Analyzing the Impact of Climate Change on Wheat Acreage and Yield Responses in Barani Area of Punjab

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CERTIFICATE

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Dedicated to

My Beloved Sister Maha Jabeen

And

My Respected Husband AliAkbar

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List of Abbreviations

IPCC	Intergovernmental Panel on Climate Change
GHGs	Green House Gases
GDP	Gross Domestic Products
PMD	Pakistan Meteorological Department
GMM	Generalize Method of Movement
NFDC	National Fertilizer Development Center
ASP	Agricultural Statistics of Pakistan
PBS	Pakistan Bureau of Statistics
NARC	National Agriculture Research Centre
UNFCCC	United Nations Framework Convention on Climate Change
WDR	World Development Report
GFDRR	Global Facility for Disaster Reduction and Recovery
TFCC	Task Force on Climate Change
FEM	Fixed Effect Model
REM	Random Effect Model
ESP	Economic Survey of Pakistan
PARC	Pakistan Agriculture Research Council

ABSTRACT

The present study analyses the impact of climate change on wheat acreage response and wheat yield in Barani Punjab. This research uses fixed effect model to evaluate the yield responsiveness of wheat to climate change and Arellano Bond GMM estimation technique to estimate the acreage response to climate change. The data considered for this study is the annual data from 1981 to 2010 for Barani four districts of Punjab. The significant impact of climate change on wheat area is observed. The study shows different impacts of climate change in each phenological stage for wheat acreage responsiveness. The results indicate that wheat area is sensitive to temperature at sowing stage, and precipitation at pre-sowing stage has negative relation with wheat area. Wheat area has significant positive relation with own price and negative relation with competing crops price. Fertilizer prices also effect acreage allocation of wheat crop. The result for wheat yield showed that wheat crop is more sensitive to temperature at sowing stage, while temperature in January and February enhance wheat productivity. Precipitation normals have positive impact on wheat yield. The results reveal that climate change may influence the yield and acreage of wheat in Pakistan. Therefore, appropriate adaptive and mitigative techniques as well as measures like timely cultivation, better irrigation system and new technology are recommended to be evolved to cope with hazards of global climate change on wheat yield in Pakistan.

Chapter 1

Introduction

Climate change is a condition which refers to the change in the state of climate that can be identified and remains for a long period, usually a decade or longer. The climate change is happening due to natural variability or consequences of anthropogenic activities (IPCC, 2007). According to the UNFCCC, a change of climate is attributed directly or indirectly to human activities which alter the composition of global atmosphere. Human activities have increased the concentrations of greenhouse gases (GHGs) in atmosphere since pre-industrial era, from the combustion of fossil fuels, agriculture, and land-use changes (IPCC, 2001). GHG's include carbon dioxide (CO_2), chlorofluorocarbons, methane (CH_4) and nitrous oxide (N_2O). Climate change increases the global warming due to which average global temperature has increased by 0.74°C over last century. Due to this global warming the quantity of greenhouse gases, intensity of extreme events floods, droughts, and heavy precipitation events, are on the rise (UNFCCC, 2007).

It is estimated that the earth would warm up by 3°C by 2100. Even if countries reduce their GHGs emissions by controlling their anthropogenic activities, the earth will continue to warm (UNFCCC, 2007). Climate change will create new risks for natural and human systems; these risks are widespread and disturb the development of countries (IPCC, 2014).

Climate change threatens all countries, but it has more adverse impacts on developing countries. Developing countries have poor economies and weak socio-economic structures. Therefore, extreme events from climate change such as cyclones, droughts, and floods have serious consequences on their economies because they have limited coping abilities from such disasters (Gross, 2002). It is estimated that developing countries would bear 70 to 80 percent of the cost of damages caused by the changing climate. The developing countries lack financial and technical capacities to overcome risk of climate change. These countries also depend more directly or indirectly on climatic-sensitive natural resources for income and well being. Moreover, due to climate change the extremes in temperature would disturb the ecosystem that is essential for the survival of human societies and economies such; e.g., complete loss of glaciers in the Himalayas (WDR, 2010).

There is a positive relationship between climate change and increasing global temperature that has severe adverse impacts on several climate-sensitive sectors like water resources, agriculture and food security, human health and ecosystem (Hitz and Smith, 2004; Stern Report, 2006).

One fifth of the world's population lives in South Asia. High population growth rate and prevalence of poverty food and insecurity make South Asia the most vulnerable region to climate change (Sivakumar and Stefanski, 2011). According to World Bank Report (2010), rise in temperature by 2°C could result in a 4 to 5 percent permanent decrease in annual per capita income in South Asia. These losses are mainly due to impacts on agriculture, which is an important sector for South Asian economies. High prices of food commodities are associated with climate change risks and frequently occurring of extreme weather events—floods and droughts, and are repealing the progress in food security efforts in many low income countries of South Asia. It is also predicted that crop yields would decline by 30 percent, creating a high risk of hunger in this region (UNFCCC, 2010).

Pakistan is the second largest country in South Asia. Pakistan has generally warm climate due to which it is more susceptible to the effects of climate change .The temperature in Pakistan is expected to rise more than the global temperature (Task Force Report, 2010). The estimated temperature increase in north is somehow higher than in south region; moreover, the increase in temperature is expected to be higher in winter than that of in summer. It is expected that yield of wheat and rice can decrease in whole country except northern mountains. Climate change has affected the monsoon patterns and resulted in erratic rainfall in the region. The rains occur either earlier or later than the historical patterns with varied intensities—results in frequent floods or droughts, seriously affecting agricultural production (Pachauri, 2007). Climate change affects many sectors of Pakistan. Water and agriculture are the most sensitive sectors to climate change. The availability of fresh water is becoming vulnerable to climate change, and arid and semi-arid regions would face severe water stress (Farooqi *et al.*, 2005).

