Economic Impact Assessment of Climatic Change Sensitivity in Rice-Wheat Cropping System of Pakistan

Tayyaba Hina[1*], Sultan Ali Adil[1], Muhammad Ashfaq[1] and Ashfaq Ahmad [2]

[1]Institute of Agricultural and Resource Economics, University of Agriculture Faisalabad, Faisalabad–38000, Punjab, Pakistan; tayyaba_hina@outlook.com, sultan.adil@uaf.edu.pk, ashfaq9@hotmail.com
[2]Department of Agronomy, University of Agriculture Faisalabad, Faisalabad–38000, Punjab, Pakistan; ashfaqchattha@uaf.edu.pk

Abstract

Objectives: To measure the impacts of climate change sensitivity and how it is affecting economic conditions of farmers in current rice wheat cropping system. **Methods/Statistical analysis**: Cross-sectional data of 210 farmers from the seven different strata were collected from Punjab, Pakistan. Climate data of baseline (1980-2010) and future (2039-2040) under representative concentration pathways 4.5 and 8.5 for five global circulation models were collected from secondary sources. The climate scenarios were used in two crop simulation models, i.e., DSSAT and APSIM. Tradeoff Analysis Model for Multidimensional Impact Assessment (TOA-MD) was used for the economic analysis. **Findings:** The crop modeling results of the study using different GCMs and RCPs show that there was negative impact of climate change on the yields of both major crops i.e., rice and wheat. The comparison of both CSMs given the insight that the percent losses were higher in APSIM as compared to DSSAT. The economic analysis endorsed the negative impacts of climate change on farming community. The major economic indicators (net returns, per capita income and poverty) of the study area expressed the declining trend in both RCPs (4.5 and 8.5) and all five GSMs. The observed household vulnerability to climate change percentage was more intense in RCP 8.5 as compared to RCP 4.5, however, among GCMs the figures shown higher vulnerability in hot dry climate conditions and lower in cool wet. The poverty of the study area increased with climate change and it was more prominent while using RCP 8.5 as compared with RCP 4.5.The highest increase in poverty was observed using APSIM crop model for hot-dry conditions. **Application/Improvements:** The study concluded that to ensure food security, poverty alleviation and to minimize climatic risks there is the need to update agronomic practices and develop adaptation strategies.

Keywords: Climatic Change Sensitivity, Economic Assessment of Climate Change, Pakistan, TOA-MD, Rice Wheat Cropping System

1. Introduction

The most threatening concern of this century for the coming generations is climate change (CC), and the expected consequences of it would be considerable[1–3].The climate variability and change have substantial impacts on all biological and human systems[4]. The problem of climate change gets worse because its impacts could be felt at the places far beyond its origin[5]. Climate change intensity and effects vary in different regions, countries, sectors and communities according to the prevailing environmental conditions[7]. Cool temperate regions will observe the positive impacts on climatic factors such as temperature and precipitation while the tropical regions with already hot climatic conditions will face further rise in average temperature due to CC over the period of time[5,6,7]. The potential climate change risks disturb the whole economic system. Among all major sectors of an economy agriculture is more prone and susceptible to climatic changes. As a result, the developing countries get worse off due to

climate change because of the high dependence of their economies on agriculture sector[8,9].

Agricultural farming systems are diverse because of their inherent link to climate and natural resources (water and soil), which make it most susceptible to the changes in climate[10–12]. The global food system is at risk due to one of the most concerning issues of agricultural vulnerability to climate change[13,14]. Worldwide, millions of households depending upon agriculture for the livelihood are fluctuating above and below poverty line because of climate variability. These climatic variabilities and changes are a constant threat to the food security and stable food supply by impacting availability, accessibility and utilization of food[15–17].

Climate change excessively affects farmers with small landholding and limited financial stability by further worsening the risks that they face[18].Adverse impacts of CC on agricultural production and the linked livelihoods have been observed especially in recent two-three decades[19–23]. The identified impacts as stunted crop growth and increase in pest attacks lower the crop yields, hence, reducing the crop revenue worsening the situation of food insecurity[24–27].

In South Asia, the rise in temperature more than the global average is a major concern for the existing ecological, economic systems and especially for the sensitive sectors; water, biodiversity and agriculture[8,28]. The increasing climatic concern for the region is due to less adaptive behavior of the countries. Therefore, the food security situation is also very poor in this region. South Asia will be home to highest figure of food insecure masses in the coming years[29,30]. Pakistan is one of the most affected countries in South Asia to climate change[31,32]. Global Climate Risk Index and the World Bank report have placed Pakistan at 7th position in the index of the countries facing climatic extremes in the time period 1998-2012[33].

