Climate change impacts and vulnerability of fallow-chickpea based farm households in India: Assessment using Integrated modeling approach

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Abstract:

The rainfed farming in India is characterized by low productivity, frequent weather variability, policy bias, poor market and infrastructure and degraded natural resources, which leads to low farm income and farm households vulnerability. Along with these challenges, changing climate and socio-economic conditions in the future are serious threat to the rainfed farming and household farm profitability. In this paper we use the AgMIP Regional Integrated Assessment (RIA) methods which integrates climate, crop and economic modeling to assess potential impacts of climate change on economic vulnerability of farm households, average farm net returns and poverty in semi-arid region of Andhra Pradesh, India. This study used the socio-economic data from representative household survey, together with down-scaled climate data, site-specific crop model simulations. The simulation results shows that the majority of fallow-chickpea based farm households are vulnerable (68% in warmer climate and 42% in wet climate) to climate change if current production systems are used in the future. Vulnerability is not uniform across the Kurnool district and climate impacts vary across climate scenarios. Therefore, development and promotion of location specific adaptation strategies linking technologies, policies and infrastructure is need to improve the resilience and adaptive capacity of farm rainfed farm households to climate change.

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JEL Codes: O13, C63

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Abstract

The rainfed farming in India is characterized by low productivity, frequent weather variability, policy bias, poor market and infrastructure and degraded natural resources, which leads to low farm income and farm households vulnerability. Along with these challenges, changing climate and socio-economic conditions in the future are a serious threat to the rainfed farming and household farm profitability. In this paper we use the AgMIP Regional Integrated Assessment (RIA) methods which integrates climate, crop and economic modeling to assess potential impacts of climate change on the economic vulnerability of farm households, average farm net returns and poverty rate in semi-arid region of Andhra Pradesh, India. This study used the socio-economic data from representative household survey which represent chickpea-based rainfed farming systems, together with down-scaled climate data, site-specific crop model simulations. The simulation results shows that the majority of fallow-chickpea based farm households are vulnerable (68% in warmer climate and 42% in wet climate) to climate change if current production systems are used in the future. Vulnerability is not uniform across the Kurnool district and climate impacts vary across climate scenarios. Therefore, development and promotion of location specific adaptation strategies linking technologies, policies and infrastructure is need to improve the resilience and adaptive capacity of farm rainfed farm households to climate change.

Keywords: Rainfed agriculture; climate change; Inegrated assessment; vulnerability

JEL codes: O3; Q16; Q17

Introduction

Climate change impacts on food production system and food security are more widely felt in the developing countries than in developed countries, due to their higher dependence on agriculture for their livelihoods, greater vulnerabilities and poor technological and financial abilities to invest in adaptation and mitigation to climate change (Nelson et al., 2010; Iizumi et al., 2014). The impacts of climate change are likely to be severe for the developing countries like India which is agriculture-based economy and supports about 58% of the rural households and provide 50% of employment. Moreover, agriculture in India is predominately rainfed (more than 55% of net sown area) and produces 40% of total food grain production which means that major impact of climate change and vulnerability could be on rainfed agriculture production system due to changes in rainfall pattern, temperature, floods, droughts, and negative effects on water and land resources (Di Falco and Chavas, 2009; Mendelsohn 2014).

Several studies reported that in India climate change will affect crop productivity (Masutomi et al., 2009; Singh et al., 2017; Singh et al., 2015; Birthal et al., 2014) which could cause food security problems in the future. Kreft et al. (2014) reported that India is one of the highly vulnerable countries to climate change and ranked 17th by Global Climate Risk Index (GCRI) in terms of exposure to extreme weather conditions for the period from 1993 to 2012 (Kreft et al., 2014). If climate change affects the productivity of the agriculture sector, a large number of farm households depend on agriculture for their livelihood will be at risk which could increase the problem of food insecurity and vulnerability in country.

The literatures on climate change impacts assessment is based on individual crops using process based crop model (Singh et al., 2017; Singh et al., 2015) and econometric models (Mendelsohn and Dinar, 2009; Birthal et al., 2014) and global trade models (Nelson et al., 2010; Islam et al., 2015). The main limitation of these methodologies are subjective assessment of the riskiness associated with crops for changing temperature and precipitation at field or region or global scale; assuming no variation in the crop choices and production technologies changed by farmers over time; existing studies deal with major crops ignoring crop production systems in which farmers cultivate pulses, oil seed crops and plantation crops as intercropping and mixed cropping especially in the low input rainfed farming to mitigate climate risk in rainfed farming.

Against this background, to assess the impacts and uncertainty of climate change on agriculture production system, household level income and poverty we need a systems approach with multi-dimensional assessments that could consider agricultural system performance in economic, environment and social dimensions and tradeoffs among these dimensions (Antle 2011; Antle et al., 2014). To the best of our knowledge, there is no previous literatures that has used integrated systems approach to assess the climate change impacts at household or regional scale by combining biophysical (climate and crop) and economic model in south Asia and especially in India. In this study, we used a Regional Integrated Assessment (RIA) methods developed by the Agricultural Model Inter-comparison and Improvement Project (AgMIP) for climate impact assessment (Antle et al. 2015; AgMIP 2015).

The objectives of this paper are to (i) assess sensitivity of current rainfed crop-livestock production system to climate change in Kurnool district of Andhra Pradesh and (ii) assess household vulnerability, change in farm household net returns, per-captia income and poverty rate across different climate change scenarios.

Data and Methodology

Study area

This study was conducted in Kurnool district in the state of Andhra Pradesh (Figure 1) which is located in the west-central part of the state lies between the North latitudes of 140 54'& 160 18'and East longitudes of 760 58' and 790 34'. The major livelihood activity in the districts is agriculture, mostly rainfed and major crops grown in the district are chickpea, rice, sorghum, cotton, sunflower, pigeonpea, black gram, groundnuts and onions. Among these crops, chickpea occupies about 23% of the total cropped area in the district in 2008-10 followed by groundnut (20.8%), sunflower (12.3%) and rice (12.7). The soils in the district are predominantly covered by black cotton soils (Vertisols) of about 0.76 million hectares followed by red soils (0.2 million ha) and other soils (0.051 million ha).