Agriculture is very important and essential sector of any economy because its products are essential for life with almost no substitutes. Agriculture shares about 2 percent of GDP in developed countries, while it contributes over 1/4th of GDP in developing countries (Ackerman and Stanton, 2013). Climate change is the basic determinant of agricultural productivity. Increase in temperature and precipitation have positive as well as negative effect on crop yields and quality of many crops depending upon the existing climatic conditions in the area (Adams and Hurd, 1998).

Agriculture production is particularly more sensitive to climate change, because large parts of crop yields depend on climate conditions. Climate change influences agricultural production in different ways. Increase in temperature lead to higher rate of respiration which affects the quality of grain due to which crop productivity decrease. Moreover raise in temperature increase the evaporation which reduces the soil moisture (Adams, 2000).

The hydrological cycles increase soil erosion, floods and droughts in agricultural regions which destroy the crops (Bosello and Zhang, 2007). Due to change in patterns of precipitation (rainfall) wet areas are becoming wetter and dry areas are becoming drier which raises water requirements further (Stern Report, 2006). CO^2 concentration in atmosphere is reason of climate change that affects the crop plant and weeds (Mahato, 2014). Increasing temperature and changing precipitation patterns increase the risks of pests, diseases and weeds (Aydinalp and Cresser, 2008).

The agricultural land is influenced by climate change. Rise in temperature increases the sea water level to rise which has serious threats for countries whose lands are at sea level resulting into higher salinity of groundwater in coastal areas. The floods and droughts have serious impacts on agricultural lands including serious land degradation (Beltagy and Madkour, 2012).

Agriculture is lifeline of Pakistan's economy and 70 percent of its population directly or indirectly is linked to this sector and it contributes 21 percent to gross domestic product (GDP), while it is extremely vulnerable to climate change. In southern region of Pakistan major cereals yields is predicted to decline by 15-20%. Climate change reduces water availability for irrigation which is changing the crop rotation and cropping patterns (IUCN, 2009). Pakistan vulnerability to floods and droughts is estimated to increase as the intensity of severe events increase. Floods inundate fertile land, demolish standing crops, and reduce yields (GFDRR, 2011). In Pakistan 38 percent of the cultivated land is suffering from environmental damage—17 percent due to water erosion, 8 percent due to wind erosion, 5 percent due to water logging, 8 percent due to salinity (TFCC, 2010).

Wheat is the main staple crop of Pakistan, and is grown in winter season (Rabi Crop). It is grown on more than 1/3rd of the total cultivated area in the country. Wheat contributes 10 percent to the agriculture and 2.1 percent to GDP. Area under wheat has decreased to 9180 thousand hectors in 2014 to 2015 from last year's area of 9199 thousand hectors, which shows the decrease of 0.2 percent n area. The production of wheat decrease 1.9 percent over the year of 2013 o 2014. The decrease in production is due to prolonged winter season and unprecedented rains during month of April and May, and caused damage during harvesting time (ESP, 2015). The optimum temperature for wheat is 25°C, with minimum growth temperature of 3°C to 4°C and maximum of 30°C to 32°C (PARC, 2014). The climate change is affecting wheat productivity significantly. Results of a more recent study show that 1°C increase in average temperature during the sowing stage (November and December) would reduce the wheat yield by 7.4 percent (Ahmad *et al.*, 2014). The estimated increase in temperature normal during the study period for the months of November-December was projected to be 0.765°C. Therefore, the overall potential wheat yields got depressed by 5.67 percent during the last three decades (Ahmad *et al.*, 2014).

1.1 Significance of Study

The previous literature mainly emphasized on analyzing the impact of climate change on crops productivity/yield. However, some studies are found analyzing crop acreage response to different variables including climate and non-climate. Climate change is the long term phenomena which can be observed in decades but previously conducted studies could not capture the long run impacts of climate change. The most commonly used weather variables include current temperature and rainfall, which relate only to weather. Moreover, most of the previous the studies used aggregate time series data at national level. Nonetheless, the impact of climate change is most commonly analyzed using yield/production function. The study could not find much work on acreage response to climate change in general and in Pakistan in particular, except a recent study on sugarcane. This study would use the district level data to analyze the impact of climate change on wheat acreage and wheat yield incorporating various phenological stages of crop growth. The study also includes important economic variables such as fertilizer, own price of wheat, expected yield, and other competing crops prices. The major objective of this study is to test the findings of a recently conducted Rapid Rural Appraisal in selected districts of Pakistan that due to changing patterns of climate over the last three decades farmers are reducing area allocation to those crops which require more water, greater investment and are shallow rooted like wheat and are adapting crops demanding low delta of water, deep rooted and less investment like mustard (Ahmad, Iqbal and Khan, 2013). The study argues that such adaptation is more prominent in rainfed areas. Therefore, the study underhand is unique in nature that it covers the major rainfed/barani[1] area of Punjab to test the Ahmad, Iqbal and Khan (2013) findings using long-term area allocation to wheat and the other competing crops. Furthermore, the present study would also analyze the major drivers of changes in cropping pattern—whether the changes are forced purely by the climate or the adjustments are backed by the profitability of the crops.

