Measuring the Impact of Climate Variability on Rice and Finger Millet: Empirical Evidence from a Drought Prone Region of India

P.R. Jena; R. Kalli

National Institute of Technology Karnataka, Surathkal, School of Management, India

Corresponding author email: jpradyot@gmail.com

Abstract:

There is clear evidence of climate variability over a period of time in the developing countries and these countries are vulnerable to devastation caused by drought and floods. Analysis accompanied with robust results will create an opportunity to enhance the rural livelihoods that are prone to frequent climate shocks. We consider a southern state of India namely Karnataka, which belongs to a sub-tropical region facing a huge threat from climate change. In this article, we link agricultural production to climate variables to examine the impact of climatevariability on the crop yields. We follow a distinct approach using the nonlinear transformation of climatic variables to confirm climate damage on rice yields. The proposed econometric technique used in this paper is fixed effect panel regression model to identify the causal relationship between the yield and climate variables (rainfall and temperature). A panel of district wise cross section for a period of 1992-2013, with necessary inputs, is used in the model. The analysis in this paper is based on the smaller spatial scale (district wise) with updated climatic data emphasizing on Kharif season which helps to provide better insight on climate change effect and mitigation of climate-induced damages.

Acknowledegment:

JEL Codes: Q01, C52

#2351

Measuring the Impact of Climate Variability on Rice and Finger Millet: Empirical Evidence from a Drought Prone Region of India

Abstract

There is clear evidence of climate variability over a period of time in the developing countries and these countries are vulnerable to devastation caused by drought and floods. Analysis accompanied with robust results will create an opportunity to enhance the rural livelihoods that are prone to frequent climate shocks. We consider a southern state of India namely Karnataka, which belongs to a sub-tropical region facing a huge threat from climate change. In this article, we link agricultural production to climate variables to examine the impact of climatevariability on the crop yields. We follow a distinct approach using the nonlinear transformation of climatic variables to confirm climate damage on rice yields. The proposed econometric technique used in this paper is fixed effect panel regression model to identify the causal relationship between the yield and climate variables (rainfall and temperature). A panel of district wise cross section for a period of 1992-2013, with necessary inputs, is used in the model. The analysis in this paper is based on the smaller spatial scale (district wise) with updated climatic data emphasizing on Kharif season which helps to provide better insight on climate change effect and mitigation of climate-induced damages.

Key Words: Climate variability, spatial scale, rice, millet, fixed effects model

1. Introduction

Uncertain climate is the most concerning issue for both developed and developing nations. This concern has made researchers worldwide to understand the effect of climate change on the ecosystem. Fewofthe countries would benefit from climate change, whereas it is devastating for most of them. As 1^0 C increase in countries along temperate zone would boost their productivity and countries along the equator would face major disaster. Global economies have signed the pact to stabilize greenhouse gases which are speculated asacauseof global warming. However, still researchers strive to account how harmful the effect of climate change on biodiversity. The impact has both direct and indirect effect on almost every sector, whereas the largest component of effect is on agriculture. Agriculture being the primary sector for most of the developing economies acts as the major source of food security for its inhabitants. Apart from generating food it also acts as a major source of employment. In spite of significant growth in agriculture production high level of poverty and food insecurity persist in Sub-Saharan Africa and South Asia [1]. High food price, rapid urbanization and labour shortage are some of the bottlenecks that are impeding agricultural production significantly[2]. Increased consumption of fossil fuels induces an increase in atmospheric carbon dioxide emissions. This change is causing a severe shift in the climate patterns. This pattern largely attributes to delay in precipitation, increasing temperature levels, sea level rise and extreme events (Drought, Cyclones). This trend in the climate variation since mid of 20^{th} century is causing an ill effect on almost every sector and dominantly on agriculture. The risk involved in the climate change vulnerability may lead to reduce in crop production and cause a significant impact on rural livelihood. Climate change may benefit for few cold countries whereas, developing economies face a huge threat due to lack of adaptation strategies. Based on the estimates of climate impact, one can identify the potential impact of climate sensitiveness on crop production. Further, depending on the extent of adaptation and impact assessment, a better comprehensive policy can be framed to mitigate climate change impact.

