quantity and monetary) of food-grain and cash crops in India. The brief overview of existing studies and their prime conclusions are given as: Saseendran et al. (2000)found that rice yield is to be declined as increase in temperature by 5^0C, and every 1^0C increment in temperature would be caused to decrease rice yield by 6% in Kerala (India).Kumar and Parikh (2001)estimate the projected productivity of rice and wheat crops due to climate change in India. It detected that productivity of both the crop would be declined by 2060, and it would be caused to decrease food security of one billion peoples in India. Attri and Rathore (2003) appraise the impact of climate change on growth of yield of wheat crop in India. It provide a proof that wheat yield may be increased by 29-37% and 16-28% under rainfed and irrigated conditions respectively in different genotypes under a modified climatic conditions. Kumar et al. (2004) examine the relationship of rice, wheat, sorghum, groundnut, sugarcane, cereal and oilseed crops with climatic factors in India using correlation coefficient technique. It determined that yield of most crops are negatively influenced due to variability in monsoon rainfall, while yield of sorghum crop is likely to be declined due to variability in rainfall in India. Nandhini et al. (2006) examine the impact of rainfall variability on cultivable land under rice crop in Tamil Nadu (India). It observed that arable land under rice is deteriorated due to scarcity of inputs and scanty rainfall in Tamil Nadu (India).

Hundal et al. (2007) observed that an increase in temperature by 1^0C then yield of rice and wheat crops are likely to be decreased by 3% and 10% respectively in Punjab (India). Kalra et al. (2008) found that yield of wheat, mustard, barley and chickpea crops have a tendency to be declined as increase in 1^0C maximum temperature in Punjab, Haryana, Rajasthan and Uttar Pradesh. Kar and Kar (2008) observed that low rainfall would affects crop production and income of the poor farmers in Orissa (India). Kaul and Ram (2009) inspected the effect of rainfall and temperature on yield of jowar crop in Karnataka (India), and it concluded that excessive rainfall and variation in temperature are caused to decrease jowar production. Palanisami at al. (2010) examine the effect of yield of rice crop in India and it observed that rice productivity would be declined as increase in temperature. Hariss et al. (2010)is also observed that rice yield is decreased as increase in temperature in Bihar, India.

Jha and Tripathi (2011) measure the temperature and rainfall impact on wheat productivity in Haryana and Bihar states of India. It observed that maximum temperature is a crucial factor to affect the wheat productivity among the other climatic factors. Wheat crop is highly climate sensitive during flowering and gain filling time in which wheat productivity is also negatively impacted due to climate change. Kumar et al. (2011b) observed that irrigated area for maize, wheat and mustard crops in northeastern and coastal regions, and irrigated area for rice, sorghum and maize crops are declined in Western Ghats due to climate change in India. Kumar et al. (2011a) observed that weather condition to choose a specific crop for cultivation has shifted due to climate change, therefore growing time of rice and sugarcane crops are also negatively affected in Uttarakhand and Uttar Pradesh. Geethalakshmi et al. (2011) also found that productivity of rice has declined by 41% as 4^{0}C increase in temperature in Tamil Nadu (India). Asha latha et al. (2012) investigate the impact of drought on yield of sorghum, maize, tur, groundnut, wheat, onion and cotton crops in India. It observed that yield of groundnut and cotton crops decrease by 34.09 and 59.96 Kg/Ha respectively in rainfed areas. It also reported that reduction in the rainfall is the significant reason for yield reduction in Dharwad district in Karnataka (India). Gupta et al. (2012) investigate the influence of climatic factors on yield of rice, sorghum and millet crops in India. It found that yields of these crops are likely to be declined due to climate change. Panda et al. (2012) estimate the climate variability impact on productivity of maize crop in Punjab (India). It concluded that air temperature show a negative impact on maize yield. However, this study implies that temperature would have a positive impact on mean yield of maize crop up to a certain extent.

Kumar and Sharma (2013a) evaluate the impact of climatic factors on land productivity (monetary term) of 15 food-grain and commercial crops in India using state-wise panel data. It found that agricultural productivity to be declined as increase in maximum and minimum temperature in India. Kumar and Sharma (2013b) examine the influence of climate change on mean yield of food-grain and commercial crops, and agricultural productivity (monetary term) of food-grain crop and cash crops in India using state level panel data. It observed that mean yield of food-grain and cash crops are climate sensitive. Bhattacharya and Panda (2013) recognize the impact of seasonal variability in climatic factors on rice yield in India. It found that rice yield to be declined as increase in temperature, while rainfall is useful to increase rice yield.

Kumar and Sharma (2014) estimate the impact of climatic and non-climatic factors on mean yield of sugarcane crop in using linear, non-linear and log-linear regression models in India. Estimates indicate that sugarcane productivity would be declined as increase in maximum and minimum temperature and rainfall variability during different growth period of sugarcane crop in India. Kumar et al. (2014) evaluate the climate change impact on mean yield of various food-grain crops in India using Cobb-Douglas production function model. It concluded that productivity of food-grain crops have a tendency to be declined as increase in variability of climatic factors. Birthal et al. (2014) investigate the impact of variability in climatic factors (i.e., temperature and rainfall) on yield of rice, wheat, sorghum, maize, barley, chickpea, pigeon pea, groundnut, rapeseed-mustard crops in India. It found the negative association of maximum temperature with productivity of rice, maize, sorghum, pigeon pea and groundnut crops, while minimum temperature positively correlated with these crops. Mondal et al. (2014) measure the inter-annual climate variability impact on wheat crop in India. It found that day time mean temperature is seemed negative impact on wheat crop in India. Yadav et al. (2015) estimate the trend in yield of rice, maize, Jowar, bajra, wheat, barley crops in India. It proved that yields of rice, maize, jowar, bajara and wheat crop would be decreased as increase in temperature. Mondal et al. (2015) measure the inter-annual climate variability impact on winter and monsoon crops, and seasonal crop cover in agro-eco-sub-regions in India. Climate variability is appeared a negative impact on winter and monsoon crops. Kumar et al. (2015a) estimate the impact of climatic factors on mean yield and yield variability of sugarcane crop in India. It observed that mean yield of sugarcane crop is negatively associated with climatic factors in India. Kumar et al. (2015b) estimate the impact of climate change on agricultural productivity of Rabi and Kharif crops seasons in India using Cobb-Douglas production function model. It concluded that productivity of both the crops would be declined due to change in climatic factors. Kumar et al. (2015c) measure the influence of climatic factors on mean yield and yield variability of cash crops in India using stochastic production function model. It observed that productivity of cash crops would be in alarming position due to climate change in India in near future.