[1] The word 'Barani' refers to the agricultural area that depends on rainfall for cultivation.

1.2 Objectives of the study

The major objective of this study is to evaluate the impact of climate change on allocation of area (un-irrigated, irrigated and total area) under wheat and responsiveness of wheat yield in rainfed region of the Punjab. The specific objectives are:

- To analyze the impact of long run temperature and precipitation normals on wheat acreage response in barani area of Punjab;
- To analyze the responsiveness of wheat yield to climate change; and
- To provide policy implications on the basis of results of the analysis.

1.3 Hypotheses to be tested

Hypothesis I

- H_0: Long-term temperature has no effect on wheat acreage.
- H_1: Long-term temperature does affect wheat acreage allocation.

Hypothesis II

- H_0: Long-term precipitation has no effect on wheat acreage allocation.
- $H_{1:}$ Long-term precipitation does effect on wheat acreage allocation.

Hypothesis III

- H_0: Long-term temperature has no effect on wheat yield in barani Punjab.
- H_1: Long-term temperature does affect wheat yield in barani Punjab.

Hypothesis IV

- H_0: Long-term precipitation has no effect on wheat yield in barani Punjab.

- $H_{1:}$ Long-term precipitation does effect on wheat yield in barani Punjab.

1.4 Organization of Study

The remaining document is organized as follows: Section 2 reviews the literature on acreage response of agricultural crops and impact of climate change on crop acreage and yield response. Section 3 explains theoretical framework for the study. Section 4 presents data, variable construction and methodology. Trends and graphs of variables are outlined in Section 5. Results are comprehensively discussed in Section 6. Finally, Section 7 concludes the study and suggests policy recommendations.

Chapter 2

Literature Review

There is no dearth of literature that assesses the supply response of agricultural crops. Most of these studies used price volatility, price uncertainty, government programs, yield risk, biophysical factors, competing crops prices and yields, inputs, weather fluctuations as important factors to see impact on crop acreage. The relevant literature that analyzed the acreage response under different factors is reviewed in this chapter.

Bailey and Womack (1985) analyzed wheat acreage response for five production region of United States. The regional data was used over the period of 1962-1981. The study applied Ordinary Least Squares (OLS) techniques. The estimated results showed that there was regional divergence due to government program variable. The result indicated that increase in expected price of wheat also increased wheat acres in all five regions. Moreover, 100 percent increase in area of competing crop (soybean) reduced wheat acres by 18 percent.

Chavas and Hol (1990) examined risk responsive acreage decision for corn and soybeans in United States. The time series data was used for period of 1954-1985. The study developed acreage supply response under expected utility maximization for crops. The results of study showed that risk and wealth variables played an important role in acreage decision of corn and soybeans. The study showed that cross-commodity risk reduction is important in acreage allocation decisions.

Chembezi and Womack (1992) examined the impact of farm programs on regional acreage response of corn and wheat in United States. The study used annual time series data for period of 1966-1989. The Generalized least square (GLS) was applied for estimation of study. The results indicated that policy variables played important role in production decisions of wheat and corn. It also showed that government programs had effectively reduced planting of wheat and corn. In addition, non program acreage was more reactive to price change as compared to program planted acreage.

Ali and Abdullah (1998) examined the factors that affected the demand and supply of Pulses (Mungbean, Gram, Mash, Lentil) in Pakistan. The district level data was used for this study. The OLS methods were used for estimation. The results showed that pulses production, especially of mungbean, is affected by other crop prices (competing crop mash). Moreover mungbean and lentil productions are negatively affected by the increasing wage rate as both crops need high labor.

Lansink (1999) studied area allocation and production level under price volatility on Dutch arable farms of Flevoland. The study used winter crops (wheat, barley, oats and oilseeds) and root crops (sugar beet, ware potatoes, seed potatoes and starch potatoes). It covered the panel data over the period of 1975-1992 and used Full Information Maximum Livelihood (FIML) method for estimation. The results of study indicated that increase in price of pesticides lower the winter crops area and winter crops were more dependent on pesticides than other outputs. It also showed that Dutch farmers were risk averse.

Mushtaq and Dawson (2002) examined the acreage responses of wheat, cotton, sugarcane and rice in Pakistan. The Co-Integration techniques and Impulse Response analysis were used for study. The results of study indicated that the acreage of wheat and basmati rice did not respond significantly to shocks in own-price while cotton, sugarcane and high yielding variety rice did respond.

Gbetibouo and Hussan (2005) used Ricardian model for measuring the impact of climate change on crops in South Africa including maize, wheat, sugarcane, sunflower, groundnut and soybean. This study used crop revenue data of 300 districts from South Africa for the period 1970-2000. The results showed that, there was a quadratic relationship between climate variables and net revenue per hectare. Furthermore, the climatic variables have a hill-shaped relationship with net revenue in winter whereas in summer climatic variables have a U shaped relationship. They found that crops were more sensitive to change in temperature as compared to that in precipitation. Change in temperature affected net revenue positively, whereas change in precipitation affected negatively.

Mythili (2006) studied the supply response for major crops (Wheat, Cotton, Rice, Cereals, Pulses, Sugarcane) during pre and post reform periods in India. The dynamic panel data approach was used with pooled cross section and time series data across states for India. The duration of data was 1970-71 to 1999-2000. The Generalized method of moments (GMM) was used for estimation of study. The study found no significant difference in supply elasticities between pre and post reform periods for majority of crops. The results confirmed that farmers respond to price incentives equally by more intensive application of non-land inputs.