The major motivation behind the present study is to analyze the impact of climate change on several crops at regional scale. This in turn, will help improving the rural livelihood that get affected by climate shocks. One of the major challenges faced by the researchers in climate change studies is the inability to link the environmental factors with agriculture to measure the climate sensitiveness. There are several predominant factors adding to the inability to measure agricultural production like unavailability of data, lack of measuring technological advancement, soil-health, climatic variability, land use, lack of data on farmer's self-consumption and water. As agriculture is dependent on the biological system for the plant growth, the significant shift in ecosystem makes it vulnerable. Process-based models, simulation and statistical analysis are the different approaches used to quantify climate variability on crop production. Each of these approaches has their own shortcomings -process-based and simulation models have the rich theoretical background where the farmer's adaptation strategies and some of the distinct physical characteristics are not captured. In case of simulation or statistical approaches choice of weather data plays an important role. In statistical approach, aggregation of both climate and agriculture variables sometimes create a bias in the model. The statistical approachprovides rational results as it captures both farmers crop choice and climate scenario, where process-based models experiment in the laboratory or few specific plots. The analysis in agronomic models are restricted to few crops and also do not represent the natural environment. Hence to overcome this bias, statistical models serve as the best alternative to capture the true impact of climate damages on agriculture.

The backbone of Indian economy can be referred as Indian agriculture and most of the economic indicator depends upon the monsoon rainfall. Nearly 60 to 70% of rural population in India still depends on agriculture and allied activities which make it one of the major sources of employment. Crop production in India can be broadly classified into two seasons namely Kharif and Rabi seasons. Kharif (June to September) season is dependent on the south-west monsoon which is the crucial period for crop production[3]. Indian agriculture extensively covers a large geographical area and diverse climatic zones; the production also varies according to the suitable demography. The national production in India showed a strong significant relationship with monsoon rainfall and spatial variations when accounted without physical characteristics [4]. Countries with larger geographical diversity have a scope for critical evaluation of climate change in smaller spatial scale, which helps to provide better results and to mitigate the climate impacts depending on the climate subdivision. The Kharif season contributes more than 60% of annual production in India, which makes it necessary to study the climate change impact on agriculture. Besides therise in temperature and variation in rainfall, farmers are more concerned about adverse events like frequent drought and floods. The projected surface temperature may rise up to 4% and the rainfall may decline in some regions below the baseline by the end of this century [5]. In this study, we chose Karnataka state, the second most drought-prone state after Rajasthan to face climate disaster in terms of total geographical area [6].

Karnataka lies between 12^0 to $18^0 45^1$ north latitude and 74^0 to $78^0 50^1$ east longitude. Administratively the state includes 30 districts but on the basis of climate, it is divided into three divisions i.e. North interior Karnataka (scanty rainfall region), coastal Karnataka (heavy rainfall region) and south interior Karnataka (medium rainfall region). Over the recent period the state had experienced high-intensity drought situation and also significant decreasing trends of monsoon especially in the northern and southern part of Karnataka [6], [7]. The onset of the Southwest monsoon in Karnataka begins from end of May to beginning of June, sowing differ accordingly.