Kumar at al. (2016) investigate the impact of climatic factors on agricultural productivity of major food-grain and cash crops in India using Cobb-Douglas production function model. Singh et al. (2016) estimate the influence of climate sensitive on mean yield and yield variability of major food-grain crops in India. It found that productivity of food-grain crops would be in stress due to climate change in India. Kumar et al. (2017) estimate the impact of climate change on per capita food-grain availability in India. It observed that per capita availability of food-grain is negatively impacted due to variability in climatic factors in India. Singh et al. (2017b) investigate the influence of cropped area, production and mean yields of groundnut, sesame, cotton and potato crops in India using Cobb-Douglas production function model. It estimates the future projection of cropped area, production and mean yield of cash crops using marginal impact analysis technique. Singh et al. (2018) estimate the impact of climatic and non-climatic factors on mean yield, production and cropped area of sugarcane crop in India using stochastic frontier production function approach. It observed that climatic factors have a negative and significant impact on sugarcane crop farming in India.

MATERIAL AND METHODOLOGY

The present study includes information on agricultural and climatic factors for time series of 31 years (i.e., 1980-2010). While, interpolation and extrapolation method are used to identify the missing value in the data series (Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a,b,c; Kumar at al., 2016; Singh et al., 2016; Kumar et al., 2017; Singh et al., 2017b; Singh et al., 2018). The data for agricultural, demographic and climatic variables are taken following sources:

Agricultural Data: Crop-wise total production, crop-wise area sown, crop-wise irrigated area sown, crop-wise use of fertilizer, and crop-wise use of tractor pumpset are taken from Centre *for Monitoring Indian Economy* (CMIE). Forest area is also taken from CMIE. Average size of land holding is derived from the different publications of Agricultural Census, Ministry of Agriculture (GoI), it was available in the intervals of five years (i.e., 1971-72, 1975-76, 1981-82, 1996-97, 2001-02 and 2005-06). Thus, remaining data points are estimated through interpolation and extrapolation methods. Crop-wise use of agricultural labour is taken from the different publication of Census (GoI), it is also available in decadal periods (i.e., 1981, 1991, 2001 and 2011), and therefore to covert it in time series interpolation method is used. Aforesaid data is taken for 13 states (i.e., Bihar, Orissa, Uttar Pradesh, Punjab, Haryana, Gujarat, Madhya Pradesh, West Bengal, Maharashtra, Rajasthan; Andhra Pradesh, Tamil Nadu, Karnataka, Andhra Pradesh, Karnataka, Tamil Nadu, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Haryana, Punjab Uttar Pradesh, Bihar, Orissa and West

Bengal) of India, while aggregate values of each variable for 13 states is incorporated in empirical model.

Demographic Data: State-wise literacy rate is taken from the Planning Commission (GoI). It was available in decadal period(i.e., 1951, 1961, 1971, 1981, 1991, 2001 and 2011). To make it in time series interpolation method is used.

Climatic Data: Minimum and maximum temperature, and rainfall data is derived from the *Indian Meteorological Department* (*IMD*) (GoI) database. Information on climatic factors are available on daily intervals with latitude and longitude information of monitoring stations. Due to unavailability of city-wise data of climatic factors, the stations pertaining to specific latitude and longitude information are recognized. Geographical regions are identified based on latitude and longitude of information in a specific states. Then from the groups of such stations different geographical region are used to arrive at the state level data points. Aforesaid data are converted in monthly averages city-wise, after that data transformed in state-wise monthly maximum and minimum temperature, and monthly rainfall for selected specific city, these are taken from the 354 meteorological stations in thirteen states of India. To process basic information on climatic factors like rainfall, minimum and maximum temperature data, the C^{++} software is used. SPSS statistical software is used to extract and bring data to excel format. For all crops average minimum temperature, average maximum temperature and actual rainfall in entire crop duration is included for regression model.

ECONOMETRIC ANALYSIS

In order to investigate the impact of climate change on productivity of food-grain crops in India. For this, 8 major food-grain crops (i.e. wheat, rice, jowar, bajra, gram, arhar, barley and ragi)are included in this study. All these crops cover more than 75% of the total agricultural cropped area of the country (Singh, 2017). Thirteen agriculture intensive states of India (i.e., Andhra Pradesh, Bihar, Haryana, Gujarat, Uttar Pradesh, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu and West Bengal)are included in this study. To evaluate the impact of climate change on food-grain productivity; the group of states are bundled together, and gross production of each crop is divided by gross sown area of concern crop, thereafter it is considered as a crop productivity for respective crop. Cobb-Douglas production function model is applied to evaluate the climatic impact on productivity of food-grain crops (Nandhini et al., 2006; Kar and Kar, 2008; Gupta et al., 2012; Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Kumar at al., 2016; Singh, 2017). It accepts that agriculture production is a function of many factors like arable land, irrigated area, use of fertilizer and agricultural labour, size of land holding, mechanization in agricultural (i.e., use of tractor and pumpset), literacy rate of farmers. These all variables may be useful to increase the agricultural production (Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015b; Kumar at al., 2016; Singh et al., 2016; Singh, 2017; Singh et al., 2017b; Singh et al., 2018; Singh and Narayanan, 2018). Also, forest area is a significant factor which may affect the agricultural production indirectly. In this study, total production is considered as a function of socio-economic variables, which may be in following functional form:

$$(TP)_{it} = f\ \{(AS)_{it},(IA)_{it},(TF)_{it},(AL)_{it},(TT)_{it},(TPS)_{it},(FA)_{it},(ASLH)_{it},(LR)_{it}\} \quad (1)$$

Here, *TP* is total production for crop *i*; *t* is the time series (i.e. 1980 to 2010); *AS*, *IA*, *TF*, *AL*, *TT* and *TPS* are crop-wise area sown, crop-wise irrigated area, crop-use of total fertilizer, crop-wise use of agricultural labor, crop-wise use of tractor and crop-wise use of pumpset for crop *i* respectively; *ASLH*, *FA* and *LR* are average size of land holding, forest area, literacy rate respectively. Dividing by AS_i (area sown for each crop *i*) to each variables in equation (1), it may be written in production/hectare land and ratio of all explanatory variables which is explained as:

$$(TP/AS)_{it} = f\{(IA/AS)_{it},(TF/AS)_{it},(AL/AS)_{it},(TT/AS)_{it},(TPS/AS)_{it},(FA/AS)_{it},(ASLH/AS)_{it},(LR/AS)_{it}\} \quad (2)$$

Aforementioned equation can be written in small capitals which show per unit of agricultural land quantity of each variable:

$$(tp)_{it} = f\{(ia)_{it},(tf)_{it},(al)_{it},(tt)_{it},(tps)_{it},(fa)_{it},(aslh)_{it},(lr)_{it}\} \quad (3)$$

Here, it also assumes that climatic factors works as an input factors for crop growth. Thus, three climatic factors i.e. actual rainfall, and average minimum and maximum temperature for entire crop duration are included to capture the climate change impact on productivity of each crop. Therefore, equation (3) is used as:

$$(lp)_{it} = f\ \{(ia)_{it},(tf)_{it},(al)_{it},(tt)_{it},(tps)_{it},(fa)_{it},(aslh)_{it},(lr)_{it},(arf)_{it},(amint)_{it},(amaxt)_{it} \quad (4)$$

