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Assessing the Climate Change Impact on Rice and Wheat Production in Uttar Pradesh and Haryana States of India

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ABSTRACT

This study investigates the impact of climate change on rice and wheat production in Uttar Pradesh and Haryana using a time series analysis. For this, simple production function approach, Cobb-Douglas production function approach and Ricardian multi-regression approach are used. Rice and wheat production as a dependent variable is regressed with different socio-economic and climatic variables such as crop-wise area sown, irrigated area; crop-wise use of fertilizer, tractor, pumpset; literacy rate, forest area, population density; minimum, maximum and mean temperature; and rainfall. Empirical results show that increase in rainfall, maximum and minimum temperature have a negative impact on rice production in Haryana and Uttar Pradesh. Rice and wheat production are negatively affected due to increase in maximum temperature in both the states. Furthermore, climatic factors do not similar impact on rice and wheat production in Uttar Pradesh and Haryana. Moreover, results based on Ricardian model infer that there is non-liner relationship between climatic factors and crop production. It also proves that the impact of climate change on crop production have become more sensitive after 1991 due to changing in non-climatic factors. It is suggested that Ricardian model is found suitable technique to assess the climate change impact on agricultural production system.

Keywords: Uttar Pradesh; Haryana; India; Climate Change; Wheat and Rice production; SPFA; CDPFA; RRA.

1. INTRODUCTION

To assess the climate change (i.e. temperature, precipitation, relative humidity and atmospheric gases composition and other weather conditions) impact on a specific activity in an economy is a crucial research area in many perspectives. For instance, to measure the climate change impact on agricultural production, human health, industry, trade, water resources, forest area, labour productivity are the emerging issues for researchers of social sciences, environmental science and biological sciences. Increase in temperature of atmosphere above average, may cause to increase fluctuation in rainfall patterns. Many scientific studies have provided evidence that climatic factors are being fluctuated due to increasing quantity of GHGs emissions in atmosphere. For this, human and natural activities are answerable to increase greenhouse gases (GHGs) in atmosphere (Gadgil, 1995; Kumar et al., 2014; Kumar et al., 2015d; Singh, 2018; Singh et al., 2019a; Singh et al., 2019b). Natural activities such as volcanic eruption, earth's velocity, sun's intensity, fluctuation in the ocean and forest fires are highly responsible for GHGs emissions in the atmosphere.

Human activities such as rapid industrialization, high economic growth and development, population growth, overwhelming urbanization, human settlements and migration, reduction in forest area, use of mechanization in agriculture, use of fertilizer and pesticides in agriculture, transportation and building construction have also increased the high probabilities for climate change (Ahmad et al., 2011; Patnaik, et al., 2010; Kumar et al., 2014; Singh & Issac, 2018; Singh, 2018). Aforementioned anthropogenic activities are caused to increase CO_2, CH_4 and CFC and other gases in atmosphere (Ayyogari et al., 2014). Moreover, global warming is increasing due rising the quantity of GHGs emissions in atmosphere. For example, China has seen high population growth, urbanized and exceedingly rapid erosion, deforestation and desertification, pollution of land, air, fresh water and marine coastal environment after 1978 (McBeath et al., 2009). Thus, China is facing a lot of problems such as more variability in climatic factors. Hence, quantity of GHGs emissions in the atmosphere is increased due to human and natural activities (Kumar et al., 2014; Singh, 2018; Singh et al., 2019a). Since 1970, the amount of carbon dioxide, methane and nitrous oxide has increased by approximately 31%, 151% and 17% respectively in atmosphere due to human activities (Pant, 2009).

Previously mentioned activities are the responsible for variability in temperature, monsoon rainfall, floods, hail storm, drought, rising sea level, heavy wind, cyclone and earthquake (Gadgil, 1995). Ecosystem services are also adversely affecting due to changing human and natural activities (Kumar et al., 2015c; Singh et al., 2019a). Further, previous studies have also claimed that CO_2 and GHGs emissions have a negative implication on available natural and environmental conditions (Singh et al., 2019a). Current climate change scenarios have predicted that an increase of CO_2 concentrations of approximately 575 parts per million (ppm) to 740 ppm are expected to result in large shifts in Indian forest area by 80% of the total forest area by this century (Ranuzzi et al., 2012).Thus, climate change and its impact on agriculture production and food security is very serious concern for every country (Kumar et al., 2014; Sharma & Singh, 2017; Singh et al., 2017a; Kumar et al., 2017; Singh & Sharma, 2018a; Singh & Jyoti, 2019b).

Most of developing economies are located at low latitude and these have insignificant technological progress, inappropriate physical and financial resources to mitigate the adverse effect of climate change, and greater dependence of populations on agriculture production (Nath, et al., 2011; Kumar & Sharma, 2014; Kumar et al., 2014; Singh et al., 2017a; Singh & Sharma, 2018b). Thus, climate change impact will be higher in developing countries as compared to developed economies (Kumar et al., 2016; Singh et al., 2017a; Singh & Narayanan, 2018). Also, most farmers in developing countries are marginal, therefore loss of agricultural production due to climate change will lead to increase food insecurity (Kumar et al., 2015c; Kumar et al., 2017; Singh & Issac, 2018; Singh &Narayanan, 2018). These economies also have an inter-regional disparity in socio-economic structure and natural resources

(Kumar et al., 2016). Thus, developing have low adaptation capacity to cope with climate change (Kumar et al., 2016; Singh et al., 2017a; Kumar et al., 2017).

As agriculture provides the food-grain for consumption, create additional jobs and raw material for industries, thus it is a vital sector of an economy. It is a sole source of livelihood security of 36% of the world's total workforce. It is a most sensitive sector due to climate change as compared to other sector of the economy (Singh et al., 2019b). Thus, agricultural production and food security are negatively associated with climate change (i.e. changes in temperature, precipitation and soil moisture, distribution and frequency of rainfall) in developing countries (Sharma & Singh, 2017; Singh et al., 2017a; Singh et al., 2017b; Kumar et al., 2017; Singh, 2018; Singh & Sharma, 2018a). Change in climatic factors will be caused to increase several infection like pests, insects, diseases or weeds in crops (Nath, et al., 2011; Kumar et al., 2015b; Singh et al., 2017a). Moreover, existing studies have observed that climate change would be caused to decrease in GDP of world's economies. For instance, Horowitz (2009) mentioned that increase in 1^0C temperature across all countries will be produced a decrease in 3.8% world's GDP.

2. INDIAN AGRICULTURAL AND CLIMATE CHANGE

India is agriculture intensive country and agriculture provides food to2ndlargestpopulated country and around 700 million people's employment opportunities is based on it and its allied sector (Kumar et al., 2014). Furthermore, about 52% Indian population are engaged in agricultural sector which strengthen the growth of Indian economy (Kumar et al., 2015a). So, it is expected that any fluctuation in agricultural production certainly affect the growth pattern of Indian economy in several ways such food insecurity, rising price of food-grain product, reduction in farm's income, increasing poverty, child malnutrition and decrease in jobs (Kumar et al., 2015a; Kumar et al., 2016; Singh et al., 2017a; Kumar et al., 2017; Singh et al., 2017b; Singh, 2018). As India is a 2nd largest agriculture intensive economy and have a relatively lower adaptation capacity to mitigate the negative consequences of climate change in crop farming (Singh & Narayanan, 2018). Also, most of Indian farmers have a high dependency on rainfall in monsoon season for cultivation (Singh, 2010).

Earlier studies have provided an evidence that India may be in serious position in the world due to several reasons such as India is located at low latitude, it has different climatic zone, it has different weather season, lower technology to mitigate the adverse effect of climate change, and more than 50% farmers are marginal and subsistence (Aggarwal, 2008). Also, around 78% Indian farmers are smallholder who has land size of less than 2 hectare and these famers have dryland framing system which counts around 70% of total arable land. Furthermore, geographical location of India would be unfavorable for agricultural production system in presence of climate change. Previous studies like Kumar & Sharma (2013b) have argued that agriculture productivity would be declined due to climate change in low latitude economies. In addition, Indian states have high diversity in socio-economic, climatic and natural resources related activities, and agriculture farming system (Singh & Jyoti, 2019b). Thus, it is expected that India's climate would be warmer due to increase in CO_2emission in atmosphere in future (Kumar & Gautam, 2014).

Moreover, climate change would bring several negative effects on food security, poverty eradication policies, farmer's income, job opportunities, and development path in India (Kumar & Sharma, 2013b; Kumar et al., 2016; Sharma & Singh, 2017; Singh et al., 2017a; Singh et al., 2017b; Singh, 2018; Singh & Sharma, 2018a). Further, it is also expected that in India, gross domestic product (GDP) may decrease by 6.2% and agriculture production may decrease by 24% by 2080 due to climate change, low rainfall and natural disaster (i.e. droughts and the frequency of cyclone; soil-erosion, landslides, hailstorms and earthquakes) (Zhai et al., 2009a; Zhaiet al., 2009b). There will be needed of 276 million tons more food by 2021 as against current production 230 million tons. Thus, it may increase the competition for resources such as land, water, capital, labour and other precious natural resources in India (Ahmadet al., 2011; Kumar et al., 2017; Singh & Issac, 2018). Therefore, agriculture system would be in highly vulnerable due to climate change in India (Singh & Jyoti, 2019a).