2. Theoretical Background

Crop production at farm level can be modeled as the relationship between yield per acre and the factors affecting the yield. The factors could be soil characteristics, input provided such as pesticides and fertilizer, farm management practices and also the climate. The farm management includes irrigation, application of modern equipment and other practices followed by the farmers. Climate and soil are exogenous factors which influence farming, whereas the inputs like fertilizer and other practices are controlled by farmers. With the application of this dataset, one can statistically analyze the impact of climate variables. Accounting for this informationon at a large scale is a challenging task for researchers. In countries like India, self-consumption by farmers and also the cost involved in family labour or seeds may not be accounted. Further, the aggregation of the yield over a country or in the large-scale geography may not be appropriate. For example, in a country like India, due to better irrigation facilities and soil characteristics, the rice yield in the northern part is much higher than the southern region. Moreover, crop production depends upon the topography of natural environment, where soil fertility and climate characteristics play an important role in plant growth. As it relies on most of the independent factors that are not controlled by farmers, one has to carefully aggregate the agriculture variables. By identifying the smaller unit of geography and analyzing the climate impacts within that would precisely provide a better understanding of the impact of climate change on agriculture. Quantifying climate impacts based on the economic value can also be determined by identifying cost involved in the production. The price of both input and output variables is accounted with climate variables to assess the economic loss of crops due to climate change. This technical framework can be modeled with the revenue earned by the farmers to the expenditures incurred on inputs with the application of climate variables. The potential drawback in this modelling is the assumption that prices are constant across the region. Over the cross sections all the farms do not earn the same revenue as it depends on the input used by the farmers by changing their practices to earn better revenue. The most widely used approach in climate change impact assessment on agriculture is the Ricardian approach. Mendelsohn et al. (1991) proposed the application of the renowned theory of rent by Ricardo, where the effective utilization of farm can be measured in terms of net revenue and farmland value. As farmland value within the regions and also a farm near to urban location would have the bias of higher prices. Hence, the use of farmland as an indicator does not capture the true impact of climate change. The net revenue as an indicator determines that farmers try to maximize their revenue by efficiently utilizing the land. This approach captures the long-term effect of climate impacts on agriculture and also accounts for the farmer adaptation, acts as an advantage over the process-based models. The assumption of prices as a constant over a time ignores the control of prices in the model. Like another approach, the Ricardian approach faces few limitations. Farmers in countries with large geographical areas follow various strategies due to varied climatic zones and soil properties, which are neglected in the model. Developing countries with dependency on agriculture have policies to support the farmers by providing subsidies. Transition cost and the government incentives provided to the farmers are the major concerns of the Ricardian approach [8].

Although one can easily sample agriculture variables, the application of meteorological data in climate studies plays an important role. As weather variables are exogenous in nature makes them as efficient estimators to understand the long-term impact of climate shocks on agriculture. The majority of studies identifying causality among climate variability and agriculture have used global climate models and station wise data set. Worldwide more than twenty different climate models are available to understand the significant past and future changes in climate models. The major attention researchers have to focus is choice of the climate model they choose and region for evaluation need to be carefully designed. As global climate models provide the dataset in the form of a grid, where the earth is divided in to a smaller scale. This scale of the grid in climate models are in the size of 2 × 2 degrees resolution, this could be a smaller in size when one compared to overall earth. But, in the discipline of climate studies to examine the climate effect on human or human-inducedsystem, 2 × 2-degree resolution would be a coarser resolution. Hence, studies suggest using smaller resolution dataset to estimate the severity of climate variability on human and human-induced system. Use of station wise data would be beneficial, but one has to really focus on the distance from the station and also careful weight the matrix to report the data. In developing countries context, the pitfall of station-wise data are missing observation, it is advisable to fill the dataset based on the nearest station available and then use in analysis. Further, one should carefully construct the variable to reduce the noise in the data to arrive better estimates. With this phenomenal challenge,researchers have strived to determine climate impacts with the available resources. In this study, we link agriculture yield to climate properties and other inputs in small-scale restricted to a specific region and twocrops (rice and finger millet) to determine the possible effect of climate sensitiveness on agriculture.

3. Empirical Methodology

We use a log-linear relationship to estimate climate impact on agriculture. We use the following specification (1) to assess the climate change impact on rice and finger millet crop in Karnataka region. The specification is as follows -

$$\boldsymbol{log\, Y_{it} = c_i + \gamma_t + \beta_0 + \beta_1\, Rain_{it} + \beta_2\, GDD_{it} + \beta_3\, Irrigation_{it} + \beta_4\, Fertiliser_{it} + \beta_5\, Area_{it} + \varepsilon_{it}}$$

Where $\boldsymbol{log\, Y_{it}}$ refers to the yield per hectare expressed in natural logarithm form, $\boldsymbol{Area_{it}}$refers to the total croppped area under each crop, $\boldsymbol{Irrigation_{it}}$refers to the proportion of irrigated land under each crop, $\boldsymbol{Rain_{it}}$refers to the total rainfall, $\boldsymbol{Fertiliser_{it}}$ refers to the average fertiliser used per hectare of land. $\boldsymbol{GDD_{it}}$ measures the growing degree days, a variable to measure temperature effect. The construct of this variable is discussed in the later section. we use linear time trend γ_t to capture the inputs. c_i refers to the district fixed effect model.