Here $(lp)_{it}$ is a production/hectare land or productivity of food-grain crop; *ia*,*tf*, *al*,*tps*,*aslh*and *lr* are the ratio with cropped area for crop *i* respectively. Equation (4) signifies production/hectare land as a function of irrigated area, use of fertilizer, use of agricultural labour, use of tractor, and use of pumpset per hectare land respectively; ratio of average size of land holding and literacy rate with cropped area of crop *i;* and *arf*, *amint* and *amaxt* are actual rainfall, average minimum and maximum temperature during crop growth respectively. Equation (4) would take following form after applying Cobb-Douglas production function model:

$$\ln (tp)_{it} = \beta_0 + \beta_t(year)\ \beta_1 \ln (ia)_{it} + \beta_2 \ln (tf)_{it} + \beta_3 \ln (al)_{it} + \beta_4 \ln (tt)_{it} + \beta_5 \ln (tps)_{it} + \beta_6 \ln (fa)_{it} + \beta_7 \ln (aslh)_{it} + \beta_8 \ln (lr)_{it} + \beta_9 \ln (arf)_{it} + \beta_{10} \ln (amint)_{it} + \beta_{11} \ln (amaxt)_{it} + u_{it} \quad (5)$$

Here, *ln* is the natural logarithm of associated variables. Equation (5) signifies the real functional form of Cobb-Douglas production function model. $\beta_0$is the constant coefficient, β_t is the regression coefficient of time trend factor that is comprised to capture the impact of technological change on crop productivity (Kumar et al., 2015a; Kumar et al., 2015b; Singh et al., 2016; Singh, 2017). It also captures the influence of other factors like seed quality, technological innovation, farmer's consciousness, market accessibility and other variables in crop farming (Carew et al., 2009; Kumar et al., 2015b; Singh et al., 2016; Singh, 2017). Similar model is used by Nastis et al. (2012); Gupta et al. (2012); Kumar and Sharma (2013b); Kumar and Sharma (2014); Kumar et al. (2014); Kumar et al. (2015b); Kumar et al. (2015c); Kumar at al. (2016); Singh et al. (2016); Singh et al. (2017b) Singh (2017) to assess the climate change impact on crop productivity in developed and developing economies. The explanation of dependent and independent variables are given in Table-1.

Selection of Appropriate Model

Before doing any multi-regression for empirical analysis following proceed is used. To test the property of stationary and non-stationary of each variable in time series data, first and second lagged of each variable is regressed with original variable (Nastis et al., 2012; Ayindeet al., 2011; Singh, 2018b). Null hypothesis of non-stationary is accepted at first lagged and second lagged for most factors (Refer to Appendix: A). Augmented Dickey Fuller (ADF) test is applied to check the existence of unit root test in time series. Unit root test is calculated by first and second difference of each variable and it is regressed with respective original time series (Nastis et al., 2012; Ayinde et al., 2011; Padhan, 2012; Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Singh et al., 2016; Singh, 2017; Singh, 2018b). Several regressions are done but certain variables for different crops are dropped from the regression models due to incidence of high multicollinearity or due to their high insignificant level. Mostly those combinations of variables are dropped which have a value of mean of variance inflation factor (VIF) more than 10, and have a very little significance level. Furthermore, Cameron and Trivedi's decomposition of IM-test and Breusch-Pagan/Cook-Weisberg test are used to address the problem of Heteroscedasticity (Gupta et al., 2012; Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Singh, 2018b). Durbin-Watson d-statistic,Durbin's alternative test and Breusch-Godfrey LM testareused to recognize the presence of auto-correlation in time series (Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Singh, 2018b). Newey-West model or Newey-West Standard Errors model or HAC model (Heteroscedasticity and Autocorrelation Consistent model) are used to remove the presence of autocorrelation in time series data (Nastis et al., 2012; Singh, 2018b).

Appraisal of Projection in Yield of Crop in Various Climate Change Scenarios

Projected trend in land productivity of each food-grain crop in various climate change scenarios (i.e., 2025, 2040, 2080, 2075, 2100) are estimated using marginal impact analysis technique. It is given in following form that is adopted from Gupta et al. (2012); Singh et al. (2017b):

$$\Delta lp = \left[\left(\frac{\delta lp}{\delta arf}\right) * \Delta arf + \left(\frac{\delta lp}{\delta amaxt}\right) * \Delta amaxt + \left(\frac{\delta lp}{\delta amint}\right) * \Delta amint\right] \quad (6)$$

Here, Δlp is change in productivity of food-grain crop; Δarf is rise in actual rainfall; $\Delta amxt$ is change in mean maximum temperature; and $\Delta amint$ is change in mean minimum temperature in various climate change scenarios. Whereas, ($\delta vp/\delta arf$), ($\delta vp/\delta amxat$), and ($\delta vp/\delta amint$) are measured using equation (5) (Gupta et al., 2012; Kumar et al., 2016; Singh et al., 2017b). The projected yield of food-grain crops are estimated that climatic factors would be change as per given table-2.

DISCUSSION ON EMPIRICAL RESULTS

Empirical results which assess the impact of climatic and non-climatic factors on yield of food-grain crops in Kharif and Rabi season are given in Table- 3 and 4 respectively. Regression coefficients of explanatory variables are estimated using Newey-West standard errors model.

Time Trend Factors: Regression coefficient of time trend factor is positively associated with productivity of rice, bajra, jowar, wheat, ragi, gram and barley crops are positive. Thus, productivity of these crops would be improved as adoption of technology in farming of these crops. Estimates are consistent with earlier studies which are also observed positive association of application of technology up-gradation in cultivation (Carew et al., 2009; Kumar et al., 2015b; Singh et al., 2016; Singh, 2017). Technology can be used in various ways such as seed quality, high yielding verities of seed, change in farming techniques, drip irrigation, change in irrigation methods, water management and conservation techniques, mixed cropping pattern, dual cropping pattern etc. technological innovation, farm management policies, farmer's consciousness, market accessibility and other variables in crop farming (Carew et al., 2009; Kumar et al., 2015b; Singh et al., 2016; Singh, 2017).

Area Sown: Cropped area is a most crucial factors for cultivation. As crop farming is not possible without arable land. Thus, cropped area has a positive and significant association with crop production. Therefore, regression coefficients of area sown with productivity of rice, bajra, jowar, wheat, ragi, gram and barley crop is observed positive. Hence, it is suggested that crop productivity of these crops are likely to be increased as increase in area sown under these crops (Kumar and Sharma, 2013b). However, it is also observed that crop productivity would have a positive association with cropped area at decreasing rate (Cabas et al., 2010; Kumar et al., 2015a).