By the year 2100, the increase in temperature will decline the yields of cereal crops 25 to 30 percent and the water availability will decline to 37 percent in South Asian region[34,35]. The other threat to the agricultural production systems of the region is uneven rainfall patterns, risks of floods and droughts which will lower the crop production. Different studies in Pakistan have revealed that cereals and other crop productions are expected to decline due to rise in temperature[36,37]. Wheat production in arid, semi-arid and sub-humid regions of Pakistan would decline by 6 to 9 percent while it is expected to increase in the humid areas[38]. In the northern areas of Pakistan, for swat district,

the increase in temperature by 1.5 to 3°C would decrease the wheat production by 7 to 21 percent, and for district Chitral, the decrease would be 14 to 23 percent[39,40]. The declining effect of the rise in temperature on rice yield for semi-arid regions of Pakistan could decline by 15 percent for early midcentury 2012 to 2039 and 36 percent for late century 2070-2099[41,42]. Decreasing rainfall effects on crop production are also negative. The net irrigation water requirements in Pakistan will increase by 30 percent by 6 percent decrease in rainfall. The negative effects of decreasing rainfall would affect 1.3 million rural farm households in Pakistan for cereal crops, fruits, and vegetables[43].

Climate models suggest that temperature will increase up to 0.5-2°C by 2030 and between 1-7°C by 2070 in the Asian Pacific region[44]. Wheat crop is sensitive to rise in temperature at the early stages of crop growth. The higher temperature than 30°C can accelerate senescence by damaging leaf photosynthetic system which results in a reduction of grain filling[45–47]. Rice crop is little less sensitive to a high temperature before microsporogenesis, and at tilling stage of crop growth, the temperature range between 27-32°C is optimal[48]. Temperature above this may lead to pollen unavailability, reduced pollen disposition, embryo abortion, and spikelet sterility ultimately lowering grain yield[48–50]. High night time temperature is also a concern for Rice. However, challenges other than rise in temperature for both rice and wheat due to climate are increase in floods, soil salinity, pest attack, weed competition, though these issues vary with geographical location and crop management practices[51–53].

Indo-Gangetic Plains are the hub of rice-wheat cropping system (RWCS) and almost cover about 13 million hectares from Pakistan to Bangladesh. Rice and wheat are the key global food crops which are vital to ensure food security. Rice and wheat are the two main staple cereal crops of Pakistan and are grown almost in all agro-ecological zones of the country in different climatic and hydrological conditions[54]. The concern about the productivity of Rice and Wheat crops is very crucial because these two crops contribute about 20 and 75 percent in average daily calorie intake of Pakistanis'[55]. The study area was chosen for the significance of both major crops of agriculture sector wheat and rice in the food security situation of the country.

There is a plethora of research on climate change and its impacts on agriculture. And recent literature in last two decades has evolved from research on mitigation

strategies[56–59] to climate change impact assessment[60–64]. The studies on climatic change sensitivity on the integrated agricultural production system for Pakistan are rare and few[3,63,65–67]. The focus of the previous studies was either on crop modelling or econometric modeling. This study is unique and innovative in the sense that it uses an integrated approach using climate, crop, and economic modeling.

The study also included representative agricultural pathways (RAPs) for the non-modelled activities (minor crops and livestock) as RAPs are the climate, economic and social environment, or socio-economic settings in which production systems operate. These are basically qualitative storylines, which are developed with the help of a team of a transdisciplinary scientist by following the nested approach as was used by IPCC for SSPs[68]. The impact of climate change in this study is calculated on current integrated rice-wheat cropping system (including major, minor crops and livestock) for both mild and harsh RCPs (4.5 and 8.5), using APSIM and DSSAT crop simulation models. Undertaking the integrated climate-crop-economic modelling assessment is important to enable a wide-ranging investigation of climate change impacts on agriculture sector, to characterize the actual situation of food security and poverty of the study region and also to highlight how the climatic changes affect the future agricultural productions[69,70].

Specifically, the basic objectives of the study are; what is the impact of climatic change sensitivity on the integrated RWCS across different RCPs and GCMs? And what is the impact of climatic changes on the socioeconomic conditions (Net Returns (NR), Per Capita Income (PCI), and poverty) of the farmers? The remainder of the paper is followed by the materials and methods in section 1. Results of the analysis are provided in section 2. Section 3 provides the discussions of the results and conclusions are provided in section 4.

2. Materials and Methods

2.1 Description of the Study Area

In Pakistan, Punjab is the most populated province and contributes the largest share in national agriculture production sector. There are five major agro-ecological zones of Punjab province namely, Cotton-Wheat zone, Rice-Wheat zone, Mixed-Cropping zone, Low-Intensity zone, Rain-Fed zone. Rice-Wheat zone is specifically chosen for the study because of its importance in ensuring food security of the country and the importance of export revenue earned through both crops. The rice-wheat cropping system is the major one which account for total 2.2mha of area, supporting the livelihood of 1.1 million farm families[71]. In Pakistan, the rice-wheat cropping areas are mainly located in central Punjab (main districts include Sheikhupura, Nankana Sahib, Hafizabad, Gujranwala, Sialkot, Gujrat and Mandi Bahauddin) followed by Sindh. The study covers RWCS of Punjab province comprising on the seven famous strata mentioned earlier, forming a heterogeneous sample size.

