

Assessment of Impact, Vulnerability and Farm Household's Adaptation to Climate Change: A Study of Telangana

*A thesis submitted to the University of Hyderabad
in partial fulfillment of the requirement for the award of*

DOCTOR OF PHILOSOPHY
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ECONOMICS

By

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October 2021

**Dedicated
to
My Parents and Teachers**



**School of Economics
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DECLARATION

I, Mr. Guntukula Raju, hereby declare that this thesis entitled “**Assessment of Impact, Vulnerability and Farm Households’ Adaptation to Climate Change: A Study of Telangana**” submitted by me under the guidance and supervision of Prof. Phanindra Goyari and Dr. K. Ramachandra Rao, School of Economics, University of Hyderabad, is a *bonafide* research work, which is also free from plagiarism. I also declare that it has not been submitted previously in part or full to this University or any other University or Institution for the award of any degree or diploma. I hereby agree that my thesis can be deposited in Shodganga/INFLIBNET.

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CERTIFICATE

This is to certify that the thesis entitled “Assessment of Impact, Vulnerability and Farm Households’ Adaptation to Climate Change: A Study of Telangana” submitted by Mr. Guntukula Raju bearing registration number 15SEPH18 in partial fulfillment of the requirements for award of Doctor of Philosophy in the School of Economics is a bonafide work carried out by him under our supervision and guidance. This thesis is free from plagiarism and has not been submitted previously in part or in full to this or any other University or Institution for award of any degree or diploma. The candidate has satisfied the UGC Regulations of publications and conference presentations before the submission of this thesis. Details are given below:

A. Publications

1. Raju Guntukula and Phanindra Goyari (2020): “Climate change effects on the crop yield and its variability in Telangana, India”, in: *Studies in Microeconomics*, Vol.8, Issue 01, pp.119-148, Print ISSN: 2321-0222 and e-ISSN: 2321-8398, ABDC Ranked C, Scopus and UGC CARE listed journal, Source: <https://journals.sagepub.com/doi/full/10.1177/2321022220923197>
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B. Presentations in conferences:

1. Presented a paper: “Impact of climate change on major crop yields in Telangana: A panel approach study”, in: 54th Annual Conference of The Indian Econometric Society (TIES), at Shri Mata Vaishno Devi University (SMVDU), Jammu, 7-9 March 2018.
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List of Abbreviations

ACZ	Agro-Climatic Zone
ADF	Augmented Dicky Fuller
ADH	Away to District Headquarter
APD	Adjusting Planting Dates
BLM	Binary Logistic Model
CO ₂	Carbon Dioxide
CV	Coefficient of Variation
CVI	Climate Vulnerability Index
DES	Directorate of Economics and Statistics
EPIC	Erosion Productivity Impact Calculator
FE	Fixed Effects
FGLS	Feasible Generalized Least Squares
GCA	Gross Cropped Area
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GIS	Geographical Information System
GOI	Government of India
GOT	Government of Telangana
GVA	Gross Value Added
HDI	Human Development Index
HYVs	High-Yielding Varieties
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
IVA	Integrated Vulnerability Analysis
JP	Just and Pope
LVI	Livelihood Vulnerability Index
MC	Multiple/Mixed Cropping

MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MK	Mann-Kendall
MLE	Maximum Likelihood Estimation
NDH	Near to District Headquarter
NSSO	National Sample Survey Office
OBC	Other Backward Class
OC	Other Classes
RE	Random Effects
SC	Scheduled Castes
SD	Standard Deviation
SEO	Socio Economic Outlook
SHGs	Self-Help Groups
ST	Scheduled Tribes
SVI	Socioeconomic Vulnerability Index
TAR	Third Assessment Report
TVs	Traditional Varieties
UDV	Using Different Varieties
UEMV	Using Early Maturing Varieties
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VRO	Village Revenue Officer
WMO	World Meteorological Organization

Assessment of Impact, Vulnerability and Farm Household's Adaptation to Climate Change: A Study of Telangana

Abstract

Climate change is one of the most important global environmental challenges facing the humanity with implications for several sectors, particularly agriculture in developing countries like India. In this background, the present study has examined the impact of climate factors on major crop yields in Telangana. This study also analysed the farm households' vulnerability and adaptations to climate change. Specific objectives of the study are: (i) to analyse the trends of rainfall and temperature both at the aggregate and district levels in Telangana, (ii) to evaluate the effects of climatic factors on major crop yields and their yield variability, (iii) to assess the farm households' vulnerability to changing climate in both irrigated and rainfed ecosystems and (iv) to examine adaptation strategies of the sample farmers and determinants of adaptation measures in the study area.

The study utilized both secondary and primary data. Primary data at the household levels were collected from two sample villages (one in Karimnagar district representing irrigated region and one village in Mahabubnagar district representing the rainfed region) in Telangana using the structured survey form. Econometrics techniques and cross tabulations were used to analyze the collected data on the stated objectives. Mann-Kendall trend test and Sen's slope test were used to explore the trends and patterns in the rainfall and temperature. Further, the Just and Pope production function and the three-stage feasible generalised least squares estimation procedure were applied to evaluate the effects of climatic factors on mean yields and yield variability of major crops. To examine the climate-induced vulnerability at the village level, the study adopted an indicator-based method and generated a "climate vulnerability index", based on which the extent of climate-change vulnerability of sample villages was indexed. This study found that changes in rainfall and temperature have significant impact on the mean yield and yield variability of major crops. In addition, the study has revealed that the farm households of rainfed village are highly vulnerable to climate change because of high exposures. The more vulnerable village is characterized by less irrigation and water conservation, less crop diversification, high impact of droughts and other problems. The study area farmers reported that the most commonly practiced adaptation strategies are early maturing varieties, adjusting planting dates, adoption various irrigation facilities, use of different fertilizers and manures, using a different variety of crop seeds, engaging in non-farm activities, migration and crop insurance. Education level, household size, gender, yearly income, landholding size and perceptions on climatic variables are the significant factors driving the probability of adaptations in the study area.

Keywords: Climate change, Agriculture, Crop yields, Farmers, Vulnerability, Adaptation

JEL Classification Codes: Q10, R20, Q18, Q54, C30

Chapter 1

Introduction

1.1 Background

Understanding complex systems like climate and human interactions and response is a fundamental global challenge in the present century. Climate has a profound effect on life on the earth (Oo et al., 2018). The climate in normal parlance is defined as the “average weather” over long period. However, climate and weather are two different stuffs. Weather is a rapidly changing state of the atmosphere (regarded as rainfall, temperature, and other components) in the short-term period at a particular location and time (Reddy, 2015). Moreover, it has merely limited predictability, not further than a week. On the other hand, “climate” denotes the normal weather conditions in terms of the average and its variance over a certain decades or longer periods and locations (Baede et al., 2001). As specified by the “World Meteorological Organization” (WMO), this time period must be thirty years or more. The “United Nations Framework Convention on Climate Change (UNFCCC-1992)” defines climate change as “change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. This definition is not an appropriate one because it focuses only on anthropogenic climate change, but it does not reflect climate change due to natural factors. However, scholarly traditions considered the definition given by the “Intergovernmental Panel on Climate Change (IPCC) in its third assessment report (TAR-2001)” as the comprehensive definition of climate change. According to IPCC, “Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use” (IPCC, 2001a).

The increasing concentration of greenhouse gases (GHGs), namely, methane (CH₄), carbon dioxide (CO₂), chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), nitrous oxide (N₂O), carbon tetra fluoride (CF₄), sulfur hexafluoride (SF₆), aerosols and water vapors in the atmosphere is the major reason for climate change (Montzka et al., 2011). As

mentioned earlier, changing climate is taking place due to both anthropogenic activities as well as natural variance. Natural change or variability originates from the inside climate system, for instance, volcanoes, continental drift, the earth's tilt and ocean currents. However, scholars across the world have acknowledged that man-made activities are the primary sources of climate change. These human activities include fossil fuel and biomass combustion, changes in land-use patterns, urbanization, production of goods and land transformation for agriculture and forestry. The influence of human-induced activities on the climate system has substantially risen since the advent of the industrial revolution (Zhang et al., 2008). Historically, the responsibility for greenhouse gases emissions rise lies mainly with the advanced countries. However, the underdeveloped countries are likely to be the most important basis of an increasing proportion of future emissions of greenhouse gases (Prakash et al., 2016).

The assessment reports of IPCC have significantly evidenced that the earth's climate system is changed at global, national or local scales, particularly during the preceding century. The average surface temperature of the globe has risen by nearly 0.74 degrees during the last century (1906-2005) (IPCC, 2007b). The decadal upsurge of global average air temperature is about 0.12°C per decade over 1951-2012 (IPCC, 2013). The projected increase of the global mean temperature by the completion of the current century (2081-2100) is going to be 0.3-1.7 degrees (IPCC, 2014). The number of warm and dry days all over the world presents a significant increase over the last several decades. However, observed changes in rainfall disclose robust regional differences or spatial variabilities. According to IPCC (2014), a longer period (1900-2005) of rainfall patterns demonstrated that central and northern Asia, eastern areas of America and northern Europe are getting substantial rainfall. However, less rainfall is observed in southern Africa, Sahel and some areas of South Asia. Extreme rainfall events over rainy tropical areas will likely turn out to be more frequent and more intense. The upsurge in average temperature (surface and ocean), changes in rainfall, droughts, floods, sea-level rise, melting of ice, heat waves, etc., are all the most impeccable signs of changing climate.

The scholarly community widely established the statement that the earth's climate is changing. This changing climate affects the biophysical, ecological, socio-economic systems

worldwide (IPCC, 2007b). It is also a well-known fact that among various sectors affected by changing climate, agriculture is regarded as the more vulnerable and more sensitive sector to climate change (Reilly, 1995; Kumar and Parikh, 2001a; Khan et al., 2009). The primary reason for the higher vulnerability of farming to climate is due to its dependence on climatic factors, and these factors are direct inputs to agricultural activities (Barnwal and Kotani, 2013). The population growth rate at the global level is increasing rapidly, which will enhance the burden on farming for food and livelihood. This necessitates the increase in agricultural production and productivity, but changing climate leading to unfavorable effects on crop yields. The impact assessment models at global and regional scales highlight that a small change in climate factors will have unfavorable effects on principal cereal crops comprising wheat, paddy and maize (Lal et al., 1993; Mall et al., 2006; Wart et al., 2013). For instance, the maize, barley and wheat productivity impacted adversely to increasing mean temperature at global level (Lobell and Field, 2007). Cline (2007) reported that the projected global agricultural yields would decrease around 3-16 percent by the 2080s. Using aggregate statistics from 1976 to 2006, Kucharik and Serbin (2008) assessed the impact of climate on soybean and maize yields in the northern US Corn Belt regions and shown the adverse effect on crops owing to rising temperature. The rice (4%) and wheat (11%) yields are projected to decrease in South Asia due to changing climate by the year 2030 (Bandara and Cai, 2014). One-degree increase in average temperature may reduce rice productivity up to 7.4 percent in Asia (Murdiyarso, 2000). These yield losses will be more in Africa and South Asia in the future (Knox et al., 2012). However, the impact of climate change can be higher in semi-arid tropical climate regions of the world. Developing nations like India are extremely vulnerable to the impacts of changing climate due to larger dependence on agriculture for livelihood and lesser adaptive capacity (Nath and Behera, 2011).

1.2 Climate change in Indian context

Changing climate is not only a significant environmental issue at the global level, but it also a major worry for developing nations like India. Like many other parts of the globe, the climate is changing rapidly in the Indian sub-continent due to increased greenhouse gas emissions, mostly from human-made activities. Climate change triggers altering precipitation patterns, temperature rise, and increased extreme climate events, namely

droughts, heatwaves and floods, to become more recurrent and intensive. For example, the average surface air temperature in India has increased by 0.51°C during 1901-2007 (Kothawale et al., 2010). However, the rapid changes in temperature were evidenced in the recent period (1971-2007), largely due to extreme warming in the most recent period (1998–2007). The decadal increment in average temperature is around 0.2°C per decade for the period 1981-2010 (Srivastava et al., 2017). However, the higher rising trend in temperature was witnessed in the winter and post-monsoon seasons during 1901–2010. The projected upsurge in the surface temperature would be +2 degrees by the mid of the present century and +3.5 degrees by the end of 21st century (Kumar et al., 2011). The level of warming and its effects can be higher in tropical semi-arid areas (Huang et al., 2012; Liu et al., 2013). This substantial increase in temperature can lead to warming extremes that could be harmful to agricultural activities.

India receives a substantial volume of precipitation during the southwest (June–September) and northeast (October–December) monsoon seasons. One of the major ramifications of global climate change is altering the seasonal and annual rainfall patterns. Substantial changes have been occurring in rainfall and extreme rainfall events in India over the last century. For instance, yearly precipitation presents an average declining trend (0.3%) in the Indian sub-continent per 100 years (Kumar et al., 2010). However, within India, the peninsular region displays a rising trend, whereas the west-central region has a declining rainfall trend. The average annual rainfall in both Kharif as well as Rabi seasons was declined by 26 and 33 millimeters, respectively, during the period 1970-2015 (Government of India, 2018). The summer monsoon precipitation also presented a declining trend in the northeast region and major parts of the peninsular area over 1871-1984 (Kumar et al., 1992). Further, Dash et al. (2004) presented a declining trend in monsoon precipitation, while post-monsoon and pre-monsoon seasons show a rising trend during 1871-2002. However, an increasing trend (about 10-12 percent) in rainy-season precipitation has been documented over northwest, west coast India and central peninsula (Kumar et al., 2010).

A wide range of climate scenarios advocates an upsurge in frequent and intense rainfall events that can pose severe risks to societies in terms of lives and livelihoods due to floods connected with extreme rainfall. The incidence of extreme rainfall events during the

monsoon season has presented a growing trend over many Indian regions, while a declining trend has been witnessed during other seasons like winter and summer seasons (Sinha Ray and Srivastava, 2000). The central part of India evidenced a substantial increase pattern in the extent and incidence of extreme rainfall events and a considerable decline in moderate rainwater events during rainy seasons for the period 1951-2000 (Goswami et al., 2006). Several sub-regions in Indian peninsular coastline Andhra Pradesh and Karnataka, Telangana, Rayalaseema have revealed a rising trend of about 7-9 percent in rainfall, whereas Vidarbha, Eastern Madhya Pradesh and Chhattisgarh have evidenced a declining trend of around 5-10 percent in rainfall over 100 years (Kumar et al., 2010). On the other hand, it is observed that an increase in the number of drought events over the Indian sub-continent (Gregory, 1989; Mishra and Liu, 2014; Gautam and Bana, 2014). Further, the projected increase in rainy season rainfall is about 20 percent in India and the anticipated rise in overall precipitation across states excluding Tamil Nadu, Punjab and Rajasthan (Kumar et al., 2006). These pieces of evidence suggest that the alterations in rainfall patterns and an increase in extreme rainfall events such as floods and droughts will be severe in the future across India.

A wide variety of climatic conditions has been in existence in the Indian sub-continent (Narayanan and Sahu, 2016). For instance, from the cold climate of Himalayan ranges to the tropical weather of the Indian peninsular, from the humid rainy weather in the northeast region to the desert parts (Great Indian Desert) in the northwest region, from coastal plains (east and west coastal climate) to the semi-arid continental weather in the inland. The coastal and tropical semi-arid regions are more vulnerable to changing climate (Panda et al., 2017; Padakandla, 2016).

1.3 Climate change and Indian agriculture

‘If agriculture sector survives, India survives’ is the appropriate statement to indicate the significance of agriculture sector to the country. As the backbone of India's economy, the agriculture sector, including allied activities, contributes about 14 percent of gross domestic product (GDP) in the country (Sharma et al., 2018). Even though the portion of agriculture in the overall gross domestic product has declined over the years, more than half of the

Indian population still relies on farming for livelihood. As far as India is concerned, the agriculture sector provides employment for almost 50 percent of the labour force (De Roy, 2017). In terms of agricultural exports, India is ranked 7th place at the global level, and the share of agricultural exports in the world trade was about 2.2 percent in 2015-16 (Anjum and Khan, 2017). However, Indian agriculture is now facing a lot of pressure due to worsening soil fertility, deterioration of the ground-water, augmented food demand from the growing population, rainfed cultivation and extreme weather events. About 60 percent of the cultivation area registered under rainfed farming, and agricultural activities are strongly influenced by the monsoon rainfall (Rao et al., 2015). This makes farming in the country more vulnerable to climate change and climatic extremes. About 75 percent of overall rainfall in the country receives from south-west monsoon season (June–September). There are two major crop growing seasons in India, namely Kharif or summer season and the other one is Rabi or winter season. Paddy (rice), maize, cotton, jowar (sorghum), sugarcane, etc., are the principal cultivation crops during the Kharif season. The major Rabi crops comprise wheat, maize, gram, barley, rapeseed-mustard, sesame, etc.

Moreover, India is an emerging country with a population of over more than one billion. The majority of the people live in the rural areas of the country and fundamentally depending on climate-sensitive sectors such as agriculture and allied activities for their sustenance and livelihoods. There are several factors which are making Indian farming and farmers more vulnerable. Some of those are: (i) its geographical location in tropics, (ii) arid and semi-arid climatic conditions, (iii) higher population concentration, (iv) frequent droughts and floods with more intensity, (v) largely rain-fed as already mentioned, (vi) higher pressure on land and water, (vii) dominance of small and marginal farmers and (viii) lack of proper institutional support. Furthermore, due to the limited availability of investment resources and access to infrastructure and technology, farming communities in the country are not as capable of introducing and implementing adaptation strategies to diminish their susceptibility to changing climate (Lemos et al., 2013; Birthal et al., 2014).

Changing climate can affect the crop sector in several ways. According to a study by Hulme (1996), climate change is likely to physically affect crops in the following ways. First of all, alterations in rainfall and temperature might affect soil moisture and alter the

time-period and length of crop growing season. Therefore, water availability as influenced by rainfall and length of the crop growing period are essential for determining the favorable or unfavorable effects of climate change on agricultural yields. Second, yield losses can take place from changing climates, such as alterations in the rainfall and temperature, or because of extreme weather events, droughts and floods (Hulme, 1996). Third, the upper carbon dioxide levels in the atmosphere may have a favorable effect on agricultural yields owing to the increased rate of photosynthesis. This process is popularly known as the carbon fertilization effect in the climate literature (Mahato, 2014). For example, elevated carbon dioxide concentration at 425 ppm (parts per million) has significantly increased crop yields assuming no upsurge in the temperature (Aggarwal and Sinha, 1993). However, empirical literature evidenced that the adverse effects of the increased temperature have overcome the favorable influence of carbon fertilization (Aggarwal and Mall, 2002; Mall et al., 2006). The increased surface air temperature may have a substantial influence on the crop physiology (plant growth) that can affect crop yields (Hatfield and Prueger, 2015). Therefore, there are several direct and indirect ways in which climatic factors affecting the agriculture and livelihoods.

Scholarly studies on the impact of changing climate on agricultural yields or output in India have been increasing significantly over the last couple of decades. This area attracts significant research interest due to the direct dependence of agricultural practices on various climatic factors. For example, a study by Aggarwal et al. (2000) has reported that an increase in temperature reduced the rice yields in northern India during the last three decades. Similarly, in another study Aggarwal (2008) projected that crop yields would decline by around 10-40 percent due to an upsurge in the average temperature by the end of this century (2080-2100). Moreover, Kumar and Parikh (2001a) explored the functional association between climatic factors and farm revenue to investigate the sensitivity of Indian agriculture to changing climate. This study documented that around 8.4 percent of farm-level net-income is decreasing due to alterations in rainfall and temperature. The changing climate is anticipated to decrease irrigated rice yields by 4 percent and rainfed rice yields by 6 percent in the coming two decades (Soora et al., 2013). However, long term projections indicate that irrigated rice yields are more vulnerable than the rainfed. Using the Info-Crop-WHEAT model, Kumar et al. (2014) documented the anticipated sensitivity of wheat yields

to changing climate in the country and found that wheat yields will diminish by 6-23 percent by half period of this century.

The Government of India (2012), in its second national communication to the UNFCCC report, indicated that a one-degree increase in temperature could decrease the yields of rice (14 %), potato (9.5%), soybean (8.8%), wheat (7.3%) and green gram (7.2%). On the other hand, about 23 percent shortfall of rainfall in overall rainfall during the rainy season (south-west monsoon) in the year 2009-10 severely affected agricultural output of Kharif season, and it directed to 0.2 percent reduction in agricultural GDP (Prakash et al., 2016). About 15 percent of Indian crop acreages are more likely to be adversely affected due to increasing temperatures by the year 2030 (World Bank, 2013). In the absence of adaptation climatic impacts can be higher on crop yields. For example, Guiteras (2009) projected that changing climate decreases primary crop productivity by 4-9 % over 2039 in the paucity of climatic adaptation. In India, the rice yields are more vulnerable to changes in rainfall and temperature than the millet crops (Gupta et al., 2014). Further, Krishnamurthy (2012) reported that wheat output is reducing more than rice output due to climate change. These studies point out that in the absence of substantial changes in farming practices and enhancement of agricultural risk management measures, changing climate is likely to raise food and nutritional insecurity, as the outcome of declined crop yields at the national (or sub-national) level.

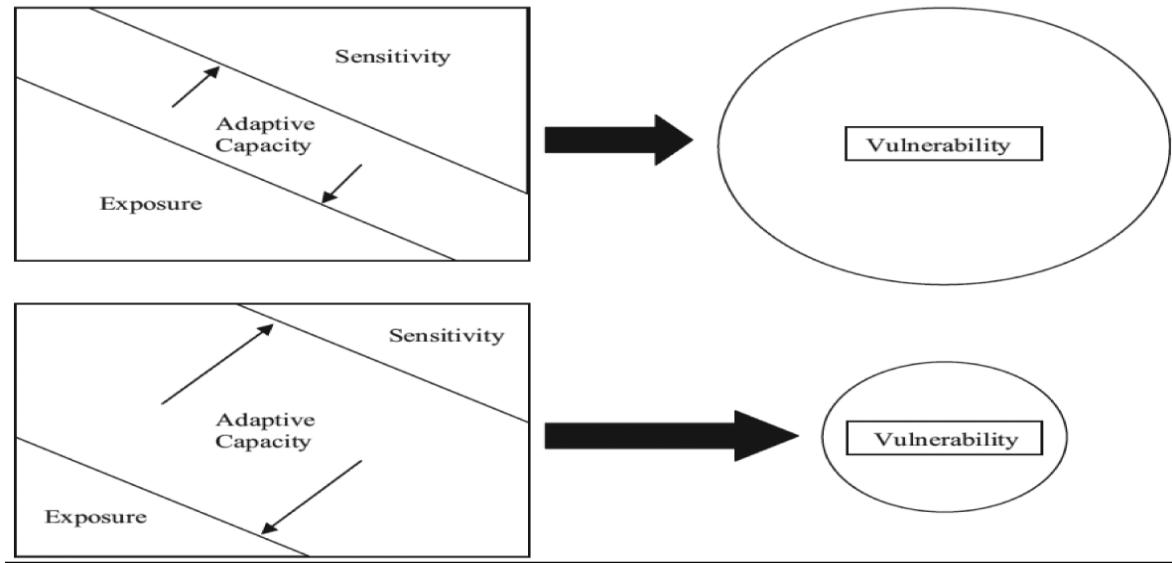
The above discussion demonstrates the potential adverse effects of changing climate on India's agricultural sector and the climate sensitivity of the farming communities. In this background, there are various issues that are essential to study. First, how do the alterations in climate variables affect major crop yields and yield variabilities at the sub-national level? Second, how climate variables will affect the vulnerability of farming communities due to climate change and extreme climatic events? Third, what are the adaptation strategies of the farmers to cope with climate change, and what are the determining factors of farmer's adaptation adoptions? Fourth, what are the constraints faced by farmers while practicing effective adaptation measures?

The level of impact and vulnerability of agriculture to changing climate is higher in the tropical regions, particularly the semi-arid areas (Parry et al., 2004; Simane et al., 2016). Under the expected climate change scenario, Indian agriculture is subjected to changing climate and weather extremes. It will have effects on the agriculture performance of Telangana too, as the substantial cultivation area falls under rainfed climate conditions. The effects of climate change on the agricultural performance of Telangana are more obvious due to the fact that a significant share of the geographical area of Telangana is situated in the dry-lands of the country (Padakandla, 2016). Moreover, among all the southern states of India, Telangana is highly vulnerable to climatic events such as erratic rainfall and droughts. The geographical area of Telangana falls in the semi-arid region of peninsular India (Bhavani et al., 2017) and has a predominantly hot and dry climate. The agriculture sector of Telangana contributes significantly to its gross domestic product and is the largest employment provider to more than 50 percent of the workforce. The adverse effect of climate change on agriculture in Telangana state will have severe implications for sustenance and livelihood.

1.4 Vulnerability to climate change

In the most general sense, vulnerability implies the conception of being susceptible to damage or harm. There is no commonly agreed definition of vulnerability because the idea of vulnerability is originated from natural hazards expanded to several areas of research such as poverty, disease risk, ecology, food insecurity, climate change, etc., with different meanings and interpretations. In recent years, the research area of vulnerability to climate change has emerged as an important one for adaptation policymaking. Broadly, the scholarly works evidenced three approaches to vulnerability such as biophysical (risk-hazard), socio-economic (political economy) and ecological resilience (Füssel and Klein, 2006; Eakin and Luers, 2006). The socio-economic approach emphasizes the socio-economic, political and cultural factors that collectively explain differential exposure to climate risks, differential sensitivities, and predominantly differential capabilities to restore the observed impacts and adapt to projected climate risks (Brooks et al., 2005).

Figure 1.1: Role of adaptive capability in determining vulnerability.



Source: Compiled from Engle (2011).

According to IPCC (2007b), “Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. Therefore, vulnerability to changing climate and climatic extremes can be defined in terms of the sensitivity, exposure, and adaptive capacity to climate's unfavorable impacts. For instance, exposure of farming systems to increased temperatures, the sensitivity of crop productivity to changes in temperature and rainfall, and adaptive capacity of farm households to shift the crop varieties to cope with climate change.

Adaptive capacity plays a momentous role in minimizing unfavorable climate change impacts and vulnerability (Smit and Wandel, 2006). Figure 1.1 presents a fundamental representation of the role of adaptive capacity in determining vulnerability. It demonstrates that farming systems are more vulnerable if it is sensitive and exposed to the impact of changing climate and less capable of dealing with it. On the other hand, the farming system is less vulnerable if it is slightly sensitive and exposed and having a greater adaptive capacity to cope with climate change. However, the research works emphasize on

the climate change impacts on Indian agriculture with reference to vulnerability is imperative as agriculture is considered to be one of the extremely sensitive sectors to climate change.

1.5 Adaptation to climate change in agriculture

Even if the climate mitigation policies are implemented appropriately, there will be a significant range of warming because of the inertia of emissions already existed on the surface. Therefore, it is widely accepted that the adaptation is a vital policy response to climate change. Similarly, effective adaptation in agricultural activities is recognized as an important policy decision to minimize the climatic impacts and vulnerability (Bradshaw et al., 2004). Farming communities have a long history of adapting to changing climate extreme weather events through a range of adaptation practices. It is significantly evidenced that alterations in temperature and rainfall reduces the agricultural yields and makes farmers vulnerable. This necessitates the farmers to undertake adaptation measures to reduce the adverse effects. Adaptations are modifications or initiatives that take place in order to cope with losses or to grab the advantage of the possibilities provided by a changing climate (IPCC, 2001a).

Moreover, adaptation is the mechanism to enhance the adaptive capacity of the society to deal with climate change over time scales, from short-term to long-term (Nath and Behera, 2011). The appropriate varieties of adaptations have the potential to minimize the adverse impacts and improve agricultural yields substantially. According to third assessment report of IPCC, “Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change” (Smit and Pilifosova, 2003). The present study primarily focuses on the agricultural sector's adaptation. Therefore, adaptation for this study is characterized as farm-households real or proposed adjustments in farming and socio-economic systems in response to observed and anticipated climatic stimuli and their ramifications and effects, which minimize damages due to climate change. The literature identified several adaptation strategies across the world depending upon socio-economic and

cultural, geographical background. The study of adaptation measures at the farm-level is essential for policymaking to enhance farmer's adaptive capacity.

1.6 Research gaps

From the above background and literature review (see chapter 2), it is evidenced that several research works are available on impact, vulnerability and adaptation in the context of climate change in agriculture across the globe and particularly in India. However, there are some specific research gaps on which this study would like to focus.

First, most of the impact assessment works on agricultural yields in India are documented at the aggregate or national level and the level of development of impact assessments at the local scale is quite at its infancy stage. These local-scale studies evidenced a considerable difference in terms of the impact. Moreover, although lots of empirical studies estimate the impact of climate change on crop yields, only a few works address the impact on yield variability. It is essential to understand the yield variance as climate change significantly affects yield variance (Chen et al., 2004; Sarker et al., 2014). Against this backdrop, this study aims to fill the gap by evaluating the climatic effect on the principal crop yields and their yield variabilities in the Indian state of Telangana.

Second, unlike African countries, climate-related vulnerability studies in the context of Indian farming and farmers are very limited. Most of these works are conducted at aggregate scales (national or state level) using secondary data. There are very few studies that have focused on climate change vulnerability at the farm-household level. Particularly, there is no organized study in Telangana state. It is essential to identify the people and places that are vulnerable to climate change impacts for making appropriate policies.

Third, research works on adaptation to changing climate among agricultural households is essential in India because a large number of the population depends on agriculture and allied activities for sustenance and livelihoods. However, there are very limited studies on the farmer's adaptation to changing climate and their determinants at the household level. No single systematic study investigated the adaptation strategies of farmers and determinants of adaptation to changing climate in Telangana.

Fourth, prior to the assessment of climatic factors influence on agricultural yields, it is crucial to determine whether there have been any alterations in the rainfall and temperature patterns. In India, minimal studies have actually looked into historical climatic data at a disaggregate level. Moreover, sub-national or local scale descriptions of historical rainfall and temperature trends assume additional significance for large geographical countries like India because there are large provincial (or regional) differences in the climate of India where one region may be experiencing drought, and another part may be experiencing flooding.

Finally, several reports of IPCC pointed out that “disasters occur first at the local level and affect local people. These localized impacts can then cascade to have national and international ramifications. As a result, the responsibility for managing such risks requires the linkage of local, national, and global scales”. Therefore, it is essential to study the vulnerability and adaptation in the context of changing climate at the micro-level, taking farming households as a fundamental unit of investigation.

1.7 Objectives of the study

Based on the elaborated background, literature review and reported research gaps, this research proceeds to examine the following specific objectives:

- (i) to analyse the trends of rainfall and temperature in Telangana,
- (ii) to evaluate the effects of climatic factors on major crop yields and their yield variability in Telangana over the period 1956-2015,
- (iii) to assess the farm households’ vulnerability to changing climate in the study area and
- (iv) to examine adaptation strategies of the sample farmers and determinants of adaptation measures in the study area.

1.8 The study area

The location for the present study is Telangana state, which is situated in the ‘Deccan Plateau’ of the central stretch of the ‘Indian Peninsula’. The bulk of economic activity takes place in the primary sector which employs around 55 percent of the total workforce of the state, either as cultivators or agricultural laborers. Having tropical semi-arid climate

conditions, the state is also prone to frequent extreme climatic events like droughts and floods with varying intensity. A substantial portion of the cultivation land of the state falls under rainfed farming. The state of Telangana experiences a semi-arid climate characterized by higher temperatures, heatwaves, erratic and uncertain rainfall. Telangana receives substantial rainfall (more than 80 percent) from the south-west monsoon, which usually begins in the month of June and ends in September. The average rainfall of the Telangana state is 906 mm.

The study area covers the entire Telangana covering of undivided¹ nine districts excluding Hyderabad due to its insignificant cultivation area. For evaluating vulnerability and adaptation to changing climate among farmers, one sample village from irrigated district (Karimnagar) and another sample village from rainfed district (Mahabubnagar) were selected. The two districts were selected not only on the basis of the amount of irrigation but also on the extent of rainfall. Karimnagar district falls under the northern agro-climatic zone, which receives higher rainfall (900-1150 mm), and Mahabubnagar district falls under the southern agro-climatic zone, which receives lesser rainfall (600-780 mm).

1.9 Data Sources and methodology

This study has utilized both secondary and primary data to examine the research objectives. The secondary data related to climatic factors such as rainfall and maximum and minimum temperatures were gathered from various government and non-government sources, like the Meteorological Department center (Hyderabad), Directorate of Economics and Statistics (Telangana), indiawaterportal.org, and other institutional sources. This data set was collected based on monthly, seasonal and annual from 1901 to 2015. Similarly, secondary data regarding agricultural related variables such as crop yields, cropped area, production, land utilization pattern, occupational pattern, etc. are collected from the Department of Statistics and Department of Agriculture, Government of India, and Directorate of Economics and Statistics (Telangana) at various levels such as state and district levels. For the collection of primary data, structured questionnaires have been used in the two sample villages. Total sample of 304 farm-households are collected, out of which 152 are from the

¹The government of Telangana bifurcated its ten districts and the number reached to 33 districts in 2019.

sample irrigated village of Karimnagar district and 152 from the sample rain-fed village of Mahabubnagar district. A detailed description of the study area, sample design, survey data collection is discussed in chapter 3.

The present study has used different methodological approaches to fulfill the study objectives. Mann-Kendall trend test and Sen's slope test were used to explore the trends and patterns in the rainfall and temperature (monthly, seasonal and annual) at both the district and aggregate state levels. Further, the Just and Pope production function and the three-stage feasible generalised least squares estimation procedure are utilized to evaluate the effects of climatic factors on mean yields and yield variability of major crops in Telangana. Furthermore, to examine the climate-induced vulnerability at the village level, the study adopted an indicator-based method and generated a "Climate Vulnerability Index (CVI)", based on which the extent of climate-change vulnerability of the two different villages of the study region can be indexed. Moreover, percentages and frequencies are being used to analyze the farmer's perception, adaptation measures, and barriers to adaptation. In order to identify the factors driving households' adaptation, binary logistic regression has been applied.

1.10 Organisation of the study

For the convenience of analysis, the present thesis is being organized into eight chapters. Chapter 1 presents the introduction of the study comprising background, research gap, objectives, data sources, and methodology.

Chapter 2 reviews the literature on climatic effects on agricultural yields, climate-induced vulnerability, and adaptation to changing climate.

Chapter 3 presents the historical description of natural disasters in Telangana, and describes the sampling strategy and data collection and profile of the sample farm households.

Chapter 4 reports the trends of rainfall and temperature in Telangana.

Chapter 5 deals with the impact of climatic factors on major crop yields. It also analyses the yield variance due to climate change in the state.

Chapter 6 analyzes the farm household's vulnerability to climate change at the village level in the study area.

Chapter 7 documents the farmer's perception of climate change and their adaptation strategies. It also presents determinants of adaptation and constraints or barriers to the effective adaptation in the study area.

Chapter 8 presents the summary of findings, conclusions and policy suggestions of the study.

Chapter 2

Review of the Literature

2.1 Introduction

As described in the first chapter, the broad objectives of the study are to examine impact assessment of changing climate on crop yields, farm-household's vulnerability and adaptation to changing climate and extreme climatic events in the Indian state of Telangana. Accordingly, this chapter attempts to review the existing literature relating to the aforementioned goals of this research work at various levels such as global, national, state and local scales. In view of that, an extensive and meticulous survey has been conducted to gather as well as review literature on various aspects of the present investigation. This has been done in the following sections. The studies that measure the impact of changing climate on agricultural yields are discussed in section 2.2. Section 2.3 presents the studies on vulnerability to changing climate relating to agriculture. Further, the research works on farmer's adaptation practices to changing climate are discussed in section 2.4. Lastly, section 2.5 concludes this chapter and provides few research gaps.

2.2 Studies on impact of climate change on agriculture (crop yields)

This section briefly reviews the literature on different methods and approaches utilized to quantify the economic impact of changing climate on agricultural yields and output. It also discusses the advantages and disadvantages of each strategy. Especially, the empirical research works measuring the effects of climate change on agricultural yields are reviewed. Several methodologies have been used to estimate the impact of global change on agriculture. However, this chapter has focused on three major types of approaches: (i) studies that rely on crop simulation models (agro-economic simulation models), (ii) cross-sectional or Ricardian models and (iii) empirical panel data models including production function approaches.

2.2.1 Crop simulation studies

There are many studies that have measured the effect of changing climate on agricultural productivity across the world utilizing crop simulation methods. Crop simulation approaches are based on well-organized experiments where plants are grown-up in laboratory circumstances or fields, simulating various effects of weather and carbon fertilization. Using these simulations, several studies have conducted analysis across the world, for instance, Adams et al. (1990), Kaiser et al. (1993), Phillips et al. (1996), Mearns et al. (1997), Tubiello et al. (2002), Rosenzweig et al. (2002), Reilly et al. (2003), Jones and Thornton (2003), Leng and Huang (2017) and Li et al. (2019). Adams et al. (1990) attempted to examine the possible consequences on US agriculture because of the severity of climate change and the increased CO₂ connected with it. The study revealed by using forecast of GCMs that variations in temperature and precipitation result in reduction in yields of wheat, maize and soybeans, and increases crop water demands. Moreover, it also revealed that increased CO₂ concentration enhances crop yields and plays a compensatory role in mitigating a portion or all of climate-induced yield changes.

A study carried out by Iglesias et al. (2000) assessed the impact of changing climate across altitudinal scales in main wheat cultivation areas of Spain using a CERES-Wheat model. Using the model, the authors examined the response of irrigation, temperature, precipitation and CO₂ concentration on wheat yield. The spatial exploration showed comparable findings to those obtained from the CERES-Wheat crop growth model. The significant inference from the empirical findings is that the variation of the simulated yield is substantially affected by water (rainfall and irrigation) and temperature fluctuations during the growing period. Further, Schneider et al. (2000) utilized an “Erosion Productivity Impact Calculator (EPIC) crop simulation model” to see how farmers respond natural variability to climate changes on in the US Great Plains. They used EPIC model, under a doubling of CO₂ scenario, to measure crop yield shifts for three classes of farmers based on their adaptation practices: absence of adaptation, twenty-year lagged adaptation and impeccable adaptation. Their findings suggest that hotter temperatures have allowed farmers to grow earlier in the spring, avoiding the possibility of heat damage during critical reproductive periods in mid-summertime. Additionally, farmers have been able to achieve higher yields with long ripening species with longer grain filling times with a longer growing season.

Another study by Rosenzweig and Parry (1994) attempted to analyse the potential effect of changing climate on food supply at a global level. They find the small decrease in global crop production due to the doubling of atmospheric CO₂ concentration, even when its beneficial effects and farm level adaptation are taken into account. The analysis also found that climate change creates a disparity in production of cereals between developing and developed countries. The food production in the developed world has benefited from climate change, whereas it has declined in the developing world. On the other hand, farm level adaptation does little to disparities, and rather aggravates it in the face of increasing cereal prices thus increasing hunger and malnutrition in the developing countries. Similarly, Kaiser et al. (1993) expounded relevant simulation models of economic, agronomic, and climatic processes and try to connect the three models to tackle the problems of climate change impacts and agricultural adaptability. They found that corn yield declines for the water stress in the drier climate due to the decrease in precipitation.

Like other parts of the world, several studies assessed the climatic impact on Indian agriculture using crop simulation models. For instance, Aggarwal and Sinha (1993), Lal et al. (1999), Aggarwal and Mall (2002), Geethalakshmi et al. (2011), Hebbar et al. (2008), Saseendran et al. (2000), Byjesh et al. (2010), Soora et al. (2013), Kumar and Parikh (2001b) and Banerjee et al. (2016) have investigated the influence of climate change and variability on crop yields. Aggarwal and Sinha (1993) discussed the effect of increasing CO₂ and temperature on the production of wheat in India. Using dynamic crop growth simulation, the study revealed that wheat yield has increased significantly with CO₂ at 425 ppm without any change in temperature for all levels of production. Moreover, one-degree Celsius temperature rise has showed insignificant impact on wheat yield, but in most places, production depending on irrigation and rainfall has increased. For two-degree Celsius temperature, wheat yields have decreased at most places. Geethalakshmi et al. (2011) examined the effect of climatic variables on rice yield in Tamil Nadu. They reported that rice yields have deteriorated around 41 percent with a 4°C upsurge in high temperature. Hebbar et al. (2008) investigated the climate-cotton production relationship using the Info-crop model in four rainfed and irrigated districts of India. The authors found more accurate results in irrigated districts than the dryland areas.

Similarly, Aggarwal and Mall (2002) explored the climate change influence on rice output in various regions of India using CERES-rice and ORYZA1N crop-simulations. The authors found that a rise in temperature from 1-2 °C at present CO₂ levels can lead to a 3-17 % reduction in yield in different regions of India. In India, Byjesh et al. (2010) analyzed the effect of climate change on maize yield in the most important crop-producing regions using the Info Crop-MAIZE approach. They documented that the rainy season maize yield is declined more in the Southern Plateau (about 35 %), whereas the winter season output is fallen more in the Mid Indo-Gangetic Plains. However, maize yields are moderately less affected in the Upper Gangetic Plains. Soora et al. (2013) studied the effect of climatic factors on regional rice production of the 21st Century in India. They reported that the rice yield of rainfed in India is probable to be declined 6 percent in the 2020s scenario. Lal et al. (1999) used “CROPGRO-soybean model” and projected 50 percent improved production of soybean for a doubled CO₂ in central India. However, a three-degree Celsius temperature rise has neutralized the positive impacts of enhanced CO₂ by reducing the total duration of crop.

Furthermore, a phenomenal study by Kumar and Parikh (2001b) analyzed the effects of weather sensitivity on rice produce using crop simulation models at four different locations namely northern, eastern, southern and western regions of India. The authors documented that climate change by 2060 (without carbon fertilization impacts) could decrease dryland yields across different regions up to 16 to 43 percent. The latest study by Banerjee et al. (2016) found that projected rice yields for the Kharif season could be declining by 20 percent in 2025 and 28 percent in 2050. A systematic review of simulation models by Mall et al. (2006) shows a clear deterioration in yields of principal cereal crops such as maize, wheat and rice under weather change. All the studies which utilized crop simulations reveal that crop production is extremely vulnerable to climate change. The main disadvantage of the crop simulation models is not including the farmer’s adaptation to climate change (Mendelsohn and Dinar, 1999). Moreover, by not permitting complete range of adjustments, crop simulation method overestimates the damages from environmental changes (Mendelsohn et al., 1994).

2.2.2 Cross-sectional (Ricardian) studies

This sub-section has reviewed some studies related to the category of cross-section studies or Ricardian approach.

Mendelsohn et al. (1994) proposed a cross-sectional method for examining how farmland value changes in response to exogenous variables such as economic, climatic, soil, and other environmental influences. The “Ricardian Method” is named after David Ricardo (1772-1823), a 19th-century classical economist who observed that land prices would represent land profitability in a perfectly open sector. The cross sectional Ricardian approach is a direct method of measuring climate sensitivity across locations. This approach utilizes the cross-sectional statistics to quantify the effect of climatic factors on net farm-revenues farm-land values (Mendelsohn et al., 1994; Mendelsohn and Dinar, 1999). The cross-sectional methodology has the benefit of thoroughly incorporating the adaptation measures of the farm households. Hence, one can obtain more accurate results using this method. As a result, the Ricardian approach has been utilized extensively in the vast number of countries across the world (for instance; Mendelsohn et al., 1994; Polsky and Easterling, 2001; Chang, 2002; Kurukulasuriya and Ajwad, 2007; Kurukulasuriya and Mendelsohn, 2008; Deressa and Hassan 2009; Wang et al., 2009; Mendelsohn et al., 2010; Budhathoki, 2013).

The economic effect of changing climate on land prices was estimated by Mendelsohn et al. (1994). A significant contribution of the analysis is that the development of the Ricardian approach which incorporates farmer’s adaptation because it captures their behavior to local climate conditions. The research was focused on cross-sectional statistics from around 3000 counties in the United States on temperature, rainfall, agricultural land values, and other economic and regional data. The main outcome of the analysis was that the evaluated effects of global change on US agriculture, involving farmer’s adaptations, were considerably smaller than projections of the conventional approach, even without the consequences of carbon fertilisation. Further, Kurukulasuriya and Mendelsohn (2006) examined 7296 farmers’ choice of crops across wide climatic range of 11 countries in Africa. Using a multinomial logit model, they regressed choice of nine most important crop

or crop-combinations on climate, soils, and other factors. The study indicated that both temperature and rainfall are extremely responsive to crop preference in African nations.

Another study by Wang et al. (2010) used a “multinomial logit model” to estimate the crop selections among the nine most popular crops on climate, soils, and other factors across China. Farmers are more likely to choose wheat when there is more rainfall, and less likely to choose vegetables and potatoes when there is less rainfall. They revealed that the existing crop distribution in each area is very different, and that each region would react to climate change in a different manner. The study proposed that the changing climate by the end of this century would encourage Chinese farmers to adjust the crop composition. Through associating choice of 949 farmers who face different climate condition across the landscape, Seo and Mendelsohn (2008) developed a multinomial logit model among the seven most popular South American crops to examine how farmers adjust their crop choice to the climate conditions they face. From the cross-sectional study the authors observed that farmers have adapted their existing crop choices to suit their local environment conditions, and crop choice/changing is in line with extensive studies about where plants are actually found. According to the empirical model, it is anticipated that farmers will move from cool-loving crops native to South America to warm-loving crops presently grown up in South America. Further, Budhathoki (2013) studied the influence of changing climate on Nepalese agriculture employing Ricardian analysis across 15 districts from all three ecological regions using a sample of 2750 farms. The study revealed that many climate variables are significant which indicate climate variable are important determinants of land value. The significant coefficients of squared terms of climate variable indicated that the relationship is non-linear.

In the context of India, several studies have utilized the Ricardian approach such as Kumar and Parikh (1998), Kumar and Parikh (2001a), Sanghi and Mendelsohn, (2008), Kumar (2009), Mendelsohn and Dinar (1999), Kumar (2011), Mishra and Sahu (2014a) and Mishra et al. (2016). The alterations in climatic variables, viz. rainfall and temperature, can lessen the rice productivity by 15 to 25 percent and 30 to 35 percent of wheat output (Kumar and Parikh, 1998). Mishra and Sahu (2014a) investigated the effects of climatic factors on agriculture in Odisha by employing the Ricardian method. They found that the climatic variables have a significant effect on farm-revenue. However, rising

temperature can affect agriculture negatively. Sanghi and Mendelsohn (2008) used Ricardian method to quantify the climate sensitivity of agriculture in two large developing countries Brazil and India. On the basis of the estimated relationship, they predicted from given broader range of possible climate change could cause annual damages between 4% and 26% in India and between 1% and 39% for Brazil by the end of the century in the absence of carbon fertilization effect.

A study by Kumar and Parikh (2001a) examined the functional relationship between climate variables and net farm revenue by introducing linear, quadratic and interaction terms. The study revealed that a climatic scenario (i.e., a 2-degree temperature rise and a 7 percent precipitation rise) have negative impacts, nearly a loss of about 8.4 percent of total net farm revenue for India. The reason for this is the negative effect as a result of temperature rise which outweighs the small positive effect as a result of precipitation rise. The study also revealed an important finding that the “temperature response function” is of inverted ‘U’ shaped i.e. with higher temperature, the loss of net farm revenue will be higher. Further, Mishra et al. (2016) conducted an investigation into the impact of climate change on agricultural production in Odisha by using “Ricardian approach”. The climatic settings (a 5 percent increase in rainfall along with a 3 to 4-degree temperature rise) enhanced the net farm revenue. All other climatic scenarios (a 15 percent increase in rainfall and 2 to 4-degree Celsius temperature rise or a 5 percent increase in rainfall and 2-degree Celsius temperature rise) yield the negative impacts on the net farm revenue. However, the major limitation of the Ricardian approach is the inability to account for time-independent location-specific factors viz. the land quality and unobservable abilities of crop growers (Barnwal and Kotani, 2013).

2.2.3 Empirical panel data models

More recently, a growing number of investigations have tended to utilize panel data approaches to evaluate the effects of climate change on crop yields. The important studies in this research method across the world are Chen et al. (2004), Deschenes and Greenstone (2007), Chen and Chang (2005) Isik and Devadoss (2006), McCarl et al. (2008), Kim and Pang (2009), Cabas et al. (2010), Lobell et al. (2011), Poudel and Kotani (2013) and Sarker et al. (2014). A pioneering study by Chen et al. (2004) evaluated the impact of climate

change on five major crop yields in the U.S. by employing Just and Pope yield function. The study found that rainfall and temperatures are risk-enhancing variables for sorghum. Likewise, climate variables are found to have an adverse influence on corn output. Chen and Chang (2005) explored the effect of climate variables on the productivity of main crops in Taiwan by utilizing panel the data approach during 1977-1996. They reported that climatic conditions contribute considerably to crop yield variance. Schlenker and Roberts (2008) found that crop yields (corn, cotton and soybeans) are increased slightly up to 29-30 oC temperature and then decreased severely due to higher warming in USA over 1950-2005.

Similarly, Isik and Devadoss (2006) documented that rainfall and temperature have a significant adverse effect on wheat, barley, potatoes and sugar beets in Idaho, USA during 1939-2001. Yield variability of wheat and barley is reducing due to climatic factors. A systematic study by Sarker et al. (2014) examined the effects of climate factors on rice productivity in Bangladesh spanning the period 1972-2009. The authors found that climatic factors are risk-enhancing for Boro, Aus and Aman rice output. Cabas et al. (2010) described that an upsurge in the variance of rainfall and temperature decrease mean yields and increase yield variability in Ontario, Canada for the period 1981-2006. Yield variability is poorly determined by both seasonal and monthly climate variables. Chen and Chang (2005) found that the changes in weather conditions contribute substantially to major crop yield uncertainties in Taiwan during 1977–1996. Crop insurance stabilizes revenues of farmers. Kim and Pang (2009) reported that the average rice yield is favorably associated to temperature and adversely associated with precipitation in Korea. However, both rainfall and temperature variables are risk-increasing factors. Poudel and Kotani (2013) examined the effects of climate change on crop yields and its variability cross seasons, altitudes and crops in Nepalese agriculture. They documented that the rice and wheat yields are negatively related with the variation of climate and crop yields more sensitive in low altitude regions. Hasan et al. (2016) examined the differences in effects of changing climate between HYVs (high yielding varieties) and TVs (traditional varieties) in Bangladesh. The primary conclusion is that HYVs for both Aman and Boro are less capable of coping with climate change pressures than TVs. Furthermore, estimation median regressions and using averages indicated that mean temperature has an extensively positive association with Aman TVs, however was adverse for Aman HYVs in all provinces of the country.

In the context of India, Guiteras (2009), Moorthy et al. (2012), Barnwal and Kotani (2013), Gupta et al. (2014), Pattanayak and Kumar (2014), Birthal et al. (2014), Kumar et al. (2015), Saravanakumar (2015), Padakandla (2016) and Nath and Mandal (2018) have utilized panel models to evaluate the impact of climatic variables on agricultural yields. For instance, Guiteras (2009) explored the influence of climate change on agricultural productivity using district-level panel information. The study found that anticipated weather change for the period 2010-2019 decrease the productivity of primary crops by 4.5 to 9 percent. Barnwal and Kotani (2013) reported that mean rice yield and its variance are adversely impacted by alterations in rainfall and temperature.

Further, Birthal et al. (2014) have assessed the sensitivity of Indian agriculture to changing climate using district level panel data during the period of 1969 to 2005. The results revealed that an increase in temperature would decline agricultural yield, while precipitation unless it was in surplus, will tend to counterbalance precarious effects of temperature. They assessed results displayed that increase in temperature in kharif and rabi seasons have a negative effect on agricultural yield. The forecasts indicated that by end of this century, a significant change in climate may reduce the yield of Indian agriculture in the short run is slight (6 %) by 2035, but will rise to 12 % by 2065 then 16 % by 2100. Krishnamurthy (2012) analyzed the effects of climatic factors on wheat and rice yields in India using district-level cross-sectional time series data. Using the fixed effects model, the author found that Northern and Eastern regions are benefiting from warming while Southern states are facing more losses. More recently, Nath and Mandal (2018) reported that temperature has a favorable effect on summer, winter and autumn rice productivity whereas precipitation has a negative impact on winter and autumn rice output in Assam (India) during 1978-2005. Gupta et al. (2014) documented that paddy yield is sensitive to the climatic factors such as rainfall and temperature. However, millets are less affected by climate factors during 1966–1999.

Using fixed effects model, Pattanayak and Kumar (2014) evidenced that both daytime and nighttime temperatures unfavorably affect rice yield during different growth stages in India over 1969–2007. Similarly, Saravanakumar (2015) found that a quadratic (inverted U shaped) relationship between (climatic factors and crop yield rice and sorghum)

in Tamilnadu, India. Padakandla (2016) reported that rice, tobacco and jowar yields are adversely impacted by temperature in Andhra Pradesh, India during 1981-2010. Further, cotton and tobacco crop yields are more sensitive to rainfall variability.

2.3 Selected studies on vulnerability to climate change

Farming and farming communities are among the first to get affected by the changing climate because of their greater dependence on the climate-sensitive sector. Several studies have evaluated the vulnerability of agriculture and farming communities to changing environments at different spatial and temporal scales. However, the conceptualization and operationalization of vulnerability are different by various scholarly communities. Moreover, approaches to evaluating vulnerability depend on the conceptualization of vulnerability. Here, this section provides a review of agricultural and farmers' vulnerability to climate change and extreme climatic events using different methodologies, particularly using composite index methodology across the world, especially for India.

2.3.1 Evidence from global studies

Studies like Gbetibouo and Ringler (2009), Deressa et al. (2008), Deressa et al. (2009b), Adger and Vincent (2005), Vincent (2004), Adger (1999), Luers et al. (2003), Eakin and Bojórquez-Tapia (2008), Acosta-Michlik and Espaldon (2008), Hahn et al. (2009), Harvey et al. (2014), Shah et al. (2013), Dumenu and Obeng (2016), Notenbaert et al. (2013), Shewmake (2008), Etwire et al. (2013), Panthi et al. (2016), Gwimbi (2009), Thorlakson and Neufeldt (2012), Malone and Engle (2011) and Atedhor (2015) assessed the climatic vulnerability of agriculture and farming communities in several parts of the globe. For instance, Gbetibouo and Ringler (2009) studied the vulnerability of South African farmers to changing climate in different regions of South Africa provinces. The study by using principal component analysis for weight assignment revealed that the Western Cape, characterized by high exposure to changing climate and also has greater capability to for adaptation to global change. This higher adaptive capacity is largely attributed to the nation's greater prosperity, advanced infrastructure, and easy access to capital.

A study by Tesso et al. (2012) analysed the vulnerability as well as resilience levels of 452 farm households in North Shewa (Ethiopia) using a primary survey of households during 2011-12 based on the classification of agro-ecological zones. Integrated Vulnerability Analysis (IVA) approach was used to develop indexes for biophysical and socioeconomic indicators. The analysis showed that farmers who live in highlands are more susceptible to natural disasters than those who live in lowlands. Similarly, mid highland farmers were less vulnerable to climatic risks compared to highland farmers. One of the early works and an important study on social vulnerability to climate change was by Adger (1999) in Xuan-Thuy district of coastal Vietnam. The study used a survey of 81 households and 11 government officials and indicator-based individual and social vulnerability analysis. The analysis revealed that the poorer households with fewer resources are more susceptible to the impacts of climatic extremes. The study exposed that social vulnerability can be enhanced by institutional and economic factors.

Among different climate related extreme events, drought and/or famine is often identified as the main threat to the agriculture sector and also livelihood security of farm households, in many semi-arid and arid regions of the unindustrialized world. Keshavarz et al. (2017) studied the ‘livelihood vulnerability’ of farm households to drought and also determined the key drivers of the ‘livelihood vulnerability’ in the condition of drought and famine in rural Iran using Tree analysis. They found that widespread famine has caused adverse impacts on various parts of Fars province, results shown that rural farmers’ livelihood vulnerability is unlike similar in various drought affected zones. Moreover, results evidenced that various adaptation activities were employed by the low, moderate and higher vulnerable households in order to cope with drought. Further, Luers et al. (2003) assessed the vulnerability as well as sensitivity of agricultural yields to changing climate and market fluctuations at farm unit level in Yaqui Valley, Sonora Mexico. The study utilized information from “remote sensing” and “Geographical Information System” (GIS). The study revealed that soil types and management practices and price fluctuations in the market influences the susceptibility and sensitivity of the agricultural yields to changing climate.

Moreover, Deressa et al. (2009b) analysed the farmers’ vulnerability to changing climate and extreme climatic events such as droughts, floods, and hailstorms in Dega,

Weynadega, and Kola districts of Nile Basin of Ethiopia. The study made use of a survey of 1000 households and probability estimation of vulnerability as expected poverty. The study revealed that growing income levels will enable farmers to meet their daily necessary requirements that diminish their susceptibility to extreme climatic conditions. Similarly, Deressa et al. (2008) evaluated the farm-household's vulnerability to changing climate in seven agriculture-based provincial states of Ethiopia using socioeconomic and biophysical indicators. The outcomes of the study evidenced that less-developed areas (semiarid areas) such as Somali and Afar are extremely susceptible to changes in climate. The other provinces like Oromia, Tigray are also vulnerable due to frequent droughts.

Shewmake (2008) estimated the potential impacts of droughts on rural South African households in Limpopo River Basin in South Africa. The study adopted the household survey of 800 farmers in 20 districts and used econometric analysis to analyze household vulnerability. The analysis suggested no statistically significant impacts of droughts on income. Rural communities of Setswana and SeSwati are highly vulnerable in comparison with other communities. Further, rural households who are lacking livestock and depending rainfed farming are also highly vulnerable. The study by Adger and Vincent (2005) suggested using "social vulnerability index" that "the country with the highest level of social vulnerability is Niger, followed by other Sub-Saharan countries such as Sierra Leone, Burundi, Madagascar, Burkina Faso, Uganda, Ethiopia and Mauritania. The less vulnerable countries are Algeria, Mauritius and Djibouti in Africa". Further, Vincent (2004) designed a socio-economic vulnerability index to evaluate relative positions of "social vulnerability" to alterations in climate and compare vulnerability at the cross-country level in Africa. The composite index results point out that "Niger, Sierra Leone, Burundi, Madagascar, and Burkina Faso" are extremely vulnerable nations in Africa to alterations in climate and water accessibility. Countries like "Djibouti, Mauritius, Algeria, Tunisia, South Africa and Libya" are less vulnerable to changing climate and water.

A pioneering study by Hahn et al. (2009) created the "Livelihood Vulnerability Index (LVI)" to measure the households' vulnerability to changing climate in two districts such as Moma and Mabote of Mozambique. They gathered survey data of 400 households on seven sub-components such as "socio-demographics, livelihoods, social networks, health,

food and water security, natural disasters and climate variability”. The outcomes of the composite index demonstrated that Moma district households are highly vulnerable due to water unavailability whereas Mabote district households are susceptible due to socio-demographic organization. Moreover, Notenbaert et al. (2013) empirically analyzed the vulnerability of agro-pastoralists in Mozambique using a vulnerability index at the household-level. Further, they also evaluated the acceptability of frequently utilized indicators of vulnerability using survey data. The outcomes of the study revealed that among 26 indicators, only nine have a substantial association with the vulnerability of study households.

A study by Shah et al. (2013) assessed the livelihood vulnerability of two rural communities in Trinidad and Tobago to changing climate using a “Livelihood Vulnerability Index.” The authors gathered survey data at the household level and combined it into composite LVIs of both communities, such as “Nariva” and “Caroni.” The outcomes of the research indicate that the households in the Nariva community are extremely vulnerable in relation to “socio-demographics, health and water security, natural disaster and climate variability.” Further, households in the Caroni community are highly vulnerable due to other LVI indicators, excluding food security. Lastly, they also found that the households having female heads are somewhat more susceptible than the households having male heads.

2.3.2 Evidence from Indian studies

In India, the scholarly works on climate-related vulnerability can be subdivided into two major categories. The first category studies generally evaluate the vulnerability of agricultural systems to changing climate at different geographical scales such as sub-national, districts and others using secondary or climate modeling data. The second category of research works deals with vulnerability to changing climate by employing household-level or community-level statistics.

2.3.2.1 Selected Indian studies on agricultural vulnerability to climate change

Several research works have been carried out in India on climate change vulnerability utilizing secondary data (namely; O’Brien et al., 2004; Patnaik and Narayanan, 2009;

Ravindranath et al., 2011; Sridevi et al., 2014; Feroze et al., 2014; Bahinipati, 2014; Varadan and Kumar, 2015; Maiti et al., 2015; Kumar et al., 2016; Rao et al., 2016; Palanisami et al., 2014; Maiti et al., 2017; Tripathi, 2017; Sendhil et al., 2018). For example, O'Brien et al. (2004) attempted to analyse the vulnerability to both climate change and globalisation at the district level in India. The analysis by adopting climate modeling and indicator-based method revealed that the districts located in states like Gujarat, Rajasthan, Madhya Pradesh are incredibly vulnerable to changing climate as well as globalisation. Similarly, the southern districts of Bihar and western districts of Maharashtra are also more vulnerable to global change. The agricultural systems in these districts are likely to face severe challenges due to changing climate. However, the districts that lie under Indo-Gangetic plains are somewhat less vulnerable areas.