Irrigated Area: Irrigated area play a significant role to maintain the production per hectare land in cultivation. As irrigated land have higher yielding capacity as compared to non-irrigated area (Kumar et al., 2014; Kumar and Sharma, 2014; Mondal et al., 2014; Birthal et al., 2014; Kumar et al., 2015b). Estimates of this study is also found positive association of irrigated area with productivity of rice, bajra, jowar, wheat, ragi, and barley crops. Hence, irrigated area under aforementioned crops would be useful to increase the productivity of these crops. Most studies appealed that irrigated area has a high probability to increase the productivity of food-grain and cash crops. Furthermore, irrigated area has a better adaptability to mitigates the negative impact of climate change in cultivation (Gupta et al., 2012; Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar and Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a; Kumar et al., 2015b; Singh et al., 2016; Singh et al., 2017b; Singh, 2017; Singh et al., 2018; Singh and Narayanan (2018). Here, it can be concluded that Indian policy makers required to provide appropriate water source to meet the irrigation requirement in agricultural sector.

Application of Fertilizer: Regression coefficients of fertilizer with productivity of rice, arhar, jowar, wheat, gram crops are appeared positive. Thus, it is suggested that application of fertilizer in farming of these crops would be useful to improve the productivity of these crops. Estimates are similar with existing studies like Kumar and Sharma (2013b; Kumar et al. (2014); Singh et al. (2016). While, productivity of bajra, ragi and barley crops would be declined as application of fertilizer in farming of these crops. For this, several studies suggested that extensive application of fertilizer in cultivation would be harmful for crop productivity (Singh et al., 2016; Pandey, 2009; Ramsundar and Jaydeb, 2011). These studies claimed that fertilizer application is prime cause to increase GHGs emission in atmosphere, therefore it would be caused to increase more variability in climatic factors (Kumar and

Table 1 Overview of dependent and explanatory variables

Explanation of Variables	Symbol	Unit	Source of Data
Total production of respective crops	*tp*	000 tonne	CMIE
Land productivity	*lp*	Kg./Ha.	
Area sown of respective crops	*as*	000 Ha.	
Irrigated area of respective crops	*ia*	000 Ha.	
Application of fertilizer under respective crops	*tf*	Kg./Ha.	
Application of tractor under respective crops	*tt*	Numbers	
Application of pump set under respective crops	*tps*	Numbers	
Forest area	*fa*	000 Ha.	
Application of agricultural under respective crops	*al*	Numbers	Census (GoI)
Average size of land holding	*aslh*	Ha./Holding	Agricultural Census, Ministry of Agriculture (GoI)
Rural literacy rate	*lr*	%	Planning Commission (GoI)
Actual average rainfall	*aarf*	mm	IMD (GoI)
Average minimum temperature	*aamint*	^{0}C	
Average maximum temperature	*aamaxt*	^{0}C	

Table 2 Expected change in climatic factors by 2025, 2040, 2050, 2075 and 2100

Years	Average minimum temperature (*amint*) (in ^{0}C)	Average maximum temperature (*amaxt*) (in ^{0}C)	Actual rainfall (*arf*) (in mm)
2025	1.50	1.00	5.00
2040	1.75	1.25	8.00
2050	2.00	1.50	9.00
2075	2.25	1.75	6.00
2100	2.50	2.00	7.00

Source: Author's assumption based on existing studies.

Table 3 Regression coefficients of non-climatic and climatic factors with productivity of food-grain crops in Kharif season

Crops	Rice		Arhar		Bajra (Millet)		Jowar (Sorghum)	
No. of obs.	31		31		31		31	
F-Value	200.14		29.73		173.85		102.99	
Prob>F	0.000		0.000		0.000		0.000	
lp=DV	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*
year	0.0025	0.0025	-0.0045	0.0066	0.0460*	0.0113	0.0417*	0.0086
as	0.0956	0.2425	-0.1434	0.3953	1.9084*	0.3816	1.0690*	0.2136
ia	0.0925	0.1382	-0.1185	0.0832	0.0836	0.1107	0.1997*	0.1055
tf	0.3007*	0.0714	0.2356	0.2114	-0.3933	0.3074	0.0337	0.1447
fa	-0.1496	0.1490	-0.0787	0.0895	0.3921*	0.0800	0.0954	0.1083
al	-0.0519	0.0332	0.0944	0.0642	0.0667	0.0763	-0.0485	0.0343
amint	-0.0939	0.6118	-0.1858**	0.0720	-0.0100	0.1572	-0.1050	0.6120
amaxt	0.2076	0.2518	-0.3084***	0.1882	-0.6376*	0.3023	-0.1125	0.0818
arf	-0.0145	0.0118	0.0055	0.0352	0.0498	0.0338	0.0271**	0.0114
Reg. Coef.	0.2511	5.0091	15.2375	14.4844	-99.1426*	23.4604	-85.3420*	19.2605

Source: Author's estimation. **Note:***, ** and *** indicate that regression coefficients are statistically significant at 1%, 5% and 10% significance level respectively.

Table 4 Regression coefficients of non-climatic and climatic factors with productivity of food-grain crops in Rabi season

Crops	Wheat		Ragi		Gram		Barley	
No. of obs	31		31		31		31	
F-Value	749.36		29.95		17.36		195.31	
Prob>F	0.000		0.000		0.000		0.000	
lp=DV	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*	*Reg. Coef.*	*Std. Err.*
year	0.0070**	0.0025	0.0184**	0.0089	0.0116*	0.0045	0.0141*	0.0043
as	0.2723	0.2193	2.4175**	0.9657	0.0569	0.2716	0.7356	0.6134
ia	0.1515*	0.0716	0.0461	0.1634	-0.1189	0.1008	0.0569	0.1064
tf	0.0050	0.1267	-1.8730*	0.7911	0.0454	0.1764	-0.8865	0.5810
fa	0.0612**	0.0210	0.8203*	0.2891	0.1357	0.1697	0.1110**	0.0423
al	0.0873***	0.0297	0.0203	0.0423	0.0139	0.0991	0.0932***	0.0538
amint	-0.1171	0.0387	-0.1269	0.1637	-0.2268	0.5876	0.5266*	0.3006
amaxt	-0.0006	0.0097	0.0278	0.2377	0.0159	0.0584	0.0955	0.0974
arf	-0.6040	0.3829	-0.0059	0.0450	-1.8815	1.5426	-0.6931	0.5007
Reg. Coef.	-8.1166	6.2424	-39.5036*	21.5965	-7.9753	14.5676	-20.2197*	9.0281

Source: Author's estimation. **Note:** *, ** and *** indicate that regression coefficients are statistically significant at 1%, 5% and 10% significance level respectively.