Deschenes and Greenstone (2007) studied the economic impact of climate change on agricultural land of United States. The study used county-level panel data over the period of 1978-2010. The hedonic approach was used for impact of climate change on agricultural land. The results found that climate change increased 4 percent annual agricultural profit. It also showed that increase in temperature and precipitation had no effect on important crops yields and hedonic approach revealed that climate change increased value of agricultural land.

Kalra, *et al* (2008) investigated the effect of growing temperature in the northwest India on yield of barley, wheat, mustard and chickpea winter crops. The Wheat Growth Simulator (WTGROWS) model was used to examine the relationship between rising temperature and yield of winter crops. The results of the study showed that rise in temperature has badly affected the yield of these four winter crops and the reduction in wheat and barley yields are greater as compared to that in case of other crops. The rising temperature in study area has also resulted in changing optimal date of sowing for these crops.

Niamatullah and Zaman (2009) determined the effect of price factor (market price), non price factors (rainfall, irrigation) on wheat and cotton production and acreage. The study used OLS techniques for estimation. The time series data was used from 1981-82 to 2006-07 for rainfed areas and from 1991-92 to 2007-08 for irrigated areas in Pakistan (NWFP). The results showed that there was positive relation between rainfall and wheat production and there was no relationship between market price and wheat acreage.

Khan and Zaman (2010) analyzed the effect of market price (price factor) and rainfall (non-price factor) on wheat production and acreage in Pakistan (NWFP). The time series data was used over a time period of (1981-82 to 2007-08). The study used Ordinary Least Squares (OLS) technique. The results revealed positive and significant relationship between rainfall and wheat production, while no significant relationship of the market price was observed with the production and acreage of wheat in NWFP.

Huang and Khanna (2010) estimated the impact of climate variables, technology and crop prices on crop yield and on crop acreage in the US. The list of crops included corn, soybeans, and wheat. The panel data was used for the period of 1977-2007. The dynamic panel GMM estimation method was applied. The results indicated that corn, soybean and wheat yields all respond positively to their own prices and that corn and wheat yields respond negatively to fertilizer prices. The climate variables have significant impact on the yields for all three crops and high temperature could lead to reduced crop yields while more precipitation will just enhance corn and soybean yields.

Janjua, *et.al* (2010) estimated the effect of climate change on wheat production in Pakistan using data for the time period 1960-2009. The study found no significant affect of climate change on wheat production in the country. However, future wheat production would be heavily dependent on acreage allocated to wheat production and the climatic factors. It is projected that area under wheat and the climatic variables respectively would cause about 30 percent and 34 percent variation in wheat production.

Ashfaq *et al.* (2011) analyzed the impact of climate change on wheat productivity in Pakistan (Mixed zone of Punjab). The time series data was used for period 1980-81 to 2008-09. The OLS techniques were used. The results showed that at sowing stage one degree centigrade increase in mean minimum temperature will increase wheat production by 146.57 kg ha^{-1}; and at vegetation stage increase in mean temperature will decrease production. Climate change is important determinant at different stages of wheat growth.

Liang *et al.* (2011) analyzed factors impacting crop prices and yield to examine the supply response of major crops (cotton, soybeans and corn) in Southeast of United States. The study utilized panel data of eight states of Southeast US over the period of 1991-2007. The Seemingly Unrelated Regression (SUR) was used to estimate acreage response model. The results showed that corn and cotton acres responded more to price changes and soybean acres responded less to price changes. Increased in input costs had affected farmer crop acreage decision.

Yaseen and Dronne (2011) analyzed supply response of main crops (wheat, cotton, rice, maize, sugarcane, dry beans, rapeseed, soybeans, and sorghum) in Pakistan and India. The study estimated the combined influence of prices and yields for allocation of land between crops. The study used annual data set from Pakistan and India over 42 years (1966 - 2008). The study applied the Maximum Likelihood Method (MLM) technique. The results indicated that farmers of both countries were more or less responsive to gross income per hector. The farmers of Pakistan and India were influenced by last year yields and prices. Moreover in case of Pakistan, lowest elasticities were observed.

Boussios and Barkley (2012) examined the supply response for agricultural commodities (wheat, corn, soybeans, and sorghum) in Kansas. The study also analyzed the impact of potential climate changes on total grain supply. The country level data was used from 1977-2007. The fixed effect model was used. The results suggested complicated relationship between the two supply response components, acreage and yield. It also showed that producers' land use decisions were sensitive to both weather and prices.

Barmon and Chaudhury (2012) studied the impacts of price and price variability on acreage allocation of rice and wheat production in Bangladesh. The time series data was used for the period of 1983-84 to 2007-08. The Nerlovian model was applied for the analysis. The results indicated that the wholesale price of rice and wheat had significant impact on the allocation of land for crops production. The study found positive relationship between wholesale price of rice and area allocation for rice.

Cai, *et al.* (2012) analyzed the effect of weather variations on corn yields using the balanced panel data regarding 985 corn producing districts in U.S for the period 2002-2006. Monthly temperature and precipitation data for the growing season was used for empirical estimation. The results of study showed that the relationship between weather variables and corn yield has large spatial variability. In warmer regions temperature negatively affected corn yield, while in cooler region it affected corn yield positively. The spatial pattern of precipitation effects is more complicated since it is expected to be largely affected by local irrigation systems. The results of OLS regression model show that corn yields are negatively related to both precipitation and temperature.