Another Pan-India study by Rao et al. (2016) estimated the vulnerability to changing climate using district-level data for 572 districts of the country. In order to develop a “composite vulnerability index,” the study selected and utilized thirty-eight indicators representing “exposure, sensitivity, adaptive capacity.” The findings of the study revealed that India's peninsular and western districts are extremely susceptible to global change. Further, it is also evidenced that the Indo-Gangetic region is comparatively highly sensitive but not vulnerable for the reason that of greater adaptive capacity.

Similarly, Brenkert and Malone (2005) evaluated the climate change vulnerability of India and Indian provinces by employing the “Vulnerability-Resilience Indicator Prototype” model. The outcomes of the work presented that the Indian coastal states are highly vulnerable, particularly the states having higher population densities. “The small mountainous northern inland states show the highest resilience among Indian states.” Orissa and Tamil Nadu also show increased sensitivity to sea-storm surges. Orissa is one of the highly vulnerable states in India. Moreover, outcomes present nine states reasonably resistant to global change.

Furthermore, Sridevi et al. (2014) analyzed the vulnerability to changing climate for the districts of four south Indian states, such as Kerala, Karnataka, Tamil Nadu and undivided Andhra Pradesh. The study has chosen five vulnerability component sources such as “socio-demographic, climatic, agricultural, occupational and common property resources”

to calculate the “composite vulnerability index.” The outcomes of the composite index indicate that Kasaragod, Thiruvapur, Chamarajanagar and Adilabad are extremely vulnerable districts of Kerala, Tamil Nadu, Karnataka and undivided Andhra Pradesh, respectively. However, Kottayam, Thoothukudi, Belgaum and Hyderabad districts are the slightest vulnerable districts of Kerala, Tamil Nadu, Karnataka and undivided Andhra Pradesh, respectively.

A study by Ravindranath et al. (2011) endeavored to develop the vulnerability profiles under current and projected climate change settings for agriculture, water and forest sectors at district level of North-eastern region of India. By applying vulnerability index, principal component analysis and PRECIS model the study revealed that agriculture in Tirap, West Siang, Nalbari, Changlang and Dibrugarh districts are the most vulnerable districts to current climate change. But Kolasib, N.C.Hills, Cochar, Ukhrul and Morigaon are the districts with the least vulnerability. Palanisami et al. (2014) examined the climate change vulnerability in different districts falling in Godavari, Krishna and Cauvery river basins (GRB, KRB and CRB). The study analysed the vulnerability by using index approach. It was found that Adilabad of GRB, Anantapur of KRB, and Salem and Coimbatore of CRB are the extremely vulnerable districts to changing climate, whereas East and west Godavari of GRB, Guntur and Krishna of KRB, and Thiruvapur and Perambalur of CRB are the less vulnerable districts.

Varadan and Kumar (2015) have analyzed the agriculture vulnerability to changing climate in the southern state of India, Tamil Nadu, using district-level data. While examining the agriculture vulnerability of the State to changing climate, they tried to develop the vulnerability assessment approach. To understand the relative vulnerability position of study districts, the study assessed the growth as well as instability of various performance indicators. The outcomes of the study demonstrated that total districts of agro-climatic zones do not come under the similar category of the agricultural vulnerability of the state of Tamil Nadu.

2.3.2.2 Selected vulnerability studies using community or household level information

Very less number of vulnerability works has been done in the Indian context using community or household level information. Studies such as Pandey and Jha (2012), Panda (2017), Shukla et al. (2016), Chaliha et al. (2012), Sarkar et al. (2017), Jamir et al. (2013), Yadav and Barve (2017), Sam et al. (2017), Madhuri et al. (2014) and Bhattacharjee and Behera (2018) have been carried out at the community level. For instance, Chaliha et al. (2012) assessed the farm-household's vulnerability to changing climate and floods in Majuli island of Jorhat district of Assam using a "composite vulnerability index" and indicator-based method. The results of the analysis showed that biophysical indicators had the most significant effect on the overall vulnerability of sample villages. The authors also suggested that appropriate scientific management and planning has necessary to safeguard Majuli Island from the negative impacts of floods.

Pandey and Jha (2012) estimated the vulnerability of rural communities to changing climate using the "Climate Vulnerability Index (CVI)" in Srinagar, Uttarakhand, India and the index comprise of rural household factors of susceptibility such as "exposure, sensitivity and adaptive capability." The household information collected from two major areas such as "away to the district (ADH)" and "near to district (NDH)" and calculated using the composite index. The households that are far from the district are extremely vulnerable in terms of nourishment, natural disaster and livelihood strategies. However, the households that are close to the district are greatly vulnerable in terms of water and health. Finally, a high level of overall vulnerability was observed in the households near to district.

A study by Panda (2017) estimated the farmer's socio-economic vulnerability to changing climate and droughts in one of the most vulnerable states, Odisha (India), using an Indicator based framework. An intensive primary survey was undertaken to collect information on several demographic, livelihood and socio-economic indicators among 183 farm households in four villages of the State. The household information grouped using a "composite index" and compared vulnerability of the sample villages. The outcomes suggested that a better adaptive capability of the households in vulnerability index (VI) does not essentially direct that they are lesser vulnerable to the impacts of climate change and

vice-versa. The study also discovered that the most susceptible villagers to climatic threats are also those that engage in a variety of agricultural adaptation practices. Results exhibited that the most vulnerable villages are represented by certain features such as high level of poverty, less coverage of crop insurance, high levels of borrowing, higher migration, limited crop diversity, high dependence on agriculture for livelihood and low literacy rate.

Similarly, a study by Sam et al. (2017) estimated the rural household's vulnerability (socio-economic and livelihood) to droughts and climate change in the state of Odisha. The "Socioeconomic Vulnerability Index" and "Livelihood Vulnerability Index" were developed to understand the rural household's vulnerability using a sample of 157 households. Sample households are highly vulnerable due to socio-demographic features like illiteracy, fragile house structures and higher dependence. However, social networks reduced rural household's vulnerability. Finally, the outcomes of the study presented that rural family's vulnerable not only because of droughts but also due to inequality and poverty.

2.4 Selected studies on farmers' adaptations and determinants of adaptation

Numerous scholarly works have been carried out to understand the adaptation measures and their determining factors in different parts of the globe (for instance: Gbetibouo, 2009; Deressa et al., 2011; Fosu-Mensah et al., 2012; Below et al., 2012; Tambo and Abdoulaye, 2013; Seo and Mendelsohn, 2008; Okonya et al., 2013; Fisher et al., 2015; Ndamani and Watanabe, 2015; Tessema et al., 2013; Sarker et al., 2013; Alauddin and Sarker, 2014; Ali and Erenstein, 2017; Biggs et al., 2013; Esham and Garforth, 2013; Yila and Resurreccion, 2013; Abid et al., 2015; Hassan and Nhemachena, 2008; Deressa et al., 2009a; Nabikolo et al., 2012; Arimi, 2014; Belay et al., 2017; Khanal et al., 2018). A study by Deressa et al. (2009a) analysed the farmer's major adaptation practices to global change and determining factors of adaptation among Ethiopian farmers in the Nile Basin. The identified adaptations are tree plantation, irrigation, altering planting dates, soil conservation and use of various crop varieties. The outcomes of the "discrete choice model" revealed that literacy, age, sexual category, household wealth, credit facilities, extension, social capital and information on climatic factors are the major determining factors of adaptation.

Similarly, Deressa et al. (2011) identified farmer's awareness of changing climate and adaptation approaches to cope with changing climate in Ethiopia's Nile basin. The outcomes of the study indicated that the age of the farmer, household wealth and social capital are the major determining factors of perception on global change. Similarly, literateness, family size, gender, ownership of livestock, extension and credit facilities are substantially affecting farmer's adaptation to changing climate. Belay et al. (2017) examined how smallholder farmers aware of climate variability or change, what adaptation approaches they practice, and determining factors of adaptation practices in the Oromia Regional State (Rift-Valley) of Ethiopia. Authors found that about 90 percent of farmers have observed climate change, and nearly 85 percent farmers made efforts to adapt using practices like irrigation facilities, crop diversification, planting date adjustment, soil and water conservation, intensive use of inputs and integrating crop with livestock. The results of the model indicated that family size, age, education, gender, farming experience, livestock ownership, farmland size, access to climate information, access to the market, income and extension were the important factors determining small farmers' choice of adaptation.

Hou et al. (2017) estimated the key factors those are influencing farmer's perceptions of drought and other extreme climatic events and examined how perceptions affect adaptation performance among nine provinces in China using household level survey information. The results revealed that nearly half of the sample farm-households perceived that the drought extremity and intensity had increased during the last decade. The econometric analysis shows that around 8 percent additional farmers will adopt surface irrigation pipes in response to famine if early cautionary information about famine is provided. Moreover, farmers that observed increasing famine severity are more expected to adapt by adopting irrigation and water-saving technologies. A synthesis of adaptation studies in Canadian agriculture was presented by Smit and Skinner (2002), which established four major categories: (i) technological progress contain the development of crops, climate and weather information, resource management, innovations and irrigation, (ii) government programs, subsidy and support programs and crop insurance, (iii) farm financial management contain usage of crop insurance and investment in crop futures & shares, and (iv) farm production practices contain crop diversification, crop intensification, changes in land use and livestock production.

Okoroh et al. (2016) identified the adaptation measures employed by the farming communities to cope with climate change using survey data of 220 farmers in Imo State, Nigeria. The significant portions (more than 75 percent) of the farmers were conscious of climate change. Experience and self-observation over the years were the important factors that are influencing awareness of climate change. The most number of the farmers opined that in latest periods, droughts and flooding had increased which is a sign of climate change. The study evidenced that crop rotation practice was the major adaptation strategy practiced by the farmers against the adverse effects of changing climate.

Hassan and Nhemachena (2008) studied the determining factors of adaptation measures at the farm-level in 11 African nations using the “multinomial choice model” by employing survey data of 8000 farms. The outcomes presented that “mono-cropping” is a significant agricultural exercise sensitive to changing climate. The sample farmers are practicing multiple cropping, livestock and irrigation. Access to local market, credit and extension facilities, higher land and investment and technology are crucial factors for adaptation. Yila and Resurreccion (2013) evaluated the determining factors of small-scale farm household’s adaptation measures to changing climate in the semi-arid area of Nguru, Nigeria. The results of the “stepwise multiple linear regression model” have presented that nine factors are significantly determining the farmers’ adaptation. The crucial determinants of adaptation are literacy, land tenancy, the gender of the farmer, migration, credit and extension accessibility, family size and farming experience.

Sarker et al. (2013) investigated paddy grower’s adaptation approaches to climate change and determining factors of coping and adaptation in a high drought-affected district of Bangladesh using survey data of 550 farm households. The effective coping practices of farmers are improvement in irrigation facilities, direct paddy seeding, short-period paddy varieties, shifting sowing and harvesting dates, shifting land under paddy to mango and agroforestry and use of several crop varieties. The outcomes from the “multinomial logit model” revealed that age, literateness, sexual category, farmer’s assets, yearly agricultural income, operational holding size, credit and extension facilities and accessibility of electricity and subsidy are the significant determining factors of farmers’ adaptation in the sample region.

Dhakal et al. (2016) identified the adaptations in the agriculture sector in the Rautahat district of Nepal by examining adaptation practices using primary data. It was witnessed that farmers had been using various adaptation activities like the improved irrigation system, use of high-yielding variety seeds (HYVs) and moving to hybrid seeds, developed production technology and enhanced access to pesticides. Fenton et al. (2017) evidenced that microfinance assists coping by decreasing sensitivity to environmental hazards. The study also found evidence that microfinance enables adaptation by assisting households to overcome financial hurdles of adopting adaptation activities which decrease sensitivity or exposure.

Agrawal and Perrin (2008) analysed the adaptation strategies in less developed countries and authors have mentioned about five basic coping strategies i.e. mobility across space, storage across time, diversification across assets, communal pooling across households and exchange across market (weather related insurance schemes). Yu et al. (2014) in their analysis of adaptation strategies in North East China have found that farmers opted for longer season varieties for maize and rice which lead to a significant increase in yield and that bio physical factors are critical in determining adaptation strategies. Mertz et al. (2009) have concluded in their study of farmers' adaptation that socio economic factors are more important for changes in adaptation. These include poverty, extension, micro-credit and social capital.

In the context of India, studies like Udmale et al. (2014), Tripathi and Mishra (2017), Singh et al. (2017), Sahu and Mishra (2013), Patnaik et al. (2016), Pandey et al. (2018), Panda et al. (2013), Panda (2013), Mwinjaka et al. (2010), Mishra (2012), Mehar et al. (2016), Kharumnuid et al. (2018), Jha et al. (2018), Jain et al. (2015), Banerjee (2015), Bahinipati and Venkatachalam (2015), Sharma et al. (2014), Mishra and Sahu (2014b), Narayanan and Sahu (2016) and Dhanya and Ramachandran (2016) have investigated to analyse the adaptation measures and their determinants. For example, Mwinjaka et al. (2010) identified the farmers coping measures and government policies in the state of Gujarat using a survey of 160 respondents. The study outcomes presented that involvement in income stabilization activities, shifting to non-farm activities, altering planting dates, irrigation and soil conservation are the effective coping strategies of the farm households.

Moreover, considerable farmers are accessing policy support from the government. However, crop insurance and credit facilities remain out of reach for farm households.

Panda et al. (2013) has examined the household level factors in Odisha (India) that let farmers adapt to climate variability and change in several ways and specific adaptation activities which increase their adaptive capacity. Results that found in this study have seen in two ways. First, households with a decent source of water facility for irrigation can plant water-intensive crops, since if required they can substitute work in pumping water for scanty rainfall. Second, farmers with access to crop insurance can plant high yielding variety crops. Overall, this study concludes that the importance of crop insurance to adapt to climate change to mitigate agricultural yield loss at the household level.

Bahinipati and Venkatachalam (2015) evaluated the farming households' adaptation activities to extreme climatic events such as floods and cyclones in three flood-affected districts of Odisha using a survey of 285 farm households. This study also identified determining factors of adaptation adoptions. The observed adaptation practices are salinity and flood-tolerant local seeds, soil conservation, acreage reduction, mixed cropping, crop diversification and pest and insect management. The reported determining factors are access to extension services, access to MGNREGS work, crop loss reimbursement and credit facilities.

Mishra and Sahu (2014b) investigated the farm household's perception about climate change and their adaptation behavior to changes in precipitation and temperature in the Kendrapara district of Odisha using survey data of 150 farm-households. The authors also presented determinants of adaptation using the "multinomial logit" model. Primary adaptation practices are double seeding, irrigation, migration, crop variety change and shifting land to commercial crops. The study outcomes reported that irrigation facility, education, land ownership and holding size are influential determinants of adaptation.

Tripathi and Mishra (2017) have made an attempt to address an important question associated with climate change strategy, i.e., how to motivate farmers to adapt to climatic changes using group data gathered from farmers in Uttar Pradesh India on climate change. Outcomes exhibited that although farmers are conscious of long-term changes in climatic variables (rainfall and temperature, for instance), they are not able to identify these vagaries

as climate change. The study found that farmers are shifting their agrarian and farming practices. These include changing sowing and harvesting time, farming of crops of short period varieties, changing cropping pattern, intercropping and investment in irrigation. Thus these changes can be considered as the inactive response or adaptation plans to climate change.

Udmale et al. (2014) analyzed the farm household's perception of climate change and drought and adaptation measures in the "Upper Bhima" catchment area of Maharashtra using survey data of 223 farm-households. A substantial portion of farmers are observed with regard to climate change and its harmful impacts on farming systems. The study demonstrated that crop harvest storage, migration, savings, selling livestock, etc., are the effective drought management practices of the farming community. Moreover, shifting planting and harvesting dates, drought-resistant crops, acreage reduction, drip and other modern irrigation methods are the significant adaptation practices of the farm households.

Several studies evidenced the barriers or constraints to undertake adaptation strategies by the farming households across the world. For example, Deressa et al. (2009a) reported that capital and financial constraints, lack of accurate information on coping measures are the main barriers to climate adaptation. Moreover, Sarker et al. (2013) reported the practical barriers of several adaptation strategies by the farming communities. The significant barriers include lack of awareness on suitable adaptations, lack of climate information, inadequate credit facilities, shortage of labour and limited irrigation facilities. Further, Mishra and Sahu (2014b) documented the barriers faced by farming households while adapting to climate change. The socio-economic background, poor financial conditions, inadequate infrastructure facilities, lack of irrigation and extension service are the important constraints to undertake adaptations. Another study by Panda (2016) evidenced that inadequate irrigation facilities, lack of weather information, lack of government support and lack of drought-resistant seeds on time are significant barriers to adaptation to changing climate.

2.5 Summary and Research Gaps

Based on the above literature review, this study has found some research gaps and those gaps have already been presented in a detailed manner in the first chapter (see section 1.6). This section provides some essential issues from the literature as mentioned earlier. While most of the empirical studies have focused on aggregate level, very few attempts have been made to study the impact of climate change on agriculture at sub-national or regional level. Moreover, given the fact that the agricultural system of a particular region is different from that of another region therefore, the issue should be carefully addressed for region. Moreover, scholarly works did not focus on the agricultural yield variability due to changes in climatic factors in the Indian context. However, it is essential to understand the yield variability due to changes in climate factors (Kim and Pang, 2009). It can be observed that most of the vulnerability studies have concentrated in African nations. In the context of India, several studies have measured the vulnerability of farming and farmers to climate change but a significant portion of works was based on secondary data or simulation-based studies. However, it is important to understand the farm or rural household's vulnerability to climate change at the household or community level. Furthermore, unlike African countries, climate-related adaptation studies in the context of Indian farming and farmers are very limited. Research works on adaptation to changing climate among agricultural households is essential in India because a large number of the population depends on agriculture and allied activities for sustenance and livelihoods.

Chapter3

Study Area, Sample Design and Profile of the Sample Households

3.1 Introduction

This chapter proceeds to discuss the socio-economic profile of the sample study area in Telangana. It also highlights the sampling procedure involved in primary data collection and the rationale behind selecting the districts, then mandals and finally the study villages. A broad overview of two sample districts and a brief profile about the study villages are dealt with subsequently. More specifically, the chapter attempts to highlight geographic and demographic features, administrative set-up, occupational distribution, and distribution of operational land holdings, land utilization pattern, cropping pattern and irrigation development of these two districts. These descriptions are based on the information collected in field surveys in two regions and also from some published sources. More precisely, this chapter has been classified into four parts. The first part, after a brief introduction about Telangana, deals with the selection of districts and study villages and the rationale behind the selection. The second part deals with the field survey and data collection with survey schedule. The third part deals with the profiles of selected districts and the fourth part deals with the profiles of the study villages and farmers.

3.2 A brief introduction to Telangana state

The Indian state of Telangana is located in the south-central part of peninsular India on the Deccan plateau. Geographically, it is located around 18.1124° North latitude and 79.0193° East longitude. Telangana is sharing its borders with four states; Karnataka to the West, Maharashtra to the North and North-West, Chhattisgarh to the North, and Andhra Pradesh to the South, East and North-East. It is India's 12th largest state in terms of both populations (3.52 crores) and geographical area (112,08 lakh hectares) (Government of Telangana, 2016). The state has 42 revenue divisions and 459 revenue mandals in 10 districts. There are 8695 gram panchayats and also 10434 revenue villages in the state. The geographical area of the state is categorized into three agro-climatic zones. Table 3.1 shows information about three agro-climatic zones along with the districts in respective zone, climatic conditions, soil

types, major crops and percentage share of the agro-climate zones in overall geographical area of state. Geographically, the state is positioned in a semi-arid area with a fundamentally hot and dry weather. The climate of the state is predominantly characterized by erratic rainfall and high temperatures. The agricultural systems in the state are susceptible to extreme climate events such as droughts, floods and heatwaves. The normal rainfall of the state is around 905.3 mm. Almost 80 percent of yearly rainfall is received from the south-west monsoon (June to September). The average high temperature of the state is around 42°C during summer (March-May) and about 22–23°C in the winter season (late November to early February).

Table 3.1: Agro-climatic (A-C) zones of Telangana and their characteristics

A-C zones	Northern A-C Zone	Central A-C Zone	Southern A-C Zone
Districts	Karimnagar, Adilabad, Nizamabad	Warangal, Medak, Khammam	Nalgonda, Ranga Reddy, Mahabubnagar
Total Area	35.5 lakh ha, 33.68%	30.6 lakh ha, 29.03%	39.3 lakh ha, 37.29%
Annual Rainfall	Normal rainfall 900-1150 (mm)	Normal rainfall 800-1150 (mm)	Normal rainfall 500-670 (mm)
Soil type	Red earths with loamy soils (Chalkas) and Black Cotton soils	Red earths with loamy soils (Chalkas), Black Cotton soils and Red sandy soils	Red soils, Chalkas
Major crops	Rice, Maize, Cotton, Jowar, Groundnut, Redgram, Soybean	Rice, Cotton, Maize, Groundnut, Greengram, Jowar, Chilli	Cotton, Maize, Rice, Redgram, Groundnut, Jowar, Greengram

Source: Compiled from the Drought Manual, Telangana, 2016.

The population of Telangana, which was 309.87 lakhs in 2001, rose to 350.04 lakhs in 2011, demonstrating a decennial growth rate of 13.58 percent as against 18.77 percent in the preceding decade. The sex ratio is 977 in the state. The density of population is 312 per sq. km in 2011, which is lesser than the Pan-India average of 382 per sq. km as per the 2011 census. The literacy rate is 66.54 percent in 2011. Male literacy stands at 75.04 percent and female literacy at 57.99 percent in 2011. Further, agriculture is the mainstay of the state

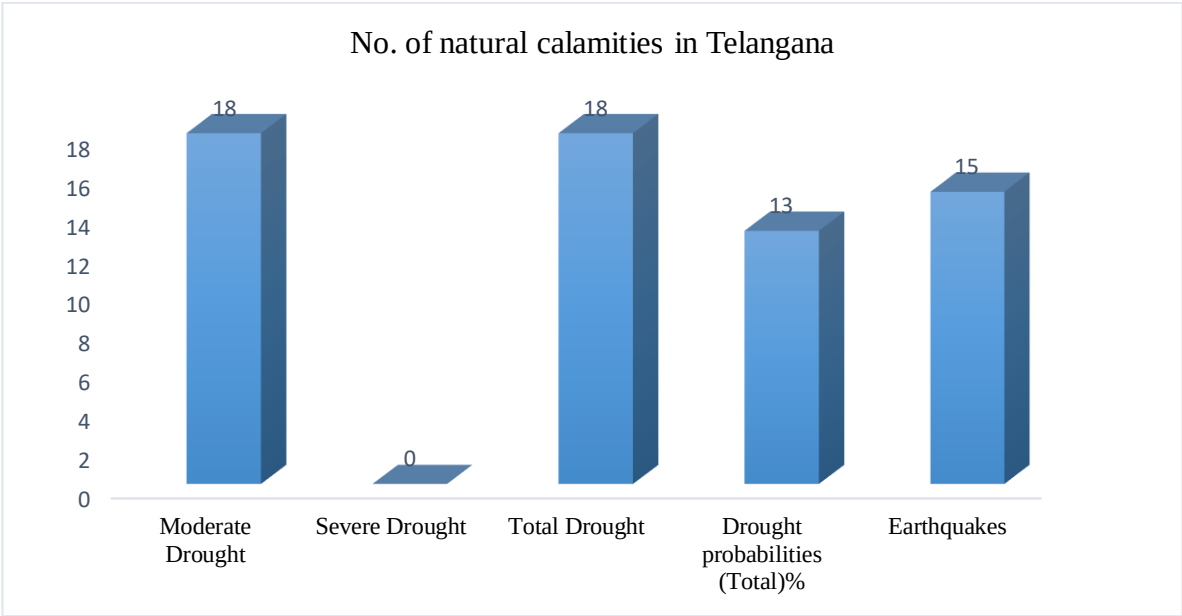
economy of Telangana with agriculture and animal husbandry sector together contributing 14 percent to Gross Value Added (GVA) at current prices for the year 2015-16 as against 16.1 percent in 2012 (Government of Telangana, 2016). It is an important sector in providing employment to more than half of the state's population for their livelihood. However, agriculture caters a deal of demand of industrial sector so far as the raw material requirements and other inputs are concerned. Thus, considering both forward as well as backward linkages with other sectors, the contribution of agriculture will be much more than what is being estimated. Therefore, it plays a pivotal role in the state economy of Telangana and also in providing decent livelihood to majority of her Population.

The major crop growing seasons such as Kharif (rainy or monsoon) and Rabi (summer) are called as 'Vanakalam' and 'Yasangi' in Telangana. The Kharif is an important cropping season in Telangana and rice, cotton, maize, soybean and pulses are the main crops in this season. Similarly, rice, maize, jowar, groundnut, sesame, sunflower are the primary crops in the Rabi season. However, the major crops grown in Telangana are paddy, cotton, maize, jowar, bajra, sugarcane, soybean, groundnut, sesame, sunflower, mango, redgram, greengram, vegetables etc. In addition, the net area sown and gross cropped area of Telangana during the year 2014-15 were 43.77 lakh hectares and 53.15 lakh hectares respectively. Further, the cropping intensity is 1.21 percent during 2014-15. Moreover, about 85 percent of farmers in the state are either marginal or small.

Among the different states of India, Telangana is one of the most vulnerable state to the impacts of weather related extreme events like droughts, increased warming and floods. Since more than 50 percent of the cultivation area is rain-fed, which making the crop sector more vulnerable to the vagaries of monsoon. As a result, rainfall plays a significant role in Telangana's agricultural economy. The actual precipitation received differs from district to district. Almost 80 per cent of rainfall is received for the period of June to September (South-west monsoon). Even though the received amount of rainfall is relatively high, its distribution throughout the monsoon season is highly irregular as well as erratic. Given the less amount of normal rainfall in the state, the natural calamities like increased warming and drought have made it one of the very much vulnerable regions to the impacts of weather

extremes in India. Droughts, increased warming and floods occur often with varying frequencies and intensities.

Figure 3.1: Natural Calamities in Telangana state (During 1800-2010)



Source: Climate profile of India 2010 and Compendium of Environment statistics, Andhra Pradesh 2011-2012.

Figure 3.1 shows the number of years that the state faced the natural calamities over the period 1800 to 2010. It can be seen from Figure 3.1 that between 1800 to 2010 Telangana has faced 18 moderate drought years, 15 earthquake years. The drought probability for the state is 13 percent. Frequent natural tragedies in the state have affected the agricultural output and livelihood of the farmers. In addition to an existing scenario of frequent disasters, climate change in future is anticipated to have adverse implications for the agriculture in Telangana. In observation of the vulnerability of Telangana to natural calamities (weather extremes) and the possible impacts of climate change on agricultural sector through the changes in precipitation and temperature Telangana is ideally appropriate for undertaking the present investigation. The main emphasis of the study is to measure the effect of

changing climate on agricultural productivity at state level, vulnerability of farm-households to weather changes and droughts and also to explore adaptation behavior of rural farmers at the household level. Furthermore, Figure 3.2 to 3.4 presents the map of Telangana, the map of Karimnagar and Mahabubnagar districts.

Figure 3.2: Telangana state map with former ten districts



KARIMNAGAR MANDAL/TEHSIL MAP

Adilabad

Maharashtra

Chhattisgarh

Nizamabad

Medak

Warangal

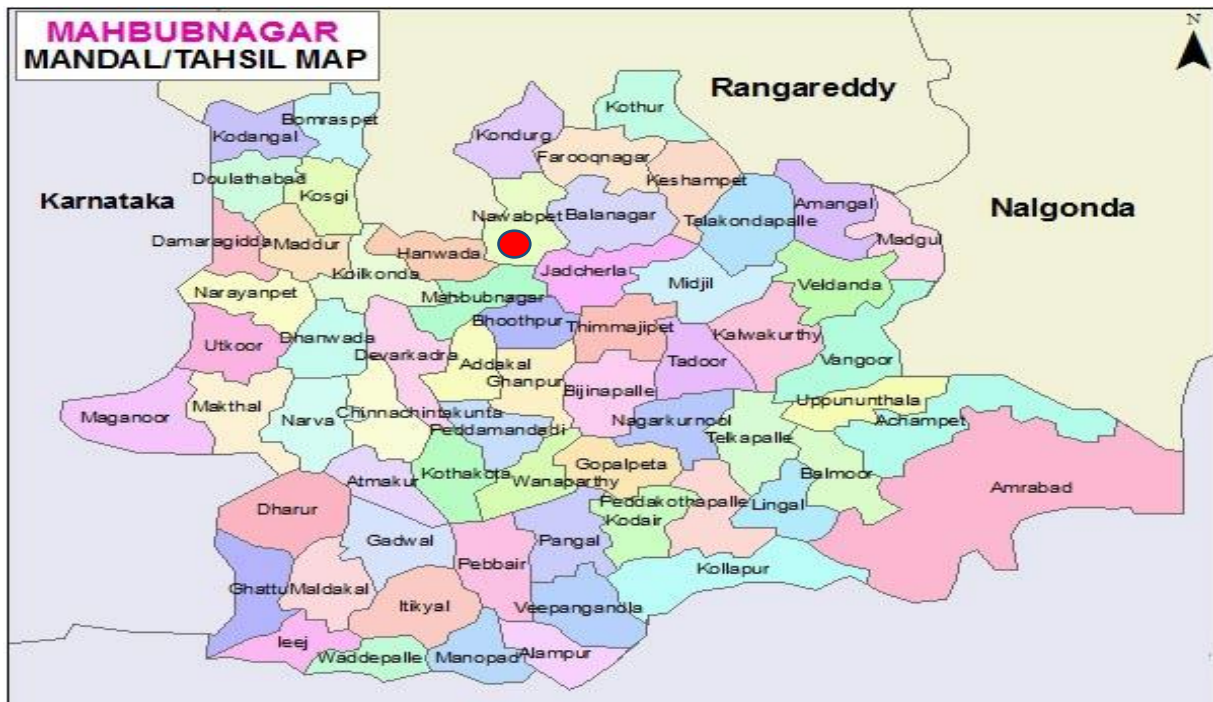
Legend

- State Boundary
- District Boundary
- Mandal/TeHSil Boundary

0 4 8 16 24 Miles

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(Last Updated on 25th Aug 2015)

Figure 3.4: Mahabubnagar district map of Telangana



3.3 Selection of sample districts and study villages

The fact that macro-level research works can merely explain the current state affairs in Telangana's agriculture sector at the sub-national level and its relative place compared to the agricultural sector elsewhere in the world makes it necessary to perform a primary survey. Therefore, in order to gain an understanding of the particular factors/barriers involved in the region's agricultural sector, such as farmers' production decisions in changing climatic conditions, their adaptation activities to cope with climate change, strategies to improve crop yields, etc., we need to study things at micro-level taking into account individual farm-households as units of observation. This in turn calls for a field survey at farm-household level. In the primary survey, there involves a long process to land on the primary survey unit, i.e., household and for that we need to pinpoint the respective districts and all the way to the sample villages. The sample districts and villages are chosen based on the fundamental objective of this work to provide a comparative analysis of crop-production decisions, coping and adaptation strategies to changing climate, determinants of adaptation

measures, understanding farmer's socio-economic vulnerability, etc. in both irrigated ecosystem and rainfed ecosystem. Climate sensitivity of farming and farmer's vulnerability to changing climate and extreme climate events for example droughts and floods in both areas is another reason for selecting two specific districts.

For this study, Karimnagar and Mahabubnagar districts are selected. The Karimnagar district is an irrigated one whereas Mahabubnagar is a rainfed district based on the claim that if one district has more than 60 percent of its overall cultivation area irrigated by tanks, canals or some other source other than rainfall, it is regarded as the irrigated area, if not it is characterized a rainfed area (Chand et al., 2010). The Karimnagar district is having 71.67 percent of the irrigated cultivation area whereas Mahabubnagar is having on 33.91 percent of irrigated area (Statistical Year Book, 2016). Therefore, this study has chosen two districts belonging to two diverse ecosystems; this helps to study the differential aspects of the above-mentioned agricultural sector issues in both areas. A lengthy procedure was involved while choosing the sample villages and many underlying principles were prioritized. Hence, the step-by-step procedure involved in selecting sample villages begins with the selection of study districts, then the revenue mandal, finally the study villages. The sample villages are chosen based on the following reasons, keeping the study objectives exclusively in mind:

1. The irrigated village is well connected with canal and tank irrigation, and farmers are able to cultivate in two seasons. In other words, the assured canal and tank water facility may allow the farmers to go for cultivation in both Kharif and Rabi seasons. On the other hand, village farmers who live in rainfed areas only begin farming after getting southwest monsoon rains, and they only do so once a year during the Kharif season.
2. The extent of sensitivity and susceptibility of farmers to changing climate and extreme climatic events may not be the same in the sample villages. Droughts, erratic rainfall and floods are the major climatic risks for both study village farmers. It is essential to understand the different coping mechanisms of farmers in these villages.

The selected two districts are Karimnagar and Mahabubnagar. Out of 57 revenue mandal of Karimnagar, this work selected one representative mandal as Dharmaram. Finally, one village (Pattipaka) from that mandal is selected as study village. In the same way, out of 64

revenue mandal of Mahabubnagar, this work selected one representative mandal as Nawabpet. Finally, one village (Ippatur) from that mandal is selected as the study village. The sampling strategy used in choosing the samples in each position was that of two-stage random sampling, in which villages constituted the primary sampling units and the secondary and final sampling unit were the farm-households. We surveyed all the sample farmers in both villages. Information items from a total sample of 304 farm-households were collected, out of which 152 are from rainfed village of Karimnagar district and 152 from irrigated village of Mahabubnagar district. The distance of the study village (Pattipaka) from the major city Karimnagar is around 33 km and about 24 km in the case of the study village (Ippatur) of Mahabubnagar district.

Table 3.2: Sample selection for primary data collections

State	District	Mandal	Village	Total Households	Total No. of sample households
Telangana	Karimnagar (Irrigated)	Dharmaram	Pattipaka	721	152
	Mahabubnagar (Rainfed)	Nawabpet	Ippatur	757	152
Total				1478	304

Source: Author's field surveys.

3.4 Field survey and data collection

The primary survey was conducted in the study villages during the time of November 2018 to April 2019, during six months period. At first, the details about the land holding of the farmers of the particular village were collected from the office of the revenue inspector (RI) and village revenue officer (VRO). Even the Sarpanch and village elders were also consulted regarding the landholding records of farmers in that particular village. This helped in cross-checking the response of farmers when asked about the farm size. Most of the illiterate farmers thought me to be as a government agriculture officer and me doing the survey for some of their immediate benefits. However, I had to convince them that this was

purely for my research work and the data collected would be kept confidential. Sometimes, some farmers even denied to spare some time but, allowed me to carry out their interview after getting convinced.

For the purpose of field survey, the definition of ‘household’ given by NSSO 61st round is being used which says that “the household is defined as a group of persons, closely related in blood relations, living together and usually having their meals from a kitchen.” Data on general background and the farming methods of each farm household in the sample village have been collected by interviewing the head of the household. For carrying out this survey one schedule of questions was used. The questionnaire is given in the **Appendix-3.A**. The data collected by that survey schedule are described briefly as follows:

3.4.1 General household information

Data collected under this head contains asset structure of the household, income from different sources such as agriculture, livestock, petty business and trade, waged labour, and other income sources. This information was little difficult to extract from the households. Generally, income from agriculture is difficult to estimate. But, we calculated this one on the basis of the average crop production that a farmer gets from one acre of land multiplied by its price. Similarly, pricing livestock is also difficult. But, consulting with the household head and taking his approximation is the only way to determine the price of livestock. However, other components can be estimated easily. The data on contact with extension service, off-farm income source, access to credit market, distance to local market, expenditure for food consumption, education are collected directly from the respondent.

3.4.2 Demographic information

The demographic particulars like age, gender, relationship with the head, education level, occupation and its type are collected easily. Age is measured in terms of number of years while education is measured in terms a scaling technique where 0 indicates illiterate, 1 for primary, 2 for high school and 3 for higher education. However, this can be measured by the number of years spent in school and colleges. But an inherent loophole of this technique is

that sometimes if someone spends more than one year in the same class, then it gets over estimated. So the scaling technique is appropriate one.

3.4.3 Information on land size and input use

Information regarding farm size, land ownership, input use and sources of irrigation has been collected under this head. Details about the plots regarding their positions, soil quality, lease status, terms of the lease and the source of irrigation are collected from the household. The land takes three positions like lower, middle and uplands. Lease status is measured by using the same scaling technique where 1 represents for ownership, 2 for leased in and 3 for leased out and so on. Terms of lease also varied from one farmer to another within one location. It may take place as 50-50 share cropping where both parties share both cost and benefit equally. It might take place in the form of cash rent where share cropper just pays a certain amount of cash for a particular unit of land. The data on input use includes data on a variety of seeds, whether it is the high yielding variety (HYV) or traditional/local variety, the quantity of fertilizer, its type (NPK) and quantity per unit of land.

3.4.4 Information on credit

The information about credit, its sources and the purpose of loan taken are recorded. Data on the amount of money taken/borrowed by the farmers from various sources like the commercial banks, money lenders, cooperatives, friends, relatives, self-help groups (SHGs) in the village, and so on and their corresponding interest rates are collected. Because, the interest rate varies from one source to another, sometimes from farmer to farmer in the same source depending on the amount of loan, especially in case of the loan taken from the informal sector. The loan taken in particular year is also recorded. Important information related to outstanding amount has also been collected. However, these data are very difficult to record since households are very hesitant to reveal the information about the loan outstanding amount. However, I have tried my level best to convince them that the information will be highly confidential and to be used for my research study somehow solve the issue.

3.4.5 Information on climatic damages and coping mechanisms

This set of information is pivotal in the study since it explains the last objective of the study. Here we collected the entire area being devoted to a particular crop and how much of that is being damaged by different climatic risks like drought (different types), floods and weather-induced diseases etc. Then the farmers' coping mechanisms to tackle those menaces are recorded very carefully. The problem here is a big gap between the coping mechanisms cited by the literature and the ones adopted by the farmers in the field. Again, these coping mechanisms are not universal. So sometimes we face difficulties to identify their coping mechanisms by directly asking them what they do to tackle those menaces. But, when crosschecking with few educated farmers we modified slightly and mentioned their coping mechanisms which pretty much localized. The coping mechanisms are also categorized for various climatic risks separately. Because, the very nature of climatic risks faced by the farmers in different ecosystems also varies.

3.4.6 Information on farmer's awareness on climate change

We collected data on the awareness of farmers about climate change and the recurring nature of extreme weather events in both regions are documented by collecting data on erratic rainfall pattern, rising temperature, recurring extreme weather events, information received from news and weather forecast, from other farmers, and finally the adaptation measures implemented by the farmers to cope with changing climate in Karimnagar and Mahabubnagar districts. We collected data on farmer's adaptation to changing climate in both regions are documented by collecting data on several coping strategies such as changing planting dates, irrigation, changing crop varieties, crop insurance, etc. Lastly, observed barriers to adaptation are also collected in the sample villages.

3.4.7 Information on farmer's vulnerability to climate change

Information regarding vulnerability indicators is collected in the sample villages. There are three components of vulnerability such as exposure to climate, the sensitivity of systems and adaptive capacity of farming systems. In each component, there are several indicators. The

information regarding each indicator was collected. These indicators are useful to construct an index to assess the farm-household's vulnerability to changing climate.

3.5 Brief profile of selected sample districts

As mentioned earlier, two districts are selected for our study, namely Karimnagar and Mahabubnagar, belonging to two diverse ecosystems. Karimnagar district belongs to the irrigated ecosystem whereas Mahabubnagar belongs to the rainfed ecosystem. In this section, this study gives a brief profile of both the districts.

3.5.1 Geographical characteristics of sample districts

Karimnagar district is one of the northerly-situated districts of Telangana and lies around between 18°00' to 19°00' North latitudes and 78°30' to 80°00' East longitudes. The district is surrounded in the west by Nizamabad, south by Medak and Warangal districts, north by Adilabad district and Maharashtra state and east by Chhattisgarh state. It lies in the northern agro-climatic zone of Telangana. It has an overall geographical area of 11,823 sq. km, being ranked as the sixth (6th) among the districts.

Similarly, Mahabubnagar, the southern district of Telangana, lies approximately between 15°55' to 17°20' North latitudes and 77°15' to 79°15' East longitudes. The district is surrounded by the northern district of Rangareddy, the east districts of Nalgonda, Prakasam and Guntur, the south district of Kurnool and the west state of Karnataka. Mahabubnagar district is under the southern agro-climatic zone. The district has an overall geographical area of 18,432 sq. km, being ranked as the first (1st) among the districts.

3.5.2 Administrative Setups of sample districts

Table 3.3 presents the administrative setup of Karimnagar and Mahabubnagar districts. The administrative setup of Karimnagar district includes five revenue divisions, namely Karimnagar, Jagtial, Sircilla, Peddapalle and Manthani divisions, and 57 mandals. It has 13 assemble constituencies, four municipalities and 1207 gram panchayats. Further, the administrative setup of Mahabubnagar district includes five revenue divisions viz.

Mahabubnagar, Gadwal, Narayanpet, Nagarkurnool and Wanaparthy. It has 64 mandals, 14 assemble constituencies, five municipalities and 1330 gram panchayats.

Table 3.3: Administrative setups of selected districts

S.No.	Administrative setups	Karimnagar	Mahabubnagar
1	Geographical area (sq. kms.)	11,823	18,432
2	Revenue divisions	5	5
3	Mandals	57	64
4	Census villages	1,079	1,537
5	Gram panchayats	1,207	1,330
6	Nagar panchayats	5	6
7	Municipalities	4	5
8	Municipal corporations	2	0
9	Assembly constituencies	13	14

Source: Statistical Year Book (2016), Directorate of Economics and Statistics, Telangana.

3.5.3 Demographic features of sample districts

The demographic profiles of population in sample districts are demonstrated in Table 3.4. The overall population of Karimnagar district is 37.77 lakhs as per 2011 census, out of which overall male population is 18.81 lakhs and the total female population is 18.95 lakhs. The district covers 10.55 percent of the state's territory and supports 10.78 percent of state's overall population. The density of population of Karimnagar district is 319 (per sq. km) as against 312 people per sq. km of Telangana. The district's sex ratio is 1008 female per 1000 male, which is more than the state's average (988). The overall literacy rate of the district is 64.15 percent, and the male and female rate is 73.65 and 54.79 percent, respectively.

Likewise, the total population of Mahabubnagar district is 40.53 lakhs as per 2011 census, out of which overall male population is 20.50 lakhs and the total female population is 20.03 lakhs. The district covers 16.45 percent of the state's territory and supports 11.58 percent of state's overall population. The density of population of Mahabubnagar district is 220 (per sq. km) as against 312 people per sq. km of Telangana. The district's sex ratio is 977 females per 1000 males, which is less than the state's average (988). The overall literacy rate of the district is 55.04 percent, and the male and female rate is 65.21 and 44.72 percent, respectively.

Table 3.4: Demographic profile of population in Karimnagar and Mahabubnagar

S.No.	Characteristics of Population	Karimnagar	Mahabubnagar
1	Total population	37,76,269	40,53,028
2	Male population	18,80,800	20,50,386
3	Female population	18,95,469	20,02,642
4	Sex ratio	1,008	977
5	Density of population (per sq. km)	319	220
6	Decadal growth rate of population	8.15	15 .34
7	Child population (0-6 years)	3,36,053	5,27,230
8	Male child population	1,73,647	2,73,914
9	Female child population	1,62,406	2,53,316
10	Literacy rate (in percentage)	64.15	55.04
11	Male literacy rate (in percentage)	73.65	65.21
12	Female literacy rate (in percentage)	54.79	44.72
13	Percentage to total population of the state	10.78	11.58

Source: Statistical Year Book (2016), Directorate of Economics and Statistics, Telangana.

3.5.4 Occupational distribution of sample districts

The occupational distribution of workers in Mahabubnagar and Karimnagar districts are shown in Table 3.5. The overall number of workers in Karimnagar district is 1876768 out of which main workers constitute 1590304 or 84.74 percentage of overall workers. The marginal workers constitute around 15.26 percent or absolute number 286464. Moreover, further classification of main workers presents some light on the composition of main workers, where we got to know that out of total workers 21.67 percent are cultivators, agricultural laborers constitute 36.76 percent, household industrial workers constitute 9.12 percent. Other workers constitute around 32.45 percent.

Table 3.5: Occupational distribution of workers in selected districts (2011 Census)

Districts Classification	Karimnagar		Mahabubnagar	
	Total	Percentage	Total	Percentage
Main workers	15,90,304	84.74	18,15,643	87.18
Marginal workers	2,86,464	15.26	2,66,858	12.82
Total	18,76,768	100	20,82,501	100
Main workers classification				
Cultivators	3,44,598	21.67	5,48,983	30.24
Agricultural labourers	5,84,654	36.76	7,62,853	42.02
Households industry	1,44,953	9.12	46,497	2.56
Other workers	5,16,099	32.45	4,57,310	25.18

Source: Same as in Table 3.4

On the other hand, the total number of workers in Mahabubnagar district is 2082501 out of which main workers constitute 1815643 or 87.18 percentage of overall workers. The marginal workers constitute around 12.82 percent or absolute number 266858. In addition, further classification of main workers presents some light on the composition of main workers, where we got to know that out of total workers 30.24 percent are cultivators, agricultural laborers constitute 42.02 percent, household industrial workers constitute 2.56 percent. Further, other workers constitute around 25.18 percent. A comparison of the occupational distribution between two districts shows that there are more cultivators and agricultural labourers in Mahabubnagar district than Karimnagar.

3.5.5 Major indicators of agricultural sector in sample districts

The major indicators of the agricultural sector of sample districts are reported in Table 3.6. The overall cropped area of Karimnagar district is 699618 hectares and 888224 hectares' area is gross cropped area and 511012 hectares is the net sown area. Cropping intensity refers to growing of several crops from the same field over the course of a single farming year. It is one of the major indicators of agricultural development, presents a notable percentage, i.e., 173 percent for Karimnagar. The net irrigated area is 315658 hectares, similarly, the gross irrigated area is 501440 hectares. The annual fertiliser consumption is about 1.70 lakh tonnes.

Table 3.6: Major indicators of agricultural sector in selected districts

S.No.	Major indicators (Area in Hectares)	Karimnagar	Mahabubnagar
1	Total cropped area	6,99,618	9,78,287
2	Net area sown	5,11,012	8,66,004
3	Gross cropped area	8,88,224	10,90,606
4	Area under food crops	4,52,453	5,56,699
5	Area under non-food crops	2,47,165	4,21,588
6	Cropping intensity (in %)	173	125
7	Net irrigated area	3,15,658	2,48,669
8	Gross irrigated area	5,01,440	3,31,759
9	Fertilisers consumption (in Tonnes)	1,69,710	1,24,485

Source: Statistical Year Book (2016), Directorate of Economics and Statistics, Telangana.

Furthermore, the total cropped area of Mahabubnagar district is 978287 hectares and 1090606 hectares' area is gross cropped area and 866004 hectares is the net sown area. Cropping intensity, one of the major indicators of agricultural development shows a moderate percentage, i.e., 125 percent for Mahabubnagar. The net irrigated area is 248669 hectares, likewise, the gross irrigated area is 331759 hectares. The annual fertiliser consumption is about 1.24 lakh tonnes which is more or less similar to the state's average consumption.

3.5.6 Patterns of land use in sample districts

Table 3.7 demonstrates the land utilization patterns of selected districts of Telangana. The Karimnagar district has an overall geographical area of 1182 thousand hectares, with forest covering approximately 21.2 percent (250 thousand hectares) and miscellaneous groves and trees accounting for around 0.9 percent. Moreover, permanent grazing covers around 3.5 percent of overall land, while culturable waste covers 2.1 percent. Further, large percentage of land (8.1 percent) is being used for non-agricultural purposes. Uncultivable as well as barren land represents approximately 8.1 percent of the total, while new fallow land accounts 10.6 percent. However, just 2.3 percent of the overall area is represented by other fallow land. Furthermore, approximately 43.2 percent of the overall geographic area is the net sown area of Karimnagar district.

Table 3.7: Pattern of land utilization in selected districts

Land use pattern	Karimnagar	Mahabubnagar
Forest area	2,50,410 (21.2%)	2,55,596 (13.9%)
Barren and uncultivable land	95,963 (8.1%)	87,562 (4.8%)
Land put to non-agricultural uses	96,249 (8.1%)	1,00,163 (5.4%)
Culturable waste	24,253 (2.1%)	28,479 (1.5%)
Permanent pastures and other grazing lands	41,283 (3.5%)	17,560 (1.0%)
Land under various tree crops and groves	10,770 (0.9%)	6,466 (0.4%)
Current fallows	1,25,386 (10.6%)	3,01,248 (16.3%)
Other fallow lands	26,974 (2.3%)	1,80,122 (9.8%)
Net area sown (includes fish & prawn ponds)	5,11,012 (43.2%)	8,66,004 (47.0%)
Geographical area	11,82,300 (100%)	18,43,200 (100%)

Source: Statistical Year Book (2016), Directorate of Economics and Statistics, Telangana.

On the other hand, Mahabubnagar district has an overall geographical area of 1143 thousand hectares, with forest covering approximately 13.9 percent (256 thousand hectares) and miscellaneous groves and trees accounting for around 0.4 percent. In addition, permanent grazing covers around 1 percent of overall land, while culturable waste covers 1.5 percent. Further, large percentage of land (5.4 percent) is being used for non-agricultural purposes. Uncultivable as well as barren land represents approximately 4.8 percent of the total, while new fallow land accounts 16.3 percent. About 9.8 percent of the overall area is represented by other fallow land. Furthermore, approximately 47 percent of the overall geographic area is the net sown area of Mahabubnagar district.

3.5.7 Distribution of operational land holdings in sample districts

The dissemination of operational holdings of sample districts is presented in Table 3.8. The marginal farm households with an average farm holding of 0.44 ha represent approximately 67.5 percent in the district of Karimnagar. Subsequently, the small farm households, with an average of 1.40 hectares of farm-land, account for 21.9 percent of the overall operational holdings. Semi-medium farm households account for 8.4 percent of overall farmers, with an average farm area of 2.6 hectares. Next, around 2.09 percent of the rural farmers are medium-sized and have an average of 5.45 hectares of landholdings. Lastly, large farm

households of Karimnagar represent just about 0.16 percent but possess 15.6 hectares of average land.

Table 3.8: Operational holdings by major size groups in sample districts (2010-11).

Size groups	Karimnagar			Mahabubnagar		
	No. of Operational holdings	Area Operated (in ha)	Average Holding size (in ha)	No. of Operational holdings	Area Operated (in ha)	Average Holding size (in ha)
Marginal (<1.0 ha)	4,47,037 (67.49)	1,97,256	0.44	5,69,133 (57.94)	2,65,070	0.47
Small (1.0-2.0 ha)	1,45,008 (21.89)	2,03,103	1.40	2,49,386 (25.39)	3,55,356	1.42
Semi-medium (2.0-4.0 ha)	55,390 (8.36)	1,46,025	2.64	1,24,201 (12.64)	3,28,081	2.64
Medium (4.0-10.0 ha)	13829 (2.09)	75425	5.45	36014 (3.67)	202455	5.62
Large (>10.0 ha)	1081 (0.16)	16881	15.62	3580 (0.36)	53901	15.06
All classes	6,62,345 (100)	6,38,690	0.96	9,82,314 (100)	1,204,862	1.23

Note: Figures in parentheses denote percentage shares of each size category to the total sum.

Source: Same as in Table 3.4

On the other hand, the marginal farm households with an average farm holding of 0.47 ha represent approximately 57.9 percent in the district of Mahabubnagar. Subsequently, the small farm households, with an average of 1.42 hectares of farm-land, account for 25.4 percent of the overall operational holdings. Semi-medium farm households account for 12.6 percent of overall farmers, with an average farm area of 2.64 hectares. Further, around 3.7 percent of the rural farmers are medium-sized and have an average of 5.62 hectares of landholdings. Last of all, large farm households of Mahabubnagar district represent just about 0.36 percent but possess 15.06 hectares of average landholdings. Another comparison between Karimnagar and Mahabubnagar districts about the distribution of operational landholding; it can be observed that operating holdings in Mahabubnagar District are larger

than the district of Karimnagar. Mahabubnagar district has more marginal farmers than Karimnagar district along with average land holding being more in the case of Mahabubnagar district.

Table 3.9: Cropping pattern of selected districts (2014-15)

Districts		Karimnagar		Mahabubnagar	
Crops	Area	% to total cropped area	Area	% to total cropped area	
Rice	2,78,433	39.80	1,60,770	16.43	
Maize	1,08,091	15.45	1,82,493	18.65	
Cotton	2,14,586	30.67	2,67,683	27.36	
Sugarcane	2,046	0.29	1,320	0.13	
Total cereals & millets	3,89,302	55.64	3,70,822	37.91	
Total pulses	17,551	2.51	1,29,509	13.24	
Total foodgrains	4,06,853	58.15	5,00,331	51.14	
Total oilseeds	32,511	4.65	1,49,624	15.29	
Total food crops	4,52,453	64.67	5,56,699	56.91	
Total non-food crops	2,47,165	35.33	4,21,588	43.09	
Total cropped area	6,99,618	100	9,78,287	100.00	

Source: Statistical Year Book (2016), Directorate of Economics and Statistics, Telangana.

3.5.8 Cropping pattern of selected districts

Table 3.9 demonstrates the cropping pattern of sample districts of the study. Rice and cotton are the dominant crops in Karimnagar district occupying around 69 percent of overall cropped area. Overall cereals and millets account for the majority of land area allocated to food crops, while pulses only occupy less than 2.5 percent of total cropped area. However, oilseeds occupy about 4.65 percent of total cropped area in Karimnagar. On the other hand, in Mahabubnagar district, cotton, maize and rice are the principal crops occupying around 62 percent of overall cropped area. Overall cereals and millets account for the majority of land area allocated to food crops. Moreover, pulses and oilseeds are also major crops in Mahabubnagar occupying around 28.5 percent of total cropped area.

3.5.9 Irrigation scenario in sample districts

The distributions of net-irrigated areas by different sources for selected districts are presented in Table 3.10. Karimnagar district is situated in irrigated ecosystem having more than 71 percent irrigated area to total cultivated area. Among sources of irrigation, dug-wells is the main source of irrigation in Karimnagar. However, tanks and tube wells are also covers a substantial portion of irrigated land.

Table 3.10: Distribution of net-irrigated area by different sources in selected districts

Net-irrigated area sources (in ha.)	Karimnagar	Mahabubnagar
Tanks	18,451	3,727
Canals	810	29,579
Tube wells	51,354	1,97,940
Dug wells	2,44,984	4,472
Other sources	59	12,951
Total	3,15,658	2,48,669
Area irrigated more than once	1,85,782	83090
Gross area irrigated	5,01,440	3,31,759
% of irrigated area to total cultivated area	71.67	33.91

Source: Similar to Table 3.9

On the contrary, Mahabubnagar district is situated in rainfed ecosystem having less than 34 percent irrigated area to total cultivated area. Among different sources of irrigation, tube-wells is the main source of irrigation in Mahabubnagar. However, canals and other sources are also covers a considerable portion of irrigated land. Another comparison between Karimnagar and Mahabubnagar districts about the percentage of irrigated area; it can be observed that irrigated area in Karimnagar district is higher than the district of Mahabubnagar.

3.6 Profile of study villages and sample respondents

The brief profile of the selected villages and sample farmers is described in the current section. This section primarily analyses about the location of the study villages, the demographic profile of sample households and household characters, occupation and

sources of income and its distribution, infrastructural facilities including the transport and electricity facilities, irrigation facilities, credit availability and its accessions, ownership of agricultural implements and asset position. Lastly, we discuss farm size and its ownership, the average size of holding, land type along with land position and soil quality and so on.

3.6.1 Location of study villages

The study villages were selected from two mandals of two districts, Karimnagar and Mahabubnagar. From each mandal one village was chosen for primary survey. The study village (Pattipaka) is situated under Dharmaram mandal of Karimnagar district (See Figure 3.3 of administrative division map of Karimnagar district). The main reason for choosing this mandal of Karimnagar district for the present study is the higher developmental facilities like irrigation for agriculture as compared to the Eastern part of the district. Agricultural machineries and irrigation facilities are better in Central and Northwestern parts. This village is well connected with tank and canal irrigation. The village under study is 10-14 kms from the local town called Dharmaram town and 33 kms away from Karimnagar, the main town. Moreover, the climate of this village is warm and temperature usually reaches the highest in April-May and the lowest in January.

Table 3.11: Social background of the sample farm-households

Social background	Pattipaka	Ippatur	Total
Scheduled Tribes (ST)	12	16	28
Scheduled Castes (SC)	44	31	75
Other Backward Class (OBC)	85	87	172
Other Classes (OC) or General	11	18	29
Total	152	152	304

Source: Author's field surveys.

Similarly, the study village (Ippatur) was selected from Nawabpet mandal of Mahabubnagar district. This village is having a purely rainfed ecosystem for crops cultivation. There is no assured irrigation in the form of a tank, canal, or lift irrigation for this village. The farming practices get started only after receiving Southwest monsoon. However, in rest of the year,

there is no water for cultivation leading significantly stopping or reducing of cultivation. Hence, this suited to our purpose of studying the farming practices in purely rainfed ecosystem. The village under study is 6-7 kms from the local town called Nawabpet town and 24 kms away from Mahabubnagar, the major town. This village shares similar soil quality. Furthermore, the climatic condition of this village is warm and temperature usually reaches highest in April-May and lowest in January. Table 3.11 presents the social background of the sample farm-households in selected villages.

3.6.2 Demographic Profile and Household Characteristics

The distribution of the family size of sample farmers in the selected villages is reported in Table 3.12. The household size was divided into three categories: small size with five members or less than five, medium family size with 6-9 members, and large family with ten members or more than that. In irrigated village viz. Pattipaka, the total surveyed farmers were 152. Out of 152 surveyed farmers, 98 farm-households belong to small family size, 48 farm-households belong to medium family size, and the rest six farm-households belong to large or big family size. On the other hand, in the rainfed village, namely Ippatur, 152 farm-households were interviewed. Out of 152 surveyed farmers, 110 farm-households belong to small family size, 40 farm-households belong to medium family size, and the rest two farm-households belong to large or big family size. The rainfed village households are relatively in the category of small and medium size.

The age structures of sample farmers in both villages are presented in Table 3.12. It can be seen that the young farmers are significantly less in number. Only three farmers are observed in both villages. The majority of farmers are over 51 years of age and 40-50 in both villages. This suggests that most farmers are experienced in agricultural operations. However, there is a slight disproportion in the 31-39 age group of farmers in sample villages, suggesting that more farmers are young in the rainfed village as compared to an irrigated village. Conversely, it can be observed that in the 40-50 age group more farmers are young in the irrigated village as compared to a rainfed village. Further, in terms of educational level, the picture in the irrigated village is different from that in the rainfed village. In the irrigated village, a higher number of farmers are illiterates, and they have below-primary, primary and secondary levels of education. The higher secondary level of

education for farmers is the least recorded in the study villages. It can be evidenced that only eight farmers in the irrigated village and six farmers in the rainfed village belong to the higher secondary level of education. The comparison reveals that in the rainfed village, more farmers are educated than irrigated area.

Table 3.12: Household sizes, age and educational level of farmers in sample villages

Household Size	Pattipaka	Ippatur	Total Household
≤ 5	98	110	208
6 to 9	48	40	89
≥ 10	6	2	7
Total	152	152	304
Age Structure			
≤ 30	1	2	3
31 -39	21	28	49
40 - 50	57	47	104
≥ 51	73	75	148
Total	152	152	304
Level of Education			
Illiterate	77	59	136
Below primary	24	35	59
Primary	22	34	56
Secondary	21	18	39
Higher secondary	8	6	14
Total	152	152	304

Source: Author's primary surveys.

3.6.3 Occupation, Income Distribution and Sources

This section presents the income distribution through several occupations of sample households surveyed in the study villages. Among different income sources, it has been reported that farm-households in the study area dependent on agriculture significantly. However, agriculture comprises both own as well as leased cultivations. The yearly income from several sources of farm-households is presented in Table 3.13. It has been evidenced that farmers in the irrigated village are getting a substantial portion of the income from agriculture, followed by labour and employment. However, livestock takes up a relatively

insignificant portion of the farm-household income. Agriculture is contributing around 73.2 percent, whereas private and government employment contributing 7.9 percent of overall yearly income in the irrigated village. Likewise, labour and livestock are contributing 11.1 and 2.2 percent, respectively. Further, it has been witnessed that farmers in the rainfed village are getting a significant share of the income from agriculture, followed by labour and employment. Agriculture is contributing around 69.9 percent, whereas waged labour contributing 9.8 percent of overall yearly income in the rainfed village. Similarly, employment and livestock are contributing 6.9 and 2.1 percent, respectively.