3. BRIEF REVIEW OF LITERATURE

Numerous studies have used simple production function model, Cobb-Douglas Production function model (C-D model), Ricardian cross-sectional regression model and other methods to assess the climate change impact on agricultural production and yields of food-grain and non-food-grain crops across economies. One groups of researchers have applied linear, non-linear and C-D models under production function approach in different economies. Kar and Kar (2008) (based on C-D model) have observed that low rainfall is adversely affects the crop production and income of poor farmers in Orissa (India). Vaseghi et al. (2008) have applied non-linear regression model and detected that climate changes have a non-linear impacts on net revenue/hectare in Iran. It also claimed that due to increases in GHGs in atmosphere and temperature may be caused to reduce land revenue by 41% by the year 2100.

Mongi et al. (2010) have applied simple regression model and witnessed that most important concern is about the continuous decrease in rainfall and increase in temperature have a negative implications on agriculture production in Tanzania. Auffhammer et al. (2011) have applied linear regression model to assess the climate change impact on rice yield in India. Gupta et al. (2012) have used C-D model to assess the impact of climate change on yields of rice, sorghum and millet crops in India. Nastis et al. (2012) have found that in average temperatures would have a decrease in agricultural productivity in Greece. The empirical results of this study were based on C-D model.Kumar & Sharma (2013a,b) have explored the impact of climate variability on yields of food-grain and non-food-grain crops in India using C-D model. Kumar & Sharma (2014) have used simple linear regression, Ricardian regression and C-D model to assess the climatic and non-climatic factors on sugarcane crop farming in India.

Mondal et al. (2014) have assessed the influence of climate change on wheat and pulses crops using linear regression model in India. Kumar et al. (2014) have used C-D model to assess the climate change impact on yields of rice, maize, sorghum and ragi crops in India. Kumar et al. (2015a) have applied C-D model to assess the influence of climate change on value of productivity of Rabi and Kharif crops in India. Kumar et al., (2015b) have used stochastic production function model to assess the influence of climate change on yield of cash crops in India. Kumar et al. (2015c) have assessed the influence of climatic factors on yield of sugarcane crops in India. Kumar et al. (2016) have evaluated the climate change impact on value of production of food-grain and non-food-grain crops in India using C-D model. Singh et al. (2016) have used linear and log-linear regression models to assess the influence of weather factors on yield of wheat, chickpea, rice and maize in India.

Singh et al. (2017b) have applied C-D model to predict the area, production and yield of cash crops in India. Singh and Sharma (2018b) have assessed the influence of climatic factors on yield of food-grain crops in India. Singh et al. (2019b) have used stochastic frontier production function model to assess the sensitivity of sugarcane crop due to climate change in India. Panda et al. (2019) have used correlation and multiple regression techniques to assess the impact of climate variability index on yields of rice and maize crops in Odisha (India). Singh and Jyoti (2019a) have assessed the impact of climate change on production, yield and area sown of potato, cotton, groundnut and sesame crops in India using C-D model.

Another group of researchers have used Ricardian cross-sectional regression model to examine the climate change impact on land productivity (in monetary term), crop production and yield in developed and developing economies. Firstly, Mendelsohn et al. (1994) have used Ricardian regression model to investigate that impact of climate change on agriculture productivity in USA. Seo et al. (2005) have applied Ricardian approach and concluded that increases in rainfall would be beneficial, however increases in temperature is expected to be harmful for Sri Lankan agriculture. Eid et al. (2006) have recognized that a rise in temperature would have negative effects on farm revenue and irrigation could defeat the adverse effect of higher temperature on it in Egypt. Mano (2007) have applied Ricardian regression model and found that net farm revenues are being adversely affected due to increases in temperature in Zimbabwe.

Maddison et al. (2007) have applied Ricardian method to assess the climate change impact on African agriculture. Kumar (2011) have applied Ricardian cross-sectional model to assess the impact of climate sensitivity on productivity of various crops in India. Kurukulasuriya and Mendelsohn (2008) have used Ricardian model and observed that climate change will be caused to reduce net revenues in agriculture in USA. Benhin (2008) have used Ricardian model for South African countries. It found that a 1% increase in temperature will lead to decrease by US $80.00 of net crop revenue and a 1 mm/month fall in precipitation will lead to decrease net revenues/hectare by US $2.00. Molua (2009) have identified that a 7% decrease in precipitation would be caused to fall in net revenues by US$2.86 billion, and a 14% decrease in precipitation would be caused to decrease net revenue by US$3.48 billion in Cameroon. Ajetomobi et al. (2011) have considered Ricardian approach and came to know that increase in temperature will be caused to reduce net revenue for dry land rice farms, whereas it will rise as increase in temperature for irrigated farms In Nigeria.

3.1. Authentic Research Gap and Objectives of the Study

Preceding section show that Ricardian technique is used by different researchers to assess the climate change impact on net revenue per/hectare land (in monetary terms) (Mendelsohn et al., 1994; Seo et al., 2005; Eid et al., 2006; Mano, 2007; Maddison et al., 2007; Kurukulasuriya & Mendelsohn, 2008; Benhin, 2008; Molua, 2009; Ajetomobi et al., 2011).However, limited studies such as Kumar and Sharma (2014), Singh and Narayanan (2018), Singh et al. (2016) could use Ricardian method to assess the climate impact on land productivity or total production (in quantity terms) of a specific crop in India. Due to above-mentioned drawback of previous studies, the main of this objectives are:

- To assess the impact of climate change on rice and wheat production (in quantity terms) in Haryana and Uttar Pradesh using simple production function approach (SPFA), Cobb-Douglas production function approach (CDPFA) and Ricardian regression approach (RRA).
- To suggest an appropriate method to investigate the climatic impact on crop farming.

4. OUTLINE OF EXITING APPROACHES TO ASSESS THE CLIMATE CHANGE IMPACT ON AGRICULTURE

There are six approaches are available in the literature, which can be used to evaluate the impact of climate change on agricultural production, land productivity or land value, net revenue, gross domestic product, and per capita income etc. These are given as: simple multi-regression model or production function approach, Ricardian cross-sectional model or Hedonic model or Ricardian regression approach, Agro-economic or Crop simulation model, Agro-ecological zones models or Land-zone model, Integrated assessment models and Computable general equilibrium models(United Nations Report, 2011; Kumar & Sharma, 2014; Kumar et al., 2015a). Three methods are mostly useful for social sciences researchers such as simple production function model, Cobb-Douglas production function model and Ricardian model and Computable general equilibrium model or integrated assessment model. As unavailability of experimental data other remaining models may not be use by social science researchers. If experimental data are available than other model can be used by social sciences researchers. Brief description of all technique is given below:

***Production Function Model (PFM)*:** Production function model is a simple multiple regression technique (Kumar and Sharma, 2014). It includes climatic variables as an inputs to investigate the impact of climate change on yield or production of a specific crops (Ahmed et al., 2011; Kumar & Sharma, 2014; Kumar et al., 2015c). There is one weak point of this model, it does not include the adaptation methods that are applied by farmers to mitigate the adverse effect of climate change in cultivation (Unites Nations Report, 2011). This model explicitly links climate, crop yield and market equilibrium conditions (Haim et al., 2008).

***Ricardian Cross-sectional Model (RCM)*:** It is a cross-sectional method which includes single year data to analyze the impact of climate on land value or farm revenue. It is a crucial technique which captures the adaptations that farmers make in response to local environmental conditions (Ranganathan et al., 2010). Firstly, Ricardian method was used by Mendelsohn et al. (1994) to evaluate the climatic impact on agriculture productivity in USA. It is based on multiple-regression approach which includes farm value/land revenue as a dependent variable that is regressed with climatic variables such as temperature, rainfall, rate of rainfall, soil type and erosion, salinity, flood probability, wind soil erosion; and socio-economic features of farmers (Kurukulasuriya et al., 2006). Kumar (2011), Kumar and Sharma (2014) have used this method to assess the climate change impact on crop production and yield in different economies. Kumar et al. (2017) have applied linear and non-linear regression models to assess the association of climatic and non-climatic factors with per capital food-grain availability in India.

***Agro-economic Model (AEM) or Crop Simulation Model (CSM)*:** It represent the relationship between crop productivity and environmental factors using simulation modeling. The results of the simulation model is then fed into economic models in order to predict the impact on the economy in general. AE model examine the impacts of climate change and variability on crop yields, vulnerability of production techniques to climate change where vulnerability is defined as the probability of crop failure. Crop failure occurs when a crop does not nurture to produce seed or grain. It can be used in social sciences if the data is available to incorporate in regression model (Unites Nations Report, 2011).