2.2 Collection of Farm Surveyed Data

Both primary and secondary data were collected and used in this study. Primary data were collected from farmers after taking their consent to provide information using a well-structured questionnaire. For secondary data, different government sources and surveys, i.e., Soil Surveys, Economic Surveys, Pakistan Meteorological Department and Pakistan Bureau of Statistics were used.
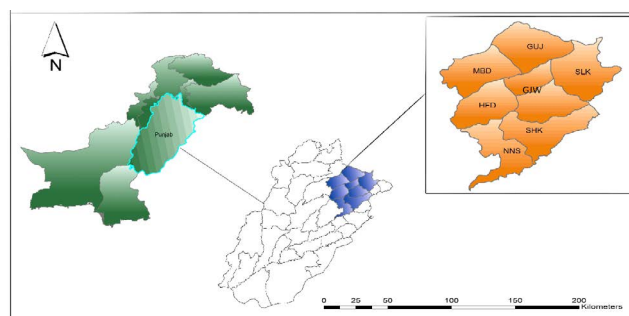

Figure 1.Map of the study area.

The farming population is heterogeneous, so, multistage stratified random sampling technique was employed to collect the primary data following Naseer, Ashfaq[72]. In the first stage, the RWCS was chosen for this study due to its importance of both major crops rice and wheat, used as staple food. In the second stage, seven rice-producing districts were chosen from the RWCS, i.e., Sheikhupura, Nankana Sahib, Hafizabad, Gujranwala, Sialkot, Gujrat and Mandi-Bahauddin which form the seven strata of the study (Figure 1). In the third stage, three villages from each stratum were chosen randomly. In the last stage, ten respondents from each village were chosen randomly which makes the total sample size of 210 respondents.

2.3 Climate Change Projections

A baseline daily weather dataset (1980-2009) was collected from Pakistan Metrological Department (PMD) and calibrated for future scenarios by using a well-developed climatic methodology following Coupled Model Intercomparison Project (CMIP5)[73]. Statistical downscaling and climate change scenarios were produced by Pakistan Metrological Department (PMD), a method described by Ruane, Goldberg[74]. Future climatic projections of the midcentury 2040-2069 were made for both RCP 4.5 (mild climatic conditions) and RCP 8.5 (harsh climatic conditions). The carbon dioxide concentration of 499ppm were used for RCP 4.5 and 571ppm for RCP 8.5[75].

Future climate scenarios were developed by using GCMs, representing physical processes in the atmosphere, ocean, cryosphere and land surface. GCMs are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. For this study five best GCMs were used. These models were same for both RCPs (4.5 and 8.5) and are namely; BCC-CSM (cool wet), CCSM4 (cool dry), BNU-ESM (middle), CMCC-CM (hot dry) and MIROC-ESM (hot wet).

2.4 Crop Modeling

In this study, two famous Crop Simulation Models (CSMs); the Agricultural Production Systems Simulator (APSIM)[76] version 7.5 and the Decision Support System for Agrotechnology Transfer (DSSAT)[77,78] version 4.6 were used and economic results were evaluated using the simulated yields of both CSMs (for both RCPs and all five GCMs). Both CSMs used four data files for simulation run; (i) weather file with daily solar radiation, maximum and minimum air temperature and precipitation; (ii) soil file of the study area having physical and chemical properties of soil; (iii) crop management file including all input use and application dates; (iv) genetic coefficient file. The detailed information can be found in earlier studies[41,79]. For the analysis, the average crop yields of the farm activities over the time period were also used. For the non-modeled activities (minor crops and milk production) regional representative agricultural pathways (RAPs) were used for the future projections.

2.5 Economic Modeling

Economic assessment of climatic change sensitivity was done with the tradeoff analysis model for multidimensional impact assessment (TOA-MD) version 6.1 in this study[55-57]. The economic analysis was done on the per farm basis. All farm-based activities; major crops (rice and wheat), minor crops (fodder) and livestock was included for the true representation of the existing socioeconomic conditions of the farming community of the surveyed farms. The analysis was done for both CSMs (APSIM and DSSAT) and both RCPs (RCP 4.5 and RCP 8.5) for each GCM simulation separately.

The model considers farmers as economically rational beings to make decisions on the predictable value and that's why uses binary codes[58]. The farmers may choose to stick to system 1, or they can choose to move to the alternative system 2. Generally, system 1 is described as the current production system (base technology) with current climate and system 2 as current production system (base technology) with changing climate. The productivity of the system depends largely on two factors technology and climate. Farmers decision making of whether to operate in system 1 or system 2 depends upon the opportunity cost (gains/losses) from switching.

$$\omega = v_1 - v_2 \tag{1}$$

In Equation 3, v_1 and v_2 are net returns from System 1 and 2, respectively.

Poverty line was set US$ 1.25/person/day (US$ 1= PKR 103) in the analysis according to international standards which was to check the vulnerability level of households with respect to climatic changes[59].

For Climate Change Impact Assessment (CC-IA) analysis all the prices of inputs/outputs were site specific according to the production system(s) and net returns were accordingly.