Table 3.13: Overall annual income and its different sources.

Income sources (in lakhs)	Pattipaka	Ippatur	Total
Agriculture	80.21 (73.2%)	78.55 (69.9%)	158.76 (71.6%)
Labour	12.11 (11.1%)	10.98 (9.8%)	23.09 (10.4%)
Livestock	2.42 (2.2%)	2.32 (2.1%)	4.74 (2.1%)
Employment*	8.64 (7.9%)	7.72 (6.9%)	16.36 (7.4%)
Others	6.20 (5.7%)	12.73 (11.3%)	18.93 (8.5%)
Total	109.58 (100%)	112.30 (100%)	221.88 (100%)

Note: * indicates private/govt employment and “Others” income includes self-employment, petty business and others. Source: Primary surveys.

3.6.4 Operational land holding and average land holding

Following the existing literature and National Sample Survey (NSS) classifications, this study made slight modifications and then categorized farmers into four landholding groups. The categorization is as follows: marginal farmer (< 1 hectare or 2.47 acre), small farmer (1-2 hectares or ≥ 2.47 to < 4.94 acres), medium farmer (2-5 hectares or ≥ 4.94 to < 12.35 acres) and large or big farmer (more than 5 hectares or ≥ 12.35 acres). The distributions of sample households by farmer category are shown in Table 3.14. The study regions are dominated by large number of marginal and small farmers. More than 80 percent of farmers belong to these two farmer categories in both study villages.

Table 3.14: Distribution of sample households by farmer category

Farmers types	Pattipaka	Ippatur	Total
Marginal farmers	85 (55.9%)	78 (51.3%)	163 (53.6%)
Small farmers	42 (27.6%)	51 (33.6%)	93 (30.6%)
Medium farmers	25 (16.4%)	20 (13.2%)	45 (14.8%)
Large farmers	00 (00%)	3 (2.0%)	03 (1.0%)
Total farmers	152 (100%)	152 (100%)	304 (100%)

Source: Primary surveys.

Table 3.15: Distribution of operational landholding and average holding

	Pattipaka		Ippatur		Total	
Farmers types	Total Operational Holding	Average Operational Holding	Total Operational Holding	Average Operational Holding	Total Operational Holding	Average Operational Holding
Marginal	106.80	1.26	118.54	1.52	225.34	1.38
Small	134.82	3.21	177.05	3.47	311.87	3.35
Medium	147.66	5.91	138.88	6.94	286.54	6.36
Large	00	00	38.50	12.83	38.50	12.83
Total	389.28	2.57	472.97	3.12	862.25	2.84

Source: Primary surveys.

The distribution of operational land holdings and average holdings in the sample villages are reported in Table 3.15. It can be evidenced that the overall operational holding as well as average holding of the irrigated village is less than the rainfed village. Similarly, it is witnessed that in the case of marginal and small farmers, the overall operational holdings as well as average holdings in the irrigated village are lower compared to the rainfed village. However, in the case of medium peasants, aggregate operational holding in the irrigated village is higher in contrast with the rainfed village. In the irrigated village (Pattipaka), the overall operational holding is 106.8 acres in the case of marginal farmers, making an average holding of 1.26 acres, while the overall operational holding of small farmers is 134.82 acres, the average holding being 3.21 acres. The overall holding is 147.66 acres for

medium farmers and the average holding is 5.91 acres. In the rainfed village (Ippatur), the overall operational holding is 118.54 acres in the case of marginal farmers, making an average holding of 1.52 acres, while the overall operational holding of small farmers is 177.05 acres, the average holding being 3.47 acres. The overall holding is 138.88 acres for medium farmers and the average holding is 6.94 acres. The average holding of large farmers is 12.83 acres.

3.6.5 Irrigation Facility

In the irrigated region, the farmers mainly depend on tank and canal irrigation, which are assured sources. Apart from that, there are dug wells and tube wells where canal and tank irrigation does not reach; farmers depend on them and use modern methods to irrigate. The plots are irrigated by using the lift irrigation from dug well or nearby river flows, and mostly water is fetched by a pipe with an electric motor. The major sources of irrigation in Pattipaka village are tank, canal, dug and tube wells, etc. However, on the other hand, there is a deficiency of irrigation in the rainfed village (Ippatur). Farmers initiate farming practice after receiving the monsoon rainfall. However, during the rainy season, a natural stream originates from the hill near the fields. Thus, the plots near the stream which flows in-between get irrigated by the stream. But, the plots are having big height of bund which helps in absorbing the rainwater. A small number of farmers are depending on bore wells and tanks for irrigation.

3.6.6 Credit Facility and Accessibility

Table 3.16 shows the various sources of credit as well as the purposes of borrowing. It is found that majority of farmers still depends informal sources like friends and relatives as well as the village rich or the village money lenders. In the sample villages most of the farmers depends on cooperative and commercial banks. However, the major source of borrowing is friends and relatives, followed by village money lenders. The reason behind this is the complicated procedure that the farmers face while applying for the loan in formal credit institutions. But, the easy availability and accessibility of informal credit attracts the farmers, even though the interest rate is quite high in comparison to bank interest rate. In the

rainfed village, commercial banks, relatives and friends and moneylenders are the major credit sources. Similarly, in the irrigated region, cooperative banks and relatives and friends are the important sources of credit.

Table 3.16: Sources and purposes of credit received in sample villages

Loan Sources	Pattipaka village	Ippatur village
Relatives and friends	43 (28.3%)	17 (11.2%)
Moneylenders	8 (5.3%)	25 (16.4%)
SHGs saving group	7 (4.6%)	19 (12.5%)
Cooperative bank	62 (40.8%)	9 (5.9%)
Commercial bank	3 (2.0%)	76 (50.0%)
Purpose of Loan	Pattipaka village	Ippatur village
Agriculture	66 (43.4%)	43 (28.3%)
Education	8 (5.3%)	23 (15.1%)
Social Activity	12 (7.9%)	11 (7.2%)
Meet basic needs	16 (10.5%)	32 (21.1%)
Medical expenditure	9 (5.9%)	5 (3.3%)
Purchase of land/house	18 (11.8%)	11 (7.2%)

Source: Primary surveys.

Table 3.17: Cropping pattern in study villages

Crops	Pattipaka		Ippatur	
	Area (acres)	% of total area	Area (acres)	% of total area
Rice	193.47	49.70	80.67	17.06
Cotton	137.15	35.23	178.75	37.79
Maize	8.30	2.13	137.95	29.17
Turmeric	3.2	0.82	00	0.00
Mango	35.30	9.07	4.00	0.85
Pulses	11.86	3.05	71.60	15.14
Total	389.28	100	472.97	100

Source: Primary surveys.

The analysis of purposes of borrowing shows that in irrigated region, people take loan for various purposes among which the major one is agriculture, followed by the basic needs, purchase of land or house construction, social activities like marriage, major festivals etc. However, in rainfed region, farmers borrow for agricultural purposes and basic needs, education and social activities. The mode of borrowing in case of informal credit market is

not fixed one. It is governed by many socioeconomic factors like the amount of loan being taken, the amount of mortgage being put and the economic condition of the borrower and finally the kind of relation that exists between the lender and borrower.

3.6.7 Crops and Cropping Pattern

The cropping pattern of both the sample regions is presented in Table 3.17. In the irrigated village, farmers are growing several crops including paddy, cotton, maize, turmeric, mango and pulses. However, the number of crops grown in study region is peculiar one in the sense that mostly rice is grown in large areas in the irrigated region (about 50 % of GCA). The cropping pattern is highly skewed and biased towards rice. Other crops are grown in smaller proportion. Cotton crop is the second most cultivated crop in irrigated village. Similarly, in the rainfed village, farmers are growing several crops including paddy, cotton, maize, turmeric, mango and pulses. The cropping pattern in rainfed village is considerably skewed and biased towards cotton and maize. Other crops are grown in smaller proportion. Paddy crop is the third most cultivated crop in rainfed village.

3.7 Summary

In this chapter, we have highlighted a broad profile of Telangana state economy and the selection of study districts and finally the sample villages in the study region which is divided into two ecosystems, i.e., irrigated region and rainfed region. The rationale for selecting the villages for the field survey is also discussed. The discussion about data collection and problems encountered during the field survey in general and for specific variable in particular follows after that. We then proceeded on to discuss the various aspects of two districts on comparative basis. We discussed a brief profile of two districts on comparison basis which comprises demographic, socio economic and agrarian structure of the districts economy. Finally, we discussed the demographic profiles, distribution of land holding, sources of income through various occupational structures, crops and cropping pattern, irrigation facilities, credit facility and accessibility and other facilities available in the study villages.

Chapter 4

Analysis of Rainfall and Temperature Trends in Telangana

4.1 Introduction

In the previous chapter, we discussed about the socio-economic profile and other characteristics of the survey households in the sample villages. In the milieu of changing climate, detecting the trends of precipitation (rainfall) and temperature in Telangana and its sample districts is important to understand the impacts of these changes on crop yields and vulnerability of farming communities. The goal of the present chapter is two-fold, first, to analyze the rainfall and temperature trends in Telangana that took place for the last century (precisely: 1901-2015). Second, to estimate the rainfall as well as temperature (mean, minimum and maximum) trends in our study districts of Karimnagar and Mahabubnagar. To accomplish the aforementioned aims, we collected available rainfall and temperature data and applied various statistical techniques to analyze the changes in climatic factors.

Studying temperature and precipitation trends and patterns has been a major concern during the past century because of the shreds of evidence that the earth's climate has undergone a change (Callendar, 1961). This increasing concern about recent climate change has heightened the need for studying the pattern and trends of precipitation and temperature at the global, regional, sub-regional and local scales. According to studies, the earth's surface warmed at a rate of 0.74 ± 0.18 degrees celsius in the 1906-2005 timeframe (IPCC, 2007b). The IPCC (2007b) "fourth assessment report" demonstrated that most of the rise in temperature had been observed during two different periods: 1901-1940 (0.350°C) and following since 1970 (0.55°C). A more recent analysis of global surface temperature records displays that the increase in average annual global land surface temperature is about $0.61 \pm 0.16^{\circ}\text{C}$ in the past 150 years (Folland et al., 2001), and increase in mean land temperature is around 0.9°C in the past 50 (1950-2000) years (Rohde et al., 2013). The changes in temperatures have not been identical globally, but different over regions of the world. Rainfall has raised greater than before in the 20th century in the northern Europe and northern, central Asia and eastern parts of south and north America, while it declined in the

Mediterranean, Sahel, South Africa and regions of Southern Asia, and the drought affected area have likely to increased more since the 1970s in the world (IPCC, 2007b).

The portions of evidence suggested that changing climate has affected the rainfall and temperature characteristics globally. The alterations in climatic factors are not uniform across all regions or sub-nations and have varying degrees of severity. This necessitates the understanding of changes at various scales. In addition, regional, state and local level analysis of the trends and patterns in precipitation and temperature assume added significance for a big country like India because of its sizeable regional weather differences. Although one region of the country could experience heavy rains and floods, another region of the nation might reel under drought. In this given background, it is more important to detect and analyse the trends and patterns of temperature and rainfall of Telangana state and selected study districts.

4.2 An overview of rainfall and temperature trends in India

Before we plunge into the trend analysis in Telangana and selected districts, a brief overview of rainfall and temperature trends in India is discussed in this section. Among all the weather variables, rainfall and temperature are the most important for the country like India where a huge number of the population still depends on agriculture and allied activities for their livelihoods. In order to assess the changes in temperature and rainfall patterns, a large number of research works have been conducted in India. The first systematic study of trends and fluctuations in the annual rainfall for the entire Indian sub-continent was conducted by Pramanik and Jagannathan (1953). Their study considered 30 stations uniformly spread all over India, Pakistan and Bangladesh and the rainfall data was examined for the period 1813 to 1950. Their analysis of first coefficient of polynomials (i.e. linear trend) showed a rising trend in the rainfall for the area comprising “North West Madras coast (coastal Karnataka), Hyderabad and Deccan regions” whereas North West India reported a decreasing trend.

Another study by Rao and Jagannathan (1963) analyzed South West monsoon rainfall data of 25 sub divisions of the country for the 80 years’ period from 1875 to 1954 by

fitting orthogonal polynomials up to five degrees. They found no statistically significant alterations in the precipitation in different subdivisions. Raghavendra (1974) analyzed the rainfall data of about 100 years for the four sub-divisions of Maharashtra state and found that decadal means after 1901 showed an increasing trend in all the sub-divisions apart from trend and QBO (Quasi-Biennial Oscillation). The study by Parthasarathy and Dhar (1974) of nine sub-divisions of Maharashtra and Karnataka states and adjoining areas for the period 1901-1960 noticed increasing trend of rainfall in the area. Mooley (1975) examined south-west monsoon precipitation trends of India for the time between 1947 and 1974. This study found that (i) the percentage area of India under deficient and scanty rainfall have large values during the years 1952, 1965, 1966, 1968, 1972 and 1974 (ii) the rainfall irregularities were larger during 1965-1974, compared to 1947-1964 period. Parthasarathy (1984) found that the monsoon rainfall for the two sub-divisions viz. “sub-Himalayan West Bengal & Sikkim and the Bihar Plains” reported declining trends, while for the four sub-divisions viz. “Punjab, Konkan & Goa, West Madhya Pradesh and Telangana” reported raising trends. Moreover, the recent study by Guhathakurta and Rajeevan (2006) for Pan-India summer-monsoon rainfall during the time between 1901 and 2003 did not present any discernible pattern during the four monsoon months. However, their result shows significant regional variations.

One of the more serious consequences of global change will be an uptick in the severity and occurrence of extreme rainfall events (droughts and floods) caused by the upsurge of greenhouse gases. Therefore, besides the studies on rainfall trends and patterns conducted at the Pan-India and regional levels, many other studies have been conducted during recent years to observe the trends of extreme precipitation events in India. For instance, the reports of regular precipitation for 129 Indian stations were investigated by Roy and Balling (2004) between 1910 and 2000. They found evidence of an upsurge in the rate of recurrence of severe rainfall incidents for this time frame. The evidence is strongest for the area spreading from the “Northwestern Himalayas of Kashmir through most of the Deccan plateau in the Southern peninsular region” of India. The study by Goswami et al. (2006) utilizing regular gridded precipitation statistics reveals that there has been a substantial increase in the occurrence and severity of heavy rainfall events and a decreasing trend in the occurrences of moderate rainfall events in central India over the past fifty years.

Temperature is one of the most important indicators of climatic state of a country. The several reports of IPCC have already pointed to the increasing temperature trend in many regions of the earth and it is further likely to upsurge in the future as a result of global warming. However, several scholarly works have been conducted in India to analyse the changes in temperature.

For instance, Kothawale and Rupa Kumar (2005) evidenced that the average yearly temperature per decade has increased by 0.05 Degrees Celsius over 1901-2003 using updated data groups. However, the latest period (1971-2003) demonstrated relatively enhanced warming of 0.22 Degrees Celsius per decade due to record warming for the period of 1991-2003. Recent rapid warming in India has manifested in both nighttime as well as daytime temperatures. A study by Kothiyari and Singh (1996) analysed the temperature trends in India using long-term information by employing non-parametric approaches. The study revealed that temperature has a rising pattern in the country. Rao et al. (2014) analysed trends in annual minimum temperature in the country using grid data during 1971-2009. The study reported that minimum temperature had increased 0.24 Degrees Celsius per decade. The above review of existing literature shows how the rainfall and temperature pattern is changing in India with many findings indicating towards an overall increase in the mean temperature of India.

4.3 Data and Methodology

The broad objective of the present chapter is to detect and analyse the trends and patterns in the rainfall and temperature data in Telangana state and study districts. Generally, a trend is a substantial change over time demonstrated by a random variable determined by “parametric and non-parametric” statistical tests. To achieve the aim, “non-parametric” statistical techniques used for yearly seasonal and monthly temperature and rainfall data as explained below. Moreover, rainfall characteristics such as central tendency (Mean), coefficient of variation (CV) and standard deviation (SD) were calculated for monthly, seasonal and annual data. This study used meteorological department of India’s classification of rainfall seasons such as “pre-monsoon or summer (March to May or

MAM), monsoon (June to September or JJAS), post-monsoon or autumn season (October to November or ON) and winter (December and February or DJF)”.

A time series trend analysis involves both the extent and statistical significance of the trend. Change in a series can occur in numerous ways: for example, abruptly (a step-change), gradually (a trend), or in a more complex form. However, different studies have employed different methods for trend detection. Both parametric as well as non-parametric tests are available to analyse the trends in the climatic variables. However, the non-parametric tests are extensively used in several research works to analyze rainfall and temperature statistics better (for instance: Radhakrishnan et al., 2017; Mondal et al., 2015; Jain and Kumar, 2012; Subash and Sikka, 2014; Jain et al., 2013). Because ‘non-parametric’ tests are distribution free techniques (Hirsch et al., 1982). Moreover, non-parametric statistical tests usually tolerate the outliers in the data (Lanzante, 1996). Among non-parametric tests, the most widely utilized techniques for identifying trends and magnitudes of meteorological variables are the Mann-Kendall (MK) and Sen's slope tests (Patra et al., 2012). This test initially originated by Mann (1945) and eventually “test statistic distribution” was derived by Kendall (1948). The present study utilized non-parametric trend tests such as Mann-Kendall (MK) alongside Sen's slope techniques for temperature as well as rainfall data. Several studies have been employed the aforementioned methods and evidenced reliable outcomes, for example, Jain et al. (2013), Taylor and Loftis (1989), Guhathakurta and Rajeevan (2008), Fathian et al. (2016), Dawood (2017), Gocic and Trajkovic (2013), Yadav et al. (2014) and Mondal et al. (2012).

4.3.1 Mann-Kendall test

The Mann-Kendall (M.K.) test statistic S (Mann 1945; Kendall 1948) is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(R_i - R_j) \dots \dots \dots (4.1)$$

where n is the number of data points, R_i and R_j are the data values in the time series i and j ($j > i$), respectively. The Mann-Kendall trend test statistic for a series $R_1, R_2, \dots, R_n$... is computed as follows:

$$sgn(R_i - R_j) = \begin{cases} +1 & \text{if } R_i - R_j > 0 \\ 0 & \text{if } R_i - R_j = 0 \\ -1 & \text{if } R_i - R_j < 0 \end{cases} \dots \dots \dots (4.2)$$

Usually, if a data set presents a steadily declining or rising trend, S would be negative or positive, respectively, with a greater magnitude representing the trend is more stable in its path. The variance of Mann-Kendall (M.K.) statistic is:

$$var(S) = \frac{1}{18} [n(n-1)(2n+5)] \dots \dots \dots (4.3)$$

Where, n is the number of data points.

The test statistic Z is calculated as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}} & \dots \dots \text{if } S > 0 \\ 0 & \dots \dots \text{if } S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & \dots \dots \text{if } S < 0 \end{cases} \dots \dots \dots (4.4)$$

The hypothesis of no trend is rejected if $|Z| > Z_{1-\alpha/2}$, where Z is took out from the “standard normal distribution table” and α is significance level. Scholarly works used either the 0.05 level (usually termed as 5 percent significance level) or the 0.01 (1 percent significance level). However, the present study reported 0.10, 0.05 and 0.01 level of significance.

4.3.2 Sen's slope test

The Sen's slope test is a non-parametric procedure that is employed for determining the extent of the trend path (Patra et al., 2012). This technique works by measuring the slope as a change of measurement per change of time.

$$Q = \frac{R_i - R'_i}{i' - i} \dots \dots \dots (4.5)$$

Where Q indicates slope between data points R'_i and R_i , R'_i indicates data measurement at time i' . Similarly, and R_i indicates data measurement at time i and i' indicates time after time i . Further, the variance of Sen's slope is estimated as follows;

$$var(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{p=1}^q tp(tp-1)(2tp+5) \right] \dots \dots \dots (4.6)$$

Where n indicates number of data points, tp indicates the number of ties for the pth value and q indicates the number of tied values.

Sen's slope (Q') estimator;

$$= Q \left(\frac{N+1}{2} \right) \text{ if } N \text{ is odd } \dots \dots \dots (4.7)$$

$$= \frac{Q \left(\frac{N}{2} \right) + Q \left(\frac{N+2}{2} \right)}{2} \text{ if } N \text{ is even } \dots \dots \dots (4.8)$$

Where N indicates number of calculated slopes.

To assessment of the range of ranks for the specified confidence interval of ranks

$$C_\alpha = Z_{1-\alpha/2} \times \sqrt{var(S)} \dots \dots \dots (4.9)$$

The ranks of the lower M_1 and upper M_2 confidence limits are given by

$$M_1 = \frac{N - C_\alpha}{2} \dots \dots \dots (4.10)$$

$$M_2 = \frac{N + C_\alpha}{2} \dots \dots \dots (4.11)$$

“After measuring the slopes corresponding to lower (M_1) and upper (M_2) confidence limits, the median slope is then defined as statistically different from zero (for the selected confidence interval), if the zero does not lie between the upper and lower confidence limits.” Finally, Mann-Kendall test provides the statistical significance and direction (increasing or decreasing) of the trends and Sen's slope estimator provides the magnitude of the trend.

4.3.3 Data sources

This chapter completely depends on secondary data for analysis. The relevant data on climate variables have been collected from the various government departments, related research institutions, and other online sources. The rainfall (monthly, seasonal and annual) data of Telangana and selected study districts are gathered from the several issues of Statistical Abstracts of Andhra Pradesh and Statistical Year Books of Telangana, available at Directorate of Economics and Statistics, Government of Telangana, Indian Institute of Tropical Meteorology (IITM) and [Indiawaterportal.org](http://indiawaterportal.org). Similarly, data on mean, minimum and maximum temperatures (monthly, annual and seasonal) for Telangana and selected study districts are collected from the DES of Telangana and [Indiawaterportal.org](http://indiawaterportal.org). The study period for trend analysis of temperature and rainfall is 1901-2015.

4.4 Results and Discussion

As mentioned earlier, the selected study variables are rainfall and temperature and the rainfall data has been categorized based on IMD arrangement (summer, monsoon, post-monsoon and summer). Systematic analysis and discussion are done on rainfall variables such as annual rainfall, monthly rainfall, monsoon rainfall, summer rainfall, post-monsoon rainfall, winter rainfall and on the temperature variables such as annual and monthly mean temperature and annual and monthly mean minimum and maximum temperatures.

4.4.1 Rainfall trends in Telangana

This section presents the rainfall trends in Telangana for the period of 1901-2015. Using Mann-Kendall (MK) along with Sen's slope tests, we analyse the monthly, seasonal and yearly rainfall trends of the state. Before analyzing the data, we have presented the annual and seasonal rainfall data for Telangana in graphic form. Figures 4.1 and 4.2 show the graphical trends in yearly and seasonal rainfall in the state. It can be seen from Figure 4.1 that there is a slightly increasing trend in the annual rainfall.

Figure 4.1: Linear trend of annual rainfall in Telangana (1901-2015)

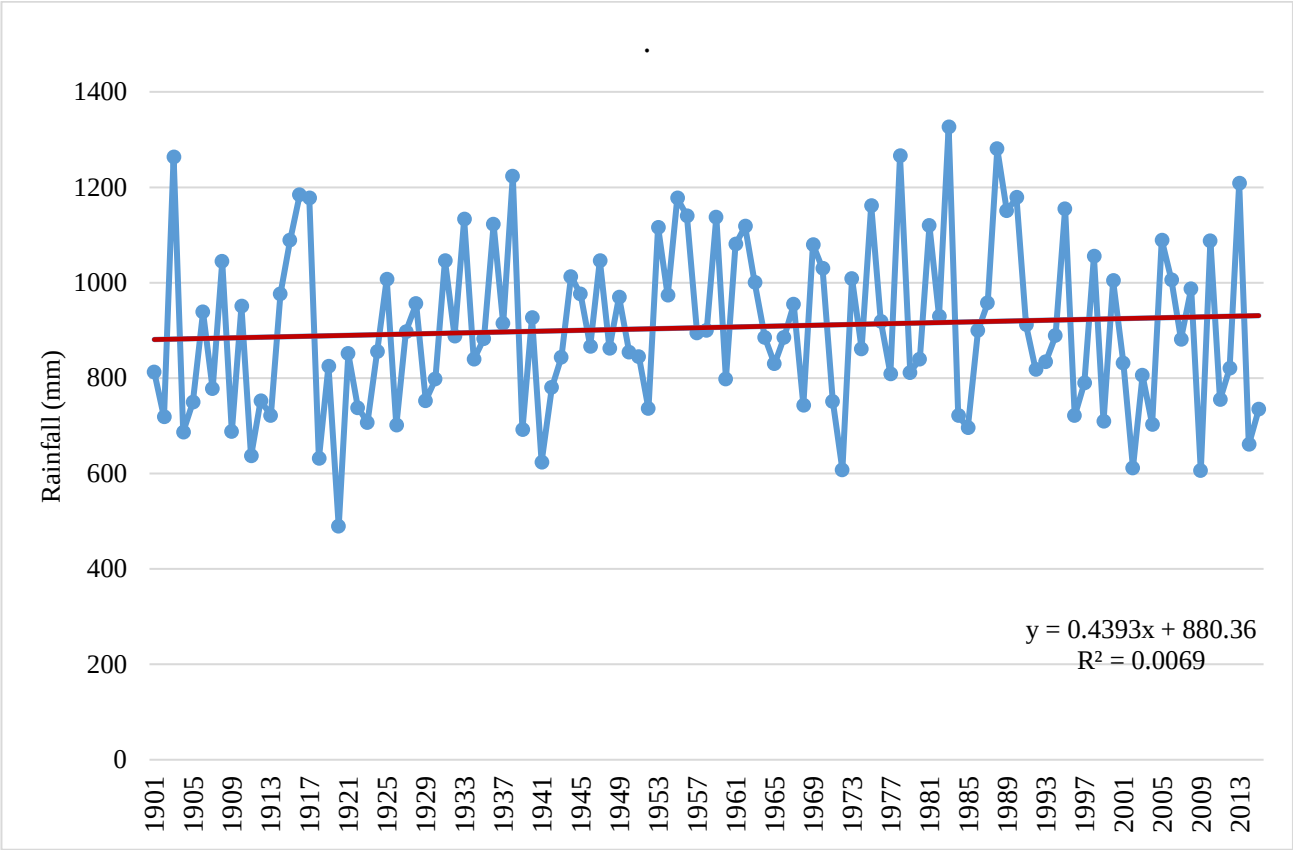
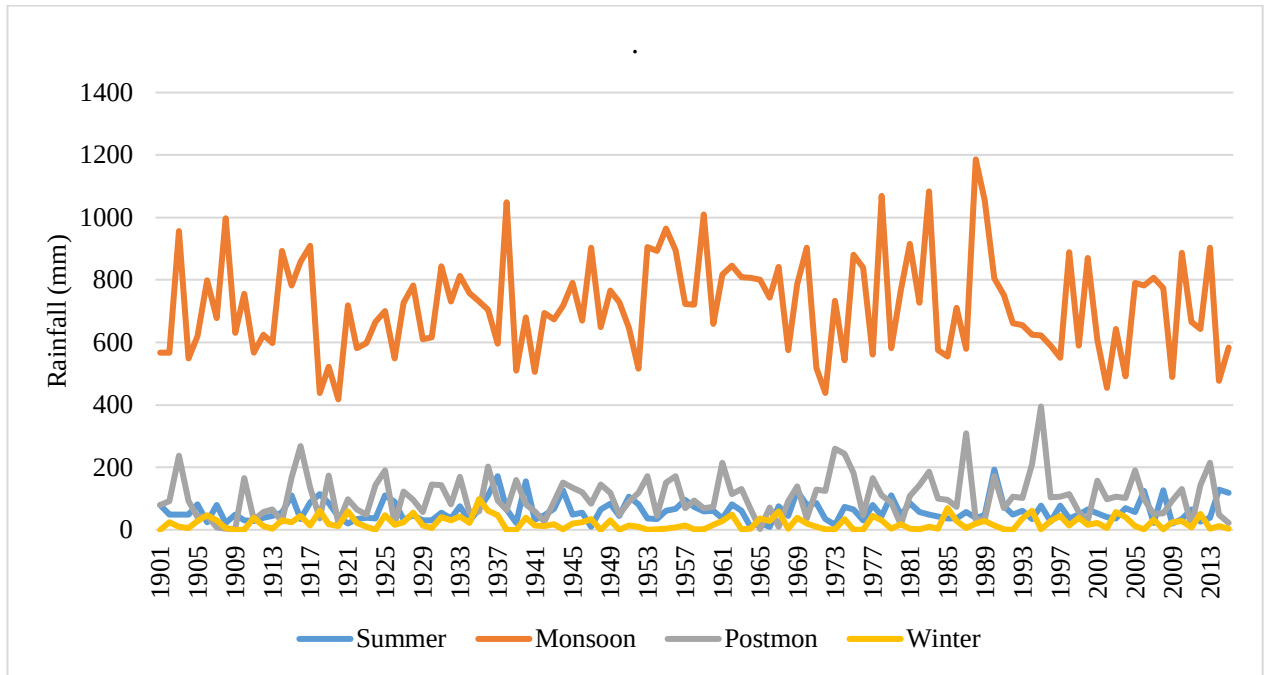


Figure 4.2: Time series plots of seasonal rainfall in Telangana (1901-2015)



After the graphical trend analysis, the results of the non-parametric statistical test for the annual, seasonal and monthly rainfall of Telangana state have been displayed in Table 4.1. The average yearly rainfall of the state is 905.8 mm over the study period. The coefficient of variation of annual rainfall is about 19.5 percent. Moreover, the coefficient of variation is very low for the monsoon season and high for the winter season compared to other seasons. Monthly rainfall analysis presents that July month was having the highest mean rainfall (220.9 mm) and lowest coefficient of variation (35.8 %) over the study period. The results of the trend detection approaches for Telangana are also reported in Table 4.1.

The yearly rainfall of the state evidences a long-term insignificant increasing trend during the study period. The value of Sen's slope estimator was about 0.467 that indicates yearly rainfall has been increasing 0.47 mm per year. Therefore, annual rainfall in Telangana state has been rising over the study period. Similarly, seasonal rainfall also displays an insignificant increasing trend excluding winter season. The rainfall during winter season has been decreasing 0.01 mm per year. However, it is not statistically significant. The Sen's slope for the monsoon and post-monsoon rainfall data is 0.179 mm/year 0.220

mm/year, respectively, while it is not statistically significant in the Mann-Kendall test. The hot weather period also displays an insignificant increasing trend in rainfall.

Table 4.1: Monthly, seasonal and annual rainfall trends in Telangana (1901-2015)

Time period	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slop
January	6.6	11.1	169.2	0.026	0.699	0.000
February	9.9	16.3	164.1	-0.048	0.466	0.000
March	11.6	18.4	159.4	0.047	0.463	0.003
April	19.9	17.9	90.4	-0.041	0.522	-0.019
May	28.9	26.2	90.8	0.027	0.669	0.020
June	130.1	52.3	40.2	-0.085	0.177	-0.196
July	220.9	79.0	35.8	0.002	0.975	0.006
August	194.6	71.3	36.6	0.168***	0.008	0.484
September	172.6	75.2	43.6	-0.059	0.351	-0.206
October	83.3	61.5	73.9	0.092	0.145	0.202
November	22.5	27.2	120.8	0.001	0.992	0.000
December	5.0	9.7	191.7	-0.034	0.617	0.000
Summer	60.3	34.3	56.8	0.025	0.694	0.029
Monsoon	718.2	157.2	21.9	0.026	0.681	0.179
Post-monsoon	105.8	68.5	64.7	0.079	0.211	0.220
Winter	20.8	19.6	94.1	-0.026	0.686	-0.014
Annual	905.8	177.0	19.5	0.053	0.403	0.467

Note: *** $p < 0.01$. Source: Author's own calculations.

The monthly rainfall analysis reveals that except for august, all the other months are not statistically significant in the Mann-Kendall test. The value of Sen's slope estimator for the august month was about 0.484 that indicates yearly rainfall has been increasing 0.48 mm per year. The empirical outcomes of the Mann-Kendall and Sen's slope tests for February, April, June, September and December months have presented a negative value which means there is a decreasing trend in these months. However, January, March, May, July, October and November months have presented a positive sign suggests that there is a rising pattern in these months. Overall, the exploration of rainfall data from Telangana state presents that there is a common upward trend in rainfall for the annual, pre-monsoon (summer), monsoon and post-monsoon season, although it is not statistically significant. After the analyzing

monthly, seasonal and annual rainfall trends, we further analyse the district level rainfall data.

Table 4.2: District wise annual rainfall trends of Telangana (1901-2015)

District	Mean	Std. deviation	Kendall's tau	p-value	Sen's slope
Adilabad	996.1	196.4	0.057	0.367	0.568
Karimnagar	922.7	185.6	0.085	0.179	0.776
Nizamabad	922.2	198.3	0.113*	0.074	1.013
Medak	844.5	178.7	0.040	0.533	0.333
Khammam	945.9	199.8	0.284***	0.001	2.563
Warangal	851.6	174.2	0.212***	0.001	1.625
Ranga Reddy	809.7	174.9	0.102	0.105	0.844
Mahabubnagar	670.3	153.0	0.106*	0.094	0.789
Nalgonda	741.5	161.2	0.084	0.185	0.649

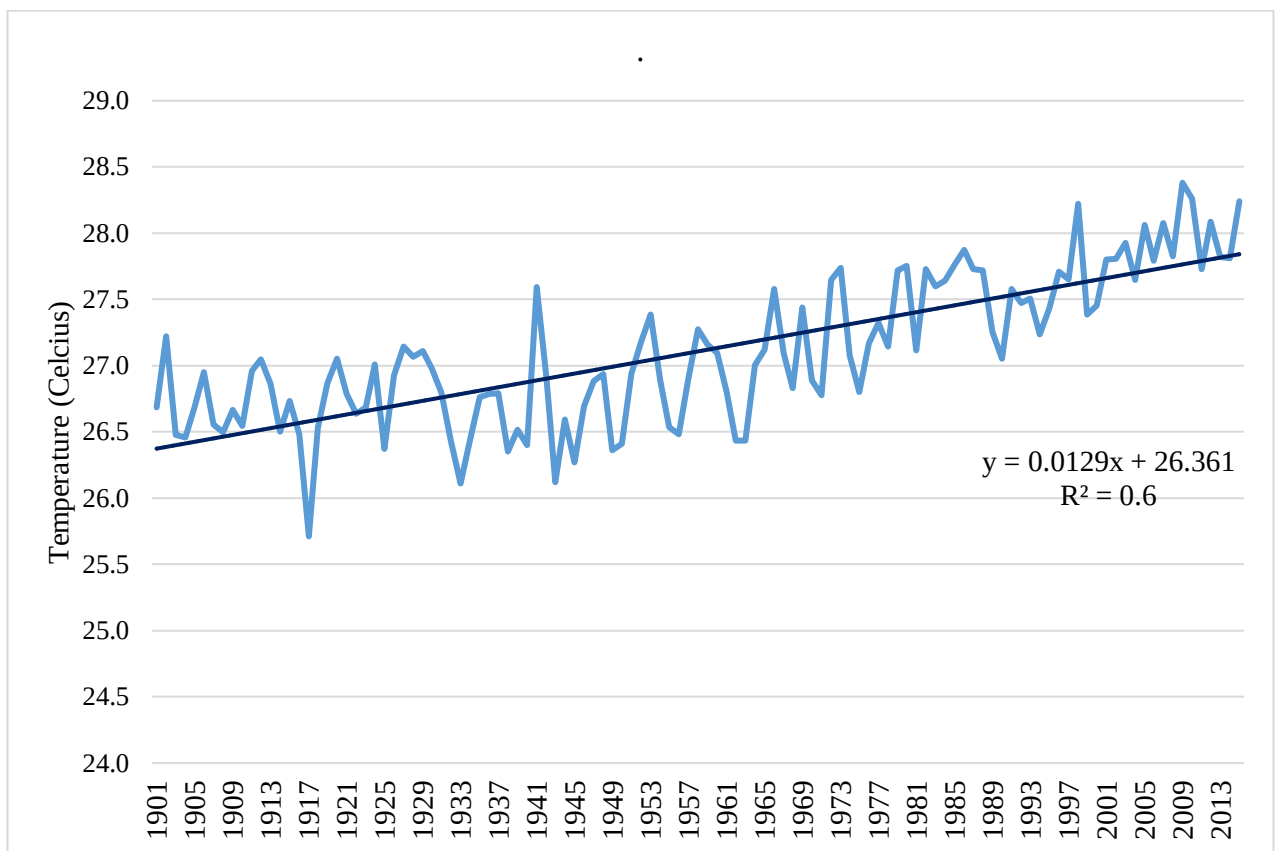
Note: *** $p < 0.01$ and * $p < 0.10$. Source: Author's own calculation.

The district-wise annual rainfall trends of Telangana for the period of 1901 to 2015 are reported in Table 4.2. The annual mean rainfall is very high in the Adilabad district (996 mm) which is higher than the normal rainfall of Telangana. Khammam district has the second-highest annual mean rainfall (945 mm). These two districts are generally having a greater percentage of forests in the overall geographical area. However, Mahabubnagar has the lowest annual average rainfall (670.3 mm) over the study period with lesser standard deviation. Districts such as Nizamabad (1.01mm/year), Khammam (2.56mm/year), Warangal (1.62mm/year) and Mahabubnagar (0.79mm/year) presented the statistically increasing trend as per the outcomes of the Mann-Kendall and Sen's slope tests. On the contrary, districts such as Adilabad, Karimnagar, Medak, Ranga Reddy and Nalgonda evidenced an increasing trend of annual rainfall but not statistically insignificant. Overall, irrespective of the statistical significance, all the study districts are presented an increasing rainfall trends.

4.4.2 Analysis of Temperature trends in Telangana

After analysing the trends of rainfall data, we also analysed the trends of mean, minimum and maximum temperatures data for Telangana state during 1901-2015. Before exploring the data, we have presented the annual mean temperature data for the state in graphic form. Figure 4.3 demonstrates the graphical representation of mean yearly temperature and it can be seen from the figure that there is a clear increasing trend in the mean annual temperature of Telangana.

Figure 4.3: Annual mean temperature trends in Telangana (1901-2015)



The monthly and annual trends of mean temperature for the state are estimated by employing Mann-Kendall and Sen's slope tests and the empirical outcomes are reported in Table 4.3. The average yearly mean temperature of the state is 27.11 degrees celsius over

the study period. The coefficient of variation of mean annual temperature of the state is about 2.04 percent. The highest annual mean temperature has been found during May month (33.17°C) and the lowest yearly mean temperature has been recorded during December month (22.11 °C). Moreover, the coefficient of variation is very low for August month (2.21 %) and high for the December month (4.78 %) compared to other months.

Table 4.3: Monthly and annual mean temperature trends in Telangana (1901-2015)

Time period	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slop
January	22.88	0.91	3.96	0.237***	0.000	0.009
February	25.31	0.91	3.60	0.423***	0.001	0.016
March	28.66	0.94	3.29	0.379***	0.001	0.016
April	31.55	0.89	2.83	0.288***	0.001	0.012
May	33.17	1.11	3.33	0.306***	0.001	0.015
June	30.19	1.17	3.89	0.197***	0.002	0.011
July	27.40	0.73	2.66	0.304***	0.001	0.010
August	26.84	0.59	2.21	0.302***	0.001	0.008
September	27.00	0.65	2.42	0.432***	0.001	0.012
October	26.38	0.68	2.56	0.360***	0.001	0.011
November	23.80	1.10	4.62	0.396***	0.001	0.019
December	22.11	1.06	4.78	0.360***	0.001	0.017
Annual	27.11	0.55	2.04	0.565***	0.001	0.013

Note: *** p < 0.01. Source: Author's own calculation.

The mean annual temperature of the state evidences a long-term statistically significant (at 1 % level) increasing trend during the study period. The value of Sen's slope estimator was about 0.013 that indicates the yearly average temperature has been increasing 0.013 degrees celsius per year. Therefore, there is an increasing trend in annual average temperature in Telangana over the study period. The monthly mean temperature analysis using the Mann-Kendall test reveals that all the months (January to December) are reported a statistically significant increasing trend over the study period. Furthermore, as per Sen's slope test results, the mean yearly temperature during January (0.009 °C), February (0.016 °C), March (0.016 °C), April (0.012 °C), May (0.015 °C), June (0.011 °C), July (0.010 °C), August (0.008 °C), September (0.012 °C), October (0.011 °C), November (0.019 °C) and

December (0.017 °C) has been increasing per month during 1901-2015. Overall, the analysis for mean temperature of Telangana state shows that there is a significant increasing trend in mean monthly and annual temperature data. After the analyzing mean monthly and annual temperature trends, we further explore the district level mean annual temperature trends.

Table 4.4: District wise trends of annual mean temperature (1901-2015)

Districts	Mean	Std. deviation	Kendall's tau	p-value	Sen's slop
Adilabad	27.23	0.45	0.439***	0.001	0.008
Karimnagar	26.91	0.68	0.544***	0.001	0.014
Nizamabad	26.73	0.72	0.563***	0.001	0.015
Medak	26.48	0.54	0.485***	0.001	0.011
Khammam	27.86	0.60	0.529***	0.001	0.011
Warangal	27.42	0.66	0.578***	0.001	0.014
Ranga Reddy	26.84	0.54	0.462***	0.001	0.011
Mahabubnagar	27.41	0.52	0.495***	0.001	0.010
Nalgonda	27.09	0.65	0.568***	0.001	0.015

Note: *** $p < 0.01$. Source: Author's own calculation.

The district-wise annual mean temperature trends of Telangana for the period of 1901 to 2015 are reported in Table 4.4. The average mean temperature is very high in the Khammam district (27.86 °C) which is higher than the mean temperature of Telangana. However, Medak has the lowest average mean temperature (26.48 °C) over the study period. Further, the district level mean annual temperature trends show a statistically significant increasing trend over the period of time. As per Sen's slope test results, districts such as Adilabad (0.008 °C), Karimnagar (0.014 °C), Nizamabad (0.015 °C), Medak (0.011 °C), Khammam (0.011 °C), Warangal (0.014 °C), Ranga Reddy (0.011 °C), Mahabubnagar (0.010 °C) and Nalgonda (0.015 °C) presented the significant increasing trend. Overall, all the study districts are presented an increasing mean temperature trends with 1 % level of statistical significance.

Furthermore, annual maximum and minimum temperature trend analysis of the state at the district level is presented in the Tables (4.5 and 4.6). The empirical results of the

Mann-Kendall (M-K) and Sen's slope tests for the district level data of annual maximum temperature reported in Table 4.5. The average maximum temperature is very high in Adilabad (33.41 °C). Conversely, Medak has the lowest average maximum temperature (32.42 °C) over the study period. Further, the district level maximum temperature trend shows a significant increasing trend over the period of time in the districts.

Table 4.5: District wise trends in Maximum Temperature in Telangana (1901-2015)

Districts	Mean	Std. deviation	Kendall's tau	p-value	Sen's slop
Adilabad	33.41	0.462	0.416***	0.001	0.008
Karimnagar	32.84	0.733	0.544***	0.001	0.014
Nizamabad	32.67	0.822	0.559***	0.001	0.015
Medak	32.42	0.657	0.572***	0.001	0.015
Khammam	33.13	0.613	0.519***	0.001	0.011
Warangal	33.13	0.790	0.579***	0.001	0.015
Ranga Reddy	32.75	0.554	0.467***	0.001	0.011
Mahabubnagar	33.31	0.556	0.488***	0.001	0.010
Nalgonda	32.75	0.654	0.547***	0.001	0.014

Source: Author's own calculations. Note: *** $p < 0.01$.

Table 4.6: District wise trends in Minimum Temperature in Telangana (1901-2015)

Districts	Mean	Std. deviation	Kendall's tau	p-value	Sen's slop
Adilabad	21.07	0.50	0.411***	0.001	0.008
Karimnagar	21.01	0.63	0.537***	0.001	0.013
Nizamabad	20.83	0.64	0.557***	0.001	0.014
Medak	20.57	0.54	0.316***	0.001	0.008
Khammam	22.63	0.62	0.517***	0.001	0.011
Warangal	21.74	0.67	0.462***	0.001	0.010
Ranga Reddy	20.97	0.55	0.424***	0.001	0.010
Mahabubnagar	21.53	0.50	0.476***	0.001	0.010
Nalgonda	21.46	0.67	0.568***	0.001	0.015

Note: *** $p < 0.01$. Source: Author's own calculations.

The district-wise annual minimum temperature trends of Telangana for the period of 1901 to 2015 are reported in Table 4.6. The average minimum temperature is very high in the Khammam district (22.63 °C). Conversely, Medak has the lowest average minimum temperature (20.57 °C) over the study period. Further, the district level average yearly minimum temperature trends show a statistically significant upward trend over the period of time. As per Sen's slope test results, Districts such as Adilabad (0.008 °C), Karimnagar (0.013 °C), Nizamabad (0.014 °C), Medak (0.008 °C), Khammam (0.011 °C), Warangal (0.010 °C), Ranga Reddy (0.010 °C), Mahabubnagar (0.010 °C) and Nalgonda (0.015 °C) presented the statistically increasing trends of minimum temperature. Overall, all the study districts are presented an increasing trend of maximum temperature with 1 % level of statistical significance. Furthermore, we also analysed the trends in rainfall and temperature of study districts such as Karimnagar and Mahabubnagar in the subsequent sections.

4.4.3 Analysis of rainfall trends in selected study districts

The district level rainfall trends of the two selected districts (Karimnagar and Mahabubnagar) in Telangana are discussed separately. So, this section deals with the trends of rainfall in the study districts. Before analysing the data using trend detection methods, we have presented the annual, seasonal rainfall data for both our study districts in graphic form. Figures 4.4 and 4.5 show the annual and seasonal rainfall trends of Karimnagar district. It can be observed from Figures 4.4 and 4.5 that there is a slight increasing trend in the yearly and seasonal rainfall in Karimnagar district. Figures 4.6 and 4.7 present the annual and seasonal rainfall trends of Mahabubnagar district. It can be observed from Figures 4.6 and 4.7 that there is an insignificant upward trend in the annual and seasonal rainfall in Mahabubnagar district. However, further trend analysis of rainfall data in study districts using Mann-Kendall and Sen's slope tests will provide a clearer picture.

Figure 4.4: Linear trends of annual rainfall in Karimnagar district (1901-2015)

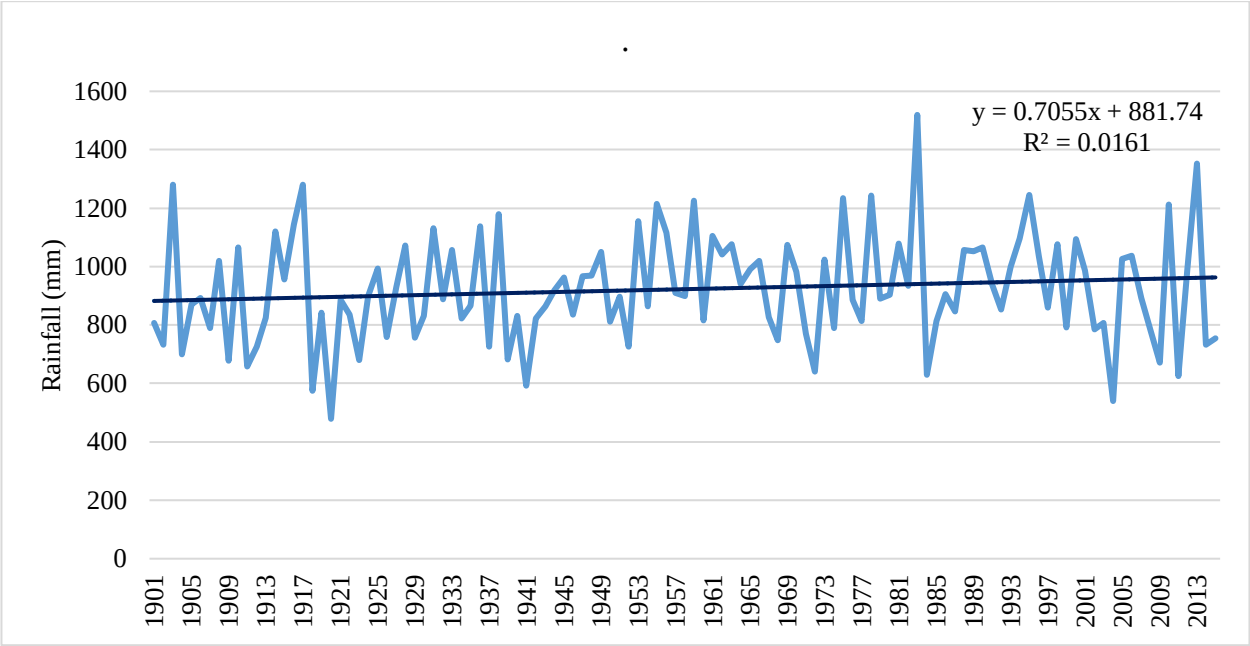


Figure 4.5: Trends of seasonal rainfall in Karimnagar district (1901-2015)

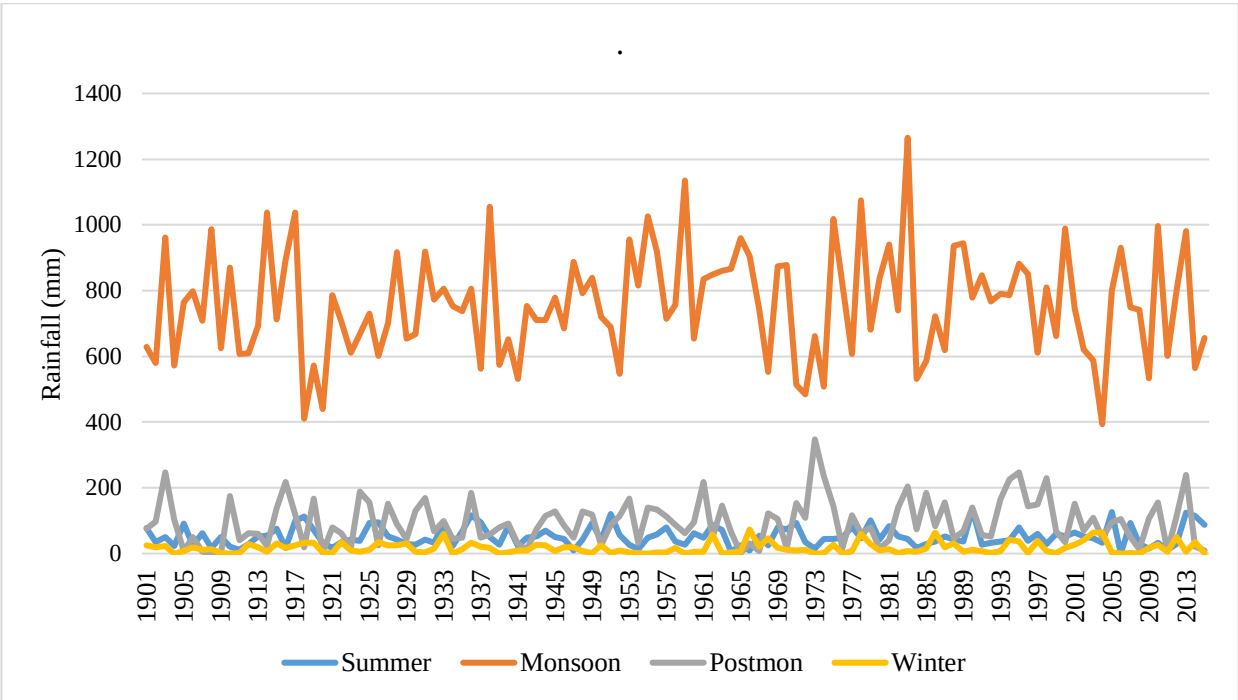


Figure 4.6: Linear trends of annual rainfall in Mahabubnagar district (1901-2015)

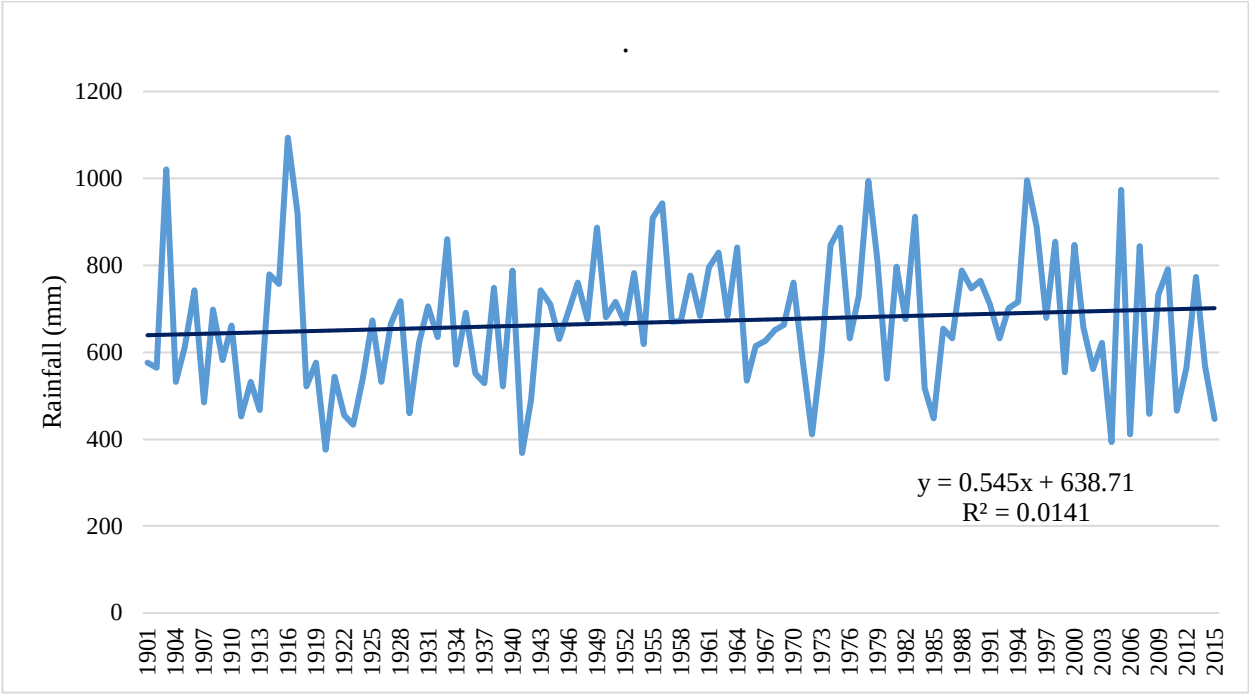
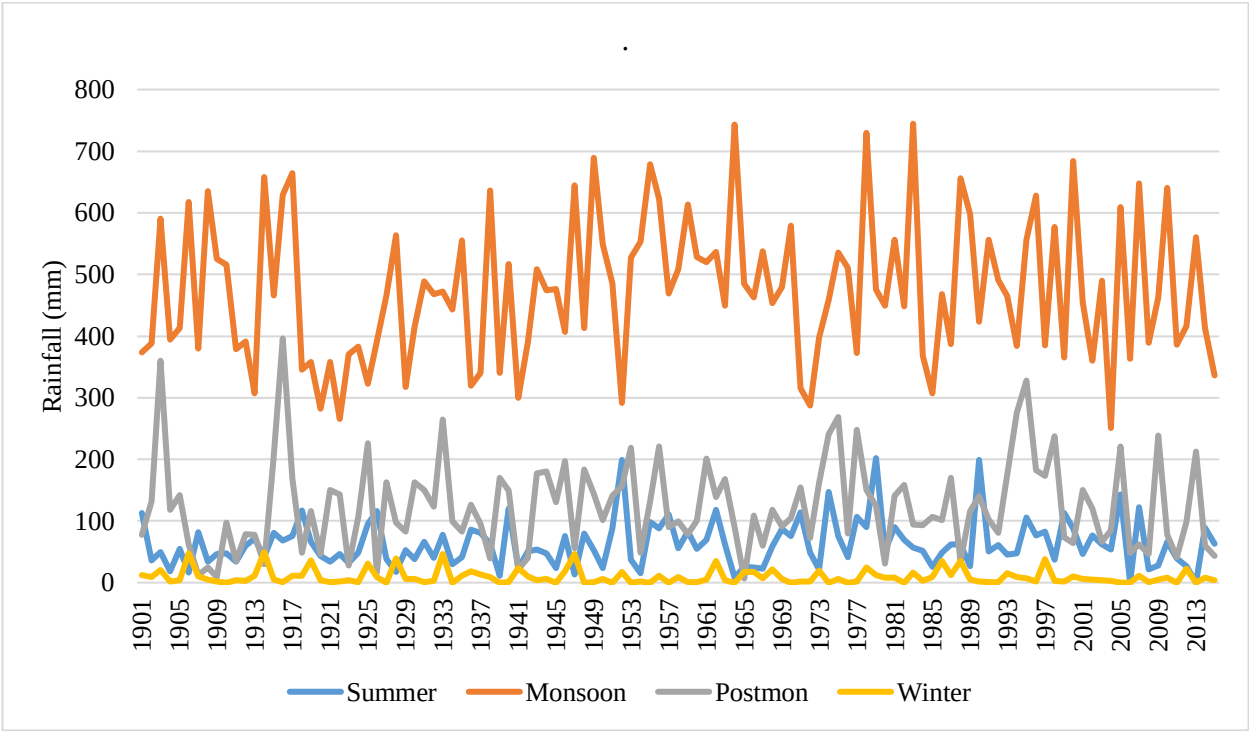


Figure 4.7: Trends of seasonal rainfall in Mahabubnagar district (1901-2015)



After graphical analysis, the results of the non-parametric statistical test for the annual, seasonal and monthly rainfall of the Karimnagar district have been reported in Table 4.7. The normal rainfall of the Karimnagar district is 922.7 mm over the study period which is higher than the state's normal rainfall. The coefficient of variation of yearly rainfall is around 20 percent, with a standard deviation of 185.6 mm. Moreover, the coefficient of variation for Karimnagar district is very low during the post-monsoon season (21.6 %) and high during summer season (100.9 %) compared to other seasons. Monthly rainfall analysis of Karimnagar district presents that July month was having the highest mean rainfall (228.7 mm) and lowest coefficient of variation (34.8 %) over the study period.

Table 4.7: Monthly, seasonal and annual rainfall trends of Karimnagar (1901-2015)

Time period	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slop
January	7.4	12.4	167.6	0.092	0.160	0.000
February	6.2	8.6	139.8	-0.083	0.196	-0.001
March	10.7	15.6	145.7	0.048	0.453	0.005
April	18.3	15.4	84.2	-0.079	0.210	-0.044
May	23.0	21.9	95.2	0.024	0.706	0.013
June	133.8	59.0	44.1	-0.069	0.272	-0.186
July	228.7	79.6	34.8	0.048	0.448	0.195
August	199.4	77.2	38.7	0.199***	0.002	0.658
September	195.5	93.4	47.8	-0.105*	0.098	-0.357
October	75.9	62.9	83.0	0.083	0.192	0.197
November	20.5	24.6	120.0	-0.015	0.814	0.000
December	3.3	6.3	191.8	-0.026	0.698	0.000
Summer	16.9	17.0	100.9	-0.005	0.936	-0.001
Monsoon	52.0	29.8	57.3	0.014	0.832	0.013
Post-monsoon	757.4	163.3	21.6	0.065	0.305	0.498
Winter	96.4	68.0	70.5	0.086	0.173	0.268
Annual	922.7	185.6	20.1	0.085	0.179	0.776

Note: *** $p < 0.01$ and * $p < 0.10$. Source: Author's own calculations.

The results of the trend detection approaches for Karimnagar district are also reported in Table 4.7. The annual rainfall of Karimnagar evidences a long-term insignificant increasing trend during the study period. The value of Sen's slope estimator was about 0.776 that indicates annual rainfall has been increasing 0.78 mm per year in Karimnagar district. Similarly, seasonal rainfall also displays an insignificant increasing trend excluding summer season. The rainfall during summer season has been decreasing 0.01 mm per year but it is not statistically significant. The Sen's slope for the monsoon, post-monsoon and winter season rainfall data is 0.013mm/year, 0.498 mm/year 0.268 and mm/year, respectively. Further, the monthly rainfall analysis of Karimnagar district reveals that except for August and September, all the other months are not statistically significant in the Mann-Kendall test. The value of Sen's slope estimator for the August month was about 0.658 that indicates yearly rainfall has been increasing 0.66 mm per year. On the other hand, the value of Sen's slope estimator for the September month was about -0.357 that indicates annual rainfall has been decreasing 0.36 mm per year. The empirical outcomes of the Mann-Kendall and Sen's slope tests for Karimnagar show an insignificant decreasing rainfall trend during February, April and June months. Overall, the study of rainfall data of Karimnagar reveals a common upward trend in rainfall for the monsoon, post-monsoon, and winter seasons including yearly analysis, though this trend is not statistically significant. After analyzing the rainfall trends of the Karimnagar district, we further analyse the rainfall trends of the Mahabubnagar district.