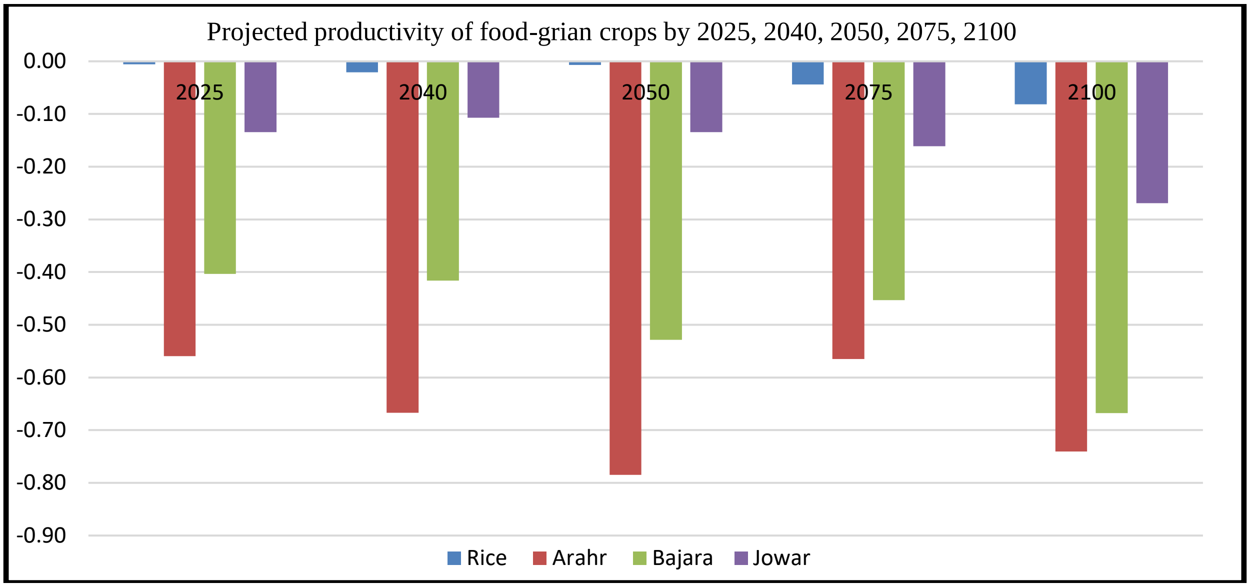

Figure 1 Projected trend in productivity of food-grain crops in Kharif season
Source: Author's estimation.

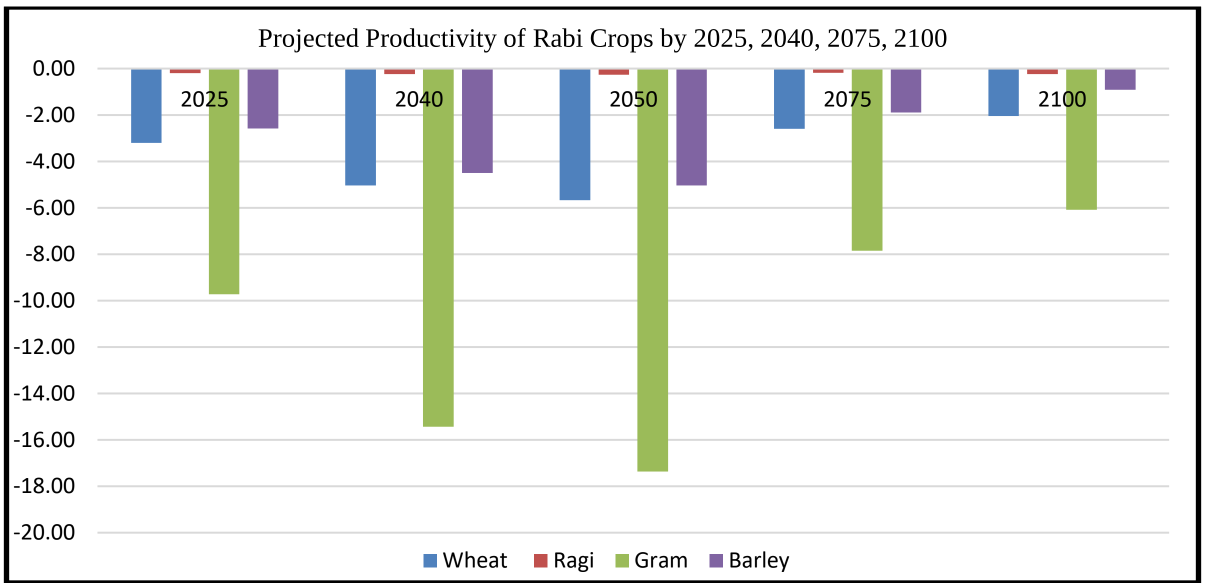

Figure 2 Projected trend in productivity of food-grain crops in Rabi season
Source: Author's estimation.

Sharma, 2014; Kumar et al., 2014). It may also increase the more environmental degradation (Ranuzzi and Srivastava, 2012). Subsequently, agricultural productivity of crop may be declined as extensive application of fertilizer (SriSubramaniam and Sairavi, 2009; Kumar et al., 2015a; Kumar et al., 2015b; Kumar et al., 2015c; Kumar at al., 2016; Singh et al., 2016; Sharma and Singh, 2017; Singh et al., 2017b; Singh, 2017; Singh and Issac, 2018).

Forest Area: As forest area is an important factor to mitigate the temperature impact in cultivation. Therefore, regression coefficients of forest area with bajra, jowar, wheat, ragi, gram and barley crops are found positive and statistically significant. Therefore, it forest area would be better adaption technique to mitigate the adverse impact of climate change in food-grain crop farming in India. Several studies are also found positive association of forest area with productivity of most food-grain and cash crops in India (Kumar and Sharma, 2013b; Singh et al., 2018). Thus, it is also recommended that increase in forest area would be significant to sustain productivity of food-grain and cash crops in larger agrarian economies.

Agricultural Labour: Human resource is a crucial variable to increase agricultural productivity. Estimates also imply that regression coefficients of agricultural labour with productivity of arhar, bajra, wheat, ragi, gram and barley crops are observed positive. Therefore, estimates show that productivity of these crops would be improved as application of more human in cultivation. Estimates are consistent with earlier studies such as Kumar and Sharma (2014); Kumar et al. (2016). However, few studies also found negative association of agricultural labour with agricultural productivity in agrarian economies (Nastis et al., 2012; Kumar et al., 2014). These studies claimed that agricultural productivity would be declined as utilization of agricultural labour due to law of diminishing return (Kumar et al., 2014).

Average Minimum Temperature: Average minimum temperature is show negative impact on productivity of rice, arhar, bajra, jowar, wheat, ragi and gram crops. While, it have positive impact on mean yield of barley crop. It concluded that productivity of these crops would be declined due to climate change in India.

Average Maximum Temperature: Productivity of arahr, bajra, jowar and wheat productivity are also negatively impacted due to increase in maximum temperature. Thus, any increment in maximum temperature has negative impact on productivity of said crops. These estimates are consistent with earlier studies like Panda et al. (2012); Gupta et al., 2012; Kumar and Sharma (2013b); Kumar et al. (2014); Birthal et al. (2014); Yadav et al. (2015); Singh and Narayanan (2018). While, maximum temperature would be useful to increase mean yield of rice, ragi, gram and barley crops.