TOA-MD model parameters for system 1 and 2, for each farm in the survey data in future period, were calculated according to[60].

$$\mu_j(T_{HH}, \gamma_H) = \beta_{y0} * y_{j0} \tag{2}$$

$$R_{j21} = \rho_H * a_{jH} * \mu_j(T_{HH}, \gamma_H) \tag{3}$$

$$C_{j21} = \beta_{c0} * C_{jH} \tag{4}$$

$$V_{j21} = R_{j21} - C_{j21} \tag{5}$$

Where,

$\Gamma = 1$, $\phi_H = 1$, $\phi_F = 1$, $\psi = 1$ for simple CC-IA on current agricultural production system

$$\mu_j(T_{HF}, \gamma_H) = r_{j2} * \mu_j(T_{HH}, \gamma_H) \quad (6)$$

$$R_{j22} = \rho_H * a_{jH} * \mu_j(T_{HF}, \gamma_H) \quad (7)$$

$$G_{j22} = {C_{j22}}/{R_{j22}} \quad (8)$$

$$C_{j22} = G_{j22} * R_{j22} \quad (9)$$

$$V_{j22} = R_{j22} - C_{j22} \quad (10)$$

2.5.1 Variables' Definition

t	= individual year or time period
H	= current time period
F	= future time period
j	= number of farms in data sample used for integrated assessment
t	= the year of data collection
$\square_{ti}$	= technology and management practices used for period, adapted to climate (t, i=H or F)
γ_{jt}	= crop yield in year t (kg/ha)
$\mu_j(\square_{ti}, \gamma_t)$	= mean yield(s) of farm j using technology $\square_{ti}$ with climate γ_t
Y_0	= observed mean yield of data
Y_H	= historical mean yields used in current period (secondary data)
β_{y0}	= Y_H/Y_0 = normalization factor of yields

$s_j(\square_{ti}, \gamma_t)$ = simulated crop yield for farm j using technology $\square_{ti}$ with climate γ_t
r_j = relative yield for farm j used for analysis
a_{jt} = total crop area on the farm in period t (ha)
R_{jt} = revenue = $p_t * y_{jt} * a_{jt}$ (rupees per farm per time)
R_{js} = net returns in system s (rupees per farm)
C_{jt} = cost of production for period t (rupees per farm per time)
C_{js} = mean cost of production in system s (rupees per farm)
C_t = mean cost of production in the current period (t=H)
β_{c0} = C_H/C_0 = normalization factor for production cost (if β_c can't be estimated, then use $\beta_{c0}=\beta_{y0}$)
G_{jt} = C_{jt}/R_{jt} =production cost relative to revenue (unit free)
V_{jt} = $R_{jt} - C_{jt}$ = crop net returns for the farm (rupees per time)
V_{jqs} = time-averaged net returns for part q and system s (rupees)
RHO12 = correlation between $\mu_j(\square_{HH}, \gamma_F)$ and $\mu_j(\square_{HH}, \gamma_H)$

The TOA-MD incorporated the statistical correlation between environmental, social and economic impacts of technology adoption into the simulation of impacts on NR, PCI and poverty. The model simulates the impacts of the full range of adoption rates from 0 to 100 percent[61].

3. Results

3.1 Data Statistics

The surveyed area in all districts range from 129.66 to 192.31 hectares, smallest in Mandi Bahauddin and largest in Nankana Sahib (Table 1). Likewise, the average land for major crops rice and wheat was dedicated by farmers

Table 1. Mean of farm area for crop activities in the surveyed are according to strata

Stratum/Crops	Total Farm Area (ha)	Wheat cultivated area (ha)	Rice cultivated area (ha)	Kharif (Summer) Fodder Area (ha)	Rabi (Winter) Fodder Area (ha)
Sheikhupura	155.26	4.25	4.28	0.80	0.76
Nankana Sahib	192.31	5.18	5.33	0.87	1.02
Hafizabad	187.04	5.04	5.08	0.99	0.99
Gujranwala	187.45	5.05	5.04	0.99	0.99
Sialkot	166.70	4.59	4.47	0.91	0.78
Gujrat	131.78	3.52	3.26	0.99	0.73
Mandi Bahauddin	129.66	3.46	3.13	1.05	0.72

of the study area accordingly, largest in Nankana Sahib and the smallestin Mandi Bahauddin. Wheat area ranged from 3.46 to 5.18 hectares in all study districts, while rice area ranged from 3.13 to 5.33 hectares. For both Rabi and Kharif seasons, the area reserved for fodder crops ranged from 0.72 to 1.02 and 0.80 to 1.05 hectares respectively.

3.2 Economic Assessment of Climatic Change Sensitivity

In this section, the isolated climate change impacts were assessed on the prevailing agricultural system. Both major cereal crops, i.e., rice and wheat were modeled and then economic analysis was performed using TOA-MD

Table 2. Climatic change sensitivity impact on economic indicators in district Sheikhupura

RCP	CSM	GCM	Vulnerable Farm Household (%)	NR with CC (PKR)	PCI with CC (PKR)	Poverty with CC (%)
4.5	APSIM	Cool Wet	69.1	589,874	113,332	11.3
		Cool Dry	71.6	576,722	110,866	11.7
		Middle	74.6	560,377	107,802	12.1
		Hot Dry	78.1	539,421	103,872	13.1
		Hot Wet	75.6	556,146	107,008	11.4
	DSSAT	Cool Wet	69.0	591,709	113,676	10.6
		Cool Dry	67.8	597,383	114,740	10.6
		Middle	73.0	570,204	109,644	11.2
		Hot Dry	78.4	539,574	103,901	11.9
		Hot Wet	77.4	545,463	105,005	11.6
8.5	APSIM	Cool Wet	75.1	556,948	107,159	12.5
		Cool Dry	74.3	560,861	107,892	12.7
		Middle	77.4	542,829	104,511	13.3
		Hot Dry	81.5	517,434	99,750	14.2
		Hot Wet	78.8	536,749	103,371	12.2
	DSSAT	Cool Wet	71.6	577,999	111,105	11.0
		Cool Dry	69.3	590,274	113,407	10.7
		Middle	76.0	553,236	106,463	11.8
		Hot Dry	80.1	528,505	101,826	12.5
		Hot Wet	79.7	531,116	102,315	12.2