The annual, seasonal and monthly rainfall of the Mahabubnagar district have been reported in Table 4.8. The normal rainfall of the Mahabubnagar district is 670.3 mm over the study period which is much lesser than the state's normal rainfall. The coefficient of variation of annual rainfall is around 23 percent, with a standard deviation of 153 mm. Moreover, the coefficient of variation for Mahabubnagar district is very low during the post-monsoon season (24.6 %) and high during summer season (125.2 %) compared to other seasons. Monthly rainfall analysis of Mahabubnagar district presents that September month was having the highest mean rainfall (155.4 mm) over the study period.

The empirical results of the Mann-Kendall and Sen's slope tests for Mahabubnagar district are also reported in Table 4.8. The annual rainfall of Mahabubnagar presents a long-

term significant rising trend during the study period. The value of Sen's slope estimator was about 0.789 which indicates annual rainfall has been increasing 0.79 mm per year in Mahabubnagar district. On the other hand, seasonal rainfall displays an insignificant increasing trend excluding summer season. The rainfall during summer season has been decreasing -0.012 mm per year but it is not statistically significant.

Table 4.8: Monthly, seasonal and annual rainfall trends of Mahabubnagar (1901-2015)

Time period	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slop
January	1.2	2.2	186.9	-0.037	0.580	0.000
February	2.3	4.2	184.6	-0.166**	0.011	0.000
March	5.6	11.8	209.1	-0.002	0.973	0.000
April	19.7	17.6	89.3	0.042	0.503	0.025
May	37.7	36.0	95.3	-0.012	0.852	-0.013
June	84.5	34.6	40.9	0.008	0.896	0.014
July	113.1	48.7	43.0	0.035	0.585	0.081
August	120.7	59.9	49.6	0.224***	0.000	0.608
September	155.4	75.4	48.5	-0.115*	0.069	-0.386
October	99.2	68.0	68.6	0.085	0.177	0.246
November	24.9	26.4	106.2	-0.024	0.704	-0.005
December	5.9	10.4	175.0	0.000	1.000	0.000
Summer	9.419	11.78	125.2	-0.071	0.261	-0.012
Monsoon	63.1	38.3	60.7	0.068	0.284	0.095
Post-monsoon	473.7	116.4	24.6	0.069	0.272	0.370
Winter	124.1	74.3	59.9	0.047	0.454	0.155
Annual	670.3	153.0	22.8	0.106*	0.094	0.789

Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.10$. Source: Author's own calculations.

Further, the monthly rainfall analysis of Mahabubnagar district using Mann-Kendall test reveals that except for February, August and September, all the other months are not statistically significant. The value of Sen's slope estimator for the August month was about 0.608 which indicates annual rainfall has been increasing 0.61 mm per year. The monthly rainfall during February and September show a significant declining trend for Mahabubnagar district. The empirical results of the trend detection tests for Mahabubnagar show an insignificant decreasing rainfall trend during January, March, May and November

months. Conclusively, the analysis for annual rainfall data of Mahabubnagar district displays that there is a significant increasing trend.

4.4.4 Analysis of temperature trends in selected study districts

The district-level temperature trends of the two selected districts (Karimnagar and Mahabubnagar) in Telangana are discussed separately. Accordingly, this section deals with the trends of temperature in the study districts. Before analysing the data using trend detection methods, we have presented the annual maximum and minimum temperature data for both study districts in graphic form. Figures 4.8 and 4.9 demonstrate the annual temperature (maximum and minimum) trends of Karimnagar district. Further, figures 4.10 and 4.11 show the annual temperature (maximum and minimum) trends of Mahabubnagar district.

Figure 4.8: Linear trend of maximum temperature in Karimnagar district (1901-2015)

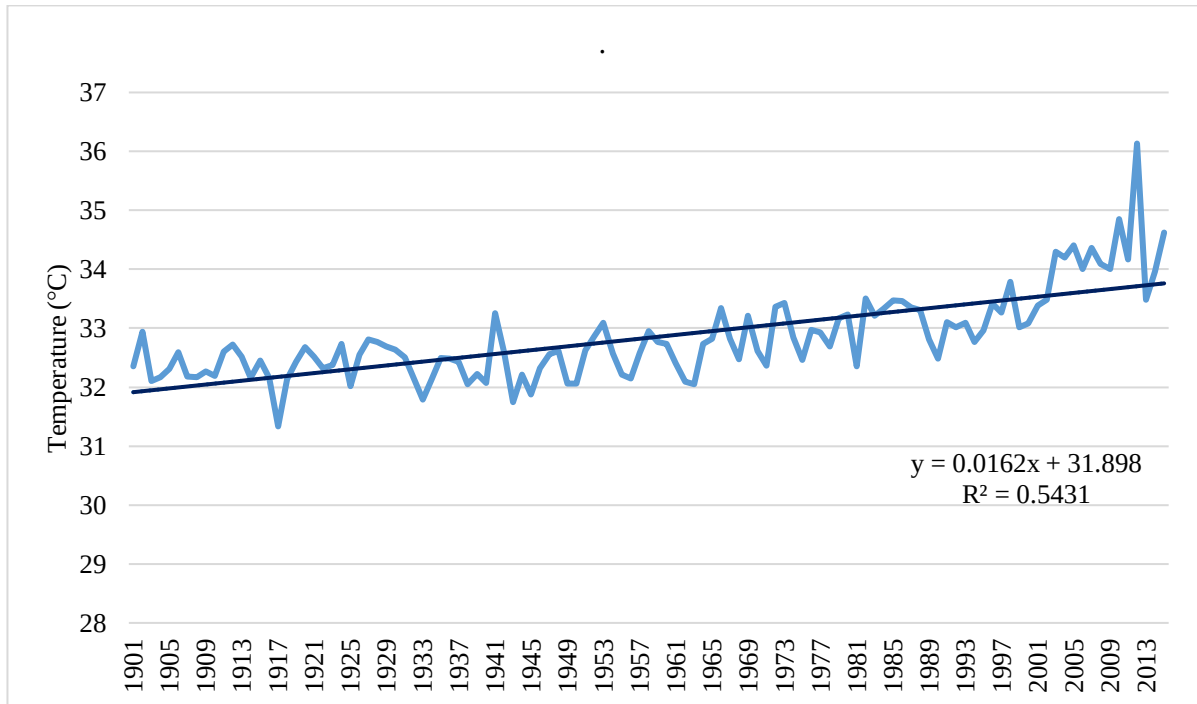


Figure 4.9: Linear trend of minimum temperature in Karimnagar district (1901-2015)

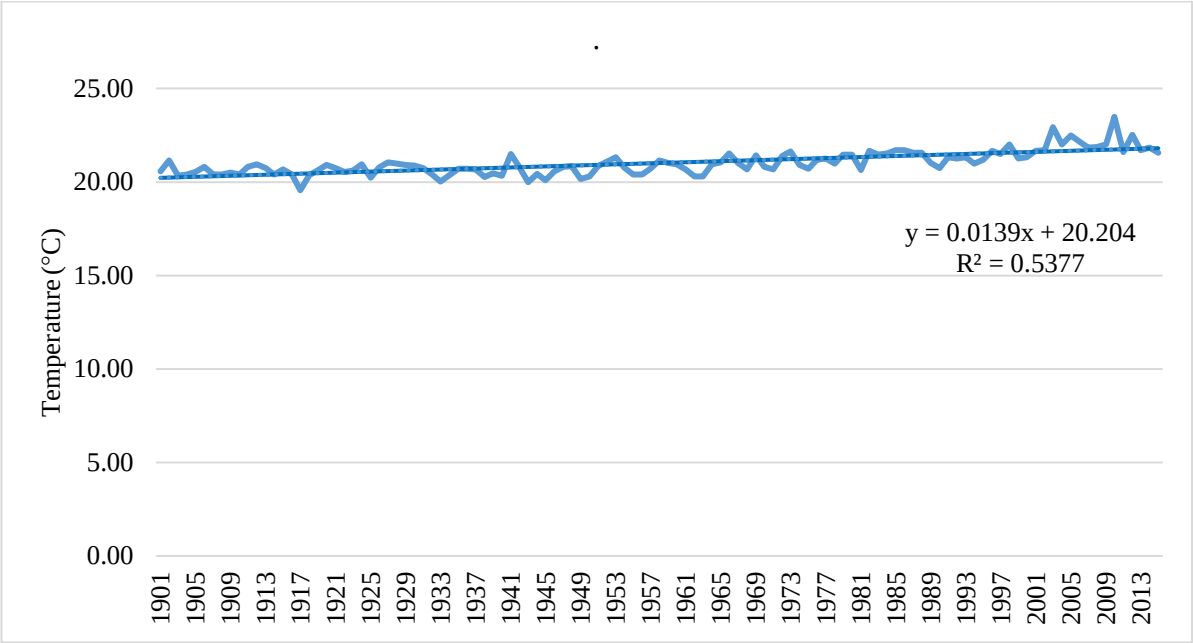


Figure 4.10: Linear trend of maximum temperature in Mahabubnagar (1901-2015)

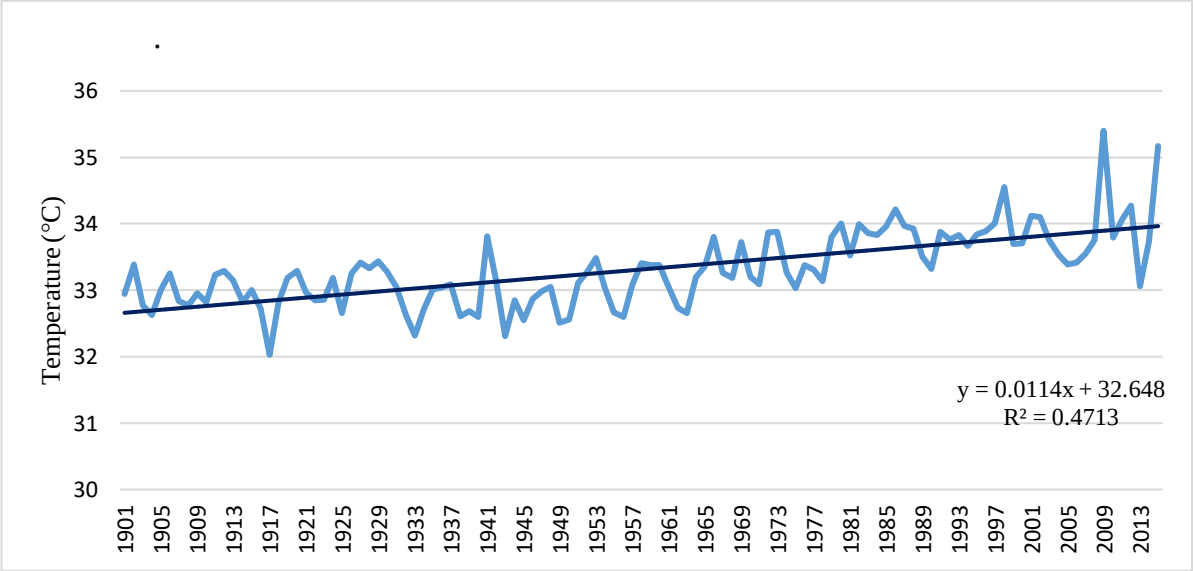
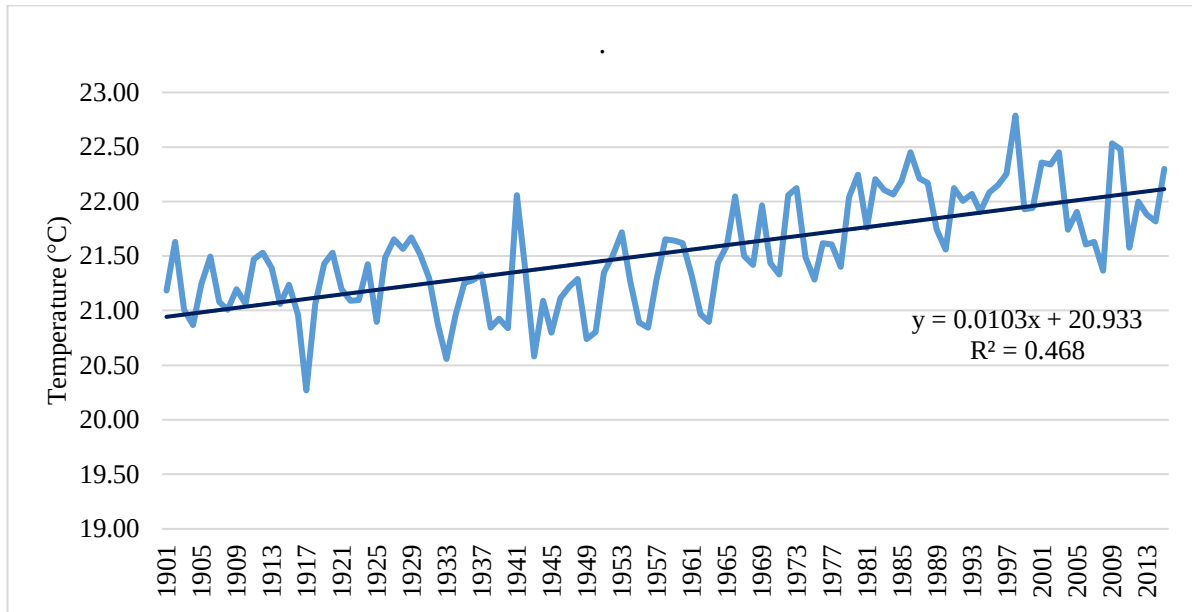


Figure 4.11: Linear trend of minimum temperature in Mahabubnagar (1901-2015)



It can be observed from Figure 4.8 that there is a clear increasing trend in the maximum temperature in the Karimnagar district. However, the trend line of the minimum temperature of Karimnagar shows a slight increase over the study period. Further, it can be observed from Figures 4.10 and 4.11 that there is a significant increasing trend in the annual maximum and minimum temperatures for the Mahabubnagar district, respectively. However, further trend analysis of temperature data in study districts using Mann-Kendall and Sen's slope tests will provide a clearer picture.

After graphical analysis, the results of the non-parametric statistical test for the monthly and annual mean temperature of the Karimnagar district have been reported in Table 4.9. The average mean temperature of the Karimnagar district is 26.91 °C during the study period which is lesser than the state's (27.11 °C) average mean temperature. The coefficient of variation of annual mean temperature is around 2.52 percent. The monthly mean temperature analysis of Karimnagar district presents that May month shows the highest mean temperature (33.58 °C) and December month presented the lowest mean temperature (21.39 °C) over the study period. The annual mean temperature of Karimnagar evidences a long-term significant (at 1 % level) increasing trend during the study period.

The value of Sen's slope estimator was about 0.014 which infers that annual mean temperature in Karimnagar has been increasing 0.014 °C per year during the study period.

Table 4.9: Monthly mean temperature trends of Karimnagar (1901-2015)

Months	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slope
January	22.35	0.96	4.31	0.215***	0.001	0.009
February	24.90	0.97	3.88	0.398***	0.001	0.017
March	28.39	1.10	3.86	0.350***	0.001	0.015
April	31.51	1.03	3.26	0.292***	0.001	0.014
May	33.58	1.29	3.84	0.292***	0.001	0.017
June	30.51	1.46	4.80	0.195***	0.002	0.014
July	27.28	0.90	3.31	0.337***	0.001	0.014
August	26.67	0.86	3.21	0.322***	0.001	0.011
September	26.92	0.88	3.27	0.441***	0.001	0.015
October	26.14	0.83	3.16	0.387***	0.001	0.014
November	23.27	1.22	5.23	0.375***	0.001	0.020
December	21.39	1.10	5.16	0.343***	0.001	0.017
Annual	26.91	0.68	2.52	0.544***	0.001	0.014

Note: *** $p < 0.01$. Source: Author's own calculations.

The monthly mean temperature analysis of Karimnagar district using the Mann-Kendall test reveals that all the months (January to December) are reported a statistically significant (1 % level) increasing trend over the study period. Moreover, as per Sen's slope test results, the mean temperature during January (0.009 °C), February (0.017 °C), March (0.015 °C), April (0.014 °C), May (0.017 °C), June (0.014 °C), July (0.014 °C), August (0.011 °C), September (0.015 °C), October (0.014 °C), November (0.020 °C) and December (0.017 °C) has been increasing per month during 1901-2015. Overall, the analysis for mean temperature of Karimnagar district shows that there is a substantial upward trend in mean monthly and annual temperature data. After the analyzing mean temperature trends of Karimnagar district, we further explore the mean temperature trends of Mahabubnagar district.

The results of the non-parametric statistical test for the monthly and annual mean temperature of the Mahabubnagar district have been reported in Table 4.10. The average mean temperature of the Mahabubnagar district is 27.41 °C during the study period which is little higher than the state's (27.11 °C) average mean temperature. The coefficient of

variation of annual mean temperature is almost 2 percent. The monthly mean temperature analysis of Mahabubnagar district presents that May month shows the highest mean temperature (32.69 °C) and December month presented the lowest mean temperature (22.89 °C) over the study period.

Table 4.10: Monthly mean temperature trends of Mahabubnagar (1901-2015)

Months	Mean	SD	CV(%)	Kendall's tau	p-value	Sen's slope
January	23.64	0.89	3.76	0.302***	0.001	0.012
February	26.09	0.91	3.49	0.411***	0.001	0.016
March	29.37	0.95	3.24	0.374***	0.001	0.016
April	32.06	0.85	2.64	0.248***	0.001	0.010
May	32.69	1.09	3.33	0.292***	0.001	0.014
June	29.65	1.08	3.63	0.134**	0.035	0.006
July	27.51	0.73	2.65	0.181***	0.004	0.006
August	26.99	0.62	2.29	0.072	0.253	0.002
September	27.08	0.71	2.61	0.203***	0.001	0.006
October	26.57	0.66	2.48	0.215***	0.001	0.006
November	24.40	1.04	4.26	0.394***	0.001	0.018
December	22.89	1.07	4.66	0.362***	0.001	0.017
Annual	27.41	0.52	1.90	0.495***	0.001	0.010

Note: *** p < 0.01 and ** p < 0.05. Source: Author's own calculations.

The annual mean temperature of Mahabubnagar evidences a long-term significant (at 1 % level) increasing trend during the study period. The value of Sen's slope estimator was about 0.010 which infers that annual mean temperature in Mahabubnagar has been increasing 0.010 °C per year during the period of study. The monthly mean temperature analysis of Mahabubnagar district using the Mann-Kendall test reveals that except for August month, all the months are reported a statistically significant increasing trend over the study period. In addition, as per Sen's slope test results, the mean temperature during January (0.012 °C), February (0.016 °C), March (0.016 °C), April (0.010 °C), May (0.014 °C), June (0.006 °C), July (0.006 °C), August (0.002 °C), September (0.006 °C), October (0.006 °C), November (0.018 °C) and December (0.017 °C) has been increasing per month during 1901-2015. Overall, the analysis for mean temperature of Mahabubnagar district shows that there is a significant rising trend in mean monthly and annual temperature data. We further analyse

the trends of maximum and minimum temperatures of selected districts in the following analysis.

The trend analysis of yearly minimum as well as maximum temperature data at the district level of study districts is reported in Table 4.11. It can be observed from Table 4.11 that there is a statistically significant increasing trend in the annual maximum temperature for the Karimnagar district, showing towards an overall increase in the maximum temperature for the period 1901-2015. The Sen's slope value is about 0.014 which suggests that annual maximum temperature in Karimnagar district has been increasing 0.014 °C per year. Similarly, the empirical results show that the yearly minimum temperature of the Karimnagar district has been increasing significantly. And the Sen's slope value is about 0.013 which suggests that annual minimum temperature in Karimnagar district has been increasing 0.013 °C per year. Conclusively, the results of trend detection methods demonstrate a significant rising trend in both minimum and maximum temperatures of Karimnagar district.

Table 4.11: Annual temperature (minimum and maximum) trends in selected districts

District	Parameter	Kendall's tau	p-value	Sen's slope
Karimnagar	Maximum Temperature	0.544***	0.001	0.014
	Minimum Temperature	0.537***	0.001	0.013
Mahabubnagar	Maximum Temperature	0.488***	0.001	0.010
	Minimum Temperature	0.476***	0.001	0.010

Note: *** $p < 0.01$. Source: Author's own calculation.

Furthermore, it can be observed from Table 4.11 that there is a statistically significant increasing trend in the annual maximum temperature for the Mahabubnagar district, showing towards an overall upsurge in the maximum temperature for the period 1901-2015. The Sen's slope value is about 0.010 which suggests that annual maximum temperature in Mahabubnagar district has been increasing 0.010 °C per year. In the same way, the empirical results show that the yearly minimum temperature of the Mahabubnagar district has been increasing significantly. Further, the Sen's slope value is about 0.010 which suggests that annual minimum temperature in Mahabubnagar district has been increasing

0.010 °C per year. To conclude, the results of trend detection methods demonstrate a significant upward trend in both minimum and maximum temperatures of Mahabubnagar district.

4.5 Summing up

The aim of this chapter is to detect and analyse the trends in rainfall and temperature for Telangana as well as study districts, namely Karimnagar and Mahabubnagar, using secondary data for the period of 1901-2015. The data has been analysed using trend non-parametric detection techniques such as the Mann-Kendall (MK) test and Sen's slope test. We also presented the mean, coefficient of variation (CV) and standard deviation (SD) values of rainfall and temperature. This analysis highlighted that the trend during the last 115 years can be taken as an indicator for the climatic path with which we are moving on to the future.

The empirical results reveal that the annual rainfall has been increasing in Telangana during the study period, although it is not statistically significant. Similarly, the seasonal rainfall of the state also demonstrated an increasing trend except during the winter season. Further, the monthly rainfall trend analysis exhibited that only August month rainfall has increased significantly over the study period. From the district-level analysis of annual rainfall trends, we observed a significant rising trend in Nizamabad, Khammam and Warangal districts. However, the remaining districts were exhibited an insignificant increasing rainfall trend.

Moreover, the annual mean temperature of Telangana presents a statistically significant rising trend from 1901 to 2015. In the same way, the monthly mean temperature of the state also evidenced a significant rising trend. Further, the district-level analysis of annual temperature (consist of mean, minimum and maximum temperatures) presents a significant increasing trend over the time of the study. Therefore, temperature (mean, minimum and maximum) levels in Telangana have been increasing substantially.

This chapter also explored the trends of rainfall and temperature in selected districts of Telangana, such as Karimnagar and Mahabubnagar. The empirical results reveal that the

annual rainfall has been increasing in the Karimnagar district during the study period, while it is not statistically significant. Likewise, the seasonal rainfall of the Karimnagar also demonstrated an insignificant increasing trend except during the summer season. The monthly rainfall trend analysis of Karimnagar district exhibited that September month rainfall has decreased significantly during the study period. Further, the empirical results evidence that the annual rainfall of Mahabubnagar has been increasing significantly. However, the seasonal rainfall of the Mahabubnagar district revealed an insignificant increasing trend except during the summer season. The monthly rainfall trend analysis of the Mahabubnagar district presented that February and September month's rainfall has decreased significantly.

The annual mean temperature of Karimnagar and Mahabubnagar districts presented a statistically significant rising trend during 1901-2015. Similarly, the monthly mean temperature of the study districts was also demonstrated a significant increasing trend over the time of the study. Lastly, the minimum and maximum temperatures of Karimnagar and Mahabubnagar districts are evidenced by a significant increasing trend during 1901-2015. Therefore, temperature (mean, minimum and maximum) levels in selected districts have been increasing substantially.

However, the present rainfall trend was not much more a cause of worry, but the temperature pattern was really alarming that the Telangana and study districts of the state were getting hotter and hotter not only during the summer season but also throughout the year. The minimum and maximum temperature trends including mean temperature have been rising in the state particularly during recent years. This will certainly have its own implications on human life in general and farming activities in particular. The agricultural impacts are thus addressed in the subsequent chapter.

Chapter 5

Impact of Climate Change on Crop Yields and Yield Variability in Telangana

5.1 Introduction

The previous chapter (chapter 4) evidenced that the major climatic factors such as rainfall and temperature are changing significantly in Telangana. Changes in rainfall and temperature pattern affect agricultural yields. Accordingly, this chapter¹ proceeds to evaluate the effects of climatic factors (rainfall, minimum and maximum temperatures) on major crop yields (rice, jowar, maize, cotton and groundnut) in Telangana using district-level panel data over 1956-2015. This chapter is categorized into five sections. This section 5.1 provides an introduction and methodological background is described in section 5.2. The empirical methodology is illustrated in Section 5.3. Section 5.4 presents data sources. Section 5.5 provides the discussion and analysis of empirical results. In the last section 5.6, we have presented the conclusion and some policy implications of the chapter.

Climate change due to natural and anthropogenic activities is considered to be one of the serious environmental issues in the world (Stern, 2006). Pieces of evidence of the changes in rainfall, temperature, and extreme climatic events have been established on a more systematic as well as scientific basis (IPCC, 2007a, 2014). Extreme climatic events, viz., floods, cyclones, droughts, heat waves, and climate change harm global socio-economic, biophysical and ecological systems (IPCC, 2014). More specifically the agricultural sector is considered to be more vulnerable to climate change (Hasan et al., 2016). Since climatic factors like rainfall and temperature serve as important direct inputs to the crop sector, any change and variability in these variables are inevitable to have a significant effect on crop yields (Barnwal and Kotani, 2013). There is also a generous

¹ The core content of present chapter has already been published by the scholar in refereed journals as below:

- a) Guntukula Raju and Phanindra Goyari (2020): "Climate change effects on the crop yield and its variability in Telangana, India", in: *Studies in Microeconomics*, Vol.8, Issue 01, pp.119-148, Print ISSN: 2321-0222 and e-ISSN: 2321-8398, ABDC Ranked C, Scopus and UGC CARE listed journal, (Available at: <https://journals.sagepub.com/doi/full/10.1177/2321022220923197>).
- b) Raju Guntukula and Phanindra Goyari (2020): "The impact of climate change on maize yields and its variability in Telangana, India: A panel approach study" in: *Journal of Public Affairs*, Vol. 20, Issue 03, pp. 1-11, ISSN: 1479-1854, ABDC Ranked B, Scopus and UGC CARE listed journal, (Available at: <https://onlinelibrary.wiley.com/doi/full/10.1002/pa.2088>).

concern about projected future changes in climatic factors due to rapidly increasing concentrations of greenhouse gases (Aggarwal, 2003) and expected changes in these climate variables would have a direct or indirect impact on food production (Krupa, 2003). Therefore, this area has captured the extensive attention of policy makers and researchers (Mall et al., 2006; Lobell et al., 2011). Such attention can be more in the less developed countries like India where agricultural production is largely affected by the climatic factors (Kumar and Parikh, 2001a).

What makes the problem so worrying in India is that it has inadequate arable land but greater dependence of the population on agriculture sector (Mendelsohn et al., 2006) and also have the less adaptive capacity and technological progress to cope with climate change (Birthal et al., 2014). Similarly, effects of climatic variables are anticipated to be severe for Indian agriculture sector because it has large rain-fed area with only about 48 percent of the cultivated area under assured water supply (Government of India, 2013). Uncertain rainfall and the shortage of irrigation facilities in India are believed to be contributing predominantly to lower crop yields (Pal and Mitra, 2018).

Therefore, agriculture as well as food production systems in India are highly vulnerable to climate change owing to their higher sensitivity to climate change (Dubey and Sharma, 2018). In India, temperature has been elevated by 0.3 to 0.8 °C per decade during the last few decades (Goswami et al., 2006). The projected climate changes up to 2100 for India show an overall upsurge in air temperature by 2 to 4 °C combined with a rise in rainfall particularly in the rainy season (Kumar, 2009). Similarly, the rainfall is projected to increase by 6 to 14 percent at the end of the century (2080) with a high intensity and frequency of precipitation (Chaturvedi et al., 2012). Lobell et al. (2012) revealed that the productivity of wheat crop is extremely sensitive to below 34 °C temperature in northern India.

The IPCC (2007a) report found that 0.5 °C elevation in winter-time, minimum temperature is expected to decrease the productivity of wheat in India by 0.45 tons/ha (Easterling et al., 2007). Future climate change could reduce yields in the short-run (2010-39) by 4-9 percent and in the long-run (2070-2099) due to lack of adaptation by about 25

percent (Guiteras, 2009). Interestingly, the projected agriculture output loss by 2100 lies between 10-40 % in India (Aggarwal, 2008). However, these studies established the fact that climate-related factors have significant effects on crop productivity. While the effects of climate change at the state or local level shows identical results with respect to all-India patterns, there are considerable regional differences as well (Saseendran et al., 2000). However, despite its great significance, only a small number of studies has been carried out to evaluate the effects of climatic factors on agricultural output and yield, particularly from the perspectives of developing nations and agriculturally backward regions (Guiteras, 2009; Barnwal and Kotani, 2013). Hence, we aim to evaluate the impact of climate change on crop yields with the focus on India's Telangana state, whose agricultural system is largely dependent on seasonal rainfall. According to few studies (like Padakandla, 2016), Telangana has been one of the region's most vulnerable state's to climate change and environmental hazards.

5.1.1 Climate change and agriculture in Telangana

Situated on the southern India, Telangana state is located between latitudes 17° 7' and 23.4624," N and longitudes 79° 12' and 31.7664" E. It is India's 12th largest state in terms of both populations (3.52 crores) and geographical area (112,08 lakh hectares) (SEO, 2016). The study area includes nine undivided districts² of Telangana and these districts mainly depend on agriculture. The yearly mean maximum temperature of the state is 42°C, whereas the mean minimum temperature is about 22–23 °C. Nearly two-thirds of the annual precipitation comes from the south-west monsoon. The northern part of state receives 900-1500 mm annual rainfall, while the southern part of state receives 700-900 mm annual rainfall (SEO, 2016). It is important to note that more than 50 percent of the overall cultivated area in Telangana is found to be under the rain-fed agricultural system. This makes the agriculture sector of the state as a rainfall dependent.

As stated above, Telangana state faces various challenges of less rainfall, low ground water levels and drought conditions all of which are directly related to the agricultural

²As already mentioned in Chapter 1, Telangana government divided the former 10 districts and the number became 33 districts in 2019. However, this study is based on former 10 districts.

output, food security and farmer's livelihood. Given the location of Telangana in the arid and semi-arid climate, agricultural productivity is extremely vulnerable to climate change and drought (Bhavani et al., 2017). Moreover, rural livelihood sector in the state is further exposed to the climatic changes and therefore, it is seen to be at a greater risk than few other Indian states (Revadekar et al., 2012). In the year 2008, World Bank (2008) report confirmed that the adverse impact of climatic change can lead to a substantial reduction in the agricultural income in Telangana region of combined Andhra Pradesh. In recent times, Telangana state has also witnessed high intensive and incidence of droughts and austere farmer suicides (Tada, 2004; Parida et al., 2018).

In this background, a well-organized and scientific research of climatic effects on crop production in Telangana state is important for various reasons. This study aims to examine the impact of climate change on mean yield as well as yield variances in major crops (rice, cotton, maize, jowar and groundnut) in three agro-climatic zones of Telangana using district-level panel data during the period of 1956-2015. To the best of our information, this study is the first to empirically examine the climatic impacts on crop yields in Telangana by unequivocally considering likely heterogeneity with respect to crop yield variability (risk) and geographical zones.

5.2 Methodological background

Over the past two decades, several studies have assessed the effects of climatic factors on crop productivity in various countries of the world. Generally, these studies have estimated the impact of climate change using either (i) crop simulations (agronomic models) or (ii) the Ricardian methodology including econometric models. Crop simulation models are based on well-organized scientific experiments where plants are grown in a laboratory or are in the field. Then, simulation experiments are done in different environmental and climate conditions and CO₂ impacts (Saseendran et al., 2000). Crop simulations have the ability to project the possible climatic effects on agricultural production and yield (Sarker et al., 2014).

Some studies that have used the agronomic models to evaluate the effects of climate factors on crop yield include Mearns et al. (1997), Rosenzweig et al. (2002), Saseendran et

al. (2000) and Mall and Aggarwal (2002). Mall et al. (2006) have presented an extensive review of crop simulation investigations. Many agronomic modeling studies have revealed the potential adverse consequences of climate change. However, some authors (such as Mendelsohn and Dinar, 1999) have pointed out that agronomic models do not take into account the farmer's adaptation measures and these models can underestimate the positive impacts and overestimate the adverse effects due to climate change.

On the other hand, the Ricardian methodology evaluates the impact of climatic factors on land values or net revenues using the cross-sectional statistics (Mendelsohn et al., 1994; Mendelsohn and Dinar, 1999). Several studies by utilizing Ricardian approach demonstrated that the changes in precipitation and temperature have an adverse effect on land revenue or income. Kumar and Parikh (1998) found that the rice yields decreased by 15-25 percent and wheat yields by 30-35 percent in India. Further, the net farm income in India decreased by 8 percent (Mendelsohn et al., 1994). Kumar and Parikh (2001a) reported that the anticipated 2°C upsurge in temperature and 7 percent upturn in rainfall can diminish farm returns by 9 percent. Similarly, Sanghi and Mendelsohn (2008) reported that net revenue of agriculture in India could drop by 4-26 %. However, the main limitation of this method is the failure to account for time-independent location-specific factors, viz., the intangible abilities of farmers and soil quality (Barnwal and Kotani, 2013). Also this approach may not be useful for developing nations because of the inefficient land markets.

Furthermore, recent investigations tend to employ panel data methods (Deschenes and Greenstone, 2007). The major studies such as Guiteras (2009), Krishnamurthy (2012), Gupta et al. (2014) and Padakandla (2016) have used the panel data methods and found significant association between climate factors and crops yields. However, these studies have been unable to measure the effects of climate change on yield variance or risk, though the yield variance was found to be affected by climatic factors in several studies (Kim and Pang 2009, Chen et al. 2004, Isik and Devadoss 2006, Cabas et al. 2010, Sarker et al. 2014, Sarker et al. 2019). Against this background, the present study examines the effect of climate change on major crop yields and variance in Telangana. We have employed and estimated the Just and Pope production function. This function allows capturing climatic effects on the mean yields and variance (Kim and Pang 2009; Sarker et al., 2019).

5.3. Methodology

5.3.1 Model specification

As already stated, we have applied and estimated the production function developed by Just and Pope (1978). Literature review shows that significant portion of empirical studies has utilized either a crop simulation or a cross-sectional model. The crop simulation model using ‘general circulation models’ is found to perform inadequately (Schlenker and Roberts, 2008). Moreover, the extensive use of ‘Ricardian approach’ is not capable to capture the impact of omitted variables on crop output which produces biased results (Deschenes and Greenstone, 2007). In order to overcome this omitted variable issue, the production function developed by Just and Pope (1978) has been successfully utilized by many studies (e.g., Chen et al. 2004; Isik and Devadoss 2006, Kim and Pang 2009; Poudel et al. 2014).

In the present study, in order to evaluate the impacts of climatic factors on the mean level of the yield and variability of the crop yields, the stochastic production function approach introduced and elaborated by Just and Pope (1978, 1979) is employed. The basic concept underpinning this method is that a stochastic production function can be decomposed into two parts: the first section is related to the mean level of productivity whereas the second section is linked with the variability of that productivity (Kim and Pang, 2009; Cabas et al., 2010; Sarker et al., 2014). The general formula of the Just and Pope production function (Just and Pope, 1978) is:

$$y = f(X) + h(X) \epsilon \quad (5.1)$$

Where y is the crop yield and X is the vector of explanatory variables. ϵ is the random error with mean zero and variance (σ^2). The parameter assessment of $f(X)$ produces the mean impact of the independent variables on the crop yield whereas $h(X)$ provides their influence on the variability of the crop yield (Chen and Chang, 2005). Based on Chen et al. (2004) and Sarker et al. (2014) the production function of following form is assessed:

$$y = f(x) + u = f(X, \beta) + h(X, \alpha) \epsilon \quad (5.2)$$

where, y is crop yield (rice, jowar, maize, cotton and groundnut), X is the vector of explanatory variables (e.g., maximum and minimum temperatures, rainfall, area, time period

and location) and ϵ is the exogenous output shock with $E(\epsilon) = 0$ and $Var(\epsilon) = \delta_\epsilon^2$. Using this function, independent variables affect both the average and variability of crop yield because $E(y) = f(x)$ and $Var(y) = Var(u) = h(\cdot)$. The factor assessment of $f(\cdot)$ provides the average impacts of the independent variables on yield, whereas $h(\cdot)$ gives the effects of the covariates on the variability of crop yield (Isik and Devadoss, 2006). It is very important to note that the positive sign on any factor of $h(\cdot)$ infers an increase in that variable, i.e., an upsurge of the variability of the crop yield. A negative sign on the variability function implies a reduction of the yield variability demonstrating that climatic variables are risk decreasing inputs.

Generally, three functional forms of production functions are used to estimate Just and Pope production function - Cobb-Douglas, quadratic and translog production functions (Chen et al. 2004; Kim and Pang 2009). Due to the multiplicative interaction between the variance and mean, the translog functional form can violate the Just and Pope assumptions (Tveteras and Wan, 2000). Therefore, purposively, the linear Cobb–Douglas form has been used for the mean and variability of the crop yield function. This functional form is consistent with the Just and Pope (1979) assumptions as argued by Kim and Pang (2009).

5.3.2 Estimation method

All the parameters in the Equation (5.2) can be estimated by employing the maximum likelihood estimation (MLE) method suggested by Saha et al. (1997) or three-step feasible generalized least squares (FGLS) method proposed by Just and Pope (1979). Most of the empirical studies have employed the FGLS estimation procedure but MLE is more consistent and efficient estimator than FLGS particularly under a small sample situation (Saha et al. 1997). Since we have a large sample size, this study has used the three-step FGLS estimation procedure as explained in Judge et al. (1985). Moreover, panel data model estimation is generally comprised of both cross-section and time series data and can solve the problems of auto-correlation and heteroscedasticity (Gujrati 2004; Hill et al. 2008). However, these two problems are addressed in a better way using the FGLS procedure as it assumes that panels are not auto-correlated and homoscedastic (Wooldridge, 2002).

Generally, the fixed effects (FE) and random effects (RE) models are designed to estimate the panel data model (Baltagi, 2005). This study selected fixed effects model based on Hausman test results and this preference of fixed effects model is consistent with few existing studies (Kim and Pang 2009; Barnwal and Kotani, 2010; Cabas et al. 2010).

5.3.3 Formulation of econometric model

As mentioned earlier, the major disadvantage of the ‘Ricardian approach’ lies in its lack of ability to include omitted variables such as soil quality and unobservable skills of the crop growers which are also known as location specific and time-independent factors (Barnwal and Kotani, 2010). In order to overcome this omitted variable issue, we have incorporated agro-climatic zone dummies in the model. However, regional agro-climatic zone dummies are included only in the average yield function but not to the yield variance function. This is based on the assumption that different agro-climate zones have different average yields with almost similar yield variabilities across zones (Sarker et al. 2014). Linear trend was incorporated to include the impact of technological change over time. We have estimated the impact of climate change on crop yields and variability by specifying three models (Model I, Model II, Model III). In model I, we have included all the explanatory variables such as rainfall, area, maximum and minimum temperatures. However, maximum and minimum temperatures are not mutually exclusive in nature. Hence, instead of taking both maximum and minimum temperatures in one model, we have framed the model II and model III independently using minimum and maximum temperatures separately.

Model I: The econometric specification of mean yield function $f(X, \beta)$ is expressed as follows:

$$Y_{it} = \beta_0 + \beta_1 MxT_{it} + \beta_2 MnT_{it} + \beta_3 Rf_{it} + \beta_4 A_{it} + \beta_5 T_{it} + \sum_{l=1}^{L-1} \alpha_l D_l + e_{it} \quad (5.3)$$

where Y_{it} is the crop yields (kg/ha) for production district i and time t ; MxT_{it} , MnT_{it} , Rf_{it} , and A_{it} are the maximum temperature, minimum temperature, rainfall and area under crop,

respectively; $\alpha_i D_i$ ($i = 1, 2, \dots$) are agro-climatic zonal dummies taking values 1 and 0. T (year) is time trend variable to capture impacts of developments in technology. Further, the yield variability function $h(X, \alpha)$ is given as follows:

$$\ln e_{it}^2 = \alpha_0 + \alpha_1 MxT_{it} + \alpha_2 MnT_{it} + \alpha_3 Rf_{it} + \alpha_4 A_{it} + \alpha_5 T_{it} + \mu_{it} \quad (5.4)$$

where, $\ln e_{it}^2$ log of squared residuals from first step ordinary least squares (OLS) is a dependent variable and explanatory variables are maximum and minimum temperatures, rainfall, area and trend. Further, α 's are the parameter estimates and other independent variables are as defined in Equation (5.3). The estimation of the model II incorporates all the study variables excluding minimum temperature. On the contrary, Model III incorporates all the study variables excluding maximum temperature.

5.3.4 Panel unit root test

To avoid possible spurious regressions, it is essential to perform panel unit root test for stationarity for each study variable before estimating the model (Chen and Chang, 2005; Poudel and Kotani, 2013). Moreover, the pre-condition of Just and Pope production function is that the study variables in the model must be stationary (Chen et al., 2004). There are several types of tests for this purpose. Some of these include tests developed by Levin, Lin and Chu (LLC) (2002), Im et al. (2003), Breitung (2001) and Fisher-type test of Maddala and Wu (1999). In this study, we have employed Fisher-type test using ADF (Augmented Dicky-Fuller) test because this test gives more accurate results (Baltagi, 2005).

➤ Fisher-type panel unit root test

Maddala and Wu (1999) and then Choi (2001) offered the Fisher-type unit root test, which pools the p-values from individual unit root tests. If π_i is well-defined as the p-value from any individual test for cross-section section i , under the null of unit root test, then, for all N cross-sections, the asymptotic results are written as follows:

$$-2 \sum_{i=1}^N \ln(\pi_i) \rightarrow \chi^2_{2N} \quad (5.5)$$

The main advantage of the Fisher-type test is that it can be employed for various lag lengths in the individual ADF-regressions (Baltagi, 2005). Moreover, this test, using ADF-regressions with bootstrap-based values, makes the best and as a result is the most preferred method for testing the existence of non-stationary in the panel data (Maddala and Wu 1999). The null and alternative hypotheses for the ADF test are: (i) Null hypothesis (H₀): Entire panels contain unit roots and (ii) Alternative hypothesis (H_a): At least one panel is stationary.

5.4 Data sources for district level panel data

This study has used district level panel data (also known as cross-sectional time-series data) for five primary crops, viz., Rice, Jowar (Sorghum), Maize, Cotton and Groundnut from nine former (undivided Andhra Pradesh) districts in Telangana covering the period of 1956-2015. Data on the crop yields and crop-wise area under cultivation of the five principal crops in the state were collected from various issues of Statistical Abstracts of Andhra Pradesh, and Statistical Year Books of Telangana, available at Directorate of Economics and Statistics, Government of Telangana. Crop yield is measured in kilograms per hectare [kg/ha] and the crop-wise area is measured in hectare. We have also collected data of climatic variables from various sources. Statistics of annual and seasonal rainfall for the state and districts were collected from Meteorological Centre Hyderabad and Department of Economics and Statistics, Hyderabad. The mean annual, maximum and minimum temperature data were collected from indiawaterportal.org but the data were available up to the year of 2002 only at the time of collection. Temperature data since 2002 were collected from various issues of 'Statistical abstracts of Andhra Pradesh'. The panel data on rainfall were for maximum and minimum temperatures on a monthly basis. The summary statistics of the study variables are reported in Table 5.1.

Table 5.1: Summary statistics of study variables in Telangana

Variables	Observations	Unit	Mean	Std. Dev.	Minimum	Maximum
Rice	540	(kg/ha)	1948.56	772.14	308	4004
MaxT	540	(°C)	32.68	0.68	30.98	35.96
MinT	540	(°C)	21.18	0.84	18.55	25.08
Rainfall	540	(mm)	815.22	232.42	221.82	1773.88
Area	540	(hectare)	128410.4	68320.5	24283	417912
Jowar	540	(kg/ha)	654.15	271.70	187	1885
MaxT	540	(°C)	31.59	0.76	29.67	35.81
MinT	540	(°C)	20.67	0.92	18.16	25.38
Rainfall	540	(mm)	790.67	228.22	220.38	1771.71
Area	540	(hectare)	111741.3	88149.83	8	401385
Maize	540	(kg/ha)	2018.42	1257.19	296	6555
MaxT	540	(°C)	32.68	0.689	30.98	35.96
MinT	540	(°C)	21.18	0.843	18.55	25.08
Rainfall	540	(mm)	815.22	232.42	221.82	1773.88
Area	540	(hectare)	38504.07	36972.65	17	182493
Cotton	540	(kg/ha)	674.13	105.798	40	1380
MaxT	540	(°C)	32.06	0.7189	30.31	35.79
MinT	540	(°C)	20.80	0.8859	18.07	25.61
Rainfall	540	(mm)	800.76	231.0588	220.40	1771.70
Area	540	(hectare)	50351.80	74089.78	12	370363
Groundnut	540	(kg/ha)	987.60	454.22	175	2838
MaxT	540	(°C)	31.59	0.76	29.67	35.81
MinT	540	(°C)	20.67	0.92	18.16	25.38
Rainfall	540	(mm)	790.67	228.22	220.37	1771.74
Area	540	(hectare)	32398.74	40202.96	554	208802

Source: Authors' own calculations.

The study has incorporated undivided 9 districts of Telangana in which agricultural sector is dominant. These districts are Adilabad, Karimnagar, Nizamabad, Warangal, Khammam, Medak, Nalgonda, Rangareddy and Mahabubnagar. Hyderabad district area has been excluded from this investigation because it has insignificant crop cultivation area. According to the directorate of economics and statistics (DES) of Telangana, the state has been categorized into three agro-climatic (AC) zones (see chapter 3 for more information). To examine the impact of climate change on yields and yield variance, we have selected five

major food and non-food crops, namely, rice, jowar, maize, cotton and groundnut. The main reason behind selecting these crops is that they are principal crops together account to about 70 percent of the overall gross cropped area in Telangana. So, the impact of climatic factors on these crop yields can have significant implications on food security, income generation and livelihood of the farm households in the state. Secondly, consistent and comparable time-series crop-wise data are not available for other crops at the district-level.

Table 5.2: Pair-wise correlation matrix of study variables in Telangana

	Rice yield	Max. Temp.	Min. Temp.	Rainfall	Area
Rice yield	1.0000				
Max. Temp.	0.4040*	1.0000			
Min. Temp.	0.1967*	0.6293*	1.0000		
Rainfall	0.1563*	-0.1454*	0.0146	1.0000	
Area	-0.2110*	0.1321*	0.1981*	-0.3245*	1.0000
	Jowar yield	Max. Temp.	Min. Temp.	Rainfall	Area
Jowar yield	1.0000				
Max. Temp.	0.2528*	1.0000			
Min. Temp.	0.0239	0.6293*	1.0000		
Rainfall	0.0644	-0.1454*	0.0146	1.0000	
Area	-0.4530*	-0.2133*	-0.1327*	-0.1583*	1.0000
	Maize yield	Max. Temp.	Min. Temp.	Rainfall	Area
Maize yield	1.0000				
Max. Temp.	0.4790*	1.0000			
Min. Temp.	0.3197*	0.5677	1.0000		
Rainfall	0.1744*	-0.1060*	0.0332	1.0000	
Area	0.3888*	0.1391*	-0.1886*	0.0790	1.0000
	Cotton yield	Max. Temp.	Min. Temp.	Rainfall	Area
Cotton yield	1.0000				
Max. Temp.	0.0446	1.0000			
Min. Temp.	0.1685*	0.6001*	1.0000		
Rainfall	-0.0625	-0.1281*	0.0264	1.0000	
Area	-0.0682	0.5118*	0.2358*	0.1460*	1.0000
	Groundnut yield	Max. Temp.	Min. Temp.	Rainfall	Area
Groundnut yield	1.0000				
Max. Temp.	0.4040*	1.0000			
Min. Temp.	0.1967*	0.6293*	1.0000		
Rainfall	0.1563*	-0.1454*	0.0146	1.0000	
Area	-0.2110*	0.1321*	0.1981*	-0.3245*	1.0000

Source: Authors' own calculations. Note: * indicates significance at 5 % level.

5.5 Results and Discussions

5.5.1 Pair-wise correlation results

The pair-wise correlations among the study variables are reported in Table 5.2. Results are mixed. The rice yield is positively and significantly correlated with maximum temperature, minimum temperature and rainfall.

Moreover, jowar yield is positively correlated with rainfall, minimum and maximum temperatures but minimum temperature and rainfall variables are not statistically significant at 5 percent level. Similarly, maize yield is positively correlated with all climatic and other variables and correlation coefficients are statistically significant at 5 percent level. Cotton yield is positively and significantly correlated with minimum temperature only. Cotton yield is also positively correlated with maximum temperature but statistically insignificant at 5 percent level. The cotton yield is also negatively correlated with rainfall. Lastly, groundnut yield is positively correlated with maximum temperature, minimum temperature and rainfall and correlation coefficients are statistically significant at 5 percent level.

5.5.2 Panel unit root test results

Prior to estimating the Just and Pope production function, Fisher-type (ADF) panel unit root test is applied to check the stationarity properties of study variables. The panel unit root test results are presented in Table 5.3. The test statistics of the ADF regression for the crop yields (rice, cotton, maize, jowar and groundnut) and climatic variables (temperature and rainfall) are found to identical in both models with trend and without trend. The panel unit root test results indicate that all study variables are statically significant and the null hypothesis of unit roots is rejected at the 1 percent level of significance. This infers that the study variables are stationary at the level or $I(0)$.

Table 5.3: Fisher type panel unit root test results of climate variables in Telangana

Crops	Variables	Fisher test (ADF) Test statistics	
		Without Trend	With Trend
Rice	Yield	53.49 ***	272.60 ***
	Maximum Temperature	133.97 ***	239.45 ***
	Minimum Temperature	144.88 ***	206.93 ***
	Rainfall	503.53 ***	466.61 ***
	Area	161.03 ***	217.33 ***
Jowar	Yield	129.58 ***	231.45 ***
	Maximum Temperature	142.33 ***	236.99 ***
	Minimum Temperature	157.22 ***	206.28 ***
	Rainfall	512.48 ***	477.05 ***
	Area	134.23 ***	184.94 ***
Maize	Yield	52.36***	246.02***
	Maximum Temperature	503.53***	466.61***
	Minimum Temperature	133.97***	239.45***
	Rainfall	144.88***	206.93***
	Area	227.67***	284.56***
Cotton	Yield	52.66 ***	38.15 ***
	Maximum Temperature	139.66 ***	245.90 ***
	Minimum Temperature	151.62 ***	212.89 ***
	Rainfall	510.14 ***	473.10 ***
	Area	35.99 ***	35. 91 ***
Groundnut	Yield	65.04 ***	253.61 ***
	Maximum Temperature	142.33 ***	236.99 ***
	Minimum Temperature	157.22 ***	206.28 ***
	Rainfall	512.48 ***	477.05 ***
	Area	161.81 ***	174.59 ***

Source: Authors' estimations, Note: *** $p < 0.01$.

The panel unit root test results are consistent with other studies like Kim and Pang (2009), Sarker et al. (2019) and Sarker et al. (2014). Therefore, Just and Pope production function using the three-step FGLS estimation procedure can be applied to district-level panel data without any differencing.

5.5.3 Crop-wise estimation results

The present section deals with crop-wise empirical results and discussions. The effect of climate related variables on crop yields in Telangana has been examined under the panel data approach with 540 observations and 9 panel groups (i.e., (annual data for 60 years during 1956-2015 for 9 districts). The estimations of the mean yield and variability functions have been done using the three-step feasible generalized least squares (FGLS) estimation procedure. Here we present the crop-wise empirical analysis.

i) Estimated results for Rice

Rice (Paddy) has been one of the world's three major food crops (Padakandla, 2016). Being cultivated worldwide, it is the staple diet for more than 2.7 billion global populations (Singh et al., 2014). India is the principal rice-producing country and accounting for almost 20 percent of world rice production. However, this crop is grown in almost all the 29 states of India, covering more than one-quarter of the overall cropped area in India. In the same way, rice is one of the major crops in Telangana, accounting for 26 percent of the overall cultivated area and 60 percent of the overall foodgrain output in 2014-15 (Government of Telangana, 2016).

The estimated results for rice are shown in Table 5.4. The estimated coefficients of explanatory variables for three rice models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. In the mean yield function of rice, all the study variables, including agro-climatic zone dummies, are significantly influencing rice yield over the study period. Rainfall has a significant influence on average rice yield in Telangana as per results in three models. This infers that the rice cultivation in Telangana largely depends on rainfall. However, the maximum temperature is adversely associated with the rice yield in model I and model II, and it is statistically significant at 1% level of significance. This indicates that the growing maximum temperature may reduce the rice yield in Telangana. Moreover, minimum temperature has a significant positive impact on rice yield in model I and model III. The positive effect of minimum temperature may not be able to counterbalance the adverse effect of maximum temperature as observed in

Table 5.4: Estimated Results for Rice in Telangana

Rice	Model I	Model II	Model III
Mean yield function $f(x)$	Coefficient	Coefficient	Coefficient
Trend	0.016***	0.093***	0.097***
Maximum Temperature	-1.907***	-1.502***	
Minimum Temperature	0.589*		0.039
Rainfall	0.540***	0.552***	0.595***
Area	1.008***	1.005***	1.076***
Northern AC Zone	20.742***	21.210***	16.561***
Central AC Zone	20.695***	21.166***	16.527***
Southern AC Zone	20.804***	21.274***	16.634***
Constant	3.548***	0.811***	-3.827***
Yield variability function $h(x)$			
Trend	0.005***	0.005***	0.005***
Maximum Temperature	-0.050***	-0.027***	
Minimum Temperature	0.038***		0.023***
Rainfall	0.028***	0.029***	0.029***
Area	0.061***	0.061***	0.061***
Constant	3.010***	3.049***	2.878***
Model summary			
Log likelihood	1212.641	1212.557	1210.81
Wald Chi-square	749489.67	755748.94	729741.91
Prob > Chi-square	0.0000	0.0000	0.0000

Source: Authors' own estimations. Notes: *** $p < 0.01$ and * $p < 0.05$.

coefficient values. Our results are almost similar to other studies like Padakandla (2016) and Pattanayak and Kumar (2014). An increase in area under rice has a positive and significant effect on yield in three rice models. The time-trend variable is positively associated with the mean yield in three models. This infers that technological progress has a positive effect on

rice yield over time. Lastly, three agro-climatic zone variables have significant and positive influences on rice yield in three models. However, the magnitude of influence varies in three rice models. Similar empirical results were obtained in studies of other regions like Poudel and Kotani (2013).

The results of yield variability function for rice crop are also reported in Table 5.4. It can be observed that climatic factors, including area under rice and trend variable, are statistically significant at 1% level in the rice variability function. The maximum temperature has an adverse impact on the yield variance of rice. This indicates that maximum temperature is a risk-reducing factor for rice yield variability in two models. The other climatic factors such as rainfall and minimum temperature are positively influencing the yield variability of rice. This implies that the rainfall and minimum temperature are risk-enhancing factors in rice yield variance function. Similarly, an increase in cultivation area under rice crop has a positive effect on yield variability of rice in three models. This suggests that increased area under rice is a risk-enhancing factor. Interestingly, the time trend has a significant favorable effect on rice yield variance. This can be interpreted in such a way that rice yield variability possibly may be increasing over time due to technological advancements such as new HYVs seeds, irrigation and better use of fertilizers, etc.

ii) Estimated results for Jowar (Sorghum)

Jowar (*Sorghum bicolor*), also known as Sorghum, is one of India's most prominent food and animal fodder crops (Padakandla, 2016). Jowar is predominantly a drought-resistant crop that suitable for agricultural areas located in semi-arid climates (Mkonda and He, 2017). India contributes almost 16 percent of the world's sorghum output and also this crop occupies fourth place in area and production in India (Zalkuwi et al., 2014). In the state of Telangana, jowar is an important food crop and it is cultivated in both the seasons (i.e. kharif and rabi) predominantly under rain-fed conditions. This crop accounted for 3.50 percent of the overall gross cropped area under foodgrain crops in the state (Government of Telangana, 2016).

Table 5.5: Estimated Results for Jowar in Telangana

Jowar	Model I	Model II	Model III
Mean yield function $f(x)$	Coefficient	Coefficient	Coefficient
Trend	-0.302***	-0.335***	-0.289***
Maximum Temperature	5.939***	0.336	
Minimum Temperature	-7.203***		-4.693***
Rainfall	0.241***	0.189***	0.122**
Area	0.304***	0.328***	0.267***
Northern AC Zone	-153.344***	-171.125***	-133.457***
Central AC Zone	-153.399***	-171.208***	-133.509***
Southern AC Zone	-153.583***	-171.386***	-133.690***
Constant	25.840***	28.408***	24.874***
Yield variability function $h(x)$			
Trend	0.003***	0.003***	0.003***
Maximum Temperature	-0.076***	-0.019***	
Minimum Temperature	0.078***		0.048***
Rainfall	-0.002***	-0.002***	-0.001***
Area	-0.003***	-0.003***	-0.002***
Constant	3.671***	3.704***	3.484***
Model summary			
Log likelihood	868.6839	869.2676	867.954
Wald Chi-square	1.76e+06	1.72e+06	1.70e+06
Prob > Chi-square	0.0000	0.0000	0.0000

Source: Authors' own estimations. Note: *** $p < 0.01$ and ** $p < 0.05$.

The estimated results for jowar are provided in Table 5.5. Estimated coefficients of all explanatory variables for three jowar models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. The explanatory variables such as rainfall, maximum and minimum temperatures, area, and agro-climatic zone dummies are statistically significant in three jowar models. However, maximum temperature

in model II is not statistically significant in jowar mean yield function. Rainfall has a significant positive effect on mean yields in three jowar models. Jowar is a rainfed crop in Telangana and due to this reason, possibly the effect of rainfall is favorable. Likewise, maximum temperature has a significant positive effect on mean yields in model I. Jowar is considered to be mainly a heat resistant crop and hence we can say that the upper temperature may not affect the crop yield to a great extent. However, minimum temperature has an adverse effect on mean yield of jowar in two models. The positive impact of maximum temperature may be unable to offset the adverse effect of minimum temperature as observed from estimated coefficient values. Our findings of minimum and maximum temperature are contrary to findings by Padakandla (2016). An increase in area under jowar crop has a positive impact on jowar yield. Further, time-trend is adversely associated with the mean yield of jowar. All regional agro-climatic zone variables in three models are found to be statistically significant and have adverse effects on jowar mean yields in Telangana.

The yield variability function results of the jowar crop are also shown in Table 5.5. Rainfall, area, minimum and maximum temperatures are statistically significant in yield variability function. The minimum temperature has a significant and positive effect on jowar yield variability. This implies that the minimum temperature in Telangana is a risk-enhancing factor for yield variance of jowar. However, maximum temperature and rainfall have adverse impact on jowar yield variance. This indicates that the rainfall and maximum temperature are risk-reducing factors for jowar yield. Similarly, an increase in area under jowar crop has a significant adverse effect on yield variance of jowar. The increased cropped area is also a risk-reducing factor in Telangana. Lastly, the time-trend factor has a significant favorable effect on jowar yield variability. Therefore, we can conclude that the trend variable is a risk-enhancing factor for jowar crop. These results of mean yield and variability function results for jowar are almost similar to few studies like Boubacar (2010).

iii) Estimated results for Maize

Maize or corn (*Zea mays* L.) is also called as ‘Queen of Cereals’ and one of the important cereal food-grains of the world. It has become the staple diet in many regions of the world (Rouf Shah et al., 2016). Similarly, this is the 3rd most important foodgrain crop in the world surpassed only by two former grains, rice and wheat (Kyenpia et al., 2009). Maize,

which is the only cereal plant that can be cultivated in different environmental conditions because of its inordinate adaptability and it needs a moderate climate for the crop growth (Kogbe and Adediran, 2003). However, excess or less rainfall and upper temperature can affect productivity as well as quality adversely. In Telangana, maize is the important food and cash crop as well. This crop is cultivated under both the rain-fed and dry land systems and it is grown in almost all districts of the state. The area under this crop is 6.92 lakh hectares which constitute around 26.4 percent of the overall gross cropped area of food grains in Telangana during 2014-15 (Government of Telangana, 2016).

The estimated results for maize are provided in Table 5.6. Estimated coefficients of all explanatory variables for three maize models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. Most of the explanatory variables such as rainfall, maximum and minimum temperatures, area, and agro-climatic zone dummies are statistically significant in three maize models. However, rainfall and cropped area in model II are not statistically significant in maize mean yield function. Rainfall has a substantial positive effect on mean yields in three maize models. Maize crop mostly depends on rainfall in Telangana and due to this reason, possibly the effect of rainfall is favorable. Similarly, maximum temperature has a significant positive effect on mean yields in model I and model II. Likewise, minimum temperature has a positive effect on mean yield of maize in two models. An increase in area under maize crop has a positive impact on maize yield. Further, time-trend is favorably associated with the mean yield of maize. All regional agro-climatic zone variables in three models are found to be statistically significant and have positive effects on maize mean yields in Telangana.