Huq *et al.* (2013) studied supply response of wheat in Bangladesh. The study was based on time series data for the period of 1972-1973 to 2005-2006. They used co-integration technique applying Vector Error Correction Model. The study estimated that wheat acreage was influenced by price of wheat, and other competing crops such as Boro (winter) rice. The non-price factors such as weather had a highly positive effect on wheat area in the short-run.

Haile *et al.* (2013) estimated global crop acreage response to prices and price risk of main staple crops (wheat, soybeans, corn and rice). The country-level data was used for period of 1961 to 2010. The Seemingly Unrelated Regression (SUR) approach was used to estimate acreage response for this study. The planted months of crops were used as phenological stages. The results emphasized that price risk reduced the acreage of crops. It also indicated that acreage response was more effective to prices in northern hemisphere spring than in winter and response varied month to month. Corn and soybean were more sensitive to prices having price elasticities of 0.17 and 0.24, respectively than wheat and rice with elasticities 0.07 and 0.03, respectively.

Saddiq *et al.* (2013) studied acreage response of sugarcane to price and non-price factors in Khyber Pakhtunkhwa province of Pakistan. The time series data was used for 42 years for the period of 1970-2011. The Vector Auto Regression technique was used to estimate the effect of price and non-price factors on acreage allocation decisions of the farmers for sugarcane. The results revealed that acreage allocation decision was positively influenced by price, yield, and lagged area under crop. It showed that if price, yield and lagged area are enhanced, the acreage allocation of sugarcane also improved. The study also indicated that the expected price of sugarcane increased the area allocation to sugarcane.

Traboulsi (2013) analyzed the impact of climate change on acreage and yield responses for citrus crops (fresh oranges, and grapefruits) in Florida. The study used the panel data from 1980 to 2010. The Log Linear Model was used to analyze acreage response and Fixed Lag Structure Model was used for yield response. The results of study showed that own-price influences area allocation under fresh oranges and yield of grapefruits positively. Temperature has a positive impact on the acreage response of fresh oranges, whereas it impacted negatively the grapefruits' yield and there was no significant impact of precipitation.

Lokonon (2014) estimated acreage response of cotton using data from Southern Nigeria in Benin. The time series data was used over the period of 1971-2011. The study was based on Ordinary Least Squares (OLS) application. The results showed that in the long run cotton acreage depended positively on the exchange rate, total number of tractor used, and lagged real producer price of cotton seed, and negatively on lagged producer price of rice paddy while in the short run cotton acreage was significantly influenced by rural population growth, and lagged real producer price of cotton seed and was negatively influenced by lagged producer price of rice paddy.

Haile, *et al.* (2015) analyzed worldwide acreage and yield response of agricultural staple crops (wheat, corn, rice, soybeans) in newly developed multi country(included 32 countries). The study included 32 countries. The panel data was used for period of 1961 to 2010. Generalized Method of Moments (GMM) technique was applied for the analysis. The results revealed that high output prices encouraged to improve global crop supply, whereas fluctuation of output price behaved as a disincentive for global supply response. Moreover, volatility of crop price had negative correlation with crop supply. The study also found that price risk had reduced wheat production.

In Pakistan, there is a significant share of wheat in daily calories intake. So, any decline in the supply of wheat would affect the nutrition status of the people of Pakistan. Little research has been conducted in order to explore the impact of climate change on wheat yield and acreage allocation across phenological stages of wheat crop. Most of the empirical studies reviewed above analyzed the impact of prices (crops and inputs), government programs, and population density on acreage response in different regions of world. A few studies incorporated climate change in the analysis but these studies had not been analyzed for Pakistan. This study contributes to the literature in following ways: it investigates the impact of climate change on wheat yield and acreage allocation through different phenological stages in Barani area of Pakistan; and it checks the impact of climate change through panel data technique.

Chapter 3

Theoretical Framework

3.1 Climate Change and Acreage Response Model

Climate change is global phenomena, and is adversely affecting the agriculture sector mainly in developing countries. Two approaches are most commonly used by researchers for the acreage/supply response of agricultural crops: one is the use of profit maximization framework and the other is Nerlovian expectation model. To achieve the objectives, this study uses Nerlovian Expectation model.

Profit maximization framework involves joint estimation of output and input demand functions. This model is helpful in selection of crops subject to the land and variable resource constraints. This model has some drawbacks as it requires the detailed input and output prices, quantities of inputs and outputs. Moreover, agricultural markets are not well developed and no competitive environment in agricultural input markets in developing countries. The availability of data on input prices is another problem. Keeping in view these aspects this study has chosen Nerlovian Expectation Model (NEM).

The Nerlovian model was developed by Nerlove (1958) to examine farm output reaction on price expectation and partial adjustment. It shows that how farmers shape their crop acreage decision with future price expectations. The Nerlove adaptive price expectation model is a useful tool for estimation of supply response for agricultural crops. The model facilitates the analysis of both speed and level of adjustment of actual acreage toward desired acreage (Braulke, 1982).

Assuming that farmers have rational price expectations based on their information set, farmers' crop acreage decisions can be described using a typical Nerlovian adaptive price expectations model written as follows (Braulke, 1982).

$$A_t^D = a_0 + a_1 P_t^e + a_2 Z_t + u_t \text{...} 3.1$$

$$P_t^e = P_{t-1}^e + \beta(P_{t-1} - P_{t-1}^e) \text{...} 3.2$$

$$A_t = A_{t-1} + \gamma(A_t^D - A_{t-1}) \text{...} 3.3$$

In above equations, A_t and A_t^D are actual and desired area for cultivation at time t, P_t and P_t^e are actual and expected prices at time t. β and γ are the expectations and adjustment coefficients. u_t is disturbance term to capture the effect of weather and the other factors which impact crop supply response.