Actual Rainfall: Rainfall is positively associated with productivity of arhar, bajra and jowar crops. Hence, increment in rainfall would be a helpful to increase the productivity of these crops. Mean yield of rice, wheat, ragi, gram and barley crops are adversely affected due to increase in actual rainfall during crop growth periods. Estimates are supported many studies which have observed that productivity of food-grain and cash crops are declined due the change in rainfall pattern in India (Kumar et al., 2004; Nandhini et al., 2006; Kaul and Ram, 2009; Palanisami at al., 2010; Kumar and Sharma, 2013b; Bhattacharya and Panda, 2013; Kumar et al., 2014); Singh et al. (2016); Singh and Narayanan (2018).

Expected Productivity of Food-grain Crops in Different Climate Change Scenarios

Projected results based on marginal impact analysis technique indicate that yield of rice, arhar, bajra and jowar crops would be declined due to increase in average minimum temperature by 1.5^{0}C, 1.75^{0}C, 2^{0}C, 2.25^{0}C and 2.5^{0}C by 2025, 2040, 2050 and 2100 (Refer to Figure-1). Yield of rice, arhar, bajra and jowar may be declined by 0.10%, 0.79%, 0.53% and 0.13% respectively by 2050. Estimates also imply that mean yield of rice, arhar, bajra and jowar crops are likely to be declined by 0.08%, 0.74%, 9.67% and 0.27% respectively by 2100. Based on projected, it is observed that arhar and bajra crops would be highly sensitive due to change in climatic factors by 2100.

Projected results imply that mean yield of wheat, ragi, gram and barely crops would lead to decline due to climate change by 2050, 2040, 2075 and 2100 (Refer to Figure-2). The climate change impact on productivity of these crops would be more sensitive during 2040 to 2050. Thereafter, it may have positive impact on productivity of these crops after 2050. However, it may be possible if India would take the significant efforts to mitigate the adverse effect of climate variability in agricultural production activities. Productivity of wheat, ragi, gram and barley crops are expected to be declined by 5.67%, 0.26%, 17.36% and 5.04% respectively due to climate change by 2050.

CONCLUSION AND POLICY IMPLICATIONS

The prime aim of this study is to measure the impact of climatic and non-climactic factors on productivity of food-grain crops in Kharif and Rabi crop seasons, to estimate the expected productivity of rice, arhar, bajra, jowar, wheat, ragi, gram and barley crops in different climate change scenarios by 2025, 2040, 2050, 2075 and 2100, and to provide the practical and viable policy implications to mitigate the adverse impact of climate change in food-grain crop farming in India. Mean yield of aforesaid crops are considered as dependent variable and regressed with climatic and non-climatic factors under time series of 1980-2010. For this it used Cobb-Douglas production function model, while regression coefficients of explanatory variables are estimated through Newey-West standard errors model.

Empirical results show that increase in maximum and minimum temperature have a negative impact on productivity of food-grain crops in India. Rainfall also have a negative impact on yield of food-grain crops. Thus, it would be serious concern for Indian farmers to mitigate the adverse effects of climate variability in agriculture. Estimates also indicate that productivity of wheat, ragi, gram and barley crops are expected to be declined by 5.67%, 0.26%, 17.36% and 5.04% respectively due to climate change by 2050. While, yield of rice, arhar, bajra and jowar may be declined by 0.10%, 0.79%, 0.53% and 0.13% respectively by 2050. Based on aforesaid results, here it can be concluded that food security would be in alarming position due to climate change in India in near future.

Non-climatic factors also have a significant positive and negative impact on different food-grain crops. Fertilizer has a positively impact on food-grain productivity. Forest area would be crucial factor to increase the productivity of most food-grain crops. It may be a policy suggestions to increase the productivity of food-grain crops in India (Kumar and Sharma, 2013b; Singh et al., 2016). In case of socio-economic factors, here it can be concluded that these variables do not have similar impact on food-gain productivity. In brief: yield of rice, arhar, bajra, jowar, wheat, ragi, gram and barley crops are negatively affected due to climate change. As these are the main food-grain crops for Indian, thus it may be threaten for food security in India.

Here, several policy suggestions can be produced to reduce the adverse effect of climate variability in cultivation. There is essential to increase public investment in agricultural and allied sector which would be helpful to maintain and rural development, irrigation and flood control which would increase the agricultural productivity in India. Subsequently, it would mitigate the adverse effect of climatic change in Indian agriculture (Kumar and Sharma, 2013a; Kumar and Sharma, 2013b; Kumar et al., 2015a; Kumar et al., 2015b; Kumar et al., 2015c; Kumar at al., 2016; Singh et al., 2016; Singh et al., 2017; Sharma and Singh, 2017; Kumar et al., 2017; Singh et al., 2017b; Singh, 2017; Singh and Issac, 2018; Singh et al., 2018). Irrigation facility would be useful to increase the productivity of crops and to reduce the negative implications of climate change in cultivation (Kumar and Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a; Kumar et al., 2015b; Kumar et al., 2015c; Kumar et al., 2015d; Kumar at al., 2016; Singh et al., 2016; Singh et al., 2017a; Sharma and Singh, 2017; Kumar et al., 2017; Singh et al., 2017b; Singh, 2017; Singh and Issac, 2018; Singh et al., 2018; Singh and Narayanan, 2018).

Application of bio-fertilizer also may be another alternative to improve the productivity of food-grain crops and to sustain food security in India (Kumar et al., 2015b; Kumar et al., 2015c; Kumar at al., 2016; Singh et al., 2016; Singh et al., 2017a; Singh, 2017; Sharma and Singh, 2017; Kumar et al., 2017). Government expenditure on rural development must be useful to increase the agricultural productivity (Kumar et al., 2015d; Kumar at al., 2016; Singh et al., 2016; Singh et al., 2017a; Kumar et al., 2017; Sharma and Singh, 2017; Singh, 2017; Singh and Issac, 2018; Singh et al., 2018; Singh and Narayanan, 2018). Application of technology in cultivation may be essential to sustain agricultural productivity in India (Carew et al., 2009; Kumar et al., 2015b; Singh et al., 2016; Singh, 2017). Furthermore, cropping intensity, use of modern technology, infrastructure development, appropriate transport facility, market accessibility, government spending in agricultural R&D and rural development would be imperative to sustain crop productivity and food security in India (Kumar et al., 2017; Singh, 2017; Singh and Issac, 2018; Singh et al., 2018; Singh and Narayanan, 2018).