Kurnool district falls under scarce rainfall zone (VI) in the state with a rainfall of 500 to 750 mm. More than 80% of the cropped area in the district is under rainfed farming systems. The normal annual rainfall received in Kurnool district is around 670 mm, out of which 68% is received from South West Monsoon and 22% from North East Monsoon. The amount of rainfall and its distribution over the crop cycle is the determining factor for assured crop productivity. In the recent years the rainfall in the district is more erratic, insufficient and unevenly distributed. Hence, recurrent droughts are quite common in the district.

Due to low rainfall in the district coupled with labor scarcity, increasing wage rates and less scope for other irrigation sources, low water demanding and less-labor intensive rainfed crops like chickpea, groundnuts and sunflower areas are increasing over the years in the district. For example the share of chickpea area in total cropped area of Kurnool district was only 2.45% in 1991-93 but it has tremendously increased to 23% in 2008-10. 'Fallow-chickpea' system[1] is the predominant cropping pattern observed in the district.

Household survey data

The study used the household survey data collected by ICRISAT during 2012-13 for comprehensive impact assessment of chickpea technologies in Andhra Pradesh (Bantilan et al. 2014). The detailed sampling framework and survey instruments are well described in Bantilan et al. 2014. From this dataset, the present study have used Kurnool sample data to deeply understand household climate adaptation strategies. About 156 farm households from 13 *mandals* of Kurnool district were covered in household survey. Out of which, 111 sample had detailed socio-economic information including plot level crop input-output information. This dataset (111 households) was used to parameterize the crop and economic models. These households were spatially distributed and represented chickpea growing regions of Kurnool district. The locations of HHs spread over 13 *mandals* of district are shown in the Figure 2.

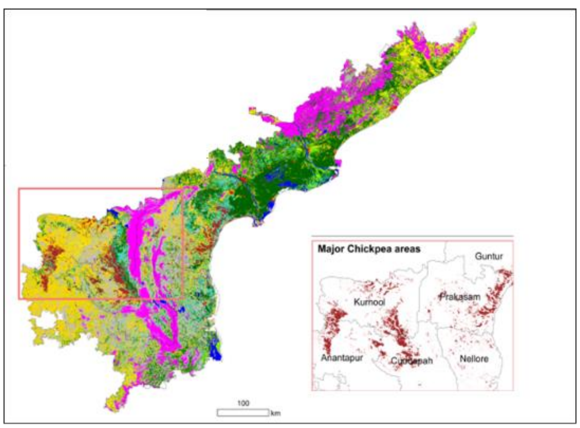


Figure 1: Spatial distribution of land-use/land-cover in Andhra Pradesh and major chickpea-growing areas(inside figure)

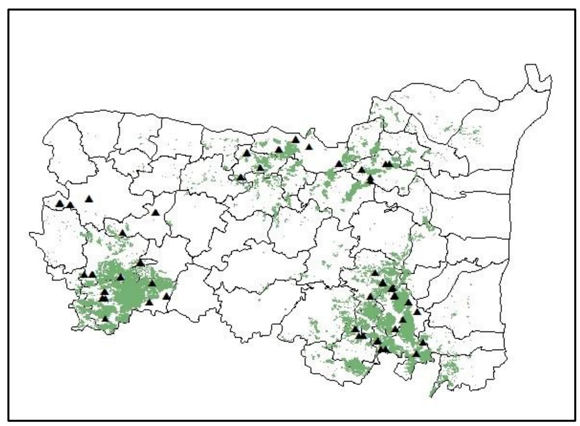


Figure 2: Kurnool district with sample household location in chickpea growing area

Characterization of farming systems in Kurnool district

Agriculture, which is mostly rainfed, has been the main occupation and source of livelihood for the farmers in the district. In the total population of 4.04 M in the district, more than 70% of the population

[1] Farmers keep their land fallow during the *kharif* (rainy season) and subsequently take up chickpea cultivation during *rabi* (post rainy) season. Chickpea farmers open up land furrows with tractors/bullocks soon after receiving the rains during rainy season (i.e., in July onwards). This practice allows the black cotton soil (vertisols) to retain rain water to the best extent possible. The retained residual moisture will allow growing chickpea crop during late September or October in a normal year. This is the most predominant practice in black soils for conserving soil moisture.

lives in rural areas and are engaged in farming. The farmers cultivate crops in two seasons namely *kharif* (rainy season – June to October) and *rabi* (post-rainy season – November to February). The major crops grown in rainy season are paddy, cotton and pigeonpea. In post-rainy season, chickpea, sorghum and sunflower are the major crops grown in the district. Presence of black soil in the district did not allow them to cultivate crops during the rainy season. Farmers keep the land fallow in the rainy season and cultivate crops in the post-rainy season on the residual soil moisture. The **'fallow-chickpea'** is the dominant cropping system observed across sample households in the Kurnool district. Nearly 60–70% of post-rainy season cropped area was alone occupied by chickpea. The net incomes generated from chickpea crop significantly influenced the household financial health. The high net profitability per ha in chickpea cultivation has increased remarkably the average agricultural incomes in the district.

Overall, chickpea area has significantly increased over time due to replacement of other crops with chickpea. The sample farmers feed the livestock with crop residues and also on common lands in the dry season. The typical farming system diagram in the region is furnished in the figure 3.

The average household size of the sample households (111) in Kurnool district is 5.2 person with operated farm size of about 6.5 ha (Table 3). The average livestock holding per household in the sample households is around 1.9 TLU. This clearly indicates that sample household also dependent on livestock rearing as a subsidiary occupation. The farmers in the region cultivate chickpea in about 4.2 ha which is more than 60% of the total operational land holding in the region. The sample household in the Kurnool district have allocated significant share of their cropped area to chickpea than any other district in the state (Bantilan et al 2014). The estimated average yields in the region is 972.8 kg/ha (Table 1).