***Agro-ecological Zones Model (AEZM) or Land-Zone Model (LZM)*:** Agro-economic model was produced by Food and Agriculture Organization of the United Nations and International Institute for Applied Systems Analysis. In AEZ model, land is divided into different units based on climate, soil, land constraints to crop production, potential productivity and environmental impact. Crops are assigned to different zones and yields are estimated under different climatic and zonal conditions (Mendelsohn, 2008). The major drawback of the AEZ model is the quality and reliability of data on AEZ across regions are always questionable (Unites Nations Report, 2011).

***Integrated Assessment Model (IAM)*:** It attempt to analyze how changes in the climate system will have impact in an economy. It examines that how nations will choose climate change policies in light of economic trade-offs and national self-interest. Further, it observe how countries/nations choose climate change policies a cooperative and noon-cooperative approach and why are countries/nations choosing three man strategies: (i) Market policy (where there is no control over carbon emissions); (ii) Cooperative policy (where countries together decide on efficient level of carbon emission); and (iii) non-cooperative policy (where countries choose the level of carbon emission in their own self-interest ignoring the impact of their actions on other countries). Nonetheless, it examines the impact of climate change on total output and no application have seen in which the model have an impact on a particular sector/economy (Unites Nations Report, 2011). It does not include non-climate factors (i.e. policies, change in population and technologies) which have significant impact on output.

***Computable General Equilibrium Model (CGEM)*:** It explicates the relationships among industries, consumers and governments across economies, and possible impacts of climate change on agriculture. Partial equilibrium model evaluates overall performance of an economy as assuming that industries have no effect on each other or rest of the economies. It looks at the economy as a complete, interdependent system; thereby it provides an economy-wide prospective to capturing link between agriculture and other sectors (Zhai et al., 2009).

4.1. Research Methodology Related Issues

Numerous methods are available to analysis the climatic impact on agriculture in the literature. Despite that, climate change have brought several methodological issues to assess the climate change impact and vulnerability assessments, mitigation and adaptation options in economic activities for climate policy action and decision making (Estrada et al., 2011). It is great challenge for economists, agriculturist, environmental scientist and policy maker to select an appropriate mathematical formulation and econometric model to investigate the impact of climate impact on agriculture or other sector of the economy. In developing countries the selection of model is a fundamental issue because there is several constraints that create obligations in interpretation of estimated empirical results. As previously mentioned methods have several advantages and disadvantages. Thus, there is a significant question to select an appropriate model to explore the climatic impact on agricultural production in context of developing countries. So, the present study used three different models to assess the climate change impact on wheat and rice production in Uttar Pradesh and Haryana. Thereupon, it provides the rationality of appropriate method that can be used to assess the climate change impact on agricultural production system.

5. PROPOSED EMPIRICAL ANALYSIS

5.1. Description of Data

This study is comprised the production of rice and wheat crops, climatic and non-climatic factors of Haryana and Uttar Pradesh states of India in a time series i.e. 1971-2010. Required information on aforementioned activities are taken from different sources. Linear interpolation and graphical projection methods are used to identify the missing values in the available data set (Kumar & Sharma, 2013b; Kumar et al., 2016a; Kumar et al., 2017; Sharma & Singh, 2017; Singh & Sharma, 2018b; Singh et al., 2019a).Crop-wise production, crop-wise area sown, crop-wise irrigated area, crop-wise use of fertilizer, crop-wise use of tractor and crop-wise use of pumpset are taken from Center Monitoring Indian Economy, and Directorate of Economics and Statistics Ministry of Agriculture (GoI), Agricultural Informatics Division National Informatics Centre Ministry of Communications and Information Technology (GoI). Literacy rate is segregated from the website of Planning Commission (GoI). Crop-wise use of agriculture labour is taken from census (GoI). Minimum, maximum and mean temperature, and rainfall related data are taken from *Indian Meteorological Department* (*IMD*)(GoI).

5.2. Simple Production Function Approach (SPFA)

Simple production function approach is a multiple regression analysis. This approach was used by Mongi et al. (2010) to investigate the impact of climate change on agriculture production in Tanzania; Haim et al. (2008) in Israel; Pant (2009) in 120 countries; Kumar and Sharma (2014), Singh et al. (2016), Singh and Narayanan (2018) in India. It assumes that climatic variables are input factors for agricultural growth as similar to socio-economic factors. Let $(TP)_i$ is the production of crop i, and it is a function of several socio-economic and climatic factors. Simple production function may be defined as:

$$(TP)_i = f\,(Socio\text{-}economic\ Factors, Climatic\ Factors) \quad (1)$$

In more amplification, equation (1) can be written as:

$$(tp)_i = f\{(cwas)_i,(cwias)_i,(lr)_i,(fa)_i,(cwuf)_i,(cwut)_i,(cwups)_i,(pd)_i,(aarf)_i,(aamaxt)_i,(aamint)_i,(aameant)_i,(d)\} \quad (2)$$

Here, $(tp)_I$ is agricultural production of crop$i$; (*cwas*), (*cwias*), (*lr*), (*pd*), (*fa*), (*cwuf*),(*cwut*) and (*cwups*) are the crop-wise area sown, crop-wise irrigated area sown, literacy rate, population density, forest area, crop-wise use of fertilizer, crop-wise use of tractor, crop-wise use of pumpset under respective crop i respectively. (*aarf*), (*aamaxt*), (*aamint*) and (*aameant*) are the annual average rainfall, annual average maximum temperature, annual average minimum temperature, annual average mean temperature in entire crop duration of a specific crop i respectively. D_i is dummy variable that is used to capture the climate change on crop production in two periods (i.e. 0 for time period 1971–1991and 1 for time period1992–2010). In form of econometric model, equation (2) may be expressed in following form:

$(tp)_i = \alpha_0 + \alpha_1 (cwas)_i + \alpha_2 (cwias)_i + \alpha_3(lr) + \alpha_4(fa) + \alpha_5(cwuf)_i + \alpha_6(cwut)_i + \alpha_7(cwups)_i + \alpha_8(pd)_i + \alpha_9(aarf)_i + \alpha_{10}(aamaxt)_i + \alpha_{11}(aamint)_i + \alpha_{12}(aameant)_i + \alpha_{13}(d) + u_i$(3)

Here, α_0 is constant coefficient; α_1, ... α_{12} are regression coefficients of associated variables respectively;α_{13} is regression coefficient for dummy variable and$u_i$is error term in the equation (3).

5.3. Cobb-Douglas Production Function Approach (C-D model)

This approach is proposed by Knut Wicksell (1851-1926), and tested against statistical evidence by Charles Cobb and Paul Douglas in 1928. Environmental effect on agricultural production using aforesaid methods was estimated by Kar and Kar (2008) in Orissa, India. It considered gross farm revenue as a dependent variable and price of agricultural inputs; labour used in man days in total crop duration, fertilizer, pesticides and weekly precipitation as independent variables. C-D model was also used by Oduol et al. (2011) in Sub-Saharan Africa; Kumar and Sharma (2013a,b), Kumar and Sharma (2014), Kumar and Sharma, 2014, Kumar et al. (2014), Kumar et al. (2016a), Singh and Narayanan (2018) in India. In this study, C-D model is used to evaluate the climatic impact on rice and wheat production in Uttar Pradesh and Haryana. Production for rice and wheat crops are considered as a dependent variable which are regressed with different socio-economic and other climatic factors. Let $(TP)_I$ is a production or output of crop *i*, and $\sum Q_i$ is the combination of input factors of crop *i*. The functional form of above association is specified as:

$(TP)_i = f \sum(Q_i)$ (4)

Now in application of C-D model, equation (4) can be written as:

$(TP)_i = (A_0 L^a_i, K^b_i)$ (5)

Here, A_0 is constant value that represents the total factor production, L_i and K_i are the units of labour and capital respectively; a and *b* are the *elasticity of* labour and capital respectively; $a + b = 1$. This is a homogeneous degree one and linear production function. Taking natural *log* both side of equation (5), than it can be written as:

$Or\ log\ (TP)_i = log\ A_0 + log\ L^a_i + log\ K^b_i$ (6)

Equation (6) is a linear form in the parameters or linear in the constants. Also, *log* (*TP*)is a linear function of $log\ L^a$ and $log\ K^b$. In transformed function, equation (6) will be a regression line for all observations in the data set. Thus, equation (6) may be written as:

$log\ (TP)_i = \beta_0 + \beta_1 log\ (L_i) + \beta_2 log\ (K_i) + Z_i$ (7)

Here, $A_0 = e^{\beta 0}$is transformed into natural logarithms or $10^{\beta 0}$ with base 10.Similar this, *a* and *b*are also transformed; Z_i is the error term in equation (7).Now in the condition of multiple-variables, equation (7) will become as:

$log\ (tp)_i = \beta_0 + \beta_1 log\ (cwas)_i + \beta_2 log\ (cwias)_i + \beta_3 log\ (lr) + \beta_4 log\ (fa) + \beta_5 log\ (cwuf)_i + \beta_6 log\ (cwut)_i + \beta_7 log\ (cwups)_i + \beta_8 log\ (pd) + \beta_9 log\ (aarf)_i + \beta_{10} log\ (aamaxt)_i + \beta_{11} log\ (aamint)_i + \beta_{12} log\ (aameant)_i + \beta_{13} (d) + z_i$ (8)

Here, the expression of dependent and explanatory variables are given in equation (2); β_0 is constant coefficient; β_1,... β_{12} are regression coefficients for associated independent variables respectively; $\beta_{13}$is regression coefficient for dummy variable; and Z_i is error terms in equation (8).