6.0 version. However, the climate vulnerability on minor crops (fodder) and milk production were adjusted according to the GCMs using RAPs. For the clear picture of the analysis, this section is further subdivided into seven subsections explaining the results of Climate Change Impact Assessment (CC-IA) for all strata individually.

3.2.1 CC-IA for District Sheikhupura

Results of Sheikhupura shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 69.1 to 78.1 percent and 67.8 to 78.4 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 685,357 per farm and PKR 131,235, respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 539,421 to PKR 589,874 per farm and PKR 103,872 to PKR 110,866 respectively. The NR and PCI with CC for DSSAT varied between

PKR 539,547 to PKR 597,383 per farm and PKR 103,901 to PKR 114,740 respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between 74.3 to 81.5 percent for APSIM and 69.3 to 80.1 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 517,434 to PKR 560,861 per farm and PKR 99,750 to PKR 107,159for APSIM. The NR and PCI with CC for DSSAT varied between PKR 528,505 to PKR 590,274 per farm and PKR 101,826 to PKR 113,407 respectively.

The observed poverty without CC was 8.5 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 11.3 to 13.1 percent in APSIM and 10.6 to 11.9 percent in DSSAT. However, for RCP 8.5 poverty varied between 12.2 to 14.2 percent in APSIM and 11.0 to 12.5 percent in DSSAT (Table 2).

Table 3. Climatic change sensitivity impact on economic indicators in district Nankana Sahib

RCP	CM	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	84.4	677,633	89,153	6.9
		Cool Dry	86.0	666,498	87,712	7.0
		Middle	87.1	658,868	86,724	7.1
		Hot Dry	91.3	621,483	81,886	9.0
		Hot Wet	87.8	652,053	85,842	8.1
	DSSAT	Cool Wet	80.0	705,820	92,801	5.7
		Cool Dry	84.8	675,827	88,919	6.4
		Middle	83.2	686,386	90,286	6.2
		Hot Dry	87.1	659,597	86,819	6.9
		Hot Wet	87.1	657,182	86,506	7.9
8.5	APSIM	Cool Wet	88.5	645,641	85,012	8.7
		Cool Dry	87.3	652,806	85,940	9.0
		Middle	91.9	612,762	80,757	10.4
		Hot Dry	91.6	615,083	81,057	10.6
		Hot Wet	90.4	630,376	83,037	8.1
	DSSAT	Cool Wet	83.1	687,308	90,405	6.2
		Cool Dry	86.6	662,826	87,237	7.0
		Middle	85.8	668,749	88,003	6.7
		Hot Dry	90.0	633,909	83,494	8.3
		Hot Wet	88.3	646,217	85,087	8.8

3.2.2 CC-IA for District Nankana Sahib

Results of Nankana Sahib shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 84.4 to 91.3 percent and 80.0 to 87.1 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 849,040 per farm and PKR 111,338 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 621,483 to PKR 677,633 per farm and PKR 81,886 to PKR 89,153 respectively. The NR and PCI with CC for DSSAT varied between PKR 657,182 to PKR 705,820 per farm and PKR 86,506 to PKR 92,801 respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between 88.5 to 91.9 percent for APSIM and 83.1 to 90.0 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 612,762 to PKR 652,806 per farm and PKR 80.757 to PKR 85,940for APSIM. The NR and PCI with CC for DSSAT varied between PKR 633,909 to PKR 687,308 per farm and PKR 83,494 to PKR 90,405 respectively.

The observed poverty without CC was 3.3 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 6.9 to 9.0 percent in APSIM and 5.7 to 7.9 percent in DSSAT. However, for RCP 8.5 poverty varied between 8.1 to 10.6 percent in APSIM and 6.2 to 8.8 percent in DSSAT (Table 3).

3.2.3 CC-IA for District Hafizabad

Results of Hafizabad shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 74.4 to 80.4 percent and 70.4 to 78.0 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 746,842 per farm and PKR 183,144 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 604,913 to PKR 647,025 per farm and PKR 140,764 to PKR 150,210 respectively. The NR and PCI with CC for DSSAT varied between

Table 4. Climatic change sensitivity impact on economic indicators in district Hafizabad