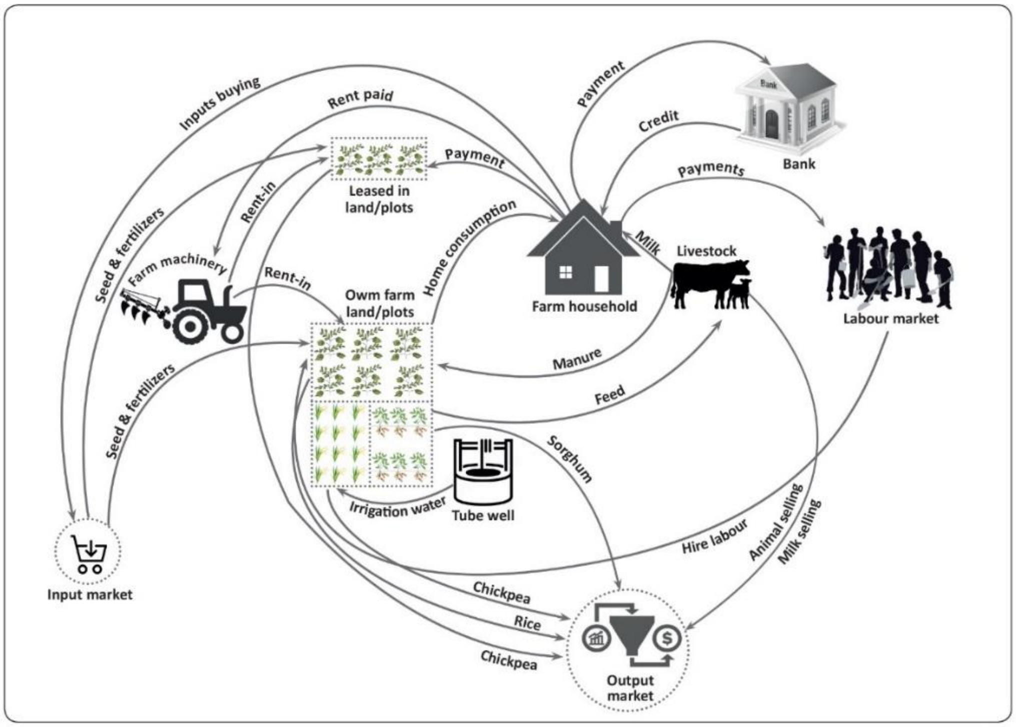


Figure 3: The general farming systems diagram in the Kurnool district.

Table 1: Characteristics of sample households in Kurnool district

Variables	Units	Obs.	Mean	Std. Dev.	Min	Max
Household size	Numbers	111	5.2	1.9	2.0	11.0
Total own land	Ha	111	5.1	3.8	0.0	16.6
Total operated land	Ha	111	6.5	4.3	0.4	23.5
Total livestock Unit	Numbers	111	1.9	2.7	0.0	20.0
chickpea area	Ha	111	4.2	3.3	0.4	20.2
chickpea yield	Kg/ha	111	972.8	666.3	149.5	2573.1
chickpea price	Rs/kg	111	37.2	5.7	25.0	50.0
chickpea TVC	Rs/ha	111	23676.5	6834.5	9525.0	37419.3
Legumes and Oilseeds area	Ha	111	0.5	1.1	0.0	6.4
Legumes and Oilseeds TVC	Rs	111	9201.6	22636.2	0.0	140330.0
Legumes and oilseeds NR	Rs	111	20217.4	57696.7	0.0	347090.0
other crops area	Ha	111	1.8	2.1	0.0	9.6
other crops TVC	Rs	111	58942.8	76558.0	0.0	400090.0
Other crops NR	Rs	111	138579.2	213371.0	0.0	1046490.0
Livestock income	Rs	111	84454.5	157417.4	0.0	880570.0
Non-agrl income	Rs	111	105958.0	156756.1	0.0	883740.8

Note: * Legumes (include green gram, black gram, horse gram, soybean, groundnuts, and castor)

Integrated multi-model approach

In this study we used Regional Integrated Assessment (RIA) methods developed by AgMIP project (http://www.agmip.org/). This approach is a protocol based which integrates global and regional climate, crop/livestock and economic modeling frameworks (AgMIP 2015; Antle et al., 2015) to assess impacts of climate change, adaptation, mitigation and vulnerability of farm households at regional scale (Antle et al., 2017).

The modelling framework is applied under various scenarios to examine the interlinked impacts of climate change, socioeconomic development, and adaptation on crop-livestock farming system in Andhra Pradesh, India. The assessment uses high emission climate scenarios representative concentration pathways (RCP) 8.5 and five general circulation models (GCM). Under each climate scenario, crop yields are simulated using proposed based crop model (DSSAT). Furthermore, both current and future agricultural systems are modelled using crop and economic models.

Climate projections

To understand the current climate conditions in the Kurnool district of Andhra Pradesh, historical long-term (1980-2010) climate (rainfall, minimum and maximum temperatures) data was obtained from two synoptic weather stations located in the regions[2]. This climate data were used to estimate the baseline climate of two different rainfall zones within the study region. The estimated baseline climate for the zones was used to generate future climate change scenarios for each rainfall zones using the delta method approach described in the AgMIP RIA Protocols. In order to capture the whole range of future climate variability, down-scaled scenarios of the mean and variability of the projected future climate were generated from all the 29 global Coupled Model Intercomparison Project (CMIP5) models (Ruane and McDermid, 2017). In this study we used high emissions scenario (Representative Concentration Pathway 8.5), together with a business as usual Representative Agricultural Pathway for mid-century. The models were categorized as either cool and wet, cool and dry, hot and wet, hot and dry or average according to their degree of warming and rainfall change relative to the median change of all the models. The five categories are illustrated in the five quadrants in Figure 4 below for Nandyal station weather for the RCP 8.5.

[2] Meteorological Observatory of Acharya NG Ranga Agricultural University located at Agricultural Research Station Anantapur and Regional Agricultural Research Station, Nandyal in Andhra Pradesh.

To illustrate the economic impacts of climate change using the AgMIP RIA framework, we selected two climate scenarios namely hot-dry and cool-wet which represent driest and wettest scenarios.