By removing unobserved variables A_t^D and P_t^e from the model, reduced form of the actual planted acreage equation can be written as:

$$A_t^D = b_0 + b_1 A_{t-1} + b_2 A_{t-2} + b_3 A_{t-3} + v_t \text{...} 3.4$$

Where, $b_o, b_1, b_2, and\ b_3$ are parameters determined by $a_o, a_1.\beta, and\ \gamma$ in equations 1-3 and v_t is a disturbance term related to u_t.

In above basic Nerlovian model, the area farmer desires to cultivate is a function of expected price and other variables (non price). The model leads to a reduced form with acreage in a given year expressed as a function of one-year lagged crop price and lagged crop acreages.

The advantages of Nerlovian model are that it is easy in provision of data requirements, undertakes the aggregate supply data for future projections, and it also handles dynamic adjustments to supply of agricultural crops. It also allows us to determine short run and long-run elasticities and also gives flexibility to include non-price factors (Mythili, 2006). Mythili, (2006) also used the Nerlovian price expectation model as the impact of climate change on wheat acreage.

3.2 Climate Change and Yield Model

In literature, there is a great debate on the analysis of crop productivity and climate change. Three different approaches have been used by researchers. Mundlak, (1978), Mundlak, *et al.* (1999), Cabas, *et al.* (2010) used production function. Mendelsohn and Dinar (1999), Kurukulasuriya and Mendelsohn, (2008) applied Ricardian approach. Reddy, *et al*. (2002) used agronomic crop simulation model.

Production Function

Production function approach is widely used technique to evaluate the climate change impact on crops yields. According to Mishra (2007), production can be defined as “relationship between the maximal technical feasible output and inputs needed to achieve this output. Solow (1956) introduced production function approach which has been further extended by many researchers over time for panel data analysis to analyze the impact of climate change on agriculture production function by using environment as input to crop production (Mundlak, 1978 and 1999). In production function approach the main feature is that all variables of left hand side are assumed as exogenous and there is no relationship between error term and these explanatory variables hence minimizing the chance of endogeneity. Moreover, this approach is based on the t scientific experiment, thus this methodology is clearly links the crop yield with climate.

The functional form of any production function can be written as:

$$Y_i = f(X_i) \qquad \text{3.5}$$

Where, *I* = 1,2,3,….,n and *Yi* is the output by using *Xi* input under some technology. For panel data this production function can be written as fallow:

$$Y_{it} = f(X_{it}) \qquad \text{3.6}$$

Where, *i*= districts (1,2,3,…..,n) and *t*= Year (1,2,3…….,t).

The regression equation of wheat yield can be written as:

$$Y_{it} = X_{it}\beta_i + U_{it} \qquad \text{3.7}$$

Where *Y* is yield of wheat in i^{th} districts during year *t* and X_{it} is vector of explanatory variables (physical variable like land, fertilizer etc.) and climatic variables (temperature and precipitation) and U_{it} is panel data disturbance term which is different from cross-section disturbance term. Production function approach provides detailed factors of understanding the physical, biological and economics responses and adjustments. This approach also produces more correct yield responses as it relies on relatively more reliable data in terms of the relationship between yield and climatic variables while controlling for the other important physical factors and socioeconomic variables.

Chapter 4

Data and Methodology

4.1 Data Sources

This study uses district level panel data that relates to four major wheat producing districts of barani Punjab for the period of 1981 to 2010. We found a study that analyzed wheat productivity growth assuming various inputs including rainfall (Ahmad and Ahmad, 1998). Ahmad and Ahmad (1998) examined wheat productivity growth in barani areas of Punjab assuming precipitation as direct input besides other physical inputs. The total precipitation during the wheat growth period ‘November-March’ was considered as quantum of water available through rains in the production function, which had a significant positive contribution in wheat output growth in barani areas. Why these districts are selected again for analysis in the present study. The facts are: the occurrence of precipitation during different phenological stages of crop could have varied impacts on crop’s outputs—negative or positive; overtime the pattern of precipitation has changed—became more intense and erratic; wheat season (winter) historically has become warmer; and temperature and precipitation have interacting effects on crops’ growth. Moreover, the purpose of this study is how climatic variables influence wheat productivity and area allocation in barani areas of Punjab. Moreover, the climate is a long-term phenomenon and thus this study uses twenty years moving average of climatic variables during various phenological stages of wheat crop growth period. These reasons justify to revisiting the analysis; but, considering temperature and precipitation as climate change variables.

The variables used in the analysis can be categorized as economic variables and climatic factors. The sources of data used and construction of both types of variables are discussed the following sub-sections.

4.1.1 Climatic Variables

The study is based on climatic variables—temperature and precipitation. These are important climatic variables because agricultural sector is more susceptible to changes in climatic conditions, which affect wheat yield and acreage allocation. Wheat is a *Rabi* crop and is grown in winter season in Pakistan. Wheat growing season mostly extends from November to the end of April covering different crop growth stages—germination/tillering, vegetative growth/flowering, and grain formation/maturing covering the periods of November-December, January-February, and March-April, respectively. For acreage response, this study uses only two growth stages of wheat crop that are pre-sowing stage—the month of October, and sowing/germination stage—November and December months *(Table 4.1).* The reason is that once a crop is sown and sowing season is over, no additional area can be allocated to that particular crop.