RCP	CM	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	74.4	647,025	150,210	6.8
		Cool Dry	75.7	638,672	148,337	6.9
		Middle	78.0	622,730	144,761	7.1
		Hot Dry	80.4	604,913	140,764	7.5
		Hot Wet	79.2	613,783	142,754	7.4
	DSSAT	Cool Wet	70.4	674,368	156,344	5.9
		Cool Dry	72.2	663,109	153,818	6.1
		Middle	74.7	646,797	150,159	6.2
		Hot Dry	77.9	624,436	145,143	6.6
		Hot Wet	78.0	623,376	144,906	6.8
8.5	APSIM	Cool Wet	79.9	608,590	141,589	7.3
		Cool Dry	79.5	610,236	141,958	7.8
		Middle	82.1	590,842	137,608	8.0
		Hot Dry	82.8	584,592	136,206	8.3
		Hot Wet	81.5	596,136	138,795	7.8
	DSSAT	Cool Wet	72.6	660,871	153,316	6.0
		Cool Dry	74.2	650,382	150,963	6.2
		Middle	76.2	636,540	147,858	6.6
		Hot Dry	79.4	613,965	142,795	6.6
		Hot Wet	79.7	611,227	142,180	6.8

Table 5. Climatic change sensitivity impact on economic indicators in district Gujranwala

CM	CC	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	68.6	639,416	66,378	23.7
		Cool Dry	70.9	627,325	65,149	23.7
		Middle	74.0	607,691	63,152	25.8
		Hot Dry	78.9	574,108	59,737	29.7
		Hot Wet	78.0	582,881	60,629	27.3
	DSSAT	Cool Wet	66.6	653,559	67,817	20.7
		Cool Dry	69.0	640,019	66,440	21.8
		Middle	71.3	626,129	65,027	23.0
		Hot Dry	77.2	588,987	61,250	26.2
		Hot Wet	77.5	586,160	60,962	27.2
8.5	APSIM	Cool Wet	75.5	594,450	61,806	28.4
		Cool Dry	75.9	592,525	61,610	28.4
		Middle	78.2	576,605	59,991	30.1
		Hot Dry	79.7	567,643	59,079	30.6
		Hot Wet	80.4	564,736	58,784	30.1
	DSSAT	Cool Wet	68.7	641,906	66,632	21.5
		Cool Dry	70.2	632,771	65,703	22.4
		Middle	73.2	614,860	63,881	23.7
		Hot Dry	77.9	584,097	60,753	26.6
		Hot Wet	79.6	571,135	59,435	28.7

PKR 623,376 to PKR 674,368 per farm and PKR 144,906 to PKR 156,344 respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between 79.5 to 82.8 percent for APSIM and 72.6 to 79.7 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 584,592 to PKR 610,236 per farm and PKR 136,206 to PKR 141,958for APSIM. The NR and PCI with CC for DSSAT varied between PKR 611,227 to PKR 660,871 per farm and PKR 142,180 to PKR 153,963 respectively.

The observed poverty without CC was 5.0 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 6.8 to 7.5 percent in APSIM and 5.9 to 6.8 percent in DSSAT. However, for RCP 8.5 poverty varied between 7.3 to 8.3 percent in APSIM and 6.0 to 6.8 percent in DSSAT (Table 4).

3.2.4 CC-IA for District Gujranwala

Results of Gujranwala shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 68.6 to 78.9 percent and 66.6 to 77.5percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 746,500 per farm and PKR 77,269 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 574,108 to PKR 639,416 per farm and PKR 59,737 to PKR 66,378 respectively. The NR and PCI with CC for DSSAT varied between PKR 586,160 to PKR 653,559 per farm and PKR 60,962 to PKR 67,817

respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between 75.5 to 80.4 percent for APSIM and 68.7 to 79.6 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 564,736 to PKR 594,450 per farm and PKR 58,784 to PKR 61,806for APSIM. The NR and PCI with CC for DSSAT varied between PKR 571,135 to PKR 641,906 per farm and PKR 59,435 to PKR 66,632 respectively.

The observed poverty without CC was 15.4 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained of both CSMs. In RCP 4.5, poverty fluctuated between 23.7 to 29.7 percent in APSIM and 20.7 to 27.2 percent in DSSAT. However, for RCP 8.5 poverty varied between 28.4 to 30.6percent in APSIM and 21.5 to 28.7 percent in DSSAT (Table 5).

3.2.5 CC-IA for District Sialkot

Results of Sialkot shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 79.0 to 86.4 percent and 72.0

Table 6. Climatic change sensitivity impact on economic indicators in district Sialkot

RCP	CM	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	79.0	495,181	66,660	24.5
		Cool Dry	81.5	478,806	64,530	26.3
		Middle	82.7	471,234	63,545	26.7
		Hot Dry	86.4	442,097	59,755	30.0
		Hot Wet	84.7	456,023	61,567	28.5
	DSSAT	Cool Wet	72.0	534,454	71,769	21.6
		Cool Dry	80.9	483,432	65,132	25.1
		Middle	80.3	487,179	65,619	24.6
		Hot Dry	84.2	459,824	62,061	28.1
		Hot Wet	85.3	451,347	60,958	29.6
8.5	APSIM	Cool Wet	87.9	428,388	57,972	31.7
		Cool Dry	82.5	472,485	63,708	26.4
		Middle	87.4	433,179	58,595	31.1
		Hot Dry	88.2	426,186	57,686	32.3
		Hot Wet	85.9	445,970	60,259	31.2
	DSSAT	Cool Wet	74.9	519,316	69,800	22.2
		Cool Dry	81.7	478,091	64,437	25.8
		Middle	82.0	475,973	64,162	25.9
		Hot Dry	85.4	450,241	60,815	29.3
		Hot Wet	86.3	443,429	59,929	30.3

to 85.3 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 642,014per farm and PKR 85,760 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 442,097to PKR 495,181 per farm and PKR 59,755 to PKR 66,660 respectively. The NR and PCI with CC for DSSAT varied between PKR 451,347 to PKR 534,454per farm and PKR 60,958 to PKR 71,769 respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between82.5 to 88.2 percent for APSIM and 74.9 to 86.3 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR