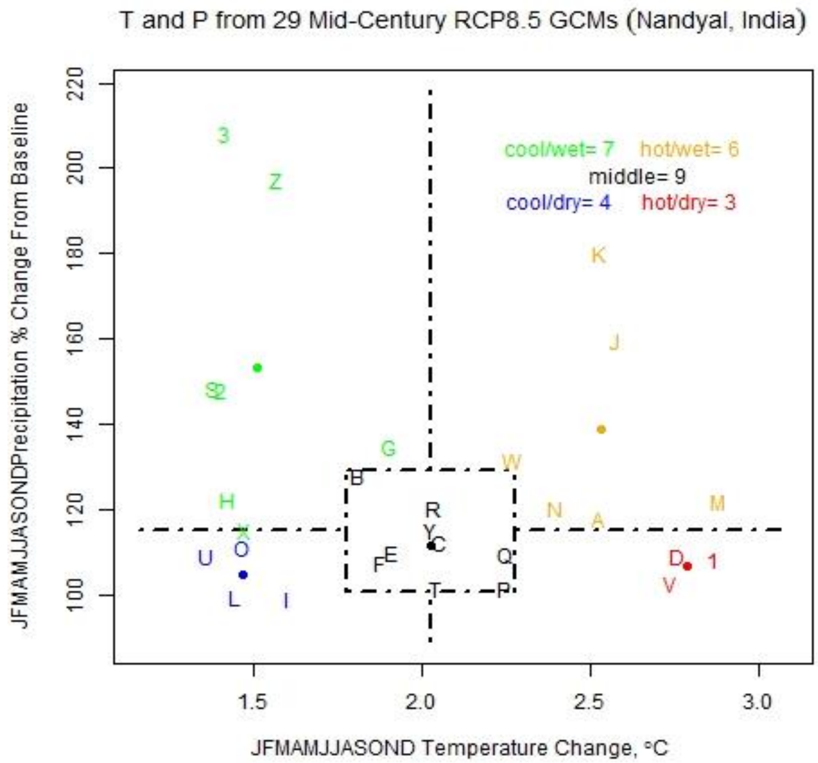


Figure 4 Projected mid-Century Precipitation and temperature changes for the 29 GCMs for Nandyal weather station for RCP8.5 (A = ACCESS1-0,B = bcc-csm1-1, C = BNU-ESM, D = CanESM2, E = CCSM4, F = CESM1-BGC, G = CSIRO-Mk3-6-0, H = GFDL-ESM2G, I = GFDL-ESM2M, J = HadGEM2-CC, K = HadGEM2-ES, L = inmcm4, M = IPSL-CM5A-LR, N = IPSL-CM5A-MR, O = MIROC5, P = MIROC-ESM, Q = MPI-ESM-LR, R = MPI-ESM-MR, S = MRI-CGCM3, T = NorESM1-M, U = FGOALS-g2, V = CMCC-CM, W = CMCC-CMS, X = CNRM-CM5, Y = HadGEM2-AO, Z = IPSL-CM5B-LR, 1 = GFDL-CM3, 2 = GISS-E2-R, 3 = GISS-E2-H)

Crop system model and model inputs

The Decision Support System for Agriculture Technology Transfer (DSSAT) v4.6 (Hoogenboom et al., 2015) was used to assess the impacts of climate change on crop production. A total of 111 chickpea growing farms were selected from the survey data. There was much variation in date of sowing and N fertilizer application among the sample farms. The sowing window mostly ranged between 2nd fortnight of September and 2nd fortnight of October. Significant variation in N fertilizer application was also observed which ranged from 7 kg to as high as 69 kg/ha. JG11, a short duration variety (90–100 days) was mostly grown in the study location was used in the simulations. The variety was calibrated using the crop data sets available in the annual reports of the All India Coordinated Research Project (AICRP) on Chickpea (1999–2011). The multi-location trail data where JG11 used as a regional check were used to calibrate and evaluate the JG11 cultivar coefficients. The crop data on sowing dates, days to physiological maturity, yield attributes and yield data from agronomic trials and phenological data from physiology trials were used for generating the genetic coefficients (Singh et al. 2014). The long term climate data was sourced from local Acharya NG Ranga Agricultural University (ANGRAU) agro-meteorological observatories and soil data was obtained from the earlier studies and ANGRAU reports. Mostly chickpea is grown in vertisols having similar soil properties and there was some difference exists in soils mostly in soil profile depth.

Economic Model

The study used the Trade-Off Analysis for Multi-Dimensional Impact Assessment Model (TOA-MD, http://tradeoffs.oregonstate.edu; Antle, 2011; Antle, Stoorvogel and Valdivia, 2014) to assess the economic impacts of climate change and vulnerability in Kurnool district of AP. It is a parsimonious model with several features to assess the climate change impacts and technologies for climate smart agriculture across heterogeneous farm populations and for different types of households (Antle et al., 2018; Antle and Valdivia, 2011; Antle et al., 2014). The model could capture the whole farm production system with different crop and livestock sub-systems and the farm household characteristics (e.g. household size, farm size and off-farm income). Furthermore, the TOA-MD is developed based on population of farms with the parameters like means, variances and correlations of the economic and the associated outcome variables of the population. The other feature of the TOA-MD model is its parsimonious, generic structure, which means that it can be used to simulate any farm system. The advantage of this model is that, unlike many large, complex simulation models, it is easy to address the inherent uncertainty in impact assessments by using a set of minimum data and sensitivity analysis to explore how results change with the relatively small number of model parameters (Antle et al., 2010).

Climate vulnerability of farm households or regions are quantified as gains and losses in farm income, per capita income or change in environmental quality and health. In this study, the TOA-MD model is designed to quantify the proportion of the population in the study region that are losers and the magnitude of loss due to climate change. Since TOA-MD model deals with heterogeneous farm population in the regions, there may be some gainers and some losers, thus the net impact of climate change in the region may be positive or negative. The model uses a statistical representation of farm households in a heterogeneous population to quantify the distribution of gainers and losers due to climate change. The distribution of losses associated with climate change is given in the Figure 5. The area under the distribution of positive side of zero is the proportion of losers which is represent the measure of vulnerability. The solid line distribution shows that a system in which more losers than gainers and dashed line distribution represent a system that is less vulnerable to climate change and has more gainers than losers. Note that in this case, even though gainers outnumber losers, there are still some losers.

In the AgMIP RIA framework, the impact of climate change on crop productivity is incorporated in to the economic model along with socio-economic heterogeneity in the farm household system due to variations in farm size, household size, and non-farm income leads to heterogeneous distribution of vulnerable farm households in the region.