Table 5.6: Estimated Results for Maize in Telangana

Maize	Model I	Model II	Model III
Mean yield function $f(x)$	Coefficient	Coefficient	Coefficient
Trend	4.729***	4.746***	3.820***
Maximum Temperature	103.392***	86.631***	
Minimum Temperature	51.990***		44.111**
Rainfall	0.191***	0.193	0.143***
Area	0.016**	0.001	0.017**
Northern AC Zone	279.677***	276.808***	907.966**
Central AC Zone	278.739***	275.165***	929.583***
Southern AC Zone	278.699***	274.557***	900.128***
Constant	1.018***	1.031***	0.649
Yield variability function $h(x)$			
Trend	0.028***	0.028***	0.036***
Maximum Temperature	0.498**	0.482***	
Minimum Temperature	-0.023		0.156
Rainfall	0.012**	0.087**	0.070**
Area	4.427	6.157	9.877
Constant	-5.822	-5.801	6.518**
Model summary			
Log likelihood	-1043.003	-1064.864	-1071.629
Wald Chi-square	350.28	281.04	260.72
Prob > Chi-square	0.0000	0.0000	0.0000

Source: Authors' own estimations. Note: *** $p < 0.01$ and ** $p < 0.05$.

The yield variability function results of the maize crop are also shown in Table 5.6. Rainfall, area and maximum temperature are statistically significant in yield variability function. The rainfall has a significant and positive effect on maize yield variability. This implies that the rainfall in Telangana is a risk-enhancing factor for yield variance of maize. Similarly, the maximum temperature has a significant and positive effect on maize yield variability. This

infers that the maximum temperature in Telangana is a risk-enhancing factor for yield variance of maize. However, the minimum temperature has an insignificant and negative effect on maize yield variability. This implies that the minimum temperature in Telangana is a risk-reducing factor for yield variance of maize. Further, an increase in area under maize crop has an insignificant positive effect on yield variance of maize. The increased cropped area is also a risk-increasing factor in Telangana but not statistically significant. Lastly, the time-trend factor has a significant favorable effect on maize yield variability. Therefore, we can conclude that the trend variable is a risk-enhancing factor for maize crop. The mixed results of the impact of climatic variables on maize productivity are somewhat consistent with Mati (2000), Li et al. (2011) and Mumo et al. (2018).

iv) Estimated results for Cotton

Cotton (*Gossypium* spp.) is also termed as ‘White Gold’ largely cultivated in tropical as well as sub-tropical climate conditions of the world (Praharaj and Sankaranarayanan, 2012). However, the most favorable temperature for vegetative growth is between 21 to 27 degrees celsius and it can bear up the upper temperature up to 43 °C (Padakandla, 2016), yet a minimum temperature lower than 21 °C is not helpful to the cotton output. India cultivates the largest part of world’s gross cropped area under cotton (12.6 million hectares) and is the second largest producing country with 27 million bales (in 2014) which is nearly account for 24 percent of global cotton output (Sundar and Palanivel, 2017). The Telangana state is one of the major cotton cultivating and producing states in India along with Maharashtra and Gujarat and other major states. This crop is predominantly grown in rainfed conditions of the state. Cotton accounted for around 25 percent of the overall gross cropped area in the former districts of Telangana state (Government of Telangana, 2016). Cotton is one of the important commercial crops in Telangana and is mostly cultivated under rainfed conditions.

Table 5.7: Estimated Results for Cotton in Telangana

Cotton	Model I	Model II	Model III
Mean yield function $f(x)$	Coefficient	Coefficient	Coefficient
Trend	0.083***	0.052*	-0.068***
Maximum Temperature	-283.787***	-74.314*	
Minimum Temperature	128.893***		113.266***
Rainfall	-12.362***	-5.262*	-19.025***
Area	1.200***	0.550*	1.985***
Northern AC Zone	780.082***	352.967*	49.955***
Central AC Zone	780.169***	353.310*	50.123***
Southern AC Zone	779.839***	352.883*	49.808***
Constant	16.580***	-8.955	8.685***
Yield variability function $h(x)$			
Trend	0.002***	0.001***	-0.001***
Maximum Temperature	-4.827***	-2.263***	
Minimum Temperature	2.165***		0.796***
Rainfall	-0.211***	-0.158***	-0.134***
Area	0.023***	0.016***	0.141***
Constant	15.159***	12.510***	2.174***
Model summary			
Log likelihood	425.3464	387.0905	394.1517
Wald Chi-square	362494.10	701337.54	729739.81
Prob > Chi-square	0.0000	0.0000	0.0000

Source: Authors' own estimations. Note: *** $p < 0.01$ and ** $p < 0.05$.

The empirical results of cotton crop are shown in Table 5.7. Estimated results of explanatory variables for three cotton models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. All the climatic variables, cotton area and agro-climatic zone variables are statistically significant in three cotton models. Rainfall has a significant adverse effect on mean cotton yield in Telangana. As mentioned earlier, cotton is a rainfed crop, an increase in rainfall may tend to decrease the cotton yield. Likewise,

maximum temperature is adversely related to mean yield of cotton. The positive impact of minimum temperature on cotton yield may be unable offset the adverse effect of maximum temperature as reflected in estimated results. Present results of minimum and maximum temperature in mean yield function of cotton are contrary to some studies like Padakandla (2016). The empirical outcomes of climatic factors in mean yield function of cotton are similar with Kumar et al. (2015). The trend factor is positively related to cotton yield. This implies that the technological progress in Telangana has a positive effect on cotton yield. All the regional agro-climatic zone variables such as southern, central and northern zones are significant and these agro-climatic zones have the favorable effect on mean yield.

The estimated coefficients of yield variability function for the cotton crop are given in Table 5.7. The mean minimum temperature has a substantial favorable effect on the yield variance of cotton. In other words, the minimum temperature is a risk-enhancing factor for cotton in Telangana. However, maximum temperature has a significant negative effect on the yield variance of cotton. This implies that the maximum temperature is a risk-reducing factor for cotton. Similarly, rainfall has a substantial adverse effect on the yield variance of cotton. We can say that the rainfall is a risk-reducing factor for cotton yield variance. Further, area under cotton is positively related to yield variability of cotton in three models. This indicates that the area is a risk-enhancing factor for cotton. Furthermore, trend is positively related to yield variability of cotton in the model I and model II, but it is negatively related to the yield variance of cotton. This implies that the technological progress in Telangana is a risk-enhancing factor for cotton in Telangana. The yield variability findings of our study are, to some extent, similar to few studies like Kumar et al. (2015). We find some interesting results for cotton crop. Variables like rainfall and maximum temperature, which have an adverse impact on mean cotton yield, are the risk-reducing factors for cotton yield variance. Variables like minimum temperature, which have a positive effect on mean cotton yield, are risk-enhancing factors for cotton yield variance.

v) Estimated results for Groundnut

The groundnut (*Arachishypogaea*) is also widely-recognized as the peanut and is one of the most common oilseed crops in the Leguminosae family (Mothilal, 2012). Groundnut is primarily a self-pollinated crop, with self-fertilization regularly occurring in the early

morning (Patidar et al., 2014). This crop is mainly cultivated in the tropical as well as sub-tropical parts of the World and it has the capability to sustain in different environments. It can be grown successfully in regions getting minimum precipitation of 500 mm and 1250 mm of maximum precipitation (Gadgil et al., 2002). In Telangana state, this crop is one of the most important commercial as well as oilseed crops. Groundnut is mainly grown under both rain-fed and irrigated conditions and it is grown in almost all districts of the state. The area under this crop is 1.28 lakh hectares which constitute around 28.18 percent of the overall oilseeds cultivated area during 2015-16 in Telangana (Government of Telangana, 2016).

The estimated results of groundnut crop are reported in Table 5.8. The estimated coefficients of explanatory variables for three groundnut crop models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. All the study variables, including agro-climatic zone dummy variables are significantly influencing groundnut yields over the study period in the mean yield function. However, the mean maximum temperature is not statistically significant in model I. Rainfall has been found to have negative effect on groundnut yield in Telangana. However, the minimum temperature is positively related to groundnut yield. Maximum temperature has an adverse effect on groundnut yield in model I, but it is not statistically significant. In model II, maximum temperature has a significant adverse effect on mean yield. In model I, the adverse effect of rainfall and maximum temperature on groundnut yield is offset by the positive effect of minimum temperature. The cropped area of groundnut has a substantial favourable effect on mean yield in three groundnut models. The time trend variable has a significant adverse effect on groundnut yield in the model I and model II. However, we found that the trend is positively related to mean yield in model III. Further, all the three agro-climatic zone variables in the mean yield function are statistically significant and related negatively to groundnut yield. The empirical findings of groundnut are almost similar to few studies like Kumar et al. (2015) and are contrary to studies like Padakandla (2016).

Table 5.8: Estimated Results for Groundnut in Telangana

Groundnut	Model I	Model II	Model III
Mean yield function $f(x)$	Coefficient	Coefficient	Coefficient
Trend	-0.084***	-0.069**	0.027***
Maximum Temperature	-0.913	5.392**	
Minimum Temperature	8.975***		7.627***
Rainfall	-1.054***	-0.819**	-0.781**
Area	0.092***	0.111***	0.098***
Northern AC Zone	-42.956***	-35.564**	-38.326***
Central AC Zone	-42.956***	-35.527**	-38.274***
Southern AC Zone	-43.007***	-35.616**	-38.358***
Constant	1.395***	4.450***	4.160***
Yield variability function $h(x)$			
Trend	0.006***	0.005***	0.006***
Maximum Temperature	-0.062***	-0.472***	
Minimum Temperature	-0.519***		-0.583***
Rainfall	0.078***	0.073***	0.078***
Area	-0.004***	-0.006***	-0.006***
Constant	4.956***	4.860***	4.947***
Model summary			
Log likelihood	957.7352	954.6335	955.2668
Wald Chi-square	881239.67	937163.39	793470.73
Prob > Chi-square	0.0000	0.0000	0.0000

Source: Authors' own estimations. Note: *** $p < 0.01$ and ** $p < 0.05$.

The yield variability function results of the groundnut crop are also reported in Table 5.8. Rainfall, area, minimum and maximum temperatures are significantly influencing the variability of groundnut yield in Telangana. Rainfall has a positive effect on yield variance. In other words, rainfall is a risk-enhancing factor for groundnut. However, maximum and

minimum temperatures have significantly adverse effect on the yield variance of groundnut. This indicates that the maximum and minimum temperatures are risk-reducing factors for groundnut. Similarly, cropped area is negatively related to the yield variance of groundnut. This implies that the area is the risk-reducing factor for groundnut. Furthermore, trend has a significant positive effect on yield variance. This implies that technological advancement is increasing the yield variability of the crop in the state during the study period. Our results on climatic factors in yield variability function of groundnut are almost contrary to studies like Kumar et al. (2015).

5.6 Conclusions and policy implications

In this chapter, we have empirically examined the effects of climatic factors on major crop yield and its variability by applying the Just and Pope production function in Telangana over the period of 1956–2015. This study has used district level panel data on five crop yields, namely rice, jowar, maize, cotton and groundnut and climatic variables such as rainfall, maximum temperature and minimum temperature. For empirical analysis, we have employed the three-stage feasible generalized least squares estimation technique.

The empirical results from the estimated econometric models have shown that the effects of the rainfall, minimum temperature and maximum temperature on major crop yields vary across different crops. However, the empirical findings have revealed that climatic factors such as rainfall and temperature have adverse effects on crop productivity in general. Maximum temperature has a significantly adverse effect on rice, cotton and groundnut yields whereas favourable effect on jowar and maize yields. Given that jowar (Sorghum) is the stress tolerant crop, it is possible that an increase in maximum temperature may not affect the jowar yield to a great extent. Some studies have shown an adverse influence of the upsurge in maximum temperature on rice productivity in India (Mall et al., 2006; Pattanayak and Kumar, 2014). However, the minimum temperature has a significantly adverse effect on jowar yield while advantageous effect on rice, maize, cotton and groundnut. Rainfall has a significantly adverse effect on cotton and groundnut yield whereas positive impact on rice, maize and jowar yields. We have found that the crop area has a significantly positive effect on all crop yields under study. In other words, an increase in

area under the study crops is positively influencing crop yield. Agro-climatic zone variables have mixed results, positive on the rice, maize and cotton but adverse effect on jowar and groundnut yields.

We have also estimated the impact of climatic factors on yield variability of five primary crops. The empirical findings have revealed that the climatic factors have significant influences on the variability of major crop yields in Telangana. Maximum temperature is a risk-reducing factor for all the study crops except maize. However, minimum temperature is a risk-enhancing factor for rice, jowar and cotton. The impact of rainfall on yield variance is negative for jowar and cotton and positive for rice, maize and groundnut. This implies that rainfall is risk-reducing factor for jowar and cotton while risk-enhancing factor for rice, maize and groundnut. The results of the study have revealed that different crops are influenced differently by the climatic factors in Telangana. Therefore, results from the present study have important policy implications for developing sub-national level adaptation strategies for farm households in Telangana. Since climate variables are beyond the control of farm households and changes in climate variables affect crop yields, there must be proper adaptation policies for both short run and long run. One measure is to implement crop insurance policy as an adaptation practice to diminish the possible monetary losses to the crop growers. The government also must support the development of new varieties crop seeds which are temperature (heat or cold) tolerant for sustainable agricultural growth.

Chapter 6

Assessment of Climate Change Vulnerability of Farm Households in Telangana: Evidence from Survey Data

6.1 Introduction

In chapter 5, it was evident that the climatic factors such as rainfall, maximum and minimum temperatures have a significant unfavorable impact on major crop yields in Telangana. Moreover, changes in these climate variables are also substantially contributed to upsurge yield variability. The present chapter attempts to document farm-household's vulnerability to changing climate at the village level in the selected study districts. The vulnerability of particular farming communities to climate change can vary considerably because of the adaptive capacity of farm-households. Vulnerability is not a directly measurable issue because of its theoretical nature. However, in this chapter, using an indicator-based framework, the vulnerability of farm-households in Telangana to changing climate is calculated.

One of the alarming challenges of the 21st century is global climate change and it is a matter of international concern. Usually, human-induced greenhouse gas (GHGs) pollutions are widely acknowledged to be the primary cause of global change (Young et al., 2010). Burning of fossil fuels, deforestation and alterations in land usage has enhanced the extent of greenhouse gas concentration in the atmosphere and can potentially change the existing climate system (Sendhil et al., 2018). The IPCC's fourth assessment report (AR-4) evidenced that the surface temperature of the Planet has elevated by 0.75° C throughout the last century. This increasing trend is likely to exacerbate (Sendhil et al., 2018) as the average surface air temperature is forecasted to increase up to 3.7 °C by completing the 21st century (IPCC, 2013). Subsequently, the consequences of changing climate have already shown themselves in the form of recurrent droughts, irregular precipitation heat waves, flash floods, melting glaciers, sea-level rise, etc. The effects of climate change are widespread, affecting all aspects of human life, including biophysical, socio-ecological systems, land and oceans (IPCC, 2014). Agricultural activities are more vulnerable to changing climate conditions, particularly in developing countries (Varadan and Kumar, 2015).

The effects of climate change on the tropical regions can be severe and these regions are predominantly consisting of developing nations like India (Rao et al., 2010). Besides, the vulnerability to changing climate is likely to be more in the Indian sub-continent (World Bank, 2003; Rao et al., 2011) because of its non-climatic hassles such as population growth, poverty, heavy dependence on the primary sector, food insecurity, unequal access to resources and inadequate financial capabilities for adaptation. This establishes the fact that a particular system's vulnerability is determined not just by its exposure to changing climate but also by the system's sensitivity and adaptive capability to adapt with changes in climatic conditions. India has ranked 14th most vulnerable nation in the "Global Climate Risk Index 2019" because of its biophysical and socioeconomic settings. As far as the effect of climate change is concerned, Indian farming systems are highly vulnerable due to its heavy dependence on the vagaries of monsoons (Sendhil et al., 2018).

In the similar way, the vulnerability can be high in the semi-arid regions of India (Singh et al., 2014), particularly the southern region (Sridevi et al., 2014). Among all the southern states of India, Telangana is highly vulnerable to climatic events such as erratic rainfall and droughts. The geographical area of Telangana falls in the semi-arid region of peninsular India (Bhavani et al., 2017) and the climate of the state is primarily hot and dry. Farmers in this region are particularly vulnerable to changing climate due to their higher reliance on agriculture that is extremely climate-sensitive. This highlights the need for collective efforts to decrease vulnerability and strengthen the adaptive capability of farming ecosystems to cope with increasing climatic challenges. Effectively accomplishing the targets of these efforts will necessitate a deeper understanding of the farming system's vulnerability to changing climate. In this background, the present chapter assesses agricultural household's vulnerability to climate change in Telangana state.

It is a challenging task to define the concept of 'vulnerability'; and most often, it is defined using the components that cover sensitivity, exposure and adaptive capacity (Smit and Pilifosova, 2003; Adger, 2006; Jamshidi et al., 2019). The third assessment report of the IPCC provides the most widely utilized definition of vulnerability in the literature on climate change. According to the third assessment report, "vulnerability is a function of the character, quantity, and degree of climate change to which a system is exposed, its

sensitivity and its adaptive capability” (Mc Carthy et al., 2001). Hence, vulnerability in the framework of changing climate can be measured through evaluating the interaction effect of these three components (Mohammed et al., 2018). Vulnerability assessments for potential impacts of climate change have risen substantially during the last couple of decades with growing focus on climate change research (Brooks et al., 2005; Adger, 2006; Smit and Wandel, 2006; Malone and Engle, 2011; Hinkel, 2011; Singh et al., 2017). There are different conceptual and methodological frameworks for determining vulnerability (Eakin and Luers, 2006; Füssel and Klein, 2006; Hinkel, 2011; Crane et al., 2017). As a result, several studies have been conducted in an effort to simplify the definitions and methodologies (Kelly and Adger, 2000; Mc Carthy et al., 2001; Ford and Smit, 2004; O’Brien et al., 2004; Füssel and Klein, 2006; Eakin and Luers, 2006; Füssel, 2007; Wiréhn et al., 2015; Mohammed et al., 2018), categorize the vulnerability knowledge into various approaches (Adger, 2006; Füssel and Klein, 2006; O’Brien et al., 2007; Joakim et al., 2015) and research review on vulnerability studies (Eakin and Luers, 2006; Singh et al., 2017; Crane et al., 2017).

Apart from the substantial portion of impact assessment works (first-generation vulnerability studies), assessing the socio-economic vulnerability in the field of climate change by using a composite index was frequently utilized for understanding socio-economic vulnerability. These research works were carried out at various levels including global, regional, national, sub-national and local levels in order to support policymakers aimed at reducing vulnerability. Research works for instance Vincent (2004), Atkins et al. (1998), O’Brien et al. (2004), Deressa et al. (2008), Brooks et al. (2005), Vincent and Cull (2010), Shukla et al. (2016) and Oo et al. (2018) have utilized the composite index framework to assess vulnerability. A study by Vincent (2004) developed an index of social vulnerability and measured vulnerability among African nations, and empirically estimated relative levels of social vulnerability. Atkins et al. (1998) constructed a composite vulnerability index to measure the vulnerability of 110 developing countries and island states and reported that small states are more vulnerable than large states. Likewise, Vincent and Cull (2010) generated an index of social vulnerability to climate change and measured the social vulnerability at household level in a village of Limpopo province, South Africa. O’Brien et al. (2004) measured the climate change vulnerability and utilized the

vulnerability scores to mapping the hot-spots of climate vulnerability at the sub-national and district levels in India.

The assessments of vulnerability at the household, community, village and local levels employed different methodologies. For instance, Fernandez et al. (2016) has evaluated the social vulnerability to floods using GIS-based multi-criteria decision analysis in Portugal. Ahsan and Warner (2014) constructed a socio-economic vulnerability index (SeVI) using an indicator-based approach in climate-affected coastal Bangladesh communities. Further, several research works have evaluated climate-vulnerability from a livelihood viewpoint, highlighting the significance of non-climate factors in vulnerability estimation (see; Hahn et al., 2009; Adu et al., 2018; Shah et al., 2013). However, determining factors as well as sources of vulnerability at the global, regional and national scales may vary from those at the village and household scales. As a result, recent research works have advocated for a multi-scalar understanding of vulnerability (Barrett, 2013). It is a well-established fact that climate-vulnerability is different for different sectors, regions and communities. This concept is called as a differential vulnerability, where two societies or groups of people exposed and sensitive to the same climate conditions may vary in vulnerability owing to other factors (Turner et al., 2003). Despite the fact that a group of people is identified as very vulnerable due to the same exposure to climatic risks, communities exhibit different levels of vulnerability, where this concept is being called as a comparative vulnerability. In view of that, recent works have called for a better understanding of differential vulnerability as well as comparative vulnerability (Baptiste and Kinlocke, 2016).

In the context of India, several works have been carried out in order to determine the vulnerability to climate change by utilizing the indicators method (see; Patnaik and Narayanan, 2009; Ravindranath et al., 2011; Sridevi et al., 2014; Varadan and Kumar, 2015; Kumar et al., 2016; Maiti et al., 2017; Tripathi, 2017; Sendhil et al., 2018; Padhan and Madheswaran, 2019; Pandey and Jha, 2012; Panda, 2017; Shukla et al., 2016; Gupta et al., 2019). Most of these works are conducted using secondary data at the district or state level. However, studies such as Pandey and Jha (2012), Panda (2017), Shukla et al. (2016) and Gupta et al. (2019) have been carried out at the community level. Pandey and Jha (2012)

constructed a composite climate vulnerability index (CVI) in order to measure the vulnerability of two communities in Srinagar, Uttarakhand, India, and documented that community situated close to district headquarters has more vulnerability score. Similarly, Shukla et al. (2016) assessed the vulnerability (biophysical and social) of mountain agricultural communities in the Indian state of Uttarakhand. They reported that social vulnerability was found to be very high due to lack of efficient institutions and inadequate infrastructure. Another study by Gupta et al. (2019) on the socio-environmental vulnerability of different altitudes in the Indian Himalayas by constructing a vulnerability index advocates that the social groups in the middle and high altitude areas are more vulnerable to climate change. A systematic study by Panda (2017) has assessed the climate-induced vulnerability using the Indicator-based method in the Eastern state of India, Odisha, and reported that socio-economic factors are determining factors for vulnerability to changing climate and extreme weather events.

In spite of substantial literature on climate change impacts and vulnerability in India, community or village level vulnerability studies based on household-level information are still inadequate. The aggregate national or state vulnerability assessments have several limitations in addressing the community level vulnerability differences and location-specific issues. Moreover, these studies are incapable of offering policy guidance for adaptation at the community level (Simane et al., 2016). Therefore, national-level studies do not address the complex distribution of existing vulnerabilities at the community level. Furthermore, in line with Hahn et al. (2009), Lindoso et al. (2014) and Panda (2017), this study suggests that significant adaptation efforts take place at the community or local scale; a more systematic analysis of vulnerability must entail obtaining information at the household level and directly from primary surveys. Therefore, climate-induced vulnerability assessments at the local level may be used to understand more about the causes and structures of vulnerability among populations that are similarly affected.

Another important research gap in India is understanding the interaction of different vulnerability components (namely; exposure, sensitivity and adaptive capacity) at the community level. Because studies such as Varadan and Kumar (2015) and Lindoso et al. (2014) suggest that higher exposure areas are not inevitably more vulnerable in the

composite index, these studies necessitate the understanding of non-linear interactions between the components of vulnerability. In this background, this study tries to fill the research gap by assessing vulnerability to climate change in the study villages situated in Telangana, India. It further analyses the interaction of different vulnerability components at the village level in the study area. This research work would be supportive of making innovative policies regarding aspects, for instance, agricultural adaptation and risk management.

6.2 Conceptual framework

Vulnerability, as a research notion, is both under-specified and over-determined (Brenkert and Malone, 2005). This statement necessitates understanding the conceptual framework of vulnerability in the context of climate change. The concept of vulnerability is rooted in several research fields such as natural hazards (Cutter, 1996), livelihood (Hahn et al., 2009), ecosystem (Holling, 1973), disease hazard (Hardy and Smith, 1988), political ecology (Blaikie et al., 1994), food and nutrition security (Watts and Bohle, 1993; Bohle et al., 1994), global environmental change (Dow, 1992) and climate change (Kelly and Adger, 2000). Vulnerability to climate change has emerged as an important concept pertaining to adaptation in research and policy debates (Young et al., 2010). Scholars from different fields adopt different approaches to understand and assess vulnerability. Broadly, there are three approaches that are using in determining vulnerability such as socio-economic approach (*Bottom-up approach*), biophysical approach (*Top-down approach*) and integrated approach (Singh et al., 2014; Shukla et al., 2016).

The socio-economic approach primarily focuses on social, economic, political aspects of people or communities, and it is widely known as the “starting point approach” (Adger, 2000; Eakin and Luers, 2006). The socio-economic status of the people or group of people tends to differ in terms of health, wealth, education, social capital, access to resources, etc. This approach is based on the hypothesis that variations in socio-economic factors are accountable to the differential vulnerability of people or group of people. On the other hand, the biophysical approach is also known as the “end-point approach” and typically linked with the physical effects of climate change on income and crop yields (Füssel and Klein, 2006; Kelly and Adger, 2000). Last of all, the integrated-assessment

approach blends both the biophysical and socio-economic approaches in order to determine the vulnerability of agricultural systems to changing climate (Füssel, 2007). Using these conceptual frameworks, studies have been extensively assessing vulnerability to understand the implications of climate change and variability at the local or micro-level (Young et al., 2010).

Research traditions in different fields have established several conceptualizations of climate change vulnerability. Although there are several definitions of vulnerability, they usually describe it as the system's exposure and sensitivity to stressors or perturbations and the capability to adapt (Smit and Wandel, 2006; Adger, 2006; Füssel and Klein, 2006). Following Deressa et al., (2008) and Panda (2017), this study adopted the vulnerability framework of IPCC (2001), where vulnerability in the context of climate change is defined as: “*Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*”. As stated by the third assessment report of IPCC, the vulnerability of a system is a function of exposure (E), sensitivity (S) and adaptive capacity (AC). This conceptualization of vulnerability to changing climate is expressed as:

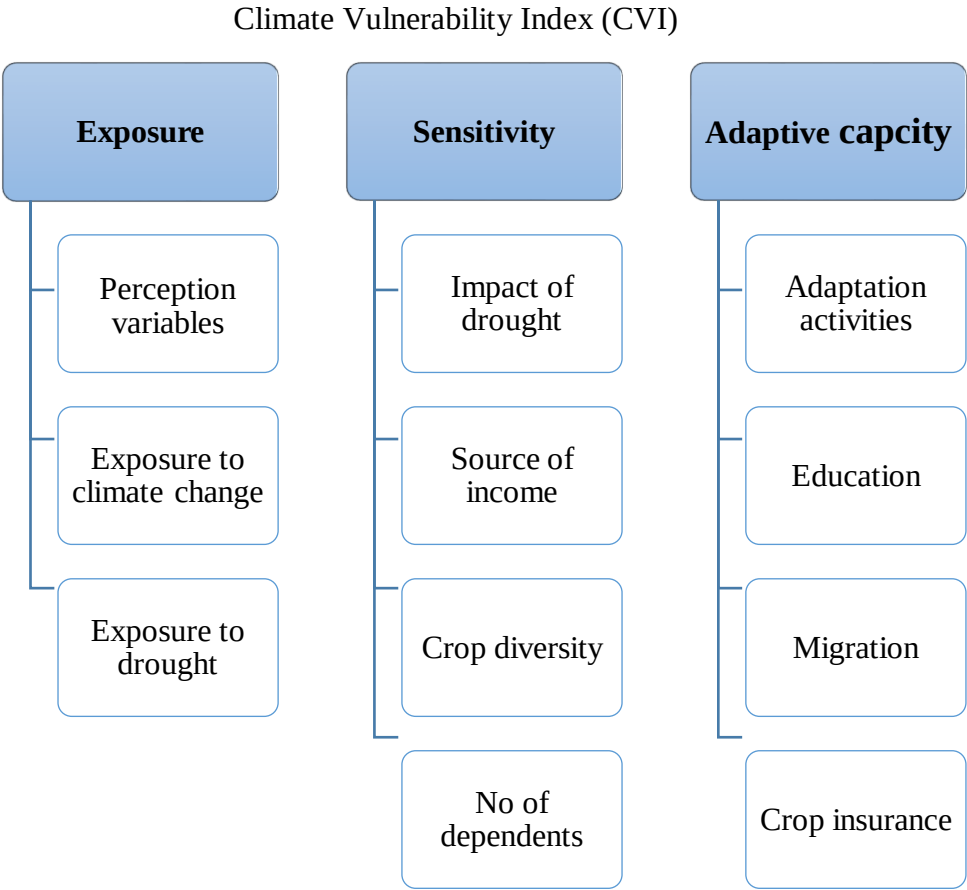
$$Vulnerability = f(E, S \text{ and } AC).$$

Here, exposure denotes to “the nature and degree to which a system is exposed to significant climatic variations”, sensitivity to “the degree to which a system is affected either adversely or beneficially, by climate related stimuli” and adaptive capacity is defined as “the ability of a system to adjust to climate change (including climate extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences” (IPCC, 2001).

For the purpose of this study, we have developed a “Climate Vulnerability Index (CVI)”, particularly for the semi-arid region of peninsular India, Telangana. The CVI index is constructed using the IPCC (2001) vulnerability framework, which has three components: exposure, sensitivity, and adaptive capability (Mc Carthy et al., 2001). There are multiple

indicators/subcomponents in each component in this system, of which many sub-components are based on literature review while some sub-components are particular to the study region. The detailed discussions on the selection of indicators are presented in section 6.4.1. The CVI index uses household-level survey data to construct a composite index for each study village in Telangana. The conceptual framework of this study including the major components of the CVI is presented in Figure 6.1.

Figure 6.1: Conceptual framework of Vulnerability



Source: Author’s own compilations

6.3 Vulnerability assessment methodologies

The scholarly works on climate change vulnerability have been increasing in recent years in order to better understand the consequences of climate change at different scales around the globe (Adger, 2006; Smit and Wandel, 2006; Singh et al., 2017). Due to varied conceptual frameworks of vulnerability, human-environment research traditions have contributed to a variety of methodological approaches for vulnerability assessment (Füssel, 2007). Usually, the techniques of assessing vulnerability often rely on the research objective and type of the assessment (village/community/household/farm level, sectoral/regional comparison, etc.) including the vulnerability drivers (Adger et al., 2005; Eakin and Luers, 2006; Eriksen and Kelly, 2007). The climate-related vulnerability has been assessing using a variety of methods for instance participatory method, comparative analysis, spatial analysis and mapping (GIS), simulation-based models, agent-based modelling, historical descriptions, multi-criteria decision analysis, statistical methods, indicator-based approach, impact modelling, qualitative methods and quantitative methods (Singh et al., 2017; Panda, 2017; Mohammed et al., 2018). However, the most extensively adopted method to measure climate-related vulnerability is the indicator-based approach (Gbetibouo and Ringler, 2009; Singh et al., 2017; Pandey and Jha, 2012; Simane et al., 2016; Panda, 2017; Neset et al., 2019).

An indicator-based technique is appropriate for vulnerability assessments because vulnerability is a theoretical concept that cannot quantify in the same way as a directly observable phenomenon can (Hinkel, 2011). The indicator-based approach makes use of indicators or variables to operationalize theoretical concepts through indicators that serve as operational representations of the system's characteristics, properties or qualities (Gallopín, 1997; Birkmann, 2006; Hinkel, 2011). Furthermore, Indicator-based approach helps to get a broader understanding of the biophysical and socioeconomic elements that influence vulnerability (Hebb and Mortsch, 2007). Therefore, the indicator-based technique is appropriate for climate vulnerability studies because different dimensions of vulnerability can be captured by using indicators (Nardo et al., 2008). Generally, the process of indicator-based assessments involves the following steps: defining the study aim, conceptual framework and background, indicators selection, data collection, calculation of indicators

(normalization and weighting) and demonstration of results (Binder et al 2010; Tate, 2012; Becker et al., 2015).

Although the indicator-based approach has several advantages and is widely recognized, it also received substantial criticism due to certain drawbacks (Oo et al., 2018). For example, Birkmann (2006) indicates the limitations pertaining to up and down-scaling of variables (indicators) and difficulties in contextualizing indicators, contexts and scales. Moreover, similar shortcomings and challenges are documented with the selection of indices (indicators) (Vincent, 2007; Binder and Feola, 2013); ambiguity in validity and strength of indicators and theoretical frameworks (Vincent, 2007; Eriksen and Kelly, 2007; Becker et al., 2015); data precision and ease of access (Becker et al., 2015); an indistinct relationship of indicators with vulnerability (Vincent, 2007); the lack of vulnerability dynamics analysis (Vincent, 2007; Eriksen and Kelly, 2007); and weighting and summation of indices (Eriksen and Kelly, 2007; Barnett et al., 2008). The choice of techniques for aggregating and weighing indicators substantially decides the overall score of a composite vulnerability index (Jones and Andrey, 2007; Wiréhn et al., 2015). Furthermore, the categorization of sub-components or indicators may be difficult in these techniques since each indicator has a specific direction and relevance within that major component that might change according to the situation in which the research is conducted study (Soares et al., 2012).

In spite of several shortcomings, the indicator-based method remains the most efficient tool for assessing vulnerability in the context of changing climate (Birkmann, 2006; Wiréhn et al., 2015). The indicator-based approach offers useful tools for scientific analysis and discussion of what determines vulnerability and how to minimize risk (Birkmann, 2007). It is suggested that the indicator selection, proper weighting and direction of the indicators can be important factors in determining the accurate results (Eriksen and Kelly, 2007; Barnett et al., 2008). Taking into consideration the gaps described earlier as suggested by the literature, the present research considered crucial parameters namely indicator selection, normalization and weighting of the indicator and functional relationship with vulnerability to accurately determine the vulnerability of farming communities to changing climate in the study area.

6.4 Research methodology

The study area is located in the state of Telangana, southern India. The primary survey was conducted at the farm-households level in the study villages in order to gather the information on different sub-components. The detailed discussion on the study area, sample selection method and collection of data are discussed elaborately in chapter 3.

6.4.1 Selection of indicators

The most important phase in vulnerability assessment is the selection of appropriate indicators to understand the climate vulnerability of a system. As mentioned earlier, this study developed a climate vulnerability index (CVI), and it comprises three components such as sensitivity, exposure and adaptive capacity. Each component consists of several indicators or sub-components. These indicators are reflective of components and are potentially useful resources for observing farm-household's vulnerability in the study region. Table 6.1 presents the components and indicators. The selected indicators are relevant to farming communities in the study region. The composition of indicators is based on the literature review (Pandey and Jha, 2012; Singh and Nair, 2014; Shukla et al., 2016; Panda, 2017; Singh et al., 2014; Pandey and Bardsley, 2015; Varadan and Kumar, 2015; Sam et al., 2017; Young et al., 2010; Simane et al., 2016; Jamir et al., 2013; Hahn et al., 2009; Shah et al., 2013) and some indicators are specific to the study area. The exposure component is captured by the perception of farm-households on changes in rainfall and temperature, drought occurrences, the average number of natural calamities experienced by farm-households and pests attack. The actual data on climate and extreme climatic events at the village level are unavailable. Therefore, this study utilized the perception of farm-households on climate change and droughts as primary data to measure the exposure of sample farmers in the survey villages.

Table 6.1: Description of indicators for constructing the “climate vulnerability index”

Components	Sub-components (Indicators)
Exposure	% of farm households aware that rainfall is declining % of farm households notice that temperature is rising % of farm households perceive that drought frequency is increasing Average number of disasters farm households have experienced % of farm households report pest attacks increased
Sensitivity	% of farm households perceived high impact of drought % of farm households have only agricultural income Average crop diversity index % of farm households having borrowings during past five years Average number of dependents % of farm households where the head of the family is illiterate % of farm households having marginal landholdings
Adaptive capacity	% of farm households changed crop variety % of farm households reported adjusting the planting dates % of farm households are having other than farm income % of farm households using early maturing (short-duration) varieties % of farm households practicing water-conservation measures % of farm households taking crop insurance % of farm households have membership in “self-help groups” % of farm households having primary and above level of education Average farming experience (years) % of farm households having migrated members % of farm households having better access to climate information % of farm households having access to better institutional credit % of farm households having livestock ownership

Source: Author’s own compilations.

Sensitivity relates to the degree to which a system is affected by climate change (Mohammed et al., 2018). This study has utilized seven indicators to represent sensitivity at the farm-households level that are perceived effects of droughts, farming as the only basis of income, marginal landholdings, crop diversity, low literacy, number of dependents and borrowings. On the other hand, this study uses actual adaptation strategies of farm-households as indicators of adaptive capacity. Based on the argument of Füssel and Klein (2006), this study uses actual adaptations as the determinants of vulnerability. The major adaptive capacity indicators are altering planting dates, crop varieties, improved irrigation, earning non-farm income, planting early maturing varieties, crop insurance, migration, livestock, etc. To construct a climate vulnerability index, this study conducted a primary survey in the sample villages. This study determined the minimum and maximum values for each sub-component based on the survey data from farm-households. Table 6.2 presents the minimum and maximum values for each indicator being used in this study.

6.4.2 Index calculations

As mentioned earlier, this study utilized indicator-based approach to generate climate change vulnerability index. All the selected indicators are not measured on a similar scale. Therefore, it is necessary to convert indicators from different scales to a particular scale to make sure that they are comparable (Vincent, 2004; Sendhil et al., 2018). This practice is known as the normalization (standardization) of indicators to be utilized in the index (Siyal et al., 2018). Based on the methodology developed by Iyengar and Sudarshan (1982) for the computation of Human Development Index by the UNDP, the values of all the indicators were standardized. This approach is statistically sound, easy to calculate and suits for this study purpose because it is used as a tool to determine the socio-economic vulnerability of the farming communities in the study area.

$$IndexS_v = \frac{S_v - S_{min}}{S_{max} - S_{min}} \dots \dots \dots (6.1)$$

Where S_v is the original indicator or sub-component for village v , and S_{min} and S_{max} are the minimum and maximum values, respectively, for each indicator determined using

primary data from the sample villages. The next step after the normalization procedure is assigning the weights to sub-components (Hahn et al., 2009; Varadan and Kumar, 2015). The literature review advocates four approaches (Varadan and Kumar, 2015; Jamshidi et al., 2019; Balaganesh et al., 2020) to assign weights to indicators of climate vulnerability i.e. expert judgment or opinion (Brooks et al., 2005; Ravindranath et al., 2011), equal weights (Sullivan et al., 2002; Hahn et al., 2009), inverse of variance (Palanisami et al., 2009) and the principal component analysis (Gbetibouo and Ringler, 2009; Sendhil et al., 2018). Each approach has its own advantages and drawbacks (Varadan and Kumar, 2015). However, balanced weights approach is the most extensively used technique to assign weights (for instance: Sullivan et al., 2002; O'Brien et al., 2004; Patnaik and Narayanan, 2009; Hahn et al., 2009; Sridevi et al., 2014; Panda, 2017; Sam et al., 2017; Oo et al., 2018; Mukherjee and Siddique, 2019; Williams et al., 2020). Therefore, balanced weighted averages method (Sullivan et al., 2002) has been adopted in the present study.

After standardization of each indicator, the sub-components were averaged using the Equation (6.2) to determine the value of each major component.

$$S_c = \frac{\sum_{i=1}^n IndexS_v i}{n} \dots \dots \dots (6.2)$$

Where S_c denotes one of the three components [Exposure (Exp), Sensitivity (Sen), and Adaptive capacity (Ac)] for the village v . Further, $IndexS_v i$ represents subcomponent, index by ' i ' and ' n ' is the number of sub-components in each major component. Once the values for the exposure, sensitivity and adaptive capacity were determined, the three contributing factors were aggregated using the Eq. (6.3) from Hahn et al. (2009) to derive the climate vulnerability index (IPCC-CVI) score at the village level.

$$CVI_v = (E_v - AC_v) * S_v \dots \dots \dots (6.3)$$

Where CVI_v is the climate vulnerability score for village v using the vulnerability framework of IPCC. E is the estimated exposure score for village v , AC is the adaptive capacity score for village v and S is the sensitivity score for village v . The level of vulnerability score scaled from 0 (less vulnerable) to 0.8 (highly vulnerable). The entire process has been

carried out for both study areas (viz., irrigated and rainfed regions) separately and in total. Table 6.2 presents the sub-component values for the construction of the CVI along with the minimum and maximum values for two study villages, namely Pattipaka and Ippatur.

Table 6.2: Sub-component (Indicator) values for CVI of study villages

Components and sub-components	Units	Pattipaka	Ippatur	Overall	Max. value	Min. value
<i>Exposure</i>						
% of farm households aware that rainfall is decreasing	Percent	85.6	92.8	89.1	100	0
% of farm households notice that temperature is rising	Percent	88.2	96.7	92.4	100	0
% of farm households perceive that drought frequency is increasing	Percent	84.2	94.1	89.2	100	0
Average number of disasters farm households have experienced	Number	3.8	4.1	4.0	6	0
% of farm households report pest attacks increased	Percent	62.5	73.7	68.1	100	0
<i>Sensitivity</i>						
% of farm households perceived high impact of drought	Percent	74.8	91.4	83.1	100	0
% of farm households have only agricultural income	Percent	79.2	69.3	74.3	100	0
Average crop diversity index	Number	0.4	0.3	0.3	1	0.1
% of farm households having borrowings	Percent	80.9	84.2	82.6	100	0

during past five years						
Average number of dependents	Number	4.5	4.9	4.7	10	0
% of farm households where the head of the family is illiterate	Percent	50.7	38.8	44.7	100	0
% of farm households having marginal landholdings	Percent	55.9	51.3	53.6	100	0
<i>Adaptive capacity</i>						
% of farm households changed crop variety	Percent	57.2	52.6	54.9	100	0
% of farm households reported adjusting the planting dates	Percent	82.2	83.6	82.9	100	0
% of farm households are having other than farm income	Percent	52.6	61.8	57.2	100	0
% of farm households using early maturing (short-duration) varieties	Percent	83.5	82.9	83.2	100	0
% of farm households practicing water-conservation measures	Percent	40.1	33.6	36.9	100	0
% of farm households taking crop insurance	Percent	47.4	59.9	53.6	100	0
% of farm households have membership in “self-help groups”	Percent	66.8	70.1	68.5	100	0
% of farm households having primary and above level of education	Percent	49.3	61.2	55.3	100	0

Average farming experience (years)	Number	28.4	26.5	27.4	56	0
% of farm households having migrated members	Percent	40.8	43.4	57.9	100	0
% of farm households having better access to climate information	Percent	52.3	51.3	51.8	100	0
% of farm households having access to better institutional credit	Percent	62.5	61.8	62.2	100	0
% of farm households having livestock ownership	Percent	42.8	51.3	47.1	100	0

Source: Author's primary surveys.

6.5 Results and discussions

This section presents the results of each component and overall vulnerability of selected villages with detailed discussion. The indexed sub-component values of exposure, sensitivity and adaptive capability of study villages are reported in Tables 6.3, 6.4 and 6.5, respectively. Further, in Table 6.6, we have reported overall values of three components and CVI score for each study village. One can compare the results of both the villages such as Pattipaka (irrigated) and Ippatur (rainfed) and analyse the farm household's vulnerability to changing climate. The results of the vulnerability assessment contain three major components of vulnerability i.e., "exposure, sensitivity and adaptive capacity." In the CVI, sensitivity and exposure values have an adverse relationship with overall vulnerability and adaptive capacity has a positive relationship with vulnerability.

6.5.1 Exposure

The present sub-section deals with the analysis of the exposure to climate change in the vulnerability framework. The vulnerability of farm households in the study villages is considered to be a function of their exposure to climate change and drought. The study of exposure to extreme weather events is an essential aspect of agrarian vulnerability. In this study, the level of exposure in our study area depends on how farm-households aware/perceive the significant change in climatic factors and extreme climatic events. In the regions with diverse exposure to severe weather risks, the sensitivity of specific farming units to climate variability will vary significantly because of the dissimilar adaptive capacity of the farming community as the adaptive capability of farm households depends on various socio-economic, demographic, psychological and administrative factors (Easterling, 1996; Crane et al., 2017).

It can be witnessed from Table 6.3 that the aggregate exposure index is higher for Ippatur village (0.851) and less for Pattipaka village (0.768). As mentioned earlier, this study incorporated five subcomponents of exposure in the climatic vulnerability assessment. The indexed values of subcomponents of exposure revealed that the Pattipaka village (0.856) has a lower awareness of declining rainfall than the Ippatur village (0.928). Similarly, the indexed values of subcomponents of exposure shown that the Ippatur village

(0.967) has a higher awareness of rising temperature than the Pattipaka village (0.882). Regarding the subcomponent of the perceived rising rate of recurrence of droughts in the study area, Ippatur village is having a greater indexed value (0.941). Another critical indicator of exposure is the average number of disasters (droughts and floods) that farm households have experienced. The research revealed that Ippatur village households (0.683) have seen more climatic disasters in the last ten years than Pattipaka village (0.634) households, as shown by the indexed indicator values. The perception of increased pest attacks in sample villages is contributing considerably to overall exposure.

Table 6.3: Indexed sub-component values of exposure

Sub-Components (Indicators)	Pattipaka	Ippatur	Overall
% of farm households aware that rainfall is decreasing	0.856	0.928	0.891
% of farm households notice that temperature is rising	0.882	0.967	0.924
% of farm households perceive that drought frequency is increasing	0.842	0.941	0.892
Average number of disasters farm households have experienced	0.634	0.683	0.666
% of farm households report pest attacks increased	0.625	0.737	0.681
Overall indexed value of exposure	0.768	0.851	0.811

Source: Author's calculations.

The level or magnitude of dryland can certainly create a higher degree of exposure to changes in climatic factors in drought prone regions (Sathyan et al., 2018). This study results reveal that the Ippatur village has greater dry land areas compared to Pattipaka. The higher contributing indicator for exposure is the perception of increasing temperature in both the study villages. The lower contributing indicator for exposure is the number of extreme climatic events have experienced by the households in Ippatur village and increasing frequency of pests' attack in Pattipaka village. Conclusively, the overall extent of exposure to climate variability and extreme climatic events is higher for the Ippatur village and lower

for Pattipaka village. Based on the analysis and discussion, it can be said that the rainfed region, i.e. Mahabubnagar, is more exposed to climate change and drought than the irrigated region, i.e. Karimnagar. The findings of the exposure are in line with other vulnerability investigations such as Pandey and Jha (2012), Panda (2017) and Sam et al. (2017).

6.5.2 Sensitivity

According to Gallopín (2003), sensitivity is defined as “the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances.” This measure represents a system's responsiveness to climatic influences, which is shaped by socio-economic and environmental settings. Moreover, sensitivity determines the extent to which the community will be impacted by climatic hassles. However, at the community level, sensitivity and exposure are almost inseparable conceptions, and it is a big challenge to characterise them (Smit and Wandel 2006). The sensitivity reflects the pattern of resource utilization, the dependence of means of sustenance on weather-sensitive activities, and the frequency and intensity of environmental and climatic hazards. The sensitivity to changing climate in farming is often determined in terms of the extent of reduction in crop yields, the decline in agricultural incomes or profits, livelihood vulnerability, increased cost of production and crop damages (Oram, 1985; Easterling, 1996; Singh and Nair, 2014).

In this study, to evaluate the climatic sensitivity of farm households at the village level, we selected indicators to reflect the farm production sensitivity through agriculture as a major source of earnings and crop diversity. Furthermore, the study utilized farmer's self-assessments of effects of droughts on them, in this state of condition sensitivity becomes a function of climatic risk perception and risk forbearance- factors that are rarely accounted in impact investigations at sectoral scales (Risbey et al., 1999; Dessai and Hulme, 2004). At the household level, the crop growers level of income, number of dependents in the family, literacy level, and the extent of borrowings are imperative in influencing their reaction to climate stress. Hence, this study included these indicators to evaluate the sensitivity.

The indexed values of the sensitivity indicators/subcomponents are reported in Table 6.4. The sensitivity index scores show that both study villages have high sensitivity due to

different factors. However, Pattipaka village (0.608) has a higher sensitivity to climate change compared to Ippatur village (0.589). The higher contributing indicator for sensitivity is the percentage of farmers perceived higher effect of drought (0.914) in Ippatur village and the greater extent of borrowings (0.809) in Pattipaka village. The lower contributing indicator for sensitivity is the average crop diversity index in both the study villages. Upon moving deeper, the study finds that what victimized the extremely sensitive village of Pattipaka from other is the higher borrowings, high dependence on only farm income, low level of literacy among farm households and a greater percentage of households having marginal landholdings.

Table 6.4: Indexed sub-component values of sensitivity

Sub-Components (Indicators)	Pattipaka	Ippatur	Overall
% of farm households perceived high impact of drought	0.748	0.914	0.831
% of farm households have only agricultural income	0.792	0.693	0.743
Average crop diversity index	0.389	0.289	0.339
% of households having borrowings during last 5 years	0.809	0.842	0.826
Average number of dependents	0.452	0.487	0.470
% of farm households where the family head is illiterate	0.507	0.388	0.447
% of farm households having marginal landholdings	0.559	0.513	0.536
Overall indexed value of sensitivity	0.608	0.589	0.599

Source: Author's calculation.

The farm-households in Pattipaka village have less income diversity when compared to Ippatur village. It has been seen that the farm-households of Ippatur village are involved in additional income generating actions for instance employment in private and public sectors, livestock, petty business near industries. Ippatur village has the advantage of substantial private sector employment availability. The farm-households in Pattipaka village have farm revenue as the only exclusive source of income. As much as 80 percent of the farm-households in Pattipaka village have farming as the only basis of income and livelihood whereas only 69 percentage of farm-households in Ippatur village depend exclusively on

farming for income. Hence, we can say that higher dependence of households on agriculture in Pattipaka village is the major reason for their high level of sensitivity to climate change.

The perceived higher influence of droughts on agricultural activities is the third most important indicator of sensitivity for Pattipaka village (0.748) and the first most important indicator for Ippatur village (0.914). Similarly, the higher level of borrowing is the first most principal component of sensitivity for Pattipaka. It can be observed that the farm-households in Pattipaka village have a higher score in terms of borrowings (0.809), which indicated that the households of this village have been very much indebted since last five years. The score of the dependency subcomponent, as observed from the “average number of dependents” in the farm-household, is higher for Ippatur village (0.487) and lower for Pattipaka village (0.452). More dependents (kids or old age people) in a farm-household is likely to enhance the sensitivity to climate change. The dependents might be required extra care and sometime they have to spend additional expenditure and foodgrains.

The “crop diversity index” depicts a variety of crops grown by farm-households in the study villages. Looking at the crop diversification index scores in the study villages, we observed that the crop diversity score is higher for Pattipaka village (0.389) and lower for Ippatur village (0.289). It is observed from our primary survey that the farmers in Ippatur village are cultivating widely two crops such as maize and cotton while farm-households in Pattipaka village were segregated their crop cultivation by cultivating paddy, turmeric, maize, cotton and pulses. To sum up, when the indicators of sensitivity were averaged, the Pattipaka village exhibited higher sensitivity and Ippatur village showed lower sensitivity. Unlike the overall exposure score, the sensitivity score presented the different pattern of ranking between the study villages, and Pattipaka turned out to be the more sensitive village to climate variability and change. Most of the findings from sensitivity analysis are in line with other studies, for instance Gbetibouo and Ringler (2009), Panda (2017) and Pandey and Jha (2012).

6.5.3 Adaptive capacity

“Adaptive capacity” is defined as the capability of societies, farm-households and individuals to formulate and enforce various adaptation activities espoused at the household

level to cope with adverse impacts of climate change and extreme weather events such as floods, droughts (Adger and Vincent, 2005). In our study, we have selected 13 major subcomponents of adaptive capacity. Farm-households in two study villages reported undertaking several kinds of adaptation activities such as adjusting planting dates, change crop variety, using early maturing varieties and moving to additional non-farm income creating activities. The indexed scores of the adaptive capacity subcomponents are reported in Table 6.5. Ippatur village (0.585) has a higher adaptive capacity compared to Pattipaka village (0.560). The maximum contributing indicator for adaptive capacity is the adjusting planting dates to climate variability in Ippatur village and using early maturing varieties in Pattipaka village. As per indexed values, the less contributing subcomponent for adaptive capacity is the water-conservation practices by farm-households in both sample villages.

As mentioned earlier, the usage of early maturing crop varieties (short-duration) is the first most important subcomponent of adaptive capability for Pattipaka village and the second most important subcomponent of adaptive capacity for Ippatur village. In Pattipaka village, around 84 percent of the farm-households reported that they have been using early maturing varieties, having an indexed value of 0.835. However, Ippatur village has a less indexed score of 0.829, where almost 82 percent of farm-households have been using early maturing varieties. The farm-households of Ippatur village told that the lack of availability of early maturing varieties of several crops in their village. With an indexed value of (0.572), 57 percent of the farm-households in Pattipaka village announced that they altered crop variety. Ippatur village, on the other hand, has a lower indexed score of (0.526), indicating that nearly 53 percent of farm-households have altered their crop variety.

Furthermore, the first most significant subcomponent of adaptive ability for Ippatur village is the adjustment of planting dates, while it is the second most important subcomponent of adaptive capability for Pattipaka village. Almost 83 percent of farm-households of Ippatur village reported that they have been changing planting dates to cope with climate change, having an indexed value of 0.836. Pattipaka village has a less indexed score of 0.822, where almost 82 percent of farm-households have been changing planting dates. It can be indicated that the farm-households in both the study villages have learned

from their past experience about changing rainfall patterns and altering their planting dates accordingly.

Table 6.5: Indexed subcomponent values of adaptive capacity

Sub-Components (Indicators)	Pattipaka	Ippatur	Overall
% of farm households changed crop variety	0.572	0.526	0.549
% of households reported adjusting the planting dates	0.822	0.836	0.829
% of households are having other than farm income	0.526	0.618	0.572
% of farm households using early maturing (short-duration) varieties	0.835	0.829	0.832
% of farm households practicing water-conservation measures	0.401	0.336	0.369
% of farm households taking crop insurance	0.474	0.599	0.536
% of households have membership in “self-help groups”	0.668	0.701	0.685
% of farm households having primary and above level of education	0.493	0.612	0.553
Average farming experience (years)	0.507	0.473	0.490
% of farm households having migrated members	0.408	0.434	0.579
% of farm households having better access to climate information	0.523	0.513	0.518
% of households having access to better institutional credit	0.625	0.618	0.622
% of farm households having livestock ownership	0.428	0.513	0.471
Overall indexed value of adaptive capacity	0.560	0.585	0.585

Source: Author’s calculations.

Around 33 percent of farm-households of Ippatur village stated that they have been performing water conservation practices, having an indexed value of 0.336. Involvement in more non-farm income making activities has been described as an important coping strategy for addressing climatic menaces in agriculture. Several farm-households in the study

villages reported being more involved in non-farm income creation strategies to offset the agricultural damage due to climate variability and change. For Ippatur village, the percentage of farm-households reported to have involved in more non-farm income creation strategies is higher (61.8) and lower for Pattipaka village (52.6). The farm-households having membership in the self-help groups (SHGs) have been taken as a proxy to represent the social network or capital of the households. The adaptive capacity of the farm-households may improve with having membership in social capital networks namely saving and credit institutions (Washington-Ottombre and Pijanowski 2013). As far as membership in SHGs is concerned, Ippatur village is higher with 70 percent of farm-households described to have become members of the self-help groups in the local area. Similarly, 66 percent of the farm-households of Pattipaka village are having membership in local area SHGs.

Crop insurance as a risk transfer mechanism or as a coping strategy has been utilized for centuries to lessen the income loss threats of the farm-households due to climate change (Warner et al. 2009). Farm-households with access to crop insurance has a benefit in tackling multiple sources of menaces through an improved capability to invest strategically in their production means. Crop insurance is found to be one of the important adaptation strategies among the farm-households in the study area. For Ippatur village, the percentage of farm-households reported to have crop insurance is higher (59.9) with having indexed value of 0.599. The number of crop insured farm-households is lower in Pattipaka village with having indexed value 0.474. Having a lower level of crop insurance can increase the vulnerability of marginal and small farmers. As observed in the field survey, most of the large and medium crop growers prefer to take crop insurance as risk coping strategy.

The level of literacy has been considered as the major indicator of adaptive capacity of the farming community in our study villages. In other words, farm-households with less than the primary level of schooling are presumed to have a lower capacity to deal with climate change and variability. In terms of educational level, two study villages have around 50 percent of the rate of literacy. The study results present that the literacy subcomponent of Ippatur village has a higher index value (0.612); Pattipaka village has a lower index value (0.493). Further, farming experience has been considered as the indicator of adaptive capacity of the farming community in our study villages. In terms of farming experience,

Pattipaka village has a higher index score (0.507). Some farm-households were reported that having better access to climate information can be useful for adjusting planting dates and shifting crop varieties as an essential approach to deal with the threats of climate change. Most of the farm-households in the study village use television, mobile, radio and traditional knowledge as well as forecast systems for cultivation practices. Approximately 50 percent of farm-households in both study villages reported that they are accessing climate information for agricultural practices.

Keeping more livestock herd may help farmers to become more resilient to changing climate. Because, it can be used as an alternate source of income or as a kind of protective measure to meet the needs of farm households during climate-related adverse events such as floods and droughts. According to the results, 42.8 percent of farm households in Pattipaka village and 51.3 percent of farm households in Ippatur village possessed livestock herd. Accessibility to formal credit facilities is considered one of the essential indicators of adaptive capacity which can determine the farmer's vulnerability (Shukla et al., 2016). According to the results, around 60 percent of farm households have access to formal agricultural credit in both selected villages. As a final point, when the overall indicators of adaptive capacity were averaged, the Ippatur village has presented a higher adaptive capacity and Pattipaka village showed a lower adaptive capacity. The results of adaptive capacity are supported by several other works such as Abid et al. (2016), Hahn et al. (2009), Shukla et al. (2016), Gbetibouo and Ringler (2009), Pandey and Jha (2012) and Sam et al. (2017).

6.5.4 Overall vulnerability index

Using the IPCC framework, the present study calculated the farm household's vulnerability to changing climate in the sample villages. For this, the average indexed values of each component (exposure, sensitivity and adaptive capacity) were utilized. The component values and the overall CVI scores for study villages are reported in Table 6.6. According to the outcomes of the Climate Vulnerability Index (CVI), the more vulnerable village is Ippatur, with an overall CVI index value of 0.157. However, the other village of Pattipaka of Karimnagar district has a lower CVI value than the Ippatur village of Mahabubnagar

district. The less vulnerable village of Karimnagar district, namely Pattipaka village, has an overall CVI index value of 0.126. The overall CVI index value of the two villages is 0.135.

Table 6.6: Component values and the overall CVI scores

CVI Components	Pattipaka	Ippatur	Overall
Exposure (E)	0.768	0.851	0.811
Sensitivity (S)	0.608	0.589	0.599
Adaptive capacity (A)	0.560	0.585	0.585
IPCC-CVI	0.126	0.157	0.135

Source: Author's calculations.

Figure 6.2: Graphical representation of vulnerability among sample villages

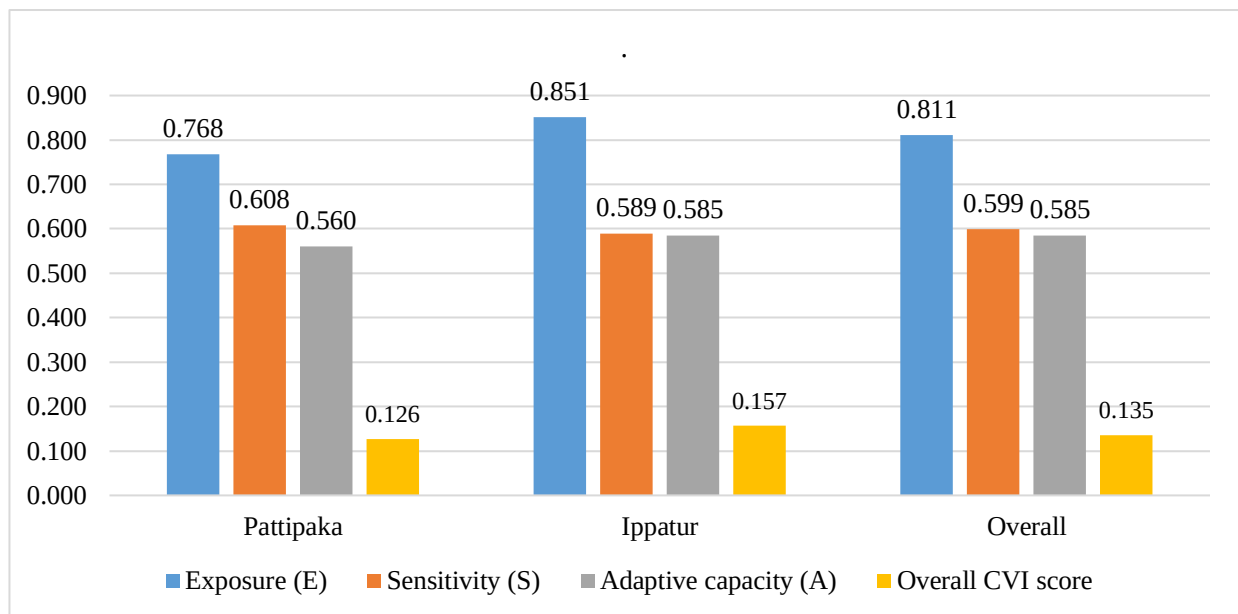


Figure 6.2 presents a graphical representation of vulnerability that demonstrates the scores of different vulnerability components of the climate vulnerability index for each study

village. Although Ippatur village has been very much exposed to climate change and variability, interestingly, it also has a higher adaptive capacity as per our climate vulnerability index score. However, taking into account of all the components, climate vulnerability index score indicates that Ippatur farm-households are more vulnerable than Pattipaka farm-households. It is also curious to understand that Pattipaka village has low scores for exposure and has less adaptive capacity. The overall CVI index presents that Pattipaka farm-households are less vulnerable. The results of this study indicate that the rainfed village of Mahabubnagar district is more vulnerable to climate change and variability than the irrigated village of Karimnagar district. The overall results of the vulnerability analysis are somewhat consistent with Deressa et al. (2008), Panda (2017), Pandey and Jha (2012).