5.4. Ricardian Regression Approach (RRA)

Ricardian regression approach was used by many researchers like Zhai and Zhuang (2009) in Southeast Asia; Ahmed and Schmitz (2011) in Pakistan; Kurukulasuriya and Mendelsohn (2008) in Africa; Gbetibouo and Hassan (2005) in South Africa; Mano and Nhemachena (2007) in Zimbabwe; Seo et al. (2005) in Sri Lanka; Kumar and Sharma (2014) in India to investigate the climatic change impact on agricultural production and yields. In this study, production of a specific crop is taken as a proxy instead of land productivity or net revenue, and other explanatory are taken in same way. Specific Ricardian regression approach is a non-linear formulation of climatic factors and a linear function of socio-economic factors (Mendelsohn et al., 1994). In Ricardian model, equation (8) can be written as:

$$(tp)_i = \theta_0 + \theta_1 (cwas)_i + \theta_2 (cwias)_i + \theta_3 (lr) + \theta_4 (fa)_i + \theta_5 (cwuf)_i + \theta_6 (cwut)_i + \theta_7 (cwups)_i + \theta_8 (pd) + \theta_9 (aarf)_i + \theta_{10}(aamaxt)_i + \theta_{11} (aamint) + \theta_{12}(aameant)_i + \theta_{13}(aarf)_i^2 + \theta_{14}(aamaxt)_i^2 + \theta_{15}(aamint)_i^2 + \theta_{16}(aameant)_i^2 + \theta_{17} d_i + \varepsilon_i \quad (9)$$

Here, description of all explanatory variables are similar to equation (2); θ_0 is constant coefficient; and $\theta_1,\ldots\theta_{16}$ are the regression coefficients of corresponding explanatory variables respectively; θ_{17} is regression coefficient for dummy variable; and ε_i is error term in equation (9). Equation (9) is linear for socio-economic variables and non-linear for climatic factors. This includes quadratic terms for climatic factors i.e. rainfall, maximum, minimum and means temperature.

Before doing any regression for empirical analysis following proceed are used. Firstly to test the properties of stationary and non-stationary of each variable in time series data, 1stand 2nd lagged of each variable is regressed with respective original variable (Ayinde et al., 2011; Nastis et al., 2012; Singh & Sharma, 2018b). For this, results are shown in Table:B1 and B2 in Annexure:B. The result show that most of the factors are found non-stationary at 1st and 2nd lagged in Haryana and Uttar Pradesh. Second to check the presence of unit root test in time series, Augmented Dickey Fuller (ADF) test is applied. Unit root test is calculated by 1stand 2nddifference of each variable and it is regressed with respective original variable (Nastis et al., 2012; Ayinde et al., 2011). Results of Augmented Dickey Fuller (ADF) unit root test are given in table: B3 in Annexure: B. Result show that all factors have unit roots at 1stand 2nddifference. Literacy rate of population do not have any unit root at first difference.

Certain variables for different crops are dropped from the regression models due to presence of high multicollinearity. Mostly those combinations of variables are dropped which had a mean of variance of inflation factor (VIF) value more than 10 or which variables have a very little significance level (Singh et al., 2016; Kumar et al., 2017; Singh & Narayanan, 2018). Cameron and Trivedi's decomposition of IM-test and Breusch-Pagan/Cook-Weisberg test are used to address the presence of Heteroscedasticity. Durbin-Watson d-statistic, Durbin's alternative test and Breusch-Godfrey LM test reused to identify the auto-correlation in time series data. Lagged model and Newey-West model or Newey-West Standard Errors of OLS Estimators 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 & Sharma, 2018b). Proposed regression models are run using STATA and SPSS software.

6. DISCUSSION ON EMPIRICAL FINDINGS

Regression results which measure the association of climatic and non-climatic factors with rice and wheat production are given in Table: 1–6. Regression coefficients of explanatory variables are estimated using simple production function approach (SPFA), Cobb-Douglas production function approach (CDPFA) and Ricardian regression approach (RRA). For this, it gives preference to Lagged model and Newey-West model to produce the regression coefficients of climatic and non-climatic factors. As R^2 and Adjusted R^2 values are found more than 97%, thus it shows that 97% variation in rice and wheat production can be explained through undertaken climatic and non-climatic factors. The detail explanation of estimated regression coefficients of climatic and non-climatic factors with rice and wheat production are presented here:

***Crop-wise Area Sown (cwas)*:** Regression coefficient of area sown with rice and wheat production are negative in Haryana, while it is seemed positive in Uttar Pradesh. Thus, it is proposed that production of rice and wheat crops would increase as increase in cropped area under rice and wheat crops in Uttar Pradesh. However, production of rice and wheat crops will not improve as increase in area sown of these crops in Haryana. The explanation of above-mentioned estimates may be expressed as area sown under a specific crop is an essential determinant for crop production (Kumar & Sharma 2014; Kumar et al., 2014; Kumar et al., 2015a,b,c; Singh et al., 2016; Singh et al., 2017b). Singh et al. (2019b) have also found positive association of area sown with production of various crops in India.

***Crop-wise Irrigated Area* (*cwias*):** As per empirical results, irrigated area under rice and wheat crops show a positive effect on production of these crops in Haryana. While, irrigated area of both the crops could not provide significant contribution in rice and wheat production in Uttar Pradesh. Thus, it is greater concern for policy makers, why does irrigated area do have negative impact on rice and wheat production in Uttar Pradesh. The detail explanation on aforesaid estimates may be presented as irrigated areas have higher yielding capacity in crop production as compared to non-irrigated area. Thus, irrigated area have a significant contribution to increase crop production(Kumar & Sharma 2014; Kumar et al., 2014; Kumar et al., 2015a,b,c; Singh et al., 2017b). Regression coefficients of irrigated area with rice and wheat production are seemed positive (Singh et al., 2016). Estimates imply that irrigated area can be considered as a best determinant to increase crop production (Singh & Sharma, 2018b). Irrigated area are also seemed a best adaptation methods to mitigate the negative consequence of climate change in crop farming (Singh et al., 2019b; Singh & Jyoti, 2019a).

Crop-wise Application of Fertilizer **(*cwuf*)**: Regression coefficients of fertilizer with production of rice and wheat crops are appeared positive and statistically significant. Thus, fertilizer application may be useful to increase the production of rice and wheat crops. Aforesaid estimates can be interpreted in way that applications of fertilizer in crop farming is useful to maintain the soil quality and fertility, thus it is effective to increase crop production(Kumar & Sharma 2014; Kumar et al., 2015a,b,c; Kumar et al., 2016). However, earlier studies have claimed that extensive application of fertilizer would be ineffective in crop farming (Kumar & Sharma 2014; Singh et al., 2017b). As application of fertilizer may be caused to increase more GHGs emissions in atmosphere, thus it may create more possibilities for climate change (Kumar & Sharma, 2014; Singh & Issac, 2018; Singh &Narayanan, 2018; Singh & Jyoti, 2019a). Another negative implication of application of fertilizer in agriculture would be caused to decreased environmental factors like soil, water, forestry and air (Ranuzzi & Srivastava, 2012; Kumar & Sharma, 2014; Kumar et al., 2015c). Previous studies have also argued that overuse of fertilizer would be caused to increase fluoride, heavy mineral and arsenic in soil (SriSubramaniam et al., 2009; Singh et al., 2019b). Singh & Jyoti (2019b) have claimed that use of fertilizer may be caused to reduce land productivity, soil quality and soil fertility in long-term. Thus, it would adversely affect the crop production and qualities of food-grain crop, thus human health would be in deteriorate position. Here, it is advisedfor farmers to avoid the extensive application of fertilizer in crop farming (Kumar et al., 2014; Kumar et al., 2015b; Singh et al., 2016; Singh et al., 2017b).