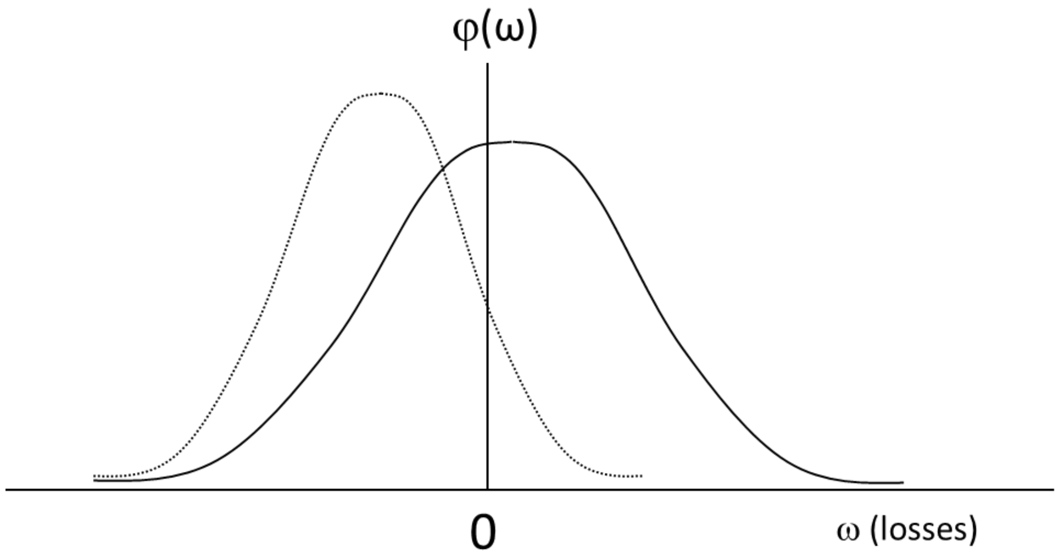


Figure 5: Distribution of losses associated with climate change (Adopted from Antle et al., 2018)

As explained in detail in the AgMIP RIA Handbook (AgMIP 2015), the AgMIP method uses crop and livestock model simulations to project the effects of climate change on the productivity of a system. In this method a yield under a changed climate is approximated as $y^c = r^c \cdot y^o$ where y^o is an observed yield and r^c is a simulated relative yield calculated as $r^c = y^{sc}/y^{so}$, where y^{sc} is the simulated yield under the changed condition, and y^{so} is the simulated yield under the observed condition. This procedure is used rather than directly using y^{sc} as an estimate of y^c to account for the fact that simulated yields do not incorporate all the factors affecting observed yields and thus tend to be biased. If this bias is (approximately) proportional and equal for both y^{sc} and y^{so} then it will cancel out. In cases where process-based models are not available for a crop or livestock species, assumptions for yield impacts are included in scenarios based on expert judgment and other available data such as behavior of similar species or studies of analog climates.In addition to the vulnerability assessment, the methodology provides the capability to simulate the magnitude of impacts on the vulnerable members of the population, as well as the impact on those that gain, and the net or aggregate impact in the population.

The economic indicators used in this paper are: farm income (INR/year), per capital income (INR/year) and the income-based poverty rate, defined as the proportion of the population living under 1.25 USD/day/person. The sample household survey and secondary data was analyzed and stratified based on agro-ecological conditions and parameterized the model.

Stratification of Households in Kurnool districts

Sample households were stratified based on amount of annual rainfall received in that particular *mandal* and availability of alternative irrigation sources - into two homogenous strata namely: (i) low rainfall region and (ii) medium and high rainfall region. Out of the total households, 42 households fell under low rainfall strata while remaining 69 in medium and high rainfall strata.

The western part (low rainfall region) of the district receives less than 500 mm of annual rainfall and has no access to alternate sources of irrigation. While the eastern part of Kurnool district (medium and high rainfall regions) receives annual rainfall between 700-800 mm and also has canal water sources for critical irrigation. The amount of rainfall received during crop period and availability of irrigation sources determines the productivity of the farming systems in the region. So all the farmers in the agro-ecological zone faces similar biophysical constraints such as rainfall, irrigation source, soil fertility, cropping pattern, etc.

Characteristics of Strata 1: low rainfall region

The average household size in the low rainfall region is 5.1 with an operated farm holding of about 6.1 ha (Table 2). The farm household also dependent on rearing of livestock such as cow, buffaloes and small ruminants. The average livestock holding per household is around 1.7 TLU. On an average, the sample farmers allocated 3.6 ha under chickpea cultivation which was more than 50% of an average operational land holding in the region. The farmers also cultivate other crops such as sorghum, groundnut, castor, green gram, black gram, cotton etc. The cultivated area occupied by legumes and oilseeds is about 0.5 ha per household while all other crops together covered under 1.9 ha. The productivity of chickpea in the region is relatively low when compared with other potential regions. The average chickpea yield in the region is about 258.5 kg/ha (Table 2). This yield is remarkably low when compared with historical low rainfall regions. The data surveyed year (2012-13) in the region was declared as a drought year. The study region got affected by drought severely and about 1/3 of the sample famers reported zero yields. Farmers planted chickpea seed with an expectation of good quantum of rainfall incurred significant losses. Alternatively, focus group discussions (FGDs) were organized to elicit required information from farmers to complement the household data. Historic yield data in the region were collected and analyzed to correct the bias in yields and to characterize the farming systems. The sample households also participate in non-farm activities which contributed about 40% of the total household net income. The details about distribution of chickpea yields and farm net returns are furnished in figure 6 and 7.

Table 2: Characteristics of sample households of low rainfall regions of Kurnool district (Strata 1)

Variables	**Units**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Household size	Numbers	42	5.1	1.6	2.0	9.0
Total own land	Ha	42	4.6	3.4	0.0	15.2
Total operated land	Ha	42	6.1	3.2	1.6	15.2
Total livestock Unit	Numbers	42	1.7	3.2	0.0	20.0
chickpea area	Ha	42	3.6	2.1	0.8	8.4
chickpea yield	Kg/ha	42	258.5	89.8	149.5	500.0
chickpea price	Rs/kg	42	35.1	4.0	28.5	40.0
chickpea TVC	Rs/ha	42	17754.0	4644.0	9525.0	31008.3
Legumes and Oilseeds area	Ha	42	0.5	1.3	0.0	6.4
Legumes and Oilseeds TVC	Rs	42	8786.0	25661.8	0.0	140330.0
Legumes and oilseeds NR	Rs	42	10901.7	31413.8	0.0	174000.0
other crops area	Ha	42	1.9	2.3	0.0	9.6
other crops TVC	Rs	42	41290.7	51118.1	0.0	209725.0
Other crops NR	Rs	42	69009.6	109105.3	0.0	515400.0
Livestock income	Rs	42	13454.8	17347.2	0.0	60000.0
Non-agrl income	Rs	42	66109.5	49873.9	4000.0	216000.0