Earlier studies, in this case have adopted cross-section regression framework. The advantage of using panel data over cross-section data is the former captures the unobserved time-invariant factors within cross-section.In this paper, we usefixed effect panel regression modelto find the causality between crop yield and weather variables. Panel models provide better results as it constitutes longitudinal data helps in capturing cross-section over a time period. The extent of analysis in past literature concerning in developing nations are theuse of fine weather data set. The relationship between climate and agriculture are non linear in nature. This non linearityis not captured in most of the studies and by using only mean or aggregate climate data will not provide better fit model. Fixed effects in panel estimate capture the unobserved heterogeneity and also omitted variable bias. The standard approach in these studies use annual yields and annual climate aggregates to estimate the climate effect. This overall aggregation may not be appropriate as the crops grown with specific season may not be influenced by any other previous or future season climate. For example, in India crops are grown in three seasons, Kharif, Rabi and Summer. Summer crops are cultivated in the regions where irrigation facilities are available. Thus accounting this yearly aggregation climate function and agriculture yield will not give the true impacts. And also allowing multiple crops in estimation may yield overall impact of climate variability on the particular region but it does not account for the specific crop damages. There is also uncertainty regarding the response of crops to climate effect. In case of rice it does not withhold that high-temperature level when compared to jowar or finger millet. And one cannot conclude the upper bound temperature when including all the crops in one basket. So it is advisable to choose a majority crop grown over a region to identify its impact with respect to climate variability. Therefore, future studies related in this framework need to focus on capturing season wise and crop wise damages.As the large-scale modeling will fail to capture the seasonal damages and also the most results are aggregated from annual production and climate characteristics, it makes difficult to conclude the real impact of climate change. Further, rainfall and temperature play an important role in plant growth, but the inputs provided by the farmers i.e., fertilizer, seeds, and soil characteristics play a major role in order to maximize their profits. In contrast to the past studies that have tried to account for the high yielding variety (HYV) seeds in the model, our estimation model in this paper emphasizes in post-green revolution analysis. Henceforth, we do not include HYV seeds but we try to capture the consumption of seeds, labour and capital investment in the form of a linear trend. Socio-economic variables such as population density and literacy rate are also few necessary characteristics which have been applied in previous models[9]–[11]. These variables influence the farmers to adapt and the modern techniques for the effective agriculture practices. However, these socioeconomic variables do not influence the yield significantly when compared to climate variables.

3.2 Data and methods

The data required for the estimation of agriculture were obtained from the Department of Agriculture and Directorate of Economics and statistics, Karnataka (DES, Karnataka). These datasets provide comprehensive information on agriculture at the district level. The information on thearea, production and yield are collected by the DES, Karnataka every year based on randomized farm trial at village level and later aggregated to thedistrict level. They also provide comprehensive data on districtwide irrigated and non-irrigated area under each crop and consumption of fertilizer. Based on this report we choose 10 districts cultivating finger millet crop and 14 districts cultivating rice, which contribute nearly 90% of total production of finger millet in the state.

Weather variables necessary for the regression were obtained from the Indian Meteorological Department (IMD). The temperature (maximum and minimum) and rainfall data for the Karnataka region included in the study were based on the daily gridded data of latitude/longitude resolution. Daily gridded weather dataset from the Indian meteorological department, for both temperature and rainfall, were considered. We use Rainfall data with 0.25° × 0.25° and temperature data with 1° × 1° fine grid scale. The construction of weather variable plays a vital role while assessing the climate change impacts of agriculture due to spatial and temporal variation.

3.2.1 Rainfall

Water is one of the major sourcesof plant growth. The relationship between plant growth and water are captured using rainfall and irrigation. Rainfall is the major source of plant growth and a constituent of irrigation. In case of theinadequate amount of rainfall, irrigation acts as anadditional source of water for the agriculture crops. At times the climate variables will fail to capture the water supplied by irrigation. Therefore, neglecting irrigation will cause the misspecification in the model [12]. Henceforth, accounting irrigated land will capture the additional water source provided through irrigation. To capture rainfall, we take a sum of the daily mean of grid observation within the district boundaries. For irrigation, we assume proportionate of finger millet and rice crop irrigated to total crop area on district basis.