As food-grain farming is the curial and sole sector to meet the food requirement of present and growing population, whereas, arable land under food-grain crops are declined due to high population growth, overwhelming urbanization and industrialization (Kumar et al., 2017; Singh and Narayanan, 2018). Consequently, quality and quantity of natural resources are also negatively impacted due to high population growth, overwhelming urbanization and industrialization, and over burden on agricultural sector. Hence, it is essential to adopt effective policies to maintain the high population growth and urbanization in India (Sharma and Singh, 2017; Singh, 2017; Kumar et al., 2017; Singh and Issac, 2018; Singh, 2018a; Singh and Narayanan, 2018).

As higher industrialization is caused to reduce quality of natural resources and ecosystem services (Kumar et al., 2017; Singh, 2017; Sharma and Singh, 2017; Singh and Narayanan, 2018; Singh and Issac, 2018). For this, initiation of small scale industries in rural area would be helpful to reduce the environmental degradation (Singh, 2017). It would create jobs in rural area, which would be useful to reduce labour migration from rural area to urban area. Subsequently, small-scale industries would be helpful to increase the economic capacity of people, thereby they can sustain their livelihood and food security (Sharma and Singh, 2017). Furthermore, initiation of agro-based industries may be useful to sustain agricultural productivity in near future. Creation of livestock rearing business opportunities also may another proposal to increase economic capacity and food security in rural India (Singh, 2017; Singh and Narayanan, 2018).

Adoption of effective law and regulation to protect the natural resources may be crucial to maintain the quantity and quality of ecosystem services (i.e. water, land, air and others) for sustainable agricultural production in India (Kumar et al., 2017; Sharma and Singh, 2017; Singh, 2017; Singh, 2018a; Singh and Narayanan, 2018). As forest area play a significant role to maintain environmental sustainability, thus it may be helpful to mitigate the adverse effect of climate change in crop farming (Singh, 2017; Singh, 2018a; Singh et al., 2018; Singh and Narayanan, 2018). Pramova et al. (2012) also reviewed that forest area works as ecosystem-based adaptation approach to reduce the negative consequences of climate change in agriculture. Water management policies would be helpful to meet the water requirement in near future (Kumar et al., 2017; Singh, 2017; Sharma and Singh, 2017; Sharma and Singh, 2017; Singh and Issac, 2018; Singh et al., 2018; Singh and Narayanan, 2018).

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Appendix: A

Table A1 Regression result for properties of each variable in time series

Crop	Ragi					Wheat				
Lagged	*1st Lagged*		*2nd Lagged*			*1st Lagged*		*2nd Lagged*		
Variable	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$
tp	0.05**	0.55*	0.06*	0.61*	-0.22	0.05**	0.73*	0.04***	0.45*	0.35***
ia	-0.08	0.91*	-0.06	0.76*	0.18	-0.21*	0.51*	-0.14**	0.44**	0.23
tf	-0.05	0.93*	-0.08	0.77*	0.13	-0.04*	0.94*	-0.05	0.62*	0.30
tt	0.07*	0.93*	0.07*	0.54*	0.41**	0.06*	0.95*	0.07*	0.55*	0.39**
tps	0.08***	0.96*	0.09***	0.76*	0.19	0.11	0.94*	0.14	0.52*	0.40**
aslh	-0.94**	0.68*	-0.41	0.42**	0.43**	-0.05	0.98*	0.07	0.71*	0.31
lrp	-0.02	0.96*	0.01	0.46**	0.52*	-0.29*	0.84*	-0.39*	0.62*	0.16
fa	0.26***	0.81*	0.17	0.34*	0.54*	-0.07	1.06*	-0.11	0.91*	0.19
al	0.47*	0.84	0.43*	1.17*	-0.32*	0.57*	0.81*	0.99*	0.44*	0.24**
amint	1.19*	0.10	1.04*	0.13	0.08	1.19*	0.10	1.04**	0.13	0.08
amaxt	1.34*	0.11	1.06**	0.11	0.17	1.33*	0.11	1.06*	0.11	0.17
arf	2.91*	0.01	2.62*	0.01	0.09	2.90*	0.01	2.62*	0.01	0.09

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. CV is constant coefficient in the table.

Table A2 Regression result for properties of each variable in time series

Crop	Gram					Barely				
Lagged	*1st Lagged*		*2nd Lagged*			*1st Lagged*		*2nd Lagged*		
Variable	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$
tp	-0.08*	0.32**	-0.04*	0.14	0.45*	0.05*	0.79*	0.04*	0.39*	0.47*
ia	-0.59*	0.31	-0.72*	0.25	-0.09	-0.06*	0.65*	-0.03	0.32**	0.45**
tf	-0.10	0.90*	-0.06	0.55*	0.37**	-0.15*	0.85*	-0.16*	0.60*	0.23
tt	0.07**	0.93*	0.04	0.75*	0.23	0.38**	0.77*	0.21	0.35*	0.56*
tps	0.11	0.94*	0.07	0.65*	0.31	0.21**	0.86*	0.24*	0.61*	0.23
aslh	-1.98*	0.44**	2.05**	0.32	0.10	-0.24	0.90*	-0.24	0.52*	0.38***
lrp	-0.49*	0.75*	-0.34	0.50	0.32	-0.02	0.95*	-0.03	0.52*	0.41**
fa	0.70*	0.16	0.68*	0.16	0.03	0.18**	0.90*	0.24*	0.54*	0.31***
al	0.72*	0.76*	1.16*	0.21*	0.40*	0.59*	0.81*	1.03*	0.36**	0.30**
amint	1.07*	0.09	0.75**	0.17	0.18	1.07*	0.09	0.75*	0.17	0.18
amaxt	1.41*	0.03	1.24*	0.13	0.01	1.41*	0.03	1.24*	0.13	0.01
arf	2.95*	-0.07	2.96*	-0.07	0.01	2.95*	-0.07	2.96*	-0.07	0.01

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. CV is constant coefficient in the table.

Table A3 Regression result for properties of each variable in time series

Crop	Bajra					Jowar				
Lagged	*1st Lagged*		*2nd Lagged*			*1st Lagged*		*2nd Lagged*		
Variable	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$
tp	-0.10**	0.45**	-0.05	0.23	0.43*	-0.08*	0.24**	-0.07*	0.17	0.17
ia	-0.82*	-0.05	-0.40**	0.46**	0.01	-1.07*	0.22	-0.97*	0.33	-0.03
tf	-0.06	0.93*	-0.08	0.44**	0.47*	-0.07	0.92*	-0.10	0.91*	-0.01
tt	0.04***	0.96*	0.05**	0.76*	0.19	-.057*	0.95*	0.07*	0.45*	0.50*
tps	0.23***	0.85*	0.24**	0.40**	0.44**	0.09***	0.95*	0.11***	0.80*	0.13
aslh	-3.75*	0.01	-3.33*	-0.07	0.19	0.02*	1.01	0.09	0.86*	0.16
lrp	-0.27	0.87*	-0.15	0.31**	0.60*	0.02	1.00*	0.04	0.66*	0.33
fa	0.45*	0.30	0.28***	0.19	0.37***	0.03	0.94*	0.03	1.04*	-0.10
al	1.17*	0.62*	1.08*	0.33***	0.31**	0.52*	0.82*	0.67*	0.78*	-0.01
amint	1.19*	0.10	1.04*	0.13	0.08	1.19*	0.10	1.04*	0.13	0.08
amaxt	1.33*	0.11	1.06**	0.11	0.17	1.33*	0.11	1.06*	0.11	0.17
arf	2.90*	0.01	2.62*	0.01	0.09	2.90*	0.01	2.62*	0.01	0.09

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. CV is constant coefficient in the table.