Crop-wise Use of Tractor **(*cwut*) and *Pumpset* (*cwups*):** Regression coefficients of tractor and pumpset with rice and wheat production are found statistically insignificant, so these variables have dropped from the regression models. However, previous studies have claimed that use of mechanization is an important factor in farming. Here, use of tractor is considered as proxy to estimate the role of mechanization in crop production. It play an actual role to preparation of land in sowing time (Kumar & Sharma 2014; Kumar et al., 2014; Kumar et al., 2015a; Kumar et al., 2016), thus it may be helpful in germination of seed. Use of tractor during field preparation for sowing time of seed reduce the moisture in soil (Kumar et al., 2017). Kumar and Sharma (2013b) have observed positive impact of tractor on arahr crop in India. Kumar et al. (2015c) have also found positive impact of mechanization on sugarcane yield in India. However, earlier studies like Kumar and Sharma (2014), Kumar et al. (2015a,b)could not observe significant impact of tractor in crop production in India. For this, Kumar and Sharma (2014) have argued that mechanization is effective in large-size of land-holdings. Pumpset is an important instrument to complete the irrigation requirement, thus application of pumpset might be useful to increase the crop production (Kumar et al., 2016).

Literacy Rate **(*lr*)**: The regression coefficients of literacy rate with rice and wheat production is seemed positive and statistically significant. While, literacy rate do have negative association with rice and what production in Uttar Pradesh. Estimates would be supportive in way that literate farmers have a greater idea and knowledge to apply better farm management technique in farming. They have also better understanding to use of appropriate quantity of seed, fertilizer and right time of irrigation (Kumar et al., 2016). Therefore, literate farmers may have crucial adaptation techniques to mitigate the adverse effect of climate change in crop farming (Kumar & Sharma 2014; Singh & Jyoti, 2019b). Here, literacy rate is used a proxy variable to capture the impact of literate farmers in crop cultivation (Kumar & Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a,b; Singh & Sharma, 2018b).

Population Density (pd): Regression coefficient of population density with rice and wheat production are found statistically insignificant in Haryana and Uttar Pradesh. Thus, this variable is dropped from the regression analysis. However, previous studies have claimed that population density is caused to increase damage of natural resources and have a high pressure on agriculture sector (Singh & Issac, 2018). Therefore, population density might be having negative impact on crop production.

Table 1 Regression Result with all factors based on *SPFA* and *CDPFA* with lagged model

Crop	Rice				Wheat			
State	Haryana		U.P.		Haryana		U.P.	
Variables	SPFA	CDPFA	SPFA	CDPFA	SPFA	CDPFA	SPFA	CDPFA
F-Value	115.2	55.74	90.05	48.08	168.82	296.39	223.93	214.52

R^2	0.98	0.94	0.97	0.94	0.98	0.99	0.99	0.99
Adj.R^2	0.97	0.93	0.96	0.92	0.97	0.98	0.98	0.98
cwas	-0.19	-1.50**	2.97*	2.26*	-0.06	-1.11*	2.49*	1.94*
cwias	1.35	0.77	-1.34**	-0.34**	-0.19	0.11	-0.06	-0.16*
lr	66.46*	–	-134.49	-2.35*	176.62*	0.62**	-176.4	-0.37
fa	-4.94*	-0.38**	0.30	–	–	–	1.71**	–
cwuf	6.43***	0.62*	–	–	0.79	0.38*	4.45**	–
aarf	-0.06	0.09	-1.65**	-0.22	0.84	0.02	0.16	-0.01
aamaxt	79.32***	0.67	-317.46**	-0.60	-44.95	-0.28	-87.14**	0.09
aamint	-32.72	-1.80	157.05	-0.15	196.86**	0.32***	259.68**	0.25
Dummy Variable	-180.53	-0.02	-161.60	-0.02	-288.58	-0.02	-974.78	-0.01
Con. Coef.	-2742.48	3.16	-5908.57	-6.69***	-926.49*	3.37*	56885.05	-4.91*
IM-test	47.74	45.8	48.22	48.21	54.17	50.24	49.30	48.01
B-Pagan/C-W Test	0.35	19.42**	2.34	19.56**	6.10**	7.92**	23.32	12.66**
Durbin-Watson d- Test	1.89**	1.59**	1.93**	1.97**	1.86**	2.02**	1.92**	2.08
Durbin's alternative	0.056	1.64	0.001	0.01	0.11	0.21	0.31	0.14

Source: Authors' observation. Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively.

Regression coefficients of original and quadratic terms of climatic factors with rice and wheat production have an opposite sign. Thus, estimates imply that climatic factors have a non-linear association with crop production in Uttar Pradesh and Haryana. Previous studies such asKumar & Sharma (2014) have found non-linear association of climatic factors with crop yield and production in India. Also, estimates are suggested that rainfall have a hilly-shaped association with rice and wheat production. While, maximum and minimum temperature have a U-Shaped and Hilly –shaped association with rice and wheat production.

Table 2 Regression result with all factors based on *SPFA* and *CDPFA* with Newey-West standard errors model

Crop	Rice				Wheat			
State	Haryana		U.P.		Haryana		U.P.	
Variable	SPFA	CDPFA	SPFA	CDPFA	SPFA	CDPFA	SPFA	CDPFA
f-value	168.67	84.26	345.17	210.25	1360.95	1048.35	889.32	478.54
cwas	-0.20	-1.41**	3.02*	2.33*	-0.06	-1.11**	2.50*	1.84*
cwias	1.35	0.85**	-1.21**	-0.42**	-0.19	0.11	-0.06	-0.18*
lr	66.46*	–	-206.92**	-1.52	176.61*	0.62*	-172.16	-0.33
fa	-4.94*	-0.35**	–	0.23*	–	–	1.64**	–
cwuf	6.43**	0.66*	–	–	0.79	0.38*	4.47	–
aarf	-0.05	0.06	-1.64*	-0.22 **	0.84	0.02	-0.13	-0.02
aamaxt	79.32*	0.67	-321.18***	-0.49	-44.95	-0.28	-675.84**	0.34
aamint	-32.72	-1.58*	18.65	0.70***	196.86**	0.32**	1205.82*	0.15
Dummy Variable	-180.53	-0.02	424.35	-0.03	-288.58	-0.02	-1002.65	-0.02
Con. Coef.	-2742.49**	3.41**	873.63	-8.84*	-926.49*	3.37*	2923.6***	-4.69*

Source: Authors' observation. Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively.

***Annual Average Minimum Temperature* (*aamint*)**: Regression coefficients of minimum temperature with wheat production are appeared positive in Haryana and Uttar Pradesh, while it have negative impact on rice production in both the states. Thus, estimates imply th3at impact of minimum temperature on crop production is significantly different in both the states. Previous studies like Kumar and Sharma (2014); Kumar et al. (2015a) have provided similar explanation on minimum temperature on crop production in India.

***Annual Average Mean Temperature* (*aameant*)**: As mean temperature is highly correlated with minimum and maximum temperature, thus it is dropped from the regression models.

Dummy Variable (0 =1971–1991 and 1 =1992–2010): Regression coefficients of dummy variables with rice and wheat production are perceived negative as considering climatic and non-climatic factors in regression model. It provides an evidence that climate change impact on crop production seemed negative. While, regression coefficients of dummy variable with rice and wheat production are found positive as considering climatic factors in regression model. It proves that the impact of climate change on crop production have become more sensitive after 1991 due to changing in non-climatic factors in Uttar Pradesh and Haryana.

Table 3 Regression result for all factors based on *RRA* with Newey-West standard errors model

State	Rice		Wheat	
Method	Ricardian Regression Approach		Ricardian Regression Approach	
Variable /Crop	Haryana	Uttar Pradesh	Haryana	Uttar Pradesh
F-Value	210.95	653.52	1808.72	1391.51
cwas	3.31*	3.38*	3.425677*	2.45*
cwias	-2.20	-1.23***	-1.12*	-0.03
lr	58.29***	–	–	–
fa	2.08	–	–	–
cwuf	13.30*	2.28***	1.80**	3.81
cwut	-0.01	–	0.01	–
cwups	-0.02**	-0.04**	–	-0.01
aarf	-1.04	-9.03	-21.34**	-38.63
(aarf)²	0.01	0.01	0.07***	0.10
aamaxt	3657.68	-6172.57**	-4472.17	-195443.2***
(aamaxt)²	-57.97	93.99**	80.78	3379.18***
aamint	7.21**	-46183.5*	289.12	36097.07***
(aamint)²	-4.55 **	992.52*	-4.82	-1320.45***
Dummy Variable	-151.67	45.95*	766.96*	-1371.911**
Con. Coef.	21372.9	-790108.10*	-18762.26	277629.20**

Source: Authors' observation. Note: *, ** and *** indicates the 1%, 5% and 10% significance level respectively.