3.2.2 Growing Degree days

The growth of the plants is strongly related to temperatures. Significant variation in the day and night temperature diminishes plant growth.The use of mean temperature is the common specification used by the studies. Whereas, mean temperature does not capture the impact of higher and lower critical threshold frequency [13]. To capture this day and night affect the most widely used concept in agronomy is growing degree days. Growing degree days are the sum of cumulated daily degrees within the threshold. Where a suitable threshold of temperature is fixed depending upon the crops. For example, if finger millet plant growth diminishes below 8^0 C and above 36^0 C, for each degree above 8^0 C is contributed as 1 degree day (9^0 =1, 10^0 = 2, 36^0 C = 28^0 C). Further, any temperature above 36^0 C will also be considered as 28^0 C. This process of transformation will help in capturing the nonlinearity effect of temperature on crop yield rather using quadratic terms. Recent studies pertaining to the United States have widely used growing degree days and suggest fine scaled weather data transformation to growing degree days provide better results.

$$GDD = \begin{cases} 0 & \text{if } h \leq 8 \\ h-8 & \text{if } 8 < h < 36 \\ 28 & \text{if } 36 \leq h \end{cases}$$

4. Results

Before we present the regression results of the study, we test the presence of unit root using Im Pearson Shin test based on augmented dickey fuller statistics[14].The test is performed with and without trend to find the existence of unit root. The variables being significant suggested that series are stationary and can be used for the regression. The regression estimates obtained using the fixed effect model are reported in table 1 for finger millet. We include three different specifications to show the net impact of climate change and also the possible outcome of area and irrigation on the dependent variable. We link finger millet and climate varaibles using three different specification. In the model-1 we include all possible varaibles which effect the yield. In model two and three we drop irrigation and area, to understand the net effect of climate change on agriculture production. Results from previous studies have shown the crtical effect of temperature on crop yields, similar is proven by process based model. Most of the studies related to the climate change impact on crop yields have assesed crops like rice, corn and soyabean which are the largest cultivated crop worlwide. When it comes to adaptation or water scarcity, farmers will face huge dawback of cultivating these crops. In this study we show how finger millet being a drought-adapted crop has been effected by past climate over a period of time. Several features of the results were expected, but despite being a drought resistant crop it was surprising to see the decrease in the productivity of finger millet yield upto 17% due to variation in temperature level.The cumulative sum of degree days help in capturing the true imapcts of climate change than averaging. This evalutation has an upper hand over other studies as most of the studies have averaged tempearture over the growing season. Rainfall is positive and not significant in all the three models. This shows that rainfall do not inflence the yield. As we have discussed finger millet is a drought-adapted crop and also do not require abundant water source for cultivation is also well captured in model by rainfall resulting with lack of statistical signficance. Further, irrigation is also found to be statistically insignificant. But irrigation can also be neagtive for cereals which do not require that high level of water.With respect to the input variable, fertilizer is found to be statistically significant at 10% level and has a positive sign. As expected that fertilizer has a positive impact on yield, the result denotes anincrease in substantial appliaction of fertilizer will increase in finger millet productivity.

We use the area as an indicator as it provides an insight of how really area under finger millet is influencing the yield. It is worth to note that the cultivation of finger millet is consistently decliningover time. This evidence was resulted with the area being positively significant and showing that increase in cultivated area will enhance the yield. The damage caused by the temperature has been proved by previous studies, wheras in the context of India the estimates of temperature is around 2 to 3%. This result of 17% is a alarming situation that warrants attention over the issue of mitigating greenhouse gases and focus on farm management practices. These results indicate that although finger millet is a drought resistant crop the monsoon’s temperature impact has a negative effect on finger millet yields.

Table 1: Panel regression results of finger millet

Variables	Model-1		Model-2		Model-3	
	Coefficient	**Sd. Error**	**Coefficient**	**Sd. Error**	**Coefficient**	**Sd. Error**
GDD	-0.1716076***	0.0314445	-0.1613557**	0.0314618	-0.1629105***	0.0297938
Rainfall	0.000061	0.0000631	0.0000845	0.0000884	0.0000829	0.0000886
Irrigation	0.004781	0.004603	-0.0012198	0.005208	-	-
Fertilizer	0.0003929*	0.0001824	0.0005211*	0.0002581	0.0005201*	0.0002565
Trend	0.008114**	0.0030079	-0.002885	0.0026254	-0.0027457	0.0026114
Area	5.83**	1.016	-	-	-	-
Constant	10.90803***	0.8824124	11.23519***	0.8097672	11.26838***	0.7747118
Observation	210		210		210	