The scientific information of production stages of these crops and their optimal temperature and precipitation were taken from the National Agriculture Research Centre (NARC), Islamabad. Different phenological stages of wheat growth along with respective duration (calendar months) were identified and are reported in Table 4.1.

Table 4.1 Different Phenological stages of wheat production

Phenological stages of wheat crop	**Month of stages**
Pre-sowing stage	October
Sowing/Tillering/Germination stage	November-December
Flowering/Vegetative stage	January-February
Grain Formation/Maturing stage	March-April

Twenty year moving average (1960-1981) of mean temperature and precipitation for each stage has been calculated that would represent the climate change normals variables. Boussios and Barkley (2010) and Cabas, *et al.* (2010) also used moving average of total precipitation and temperature for twenty years and that too during different phenological stages to find out the impact of climatic change. Furthermore, the effects of shocks are captured by using deviations in temperature and precipitation during the current year from their respective long-run means of climate normal (Cheng and Chang, 2002).

It can generally be assumed that with optimum temperature and precipitation levels, per hectare production (yield) of crop would be higher than if these indicators deviate from the ideal ranges. The empirical literature uses these variables in quadratic form. The relationship between crop yield and climate indicators (say temperature) is non-linear. The yield increases as temperature rises till it reaches at the optimum level required by the plant, and then starts declining as temperature rises above its most favorable level (Ackerman and Stanto, 2013). It is for this reason that square terms of temperature and precipitation (climatic variables) are used for this study in wheat yield model.

The data regarding climatic factors (temperature and precipitation) is collected from Pakistan Meteorological Department. Further description of the climatic variables and the units of measurement are explained in the *Table 4.2.*

Table 4.2 Sources of Climatic Variables

Variables and Units	Source
Temperature (°C)	Pakistan Metrological Department (PMD)
Precipitation (mm)	Pakistan Metrological Department (PMD)
Variation in temperature (°C)	Author’s own collection by using PMD data
Variation in precipitation (mm)	Author’s own collection by using PMD data
Square of Temperature (°C)	Author’s own collection by using PMD data
Square of Precipitation (mm)	Author’s own collection by using PMD data
Product of Temperature and Precipitation	Author’s own collection by using PMD data

4.1.2 Economic Variables:

The non-climate variables are area under wheat, market price of wheat, market price of competing crops—Barley, Gram, Rapeseed-mustard, price of fertilizer, and a yield risk variable in each selected district.

Wheat Area: Wheat area is a dependent variable as well as lagged independent variable. This variable is divided into irrigated area and un-irrigated area for the given districts. The study conducts separate analyses for rainfed and irrigated conditions to evaluate the impact of climate change on area allocation under wheat in selected districts.

Prices of Competing Crops: Barley, rapeseed-mustard and gram are used as competing crops for the estimation of area response model. These crops are also grown in winter season in Barani

Punjab. The study uses prices of Rawalpindi market for selected districts because it is nearest market of which price is available.

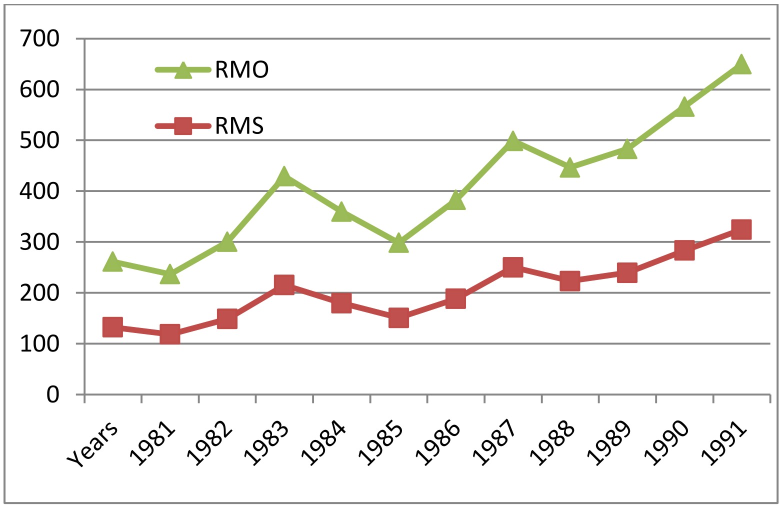
Wholesale price of gram is collected as monthly average in per 40 kgs from Agricultural Statistics of Pakistan for Rawalpindi market over the period of 1981 to 2010. Wholesale price of barley are collected as monthly average in per 40 kgs from Market Prices Bulletin[2] for Rawalpindi market over the period of 1981 to 1992. From year 1995 to 2010 the market price of barley available in World Development Indicators (WDI) in per metric ton (1000 kgs). It would be converted into per 40 kgs by using following formula:

Price in 40kg = (Price in 1000kg/1000) * 40

Wholesale price of rapeseed-mustard seed was available from Market Price Bulletin for Rawalpindi market but only for 10 years from 1981 to 1991 and rest of the data for rapeseed-mustard seed was not available. Therefore, the study would use rapeseed mustard oil as a proxy of rapeseed-mustard seed. Rapeseed-mustard oil price is also collected as monthly average in per 40 kgs from Market Prices Bulletin for Rawalpindi market over the period of 1981 to 1992. From year 1998 to 2010 the data is obtained from Agricultural Statistics of Pakistan. *Graph 4.1* shows close association between rapeseed-mustard seed and rapeseed-mustard oil, and correlation coefficient is 0.999 implying almost perfect correlation.