*Note: * Legumes (include green gram, black gram, horse gram, soybean, groundnuts, and castor)*

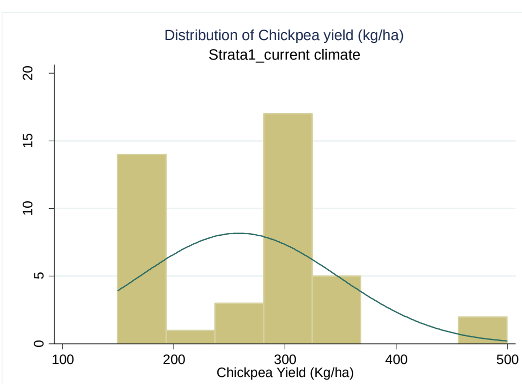


Figure 6: Distribution of chickpea yield (Kg/ha) in current climate of low rainfall region (strata 1)

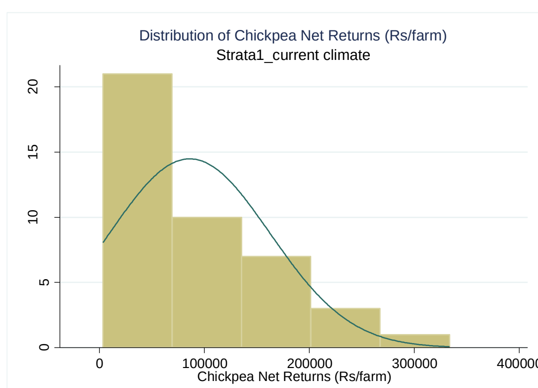


Figure 7: Distribution of chickpea net returns (Rs/farm) in current climate of low rainfall region (strata 1)

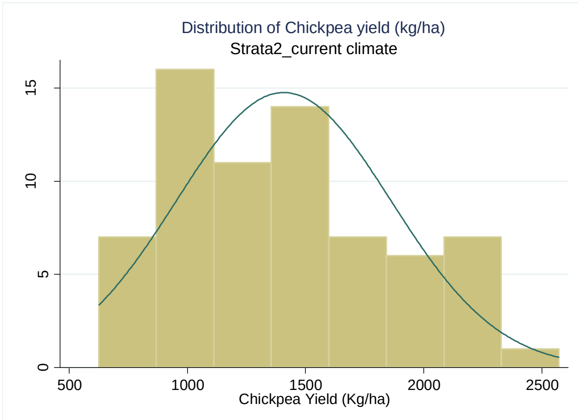
Characteristics of Strata 2: medium and high rainfall regions

The average household size in medium and high rainfall region is 5.3. The operated farm holding size is about 6.7 ha (Table 3). The average livestock holding per household is around 2.5 TLU. The sample farmers distributed about 4.6 ha cropped area under chickpea cultivation which is > 60% of the total operational land holding in the region. This region receives higher quantum of rainfall about 800mm and also has access to alternate sources of irrigation. The average yield observed from sample farmers in the region was 1407.6 kg/ha (Table 3). Even though the survey year was considered as a drought year, the yields in region did not affect much because of supplemental irrigation facilities during critical stages. The distribution of chickpea yields and household net return of sample farmers are given in figure 8 and 9.

Table 3: Characteristics of sample households of medium and high rainfall regions of Kurnool district (Strata 2)

Variables	**Units**	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Household size	Numbers	69	5.3	2.1	2.0	11.0
Total own land	Ha	69	5.4	4.0	0.4	16.6
Total operated land	Ha	69	6.7	4.8	0.4	23.5
Total livestock Unit	Numbers	69	2.0	2.5	0.0	14.1
chickpea area	Ha	69	4.6	3.8	0.4	20.2
chickpea yield	Kg/ha	69	1407.6	454.3	625.0	2573.1
chickpea price	Rs/kg	69	38.5	6.2	25.0	50.0
chickpea TVC	Rs/ha	69	27281.6	5263.6	11460.8	37419.3
Legumes and Oilseeds area	Ha	69	0.4	1.0	0.0	5.6
Legumes and Oilseeds TVC	Rs	69	9454.5	20776.3	0.0	108550.0
Legumes and oilseeds NR	Rs	69	25887.9	68584.1	0.0	347090.0
other crops area	Ha	69	1.7	1.9	0.0	9.6
other crops TVC	Rs	69	69687.6	87155.6	0.0	400090.0
Other crops NR	Rs	69	180926.0	248315.4	0.0	1046490.0
Livestock income	Rs	69	127671.7	186803.4	0.0	880570.0
Non-agrl income	Rs	69	130213.5	191499.6	0.0	883740.8

*Note: * Legumes (include green gram, black gram, horse gram, soybean, groundnuts, and castor)*



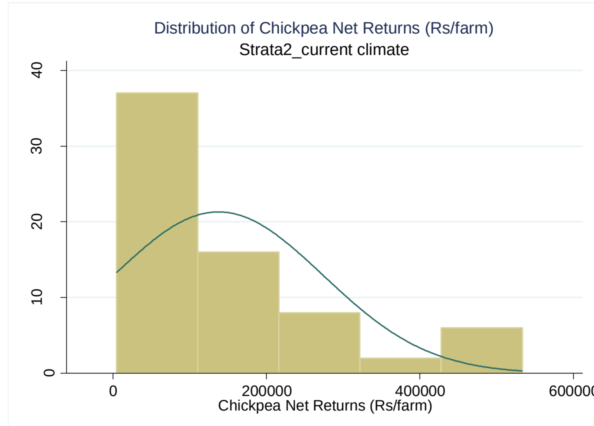


Figure 8: Distribution of chickpea yield (Kg/ha) in current climate of medium and high rainfall region (strata 2)

Figure 9: Distribution of chickpea net returns (Rs/farm) in current climate and of medium and high rainfall region (strata 2)