Table 4 Regression result for climatic factors based on *RRA* with Newey-West standard errors model

State	Rice		Wheat	
Method	Ricardian Regression Approach		Ricardian Regression Approach	
Variable /crop	Haryana	Uttar Pradesh	Haryana	Uttar Pradesh
f-value	116.51	279.27	451.58	228.4
aarf	-2.77	-4.37	-24.40	-126.74***
(aarf)²	0.01	0.01	0.08	0.30***
aamaxt	4901.20*	-6179.36	-13891.68*	117360.6
(aamaxt)²	-77.52*	82.85	243.30**	-1975.38
aamint	7.22 *	36305.40*	-1516.09	-80378.14*
(aamint)²	-4.55***	-803.20*	56.96	2953.11*
Dummy Variable	329.29 **	1901.14*	1380.97*	2041.36***
Con. Coef.	-71195.04*	572367.10*	-134951.20	-2282964.10

Source: Authors' observation. Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively.

Table 5 Comparison of empirical results with Newey-West standard errors in Uttar Pradesh

Crops	Rice			Wheat		
Variables	SPFA	CDPFA	RRA	SPFA	CDPFA	RRA
f-value	47	18.45	279.27	24.43	13.33	228.4
aarf	-2.97***	-0.45***	-4.37	-4.28	-0.23	-126.74***
(aarf)²	–	–	0.01	–	–	0.30***
aamaxt	-869.51*	-3.71**	-6179.36	607.98***	15.34**	117360.6
(aamaxt)²	–	–	82.85	–	–	-1975.38
aamint	59.15	-0.03	36305.40*	-5017.30**	-7.03**	-80378.14*
(aamint)²	–	–	-803.20*	–	–	2953.11*

Dummy Variable	4368.94*	0.26*	1901.14*	6379.13*	0.15**	2041.36***
Con.Coef.	46608.15*	13.35*	572367.10*	-11032.2**	-14.97***	-2282964.10

Source: Authors' observation. Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively.

Table 6 Comparison of empirical results with Newey-West Standard Errors in Haryana

Crops	Rice			Wheat		
Variables	SPFA	CDPFA	RRA	SPFA	CDPFA	RRA
f-value	47.66	17.44	116.51	91.53	25.2	451.58
aarf	0.07	-0.01	-2.77	-4.48	-0.12	-24.40
(aarf)^2	–	–	0.01	–	–	0.08
aamaxt	-182.82*	-5.48**	4901.20*	-587.71*	-2.02***	-13891.68*
(aamaxt)^2	–	–	-77.52*	–	–	243.30**
aamint	258.32*	3.12*	7.22 *	77.60***	0.26	-1516.09
(aamint)^2	–	–	-4.55***	–	–	56.96
Dummy Variable	438.12*	0.13	329.29 **	2242.85*	0.21*	1380.97*
Con. Coef.	13660.51*	16.67*	-71195.04*	-1516.22*	-0.42	-134951.20

Source: Authors' observation. Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively.

Forest Area (fa)**:** Regression coefficient of forest area with rice and wheat production is found positive in Uttar Pradesh, while forest area do have insignificant association with rice and wheat production in Haryana. The consistency of aforesaid estimates may be explained as forest area is useful to sustain the quantity and quality of natural resource (Singh et al., 2019a).It also reduce the incidence of natural disaster, and high changeability in temperature and rainfall(Kumar et al., 2015d; Singh & Sharma, 2018b). Further, forest area is also useful to reduce the temperature effect on crop growth (Singh et al., 2019b; Singh & Jyoti, 2019a). Consequently, forestry may be ecosystem adaption based methods to mitigate the negative consequences on climate change in crop farming (Singh & Jyoti, 2019a).

***Annual Average Rainfall* (*aarf*)**: Regression coefficients of rainfall with wheat production is detected positive, while rainfall have a negative impact on rice production in Haryana and Uttar Pradesh. Previous studies have also found negative association of rice and wheat production in India (Kumar & Sharma 2014; Kumar et al., 2015a). However, rice crop is required extensive water during sowing time, while rainfall in growing and harvesting time will produce negative implications on rice production. Rainfall during sowing time of wheat crop will adversely affect the germination of seed, thus it would have negative influence on wheat production in Haryana and Uttar Pradesh.

***Annual Average Maximum Temperature* (*aamaxt*):** Regression coefficients of maximum temperature with rice production is seemed positive in Haryana. While, maximum temperature do have negative association with wheat production in Haryana and Uttar Pradesh. Thus, estimates show that maximum temperature would have negative impact on crop production. Previous studies like Kumar and Sharma (2014); Kumar et al. (2015a) have observed that maximum temperature would produce negative impact on crop production.

7. CONCLUSION AND PRACTICAL POLICY IMPLICATIONS

The prime am of this study was to assess the impact of climate change on rice and wheat production (in quantity terms) in Haryana and Uttar Pradesh using simple production function approach (SPFA), Cobb-Douglas production function approach (CDPFA) and Ricardian regression approach (RRA). Thereupon, it suggest an appropriate method to investigate the climatic impact on crop farming. For this, it compiles the climatic and non-climatic data in a time series (1970 – 2010) for both the states. Empirical results based on SPFA and CDPFA models shows that any increment in rainfall may have negative impact on rice production in Uttar Pradesh. Results estimated through RRA model indicate that wheat production is also negatively affected due to increase in rainfall in Uttar Pradesh. Maximum and minimum temperature have produced negative impact on rice production in Uttar Pradesh. Wheat production is being adversely affected due to increase in maximum temperature in both the states. Increasing in minimum temperature has a positive impact on rice production and negatively impact on wheat production.

In Haryana, rainfall do not have significant impact on rice and wheat production. Increment in maximum temperature has a negative impact on rice and wheat production in Haryana. Increase in minimum temperature has a positive impact on rice while no impact on wheat production is seemed in Haryana. For Haryana, it can be accomplished that there are not similar impacts of different climatic factor on rice and wheat production. Empirical results also proves that the impact of climate change on crop production have become more sensitive after 1991 due to changing in non-climatic factors. In brief, it can be concluded that changes in climatic factors negatively affect the rice and wheat production in Uttar Pradesh and Haryana. Thus, it can be concluded that all climatic factors have a negative impact on both the states. Finally, results based on Ricardian regression approach show that there is non-linear relationship between climatic factor and rice and wheat production. Estimates also provide a claim that Ricardian regression analysis is a best technique to investigate the climatic impact on agricultural production system.

Based on estimated results several policy suggestion can be provided like first of all, world's economies are required to implement policies that may be useful to reduce GHGs emissions from various production activities (Kumar et al., 2015d; Singh et al., 2016). As forest area play a significant role to absorb the CO_2 and GHGs emissions (Singh, 2018; Singh & Sharma, 2018b; Singh &Narayanan, 2018). Therefore, there must be a conducive policy to reserve the forest area to maintain the common property of natural resources and to reduce the GHGs emissions in the atmosphere (Singh et al., 2019a). For this, use of renewable energy, green technologies and green fertilizer may be positive to abate GHGs emissions (Singh & Jyoti, 2019a; Singh & Jyoti, 2019b). There is requirement to discover green technologies for manufacturing industries to reduce the GHGs emissions in India (Kumar & Gautam, 2014).

Moreover, more irrigation facilities and create more irrigation infrastructure would be beneficial for cultivation in India (Kumar & Sharma, 2014; Kumar et al., 2014; Kumar et al., 2015a; Singh et al., 2017a). Irrigated area may be a best adaptation strategy to mitigate the adverse effects of climate change in cops farming (Kumar et al., 2015b; Kumar et al., 2015c; Singh et al., 2017b). As water is a prime determinants of agricultural sector, therefore there is requirement to implement an effective policies to protect available water resources (Kumar et al., 2015c; Sharma & Singh, 2017; Singh et al., 2017b).It would be useful to meet the water demand for irrigation in agriculture sector in India in future (Singh & Sharma, 2018a).

There is needed to apply minimum quantity of fertilizer in cultivation (Kumar et al., 2016), otherwise it might be caused to increase more environmental degradation (Singh et al., 2016), and greater possibilities of climate change in future (Singh & Issac, 2018; Singh & Sharma, 2018a). Further, it would be also useful to abate GHGs emissions from agriculture sector. Thus, farmers also must be applied minimum quantity of fertilizer in crop farming to get better returns (Kumar et al., 2014; Kumar et al., 2015a; Kumar et al., 2015c). Green fertilizer may be effective to maintain soil quality and fertility in long-term (Kumar et al., 2015b; Kumar et al., 2015c; Singh & Jyoti, 2019b).