Note: Dependent variable (Yield) is expressed in natural logarithm and all exogenous variable are expressed in their physical form. Values in parentheses include robust standard errors. *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 2: Panel regression results of Rice

Variables	Model-1		Model-2		Model-3	
	Coefficient	**Sd. Error**	**Coefficient**	**Sd. Error**	**Coefficient**	**Sd. Error**
GDD	-0.0464361*	0.0270158	-0.0492457*	0.0261783	-0.0551434*	0.0283261
Rainfall	0.0001007**	0.0000435	0.0000933**	0.0000405	0.0001018**	0.0000421
Irrigation	0.0073368*	0.0039031	0.0074504**	0.003202		
Fertilizer	0.0006871	0.0004385	0.000835*	0.0004726	0.0008301*	0.0004778
Trend	0.0047875	0.003933	0.0037336	0.0043594	0.0056792	0.0042492
Area	1.89	1.12				
Constant	8.231431*	0.5789917	8.30804***	0.5464306	8.867248***	0.6934251
Observation	294		294		294	

Note: Dependent variable (Yield) is expressed in natural logarithm and all exogenous variable are expressed in their physical form. Values in parentheses include robust standard errors. *Significant at 10%; **Significant at 5%; ***Significant at 1%.

We employ fixed effect panel regression to estimate the impact of rice yields in the state of Karnataka. All the three specifications in Table 2 consistently revealed that there is a significant impact of climate variation in the rice yields. The concept of growing degree days is well proven from both agronomic literature and statistical analysis. From each specification, it is clear that the temperature played a significant role to affect rice yields. In all the three models we use growing degree days to obtain the critical effect of temperature on yield and that resulted in a decline in the rice yield. Therefore, as anticipated the increase in the temperature has decreased the rice yields by 5.5%. The input variables fertiliser has a positive impact on rice yield. This indicates that substantial increase in the fertilizer will provide better yields. With respect to another input variable, irrigation supply has been the main ingredient to cope up with the climate change. In this study, as expected, irrigation had a positive impact and also significant in nature. In instances of deficit rainfall, irrigation acts as a supplement water source to the crop and thus increases yield. This result indicates that substantial rise in use of irrigation would increase the yield.

We chose these two crops to understand the critical impact of climate on two different crops, which follow different penology. Rice is temperature sensitive crop where as finger millet is not that sensitive. Water source required by the rice is more where finger millet can be cultivated with very less water source. Where, water source for rice is important andnot that important for finger millet. But the effect of temperature is more on finger millet when compared to rice. This could be due to severalfactors, one is the cultivation of finger millet has been gradually decreased over a period of time due to less demand for it. Most of the region where rice is cultivated may have better soil fertility which yields better productivity. Due to changing food pattern a significant research has been done in developing the variety of high yielding seeds and farm practices in case of rice. Finger millet being a traditional crop the development in this instance is very low. There are no significant high yielding seeds in case of finger millet. The government incentives play a major role in farmer's choice of crop, the revenue and institutional support is high for rice cultivation. But one has to understand the scarcity of water source and due to variation in rainfall;the irrigation may be incapable of providing water source. Henceforth, necessary measures need to be considered to cultivate the cereals in long term adaptation to reduce the dependency on irrigation. So in terms of drought cereals crop may be best alternative in choice of rice.