Results and Discussion

Climate change impacts on crop productivity

Table 4 shows the comparison of chickpea simulated yields for the current period to the farm observed yields in survey year 2012. The crop model (CM0) yields are simulated for 2012 only and the CM1 yields are 30 year time-averaged simulated yields from 1980-2009. The DSSAT crop model average simulated yields are higher in medium and high rainfall zone compared to low rainfall zone. The survey year 2012 is drought year in Kurnool district and the all the farms grown chickpea crop faced terminal drought in the low rainfall region. All the farms in the low rainfall regions follows low input system and depends only on rainfall for crop production. The low rainfall region does not have any irrigation sources like surface water canals and tanks to provide supplemental or life-saving irrigation to crops during drought year. So the average simulated chickpea yield in survey year 2012 in low rainfall region is only 278 kg/ha which is very lower than the average normal yields of around 700-800 kg/ha. The medium and high rainfall region in Kurnool district receives good rainfall and also they have surface water irrigation source like KC irrigation canal and bore wells to provide supplemental irrigation to chickpea crop production (Bantilan et al., 2014). So the observed average chickpea yields in 2012 is 1408 kg/ha. Table 4 provides the correlation between the simulated and observed chickpea yields as well as the R-squared value resulting from a regression of the simulated yields on the observed yields. The correlation coefficients between observed and 2012 survey year simulated yields are 0.74 and 0.66 for low rainfall and medium and high rainfall regions respectively. The correlation coefficients between observed and 30 year time-averaged simulated yields are around 0.50 across two strata (Table 4).

Table 4: Average farm observed and simulated chickpea yield (Kg/ha) in current period in Kurnool district of Andhra Pradesh

Strata	Observed	CM0			CM1		
		simulated			simulated		
	Yield	Yield	correlation	R-squared	Yield	correlation	R-squared
Low rainfall (n=42)	257	278	0.74	0.65	715	0.45	0.59
Medium and High rainfall (n=69)	1408	1137	0.66	0.58	1346	0.56	0.62

Note: n – Number of farm households; CM0 – crop model simulated yield for survey year 2012; CM1 – crop model time averaged simulated yields from 1980-2009

Average relative yields of chickpea under different climate scenarios

The relative yield is the ratio of the simulated chickpea yield under the future climate (CM2) compared to the chickpea yield under the current climate (CM1), for a given farm. Both the CM1 and CM2 yields are 30 year averages from the crop model simulations. A relative yield of 1 indicates no climate impact on yields and a value below 1 indicates a negative and above 1 indicates positive climate impact. In both CM1 and CM2, the simulations are performed under current farm management (e.g. date of sowing, cultivar, fertilizer use, number of irrigation). The relative yields in Table 5 indicate both positive and negative impacts of climate change on chickpea yields depend on the climate scenarios. The relative yields is low in both low rainfall and medium and high rainfall regions for hot/dry climate scenario which indicates chickpea is sensitive for decrease rainfall and increase in temperature in the future. The negative impact of climate change is high in medium and high rainfall zone (0.74) compare to low rainfall region (0.88). The crop model predicted that in cool/wet climate scenario, the relative yield is above 1 for both regions. This indicates that the predicted future increase in temperature of 0.5 °C and increase in precipitation of 40% above the current level increase the chickpea yields by 33% in low rainfall region and 12% in medium and high rainfall region. The higher chickpea yields in low rainfall regions compare to medium to high rainfall regions because of the predicted 40% increase in rainfall in cool/wet scenario has provided good soil moisture for chickpea crop production which avoids terminal water stress. The chickpea crop is also a cool season crop and grown in post rainy (*rabi*) season during November to February, so the cool-wet and cool-dry climate scenarios has positive impact on chickpea yield when compare to hot-dry and hot-wet GCMs.

Table 5: Average relative chickpea yields in different climate scenarios by strata

Climate scenario	Low rainfall		Medium and High rainfall	
	Mean	CV (%)	Mean	CV (%)
Cool/wet	1.33	22.45	1.12	11.02
cool/dry	1.05	9.92	0.92	8.51
middle	0.83	6.49	0.69	6.66
hot/wet	0.95	9.27	0.76	6.12
hot/dry	0.88	8.25	0.74	6.86

Economic analysis: Household vulnerability, change in net income and poverty rate

The economic analysis provides predictions on the potential impact of climate on current agricultural production systems. The crop model results discussed above are used to quantify the impact of climate on chickpea production. However, legumes and oil seed crops, other crop activities and livestock activities are not modelled under the future climate. As such, to gain an understanding of the economic impacts of climate change on the household as a whole, we assumed legumes and oil seed crops to be impacted by the same magnitude as chickpea; in other words, the chickpea relative yield is applied to legumes and oil seed crop activity and sorghum relative yield modeled for 43 farms in the study regions is applied for other crop activities. This represents a case where the whole farm is impacted by climate.

Table 6 shows average farm net return for the activities that are included in the economic analysis. These are the observed (i.e. system 1) parameters. The impact of climate change is assessed by comparing these net return values to the corresponding values that are estimated under each GCM for the distribution of farms within each strata.

Table 6: Average farm net returns (in Rs) by strata in Kurnool district in the survey year 2012

Strata	Chikcpea		Legumes and oil seed crops		Other crop	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Low rainfall	86178.72	88.69	2115.65	299.92	27718.96	252.54
Medium and High rainfall	137540.79	99.32	16433.37	307.73	111238.3	156.21

Table 7 summarizes the range of economic results of aggregate population in the study region for 5 GCMs under RCP 8.5 using the DSSAT model. The table shows the percentage of vulnerable households, net impact on mean farm net returns (percentage), percentage change in net returns, per-capita income, and poverty rate[3] change for the GCMs from no climate change. These vulnerability percentages represent the percentage of households that are predicted to have lower income with climate change than without climate change. The aggregate results indicate that the percentage of vulnerable households ranges from 42.4% in the cool/wet GCM (lowest) to 67.8% in the hot/dry GCM (highest), which indicates the majority of households are worse off under climate change. Moreover, net economic impact is positive only for cool/wet GCM (5.4%) but for all other 4 GCMs the net economic impact is negative (-6.5% to -18.1%). Likewise, the per-capita income increases (6.6%) and poverty rate decrease (-10.9%) for cool/wet GCM but for all other 4 GCMs per-capita income decreases (-6.4% to 18.2%) and poverty rate increases (1.0% to 14.7%) for the aggregate population. Among the 5 GCMs, the highest predicted household vulnerability (67.8%) and largest magnitude of economic net impact occurs for hot/dry GCM. This is mainly attributed to the largest negative impact of climate change on chickpea productivity in the region (Table 7).