Credit accessibility for famers to buy new technology, new varieties of seed and to maintain better irrigation facilities would be useful to maintain crop production in sustainable ways (Kumar et al., 2015c; Kumar et al., 2016; Sharma & Singh, 2017; Singh et al., 2017b; Singh & Sharma, 2018a).Technological advancement in farming activities may be an effective inventiveness to increase crop production in India (Kumar et al., 2015a; Singh et al., 2017b; Singh et al., 2019b). There is also needed to increase the role of information technologies to convey the message of climate change related issues to the farmers on time (Sharma & Singh, 2017; Singh & Sharma, 2018a). It would be helpful to mitigate the adverse effect of climate change in crop farming (Kumar et al., 2015c; Sharma & Singh, 2017). Investment in agricultural research & development (R&D) would be effective to discover heat tolerance crop, drought growing crops and new varieties of crops which would have less sensitivity towards climate change (Kumar et al., 2015a; Kumar et al., 2015c; Singh et al., 2016; Sharma & Singh, 2017; Singh et al., 2017b). Further, it is expected that public spending on agricultural R&D would provide a better opportunities in farming sector (Sharma & Singh, 2017; Singh et al., 2017a; Singh & Sharma, 2018a), thus, it is suggested to increase agricultural R&D.

Government expenditure in agriculture and allied sector, and rural development to control floods may be useful to mitigate the impact of climate change and natural disasters on crop farming in India (Kumar & Sharma, 2013a). Training facilities must be initiated in the area of climate change and its implications on crops production in rural areas (Kumar et al., 2015a; Kumar et al., 2015c; Kumar et al., 2016; Singh & Sharma, 2018a; Singh & Jyoti, 2019b).

There is requirement to create an appropriate infrastructure in term of better road, transport and better connectivity or rural and urban area in India (Kumar et al., 2016; Singh et al., 2016; Sharma & Singh, 2017; Singh et al., 2017a; Singh & Sharma, 2018a). Market accessibility may be essential to make connection between rural and urban area (Singh & Jyoti, 2019b). This initiative would be helpful for farmers to buy new varieties of seed and new instruments of cultivation from the market in urban city. Rapid urbanization, high population growth, rapid industrialization, labour migration from rural to urban areas and human settlements have produced several negative implications on natural resource and arable land (Singh et al., 2017a; Singh & Issac, 2018; Singh & Sharma, 2018a). In addition, aforesaid activities may be caused to increase GHGs emission, thus these have a greater possibilities to increase more climate change (Singh & Narayanan, 2018). So, an active policy action must be taken to control aforementioned activities to maintain the common properties of natural resources and arable area in India (Sharma & Singh, 2017; Singh & Issac, 2018; Singh & Sharma, 2018a; Singh & Jyoti, 2019b).

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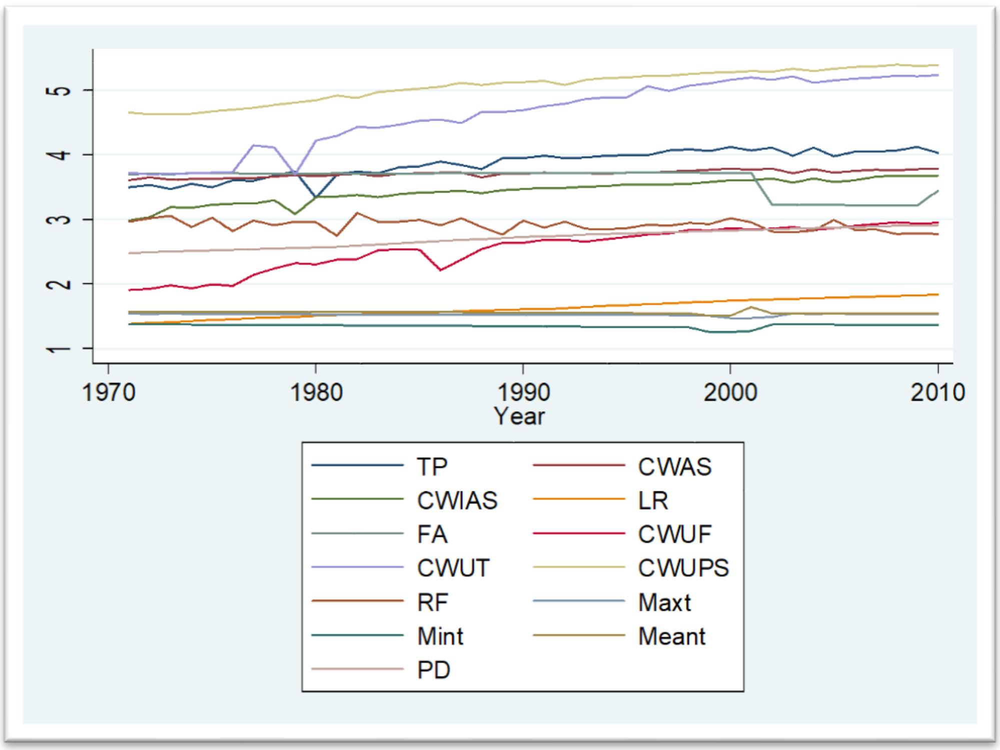
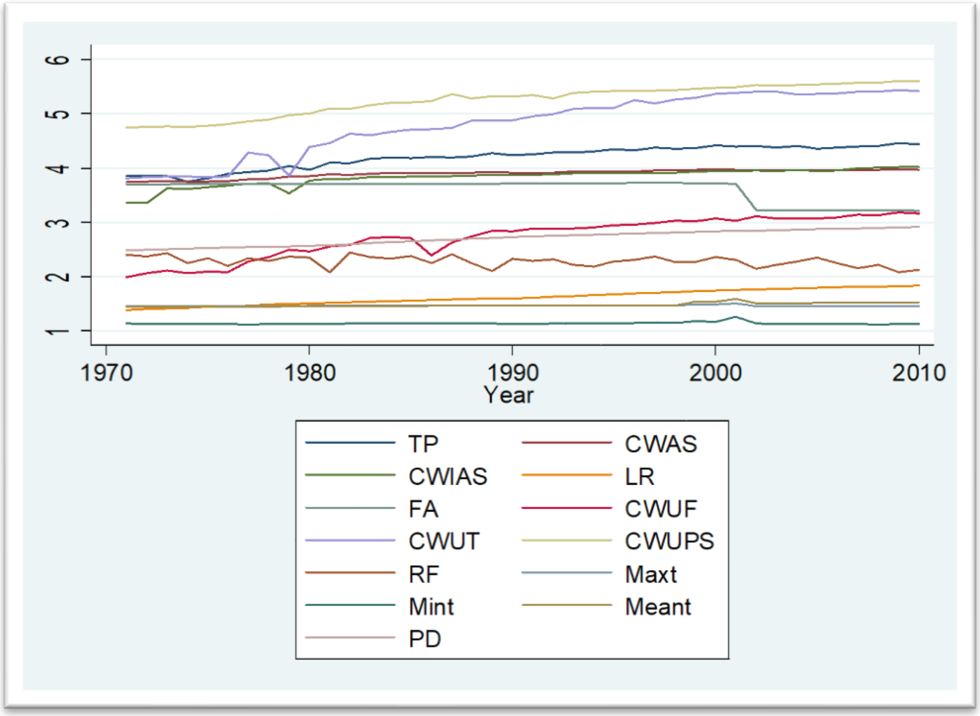
Annexure A: Trend in rice and wheat production, and inputs in Uttar Pradesh and Haryana

Figure A1 Rice production and inputs factors in Uttar Pradesh



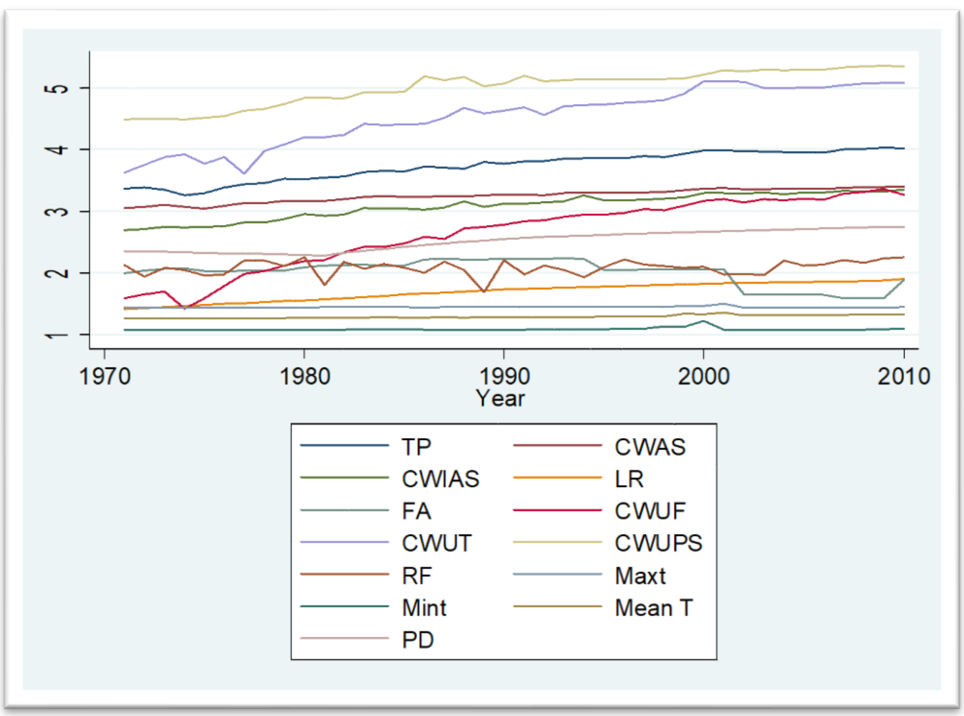
Source: Author's construction based on collected data from various sources.