5. Concluding remarks and policy implications

The immense interest in climate studies all over the world strives to account for the environmental damages to the society. This literature would benefit and make importance on the regional aspect over the modeling of countrywide analysis. This paper clearly confirms the seasonal and smaller spatial damages, provide more information to effective policy on a regional basis to mitigate the climate impact. The result summarizes the information for the decline in the yield for the particular period considered in the study. We choose finger millet crop as most of the study on other significant crops have been analyzed. From the overall results, we can conclude that the increasing temperature has a significant impact on agriculture production, especially on finger millet causing a loss of nearly 16% to 23%. The study does not use climate models; instead we use the data available from the Indian meteorological department. For further calculation, the gridded data are classified based upon the district boundaries. Most of the districts have one to two grid points and the grid line passing on the district boundaries have been accounted in both the districts. Most of the studies in Indian context have used the $1^0 \times 1^0$ grid set for both temperature and rainfall, whereas we use the finer scale of $2.5^0 \times 2.5^0$ grid data for rainfall. And also we do not account for any socioeconomic variable in the models as most of the socioeconomic variables have substantial increasing growth trend i.e. literacy, population density etc. The caveats of the study are – it does not account for any GHG emission and extreme climate events. Further, we do not account for spatial autocorrelation of the climate variables and also the loss of yield indicated is valid for the study period, not for any future scenario. With respect to Indian studies, it provides a better understanding as the data used is of finer spatial scale and for very recent time period to check the sensitivity of climate impacts and agriculture yield.

References:

[1] Food and Agriculture Organization (FAO), "World agriculture : towards 2015 / 2030 World agriculture : towards 2015 / 2030," *Organization*, vol. 20, no. 4, p. 97, 2002.

[2] EPA, "Climate Change Indicators in the United States, 2014," *Change*, 2014.

[3] R. K. Mall, R. Singh, A. Gupta, G. Srinivasan, and L. S. Rathore, "Impact of climate change on Indian agriculture: A review," *Climatic Change*, vol. 78, no. 2–4. pp. 445–478, 2006.

[4] K. Krishna Kumar, K. Rupa Kumar, R. G. Ashrit, N. R. Deshpande, and J. W. Hansen, "Climate impacts on Indian agriculture," *Int. J. Climatol.*, vol. 24, no. 11, pp. 1375–1393, 2004.

[5] K. Krishna Kumar, S. K. Patwardhan, A. Kulkarni, K. Kamala, K. Koteswara Rao, and R.

Jones, “Simulated projections for summer monsoon climate over India by a high-resolution regional climate model (PRECIS),” *Curr. Sci.*, vol. 101, no. 3, pp. 312–326, 2011.

[6] V. Jayasree and B. Venkatesh, “Analysis of Rainfall in Assessing the Drought in Semi-arid Region of Karnataka State, India,” *Water Resour. Manag.*, vol. 29, no. 15, pp. 5613–5630, Dec. 2015.

[7] P. Guhathakurta, M. Rajeevan, D. R. Sikka, and A. Tyagi, “Observed changes in southwest monsoon rainfall over India during 1901-2011,” *Int. J. Climatol.*, vol. 35, pp. 1881–1898, 2015.

[8] P. Kurukulasuriya and R. Mendelsohn, “A RICARDIAN ANALYSIS OF THE IMPACT OF CLIMATE CHANGE ON AFRICAN\nCROPLAND,” *African J. Agric. Resour. Econ.*, vol. 2, no. 8, p. 23, 2008.

[9] A. Sanghi and R. Mendelsohn, “The impacts of global warming on farmers in Brazil and India,” *Glob. Environ. Chang.*, vol. 18, no. 4, pp. 655–665, 2008.

[10] D. Mishra, N. C. Sahu, and D. Sahoo, “Impact of climate change on agricultural production of Odisha (India): a Ricardian analysis,” *Reg. Environ. Chang.*, pp. 575–584, 2015.

[11] K. S. K. Kumar and J. Parikh, “Indian agriculture and climate sensitivity,” *Glob. Environ. Chang.*, vol. 11, no. 2, pp. 147–154, 2001.

[12] R. O. Y. Darwin, “A FARMER ’ S VIEW OF THE RICARDIAN APPROACH TO MEASURING AGRICULTURAL EFFECTS OF CLIMATIC CHANGE A major hurdle to estimating the effects of climatic change on agriculture has been how to incorporate farm-level adaptation into the analysis . In early stud,” pp. 371–411, 1999.

[13] A. Pattanayak and K. S. K. Kumar, “Weather Sensitivity of Rice Yield: Evidence From India,” *Clim. Chang. Econ.*, vol. 5, no. 4, p. 1450011, 2014.

[14] K. S. Im, M. H. Pesaran, and Y. Shin, “Testing for unit roots in heterogeneous panels,” *J. Econom.*, vol. 115, no. 1, pp. 53–74, 2003.