Table A4 Regression result for properties of each variable in time series

Crop	Arhar					Rice				
Lagged	*1st Lagged*		*2nd Lagged*			*1st Lagged*		*2nd Lagged*		
Variable	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$	*CV*	$Y_{(t-1)}$	*CV*	$Y_{(t-1)}$	$Y_{(t-2)}$
tp	-0.15*	-0.01	-0.18*	-0.01	-0.14	0.05*	0.81*	0.04**	0.42**	0.43*
ia	-0.57*	0.46*	-0.40*	0.60*	0.01	-0.01	0.93*	-0.01	0.90*	0.02
tf	-0.11	0.87*	-0.10	0.48**	0.39**	-0.14**	0.69*	-0.14*	0.6*	0.06
tt	0.34*	0.90*	0.32*	0.69*	0.23	0.07*	0.95*	0.11*	0.38**	0.53*
tps	0.74*	0.86*	1.04*	0.34***	0.46*	0.19***	0.89*	0.18	0.54*	0.36**
aslh	0.40*	0.87*	-0.48*	0.80*	0.05	-0.51	0.88*	-0.54	0.63*	0.24
lrp	-0.05	0.97*	-0.01	0.76*	0.22	-0.31	0.88*	-0.25	0.69*	0.22
fa	0.12	0.89*	0.13	0.84*	0.03	0.01	0.86*	0.00	0.4**	0.52**
al	1.40*	0.78*	1.54*	0.85*	-0.09	0.51*	0.83*	0.57*	0.97*	-0.15
amint	1.19*	0.10	1.04*	0.13	0.08	1.19*	0.11	1.04*	0.13	0.08
amaxt	1.33*	0.11	1.06**	0.11	0.18	1.33*	0.11	1.06*	0.11	0.18
arf	2.90*	0.014	2.62*	0.01	0.09	2.90*	0.00	2.6*	0.01	0.09

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. CV is constant coefficient in the table.

Appendix: B

Table B1 Results for Augmented Dickey-Fuller unit root tests

Crops	Ragi		Gram		Barley		Bajra	
Variable	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*
tp	-5.45*	-6.53*	-11.37*	-12.27*	-10.771*	-11.809*	-9.513*	-13.445 *
ia	-6.09*	-8.82*	-6.61*	-8.48*	-9.008*	-11.440*	-12.478*	-14.870*
tf	-5.42*	-13.87*	-7.37*	-8.77*	-6.095*	-12.591*	-8.025*	-9.061*
tt	-8.81*	-8.92*	-7.01*	-9.93*	-9.683*	-9.620*	-5.875*	-11.560*
tps	-5.68*	-8.46*	-6.86*	-9.44*	-6.151*	-8.474*	-8.071*	-10.756*
aslh	-8.49*	-12.57*	-7.17*	-9.98*	-7.375*	-9.236*	-9.738*	-11.137*
lrp	-8.60*	-12.38*	-7.40*	-10.41*	-7.045*	-9.616*	-10.452*	-11.96*
fa	-9.46*	-13.42*	-7.84	-10.41*	-6.323*	-8.594*	-9.531*	-11.798*
al	-1.23	-10.22*	-5.88 *	-11.75*	-4.284*	-13.856*	-7.787*	-10.726*
amint	-8.35*	-10.30*	-9.40*	-11.44*	-9.400*	-11.443*	-8.359*	-10.307*
amaxt	-8.90*	-11.92*	-8.43*	-10.43*	-8.433*	-10.439*	-8.908*	-11.928*
arf	-8.35*	-11.94*	-8.53*	-10.70*	-8.534*	-10.703*	-8.359*	-11.941*

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. FD and SD are the first and second difference of each variable respectively in the table.

Table B2 Results for Augmented Dickey-Fuller unit root tests

Crops	Arhar		Wheat		Rice		*Jowar*	
Variable	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*
tp	-7.496*	-8.801*	-10.850 *	-15.837*	-8.515*	-10.443*	-8.22*	-9.775*
ia	-3.750*	-8.289*	-18.937*	-14.694*	-6.036*	-8.127*	-7.02*	-7.987*
tf	-7.525*	-9.171*	-4.752*	-8.377*	-5.673*	-12.661*	-4.59*	-12.93*

tt	-6.262*	-8.997*	-4.642*	-9.764*	-7.100*	-8.661*	-8.57*	-7.059*
tps	-5.310*	-10.341*	-8.157*	-11.140*	-7.109*	-10.327*	-5.37*	-6.890*
aslh	-4.730*	-7.260*	-7.838*	-11.984*	-6.233*	-10.492*	-5.49*	-8.219*
lrp	-6.037*	-8.565*	-6.837*	-10.004*	-6.269*	-10.748*	-6.78*	-8.538*
fa	-5.236*	-8.188*	-5.728*	-8.651*	-8.754*	-11.634*	-4.41*	-7.085*
al	-1.99	-9.280*	-2.289	-9.866*	-1.862	-8.658*	-2.044	-9.338*
amint	-8.359*	-10.307*	-9.400*	-11.443*	-8.359*	-10.307*	-8.36*	-10.307*
amaxt	-8.908*	-11.928*	-8.433*	-10.439*	-8.908*	-11.928*	-8.91*	-11.928*
arf	-8.359*	-11.941*	-8.534*	-10.703*	-8.359*	-11.941*	-8.36*	-11.941*

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively. FD and SD are the first and second difference of each variable respectively in the table.

Appendix: C

Table C1 Regression result with climatic factors with Newey-West standard errors model

Crops	Ragi	Gram	Barley	Bajra	Jowar	Arhar	Wheat	Rice
F-Value	4.28	5.35	2.57	5.39	8.29	2.84	2.58	3.73
Lagged	2	2	2	2	2	2	2	2
amint	1.23	0.67	3.86	9.73***	2.95	-3.67***	2.09	2.18
amaxt	-6.36**	-3.75**	-6.97***	-17.09**	-9.57**	3.19	-5.78***	-8.07*
arf	-0.03	0.09*	0.08	1.20**	-0.01	0.16	0.07	0.06
Con. Coef.	8.09**	4.29	5.64	8.93	10.32*	-0.49	6.16	9.29***

Source: Author's estimation. **Note:** *, ** and *** indicate that values are statistically significant at 1%, 5% and 10% significance level respectively.