426,186 to PKR 472,485 per farm and PKR 57,686 to PKR 63,708for APSIM. The NR and PCI with CC for DSSAT varied between PKR 443,429 to PKR 519,316 per farm and PKR 59,929 to PKR 69,800 respectively.

The observed poverty without CC was 14.7 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 24.5 to 30.0percent in APSIM and 21.6 to 29.6 percent in DSSAT. However, for RCP 8.5 poverty varied between 26.4 to 32.3 percent in APSIM and 22.2 to 30.3 percent in DSSAT (Table 6).

Table 7. Climatic change sensitivity impact on economic indicators in district Gujrat

RCP	CM	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	74.3	382,099	75,467	18.9
		Cool Dry	75.3	378,713	74,832	18.8
		Middle	77.5	370,507	73,294	20.0
		Hot Dry	80.8	356,706	70,706	22.2
		Hot Wet	80.0	360,774	71,469	21.0
	DSSAT	Cool Wet	68.5	401,995	79,197	16.9
		Cool Dry	72.7	388,047	76,582	18.0
		Middle	74.3	382,530	75,548	18.5
		Hot Dry	78.6	366,122	72,471	20.4
		Hot Wet	78.3	367,081	72,651	20.9
8.5	APSIM	Cool Wet	77.9	368,627	72,941	20.4
		Cool Dry	77.4	370,500	73,292	20.4
		Middle	80.8	357,181	70,795	21.6
		Hot Dry	82.7	348,798	69,223	23.1
		Hot Wet	83.2	346,812	68,851	22.6
	DSSAT	Cool Wet	72.3	389,498	76,854	17.9
		Cool Dry	75.2	379,159	74,916	18.9
		Middle	76.1	376,084	74,339	19.0
		Hot Dry	79.3	363,588	71,996	20.8
		Hot Wet	80.0	360,426	71,403	21.5

3.2.6 CC-IA for District Gujrat

Results of Gujrat shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 74.3 to 80.8 percent and 68.5 to 78.6 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 458,260 per farm and PKR 89,747 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 356,706 to PKR 382,099 per farm and PKR 70,706 to PKR 75,467 respectively. The NR and PCI with CC for DSSAT varied between PKR 366,122 to PKR 401,995 per farm and PKR 72,471 to PKR 79,197 respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between 77.4 to 83.2 percent for APSIM and 72.3 to 80.0 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 346,812 to PKR 370,500 per farm and PKR 68,851 to PKR 73,292 for APSIM. The NR and PCI with CC for DSSAT varied between PKR 360,426 to PKR 389,498 per farm and PKR 71,403 to PKR 76,854 respectively.

The observed poverty without CC was 14.0 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 18.8 to 22.2 percent in APSIM and 16.9 to 20.9 percent in DSSAT. However, for RCP 8.5 poverty varied between 20.4 to 23.1 percent in APSIM and 17.9 to 21.5 percent in DSSAT (Table 7).

3.2.7 CC-IA for District Mandi Bahauddin

Results of Mandi Bahauddin shown household vulnerability for RCP 4.5 in all five GCMs in both CSMs i.e., APSIM and DSSAT fluctuated between 75.1 to 85.3 percent and 68.2 to 81.5 percent, respectively. The observed NR and PCI without CC for both RCP 4.5 and RCP 8.5 in all GCMs were PKR 484,645 per farm and PKR 111,398 respectively. However, NR and PCI with CC in RCP 4.5 for APSIM ranged between PKR 381,630 to PKR 417,434 per farm and PKR 88,474 to PKR 96,442 respectively. The NR and PCI with CC for DSSAT varied between PKR

Table 8. Climatic change sensitivity impact on economic indicators in district Mandi Bahauddin

RCP	CM	GCM	Vulnerable Farm Household (%)	NR with CC	PCI with CC	Poverty with CC (%)
4.5	APSIM	Cool Wet	75.1	417,434	96,442	9.5
		Cool Dry	79.3	404,262	93,510	10.0
		Middle	80.5	399,949	92,550	10.4
		Hot Dry	85.3	381,630	88,474	11.8
		Hot Wet	82.6	391,657	90,705	11.4
	DSSAT	Cool Wet	68.2	437,356	100,875	8.6
		Cool Dry	71.6	427,833	98,756	9.1
		Middle	77.5	409,901	94,765	9.9
		Hot Dry	81.5	396,355	91,751	10.7
		Hot Wet	81.3	397,143	91,926	10.5
8.5	APSIM	Cool Wet	82.2	393,982	91,223	10.7
		Cool Dry	80.8	398,828	92,301	10.5
		Middle	84.0	386,853	89,636	11.2
		Hot Dry	88.4	367,199	85,263	13.2
		Hot Wet	85.7	379,102	87,912	12.5
	DSSAT	Cool Wet	71.0	429,628	99,155	8.9
		Cool Dry	72.4	425,371	98,208	9.2
		Middle	78.7	405,920	93,879	10.2
		Hot Dry	84.5	385,057	89,237	10.9
		Hot Wet	86.3	377,468	87,548	11.7