Figure A2 Wheat production and inputs factors in Uttar Pradesh



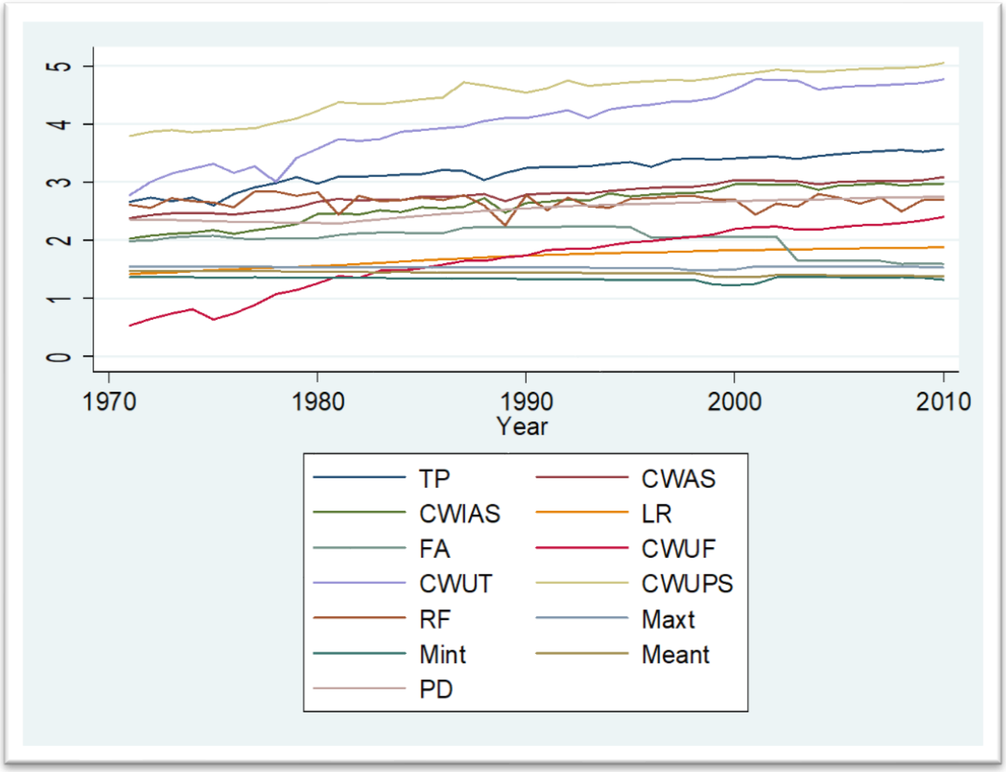
Source: Author's construction based on collected data from various sources.

Figure A3 Wheat production and inputs factors in Haryana



Source: Author's construction based on collected data from various sources.

Figure A4 Rice production and inputs factors in Haryana



Source: Author's construction based on collected data from various sources.

Annexure B: Properties of dependent and independent variables

Table B1 Regression result for properties of variables with various lagged in Haryana

Crops	Rice					Wheat				
	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	0.23***	0.93*	0.22	0.62*	0.32**	0.11	0.97*	0.12	0.90*	0.06
cwas	0.13	0.96*	0.13	0.76*	0.20	0.13	0.96*	0.12	0.99*	-0.02
cwias	0.18***	0.94*	0.20**	0.47*	0.47*	0.16	0.95*	0.18***	0.57*	0.37**
lr	0.06*	0.97*	0.01***	1.80*	-0.81*	0.06*	0.97*	0.01	1.69*	-0.69*
fa	0.01	0.99*	0.02	1.01*	-0.02	0.17	0.91*	0.19	0.99*	-0.09
cwuf	0.11*	0.96*	2.11*	0.90*	0.06	0.15**	0.96*	0.16**	0.83*	0.12
cwut	0.29*	0.94*	0.28**	0.74*	0.21	0.31***	0.93	0.30***	0.65*	.28***
cwtps	0.20***	0.96*	0.20	0.96*	0.01	0.28	0.94*	0.31***	0.66*	0.27***
aarf	2.92*	-0.10	2.71*	-0.10	0.09	2.24*	0.07	1.99*	-0.05	0.09***
aamaxt	0.38**	0.75*	0.49*	0.97*	-0.3**	0.89*	0.38	0.76*	0.31***	0.15
aamint	0.37**	0.72*	0.48*	0.94*	-0.3**	0.68*	0.37**	0.57*	0.31***	0.15
aameant	0.08	0.94*	0.08	0.84*	0.10	0.09	0.93*	0.05	0.66*	0.29***

Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively; CV is constant coefficient.

Table B2 Regression result for properties of variables with various lagged in Uttar Pradesh

	Rice					Wheat				
	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	0.60*	0.84*	0.41	0.38*	0.50*	0.20	0.95*	0.22	0.5*	0.36**
cwas	0.69**	0.81*	0.32	0.40*	0.51*	0.24**	0.93*	0.25**	0.82*	0.11
cwias	0.46**	0.87*	0.49*	0.39*	0.46*	0.72*	0.81*	1.02*	0.39*	0.3**
lr	0.02*	0.99*	0.01	1.79*	-0.79*	0.02*	0.99*	0.01	-0.79*	1.79
fa	0.31	0.91*	0.34	0.97*	-0.08	0.09	0.97*	0.09	0.97*	-0.01
cwuf	0.17***	0.94*	0.19***	0.86*	0.07	0.20**	0.93*	0.21*	0.75*	0.18
cwut	0.29	0.94*	0.32***	0.59*	0.35**	0.29	0.94*	0.33***	0.64*	0.29***
cwtps	0.14	.97*	0.22*	0.40*	0.55*	0.20***	0.96*	0.27**	0.48*	0.47*
aarf	2.63*	0.09	1.94*	0.06	0.26	1.97*	0.13	1.89*	0.09	0.07
aamaxt	0.34**	0.77*	0.45*	-0.31**	1.01*	0.679*	0.53*	0.59*	0.43**	0.15
aamint	0.34*	0.74*	0.45*	-0.31**	0.97*	0.71*	36**	0.59*	0.30**	0.16
aameant	1.48*	0.04	1.63*	0.03	-0.08	0.23***	0.84*	0.15	0.29***	0.59*

Note: *, ** and *** indicates the 1%, 5% and 10% significance level respectively; CV is constant coefficient.

Table B3 Augmented Dickey Fuller unit root tests

	Haryana				Uttar Pradesh			
Crops	Rice		Wheat		Rice		Wheat	
Variable	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*	*FD*	*SD*
tp	-8.48*	-12.27*	-6.39*	-10.01*	-11.01*	-13.78*	-8.85*	-13.93*
cwas	-7.29*	-11.19*	-5.80*	-7.83*	-11.64*	-15.85 *	-6.14*	-12.39*
cwias	-10.00*	-13.93*	-8.73*	-11.81*	-10.06*	-14.82*	-8.35*	-14.03*
lr	-0.91	-6.17*	-1.64	-2.40	-1.92	-6.05*	-1.92	-6.05*
fa	-5.96*	-9.92*	-5.04*	-8.92*	-5.42*	-9.56*	-6.10*	-10.19*
cwuf	-5.98*	-10.19*	-6.38*	-10.16*	-6.43*	-10.09*	-7.16*	-11.57*
cwut	-7.40*	-12.88*	-8.07*	-13.01*	-8.79*	-11.01*	-8.16*	-10.45*
cwtps	-5.94*	-8.85*	-7.95*	-12.04*	-9.42*	-14.96*	-9.58*	-16.60*
aarf	-5.11*	-8.81*	-11.94*	-14.63*	-12.18*	-15.67*	-10.42*	-13.06*
aamaxt	-8.35*	-10.30*	-9.30*	-14.07*	-5.15*	-8.54*	-8.68*	-13.00*
aamint	-5.24*	-8.75*	-9.33*	-13.86*	-9.64*	-8.55*	-9.52*	-13.73*
aameant	-6.87*	-12.13*	-8.37*	-14.94*	-9.64*	-11.69*	-8.67*	-14.81*

Note:*, ** and *** indicates the 1%, 5% and 10% significance level respectively; FD and SD are the first and second difference of each variable.

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