Table 7: Aggregate farm household vulnerability, net economic impacts, percent change in farm net returns, per-capita income and poverty rate by GCMs change in Kurnool district of Andhra Pradesh

GCM	**Vulnerability (%)**	**Net economic impact (%)**	**% change of current system in climate change**		
			Net Returns	**Per-capita income**	**Poverty rate**
Mid	67.2	-17.1	-22.9	-17.4	14.3
Hot-dry	67.8	-18.1	-24.0	-18.2	14.7
Cool-dry	55.9	-6.5	-8.9	-6.4	1.0
Cool-wet	42.4	5.4	7.3	6.6	-10.9
Hot-wet	64.9	-15.5	-20.8	-15.5	9.2

Impacts of climate change by farm household groups

The economic impacts of two extreme climate scenarios namely Hot/dry (highly vulnerable) and cool/wet (least vulnerable) scenarios by strata (farm groups) is shown in the Table 8. With current crop production system in the region, the vulnerability to climate change under hot/dry GCM ranges from 68.2% of farm households in low rainfall region and 67.6% of farm households in medium and high rainfall regions. But the net economic impact on mean farm net returns is negative and higher (-19.0%) for medium and high rainfall region compare to low rainfall region (-15.1%) farm households. This shows that farm net return of high rainfall region is highly sensitive to climate change. For medium and high rainfall region, the per-capita income decreases by -20.9% with increase in poverty rate by 8.5%. However, for low rainfall

[3] In the current climate scenario, there are about 27% of the farm households live in below poverty line ($1.25/day/person, i.e. Rs. 29,250/person/year) with an average per capita income of about Rs.57076/person/year

region the per-capita income decreases only by -13.5% but increases the poverty rate substantially by 19.3% (Table 8). This is because the current level of farm households income in low rainfall region is comparatively very low and even a small reduction in per-capita income in this region due to climate change will increase the number of people below poverty line.

In cool/wet favorable GCM with 40% increase in precipitation and slight increase of 0.5 °C temperature, the climate vulnerability is only 34.5% in low rainfall region and 47.2% in medium to high rainfall region (Table 8). The net economic impact on mean net farm returns is positive (13.8%) which translate into increase in per-capita income 12.4% and 16% decrease in poverty rate in the low rainfall region. The results reveals that current agriculture production system in low rainfall region is highly depend on rainfall and 40% increase in rainfall in the region has increased the chickpea yields by 33% (Table 8) in cool/wet scenario. In the medium and high rainfall region where the farmers practice high input crop production system, the increase in rainfall in cool/wet scenario has increases chickpea yields only 12% which translate into 2.8% net economic impacts, 3.2% increase in per-capita income and only a -4.0% decrease in poverty rate compare to no climate change.

The simulation results predicts that the farm households in low rainfall region with current low input crop production system and less opportunity for non-farm income are highly sensitive to both cool/wet (favorable) and hot/dry (un-favorable) climate scenarios.

Table 8: Farm household vulnerability, net economic impacts, percent change in farm net returns, per-capita income and poverty rate by farm groups (strata) under hot/dry and cool/wet climate scenarios in Kurnool district of Andhra Pradesh

GCM	**Strata**	**Vulnerability (%)**	**Net economic impact (%)**	**% change of current system in climate change**		
				Net Returns	**Per-capita income**	**Poverty rate**
Hot-dry	Low rainfall	68.2	-15.1	-20.5	-13.5	19.3
	High and medium rainfall	67.6	-19.0	-25.0	-20.9	8.5
	Aggregate farms	67.8	-18.1	-24.0	-18.2	14.7
cool-wet	Low rainfall	34.5	13.8	18.8	12.4	-15.9
	High and medium rainfall	47.2	2.8	3.9	3.2	-4.0
	Aggregate farms	42.4	5.4	7.3	6.6	-10.9

Conclusion

This study used the AgMIP Regional Integrated Assessment (RIA) framework to evaluate the sensitivity of current crop-livestock production system to climate change in Kurnool district of Andhra Pradesh, India. This framework integrates climate, crop and economic models to assess the impact of climate change, adaptation, mitigation and vulnerability of heterogeneous farm households at regional scale. This study used the socio-economic data from representative household survey conducted across state of Andhra Pradesh which represent chickpea-based rainfed farming systems, together with down-scaled climate data, site-specific weather and multi-location crop trial data to calibrate crop models. We stratified our sample households into the following: 1) farm households located in low rainfall region and 2) farm households located in medium to high rainfall region in the Kurnool district.

The paper presented here reveals interesting findings. First, the climate analysis reveals that all the five GCMs used in this study predict the Kurnool district will average higher (warmer) temperatures in the 2050s in the high emission scenario (RCP 8.5). Though all projections generally predict increased rainfall, there is clear variation across models: 3%-27% higher rainfall under the mid-range climate scenario, and 6%-40% higher rainfall across five climate scenarios.

Second, the crop model simulation revealed that the relative yields (the ratio of the simulated chickpea yield under the future climate compared to the chickpea yield under the current climate) indicated that positive and negative impacts of climate change on chickpea yields depend on the climate scenarios. The relative yields is less than one for both low rainfall and medium and high rainfall regions for hot/dry climate scenario which indicates chickpea is sensitive for decrease rainfall and increase in temperature in the future. The negative impact of climate change is high in medium and high rainfall zone (0.74) compare to low rainfall region (0.88). The chickpea crop is also a cool season crop and grown in post rainy (*rabi*) season during November to February, so the cool-wet and cool-dry climate scenarios has positive impact on chickpea yield when compare to hot-dry and hot-wet GCMs.

Based on the evidence presented in the paper suggested that the majority of fallow-chickpea based farm households are vulnerable (68% in warmer climate and 42% in wet climate) to climate change if current production systems are used in the future. Vulnerability is not uniform across the Kurnool district and climate impacts vary according to scenario. The simulation results by strata showed that the farm households in low rainfall region with current low input crop production system and less opportunity for non-farm income are highly sensitive to both cool/wet (favorable) and hot/dry (un-favorable) climate scenarios.

Overall, the integrated assessment reveals even under high favorable climate scenario (cool/wet), the current rainfed production system is vulnerable and magnitude varies across climate scenarios and farm household groups. Therefore, development and promotion of location specific adaptation strategies linking technologies, policies and infrastructure is need to improve the resilience and adaptive capacity of farm rainfed farm households to climate change.

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