396,355 to PKR 437,356 per farm and PKR 91,751 to PKR 100,875respectively. Household vulnerability to climatic changes in RCP 8.5 for all GCMs varied between80.8 to 88.4 percent for APSIM and 71.0 to 86.3 percent for DSSAT. The NR and PCI with CC for RCP 8.5 ranged from PKR 367,199 to PKR 398,828 per farm and PKR85,263 to PKR 92,301 for APSIM. The NR and PCI with CC for DSSAT varied between PKR 385,057 to PKR 429,628 per farm and PKR 87,548 to PKR 99,155 respectively.

The observed poverty without CC was 7.2 percent, while the poverty with CC varied according to the effect of climatic conditions on relative yields obtained from both CSMs. In RCP 4.5, poverty fluctuated between 9.5 to 11.8 percent in APSIM and 8.6 to 10.7 percent in DSSAT. However, for RCP 8.5 poverty varied between 10.5 to 13.2 percent in APSIM and 8.9 to 11.7 percent in DSSAT (Table 8).

4. Discussion

Most of the developing countries in the world are dependent on agriculture for the livelihood needs of its farmhands. The impacts of climate change are mostly negative in the case of the agricultural sector. Therefore, it is very important to predict these impacts on the farming community which can be dealt with economic modeling. This study is innovative in this way, as it uses an integrated approach of climate, crop, and economic modeling. In the case of Pakistan, it is in the pioneers of using such an integrated approach.

The crop modeling results of the study used for economic modelling that is relative yields show that there are negative impacts of climate change on the yields of both major cereal crops of the country i.e., rice and wheat for all GCMs and RCPs[41,63]. The results indicated that percentage losses were higher in RCP 8.5 as compared to RCP 4.5 for both CSMs. The comparison of both CSMs given the insight that the percent losses were higher in APSIM as compared to DSSAT, and DSSAT showed more gains. The empirical net impact of climate change was observed negative for both RCPs and CSMs in all districts.

The findings of the three main economic factors (NR per farm, PCI and poverty) depicted that the overall impact of climate change is negative for both RCPs and CSMs. The net returns per farm and per capita income shown the declining trend for both RCPs and CSMs, however, the intensity was higher in RCP 8.5 in comparison to RCP 4.5. Likewise, the poverty status was higher in RCP 8.5

(harsh climatic conditions) as compared to RCP 4.5 (mild climatic conditions) in both CSMs. The findings of the study re-endorsed the fact that climatic variations especially temperature and precipitation negatively affect the yields of both crops which in turn reduced net returns per farm, per capita income, and poverty rates[66,67]. Presently, Pakistan has very low adaptive capacity to climate change due to lack of extension services, infrastructure, required information to formulate and implement effective policy measures[3]. Therefore, the results of this study will act as a way forward in the formulation of current and future adaptation strategies.

The reduction in wheat productivity due to climatic factors is also evident from several other studies in Pakistan[3,66,67]. The decline in rice yield is also observed in this study. But there is less published literature on the impact of climate change on rice in Pakistan[37,63]. Naqvi, Asif[63] done a similar study in the rice-wheat zone of Punjab, Pakistan. But there were some limitations of that study which we have tried to incorporate. First, we took the whole RWCS and data was collected from all seven districts making the sample size most heterogeneous. Second, Naqvi, Asif[63] took only the rice-wheat crops in making the agricultural system, but this study used all farm-based activities; rice, wheat, minor fodder crops, and livestock. Therefore, the results of climate change impact assessment are clearly observed on the socioeconomic variables of the respondents because almost all sub-sections of agricultural income were considered in this study.

5. Conclusions

The socioeconomic conditions of farmers are vulnerable to both climatic and non-climatic risks in agriculture. The objective of this study was to measure the impact of climatic risks on currently integrated rice-wheat cropping zone of Pakistan considering both mild and harsh representative concentration pathways, i.e., RCP 4.5 and 8.5 using APSIM and DSSAT crop models. The climatic modelling reaffirmed the fact of increase in temperature for the study area. This increase in temperature resulted a decline in the relative yields for both CSMs of modeled activities (rice and wheat). The study concluded that the net economic impacts of climate change are negative for both RCPs and CSMs in the study area. The poverty of the study area will rise with climate change and it is more prominent while using RCP 8.5 as compared with RCP

4.5 in both crop simulation models. The highest increase in poverty was observed using APSIM crop model for hot-dry conditions. The study suggested that there is a dire need of adaptations strategies and to update agronomic practices to address the adverse impacts of climate risks and to ensure food security and livelihood of the people relying on agriculture in the study area. Therefore, the need of the hour is to put serious efforts in this aspect with a particular focus on the agricultural system at regional and national levels.

6. Acknowledgement

7. References

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