6.6 Summary of the chapter

The vulnerability ranking analysis of two sample villages in our study districts reveals that Ippatur village of Mahabubnagar district is the more vulnerable than the other village, i.e., Pattipaka. Our results have also revealed some interesting features of vulnerability at the community level. For example, of the two sample villages, the village with greater adaptive capability seems to be more exposed to the impacts of changing climate. As per results, Ippatur village is more exposed to changing climate and it also has a higher adaptive capability since farm households are taking various adaptation strategies to cope with it. This finding supports the results of Gbetibouo and Ringler (2009) and Panda (2017) that the communities more vulnerable to climate risks often have the greater adaptive capacity to respond to it.

Another important finding is that the village which is more vulnerable to climate change is often more interested in taking multiple adaptation actions. In this study, Ippatur village is more vulnerable than Pattipaka village and it also has a higher adaptive capability since farm households are taking various adaptation strategies to cope with it. Further, this study results evidenced that the village considered to be more susceptible to sensitivity to climate change does not necessarily correspond to more vulnerable communities. In our study, Pattipaka village's sample farmers are more sensitive to changing climate but it also a

less vulnerable village. Based on these results, we make a statement that the farm households having higher exposure to climate risks are adopting more adaptation measures and ranks in higher adaptive capacity than the farm households having a higher sensitivity to climatic risks. The more vulnerable village of Ippatur is characterized by less irrigation and water conservation, more migrants in the household, less crop diversification, high perceived impact of droughts.

Chapter 7

Farmers Perceptions, Adaptation Activities and Determinants of Adaptation in the Context of Climate Change: Evidence from Household Level Data

7.1 Introduction

Chapter 5 has evidenced that the major crop yields were significantly affected by climatic factors at the macro level. Similarly, chapter 6 revealed that farm-households in the study area are vulnerable to climate change at the micro-level. To minimize these unfavorable effects of climate change, farmers in the study area have undertaken different adaptation measures. This chapter proceeds to analyse the adaptation strategies of the farmers to cope with climate change. However, it is equally important to understand farmers' perceptions of climate change, determinants of adaptation, and barriers to adaptation. The issues related to adaptation will be addressed using survey data at farm-household level in the study area.

According to observed climatological data, global climate change has impacted a wide variety of biological, socio-ecological and physical systems in the past several decades (McCarthy et al., 2001; IPCC, 2013). The consequences of changing climate can be rampant in agricultural activities (Nelson et al., 2009; Parry et al., 2005) because these activities are enormously dependent on climatic factors. Several studies empirically evidenced the unfavorable effects of climate change on crop yields as well as farm income (Mall et al., 2006; Lobell et al., 2011; Schlenker and Lobell, 2010; Mendelsohn and Dinar, 1999; Calzadilla et al., 2013; Mendelsohn et al., 1994), and presented the vulnerability of agricultural systems to climate change (Vincent, 2004; Gbetibouo and Ringler, 2009; Hahn et al., 2009; Young et al., 2010; Shah et al., 2013; Simane et al., 2016). However, it is widely accepted that agriculture in developing nations like India is more sensitive and vulnerable to changing climate due to less adaptive capability (Kumar and Parikh, 2001a; Birthal et al., 2014; O'Brien et al., 2004; Rao et al., 2016; Narayanan and Sahu (2016).

Changing climate could place added hassles on India's socio-ecological systems, which are even now facing immense stresses from industrial development and urbanization. Moreover, according to the “global climate risk index” (2018), India is the 12th most susceptible of 182 nations to climate hazards from 1997 to 2016. Projections of climate are

likely to make Indian farmers more vulnerable due to greater reliance on climate-sensitive livelihoods (Aggarwal, 2008). Both adaptation and mitigation policy options are available for reducing the adverse effects of changing climate. In comparison to mitigation to limit the climate risks, adaptation is considered as an important policy choice in agriculture (Klein et al., 2005; Haden et al., 2012). In other words, mitigation actions can decelerate the magnitude and pace of climate change in the long run. However, adaptation to climate change is essential choice to minimize the vulnerability of farmers and farming communities directly (Wheeler et al., 2013; Huang et al., 2015). Hence, adaptation activities are effective and suitable practices to safeguard agricultural yields, minimize vulnerabilities, and improve the adaptive capability of farming systems to changing climate. One of the most widely used definitions of adaptation is given by IPCC (2001a), which defines adaptation as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Adaptation can take place at different levels, but the adaptation at the local or community level is challenging because these are the ones who experience the severity of climate change. Assessment of driving factors that lead to adaptive action is crucial for fostering adaptation to climate change.

Adaptation to changing climate and extreme weather events among farmers is not a recent phenomenon. The crop growers have relentlessly adapted to climate change over the centuries. Numerous scholarly works have been carried out to understand the adaptation measures and their determining factors across the globe (for instance: Gbetibouo, 2009; Deressa et al., 2011; Fosu-Mensah et al., 2012; Below et al., 2012; Tambo and Abdoulaye, 2013; Seo and Mendelsohn, 2008; Okonya et al., 2013; Fisher et al., 2015; Ndamani and Watanabe, 2015; Tessema et al., 2013; Sarker et al., 2013; Ali and Erenstein, 2017; Panda et al., 2013; Biggs et al., 2013). Most of these studies exploring adaptations to climate change have been undertaken primarily in African nations. Gbetibouo (2009) documented the adaptation practices of farmers to climate change in the Limpopo River Basin of Southern Africa using the “bottom-up” method. The study revealed that planting different crops as a primary adaptation measure, and inadequate credit facilities as the crucial constraining factor to adaptation. Fosu-Mensah et al. (2012) identified the critical adaptation measures to climate change in Ghana, comprising planting of short-duration varieties, crop

diversification, and changing sowing or planting dates. Similarly, Below et al. (2012) presented that literacy rate and local infrastructure are the determining factors of adaptation to climate risks in Tanzania. Another study by Ndamani and Watanabe (2015) identified that improved irrigation facilities and better crop varieties are the most fundamental adaptation strategies in the Lawra district of Ghana. Further, Alauddin and Sarker (2014) documented that stress-tolerant rice variety, shifting to non-rice crops, and excess groundwater use are selected adaptation strategies of drought prone farmers in Bangladesh.

In the context of India, Tripathi and Mishra (2017) identified that shifting cropping patterns and agro-forestry works are the practical adaptation measures of sample farmers in the state of Uttar Pradesh. Another study by Begum and Mahantam (2017) depicted that the most practiced adaptation strategies of Assam farmers are new crop varieties, additional fertilizer use and altering of planting or sowing dates. The key determining factors of adaptation are farm extension activities, credit availability and farm income. Further, Banerjee (2015) revealed that water managing practices are found to be important adaptation measures in the Indian states of Andhra Pradesh and Maharashtra. Several other studies also conducted to explore the adaptation measures and their determinants in Indian states using survey data (for example: Dhanya and Ramachandran, 2016; Singh et al., 2018; Udmale et al., 2014; Panda et al., 2013; Narayanan and Sahu, 2016; Mishra and Sahu, 2014b; Bahinipati and Venkatachalam, 2015; Sharma et al., 2014; Bahinipati, 2015; Patnaik et al., 2016). Most of the scholarly works on adaptation have taken place in Eastern India, particularly in Odisha. However, no single systematic study investigated the adaptation strategies of farmers and determinants of adaptation to changing climate in Telangana, where the whole geographical area falls in the semi-arid climate of the southern peninsula.

This study identified certain research issues based on the literature review (see chapter 2 for a more detailed review). Adaptation strategies to climate change in agriculture vary across geographical locations or areas (Sarker et al., 2013). Several of these works have evidenced that adaptation practices are typically area or location specific. Most of the time, adaptation options depend on local climate, farming systems, institutional conditions, socio-economic and other factors. As a result, a comprehensive understanding of the current adaptation activities of farmers in the context of location-specific or area-specific is

essential. Further, quite a few works have considered the typical determining factors that encourage farmers to involve in a specific adaptation strategy. However, determinants of adaptation actions to climate change are under-researched. In this milieu, scholarly works on the adaptation of farming communities to climate change and their determining factors for Telangana are minimal. Therefore, this study explores the area-specific farmer's perception of climate change, major adaptation strategies, and determinants of adaptation in the study area (located in Telangana) using survey data.

Therefore, this chapter deals with four specific research questions:

1. Are farm-households aware or perceive of climate change in the study region?
2. Are they practicing adaptation strategies to cope with climate? If yes, what are these?
3. What are the determining factors of adaptation strategies in the study area?
4. Have they faced constraints in adaptation practices? If yes, what are these?

7.2 Analytical Model

In order to assess the determinants of farmer's adaptation measures, this study employed a binary logistic model (BLM) due to the binary nature of regressand (dependent) variables. The binary logistic model is the most suitable analytical tool to deal with a dichotomous outcome. In this study, the farmer's adaptation practices are binary response variables (Y), for instance, if farmers have adopted a particular adaptation strategy (1) or otherwise (0). Therefore, the binary logistic technique takes into consideration the relationship between a dichotomous dependent variable and a set of explanatory variables (Fosu-Mensah et al., 2012). However, the explanatory variables can be continuous, binary, and other forms. Several studies have been employed the binary logistic regression and presented consistent outcomes, for instance, Fosu-Mensah et al. (2012), Adesina and Chianu (2002), Ndamani and Watanabe (2016), Panda et al. (2013), Zamasiya et al. (2017), Kgosioma et al. (2018) and Trinh et al. (2018). The general equation of a "binary logistic model" can be specified as:

$$Y_i = \text{logit}(P) = \beta_0 + \beta_1 \sum_{i=1}^n X_i + \varepsilon_i \dots \dots \dots (7.1)$$

Where Y_i is a specific binary dependent variable (one of the adaptation strategies), β_0 is the constant (intercept) term and β_1 is a set of coefficients to be assessed. Further, X represents a

set of independent variables and ε_i is an error term. The positive sign of the coefficients of explanatory variables represents to improve the probability of implementing a specific adaptation strategy to climate change. In contrast, a negative sign indicates a reduction in the likelihood of adopting adaptations.

7.2.1 Dependent variables in the estimated models

In order to find out the determinants of adaptation activities, we conduct a logit regression where the dependent variable (adaptation measure) is binary (i.e., a farm-household stated in terms of yes/no whether they undertook that specific action or not). Accordingly, we fitted ten logistic regressions for each of the adaptation measures launched by the study area farmers. The choice of dependent variables is done on the basis of field survey and existing literature. As discussed earlier, there are various adaptation options that farmers use in the study area. Table 7.1 reports the explanation of dependent variables.

Table 7.1: Dependent variables of study models

Models	Dependent variables	Units of measurement
Model 1	Using different varieties	1 = using different varieties; 0 = if not
Model 2	Using early maturing varieties	1 = using early maturing varieties; 0 = if not
Model 3	Adjusting planting dates	1=advance/delayed planting dates; 0= if not
Model 4	Irrigation	1= improved irrigation; 0 = if not
Model 5	Multiple/ mixed cropping	1 = multiple/ mixed cropping; 0 = if not
Model 6	Keeping more livestock	1 = keeping more livestock; 0 = if not
Model 7	Non-farming activities	1 = non-farming activities; 0 = if not
Model 8	Migration	1 = migration; 0 = if not
Model 9	Crop insurance	1 = crop insurance; 0 = if not
Model 10	Crop diversification	1 =crop diversification; 0 = if not

Source: Compiled from field survey data.

7.2.2 Independent variables

A range of factors influences the adaptation options. Based on literature and experiences from the field, this study takes household, farm and institutional characteristics, including physical and human resources of the household, as independent variables. This study also considers indicators on perception on changing climate among farmers, which include four explanatory variables such as the perception of the farmer on climate change, awareness on declining rainfall, awareness on the frequency of droughts and awareness on the rising temperature, including climate information. While the adaptation options at the farm level can be influenced by several factors, this study recognizes fourteen (14) independent variables mentioned below (see Table 7.2) that were considered to be most suitable in explaining the usage of farm household adaptation choices.

Table 7.2: Explanatory or Independent variables

Independent variables	Description	Measurement
Age	Continuous	Years
Gender	Categorical	1 = male, 0 = female
Level of education	Categorical	1 = Illiterate, 2 = Below primary, 3 = Primary, 4 = Secondary, 5 = Higher secondary, 6 = Others
Farming experience	Numerical	Years
Family size	Numerical	Number
Annual income	Continuous	Rupees
Land size (overall land owned)	Continuous	Acres
Credit access	Binary	1 = yes, 0 = otherwise
Membership in SHGs	Binary	1 = yes, 0 = otherwise
Perception on climate change	Binary	1 = yes, 0 = otherwise
Perception on declining rainfall	Binary	1 = yes, 0 = otherwise
Perception on rising temperature	Binary	1 = yes, 0 = otherwise
Perception on frequent drought	Binary	1 = yes, 0 = otherwise
Information on climate change	Binary	1 = yes, 0 = otherwise

Source: Compiled from field survey data.

The explanatory variables of the logit model are reported in Table 7.2. However, as mentioned earlier, the choice of explanatory variables is done on the basis of field survey and existing literature. Here, we try to give some explanation of selected explanatory variables.

(i) Age: Age of the household head is an important determinant of the adaptation behaviour of farmers. Old farmers are more risk-averse. Older farmers tend to have more experience and hence take more adaptations. However, some studies found that age can have a negative influence on adaptation (Anley et al., 2007; Mabe et al., 2014). So this variable can have both negative and positive influences on different adaptation choices.

(ii) Gender: Gender of the head of the farm-household is one of the significant determinants of adaptation measures. Studies like Deressa et al. (2009a) and Sarker et al. (2013) and survey experience suggested that male farmers are more likely to adopt adaptive measures. Hence, we expect this variable to have a positive impact on adaptation choices.

(iii) Education: This variable represents the education level of the farmers (six categories including illiterate category). Education creates awareness of the farmers and that helps to take better adaptation choices (Panda et al., 2013; Alauddin and Sarker, 2014). We expect this variable to have a positive impact on adaptation choices.

(iv) Farming Experience: Farming experience represents the number of years involved in agricultural activities or farming. The experience in farming can enhance the likelihood of uptake of several adaptation activities (Begum and Mahantam, 2017). Greater experienced farmers tend to have more understanding of changing climate and coping measures.

(v) Household or family size: House hold size is the number of family members in farmers' household. Larger family members can help in labour intensive adaptation measures. In contrary, larger families may divert a part of family member to go for nonfarm activities for more income. Household size is thus expected to have mix influence on adaptation option.

(vi) Household's income: Income of a household represents total annual income of a farmer household. It is summation of farm and off farm income of a household. Income is an important determinant of adaptation (Tessema et al., 2013). The wealthier a household, the

more they are capable of adapting new methods. Therefore, this variable is also likely to have a helpful influence on adaptation choices.

(vii) Land size: Private property (owned) increases the probability of taking adaptation measures. Farmers which have more farm area owned tend to have high propensity to invest in adaptation options. Thus this variable is expected to have positive influence on adaptation choices.

(viii) Access to credit and SHGs: Access to credit and SHGs means farmers are accessing the credit facilities and getting membership in SHGs. These are dummy variables that take value 1 if farmers are accessing credit and SHGs and 0 otherwise. Access to credit and SHGs helps a farmer to purchase new technologies and increase agricultural investment. Hence, it increases farmers' probability to choose different adaptations.

(ix) Perception variables: Perception about changing climate, declining rainfall, rising temperature and frequent droughts are important determinant factors of adaptation (Panda et al., 2013; Alauddin and Sarker, 2014). Perceived farmers can make and implement adaptation activities in a better way. Therefore, these are dummy variables that take 1 if the farmer is aware of the aforementioned aspects and 0 otherwise.

(x) Information about climate change: Awareness about climate change represents the knowledge of farmers about climate change. The farmers take adaptations if they are aware that climate change will affect their future crop yields. Most of the farmers in our study have been able to predict changes in temperature and rainfall. Thus, this is a dummy variable which takes 1 if the farmer is aware of climate change and 0 otherwise.

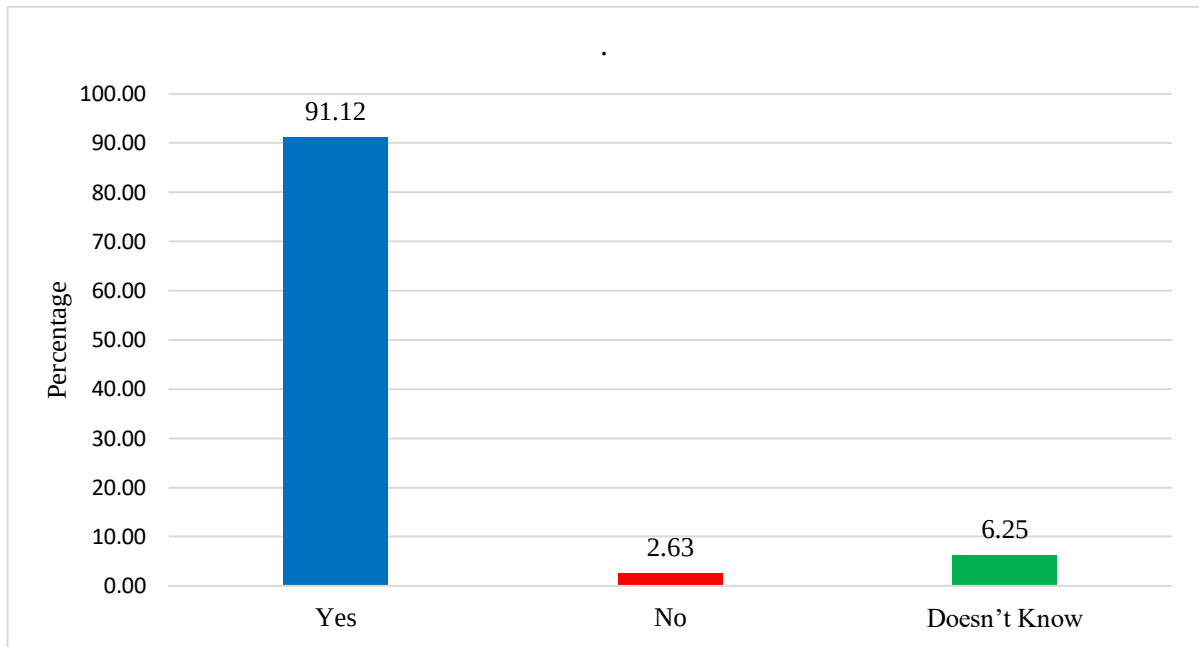
7.3 Results and Discussions

7.3.1 Perceptions of climate change

The perception or awareness on changing climate plays a significant role in farm-household's behavior regarding the adaptation to changing climate change and extreme climate events. Adaptation to changing climate and variability necessitates that farmers first perceive that the climate is changing and then recognize and implement useful adaptation strategies (Maddison 2007). In other words, the crop growers have to aware first that the

climate is changing in order to take required adaptation actions (Bryan et al. 2009). To a significant extent, the strength with which the farming community responds to climate change depends on how well it is perceived by farmers (Bostrom et al. 1994). Therefore, it is necessary to understand the farmer's perception on changing climate and alterations in climatic factors. Here, we tried to analyze the farmer's perception on climate change in selected study villages. The surveyed farm-household's heads were interviewed about their awareness on climate change, extreme weather events, alterations in rainfall and temperature pattern during the last 30 years.

Figure 7.1: Farmer's perception on climate change among sample households (%)

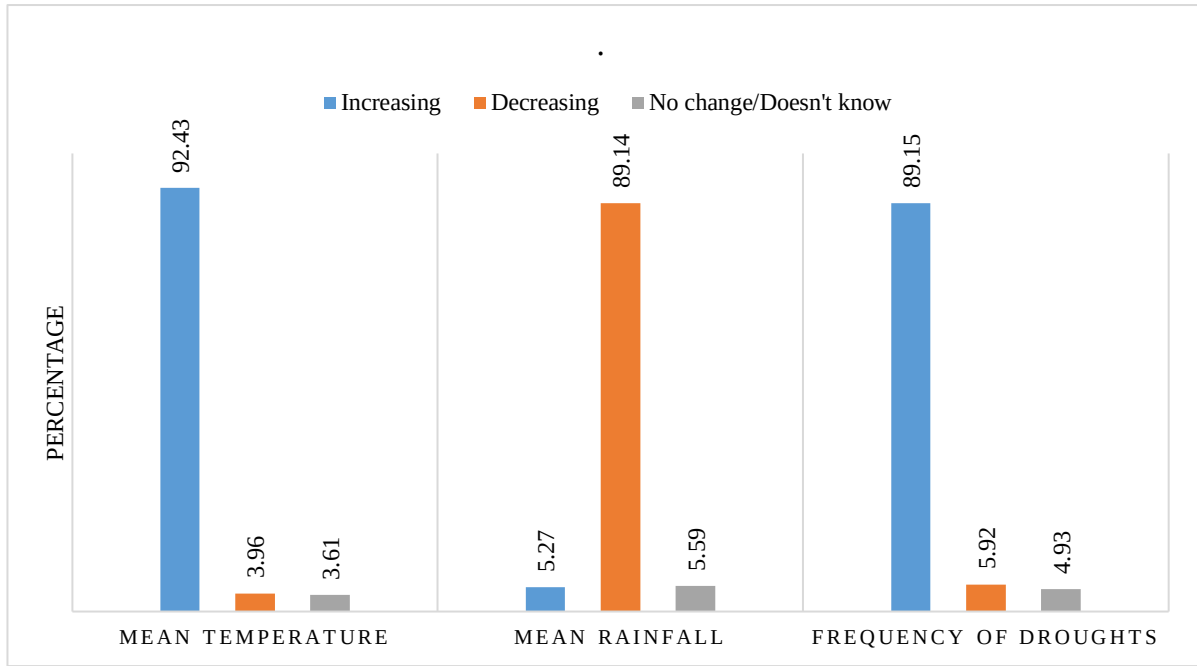


Source: Compiled from primary surveys.

The perception of farm-households regarding climate change and changes in rainfall and temperature in our study area has been presented in Figures 7.1 and 7.2 and Tables 7.3 and 7.4. From figure 7.1, it can be found that 91.2 percent of farm-households in the study region believe that the climate is changing over the last thirty years and merely 2.63 percent believe it is not changing. It indicates the fact that farm-households in the study region are conscious about the changing climate in recent years. During the field survey, 2.63 percent

of farmers were reported that climate is not changing, but the capability of our health is declining to tolerate normal changes in weather so that we feel the climate is significantly changing. Moreover, about 6.25 percent of farmers in the study villages are reported that they do not know. The reported perceptions on climate change in the study region are consistent with Sarker et al. (2013), Fosu-Mensah et al. (2012) and Panda (2016).

Figure 7.2: Farmer's perception on climate parameters among sample households



Source: Compiled from primary surveys.

Further, this study analyzed the perception on different aspects of climate as presented in Figure 7.2. After questioned about the rising temperature in the study region, 92.43 percent of respondents believe that the average temperature in the study area is rising while merely 3.61 percent feel that it is not changing. Variation in rainfall pattern in the study area is an essential aspect of climate change for agriculture. Approximately 89.14 percent of farmers perceived that the rainfall is decreasing in the study villages. The perceived changes in rainfall imply that most of the farmers have properly detected changes in rainfall patterns. Less rainfall in the study region has severe implications for food production and livelihood.

About 89.15 percent of the respondents believe that the frequency of droughts has increased vastly in the study region and also the number of hot days due to temperature rise.

Table 7.3: Perceptions about rainfall related parameters among farm-households

Parameters of Rainfall	Pattipaka (n = 152)	Ippatur (n = 152)	Overall (n = 304)
<i>Mean Rainfall</i>			
Increasing	12 (7.89)	4 (2.63)	16 (5.26)
Decreasing	130 (85.53)	141 (92.76)	271 (89.14)
Not Changing	3 (1.97)	5 (3.29)	8 (2.63)
Doesn't Know	7 (4.61)	2 (1.32)	9 (2.96)
<i>Number of Rainy days</i>			
Increased	21 (13.82)	16 (10.53)	37(12.17)
Decreased	88 (57.89)	100 (65.79)	188(61.84)
Constant	43 (28.29)	36 (23.68)	79(25.99)
<i>Frequency of Droughts</i>			
Increased	128(84.21)	143(94.08)	271 (89.14)
Decreased	13(8.55)	5(3.29)	18 (5.92)
Doesn't Know	11(7.24)	4(2.63)	15 (4.93)
<i>Frequency of floods</i>			
Increased	4(2.63)	5(3.29)	9 (2.96)
Constant	129(84.87)	135(88.82)	264 (86.84)
Decreased	19(12.50)	12(7.89)	31 (10.20)
<i>Intensity of rainfall</i>			
Increased	126 (82.89)	127 (83.55)	253 (83.22)
Decreased	8 (5.26)	6 (3.95)	14 (4.61)
Doesn't Know	18 (11.84)	19 (12.50)	37 (12.17)
<i>Changes in rainfall timing</i>			
Yes	130 (85.53)	140 (92.11)	270 (88.82)
No	21 (13.82)	4 (2.63)	25 (8.22)
Doesn't Know	1 (0.66)	8 (5.26)	9 (2.96)

Source: Compiled from primary survey. Note: Figures in parentheses indicate percentage.

The perception of farmers on different aspects of rainfall in the study region has been presented in Table 7.3. The results indicate that the majority of farmers have correctly

observed variations in rainfall patterns. Around 93 percent of farmers in Ippatur village believe that the mean rainfall is decreasing. Likewise, almost 86 percent of farmers in Pattipaka village aware that the mean rainfall is decreasing. Empirical results from chapter 4 and the farmer's perception on decreasing rainfall are more or less similar for the study region. Hence, we can say that farm households are properly observing the changes in precipitation. In terms of number of rainy days, farmers described that the number of rainy days is decreasing significantly. Approximately 57 percent of farmers in Pattipaka village and 65 percent of farmers in Ippatur village perceived that the number of raining days is decreasing. However, around 26 percent of farmers in the study villages reported that the "number of rainy days" is not changing. Drought is the inevitable phenomenon in the semi-arid regions of the country, as the Telangana region. Almost 94 percent of farmers in Ippatur village perceived that the rate of recurrence of droughts is increasing. Similarly, about 84 percent of farmers in Pattipaka village perceived that the rate of recurrence of droughts is increasing.

The occurrence of floods is an infrequent phenomenon in Telangana state. However, it is one of the important aspects of rainfall and it has several adverse impacts on crops, livestock and people. More than 86 percent of farmers in both study villages are perceived that the rate of recurrence of floods is not changing. Only 3 percent of farmers in the study region believe that the frequency of floods is increasing. Farmers are correctly perceived about the frequency of floods in the study region. Further, around 83 percent of farmers in both study villages are perceived that the intensity of rainfall is increasing. Only 5 percent of farmers in Pattipaka village and 3.9 percent of farmers in Ippatur village believe that the intensity of rainfall is decreasing. Furthermore, Changes in rainfall timing is one of the important aspects of the rainfall. Around 92 percent of farmers in Ippatur village believe that the timing of rainfall is changing. Likewise, almost 85 percent of farmers in Pattipaka village perceived that the timing of rainfall is changing. The analysis of perception on rainfall shown that farmers were perceived the alterations in rainfall in the study area.

Table 7.4: Perceptions about temperature related parameters among farm-households

Parameters of Temperature	Pattipaka (n = 152)	Ippatur (n = 152)	Overall (n = 304)
<i>Mean Temperature</i>			
Increasing	134 (88.16)	147 (96.71)	281 (92.43)
Decreasing	9 (5.92)	3 (1.97)	12 (3.95)
Not Changing	4 (2.63)	2 (1.32)	6 (1.97)
Doesn't Know	5 (3.29)	0 (0.00)	5 (1.64)
<i>Number of Hot days</i>			
Increased	114 (75.00)	121 (79.60)	235 (77.30)
Decreased	3 (1.97)	0 (0.00)	3 (0.98)
Constant	35 (23.03)	31 (20.40)	66 (21.72)
<i>Number of pests attack*</i>			
Increased	95 (62.50)	112 ((73.68)	207 (68.09)
Decreased	41 (26.97)	32 (21.05)	73 (24.01)
Constant	16 (10.53)	8 (5.26)	24 (7.89)

Source: Compiled from primary surveys. Note: * indicates other parameter and figures in parentheses indicate percentages.

The farmer's perception on temperature related parameters and others are reported in Table 7.4. About 88 percent of farmers in Pattipaka village and 96.7 percent of farmers in Ippatur village believe that the mean temperature is increasing. Drought prone village (Ippatur) farmers are described that due to an increase in mean temperature, the crop sector in the region is adversely affected. Similarly, around 75 percent of farmers aware that the "number of hot days" is increasing in Pattipaka village and 79 percent of farmers aware that the "number of hot days" is increasing in Ippatur village. The increased number of hot days has severe implications for plant growth, livestock and health of the elder households in the study region. The farmer's perception on non-climatic parameter such as pests attack is presented in Table 7.4. Almost 63 percent of farmers in Pattipaka village and 74 percent of farmers in Ippatur village believe that the number of pest's attacks is increasing. However,

about 24 percent of farm-households in both study villages perceive that the pest's attacks are decreasing. The reported perceptions on changing rainfall and temperatures in the study region are consistent with Roco et al. (2015), Banerjee (2015) and Panda (2016).

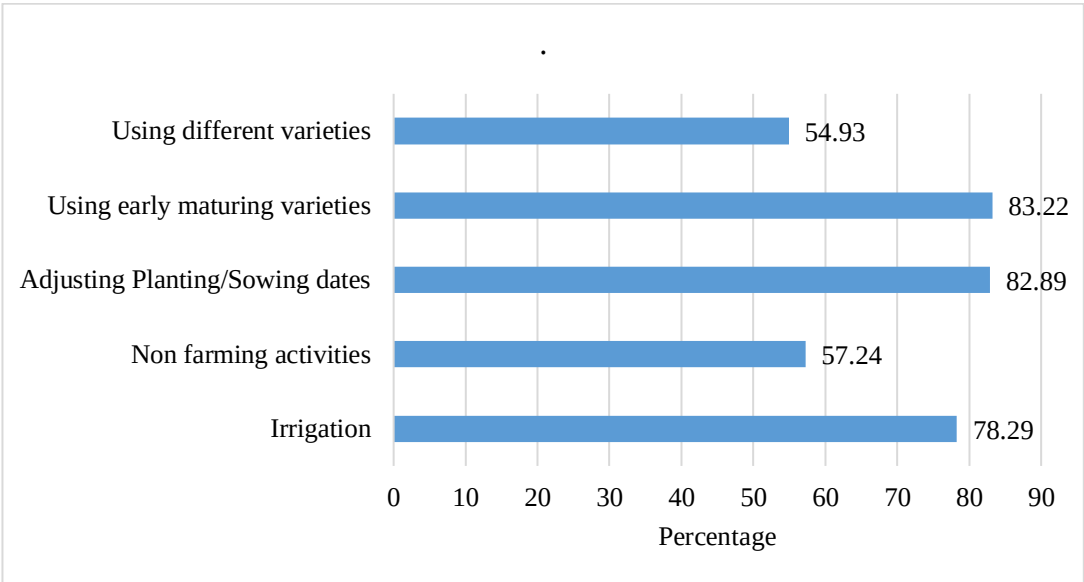
7.3.2 Adaptations activities among the farm-households

One of the fundamental aims of this chapter is to identify the major adaptation strategies among farm-households to cope with climate change and droughts at the village level in the study region. In reaction to observed long-term changes in climatic factors such as rainfall and temperature, our study area farm-households have adopted different adaptation practices. Identifying adaptation strategies is advantageous in order to gain an understanding of crop grower's adaptive capacity to climatic change (Reid et al. 2007). To achieve this, the farm-households in the sample villages were questioned about their main adaptation activities to deal with climate change. The major adaptation strategies in the study area are presented in Figure 7.3 and Table 7.5. The most commonly practiced adaptation strategies are: early maturing varieties, adjusting sowing/planting dates, enhancing irrigation facilities, use fertilizers and pesticides, using a different variety of crop seeds, multiple/mixed crops or intercropping, engaging in non-farm activities, water management practices, migration, crop insurance and livestock. This study presents the adaptation practices that are purely taking place at the farm level and do not comprise governmental interventions.

Further, adaptation strategies are broadly categorized into two sections. The first section mainly includes the adaptation practices that are intended at increasing crop productivity, and it is related to farming activities. On the other hand, the second section comprises non-farm activities directed at improving the income levels of the farm-households. The following analysis deals with adaptation activities of the farm-households in the study villages. Among the reported adaptation strategies, the use of early maturing seeds (83.2 %) is the most commonly practiced adaptation technique. Most of the farmers in the study villages are using early maturing varieties of seeds (short duration variety seeds) to cope with climate hazards. Particularly paddy farmers stated that using the traditional type of seeds is not suitable for existing climate patterns because the crop growing seasons decreased considerably. Moreover, early maturing type varieties are less susceptible to the

shorter cropping seasons, and it does not require water availability for a more extended period (Farooq et al., 2011). Therefore, farmers are changing to early maturing varieties in the sample villages. Around 16 percent of farmers reported that they are unable to adopt short period varieties due to unavailability short period seeds on time and lack of government support in providing such varieties.

Figure 7.3: Major adaptation practices of sample farmers



Source: Compiled from primary surveys.

Another most widely practiced adaptation strategy is adjusting planting/sowing dates (82.8 %) to cope with climate change and droughts in the sample villages. Year-over-year changes in sowing dates are evidenced by the farm-households according to the arrival and extent of precipitation. Farming communities, especially in the rainfed climate conditions, often have to wait for the monsoon to begin crop plantation (Laux et al., 2010; Nouri et al., 2017). Shifting sowing dates as adaptation practice may allow for considerably improved crop yields under climate change conditions (Laux et al., 2010). Farming communities in the sample villages are learned from their own experience regarding changes in precipitation patterns, and accordingly, they are shifting sowing dates for enhancement of crop yields. Diversification of crop varieties is also an extensively practiced adaptation measure and

farmers in the sample villages have adopted diversified crop varieties of paddy, maize, cotton, and other crops. Most of the crop varieties diversified from traditional varieties to HYVs, hybrid varieties. This could be due to the fact that modern varieties give better yields with lower expenses. However, the yield performance of these varieties mostly depends on other agricultural inputs. Table 7.5 shows that about 45 percent of farm-households reported the unavailability of new alternative crop varieties. They are often limited to changing crop varieties between traditional and current varieties since more suitable crop varieties are unavailable in the sample villages.

Table 7.5: Farmers adaption strategies in sample villages

Major Adaptations	Pattipaka (<i>n</i> = 152)	Ippatur (<i>n</i> = 152)	Overall (<i>n</i> = 304)
Using different varieties	87 (57.24)	80 (52.63)	167 (54.93)
Using early maturing varieties	127 (83.55)	126 (82.89)	253 (83.22)
Planting/Sowing date adjustment	125 (82.24)	127 (83.55)	252 (82.89)
Livestock	65 (42.76)	78 (51.32)	143 (47.04)
Reducing land quantity	62 (40.79)	104 (68.42)	166 (54.61)
Non farming activities	80 (52.63)	94 (61.84)	174 (57.24)
Irrigation	126 (82.89)	112 (73.68)	238 (78.29)
Water conservation	61 (40.13)	51 (33.55)	112 (36.84)
Fertilizers/manure	95 (62.50)	94 (61.84)	189 (62.17)
Multiple/mixed/intercropping	114 (75.00)	72 (47.37)	186 (61.18)
Crop diversification	77 (50.66)	96 (63.16)	173 (56.91)
Migration	62 (40.79)	66 (43.42)	176 (57.89)
Crop insurance	72 (47.40)	91 (59.90)	163 (53.60)

Source: Compiled from primary survey. Note: Figures in parentheses indicate percentage.

The study area farmers are utilizing improved irrigation facilities as an autonomous adaptation strategy for agricultural practices after the monsoon period, particularly in the drylands. Due to the paucity of rainfall during crop growing seasons, farmers are investing

more in irrigation works to reduce rainfall dependence. Farmers in the rainfed village (Ippatur) mostly depend on bore-wells and rainwater, and irrigated village (Pattipaka) farmers often rely on open wells, tanks and governmental canals to cope with erratic rainfall and droughts. Improved irrigation not only reduces water insecurity but also boosts the opportunities for shifting sowing dates and upsurges returns on other inputs such as fertilizers, HYVs, others. Although it's an essential adaptation method, small and marginal farmers are not adopting due to lack of investment capability, but mostly large farmers are adopting this method. This was evidenced in other studies like Begum and Mahantam (2017) and Dhanya and Ramachandran (2016). Further, water conservation activities are less practiced by the farmers in the study area (only 36.8 %), and those are the storage of rainwater in village tanks and creating contour bunds in high-altitude areas. Improved irrigation facilities and water conservation activities are useful to farmers in order to increase crop yields by providing water supply. Moreover, farmers in the rainfed area are reported the necessity of government support in providing irrigation facilities.

Due to erratic rainfall and inadequate returns from investment, farm-households from sample villages are forced themselves to decrease some extent of the land under farming. Farmers from the rainfed village (68.4 %) are practicing this adaptation measure more than the irrigated area (40.8 %). Farmers are reducing their acreage under cultivation mostly for the summer season (Rabi season) due to the unavailability of water sources. The rationality here is that once land-use decisions (fixed costs on land) go into effect, it is impossible to undo them. In conditions like this, it will be better for a cultivator to wait. A study by Gadgil et al. (2002) found similar results in the semi-arid Anantapur (Anantapuramu) region that farmers do not cultivate the land until unless soil moisture to be sufficient. Therefore, the flexibility in choosing agricultural production, such as reducing acreage, is the main aspect of farmers' adaptation to climate risks. Further, farmers in the study area have reported the production of livestock is an adaptation measure to improve income levels. Particularly, rainfed village farmers (51.3 %) are keeping more livestock, and it is an appropriate practice for the semi-arid tropical region. This helps farmers to earn income, especially during drought and dry periods. The livestock is also useful in agricultural activities.

Although the rural population depends mostly on agriculture for livelihoods, non-farm income can also be an essential part of rural livelihoods. The primary reason for involving in off-farm activities is that the income from non-farm streams is often climate-risk free than farm operations. Therefore, income diversification is one of the essential adaptation practices in the face of climate risks. More than 50 percent of farm-household members in the sample villages are practicing some off-farm income generation activities to cope with yield uncertainties relating to climate change. The rainfed village farm-household members are involving in labour, construction labour including centering work, labour work in the near factories, etc. However, irrigated village farm-household members depend on labour work, beedi work, MGNREGA, petty business, etc. These activities can be helpful in reducing the income risks owing to climate change. Migration to other places in search for employment or work is also an important off-farm practice in the study area. Around 40.7 percent of the farm-households in the irrigated village (Pattipaka) reported that at least one person in the family are migrated to other places, particularly to UAE, for additional income to cope with yield losses due to less rainfall. However, rainfed village (Ippatur) farmers are migrating to cities like Hyderabad, Bangalore, etc. due to crop failures. Studies like Meze-Hausken (2000), McLeman and Smit (2006) and Jha et al. (2018) also evidenced the importance of migration as an adaptation measure to global climate change.

The concept of weather-based crop insurance is an emerging issue in climate-adaptation literature. The potential role of crop insurance as a coping method to climate risks is progressively being studied by scholarly works (Swain, 2014; Falco et al., 2014; Panda et al., 2013; Adiku et al., 2017). Crop insurance plays an essential role in reducing the financial risks of farmers, particularly in the most vulnerable regions. About 53.6 percent of farmers in the study area are adopted crop insurance as an adaptation measure to reduce the adverse effects of climate change. However, more than 40 percent of farmers are not taking crop insurance due to several reasons like unaware, too much procedure, lack of information, etc. This necessitates the promotion of crop insurance in the study region to cope with climate change. Further, farm households in the study area are increased use of fertilizers or manure to improve soil fertility, which helps to get more crop yields.

Another widely practiced adaptation measure is crop diversification due to less rainfall and droughts. Diversification from turmeric, pulses, and paddy to cotton and mango garden is an essential adaptation strategy for dealing with climate risks. Ippatur village (rainfed) farmers reported that they are shifting from paddy and pulses to maize and cotton crops. Further, irrigated village (Pattipaka) farmers reported that they are shifting from turmeric, paddy and pulses to cotton and mango gardens. This diversification could be to cope with less rainfall, droughts in the study area, and also because of higher returns from these crops. The reported results infer that study area farmers are changing the cropping pattern in order to adjust to local climate conditions. To sum up, crop diversification in the study area is improving the profitability of the farmers and helping farmers to cope with the adverse effects of climate change. Studies such as Bradshaw et al. (2004), Lin (2011), Huang et al. (2014), Falco et al. (2014) and Makate et al. (2016) confirmed the advantage of crop diversification as an adaptation measure to climate change. Furthermore, mixed cropping or intercropping is also a remarkable adaptation measure in the study area. About 61 percent of farmers are practicing this method to gain more profits. Farmers reported that they mix crops like maize in turmeric crop, bengalgram in maize crop, turmeric in mango gardens, etc. Farmers found that intercropping is more profitable in the study area.

7.3.3 Determinants of adaptation measures

The empirical results of the determinants of adaptation measures using the “binary logit model” are presented in Table 7.6 and 7.7. For the ten adaptation measures, we have conducted logit regression separately using the indicators hypothesized to influence the adaptation actions. In the table, we have reported the coefficients and their significance level for different indicators. Below, we discuss each of the factors that drive adaptation actions based on the regression results in Table 7.6 and 7.7. However, following Sarker et al. (2013), only the “statistically significant” factors influencing adaptation decisions are analyzed.

(i) Age: For most of the adaptation measures, the age of the household head does not seem to have any considerable impacts. The empirical outcomes evidenced that age has played a

significant favorable role in taking crop insurance against crop loss. This infers that an increase one year of age of the household head enhances the likelihood of the practice of crop insurance. This result is not consistent with Dadzie et al. (2012) and Wąs and Kobus (2018). Further, our results also show that age did not significantly increase the probability of other adaptation measures. Our results confirm the findings by Begum and Mahantam (2017) in Assam that for many adaptation practices, increasing age did not considerably increase the likelihood of adaptations.

(ii) Gender: The empirical outcomes revealed that male-headed farm-households increase the likelihood of keeping more livestock and increasing irrigation facilities. This could be because male-headed farmers can handle livestock more effectively than female-headed households. Moreover, male-headed farm-households are generally more informed of modern technology than female-headed farmers (Deressa et al., 2009a; Sarker et al., 2013).

Table 7.6: Binary logit models results indicating determinants of adaptation strategies

	UDV	UEMV	APD	Irrigation	MC
Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Age	-0.006	0.034	0.053	-0.011	-0.008
Gender	0.639	-0.321	-0.951	1.032**	-0.133
Education	0.094**	0.347*	0.124	-0.237	-0.160
Farming Exp.	-0.036	-0.014	-0.008	-0.012	0.013
Family size	0.053	-0.173	0.138	-0.143	-0.175*
Income	0.001*	7.586	-5.986	3.186	0.001**
Land size	-0.121	-0.121	0.231*	0.021	-0.227***
Credit access	0.047	-0.356	0.429	0.119	-0.413
SHGs access	-0.528	0.061	-0.774	-1.063*	-0.105
Climate perception	0.196	1.756***	0.609	-0.091	-0.837
Rainfall perception	-0.606	-1.946**	2.079*	-0.136	0.840*
Temp. perception	1.622*	0.519	(omitted)	2.173**	0.023
Drought perception	0.589	0.891**	0.752*	0.204	0.185
Climate information	-0.301	0.031	-0.901	0.805*	0.553
Constant	0.205	-0.110	1.077	0.178	1.528

Source: Author's calculation. Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.10$. UDV= using different varieties, UEMV= using early maturing varieties, APD= adjusting planting dates, MC= multiple/mixed cropping.

Table 7.7: Binary logit models results indicating determinants of adaptation strategies.

	Livestock	Non-farm	Migration	Crop ins.	Crop Div.
Variables	Model 6	Model 7	Model 8	Model 9	Model 10
Age	0.041	0.006	0.012	0.079***	-0.031
Gender	0.971*	-0.102	-0.505	0.017	0.248
Education	-0.066	0.013**	0.055	0.126	0.069
Farming Exp.	-0.040	-0.021	0.008	-0.058**	0.037
Family size	-0.133	0.175*	0.229**	-0.029	-0.039
Income	5.707	-2.656	-3.154	-9.706**	4.876
Land size	0.011	0.089	-0.064	0.508***	0.003
Credit access	-0.001	0.411	-0.714**	0.037	-0.049
SHGs access	-0.142	-0.830*	0.889*	-0.187	-0.229
Climate perception	1.363**	0.385	-0.362	0.516	0.914*
Rainfall perception	-0.820	-0.072	1.024*	0.113	-0.545
Temp. perception	-2.198**	-0.592	-0.336	-0.731	-0.538
Drought perception	-0.524	-0.308	-0.739**	-0.155	0.531
Climate information	-0.502	-0.091	0.247	0.551	0.675
Constant	1.303	1.228	-1.602	-3.171	-0.382

Source: Author's calculation. Note: *** $p < 0.01$, ** $p < 0.05$ and * $p < 0.10$. Crop ins.= crop insurance and Crop div.= crop diversification.

(iii) Education: The higher levels of education can enhance the possibility to undertake adaptation activities (Deressa et al., 2009a; Tessema et al., 2013). Education significantly increases farmers' probability of using different varieties, using early maturing or short-duration varieties and non-farm activities as adaptation methods. Education enables the farmers to take proper decision. However, our results show that education did not significantly increase the probability of some other adaptation measures.

(iv) Farming experience: Experienced crop growers are more potential to adapt than farmers who are less experienced (Deressa et al., 2009a; Begum and Mahantam, 2017). However, in our case, the farming experience has a significant adverse impact on taking crop insurance. The result shows that farmers having more experience in terms of farming years are more likely to averse to taking crop insurance against crop failure or loss. Furthermore, for all other adaptation methods, farming experience does not show any significant impact.

(v) Family or household size: As per our study results, household size has a significant positive effect on migration, practicing non-farm activities and a significant negative impact on multiple/mixed cropping. This indicates that a bigger family size enhances the probability of undertaking off-farm activities, including migration. In other words, the additional family member involves in non-farm activities like a public or private employment, petty business, construction labour, etc. Studies like Nhemachena and Hassan (2007) and Bryan et al. (2009) have evidenced household size has a significant positive impact on adaptation choices. On the contrary, studies like Deressa et al. (2009a), Panda et al. (2013) and Mabe et al. (2014) have presented household size has an insignificant impact on adaptation choices.

(vi) Household income: The income of the household represents the wealth of the household, and we have hypothesized that the adoption of different methods in agriculture depends on the financial well-being of the household. Our results show that the overall income of the household plays a significant role in adopting different adaptation measures. It can be observed that household income has a significant positive effect on using different varieties and multiple/mixed cropping and a significant adverse impact on crop insurance. The empirical results indicate that the higher the household income, the lower the probability of farmers adopting crop insurance as an adaptation strategy. Several studies, for instance Deressa et al. (2009a), Sarker et al. (2013), Mabe et al. (2014) and Begum and Mahantam (2017), have also found a positive association between household income and adaptations.

(vii) Land or farm size: The area of land cultivated is a physical resource for the farmers. Land holding size surges the likelihood of multiple adaptations being introduced. The results, however, show that the higher the quantity of land possessed by the farmers, the

higher will be the probability of their changing the planting dates and insuring against crop failure. This implies that large farmers are more likely to change their dates of planting crops and take crop insurance because it can reduce the loss associated with changing climate. On the other hand, the results presented a negative and significant impact on the adaptation choice of multiple/mixed cropping. Hence, it can be inferred that the larger the farm size, the lesser is the tendency to practice the multiple/mixed cropping as an adaptation. The significant favorable impacts of land size on implementing various adaptation measures found in our study are consistent with research works like Bryan et al. (2009) and Sarker et al. (2013).

(viii) Access to credit and SHGs: Credit accessibility improves the possibility of adaptation. Studies like Fosu-Mensah et al. (2012), Okezie et al. (2012) and Sarker et al. (2013) have found access to credit has a significant positive impact on adaptation choices. However, access to credit does not show any significant positive impact on undertaking adaptation actions in the study area. The study results indicate that only access to credit has a significant negative impact on the possibility of migration. The farm households were having credit accessibility not migrating to other places. Furthermore, the greater percentage of farmers cited credit availability as the main barrier to adaptation. Participating in self-help groups is statistically significant for adaptation measures like migration, irrigation and non-farm activities. However, access to self-help groups has a significant favorable impact on migration. The rest of the significantly influenced adaptations, such as irrigation and non-farm activities, have influenced negatively. Access to self-help groups reduces the probability of practicing non-farm activities and irrigation in the study region.

(ix) Information on climate change: Farmers who are having information about changing climate and weather can make and practice adaptation more effectively. Our study results revealed that information about changing climate has played a significant and positive role in improving irrigation facilities. The farmers that have access to information on changing climate were spending more on irrigation to provide a continuous water supply during crop growing period. Further, for all other adaptation methods, climate information does not show any significant impact. The significant favorable impact of information of climate and

weather on irrigation is consistent with Deressa et al. (2009a) and Ndamani and Watanabe (2016).

(x) Perception of climate variables: Perceptions of climate change and extreme climatic events induce farmers to take adaptation actions accordingly (Pangapanga et al., 2012). In this study, we have taken into account the following four indicators of climate change perception among farmers: first, whether the farmers are watchful of the changing climate in their area; second, do they perceive that frequency of droughts have increased over the years; third, do they feel that the amount of rainfall has been declining over the years and, fourth, do they feel that the extent of temperature has been increasing over the years. The study results evidenced that climate change perception has a significant positive impact on using early maturing or short-duration varieties, keeping more livestock and crop diversification. This indicates that perceived farmers have more probability to uptake adaptation strategies like using early maturing varieties, livestock and crop diversification. The finding of positive impact of climate perception on several adaptations are consistent with Nhemachena et al. (2014) and Begum and Mahantam (2017).

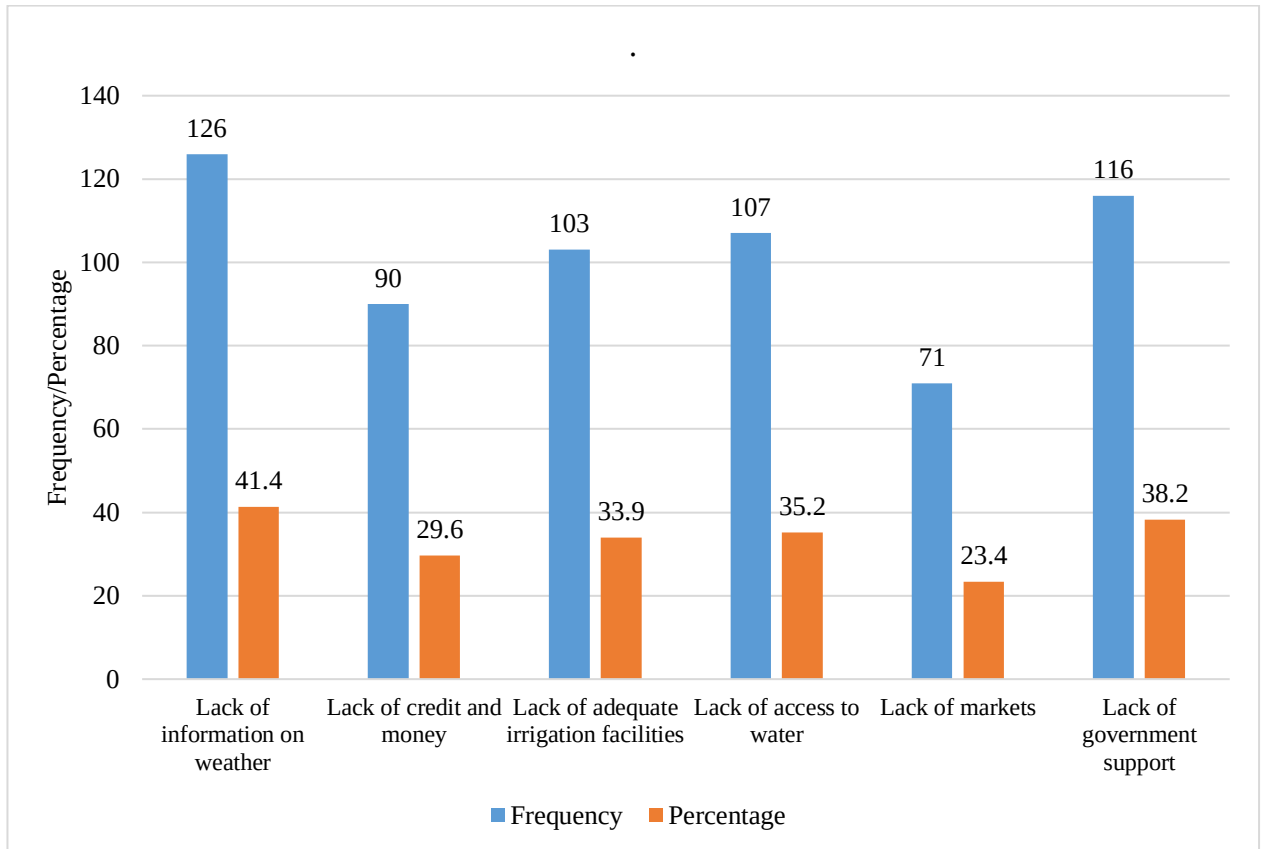
The empirical outcomes show that perception of declining rainfall has a significant positive relation with adjustment of planting/sowing dates, migration and multiple/mixed cropping and significant negative association with using early maturing types. One probable explanation for this might be that farmers prefer not to invest in early maturing types but rather prefer to adopt risk-reducing measure such as adjustment of planting dates and multiple cropping. The higher the probable perception of a late onset of monsoon, higher is the probability of farmers changing the planting dates which need no monetary investment. This is in line with the results of Pangapanga et al. (2012) and Mabe et al. (2014). Further, perception of increasing temperature has a significant favorable impact on using different varieties (stress-tolerant varieties) and investing in irrigation and substantial adverse impact on using early maturing varieties. This implies that farmers prefer to use different stress-tolerant varieties and irrigation rather than using early maturing varieties. The positive impacts of perception of rising temperature on adaptations are consistent with studies like Nhemachena and Hassan (2007), Deressa et al. (2009a) and Mabe et al. (2014).

Furthermore, our results show that perception of the frequency of droughts has a significant positive relation with using early maturing (short-duration) varieties and adjustment of planting/sowing dates and significant negative association with migration in the study region. The implication of this result is that if the farmers perceive that the frequency of drought is increasing, the probability of undertaking adaptations like using early maturing varieties and changing planting/sowing dates increases and the likelihood of undertaking migration practice decreases. One probable explanation for this might be that farmers prefer not to migrate for employment and livelihood but rather prefer to adopt risk-reducing measures such as using early maturing varieties and changing planting/sowing dates. The favorable impacts of perception of drought frequency on various adaptive measures found in this study are consistent with other works like Pangapanga et al. (2012), Panda et al. (2013) and Alauddin and Sarker (2014). Our results indicate that perception of climatic variables can also play an important role in undertaking adaptation actions. Farmers' ability to choose a particular adaptation measure has many constraints. The following section discusses some of such constraints as revealed by the farmers.

7.3.4 Constraints or barriers to adaptations

The current section deals with constraints or barriers to adaptation as reported by farm-households in the study region. There are several constraints to the willingness of farmers to choose a particular adaptation strategy. Farm-households face different barriers to adaptation and these barriers vary depending on the farmer's view on changing climate and socio-economic conditions (Bryan et al., 2009; Deressa et al. 2009a; Okezie et al., 2012). Our survey aims to find out the constraints faced by farm-households in taking various adaptation strategies in the study villages. The results showed here are intended primarily to provide an overview of the constraints but not to assess the intensity of constraints. The results on barriers to adaptation measures are reported in Table 7.8 and Figure 7.4. Farmers reported the most important constraints to adaptation as a lack of information on weather, lack of adequate irrigation facilities, lack of access to water and lack of government support. Other important barriers are a lack of credit, a lack of seeds on time and lack of information on adaptation.

Figure 7.4: Observed barriers to adaptation in sample villages



Source: Compiled from primary surveys.

Table 7.8 presents the observed barriers to adaptation among farm-households in the sample villages. The lack of information on weather is the first major constraint in the Pattipaka village (40.1 %) and Ippatur village (42.8 %) as well. About 40 percent of farmers were reported that the “lack of government support” is the second most important barrier to adaptation in Ippatur village. Similarly, around 36.2percent of farmers were reported that the “lack of government support” is the second most important barrier to adaptation in Pattipaka village. Lack of adequate irrigation facilities is an important barrier for the farm-households in Ippatur village (36.8%) which is situated rainfed and drought prone region. The farm-

households expressed the view that rejuvenating the conventional water harvesting mode in the region can go a long way to assisting crop growers to cope with the water crisis.

Table 7.8: Observed barriers to adaptation among farm households

Barriers to Adaptation	Pattipaka <i>n</i> = (152)	Ippatur <i>n</i> = (152)	Overall <i>n</i> = (304)
Lack of accurate info on weather	61 (40.1)	65 (42.8)	126 (41.4)
Lack of credit	42 (27.6)	48 (31.6)	90 (29.6)
Lack of info on adaptation	47 (30.9)	51 (33.6)	98 (32.2)
Shortage of labour	36 (23.7)	38 (25.0)	74 (24.3)
Lack of adequate irrigation facilities	47 (30.7)	56 (36.8)	103 (33.9)
Lack of access to water	52 (34.2)	55 (36.2)	107 (35.2)
Lack of seeds on time	38 (25.0)	42 (27.6)	80 (26.3)
Lack of markets	34 (22.4)	37 (24.3)	71 (23.4)
Lack of government support	55 (36.2)	61 (40.1)	116 (38.2)
Lack of awareness on adaptation	46 (30.3)	53 (34.9)	99 (32.6)

Note: Figures in parentheses indicate percentage. Source: Compiled from primary surveys.

Another major barrier to adaptation is lack credit facilities in the sample villages. Lack of credit limits the farm-household's ability to acquire new technologies that would helpful in dealing with climate change. About 28 percent of farmers in Pattipaka village and 32 percent of farmers in Ippatur village reported that the lack of seeds availability on right time is an important barrier to adaptation. About 32 percent of farmers were reported that the "lack of information on adaptation" is one of the most important barriers to adaptation in selected villages. According to the respondents in the sample villages, large and dominant farmers have very easy and timely access to seeds at the Mandal level while marginal and small farmers rarely get seeds on time from government agencies. Small farmers have to purchase seeds in the black market at a higher price. Sometimes they may get less quality and inferior seeds in the black market. Therefore, governments need to provide institutional support to

overcome barriers. The reported barriers to adaptation among farm-households are consistent with Sarker et al. (2013), Mishra and Sahu (2014b) and Panda (2016).

7.4 Summary

The aim of the present chapter was to analyse farm-household's awareness on changing climate, adaptation strategies and their determining factors and constraints faced by farmers in taking adaptation measures in the study region using survey data. The determinants of adaptation measures were evaluated employing a binary logistic model or regression. More than 90 percent of the study region farmers reported that climate is changing over the last 30 years or more. Similarly, farmers' awareness and perceptions about changes in rainfall and temperature parameters demonstrated that a significant portion of farmers perceived that rainfall is decreasing and temperatures are increasing, including the number of hot days.

Further, the study area farmers reported that the most commonly practiced adaptation strategies are: early maturing varieties, adjusting sowing/planting dates, enhancing irrigation facilities, use fertilizers and pesticides, using a different variety of crop seeds, multiple/mixed crops or intercropping, engaging in non-farm activities, water management practices, migration, crop insurance and livestock. The reported major constraints to adaptation in the study region are lack of information on climate, a lack of irrigation facilities, a lack of government support, a lack of information on adaptation. Furthermore, the empirical outcomes of the logit regression evidenced that level of education, gender, yearly income, landholding size and perceptions on climatic variables have a significant favorable impact on adaptation measures of the farm-households. This study suggests that government policies need to focus on improving the aforementioned important determinants to boost farmers' adaptation and thereby minimize vulnerability.

Chapter 8

Summary, Conclusion and Policy Recommendations

8.1 Introduction

This last chapter summarizes the main findings of the study undertaken. In pertinent to this, the broad implications and policy recommendations of the study have also been summarized. Climate change is one of the major environmental challenges confronting the world, possibly influencing food production, livelihood, water supplies, forest biodiversity, natural and socio-ecological systems. Agriculture is a complex system that is strongly linked to the climate through the direct impacts of rainfall, temperature and topography of the region. In the context of changing climate, evaluating the effect of climate change on agricultural yields and vulnerability of farming communities and understanding the farmer's adaptive measures to deal with climate change is important in semi-arid areas like Telangana state of India. Therefore, based on the literature review and reported research gaps, this research proceeded to study the following specific research objectives:

- (i) to analyse the trends of rainfall and temperature in Telangana,
- (ii) to evaluate the effects of climatic factors on major crop yields and their yield variability in Telangana over the period 1956-2015,
- (iii) to assess the farm households' vulnerability to changing climate in the study area and
- (iv) to examine adaptation strategies of the sample farmers and determinants of adaptation measures in the study area.

After presenting its introduction (in chapter 1), existing literature review (in chapter 2) and sample design, data and profile of study area (in chapter 3), the present study commenced with four principal objectives. All these objectives were analyzed in chapter 4, 5, 6 and 7, respectively, on the basis of both secondary and primary data. The first objective of the study is to examine trends of rainfall and temperature in Telangana and the study district has been addressed in Chapter 4. The actual data on rainfall and temperature at the state level and district level for the period of 1901 to 2015 has been collected from various

institutional sources. The non-parametric tests, specifically Mann-Kendall (MK) and Sen's slope tests, were utilized to examine the trends of climate variables. The analysis was based on monthly, seasonal and annual rainfall and minimum and maximum temperatures.

Chapter 5 examined the second core objective of this study, that is, to evaluate the impact of climate variables such as rainfall and temperature on primary crop yields and yield variabilities in Telangana using district-level panel data (1956-2015). The secondary information on climate variables and other agricultural variables is collected from several institutional sources. To fulfill this objective, we have employed the Just and Pope production function and estimated this production function using the three-step feasible generalised least squares (FGLS) technique. A fisher-type panel unit root test and pair-wise correlation test were also conducted before estimating the production function.

In Chapter 6, we have analysed the farm households' vulnerability to climate change and extreme climate events in the sample villages of Telangana using survey data. Using structured questionnaires, we have collected primary data of 304 farm households in two villages of Telangana, such as Pattipaka village (irrigated ecosystem) in Dharmaram mandal of Karimnagar district and Ippatur village (rainfed ecosystem) in Nawabpet mandal of Mahabubnagar. The data on indicators of major components such as exposure, sensitivity and adaptive capability were collected accordingly to construct a vulnerability index. An indicator-based approach has been utilized to develop a composite vulnerability index to rank the study villages according to their vulnerability scores.

Chapter 7 addressed the last objective of the study, that is, to analyse the farmer's adaptation measures and determinants of adaptation practices in the sample villages of Telangana. Moreover, farmer's perceptions on different climate parameters and barriers to effective adaptation were also reported in chapter 7. To fulfill these goals, we have collected a sample of 304 farm household's information in two villages of Telangana, such as Pattipaka village in Dharmaram mandal of Karimnagar district and Ippatur village in Nawabpet mandal of Mahabubnagar. Perceptions, adaptation strategies and constraints to adaptation were analysed using percentages and frequencies. In order to examine the determining factors of adaptation measures, we have employed the "binary logistic" model. Lastly, chapter 8 provided the conclusions and policy implications of the study.

8.2 Summary of the findings

8.2.1 Analysis of rainfall and temperature trends in Telangana

The present section briefly outlines the major findings of chapter 4.

- i) The empirical results reveal that the annual rainfall has been increasing in Telangana during the study period (1901-2015). However, it is not statistically significant. In the same way, the seasonal rainfall of the state also demonstrated an insignificant increasing trend except during the winter season. The monthly rainfall trend analysis of Telangana exhibited that only August month rainfall has increased significantly over the study period.
- ii) From the district-level analysis of annual rainfall trends, we found out a significant rising trend in Nizamabad, Khammam, Warangal and Mahabubnagar districts. On the other hand, the remaining districts were exhibited an insignificant increasing rainfall trend during 1901-2015 (115 years).
- iii) Moreover, the annual mean temperature of Telangana presents a statistically significant (at 1 % level) rising trend from 1901 to 2015. In the same way, the monthly mean temperature of the state also evidenced a significant rising trend.
- iv) The district-level analysis of annual temperature (consist of mean, minimum and maximum temperatures) shows a significant (at 1 % level) increasing trend for the study period. Therefore, temperature (mean, minimum and maximum) levels in Telangana have been increasing significantly.
- v) In this chapter we also explored the trends of rainfall and temperature in study districts of Telangana, such as Karimnagar and Mahabubnagar during 1901-2015. The empirical results reveal that the annual rainfall has been increasing in the Karimnagar district during the study period, while it is not statistically significant. However, the empirical results evidence that the annual rainfall of Mahabubnagar has been increasing significantly.
- vi) Likewise, the seasonal rainfall of the Karimnagar also demonstrated an insignificant increasing trend except during the summer season. However, the seasonal rainfall of the Mahabubnagar district revealed an insignificant increasing trend except during the summer season.

- vii) The monthly rainfall trend analysis of Karimnagar district exhibited that September month rainfall has decreased significantly during the study period. The monthly rainfall trend analysis of the Mahabubnagar district presented that February and September month's rainfall has decreased significantly.
- viii) The annual mean temperature of Karimnagar and Mahabubnagar districts presented a statistically significant rising trend during 1901-2015. Similarly, the monthly mean temperature of the study districts was also demonstrated a significant increasing trend over the study period.
- ix) Lastly, the annual minimum and maximum temperatures of Karimnagar and Mahabubnagar districts are evidenced by a significant increasing trend during 1901-2015. Therefore, temperature (mean, minimum and maximum) levels in selected districts have been increasing substantially.

8.2.2 Impact of climate change on crop yields and yield variability in Telangana

The present section briefly provides the major findings of chapter 5.

- i) In this chapter, we found that maximum temperature has a statistically significant adverse effect on rice, cotton and groundnut yields whereas favourable effect on jowar and maize yields in Telangana during 1956-2015.
- ii) On the other hand, the minimum temperature has a statistically significant adverse effect on jowar yield while advantageous effect on rice, maize, cotton and groundnut in the state during study period.
- iii) Rainfall has a statistically significant adverse effect on cotton and groundnut yield whereas positive impact on rice, maize and jowar yields. Further, we also have found that the crop area has a significantly positive effect on all crop yields under study. Agro-climatic zone variables have mixed results, positive on the rice, maize and cotton but adverse effect on jowar and groundnut yields.
- iv) The time trend (proxy for technological change) has a statistically significant adverse effect on jowar and groundnut yields whereas beneficial influence on rice, maize and cotton in the state during study period.

- v) We have also estimated the impact of climatic factors on yield variability of five primary crops. The empirical findings have revealed that the climatic factors have significant influences on the variability of major crop yields in Telangana. Maximum temperature is a risk-reducing factor for all the study crops except maize. On the other hand, minimum temperature is a risk-enhancing factor for rice, jowar and cotton crops.
- vi) The impact of rainfall on yield variance is negative for jowar and cotton and positive for rice, maize and groundnut. This implies that rainfall is risk-reducing factor for jowar and cotton while risk-enhancing factor for rice, maize and groundnut. Time trend variable is a risk-enhancing factor for all crops.
- vii) The empirical results from the estimated econometric models have shown that the effects of the rainfall, minimum temperature and maximum temperature on major crop yields vary across different crops. However, the empirical findings have revealed that climatic factors such as rainfall and temperature have adverse effects on crop productivity in general.

8.2.3 Farm household's vulnerability to changing climate in the study area

The present section briefly outlines the major findings of chapter 6.

- i) The vulnerability ranking analysis of two villages in our study districts reveals that Ippatur village of Mahabubnagar district is the more vulnerable than the other village, i.e., Pattipaka in the overall index score.
- ii) The chapter 6 results have also revealed some interesting features of vulnerability at the community level. For example, of the two sample villages, the village with greater adaptive capability seems to be more exposed to the impacts of changing climate. As per results, Ippatur village is more exposed to changing climate and it also has a higher adaptive capability since farm households are taking various adaptation strategies to cope with it. This finding supports the results of Gbetibouo and Ringler (2009) and Panda (2017) that the communities more vulnerable to climate risks often have the greater adaptive capacity to respond to it.

- iii) Another important finding is that the village which is more vulnerable to climate change is often more interested in taking multiple adaptation actions. In this study, Ippatur village is more vulnerable than Pattipaka village and it also has a higher adaptive capability since farm households are taking various adaptation strategies to cope with it.
- iv) Further, this study results evidenced that the village considered to be more susceptible to sensitivity to climate change does not necessarily correspond to more vulnerable communities. In our study, Pattipaka village's sample farmers are more sensitive to changing climate but it also a less vulnerable village.
- v) Based on the results, we make a statement that the farm households having higher exposure to climate risks are adopting more adaptation measures and ranks in higher adaptive capacity than the farm households having a higher sensitivity to climatic risks.
- vi) The more vulnerable village of Ippatur is characterized by less irrigation and water conservation, more migrants in the household, less crop diversification, high perceived impact of droughts.

8.2.4 Farm household's adaptation to climate change in the study area

The present section briefly presents the major findings of chapter 7. The aim of the chapter 7 was to analyse farm-households' awareness on changing climate, adaptation strategies and their determining factors and constraints faced by farmers in taking adaptation measures in the study region using survey data.

- i) More than 90 percent of the study region farmers reported that climate is changing over the last 30 years or more. Similarly, farmers' awareness and perceptions about changes in rainfall and temperature parameters demonstrated that a significant portion of farmers perceived that rainfall is decreasing and temperatures are increasing, including the number of hot days.
- ii) The study area farmers reported that the most commonly practiced adaptation strategies are: early maturing varieties, adjusting sowing/planting dates, enhancing irrigation facilities, use fertilizers and pesticides, using a different

variety of crop seeds, multiple/mixed crops or intercropping, engaging in non-farm activities, migration, crop insurance and livestock.

- iii) The study area farmers reported that the least practiced adaptation strategies are: water management practices, keeping more livestock and reducing land under cultivation.
- iv) Furthermore, the empirical outcomes of the logit regression evidenced that level of education, household size, gender, yearly income, landholding size and perceptions on climatic variables are the significant factors driving the probability of adaptations to changing climate and extreme climatic events.
- v) The reported major constraints to adaptation in the study region are lack of information on climate, a lack of irrigation facilities, a lack of government support, a lack of information on adaptation.

8.3 Policy implications and suggestions

The findings have several policy implications in the context of dealing with climate risks and vulnerability of rural households and the policies for the overall agricultural development of the state. The main suggestions and policy implications of the study can be made as follows:

1. An increase in minimum and maximum temperatures and changes in rainfall pattern may engender more drought probability in coming years. Hence, there should be more policy orientation towards a better irrigation system.
2. Since climate variables are beyond the control of farm households and changes in climate variables affect crop yields, there must be proper adaptation policies for both the short run and long run. The study outcomes will help policymakers to devise adaptive responses to minimize adverse effects. The government must support the development of new varieties of crop seeds that are stress-tolerant (including heat, cold and drought) for sustainable agricultural growth. This stress-tolerant variety of crop seeds should be made easily available to the farmers. Another measure is to implement crop insurance policy as an adaptation practice to diminish the possible monetary losses to the crop growers.

3. Rainfed ecosystem farm households are relatively more vulnerable to climate change impacts, the role of the state should be to focus mainly on developing irrigation facilities and water conservation measures and encouraging farmers to diversify their crops and income. Broadly, policy measures are essential to minimize farm household's exposure and sensitivity and improve the adaptive capability.
4. As per the empirical results of the logistic models, gender, level of education, family size, level of income, landholding size and perception of changes in climatic variables (rainfall, temperature and droughts) have a substantial favourable impact on various adaptation practices to minimize the impact of climate change. Hence, this study suggests that government policies need to focus on improving the aforementioned important determinants to boost farmers' adaptation and thereby minimize vulnerability. For instance, improving farmers' education and providing inputs at subsidiary prices can be considered essential policy options.
5. Monetary resources play a significant role while taking decision to adaptation. Credit availability is found to be one of the major constraints affecting farmers' decisions to adapt. So, policies should be oriented towards ease access to credit by the needy one.
6. Access to climate (weather) information can be helpful in making adaptive strategies to minimize the negative impacts of climate change. Our study results found that more than half of the farm households in the study region are not accessing accurate weather information. Therefore, policymakers must focus on the rapid dissemination of weather forecasts to farm households.

8.4 Limitations and directions for future research

The present research work delved deeply into the issues of climate-related impacts on crop yields, farm households' vulnerability and adaptation to climate change in Telangana. However, this study suffers from some limitations. First, the unavailability of secondary on agricultural production inputs such as irrigation, fertilizers, labour, etc., at district level is one of the major limitations of the present study. Generally, crop yields are influenced by several climatic and non-climatic variables. However, due to data unavailability on non-

climatic factors, this study estimated the production function of major crop yields by using only climate variables namely rainfall, minimum and maximum temperatures.

The second major limitation is the data coverage and time period. In fact, farm households's vulnerability and adaptation behavior of farmers is dynamic one that needs to be studied over a period of time and space. But, analyzing these issues at a particular point of time doesn't help to understand them properly. We have collected data from two different regions belonging to different ecosystems, an irrigated region from Karimnagar district and a rainfed region from Mahabubnagar district. However, the survey data are collected at a particular point of time, which might not be appropriate to study agricultural and agrarian transformations. We could have focused the study on generating a panel data set of observing the same household for a minimum three years' period or more.

Third, we have used the cross-sectional data to study the specific factors influencing the production decision, adaptation decision, and regarding the evaluation of vulnerability level of sample farmers to climate change. But problem with cross-sectional data is immense. It leads to the problem of heteroscedasticity problem with endogeneity problem. Thus the empirical results we get are subject to criticisms. Lastly, the sampling size is insufficient to reflect the whole population adequately. 'We interviewed 304 farmers, 152 sample farm households from the irrigated village of Karimnagar district, and 152 sample farm households from the rainfed village of Mahabubnagar district'. Hence, taking a sample of 304 farmers in total is not enough to study farmers' vulnerability and adaptation behavior of an agricultural economy of a particular state. Thus, it is a limitation of the study.

This research work opens up avenues for future research on issues of agricultural risks and climate change vulnerability on several lines. Since actual data of climatic variables are considered to assess the climatic impact on crop yields, this study suggests to explore future climate change and its effects on crop yields. The fieldwork done in both irrigated and rainfed region of 304 households suggests a panel data analysis of observing the same farm household in different time periods. This could give us an exact history of vulnerability scenario of the farm households. Furthermore, in vulnerability assessment, we spotlight only on the concept of "social vulnerability" while we did not consider alternative perspectives of vulnerability such as "livelihood vulnerability" and VEP analysis. Further

understanding of the cost of adaptation and the impact of adaptation measures on crop yields are also important issues that can be considered for future research works.

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Some important websites:

<https://www.indiawaterportal.org/>
<https://www.ecostat.telangana.gov.in/telangana/Home>
<https://imdhyderabad.gov.in/>
<https://www.tropmet.res.in/>

Appendix 3.A: Field Survey Form

“Assessment of Impact, Vulnerability and Farm Households’ Adaptation to Climate Change: A Study of Telangana”

By Mr. Guntukula Raju
(PhD Scholar, School of Economics, University of Hyderabad)

Name of the village:
Mandal:
District:

Date:
Time:

1. Socio-Economic and Demographic Information

1.1 Name of the respondent

1.2 Caste/category: SC/ST/BC/General_____

1.3 Does this Household belong to BPL category? Yes ☐ No ☐

1.4 Demographic details of family members

Name	Relation to Head	Age in Years	Gender	Level of education	Primary Occupation	Secondary Occupation	Farming experience

2. Housing Amenities

Is this house owned or rented?	Owned Rented
Type of dwelling unit?	Pucca/ Kuchha/ Semi-puchaa
What type of roofing material does your house have? (Tick correct one)	Concrete or cement, bricks, mud, iron sheet, asbestos, thatch/straw (Thati akulu or Gaddi), tile, Other (Specify...)
Does your household have electricity?	Yes/No
How many hours per day you are getting electricity?	
Does your household have tap water?	Yes/No
Does this household have its own, private source of drinking water?	Yes/No
What is the household's primary source of drinking water? (Tick correct one)	Open dugwell, tube well, handpump, tank, river, canal/ stream, lake/pond, Other....
Do you treat drinking water?	Yes/ No
Does your house have own, private toilet or latrine?	Yes/ No
Do you have grain storage space in your home?	Yes/ No

3. Sources of family income

Income sources	Primary (in 1000s Rs)	Secondary (in 1000s Rs)
1. Agriculture		
2. Wage Labour		
3. Livestock		
4. Petty business		
5. Govt. Employment		
6. Private sector Emp.		
7. Self employed		
8. Artisans		
9. Others		

4. Household Assets

4.1. Whether the household owns any of the following items

	Yes/No	If yes, how	Purchase Value (Rs)	Purchase Year	Remarks, if any
Car and Jeep					
Bicycle					
Motorcycle					
Bullock Cart					
Fodder cutting machine					
Tractor					
Open well/Tube well					
Water Pump					
Spray machine or pump					
Irrigation pipes					
Others					

5. Land Holdings

5.1 Current value of land owned (Approx.) Rs.....

a. Land cultivated (acre/gunta)

b. Land put non-agricultural use.....

c. Total land holding (a+b).....

6. Details about the land plots

Plot No	Plot Name	Area (Gunta/Acre)	Land Position*	Land Quality**	Lease Status***	Main Source of Irrigation
1						
2						
3						

Note: * Land position = Upper/Medium/Lower Land. ** Land quality = Alluvial/Sandy/Loamy/Mix.

*** Lease status = OW-owned, LI- Leased in and LO-Leased out.

6.1 Kharif Season Cultivation Details

	Crops				Fertilizers (kg)	Pesticides	Irrigation	Labour days
Plot No	Crop	Area (Acre)	Output (qntl.)	Yield (kg/a)	KGs per Acre (NPK)	Gram per Acre	Source	No. man days
1	2	3	4	5	6	7	8	9

Note: * Seed type = HYV or Traditional (TRV)

6.2 Rabi Season Cultivation Details

	Crops				Fertilizers (kg)	Pesticides	Irrigation	Labour days
Plot No	Crop	Area (Acre)	Output (qntl.)	Yield (kg per acre)	KGs per Acre (NPK)	Gram per Acre	Source	No of man days
1	2	3	4	5	6	7	8	9

7. Water and Irrigation for different climate conditions

Water use pattern	Good rainy year sources		Dry year sources	
	Primary	Secondary	Primary	Secondary
1. Drinking/Domestic				
2. Livestock				
3. Agriculture				
4. Other uses				

8. Livestock Assets

3.1 Does your household own any livestock? If yes, how many?

Live stock	How many	Grazing Space Stalled/Open		Monthly Income from Livestock
Poultry				
Cows				
Goats				
Sheeps				
Bullocks				
Buffaloes				
Pigs				
Others				

9. Borrowing savings and Lending

Does anyone in this household have any debts, such as loans from banks, money lenders and friends?		1. Yes		2. No	
		3. Will not say		4. Does not know	
How many outstanding loans does this household have?					
How many different entities does this household borrow money?					
Purpose of loan	Sources of loan	Amount	Interest	Remarks	
1. Purchase land 2. For marriage 3. House construction 4. To buy agricultural inputs 5. Animal Husbandry 6. To repay loan for education 7. Medical expenditure 8. To purchase durables 9. Business 10. To meet basic household needs 11. Any other(Specify..)	1. Family members 2. Friends or neighbor 3. SHG or other saving group 4. Shopkeeper 5. Moneylender 6. Commercial Bank 7. Cooperative banks 8. Others				
Have you started repaying the loan?		Yes/No			
Are you regularly paying back the loan?		Yes/No			
Does anyone in this household have a bank account or savings account/ pose office savings (excluding SHGs)		Yes / no/ will not answer			
What is the total value of all such accounts?		Rs..... Will not answer/ does			
Does anyone in the house have savings account in SHGs?		Yes/ no/will not answer/ does not know			
How many such accounts are there in the household?					
What is the total value of all such accounts?		Will not answer/ does not know			
What was your total savings last year?		Rs.....			

10. Migration

How many member	How many times in last year	How long	Type of work	Reasons for migration	Remittances per year
	1. Once 2. Twice 3. Thrice 4. Whole		1. Agricultural labor 2. Unskilled non-agriculture 3. Skilled non-agriculture 4. Service 5. Business 6. Will not stay 7. Does not know	1. Loss of wage labor 2. Loss of agriculture 3. Compensate household income 4. Food insecurity 5. Drought	

11. Perception Regarding Climate Change

Do you feel that climate/weather in your area is changing over the last thirty years in your area? Yes/No	Yes/No/ Doesn't know/ Can't answer
Have you noticed any long-term changes in the mean temperature over the last 30 years? (please explain)	Yes/No If yes 1. Increased 2. Decreased 3. Constant
What have you noticed about number of hot days over the last 30 years? (Explain)	1. Constant 2. Increased 3. Declined
Have you noticed any long-term changes in the mean rainfall over the last 30 years? (please explain)	Yes/No/Does not know If yes 1. Increased 2. Decreased 3. Constant
What have you noticed about number of rainfall days over the last 30 years?	1. Constant 2. Increased 3. Declined
Do you think the frequency of drought has increased in your area over the last 30 years?	Yes/No/Does not know
Do you think the frequency of floods have increased in your area over the last thirty years?	Yes/No/Does not know
Do you think the intensity of rainfall have increased in your area over the last thirty years?	Yes/No/Does not know
What do you think about the number of pests affecting your primary crop over the last 30 years?	1. Increased 2. Decreased 3. Constant
Do you think the timing of raining has changed over the last 30 years? (Please explain)	Yes/No/Does not know
What do you think about the length of the growing season in recent years?	Increased/Decreased

Do you think there have been any changes in the timing of monsoon rainfall (June-Sep) over the last 30 years? (Explain)	Yes No Doesn't Know	1.Coming early 2. Coming late
Do you think there have been any changes in the timing of post-monsoon (Oct-Dec) over the last 30 years?(Explain)	Yes No Doesn't Know	1.Coming early 2. Coming late
Do you think there have been any changes in the timing of pre-monsoon (Jan-May) over the last 30 years? (Explain)	Yes No Doesn't Know	1.Coming early 2. Coming late

12. Impact of Drought

What are the important climate risks you are facing? Rank in order of importance 1. Drought, 2. Less rainfall, 3. Flood, 4. Heatwaves, 5. Intense rainfall.6. Water scarcity	1. 2. 3. 4. others (applied)
How many drought episodes have you experienced in the last 10 years?	
How large do you feel is the impact of droughts on you and your family?	High/Medium/Low/No impact
Were any of your crops destroyed / affected by last droughts?	Yes/no
What are the crops destroyed / affected by droughts?	1. 3. 2. 4.
Monetary value of crops damaged (Rs. 1000)	
Cropped area destroyed? (acre)	Rice, Cotton, Others (specify)
What is the expected loss of Income from foregoing the sale of crops in the market because of droughts?	Rs
Has there been any loss of daily agricultural wage labor due to drought conditions in drought years?	Yes/No/Does not know
Loss of person days (for entire household) due to drought.	Male/Female/Children
Did you get any financial support from state/gram panchayat during drought years?	Yes/No/Others (specify)
From where did you receive the financial assistance?	1. Commercial banks 2. SHGs 3. Cooperative society 4. Money lenders
How did u cope with the burden of drought?	1. Sold Livestock 2. Sold household assets 3. Take additional loans 4. Sold lands 5. Migration 6. Any other(specify.....)
Additional spending during drought conditions? 1. On food (Rs) 2. On medicine (Rs) 3. Water for irrigation (Rs) 4. Deepening existing wells (Rs) 5. Livestock feed(Rs) 6. Installing new tube wells/pump set (Rs) 7. Seed (Rs) 8. Others (Rs)	1. 2. 3. 4. 5. 6. 7. 8.

13. Drought and Insurance

Are you aware of the crop Insurance scheme (NIAS) in your area to cover drought losses?	Yes/No/ does not know
Do you have crop insurance?	Yes/No (if no then)
Why don't you have crop insurance?	1. Not important 2. Too expensive 3. Don't know about the schemes 4. Complicated process 5. Others(specify.....)
Did you receive any compensation from crop insurance in the last drought year?	Yes/No
How much payment you received from crop insurance?	-----
How much time did it take to receive the compensation (months)?	
Has crop insurance changed your cropping patterns?	Yes/No/ Doesn't Know
Does it reduce the risks of drought?	Yes/No/ Doesn't Know
Should crop insurance be mandatory?	Yes/No/ Doesn't Know
Would you prefer cash after a drought or delivery of food?	Cash Food Both cash and food Others Doesn't know
12. Preferences for spending compensation after drought? According to priority	Highest to lowest
1. Food consumption 2. Medicine 3. Agriculture (provision for next season) 4. Hiring of pumps 5. Livestock purchase 6. Other please specify	1. 2. 3. 4. 5. 6.
Do you think the premium you pay is fair?	Yes/No/Doesn't Know
If yes how do you manage to pay the premiums?	Sell assets Take Loans Default Reduce consumption Use savings Others (specify)
Should the premium be subsidized?	Yes/No/Doesn't Know

14. Adaptation in agriculture

Do you think the present crop varieties are suitable to the weather in your area?	Yes/ No
Are you using different varieties of crops to face the changing rainfall pattern in agriculture? (If yes please explain)	Yes/No
Are you using early maturing varieties of crops to deal with less rainfall in your area?	Yes/No
Were you using any early maturing varieties of crops which are not available now?	1. 2.
Do you think the HYV seeds you are using are suitable for your local climate?	Yes/No
Have you ever changed your crops according to the changing climatic conditions like less rainfall and high temperature? (If yes please explain)	Yes/No
Do you plant different types of crops to cope with the changing climate in recent years? (If yes please explain)	Yes/No
Do you think the planting dates of the crops you are cultivating have changed in recent years? Please explain	Rice Yes/No Wheat Yes/No Maize Yes/No Pulses Yes/No Ragi Yes/No Others (specify)
Have you increased the number of livestock in your home rather than agriculture to cope with the climate variability?	Yes No Doesn't know
Have you changed the quantity of land under cultivation due to changing climate in your area?	Yes No Doesn't Know
Have you increased the non-farming activities rather than farming activities due to change in the climate in your area?	Yes No Doesn't Know
Are you using more irrigation water or increased use of ground water to cope with the water stress due to erratic rainfall?	Yes No Doesn't Know
Are you using less water to deal with the impacts of climate change in recent years?	Yes No Doesn't Know

Are you using water conservation practices these days to deal with less rainfall in your area? Please explain?	Yes/No
Are you using more chemicals and fertilizers to cope with decreased water availability and erratic rainfall in your farming?	Yes No Doesn't Know
Are you doing multiple cropping to deal with the pest problems in agriculture?	Yes No Doesn't Know
Are you adjusting the timing of irrigation these years to deal with less rainfall in your area? Please explain	Yes No Doesn't Know
During the last large drought year, did you change your farming practice? If yes, How?	Yes No Doesn't Know
During the last flood year, did you change your farming practice? If yes, How?	Yes No Doesn't Know

15. Climate Information

Do you think the traditional prediction system about the climate is going wrong in these years?	Yes No Doesn't Know
Do you get any information about the climate or about droughts and floods or rainfall?	Yes No
What are the sources of climate information?	1. Radio/TV/ Mobiles 2. Government officials 3. Community leaders 4. Friends and relatives
Are you using the information about the climate/weather in your farming activities?	Yes No
How do you use it can you explain?	
Have you ever used prediction about rainfall provided by the government to change your farming?	Yes No
Do you think better weather information will help you to adjust with erratic rainfall in your area?	Yes No Can't say

16. What coping strategies are you willing to adopt as future adaptation measures for less rainfall?

Drought Resistant Crop Varieties	Yes/ No
Crop diversification	Yes/ No
Livestock diversification	Yes/ No
Early mature crop Varieties	Yes/ No
High Yielding varieties	Yes/ No
Irrigated crops	Yes/ No
Labor migration	Yes/ No
Selling assets	Yes/ No
Water use changes	Yes/ No
Water storage method	Yes/ No
Food storage	Yes/ No
Assistance from relatives	Yes/ No
Assistance from government	Yes/ No
Assistance from NGOs	Yes/ No

17. Can you please tell why didn't you take these actions? (Check with above answers)

Why did you not	Reasons (Why)
Change crop variety	
Build a water harvesting scheme	
Implement soil conservation technique	
Buy crop/ weather insurance	
Irrigate more	
Change from crop to livestock	
Migrate to urban area	
Find off farm jobs	
Lease your land	

Key: 1: lack of money, 2: lack of information, 3: shortage of labor, 4: Other

18. What are the barriers to adaptation to climate variability?

Barriers	Answer	Explanation
Lack of Information about weather	Yes/No	
Lack of Information on climate change	Yes/No	
Lack of Information on adaptation	Yes/ No	
Lack of credit or savings	Yes/ No	
Lack of irrigation facilities	Yes/ No	
Lack of access to water	Yes/ No	
Lack of seeds on time	Yes/ No	
Adaptation not cost effective	Yes/ No	
Insecure property rights	Yes/ No	
Lack of markets	Yes/ No	
Lack of Government support	Yes/ No	
Others	Yes/ No	
No barriers to adaptation	Yes/ No	

19. Any other relevant information, if any.

Climate Change Effects on the Crop Yield and Its Variability in Telangana, India

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journals.sagepub.com/home/mic**Raju Guntukula¹ and Phanindra Goyari¹****Abstract**

This study has examined the effects of climatic factors on mean yields and yield variability of four primary crops (rice, cotton, jowar and groundnut) in Telangana state by applying the Just and Pope production function over a period of 1956–2015. Using the three-stage feasible generalised least squares estimation procedure, we have estimated the production function of four crops. The empirical results have revealed that the effects of changes in climatic factors vary among crops under study. Maximum temperature has a significant adverse effect on rice, cotton and groundnut yields. Minimum temperature has a substantial positive effect on rice, cotton and groundnut. Further, rainfall is adversely related to cotton and groundnut yields. Maximum temperature has appeared as a risk-reducing factor for all study crops while minimum temperature as a risk-enhancing factor for rice, cotton and jowar. Lastly, rainfall has been found as a risk-enhancing factor for rice and groundnut whereas it is a risk-reducing factor for jowar and cotton. Results from the study have important implications on how Telangana's farming sector will adapt to climate variability and change for sustainable agricultural development.

Keywords

Climate change, crop yields, variability, panel data, Telangana, India

JEL Codes: C23, Q18, Q51, Q54

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Introduction

Climate change due to natural and anthropogenic activities is considered to be one of the serious environmental issues in the world (Stern, 2006). Pieces of evidence of the changes in rainfall, temperature and extreme climatic events have been established on a more systematic as well as scientific basis (IPCC, 2007; 2014). Extreme climatic events, namely, floods, cyclones, droughts, heat waves and climate change harm global socio-economic, biophysical and ecological systems (IPCC, 2014). More specifically the agricultural sector is considered to be more vulnerable to climate change (Hasan et al., 2016). Since climatic factors such as rainfall and temperature serve as important direct inputs to the crop sector, any change and variability in these variables are inevitable to have a significant effect on crop yields (Barnwal & Kotani, 2013). There is also a generous concern about projected future changes in climatic factors due to rapidly increasing concentrations of greenhouse gases (Aggarwal, 2003) and expected changes in these climate variables would have a direct or indirect impact on food production (Krupa, 2003). Therefore, this area has captured the extensive attention of policy makers and researchers (see Mall et al., 2006; Lobell et al., 2011). Such attention can be more in the less developed countries like India where agricultural production is largely affected by the climatic factors (Kumar & Parikh, 2001).

What makes the problem so worrying in India is that it has inadequate arable land but greater dependence of the population on agriculture sector (Mendelsohn et al., 2006) and also have the less adaptive capacity and technological progress to cope with climate change (BIRTHAL et al., 2014). Similarly, effects of climatic variables are anticipated to be severe for Indian agriculture sector because it has large rain-fed area with only about 48 per cent of the cultivated area under assured water supply (Government of India, 2013). Uncertain rainfall and the shortage of irrigation facilities in India are believed to be contributing predominantly to lower crop yields (Pal & Mitra, 2018).

Therefore, agriculture as well as food production systems in India are highly vulnerable to climate change owing to their higher sensitivity to climate change (Dubey & Sharma, 2018). In India, temperature has been elevated by 0.3 to 0.8 °C per decade during the last few decades (Goswami et al., 2006). The projected climate changes up to 2100 for India show an overall upsurge in air temperature by 2 to 4 °C combined with a rise in rainfall particularly in the rainy season (Kumar, 2009). Similarly, the rainfall is projected to increase by 6 to 14 per cent at the end of the century (2080) with a high intensity and frequency of precipitation (Chaturvedi et al., 2012). Further, Lobell et al. (2012) revealed that the productivity of wheat crop is extremely sensitive to below 34 °C temperature in northern India.

The IPCC (2007) report found that 0.5 °C elevation in winter-time, minimum temperature is expected to decrease the productivity of wheat in India by 0.45 tons/ha (Easterling et al., 2007). Future climate change could reduce yields in the short-run (2010–2039) by 4–9 per cent and in the long-run (2070–2099) due to lack of adaptation by about 25 per cent (Guiteras, 2009). Interestingly, the projected agriculture output loss by 2100 lies between 10–40 per cent in India

(Aggarwal, 2008). However, these studies established the fact that climate-related factors have significant effects on crop productivity. While the effects of climate change at the state or local level shows identical results with respect to all-India patterns, there are considerable regional differences as well (Saseendran et al., 2000). However, despite its great significance, only a small number of studies has been carried out to evaluate the effects of climatic factors on agricultural output and yield, particularly from the perspectives of developing nations and agriculturally backward regions (Barnwal & Kotani, 2013; Guiteras, 2009). Hence, we aim to evaluate the impact of climate change on crop yields with the focus on India's Telangana state, whose agricultural system is largely dependent on seasonal rainfall. According to few studies (like Padakandla, 2016), Telangana has been one of the region's most vulnerable state's to climate change and environmental hazards.

Climate Change and Agriculture in Telangana

Situated on the southern India, Telangana state is located between latitudes 17° 7' and 23.4624," N and longitudes 79° 12' and 31.7664" E. It is India's 12th largest state in terms of both populations (3.52 crores) and geographical area (11,208 lakh hectares) (Government of Telangana, 2016). The study area includes nine undivided districts¹ of Telangana and these districts mainly depend on agriculture. The yearly mean maximum temperature of the state is 42 °C, whereas the mean minimum temperature is about 22–23 °C. Nearly two-thirds of the annual precipitation comes from the south-west monsoon. The northern part of state receives 900–1500 mm annual rainfall, while the southern part of state receives 700–900 mm annual rainfall (Government of Telangana, 2016). It is important to note that more than 50 per cent of the overall cultivated area in Telangana is found to be under the rain-fed agricultural system. This makes the agriculture sector of the state as a rainfall dependent.

As stated above, Telangana state faces various challenges of less rainfall, low ground water levels and drought conditions all of which are directly related to the agricultural output, food security and farmer's livelihood. Given the location of Telangana in the arid and semi-arid climate, agricultural productivity is extremely vulnerable to climate change and drought (Bhavani et al., 2017). Moreover, rural livelihood sector in the state is further exposed to the climatic changes and therefore, it is seen to be at a greater risk than few other Indian states (Revadekar et al., 2012). In the year 2008, World Bank (2008) report confirmed that the adverse impact of climatic change can lead to a substantial reduction in the agricultural income in Telangana region of combined Andhra Pradesh. In recent times, Telangana state has also witnessed high intensive and incidence of droughts and austere farmer suicides (Parida et al., 2018; Tada, 2004).

¹ In the year 2016, Telangana government divided the former 10 districts into 31 new districts. However, this study is based on former 10 districts.

In this background, a well-organised and scientific research of climatic effects on crop production in Telangana state is important for various reasons. This study aims to examine the impact of climate change on mean yield as well as yield variances in major crops (rice, cotton, jowar and groundnut) in three agro-climatic zones of Telangana using district-level panel data during the period of 1956–2015. To the best of our information, this study is the first to empirically examine the climatic impacts on crop yields in Telangana by unequivocally considering likely heterogeneity with respect to crop yield variability (risk) and geographical zones.

The rest of the article is organised as follows. The second section presents a review of the literature. Data sources and methodology are illustrated in the third section. The fourth section provides discussion and analysis of empirical results of climatic effects on major crop yields in Telangana. In the last section, we have presented the conclusion and some policy implications of the study.

A Brief Review on Climate Change and Crop Yields

Over the past two decades, various studies have investigated the effects of climatic factors on crop productivity in various countries of the world. Generally, these studies have estimated the impact of climate change using either (a) crop simulations (agronomic models) or (b) the Ricardian methodology or econometric models. Crop simulation models are based on well-organised scientific experiments where plants are grown in a laboratory or are in the field. Then, simulation experiments are done in different environmental and climate conditions and CO₂ impacts (Saseendran et al., 2000). Crop simulations have the ability to project the possible climatic effects on agricultural production and yield (Sarker et al., 2014).

Some studies that have used the agronomic models to evaluate the effects of climate factors on crop yield include Mearns et al. (1997), Rosenzweig et al. (2002), Saseendran et al. (2000) and Mall and Aggarwal (2002). Mall et al. (2006) have presented an extensive review of crop simulation investigations. Many agronomic modeling studies have revealed the potential adverse consequences of climate change. However, some authors (such as Mendelsohn & Dinar, 1999) have pointed out that agronomic models do not take into account the farmer's adaptation measures and these models can underestimate the positive impacts and overestimate the adverse effects due to climate change.

On the other hand, the Ricardian methodology evaluates the impact of climatic factors on land values or net revenues using the cross-sectional statistics (Mendelsohn et al., 1994; Mendelsohn and Dinar, 1999). Several studies by utilizing Ricardian approach demonstrated that the changes in precipitation and temperature have an adverse effect on land revenue or income. Kumar and Parikh (1998) found that the rice yields decreased by 15–25 per cent and wheat yields by 30–35 percent in India. Further, the net farm income in India decreased by 8 per cent (Mendelsohn et al., 1994). Kumar and Parikh (2001) reported that the anticipated 2 °C upsurge in temperature and 7 per cent upturn in rainfall can diminish farm returns by 9 per cent. Similarly, Sanghi and Mendelsohn (2008) reported that

net revenue of agriculture in India could drop by 4–26 per cent. However, the main limitation of this method is the failure to account for time-independent location-specific factors, namely, the intangible abilities of farmers and soil quality (Barnwal & Kotani, 2013). Also this approach may not be useful for developing nations because of the inefficient land markets.

Furthermore, recent investigations tend to employ panel data methods (Deschenes & Greenstone, 2007). The major studies such as Guiteras (2009), Krishnamurthy (2012), Gupta et al. (2014) and Padakandla (2016) have used the panel data methods and found significant association between climate factors and crops yields. However, these studies have been unable to measure the effects of climate change on yield variance or risk, though the yield variance was found to be affected by climatic factors in several studies (Cabas et al., 2010; Chen et al., 2004; Isik & Devadoss, 2006; Kim & Pang, 2009; Sarker et al., 2014; Sarker et al., 2019).

Existing studies have shown mixed results on the relations of climate change and crop output. We have presented the summary of main findings of few recent empirical studies on climate and crop output nexus in Table 1. Almost all studies have reported that climate change to affect or going to affect adversely the crop output and yield.

Table 1. Summary of empirical investigations on climate change and agricultural yield nexus

Author(s)	Country	Time period	Methodology	Major findings
Deschênes and Greenstone (2007)	USA	1970–2000	Panel approach	Climate factors have a neutral or probably positive effect on crop yields due to farmers adaptation.
Schlenker and Roberts (2008)	USA	1950–2005	Panel approach	Crop yields (corn, cotton and soybeans) are increased slightly up to 29–30 °C temperature and then decreased severely due to higher warming.
Lobell et al. (2011)	Major nations	1980–2008	Panel approach	The global maize and wheat production declined by 3.8 and 5.5 percent, respectively, due to changes in weather.

(Table 1 continued)

(Table 1 continued)

Author(s)	Country	Time period	Methodology	Major findings
McCarl et al. (2008)	USA	1960–2007	Fixed Effects Model	Average crop yields are affected by the mean rainfall and temperature. Higher changes in weather conditions tend to reduce the crop yields.
Mendelsohn et al. (1994)	USA	1982	Ricardian approach	The adverse impact of weather is estimated to lie between 4–6 percent of the value of farm output.
Isik and Devadoss (2006)	Idaho, USA	1939–2001	Panel approach	Rainfall and temperature have a significant adverse effect on wheat, barley, potatoes and sugar beets. Yield variability of wheat and barley is reducing due to climatic factors.
Chen et al. (2004)	USA	1970–2000	Panel approach	Rainfall has positive impact on sorghum and corn yields. Higher temperatures decrease the sorghum yields and its yield variability.
Sarker et al. (2012)	Bangladesh	1972–2009	Time series	Temperature has a significant adverse effect on rice crops (Aus Aman and Boro) but rainfall has a positive impact on three rice crops.
Sarker et al. (2014)	Bangladesh	1972–2009	Panel approach	Temperature is risk-increasing for Aman Aus and Boro rice. Rainfall is risk-increasing for Aman whereas risk-decreasing for Boro and Aus rice.

(Table 1 continued)

(Table 1 continued)

Author(s)	Country	Time period	Methodology	Major findings
Poudel and Kotani (2013)	Nepal	1990–2005	Panel approach	The rice and wheat yields are negatively related with the variation of climate and crop yields more sensitive in low altitude regions of Nepal.
Cabas et al. (2010)	Ontario, Canada	1981–2006	Panel approach	An increase in the variance of rainfall and temperature decrease mean yields and increase yield variability. Yield variability is poorly determined by both seasonal and monthly climate variables.
Kim and Pang (2009)	Korea	1977–2008	Panel approach	The average rice yield is positively associated to temperature and adversely related with rainfall. Both rainfall and temperature variables are risk-increasing factors.
Chen and Chang (2005)	Taiwan	1977–1996	Panel approach	The changes in weather conditions contribute substantially to major crop yield uncertainties. Crop insurance stabilizes revenues of farmers.
Guiteras (2009)	India	1960–1999	Panel approach	The projected weather conditions for the period 2010–2039 shrinks crop yields by 4.5–9 in short-run and 25 percent in long-run (2070–2099).

(Table 1 continued)

(Table 1 continued)

Author(s)	Country	Time period	Methodology	Major findings
Birthal et al. (2014)	India	1969–2005	Fixed Effects Model	Rice, wheat, pigeonpea and chickpea are more susceptible to rise in temperature. However, rainfall has positive impact on major crop yields.
Krishnamurthy (2012)	India	1970–2000	Quantile regression	The study found that a significant drop in wheat output (up to 11%) and moderate reductions in rice output (up to 3%) in India.
Gupta et al. (2014)	India	1966–1999	PCSE	Paddy yield is sensitive to the climatic factors such as rainfall and temperature. However, millets are less affected by climate factors.
Pattanayak and Kumar (2014)	India	1969–2007	Fixed Effects Model	The study found that both day time and night time temperatures unfavourably affect rice yield during different growth stages.
Barnwal and Kotani (2013)	Andhra Pradesh, India	1971–2004	Quantile regression	The kharif rice is more sensitive to temperature and rainfall, while the rabi rice stays mostly resilient to changes in the climate factors.
Saravanakumar (2015)	Tamil Nadu, India	1971–2009	PCSE	The study found a quadratic (inverted U shaped) relationship between (climatic factors and crop yield rice and sorghum).

(Table 1 continued)

(Table 1 continued)

Author(s)	Country	Time period	Methodology	Major findings
Padakandla (2016)	Andhra Pradesh, India	1981–2010	PCSE	Rice, tobacco and jowar yields are adversely impacted by temperature. Cotton and tobacco crop yields are more sensitive to rainfall variability.

Source: Authors' own compilations from available secondary data.

Against this background, the present study examines the effect of climate change on major crop yields and variance in Telangana. We have employed and estimated the Just and Pope production function. This function allows capturing climatic effects on the mean yields and variance (Sarker et al., 2019).

Data and Methodology

Data Sources for District Level Panel Data

This study has used district level panel data (also known as cross-sectional time-series data) for four primary crops, namely, rice, jowar (sorghum), cotton and groundnut from nine former (undivided Andhra Pradesh) districts in Telangana covering the period of 1956–2015. Data on the crop yields and crop-wise area under cultivation of the four principal crops in the state were collected from various issues of Statistical Abstracts of Andhra Pradesh and Statistical Year Books of Telangana, available at Directorate of Economics and Statistics, Government of Telangana. Crop yield is measured in kilograms per hectare {kg/ha} and the crop-wise area is measured in hectare.

We have also collected data of climatic variables from various sources. Statistics of annual and seasonal rainfall for the state and districts were collected from Meteorological Centre Hyderabad and Department of Economics and Statistics, Hyderabad. The mean annual, maximum and minimum temperature data were collected from indiawaterportal.org but the data were available up to the year of 2002 only at the time of collection. Temperature data since 2002 were collected from various issues of 'Statistical abstracts of Andhra Pradesh'. The panel data on rainfall were for maximum and minimum temperatures on a monthly basis. All the study variables are converted into natural logarithms (Guntukula, 2018). The summary statistics of the study variables are reported in Table 2.

Table 2. Summary Statistics of Study Variables in Telangana

Variables	Observations	Unit	Mean	Std. Dev.	Minimum	Maximum
Rice	540	(kg/ha)	1948.56	772.14	308	4004
MaxT	540	°C)	32.68	0.68	30.98	35.96
MinT	540	°C)	21.18	0.84	18.55	25.08
Rainfall	540	(mm)	815.22	232.42	221.82	1773.88
Area	540	(hectare)	128410.4	68320.5	24283	417912
Jowar	540	(kg/ha)	654.1481	271.7066	187	1885
MaxT	540	°C)	31.59216	.7670315	29.676	35.811
MinT	540	°C)	20.67293	.9283984	18.167	25.389
Rainfall	540	(mm)	790.6719	228.2241	220.376	1771.704
Area	540	(hectare)	111741.3	88149.83	8	401385
Cotton	540	(kg/ha)	674.13	105.798	40	1380
MaxT	540	°C)	32.06	0.7189	30.31	35.79
MinT	540	°C)	20.80	0.8859	18.07	25.61
Rainfall	540	(mm)	800.76	231.0588	220.40	1771.70
Area	540	(hectare)	50351.80	74089.78	12	370363
Groundnut	540	(kg/ha)	987.6037	454.2299	175	2838
MaxT	540	°C)	31.59216	.7670315	29.676	35.811
MinT	540	°C)	20.67293	.9283984	18.167	25.389
Rainfall	540	(mm)	790.6719	228.2241	220.376	1771.704
Area	540	(hectare)	32398.74	40202.96	554	208802

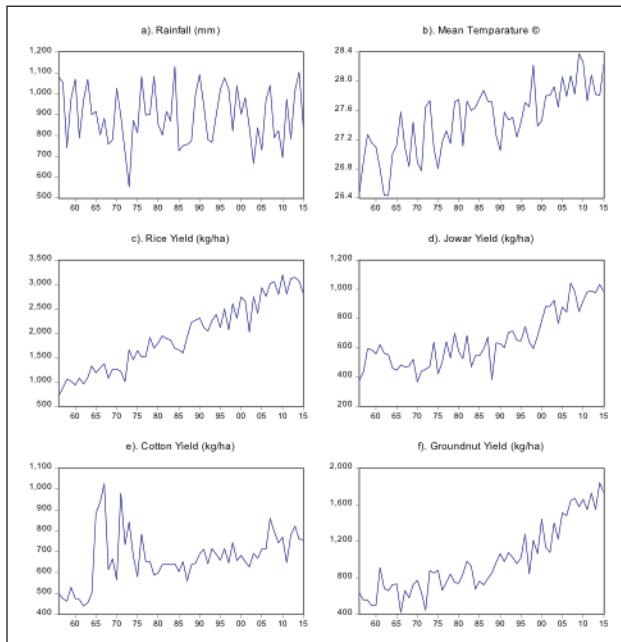
Source: Authors' own calculations.

Table 3. Agro-climatic (A-C) Zones of Telangana and Their Characteristics

A-Czones	Districts	Total Area	Annual Rainfall	Soil type	Majorcrops
Northern Zone	Karimnagar, Adilabad, Nizamabad	35.5 (lakh ha)	Normal rainfall 900-1150 (mm)	Red earths with loamy soils (Chalkas) and Black Cotton soils	Rice, Maize, Cotton, Jowar, Groundnut, Redgram, Soybean
Central Zone	Warangal, Medak, Khammam	30.6 (lakh ha)	Normal rainfall 800-1150 (mm)	Red earths with loamy soils (Chalkas), Black Cotton soils and Red sandy soils	Rice, Cotton, Maize, Groundnut, Greengram, Jowar, Chilli
Southern Zone	Nalgonda, Mahabubnagar, Ranga Reddy	39.3 (lakh ha)	Normal rainfall 500-670 (mm)	Red soils, Chalkas	Cotton, Rice, Redgram, Maize, Groundnut, Jowar, Greengram

Source: Compiled from the Drought Manual, Telangana, 2016.

The study has incorporated undivided 9 districts of Telangana in which agricultural sector is dominant. These districts are Adilabad, Karimnagar, Nizamabad, Warangal, Khammam, Medak, Nalgonda, Rangareddy and Mahabubnagar. Hyderabad district area has been excluded from this investigation because it has insignificant crop cultivation area. According to the directorate of economics and statistics (DES) of Telangana, the state has been categorised into three agro-climatic (AC) zones. Table 3 shows information about three agro-climatic zones along with the districts in respective zone, climatic conditions, soil types, major crops and percentage share of the agro-climate zones in overall geographical area of state. To examine the impact of climate change on yields and yield variance, we have selected four major food and non-food crops, namely, rice, jowar, cotton and groundnut. The main reason behind selecting these crops is that they are principal crops together account to about 60 per cent of the overall gross cropped area in Telangana. So, the impact of climatic factors on these crop yields can have significant implications on food security, income generation and livelihood of the farm households in the state. Secondly, consistent and comparable time-series crop-wise data are not available for other crops at the district-level. Trends of the climatic factors such as rainfall and mean temperature, along with trends of the yields of study crops during the study period are presented in Figure 1 (a to f). It can be seen that the rainfall has more fluctuations among the study variables. The mean temperature has shown an increasing trend over the period. The crop yields also demonstrated an increasing trend in productivity over the period. These trends are more prominent for rice, jowar and groundnut compared to cotton yield.

Figure 1. Climate Variables and Crop Yield trends in Telangana 1956–2015

Source: Authors' own compilations from available secondary data.

Methodology

Model Specification

As already stated, we have applied and estimated the production function developed by Just and Pope (1978). Literature review shows that significant portion of empirical studies has utilised either a crop simulation or a cross-sectional model. The crop simulation model using ‘general circulation models’ is found to perform inadequately (Schlenker & Roberts, 2008). Moreover, the extensive use of ‘Ricardian approach’ is not capable to capture the impact of omitted variables on crop output which produces biased results (Deschenes & Greenstone, 2007). In order to overcome this omitted variable issue, the production function developed by Just and Pope (1978) has been successfully utilised by many studies (e.g., Chen et al., 2004; Isik & Devadoss, 2006; Kim & Pang 2009; Poudel et al., 2014; Sarker et al., 2019).

In the present study, in order to evaluate the impacts of climatic factors on the mean level of the yield and variability of the crop yields, the stochastic production function approach introduced and elaborated by Just and Pope (1978; 1979) is employed. The basic concept underpinning this method is that a stochastic production function can be decomposed into two parts: the first section is related to the mean level of productivity whereas the second section is linked with the vari-

ability of that productivity (Cabas et al., 2010; Kim & Pang, 2009; Sarker et al., 2014). The general formula of the Just and Pope production function (Just & Pope, 1978) is as follows:

$$y = f(X) + h(X)\epsilon$$

where y is the crop yield and X is the vector of explanatory variables. ϵ is the random error with mean zero and variance (σ^2). The parameter assessment of $f(X)$ produces the mean impact of the independent variables on the crop yield whereas $h(X)$ provides their influence on the variability of the crop yield (Chen & Chang, 2005). Based on Chen et al. (2004) and Sarker et al. (2014) the production function of following form is assessed as follows:

$$y = f(x) + u = f(X, \beta) + h(X, \alpha)\epsilon$$

where y is crop yield (rice, jowar, cotton and groundnut), X is the vector of explanatory variables (e.g., maximum and minimum temperatures, rainfall, area, time period and location) and ϵ is the exogenous output shock with $E(\epsilon) = 0$ and $Var(\epsilon) = \delta_\epsilon^2$. Using this function, independent variables affect both the average and variability of crop yield because $E(y) = f(x)$ and $Var(y) = Var(u) = h(\cdot)$. The factor assessment of $f(\cdot)$ provides the average impacts of the independent variables on yield, whereas $h(\cdot)$ gives the effects of the covariates on the variability of crop yield (Isik & Devadoss, 2006). It is very important to note that the positive sign on any factor of $h(\cdot)$ infers an increase in that variable, that is, an upsurge of the variability of the crop yield. A negative sign on the variability function implies a reduction of the yield variability demonstrating that climatic variables are risk decreasing inputs.

Generally, three functional forms of production functions are used to estimate Just and Pope production function—Cobb–Douglas, quadratic and translog production functions (Chen et al., 2004; Kim & Pang 2009; Sarker et al., 2014). Due to the multiplicative interaction between the variance and mean, the translog functional form can violate the Just and Pope assumptions (Tveteras & Wan, 2000). Therefore, purposively, the linear Cobb–Douglas form has been used for the mean and variability of the crop yield function. This functional form is consistent with the Just and Pope (1979) assumptions as argued by Kim and Pang (2009).

Estimation Method

All the parameters in the Equation (2) can be estimated by employing the maximum likelihood estimation (MLE) method suggested by Saha et al. (1997) or three-step feasible generalised least squares (FGLS) method proposed by Just and Pope (1979). Most of the empirical studies have employed the FGLS estimation procedure but MLE is more consistent and efficient estimator than FLGS particularly under a small sample situation (Saha et al., 1997). Since we have a large sample size, this study has used the three-step FGLS estimation procedure as explained in Judge et al. (1985). Moreover, panel data model estimation is generally comprised of both cross-section and time series data and can solve the problems of auto-correlation and heteroscedasticity (Gujrati 2004; Hill et al., 2008). However, these two problems are addressed in a better way using the FGLS procedure as it assumes that panels are not auto-correlated and homoscedastic

(Wooldridge, 2002). Generally, the fixed effects (FE) and random effects (RE) models are designed to estimate the panel data model (Baltagi, 2005). This study selected fixed effects model based on Hausman test results and this preference of fixed effects model is consistent with few existing studies (Barnwal & Kotani, 2010; Cabas et al., 2010; Guntukula & Goyari, 2020; Kim & Pang, 2009; Sarker et al., 2014).

Formulation of Econometric Model

As mentioned earlier, the major disadvantage of the ‘Ricardian approach’ lies in its lack of ability to include omitted variables such as soil quality and unobservable skills of the crop growers which are also known as location specific and time-independent factors (Barnwal & Kotani, 2010). In order to overcome this omitted variable issue, we have incorporated agro-climatic zone dummies in the model. However, regional agro-climatic zone dummies are included only in the average yield function but not to the yield variance function. This is based on the assumption that different agro-climate zones have different average yields with almost similar yield variabilities across zones (Sarker et al., 2014). Linear trend was incorporated to include the impact of technological change over time. We have estimated the impact of climate change on crop yields and variability by specifying three models (Model I, Model II and Model III). In model I, we have included all the explanatory variables such as rainfall, area, maximum and minimum temperatures. However, maximum and minimum temperatures are not mutually exclusive in nature. Hence, instead of taking both maximum and minimum temperatures in one model, we have framed the model II and model III independently using minimum and maximum temperatures separately.

Model I: The econometric specification of mean yield function $f(X, \beta)$ is expressed as follows:

$$Y_{it} = \beta_0 + \beta_1 MxT_{it} + \beta_2 MnT_{it} + \beta_3 Rf_{it} + \beta_4 A_{it} + \beta_5 T_{it} + \sum_{l=1}^{L-1} \alpha_l D_l + e_{it} \quad (3)$$

where Y_{it} is the crop yields (kg/ha) for production district i and time t ; MxT_{it} , MnT_{it} , Rf_{it} and A_{it} are the maximum temperature, minimum temperature, rainfall and area under crop, respectively; $\alpha_l D_l$ ($l = 1, 2, \dots$) are agro-climatic zonal dummies taking values 1 and 0. T (year) is time trend variable to capture impacts of developments in technology. Further, the yield variability function $h(X, \alpha)$ is given as follows:

$$\ln e_{it}^2 = \alpha_0 + \alpha_1 MxT_{it} + \alpha_2 MnT_{it} + \alpha_3 Rf_{it} + \alpha_4 A_{it} + \alpha_5 T_{it} + \mu_{it} \quad (4)$$

where $\ln e_{it}^2$ log of squared residuals from first step ordinary least squares (OLS) is a dependent variable and explanatory variables are maximum and minimum temperatures, rainfall, area and trend. Further, α 's are the parameter estimates and other independent variables are as defined in Equation (3). The estimation of the model II incorporates all the study variables excluding minimum temperature. On the contrary, Model III incorporates all the study variables excluding maximum temperature.

Panel Unit Root Test

To avoid possible spurious regressions, it is essential to perform panel unit root test for stationarity for each study variable before estimating the model (Chen & Chang, 2005; Poudel & Kotani, 2013). Moreover, the pre-condition of Just and Pope production function is that the study variables in the model must be stationary (Chen et al., 2004). There are several types of tests for this purpose. Some of these include tests developed by Levin, Lin and Chu (LLC) (2002), Im et al. (2003), Breitung (2001) and Fisher-type test of Maddala and Wu (1999). In this study, we have employed Fisher-type test using Augmented Dicky-Fuller (ADF) test because this test gives more accurate results (Baltagi, 2005).

Fisher-type panel unit root test: Maddala and Wu (1999) and then Choi (2001) offered the Fisher-type unit root test, which pools the p-values from individual unit root tests. If π_i is well-defined as the p-value from any individual test for cross-section section i , under the null of unit root test, then, for all N cross-sections, the asymptotic results are written as follows:

$$-2 \sum_{i=1}^N \ln(\pi_i) \rightarrow \chi^2_{2N} \quad (5)$$

The main advantage of the Fisher-type test is that it can be employed for various lag lengths in the individual ADF-regressions (Baltagi, 2005). Moreover, this test, using ADF-regressions with bootstrap-based values, makes the best and as a result is the most preferred method for testing the existence of non-stationary in the panel data (Maddala & Wu, 1999). The null and alternative hypotheses for the ADF test are: (a) Null hypothesis (H_0): Entire panels contain unit roots and (b) Alternative hypothesis (H_a): At least one panel is stationary.

Results and Discussions

Pair-wise Correlation and Panel Unit Root Test Results

The pair-wise correlations among the study variables are reported in Table 4. Results are mixed. The rice yield is positively and significantly correlated with maximum temperature, minimum temperature and rainfall. Moreover, jowar yield is positively correlated with rainfall, minimum and maximum temperatures but minimum temperature and rainfall variables are not statistically significant at 5 per cent level. Cotton yield is positively and significantly correlated with minimum temperature only. Cotton yield is also positively correlated with maximum temperature but statistically insignificant at 5 per cent level. The cotton yield is also negatively correlated with rainfall. Lastly, groundnut yield is positively correlated with maximum temperature, minimum temperature and rainfall and correlation coefficients are statistically significant at 5 per cent level.

Table 4. Pair-wise Correlation Matrix of Study Variables in Telangana

	Rice yield	Max. Temp.	Min. Temp.	Rainfall	Area
Rice yield	1.0000				
Max. Temp.	0.4040*	1.0000			
Min. Temp.	0.1967*	0.6293*	1.0000		
Rainfall	0.1563*	-0.1454*	0.0146	1.0000	
Area	-0.2110*	0.1321*	0.1981*	-0.3245*	1.0000
Jowar yield		Max. Temp.	Min. Temp.	Rainfall	Area
Jowar yield	1.0000				
Max. Temp.	0.2528*	1.0000			
Min. Temp.	0.0239	0.6293*	1.0000		
Rainfall	0.0644	-0.1454*	0.0146	1.0000	
Area	-0.4530*	-0.2133*	-0.1327*	-0.1583*	1.0000
Cotton yield		Max. Temp.	Min. Temp.	Rainfall	Area
Cotton yield	1.0000				
Max. Temp.	0.0446	1.0000			
Min. Temp.	0.1685*	0.6001*	1.0000		
Rainfall	-0.0625	-0.1281*	0.0264	1.0000	
Area	-0.0682	0.5118*	0.2358*	0.1460*	1.0000
Groundnut yield		Max. Temp.	Min. Temp.	Rainfall	Area
Groundnut yield	1.0000				
Max. Temp.	0.4040*	1.0000			
Min. Temp.	0.1967*	0.6293*	1.0000		
Rainfall	0.1563*	-0.1454*	0.0146	1.0000	
Area	-0.2110*	0.1321*	0.1981*	-0.3245*	1.0000

Source: Authors' own calculations.

Note: * indicates the statistical significance at 5% level.

Table 5. Fisher Type Panel Unit Root Test Results of Climate Variables in Telangana

Crops	Variables	Fisher test (ADF) Test statistics	
		Without Trend	With Trend
Rice	Yield	53.49 ***	272.60 ***
	Maximum Temperature	133.97 ***	239.45 ***
	Minimum Temperature	144.88 ***	206.93 ***
	Rainfall	503.53 ***	466.61 ***
	Area	161.03 ***	217.33 ***
Jowar	Yield	129.58 ***	231.45 ***
	Maximum Temperature	142.33 ***	236.99 ***
	Minimum Temperature	157.22 ***	206.28 ***
	Rainfall	512.48 ***	477.05 ***
	Area	134.23 ***	184.94 ***
Cotton	Yield	52.66 ***	38.15 ***
	Maximum Temperature	139.66 ***	245.90 ***
	Minimum Temperature	151.62 ***	212.89 ***
	Rainfall	510.14 ***	473.10 ***
	Area	35.99 ***	35.91 ***
Groundnut	Yield	65.04 ***	253.61 ***
	Maximum Temperature	142.33 ***	236.99 ***
	Minimum Temperature	157.22 ***	206.28 ***
	Rainfall	512.48 ***	477.05 ***
	Area	161.81 ***	174.59 ***

Source: Authors' estimations.

Note: *** $p < 0.01$.

Prior to estimating the Just and Pope production function, Fisher-type (ADF) panel unit root test is applied to check the stationarity properties of study variables. The panel unit root test results are presented in Table 5. The test statistics of the ADF regression for the crop yields (rice, cotton, jowar and groundnut) and climatic variables (temperature and rainfall) are found to be identical in both models with trend and without trend. The panel unit root test results indicate that all study variables are statically significant and the null hypothesis of unit roots is rejected at the 1 per cent level of significance. This infers that the study variables are stationary at the level or $I(0)$.

The panel unit root test results are consistent with other studies such as Kim and Pang (2009), Sarker et al. (2019) and Sarker et al. (2014). Therefore, Just and Pope production function using the three-step FGLS estimation procedure can be applied to district-level panel data without any differencing.

Table 6. Estimated Results for Rice in Telangana

Rice	Model I			Model II			Model III		
Mean yield function $f(x)$	Coefficient	p-value	Coefficient	Coefficient	p-value	Coefficient	Coefficient	p-value	p-value
Trend	0.016***	0.000	0.093***	0.093***	0.000	0.097***	0.097***	0.000	0.000
Maximum Temperature	-1.907***	0.003	-1.502***	-1.502***	0.003				
Minimum Temperature	0.589*	0.072				0.039	0.039	0.881	0.881
Rainfall	0.540***	0.000	0.552***	0.552***	0.000	0.595***	0.595***	0.000	0.000
Area	1.008***	0.000	1.005***	1.005***	0.000	1.076***	1.076***	0.000	0.000
Northern AC Zone	20.742***	0.000	21.210***	21.210***	0.000	16.561***	16.561***	0.000	0.000
Central AC Zone	20.695***	0.000	21.166***	21.166***	0.000	16.527***	16.527***	0.000	0.000
Southern AC Zone	20.804***	0.000	21.274***	21.274***	0.000	16.634***	16.634***	0.000	0.000
Constant	3.548***	0.000	0.811***	0.811***	0.000	-3.827***	-3.827***	0.000	0.000
Yield variability function $h(x)$									
Trend	0.005***	0.000	0.005***	0.005***	0.000	0.005***	0.005***	0.000	0.000
Maximum Temperature	-0.050***	0.000	-0.027***	-0.027***	0.001				
Minimum Temperature	0.038***	0.000				0.023***	0.023***	0.000	0.000
Rainfall	0.028***	0.000	0.029***	0.029***	0.000	0.029***	0.029***	0.000	0.000
Area	0.061***	0.000	0.061***	0.061***	0.000	0.061***	0.061***	0.000	0.000
Constant	3.010***	0.000	3.049***	3.049***	0.000	2.878***	2.878***	0.000	0.000
Model summary									
Log likelihood	1212.641		1212.557	1212.557		1210.81	1210.81		
Wald Chi-square	749489.67		755748.94	755748.94		729741.91	729741.91		
Prob > Chi-square	0.0000		0.0000	0.0000		0.0000	0.0000		

Source: Authors' own estimations.

Note: *** $p < 0.01$ and * $p < 0.10$.

Crop-wise Estimation Results

The present section deals with crop-wise empirical results and discussions. The effect of climate related variables on crop yields in Telangana has been examined under the panel data approach with 540 observations and 9 panel groups (i.e., annual data for 60 years during 1956–2015 for 9 districts). The estimations of the mean yield and variability functions have been done using the three-step feasible generalised least squares (FGLS) estimation procedure.

1. **Estimated Results for Rice:** The estimated results for rice are shown in Table 6. The estimated coefficients of explanatory variables for three rice models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. In the mean yield function of rice, all the study variables, including agro-climatic zone dummies, are significantly influencing rice yield over the study period. Rainfall has a significant influence on average rice yield in Telangana as per results in three models. This infers that the rice cultivation in Telangana largely depends on rainfall. However, the maximum temperature is adversely associated with the rice yield in model I and model II and it is statistically significant at 1 per cent level of significance. This indicates that the growing maximum temperature may reduce the rice yield in Telangana. Moreover, minimum temperature has a significant positive impact on rice yield in model I and model III. The positive effect of minimum temperature may not be able to counterbalance the adverse effect of maximum temperature as observed in coefficient values. Our results are almost similar to other studies such as Padakandla (2016) and Pattanayak and Kumar (2014). An increase in area under rice has a positive and significant effect on yield in three rice models. The time-trend variable is positively associated with the mean yield in three models. This infers that technological progress has a positive effect on rice yield over time. Lastly, three agro-climatic zone variables have significant and positive influences on rice yield in three models. However, the magnitude of influence varies in three rice models. Similar empirical results were obtained in studies of other regions such as Poudel and Kotani (2013) and Sarker et al. (2014).

The results of yield variability function for rice crop are also reported in Table 6. It can be observed that climatic factors, including area under rice and trend variable, are statistically significant at 1 per cent level in the rice variability function. The maximum temperature has an adverse impact on the yield variance of rice. This indicates that maximum temperature is a risk-reducing factor for rice yield variability in two models. The other climatic factors such as rainfall and minimum temperature are positively influencing the yield variability of rice. This implies that the rainfall and minimum temperature are risk-enhancing factors in rice yield variance function. Similarly, an increase in cultivation area under rice crop has a positive effect on yield variability of rice in three models. This suggests that increased area under rice is a risk-enhancing factor. Interestingly, the time trend has a significant favourable effect on rice yield variance. This can be interpreted in such a way that rice yield variability possibly may be increasing over time due to technological advancements such as new HYVs seeds, irrigation and better use of fertilizers.

Table 7. Estimated Results for Jowar in Telangana

Jowar			Model I		Model II		Model III	
Mean yield function $f(x)$			Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Trend			-0.302***	0.000	-0.335***	0.000	-0.289***	0.000
Maximum Temperature			5.939***	0.000	0.336	0.645		
Minimum Temperature			-7.203***	0.000			-4.693***	0.000
Rainfall			0.241***	0.000	0.189***	0.001	0.122**	0.024
Area			0.304***	0.000	0.328***	0.000	0.267***	0.000
Northern AC Zone			-153.344***	0.000	-171.125***	0.000	-133.457***	0.000
Central AC Zone			-153.399***	0.000	-171.208***	0.000	-133.509***	0.000
Southern AC Zone			-153.583***	0.000	-171.386***	0.000	-133.690***	0.000
Constant			25.840***	0.000	28.408***	0.000	24.874***	0.000
Yield variability function $h(x)$								
Trend			0.003***	0.000	0.003***	0.000	0.003***	0.000
Maximum Temperature			-0.076***	0.000	-0.019***	0.000		
Minimum Temperature			0.078***	0.000			0.048***	0.000
Rainfall			-0.002***	0.000	-0.002***	0.000	-0.001***	0.000
Area			-0.003***	0.000	-0.003***	0.000	-0.002***	0.000
Constant			3.671***	0.000	3.704***	0.000	3.484***	0.000
Model summary								
Log likelihood			868.6839		869.2676		867.954	
Wald Chi-square			1.76e+06		1.72e+06		1.70e+06	
Prob > Chi-square			0.0000		0.0000		0.0000	

Source: Authors' own estimations.

Note: *** p < 0.01 and ** p < 0.05.

2. **Estimated Results for Jowar (Sorghum):** The estimated results for jowar are provided in Table 7. Estimated coefficients of all explanatory variables for three jowar models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. The explanatory variables such as rainfall, maximum and minimum temperatures, area and agro-climatic zone dummies are statistically significant in three jowar models. However, maximum temperature in model II is not statistically significant in jowar mean yield function. Rainfall has a significant positive effect on mean yields in three jowar models. Jowar is a rain-fed crop in Telangana and due to this reason, possibly the effect of rainfall is favourable. Likewise, maximum temperature has a significant positive effect on mean yields in model I. Jowar is considered to be mainly a heat resistant crop and hence we can say that the upper temperature may not affect the crop yield to a great extent. However, minimum temperature has an adverse effect on mean yield of jowar in two models. The positive impact of maximum temperature may be unable to offset the adverse effect of minimum temperature as observed from estimated coefficient values. Our findings of minimum and maximum temperature are contrary to findings by Padakandla (2016). An increase in area under jowar crop has a positive impact on jowar yield. Further, time-trend is adversely associated with the mean yield of jowar. All regional agro-climatic zone variables in three models are found to be statistically significant and have adverse effects on jowar mean yields in Telangana.

The yield variability function results of the jowar crop are also shown in Table 7. Rainfall, area, minimum and maximum temperatures are statistically significant in yield variability function. The minimum temperature has a significant and positive effect on jowar yield variability. This implies that the minimum temperature in Telangana is a risk-enhancing factor for yield variance of jowar. However, maximum temperature and rainfall have adverse impact on jowar yield variance. This indicates that the rainfall and maximum temperature are risk-reducing factors for jowar yield. Similarly, an increase in area under jowar crop has a significant adverse effect on yield variance of jowar. The increased cropped area is also a risk-reducing factor in Telangana. Lastly, the time-trend factor has a significant favourable effect on jowar yield variability. Therefore, we can conclude that the trend variable is a risk-enhancing factor for jowar crop. These results of mean yield and variability function results for jowar are almost similar to few studies like Boubacar (2010).

3. **Estimated Results for Cotton:** Cotton is one of the important commercial crops in Telangana and is mostly cultivated under rain-fed conditions. The empirical results of cotton crop are shown in Table 8. Estimated results of explanatory variables for three cotton models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. All the climatic variables, cotton area and agro-climatic zone variables are statistically significant in three cotton models. Rainfall has a significant adverse effect on mean cotton yield in Telangana. As mentioned

earlier, cotton is a rain-fed crop, an increase in rainfall may tend to decrease the cotton yield. Likewise, maximum temperature is adversely related to mean yield of cotton. The positive impact of minimum temperature on cotton yield may be unable offset the adverse effect of maximum temperature as reflected in estimated results. Present results of minimum and maximum temperature in mean yield function of cotton are contrary to some studies such as Padakandla (2016) and Guntukula (2020). The empirical outcomes of climatic factors in mean yield function of cotton are similar with Kumar et al. (2015). The trend factor is positively related to cotton yield. This implies that the technological progress in Telangana has a positive effect on cotton yield. All the regional agro-climatic zone variables such as southern, central and northern zones are significant and these agro-climatic zones have the favourable effect on mean cotton yield.

The estimated coefficients of yield variability function for the cotton crop are given in Table 8. The mean minimum temperature has a substantial favourable effect on the yield variance of cotton. In other words, the minimum temperature is a risk-enhancing factor for cotton in Telangana. However, maximum temperature has a significant negative effect on the yield variance of cotton. This implies that the maximum temperature is a risk-reducing factor for cotton. Similarly, rainfall has a substantial adverse effect on the yield variance of cotton. We can say that the rainfall is a risk-reducing factor for cotton yield variance. Further, area under cotton is positively related to yield variability of cotton in three models. This indicates that the area is a risk-enhancing factor for cotton. Furthermore, trend is positively related to yield variability of cotton in the model I and model II, but it is negatively related to the yield variance of cotton. This implies that the technological progress in Telangana is a risk-enhancing factor for cotton in Telangana. The yield variability findings of our study are, to some extent, similar to few studies like Kumar et al. (2015). We find some interesting results for cotton crop. Variables such as rainfall and maximum temperature, which have an adverse impact on mean cotton yield, are the risk-reducing factors for cotton yield variance. Variables like minimum temperature, which have a positive effect on mean cotton yield, are risk-enhancing factors for cotton yield variance.

4. **Estimated Results for Groundnut:** The estimated results of groundnut crop are reported in Table 9. The estimated coefficients of explanatory variables for three groundnut crop models are collectively statistically significant since the aggregate Wald Chi-square statistic has a p-value of 0.000. All the study variables, including agro-climatic zone dummy variables are significantly influencing groundnut yields over the study period in the mean yield function. However, the mean maximum temperature is not statistically significant in model I.

Table 8. Estimated Results for Cotton in Telangana

Cotton	Model I			Model II			Model III		
Mean yield function $f(x)$	Coefficient	p-value		Coefficient	p-value		Coefficient	p-value	
Trend	0.083***	0.000		0.052*	0.084		-0.068***	0.000	
Maximum Temperature	-283.787***	0.000		-74.314*	0.086				
Minimum Temperature	128.893***	0.000					113.266***	0.000	
Rainfall	-12.362***	0.000		-5.262*	0.084		-19.025***	0.000	
Area	1.200***	0.000		0.550*	0.086		1.985***	0.000	
Northern AC Zone	780.082***	0.000		352.967*	0.085		49.955***	0.000	
Central AC Zone	780.169***	0.000		353.310*	0.085		50.123***	0.000	
Southern AC Zone	779.839***	0.000		352.883*	0.086		49.808***	0.000	
Constant	16.580***	0.000		-8.955	0.120		8.685***	0.000	
Yield variability function $h(x)$									
Trend	0.002***	0.000		0.001***	0.000		-0.001***	0.000	
Maximum Temperature	-4.827***	0.000		-2.263***	0.000				
Minimum Temperature	2.165***	0.000					0.796***	0.000	
Rainfall	-0.211***	0.000		-0.158***	0.000		-0.134***	0.000	
Area	0.023***	0.000		0.016***	0.000		0.141***	0.000	
Constant	15.159***	0.000		12.510***	0.000		2.174***	0.000	
Model summary									
Log likelihood	425.3464			387.0905			394.1517		
Wald Chi-square	362494.10			701337.54			729739.81		
Prob > Chi-square	0.0000			0.0000			0.0000		

Source: Authors' own estimations.

Note: *** p < 0.01 and ** p < 0.10.

Table 9. Estimated Results for Groundnut in Telangana

Groundnut	Model I		Model II		Model III	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Mean yield function $f(x)$						
Trend	-0.084***	0.003	-0.069**	0.022	0.027***	0.015
Maximum Temperature	-0.913	0.277	5.392**	0.026		
Minimum Temperature	8.975***	0.000			7.627***	0.004
Rainfall	-1.054***	0.005	-0.819**	0.032	-0.781**	0.027
Area	0.092***	0.001	0.111***	0.004	0.098***	0.002
Northern AC Zone	-42.956***	0.003	-35.564**	0.021	-38.326***	0.006
Central AC Zone	-42.956***	0.003	-35.527**	0.021	-38.274***	0.006
Southern AC Zone	-43.007***	0.003	-35.616**	0.021	-38.358***	0.006
Constant	1.395***	0.000	4.450***	0.003	4.160***	0.002
Yield variability function $h(x)$						
Trend	0.006***	0.000	0.005***	0.000	0.006***	0.000
Maximum Temperature	-0.062***	0.000	-0.472***	0.000		
Minimum Temperature	-0.519***	0.000			-0.583***	0.000
Rainfall	0.078***	0.000	0.073***	0.000	0.078***	0.000
Area	-0.004***	0.000	-0.006***	0.000	-0.006***	0.000
Constant	4.956***	0.000	4.860***	0.000	4.947***	0.000
Model summary						
Log likelihood	957.7352		954.6335		955.2668	
Wald Chi-square	881239.67		937163.39		793470.73	
Prob > Chi-square	0.0000		0.0000		0.0000	

Source: Authors' own estimations.

Note: *** p < 0.01 and ** p < 0.05.

Rainfall has been found to have negative effect on groundnut yield in Telangana. However, the minimum temperature is positively related to groundnut yield. Maximum temperature has an adverse effect on groundnut yield in model I, but it is not statistically significant. In model II, maximum temperature has a significant adverse effect on mean yield. In model I, the adverse effect of rainfall and maximum temperature on groundnut yield is offset by the positive effect of minimum temperature. The cropped area of groundnut has a substantial favourable effect on mean yield in three groundnut models. The time trend variable has a significant adverse effect on groundnut yield in the model I and model II. However, we found that the trend is positively related to mean yield in model III. Further, all the three agro-climatic zone variables in the mean yield function are statistically significant and related negatively to groundnut yield. The empirical findings of groundnut are almost similar to few studies like Kumar et al. (2015) and are contrary to studies like Padakandla (2016).

The yield variability function results of the groundnut crop are also reported in Table 9. Rainfall, area, minimum and maximum temperatures are significantly influencing the variability of groundnut yield in Telangana. Rainfall has a positive effect on yield variance. In other words, rainfall is a risk-enhancing factor for groundnut. However, maximum and minimum temperatures have significantly adverse effect on the yield variance of groundnut. This indicates that the maximum and minimum temperatures are risk-reducing factors for groundnut. Similarly, cropped area is negatively related to the yield variance of groundnut. This implies that the area is the risk-reducing factor for groundnut. Furthermore, trend has a significant positive effect on yield variance. This implies that technological advancement is increasing the yield variability of the crop in the state during the study period. Our results on climatic factors in yield variability function of groundnut are almost contrary to studies like Kumar et al. (2015).

Conclusions and Policy Implications

In this article, we have empirically examined the effects of climatic factors on major crop yield and its variability by applying the Just and Pope production function in Telangana over the period of 1956–2015. This study has used district level panel data on four crop yields, namely rice, jowar, cotton and groundnut and climatic variables such as rainfall, maximum temperature and minimum temperature. For empirical analysis, we have employed the three-stage feasible generalised least squares estimation technique.

The empirical results from the estimated econometric models have shown that the effects of the rainfall, minimum temperature and maximum temperature on major crop yields vary across different crops. However, the empirical findings have revealed that climatic factors such as rainfall and temperature have adverse effects on crop productivity in general. Maximum temperature has a significantly adverse effect on rice, cotton and groundnut yields whereas favourable effect on jowar yields. Given that jowar (*Sorghum*) is the stress tolerant crop, it is possible

that an increase in maximum temperature may not affect the jowar yield to a great extent. Some studies have shown an adverse influence of the upsurge in maximum temperature on rice productivity in India (Mall et al., 2006; Pattanayak & Kumar, 2014). However, the minimum temperature has a significantly adverse effect on jowar yield while advantageous effect on rice, cotton and groundnut. Rainfall has a significantly adverse effect on cotton and groundnut yield whereas positive impact on rice and jowar yields. We have found that the crop area has a significantly positive effect on all crop yields under study. In other words, an increase in area under the study crops is positively influencing crop yield. Agro-climatic zone variables have mixed results, positive on the rice and cotton but adverse effect on jowar and groundnut yields.

We have also estimated the impact of climatic factors on yield variability of four primary crops. The empirical findings have revealed that the climatic factors have significant influences on the variability of major crop yields in Telangana. Maximum temperature is a risk-reducing factor for all the study crops. However, minimum temperature is a risk-enhancing factor for rice, jowar and cotton. The impact of rainfall on yield variance is negative for jowar and cotton and positive for rice and groundnut. This implies that rainfall is risk-reducing factor for jowar and cotton while risk-enhancing factor for rice and groundnut. The results of the study have revealed that different crops are influenced differently by the climatic factors in Telangana. Therefore, results from the present study have important policy implications for developing sub-national level adaptation strategies for farm households in Telangana. Since climate variables are beyond the control of farm households and changes in climate variables affect crop yields, there must be proper adaptation policies for both short run and long run. One measure is to implement crop insurance policy as an adaptation practice to diminish the possible monetary losses to the crop growers. The government also must support the development of new varieties crop seeds which are temperature (heat or cold) tolerant for sustainable agricultural growth.

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The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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ACADEMIC PAPER

WILEY

The impact of climate change on maize yields and its variability in Telangana, India: A panel approach study

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Abstract

The present study explores the effect of climate change on maize yields and its variance in Telangana utilizing Just–Pope production function, spanning the period 1956–2015. The three-step feasible generalized least squares (FGLS) method is employed to estimate the Just and Pope production function. The empirical results of the work reveal that the average minimum temperature has a significant unfavorable effect on maize yield in Telangana. Maximum temperature and actual rainfall are positively related with maize yield; however, the maximum temperature is not statistically significant. Furthermore, rainfall and minimum temperature are risk-shrinking factors, but the maximum temperature is a risk-enhancing factor for maize yields during the study period. The study results have key implications for developing suitable local level adaptation policies in Telangana.

1 | INTRODUCTION

There is a rising concern among the policymakers and scholars of the environment on changing climate due to natural and anthropogenic activities. Because the sources and scale of climate change are arguable, the scientific evidence of alterations in rainfall, temperature, and other climatological factors is unquestionable (Barnwal & Kotani, 2013; Nath & Mandal, 2018). The changes in climatic factors will have austere implications for weather-sensitive systems, namely, socioeconomic, biophysical, and ecological systems (Li, Takahashi, Suzuki, & Kaiser, 2011). Amongst several sectors adversely impacted by climate variability, farming is assumed to be the more vulnerable sector (Sarker, Alam, & Gow, 2012). The climate variables viz. temperature and rainfall are input-factors to the crop-growing sector. A slight change in these variables is inevitable to have a substantial effect on crop output (Gupta, Sen, & Srinivasan, 2014). The unfavorable effects of climate sensitivity on agriculture are more in undeveloped nations, such as India (Kumar & Parikh, 2001). The major attention of former empirical investigations has been in advanced countries. However, sensitivity and vulnerability to extreme climatic events can be higher in developing nations, where agriculture plays a more significant role in economic development (Guiteras, 2009). A very minimal number of studies have been conducted to assess the effects of climate change on agricultural productivity in the context of developing nations particularly at the regional level. Hence, this study

examines the effect of climate related factors on maize yield in the Indian state of Telangana.

The adverse effects of climate change and extreme climatic events are more severe for India because India has inadequate arable land but greater dependence of the population on farming (Mendelsohn, Dinar, & Williams, 2006; Stern, 2006). In addition, India has limited technological progress and economic capabilities for mitigation and coping with climate change (Birthal, Khan, Negi, & Agarwal, 2014). Moreover, the effects of climatic variables are anticipated to be severe because they have largely rain-fed cultivation area (about 50%). Agricultural sector is the backbone of the Indian economy. This sector has approximately 15% share in India's gross national output, and it is providing 54% of employment to the country's workforce. There are also significant forward as well as backward links to agriculture from the remaining sectors.

The average temperature has presented a significant upsurge in warming in India up to 0.4°C by utilizing statistics from 73 climatological stations spanning the period 1901–1982 (Hingane, Kumar, & Murty, 1985). Similarly, the average yearly temperature for India presents significant warming up movement of 0.51°C covering the 1901–2007 period (Kothawale, Munot, & Kumar, 2010). Moreover, the United Nation's Intergovernmental Panel on Climate Change (IPCC) has predicted that precipitation over India will rise by 10–12% with greater frequent and extreme rainfall days. Furthermore, the

mean yearly temperature will rise by 3–6°C (IPCC, 2014). Likewise, there are also significant subnational or local level differences in past and future trends of weather factors. Therefore, these substantial changes in climate variables might culminate in unfavorable effects on farming in terms of yield loss. For instance, Aggarwal (2008) documented that expected output loss of agriculture in India will be 10–40% by 2100, even with incorporating carbon fertilization. According to the study of Aggarwal (2009), a 1°C rise in temperature would reduce yields of wheat, soybean, mustard, and groundnut by 3–7%.

1.1 | Climate change and maize production in Telangana

Telangana, the southern region of India, has been one of the region's more vulnerable subnational region to climate change and environmental hazards (IPCC, 2001; Raju and Phanindra (2018). The state is located on the Deccan Plateau, between latitudes 17° 7' and 23.4624" N and longitudes 79° 12' and 31.7664" E. The Telangana is the 12th largest state in India in terms of population (3.52 crores) and geographical area (112.08 lakh hectares) as well (SEO, 2016). The study area includes nine undivided maize cultivation districts¹ of Telangana. The yearly mean maximum temperature is 42°C, whereas the mean minimum temperature is about 22–23°C in Telangana. It is important to note that around 50% of the overall cultivated area in Telangana is found to be the rain-fed agricultural system. This makes the agriculture of the state as a rainfall-dependent.

Maize or corn (*Zea mays* L.) is also called as "Queen of Cereals" and one of the important cereal food grains of the world. It has become the staple diet in many regions of the world (Rouf Shah, Prasad, & Kumar, 2016). Similarly, this is the third most important food grain crop in the world surpassed only by two former grains, rice and wheat (Kyenpia, Namo, Gikyu, & Ifenkwe, 2009). Maize is the only cereal plant that can be cultivated in different environmental conditions because of its inordinate adaptability, and it needs a moderate climate for the crop growth (Kogbe & Adediran, 2003). However, excess or less rainfall and upper temperature can affect productivity as well as quality adversely. In Telangana, maize is the important food and cash crop as well. This crop is mainly cultivated under both the rain-fed and dry land systems, and it is grown in almost all districts of the state. The area under this crop is 6.92 lakh ha which constitute around 26.4% of the overall gross cropped area of food grains in Telangana during 2014–2015 (ASG, 2016).

The motivation to conduct the present study is based on the following arguments. The country-level assessments of climatic impact on agriculture in India presented the magnitude of loss at the aggregate or national level. However, it is imperative to understand the impacts of weather changes at the regional level. Similarly, crop-specific studies at the subnational or state level in India has received trivial attention in the existing literature. With this background, the present study explores the effect of climatic factors on maize yield and its variance in Telangana. The assessment of the climatic effect

on maize crop is imperative to understand the distribution of climatic effects at the subnational or state level (Telangana). This study results can be helpful in framing the local-level adaptation policies to cope with future climate-related risks. The present paper is subdivided into five sections. Section 1 concisely presents the introduction of the agricultural impacts of climate change. Section 2 briefly documents the empirical literature on climate change and crop yield relationships. The empirical model and data sources are analyzed in Section 3. Section 4 describes the primary findings and detailed discussion about the study results. In the last section (Section 5), we present the major conclusions and policy suggestions.

2 | REVIEW OF LITERATURE

The effects of climate change on agricultural output are primarily evaluated by utilizing two specific approaches: (a) crop simulation methods (agronomic simulations) and (b) econometric modeling including the Ricardian approach (Sarker, Alam, & Gow, 2014). Our objective here is to review the prevailing literature on climate and crop yields.

2.1 | Crop simulation studies (production function approach)

There are extensive studies that have examined the effect of climate change on agricultural productivity across the world utilizing crop simulation methods. Crop simulation approaches are based on well-organized experiments where plants are grown-up in laboratory circumstances or fields, simulating various effects of weather and carbon fertilization. Most former investigations have concentrated on advanced nations (for instance, Phillips, Lee, & Dodson, 1996; Mearns, Rosenzweig, & Goldberg, 1997; Tubiello, Rosenzweig, Goldberg, Jagtap, & Jones, 2002; Rosenzweig, Tubiello, Goldberg, Mills, & Bloomfield, 2002; Reilly et al., 2003; Jones & Thornton, 2003; Leng & Huang, 2017; Li, Guan, Schnitkey, DeLucia, & Peng, 2019). In the case of India, several studies have investigated the impact of climate variability on crop yields. Geethalakshmi et al. (2011) examined the effect of climatic variables on rice yield in Tamil Nadu. They reported that rice yields have deteriorated around 41% with a 4°C upsurge in high temperature. Hebbar et al. (2008) investigated the climate–cotton production relationship using the Infocrop model in four rain-fed and irrigated districts of India. The authors found more accurate results in irrigated districts than the dryland areas.

Similarly, Aggarwal and Mall (2002) explored the climate change influence on rice output in various regions of India using CERES-rice and ORYZA1N crop simulations. The authors found that a rise in temperature from 1°C to 2°C at present CO₂ levels can lead to a 3–17% reduction in yield in different regions of India. In India, Byjesh, Kumar, and Aggarwal (2010) analyzed the effect of climate change on maize yield in the most important crop-producing regions using the InfoCrop-MAIZE approach. They documented that the rainy season maize yield

is declined more in the Southern Plateau (about 35%), whereas the winter season output is fallen more in the Mid Indo-Gangetic Plains. However, maize yields are moderately less affected in the Upper Gangetic Plains. A systematic review of simulation models by Mall, Singh, Gupta, Srinivasan, and Rathore (2006) shows a clear deterioration in yields of principal cereal crops such as maize, wheat, and rice under weather change. Soora et al. (2013) studied the effect of climatic factors on regional rice production of the 21st Century in India. They reported that the rice yield of rainfed in India is probable to be declined 6% in the 2020s scenario. Furthermore, a phenomenal study by Kumar and Parikh (2001) analyzed the effects of weather sensitivity on rice produce using crop simulation models at four different locations namely northern, eastern, southern, and western regions of India. The authors documented that climate change by 2060 (without carbon fertilization impacts) could decrease dryland yields across different regions up to 16% to 43%. The latest study by Banerjee, Das, Mukherjee, Mukherjee, and Saikia (2016) found that projected rice yields for the Kharif season could be declining by 20% in 2025 and 28% in 2050. All the studies which utilized crop simulations reveal that crop production is extremely vulnerable to climate change. The main disadvantage of the crop simulation models is not including the farmer's adaptation to climate change (Mendelsohn & Dinar, 1999).

2.2 | Econometric and statistical studies

Another approach called "Ricardian Methodology" developed by Mendelsohn, Nordhaus, and Shaw (1994) to investigate the impact of climate change on farm output. This approach utilizes the cross-sectional statistics to quantify the effect of climatic factors on net farm-revenues farm-land values (Mendelsohn et al., 1994; Mendelsohn & Dinar, 1999). The primary advantage of this methodology is that it measures the coping behavior of farmers; therefore, we obtain more accurate results. Hence, the Ricardian approach has been utilized extensively in the vast number of countries across the world (for instance; Mendelsohn et al., 1994; Polsky & Easterling III, 2001; Chang, 2002; Deressa & Hassan, 2009; Wang et al., 2009). In the context of India, several studies have utilized the Ricardian approach (see Kavikumar & Parikh, 1998; Kumar, 2009; Kumar, 2011; Mendelsohn & Dinar, 1999; Mishra & Sahu, 2014; Sanghi & Mendelsohn, 2008). Several studies reported that the changes in climatic variables, namely, rainfall and temperature, can lessen the rice productivity by 15% to 25% and 30% to 35% of wheat output (Kavikumar & Parikh, 1998). Mishra and Sahu (2014) investigated the effects of climatic factors on agriculture in Odisha by employing the Ricardian method. They found that the climatic variables have a significant effect on farm revenue. However, rising temperature can affect agriculture negatively. Sanghi and Mendelsohn (2008) found that if warming upsurge by 2°C with a rise in rainfall, farm net revenue might decline 12% in India in the absence of carbon fertilization. Further, Palanisami, Paramasivam, Ranganathan, Aggarwal, and Senthilnathan (2009) documented an adverse influence on crop output due to changes in weather factors. The major limitation of the Ricardian approach is the inability to account for time-

independent location-specific factors, namely, the land quality and unobservable abilities of crop growers (Barnwal & Kotani, 2013).

More recently, a growing number of investigations have tended to utilize panel data approaches to evaluate the effects of climate change on crop yields. The pioneering studies in this way of research are Chen, McCarl, and Schimmelpfennig (2004), Deschênes and Greenstone (2007), Chen and Chang (2005) Isik and Devadoss (2006), and McCarl, Villavicencio, and Wu (2008). Furthermore, Guiteras (2009), Moorthy, Buermann, and Rajagopal (2012). Barnwal and Kotani (2013), Gupta et al. (2014), Pattanayak and Kumar (2014), BIRTHAL et al. (2014), Kumar, Sharma, and Ambrammal (2015), Nath and Mandal (2018), and Raju and Phanindra (2018) have utilized panel models to evaluate the impact of climatic variables on Indian agriculture. Chen et al. (2004) evaluated the impact of climate change on five major crop yields in the United States by employing Just and Pope yield function. The study found that rainfall and temperatures are risk-enhancing variables for sorghum. Likewise, climate variables are found to have an adverse influence on corn output. Chen and Chang (2005) explored the effect of climate variables on the productivity of main crops in Taiwan by utilizing panel the data approach during 1977–1996. They reported that climatic conditions contribute considerably to crop yield variance.

A systematic study by Sarker et al. (2014) examined the effects of climate factors on rice productivity in Bangladesh spanning the period 1972–2009. The authors found that climatic factors are risk-enhancing for Boro, Aus, and Aman rice output. In India, Guiteras (2009) explored the influence of climate change on agricultural productivity using district-level panel information. The study found that anticipated weather change for the period 2010–2019 decreases the productivity of primary crops by 4.5% to 9%. Barnwal and Kotani (2013) reported that mean rice yield and its variance are adversely impacted by environmental change. Further, BIRTHAL et al. (2014) measured the influence of climate change on primary food crops in India during the period 1969–2005 by utilizing the fixed effects model. They revealed that precipitation and minimum temperature have an advantageous effect on crop yield. However, the maximum temperature has a harmful influence on crop output. Krishnamurthy (2012) analyzed the effects of climatic factors on wheat and rice yields in India using district-level cross-sectional time-series data. Using the fixed effects model, the author found that Northern and Eastern regions are benefiting from warming whereas Southern states are facing more losses. More recently, Nath and Mandal (2018) reported that temperature has a favorable effect on summer, winter, and autumn rice productivity whereas precipitation has a negative impact on winter and autumn rice output in Assam (India) during 1978–2005.

3 | DATA AND METHODOLOGY

3.1 | Data sources

The present study utilizes district-level panel data on maize yields and climatic factors such as rainfall and maximum and minimum

temperatures from 1956 to 2015 for nine former districts of Telangana. Out of 10 former districts, we have selected nine districts of the state. The districts incorporated were Karimnagar, Adilabad, Nizamabad, Warangal, Medak, Khammam, Nalgonda, Mahabubnagar, and Ranga Reddy. Hyderabad district omitted because it has an insignificant agricultural area (Vakulabharanam, 2004). The data on maize yield as well as the cropped area were obtained from various volumes of Statistical Abstracts of Andhra Pradesh (AP) and Statistical Year Books of Telangana. Further, this study utilizes the rainfall, mean maximum and minimum temperatures data provided by the Meteorological Centre Hyderabad and Directorate of Economics and Statistics, Government of Telangana. Prior to the estimation of the empirical model, all variables are converted into natural logarithm (Guntukula, 2018; Raghutla, Sakthivel, Sampath, & Chittedi, 2018; Raghutla, Sampath, & Chittedi, 2018).

The maize yield data were measured in kilograms per hectare (kg/ha), and cropped area statistics measured were in hectares. Furthermore, the rainfall is measured in millimeter (mm), and the average maximum and minimum temperatures are measured in Celsius ($^{\circ}\text{C}$). Table 1 presents the description of dependent and explanatory variables. In the present study, the dependent variable is maize yield. The explanatory variables are area under maize cultivation, rainfall, maximum temperature, minimum temperature, linear trend, and agro-climatic zone (ACZ) dummies. Time trend (T) incorporated in the production function serves as a proxy factor for technological advancement during the study period in Telangana. Furthermore, to

measure for probable heterogeneity in the influence of climate change across ACZs, we incorporated ACZ dummies as well.

Table 2 presents the information about three ACZs, namely, northern zone, central zone, and southern zone of Telangana along with the districts in respective zone, their physical geography, and other statistics. The table also explains the climatic conditions, principal crops, and percentage share of the ACZs in overall geographical area of Telangana. Rice, maize, and cotton are the primary crops in the state. The northern climate zone receives the greater normal rainfall and southern climate zone receives less normal rainfall. Figure 1 presents maize yield over 1960–2015, and it shows that overall trend of maize yield has increased. Figure 2 presents the actual rainfall (annual) in Telangana spanning the period of 1960–2015. Further, Figures 3 and 4 show the trend of maximum and minimum temperatures, respectively, during 1960–2015.

3.2 | Methodology

3.2.1 | Panel unit root test

The present study employs the Just and Pope production function approach proposed by Just and Pope (1978) to investigate the impact of climatic factors, namely, rainfall and maximum and minimum temperatures on mean and variability of maize yield. The pre-condition to utilize the Just and Pope production function is that the verification of time-series properties of study variables to avoid the possible false regression (Chen & Chang, 2005; Poudel, Chen, & Huang, 2014). Several kinds of unit root tests are available in the empirical literature. Those are Levin, Lin, and Chu (2002), Im, Pesaran, and Shin (2003), Breitung (2001), and Fisher-type test in Maddala and Wu (1999). This study utilizes Fisher-type test because this test produces more accurate and reliable results also achieves higher power compared with other panel unit root tests like LLC test (Baltagi, 2005).

Fisher-type panel unit root test

Maddala and Wu (1999) then Choi (2001) presented the Fisher-type unit root test which pools the p values from individual unit root tests. If π_i is well-defined as the p value from any individual test for cross-section section i , under the null of unit root test, then, for all N cross-sections, the asymptotic results are written as follows:

TABLE 1 Description of the study variables

Variables	Description
Yield	Annual average yields (kg/ha) of maize in a district level.
Rainfall	Monthly normal rainfall (mm) during growing season of maize in a district level.
Maximum temperature	Monthly average maximum temperature ($^{\circ}\text{C}$) during growing season of maize in a district level.
Minimum temperature	Monthly average minimum temperature ($^{\circ}\text{C}$) during growing season of maize in a district level.
Area	Overall cropped area (ha) under maize crop in each sample district.

TABLE 2 Agro-climatic zones (ACZs) of Telangana and their characteristics

ACZs	Districts	Total area	Annual rainfall	Primary crops
Northern zone	Karimnagar, Adilabad, Nizamabad	35.5 (lakh ha)	Normal rainfall 900–1,150 (mm)	rice, maize, cotton, jowar, groundnut, redgram, soybean
Central zone	Warangal, Medak, Khammam	30.6 (lakh ha)	Normal rainfall 800–1,150 (mm)	rice, cotton, maize, groundnut, greengram, jowar, chilli
Southern zone	Nalgonda, Mahabubnagar, Ranga Reddy	39.3 (lakh ha)	Normal rainfall 500–670 (mm)	cotton, maize, rice, redgram, groundnut jowar, greengram

Source: Based on Drought Manual, Telangana, 2016.

FIGURE 1 Maize yield in Telangana (1960–2015)

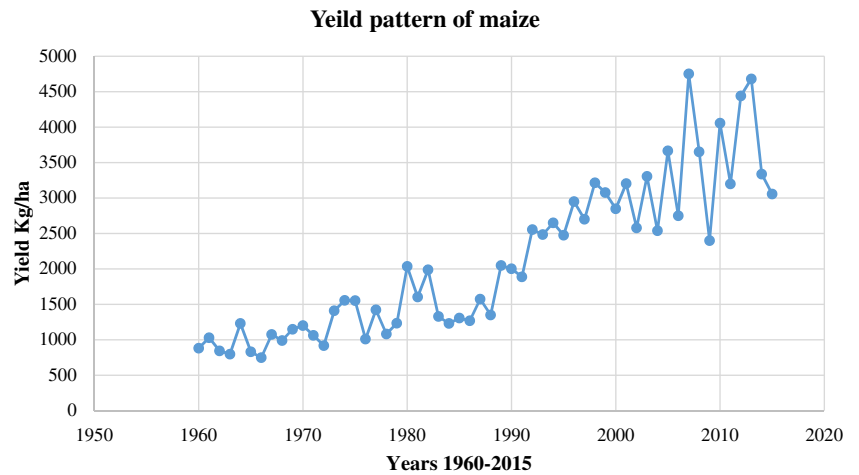


FIGURE 2 Rainfall pattern in Telangana (1960–2015)

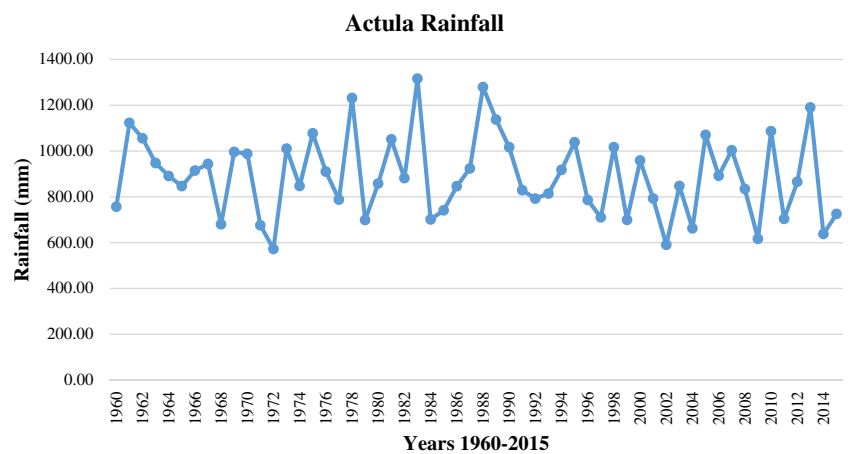
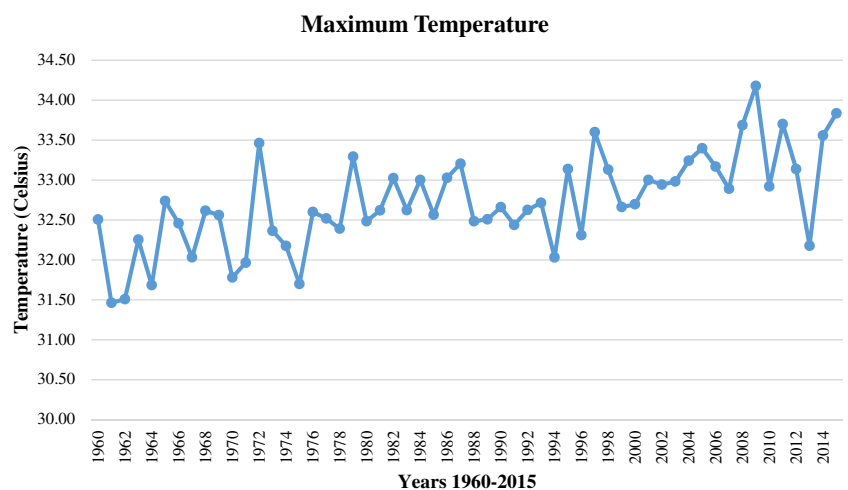


FIGURE 3 Mean maximum temperature in Telangana



$$-2 \sum_{i=1}^N \ln(\pi_i) \rightarrow \chi^2_{2N}.$$

The main advantage of the Fisher-type test is that it can be employed for various lag lengths in the individual ADF-regressions (Baltagi, 2005). Moreover, this test using ADF-regressions with bootstrap-based values

makes the best and, as a result, is the most preferred method for testing the existence of nonstationarity in the panel data (Maddala & Wu, 1999). The null and alternative hypotheses for the ADF test are

- Null hypothesis (H₀): Entire panels contain unit roots.
- Alternative hypothesis (H_a): At least one panel is stationary.

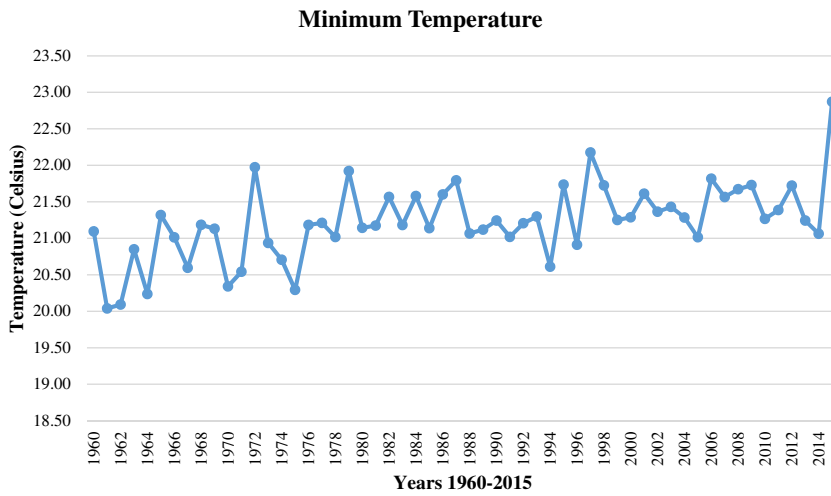


FIGURE 4 Mean minimum temperature in Telangana

3.2.2 | Empirical model

This study utilizes the Just and Pope (JP) production function approach proposed by Just and Pope (1978, 1979) to evaluate the effects of climatic factors on both the mean and variability of maize yield. The fundamental concept of this approach is to build the production function into two components: The first part is relating to the output level whereas the second component is related to the variability of that output (Koundouri & Nauges, 2005). This approach allows the investigator to distinguish the effect of input factors on output and variance. The basic specification of the Just and Pope production function is

$$y = f(X, \beta) + h(X, \alpha) \epsilon, \quad (1)$$

where y is the maize yield and $f(\cdot)$ is a production function. X is a vector of explanatory variables, β is a vector of estimated parameters related with X . Further, $h(\cdot)$ is a "risk function" associated with X and α is a vector of estimated parameters associated with the variance (risk) function. ϵ is the random error or random shock. The $f(X)$ component produces the mean effect of the independent variables on maize yield whereas $h(X)$ provides their influence on the yield variance (Chen & Chang, 2005; Koundouri & Nauges, 2005). More precisely, this study utilizes the following regression models.

The econometric specification of mean yield function $f(X, \beta)$ is expressed as follows.

$$Y_{it} = \beta_0 + \beta_1 MxT_{it} + \beta_2 MnT_{it} + \beta_3 Rf_{it} + \beta_4 A_{it} + \beta_5 T_{it} + \sum_{l=1}^{L-1} \alpha_l D_l + \epsilon_{it}, \quad (2)$$

where Y_{it} is the maize yield (kg/ha) for production district i and time t ; MxT_{it} , MnT_{it} , Rf_{it} , and A_{it} are the maximum temperature, minimum temperature, rainfall, and area under crop, respectively; $\alpha_l D_l$ ($l = 1, 2, \dots$) are agro-climatic zonal dummies taking values 1 and 0. T (year) is time trend variable to capture impacts of developments in technology. Further, the yield variability function $h(X, \alpha)$ is given as follows:

$$\ln e_{it}^2 = \alpha_0 + \alpha_1 MxT_{it} + \alpha_2 MnT_{it} + \alpha_3 Rf_{it} + \alpha_4 A_{it} + \alpha_5 T_{it} + \mu_{it}, \quad (3)$$

where $\ln e_{it}^2$ log of squared residuals from first step ordinary least squares (OLS) is a dependent variable and explanatory variables are maximum and minimum temperatures, rainfall, area, and trend. Further, α s are the parameter estimates, and other independent variables are defined in Equation (3). The linear climatic variables impact on maize yield may not be the same across the ACZs. The ACZ dummies are exogenous variables, and these dummies were included in the mean function. Linear trend was incorporated as a proxy variable to account of the impact of technological change.

According to Just and Pope (1979) and Saha, Havenner, and Talpaz (1997), all the parameters in Equation (1) can be estimated by utilizing the three-stage feasible generalized least squares (FGLS) or maximum likelihood estimation. Most empirical investigations were utilized in the FGLS estimation procedure. However, the maximum likelihood estimation (MLE) method is relatively efficient than the FGLS estimation approach when the sample size is small (Saha et al., 1997). Based on Judge, Hill, Griffith, Lutkepohl, and Lee (1988), this study employed the FGLS estimation procedure because of the large sample size. In addition, auto-correlation and heteroscedasticity problems are addressed in a better way using the FGLS procedure (Gujarati, 2004; Wooldridge, 2002). The panel type of data generally estimated utilizing either a random effects (RE) model or fixed effects (FE) model (Wooldridge, 2002). A Hausman specification test was employed to decide which method should be used. Hence, this study selected a fixed effects model based on the Hausman test result, and this preference of fixed effects model is consistent with former studies (Cabas, Weersink, & Olale, 2010; Kim & Pang, 2009; Sarker, Alam, & Gow, 2019).

3.3 | Model specification for time-series data

A micro level analysis is necessary as well as important to understand the effects of climate change on maize yield at disaggregate

district level in Telangana. The land quality, irrigation facilities, rainfall, temperatures, other climatic conditions, and geographical characteristics are different across the districts of the state. So the maize yields can be effected differently by climatic factors at district level. Hence, this study also examines the effect of climatic variables on maize yields in nine districts of Telangana using the time-series data. This disaggregate analysis is very much useful for making local level adaptation strategies and policy measures. Based on Kaul and Ram (2008) and Hasan, Sarker, and Gow (2016), this study utilizes ordinary least squares (OLS) analysis to evaluate the impact of climate change on maize yield. This method is appropriate to measure the influence of climate change on crop productivity (Sarker et al., 2012). Following Lobell, Cahill, and Field (2007) and Guntukula (2019), this study used three major climatic factors as explanatory variables, namely, minimum temperature, maximum temperature, and rainfall and maize yield as dependent variable. The following regression model is used.

$$Y_t = \alpha + \beta_1 \text{rainf}_t + \beta_2 \text{maxtemp}_t + \beta_3 \text{mintemp}_t + \beta_4 \text{area}_t + \varepsilon_t, \quad (4)$$

where Y_t = maize yields (Kg per hectare), rainf_t = rainfall (mm), maxtemp_t = mean maximum temperature ($^{\circ}\text{C}$), mintemp_t = mean minimum temperature ($^{\circ}\text{C}$), area_t = cropped area, and ε_t is the random term. α is the intercept, and β_1 to β_4 are the regression coefficients. The panel as well as time-series data estimations has been done in STATA-12 software.

4 | RESULTS AND DISCUSSION

We present summary statistics of the dependent and explanatory variables of the study for 60 years (1956–2015). These summary statistics are described in Table 3. The average productivity of maize per hectare across the sample districts is 2018.42 kg. The yield per hectare is very much low than the developed nations. The mean rainfall for the state during the study period is 815.22 (mm).

The standard deviation in rainfall is very high (232.42). The higher deviation of rainfall from normal might have adverse effects on crop sector. The average maximum temperature is around 32.68, and the mean minimum temperature is 21.18 during study period. The standard deviation is less than one for maximum and minimum temperatures in Telangana. The total number of observations is 540. And the unit of measure of study variables is also reported in Table 3.

TABLE 3 Summary statistics

Variables	Observations	Unit	Mean	Std. Dev.	Minimum	Maximum
Maize	540	(kg/ha)	2018.42	1,257.19	296	6,555
MaxT	540	($^{\circ}\text{C}$)	32.68	0.689	30.98	35.96
MinT	540	($^{\circ}\text{C}$)	21.18	0.843	18.55	25.08
Rainfall	540	(mm)	815.22	232.42	221.82	1,773.88
Area	540	(hectare)	38,504.07	36,972.65	17	182,493

4.1 | Results of panel unit root test

The present study employs Just and Pope production function methodology to estimate the impact of climatic factors on maize yield. Prior to fitting the data into the empirical model, we test the time-series properties of the study variables to giving out the possible incorrect regression. This study utilizes the Fisher-type panel unit root test using augmented Dickey–Fuller (ADF) regression. The unit root test results are reported in Table 4.

The results of the unit root test show that maize yield, cropped area, and climatic variables, namely, rainfall and maximum and minimum temperatures, are stationary at 1% level of significance. The evaluated test statistics indicate that climatic variables and maize yield show similar results with and without a time trend. This suggests that all the dependent and explanatory variables rejected the null hypotheses of unit root at 1% level of significance. This infers that all the study variables are stationary. The results of the unit root test are consistent with Kim and Pang (2009) and Sarker et al. (2019). Hence, we apply the three-stage FGLS estimation approach to investigate the influence of climate change on maize yields.

4.2 | Estimation results of mean yield and yield variability for maize

The effect of climatic variables, namely, rainfall and maximum and minimum temperatures, on mean and variance of maize yields in the former districts of Telangana has studied with the panel of 540 numbers of observations and nine panel groups. The study utilized Just and Pope production function and three-step FGLS estimation method for the empirical analysis. The estimated results for the maize are presented in Table 5. It is found that in the linear Cobb–Douglas

TABLE 4 Unit root test results

Variables	Fisher test (ADF) test statistic	
	Without trend	With trend
Maize yield	52.36*	246.02*
Rainfall	503.53*	466.61*
Maximum temperature	133.97*	239.45*
Minimum temperature	144.88*	206.93*
Area	227.67*	284.56*

* $p < .01$.

(LCD) functional form of maize, all the explanatory variables are collectively statistically significant since the whole Wald test statistic of 5,936.81 and the p value of .000. The significance level and sign of the impact of quantified coefficients for the explanatory variables vary in the mean yield and variability functions. For mean yield function, the empirical results reveal that rainfall, minimum temperature, and area under the maize crop cultivation are statistically significant. The average minimum temperature and cropped area have a significant adverse effect on maize yield during the study period. Further, mean maximum temperature and actual rainfall are positively related with maize yield. However, maximum temperature is not statistically

significant. The trend is positively associated with the mean maize yield, and it is significant at 1% level. This infers that the technological progress during the study period assisted in the growth of maize yields. Furthermore, all the three ACZ dummies in the mean yield function are individually not significant and have a negative association with the maize yields.

The second component of Just and Pope production function deals with the yield variability. The variability function results of maize are presented in Table 5. Based on the variability results, it can be found that a very few explanatory variables have the statistical significance. Only, time trend and maximum temperature are significant in the variability function. The effect of the cropped area and maximum temperature on yield variability is positive. This indicates that the area and maximum temperature are risk-increasing factors for maize yields. On the other hand, the effect of rainfall and minimum temperature on yield variance of maize is negative. This infers that minimum temperature and rainfall are risk-decreasing factors for maize yield. Similarly, the time-trend variable, that is, proxy for technological progress, has a significant adverse effect on maize yield variability. The technological progress is a risk-reducing factor for maize output. The mixed results of the impact of climatic variables on maize productivity are somewhat consistent with Li et al. (2011) and Mumo, Yu, and Fang (2018).

TABLE 5 Maize results

Variables	Mean yield $f(x)$	
	Coefficient	p value
Trend	0.137**	.000
Maximum temperature	11.866	.111
Minimum temperature	−0.536*	.026
Rainfall	0.170**	.003
Area	−0.032**	.010
Northern AC zone	−30.705	.133
Central AC zone	−31.002	.129
Southern AC zone	−31.042	.129
Constant	−17.261**	.000
	Yield variability $h(x)$	
	Coefficient	p value
Trend	−0.009*	.042
Maximum temperature	15.799*	.015
Minimum temperature	−3.087	.308
Rainfall	−0.001	.999
Area	0.003	.946
Constant	−48.958*	.016
Model summary		
Log likelihood	−1,118.12	
Wald chi-square	5,936.81	
Prob > chi-square	0.000	

* $p < .05$; ** $p < .01$.

4.3 | Linear regression results (time-series data)

Using the ordinary least squares method, we estimated climatic variables effect on maize yields in nine former districts of Telangana. District level time-series data were utilized for the analysis. The estimated coefficients of explanatory variables relating to maize yields in nine districts of the state are documented in Table 6. The level of significance and sign of the impact of quantified coefficients for the independent variables vary in the district level analysis. In Adilabad, minimum temperature has a significant negative impact on yield, but rainfall and maximum temperature are positively related to maize yield. Area under maize has a significant positive impact on maize yield. The value of R^2 point out that 43% of the variation in maize is explained by the weather factors. In Karimnagar, the influence of rainfall is negative on maize productivity, whereas maximum temperature,

District	Rainfall	Max. Temp.	Min. Temp.	Area	Constant	R-squared
Adilabad	0.193	7.811*	−0.874**	1.949***	−38.171**	0.43
Karimnagar	−0.063	7.426	0.335	1.462***	−35.442***	0.65
Nizamabad	0.120	10.882***	−0.118	0.723***	−37.473***	0.66
Medak	0.314	−2.470***	1.458**	1.447***	−6.841	0.60
Khammam	0.197**	−0.578	3.803	0.812***	−11.212	0.78
Warangal	0.301	12.302***	2.540	0.582***	−51.591***	0.60
Mahabubnagar	−0.023	−20.381***	18.74***	0.091***	20.589	0.49
Rangareddy	0.715***	6.648	3.088	0.472***	−34.267**	0.43
Nalgonda	0.137	7.191	6.061**	0.143	−38.252***	0.36

* $p < .10$; ** $p < .05$; *** $p < .01$.

TABLE 6 Linear regression results for maize

cropped area, and minimum temperature have a favorable effect on maize yield. But merely the cropped area is significant amongst all the study variables. The calculated R^2 of 0.65 be a sign of combined significance of the empirical model.

In Nizamabad, minimum temperature is adversely related with maize yield, but it does not seem to be significant. However, rainfall is positively associated with maize yield, but it is not statistically significant. Similarly, area and minimum temperature have a substantial supportive influence on productivity. The value of R^2 point out that 66% of the variation in maize productivity is explained by the weather variables. In Medak, the relationship between maximum temperature and yield is negative and also statistically significant. Rainfall has a positive effect on maize yield, but it is not statistically significant. The area and minimum temperature have a significant positive influence on maize yield. The evaluated R^2 of 0.60 indicates combined significance of the empirical model. In Khammam, maximum temperature is unfavorably related with maize productivity, but it does seem to be insignificant. On the contrary, rainfall and cropped area have a significant positive effect on maize yield. The minimum temperature is positively related on maize yield, but it is not statistically significant. The calculated R^2 of 0.78 be a sign of combined significance of the empirical model.

In Warangal, the entire study variables such as rainfall, area, and minimum and maximum temperatures have a helpful influence on maize yield, but rainfall and minimum temperature are found to be insignificant. The evaluated R^2 of 0.60 indicates combined significance of the empirical model for Warangal. In Mahabubnagar, the influence of rainfall and maximum temperature is adverse on maize yield, but precipitation is not statistically significant. The minimum temperature and cropped area have a significant positive impact on maize yield. The figure of R^2 specifies that 49% of the variation in maize produce is explained by the climatic variables. Climate variables are playing a greater role in the cultivation of maize yields in Mahabubnagar. Further, in Rangareddy, all the study variables, namely, rainfall, area, and maximum and minimum temperatures have a beneficial influence on yield. However, maximum and minimum temperatures are found to be insignificant. The calculated R-squared of 0.43 be a sign of combined significance of the empirical model. Furthermore, in Nalgonda, all the study variables such as rainfall, area, and minimum and maximum temperatures are positively associated with maize yield during the study period. However, only the minimum temperature is significant among all the study variables.

5 | CONCLUSIONS

This study explored the effect of climate change on maize yields and its variance in Telangana utilizing Just-Pope production function, spanning the period 1956–2015. The three-stage feasible generalized least squares (FGLS) is estimation method employed to estimate the empirical model. The district-level cross-sectional time-series data (panel data) for a period of 60 years have used to achieve the study objective. The study results reveal that the average minimum temperature has a significant unfavorable effect on maize yield. Maximum

temperature and actual rainfall are positively related with maize yield. However, the maximum temperature is not statistically significant. Furthermore, rainfall and minimum temperature are risk-shrinking factors, but the maximum temperature is a risk-enhancing factor for maize yields during the study period in Telangana. District-level analysis reveals that Mahabubnagar, Medak, and Adilabad districts are affected more by climatic factors. This study documented that weather factors have a substantial adverse effect on maize yields. The study results have key implications for developing suitable or sub-national local level adaptation policies.

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ENDNOTE

¹ The Telangana government has divided the former 10 districts into 31 new districts in 2016.

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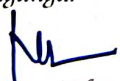
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