[2] In Markets & Prices Bulletin there was a wholesale price of agricultural commodities in important markets of Pakistan published by Agricultural and Livestock Marketing adviser (ALMA various issues). This bulletin is available in Pakistan Institute of Development of Pakistan (PIDE) library.

Graph 4.1 Graphical Presentations of Rapeseed-Mustard Seed and Oil Prices



Graph 4.1 shows that as price rapeseed-mustard seed (RMS) increases the rapeseed-mustard oil (RMO) also increases over time. The reason of increasing in the price of mustard oil is the food inflation. Mustard oil is one of the edible oils. Most of the edible oils are imported from other countries, so the prices of these oils are also depended on global prices of the edible oil (MOFAL, 2008)[3]. Therefore, rapeseed-mustard oil price can be used as proxy for seed.

Expected Yield of Wheat: Various sources of irrigation are available in barani zone including dam, tubewells, dug-wells etc. Therefore, a reasonable area of wheat under irrigation is available in barani zone. Acreage and yield respond differently to climatic and other inputs under irrigated and un-irrigated conditions. Thus, separate models for irrigated wheat and un-irrigated are estimated.

Yield of wheat (un irrigated) = wheat production (un irrigated) in thousand tones/un irrigated area under wheat in thousand hectors

Yield of wheat (irrigated) = wheat production (irrigated) in thousand tones/irrigated area under wheat in thousand hectors

[3] Report by Ministry of Food, Agriculture, and Livestock Government of Pakistan (2008)

Yield of wheat (total area) = wheat production (total area) in thousand tones/total area under wheat in thousand hectors

The expected yields of wheat are obtained as lagged five years average yield. The expected yield of crop significantly impacts crop profitability. Hence, agricultural technology has grown at various rates across crops (Boussios and Barkley, 2010). Haile, *et al*. (2015) included yield shocks as the proxy of farmers yield expectation to capture the yield trends and weather shocks, and furthermore yield expectations implied positive impact on crop supply.

Prices and share of fertilizer: The price of fertilizer is an important economic variable. The study uses prices of phosphate and urea for wheat acreage response model. It is obtained from National Fertilizer Development Centre and Provincial Bureaus of Statistics. Fertilizer includes Nitrogen, Potash and Phosphorus (NPK) in nutrient tonnes per hectare. The fertilizer data is available in aggregate form used on all crops at district level. We extracted data of fertilizer applied to wheat crop using the following formula:

$$FCC = \textit{share}FC \times TAF$$

Where FCC is fertilizer applied to wheat crop at the district level, FC is ratio of the total fertilizer nutrients used in wheat production, and TAF is total off-take of fertilizer nutrients in each selected district. The detailed information about source and units of economic variables are given below in Table 4.3.

Table 4.3 Sources of Economic Variables

Variables and Units	**Sources**
Wholesale Price of Wheat (Rs. per 40kg)	Agricultural Statistics of Pakistan

Wholesale Price of Barley (Rs. per 40kg)	Market Prices Bulletin World Development Indicator (WDI)
Wholesale Price of Rapeseed Mustard Oil/40kg	Market Prices Bulletin Agricultural Statistics of Pakistan
Wholesale Price of Gram (Rs. per 40kg)	Agricultural Statistics of Pakistan
Price of Fertilizer (Rs. Per 50kg)	National Fertilizer Development Centre (NFDC) Provincial Bureaus of Statistics
Share of Fertilizer (nutrient tonnes per hector)	National Fertilizer Development Centre (NFDC)
Area of wheat (000 ha)	Agricultural Statistics of Pakistan Crops area and Production (By Districts)
Yield of wheat (thousand tonnes per hector)	Agricultural Statistics of Pakistan Crops area and Production (By Districts)

4.1.3 Data Limitations

The study faces some limitations about availability of data for prices of crops. As barley prices are missing for some years (1992-1995), and the missing data is filled by interpolation. For the same crop, the prices data was not available after 1992. Therefore, the price of barley at country level was used. Rapeseed mustard oil price is used as its proxy due to non availability of data for rapeseed mustard seed. Through interpolation some missing values of rapeseed mustard price are also filled to overcome the data limitation issue. Moreover, data on tractors and tubewells were also missing for different years. The effect of geographic variables such as soil type and altitude are not included because panel data has the special features to absorb the effect of unobservable factors.

4.2 Empirical Model for Acreage Response

Based on theoretical and empirical presumptions of impact of climate change on acreage response of wheat crop and incorporating possibility of non-linear impacts of climatic variables—precipitation and temperature, the econometric model is specified for unirrigated area as:

$$\ln UA_{W,it} = \beta_0 + \beta_1 \ln(UA)_{W,t-1} + \beta_2 \ln(WP)_{i,t-1} + \beta_3 \ln(BP)_{i,t-1} + \beta_4 \ln(GP)_{i,t-1} + \beta_5 \ln(RMP)_{i,t-1}$$
$$+ \beta_6(PST) + \beta_7(PSP) + \beta_8(SST) + \beta_9(SSP) + \beta_{10}(PSVT) + \beta_{11}(PSVP) + \beta_{12}(SSVT) + \beta_{13}(SSVP)$$
$$+ \beta_{14} \ln(PUrea)_{i,t-1} + \beta_{15} \ln(PDAP)_{i,t-1} + \beta_{16} \ln(EY_U)_{it} + e_{it}$$

The empirical model for irrigated area is given below:

$$\ln IA_{W,it} = \beta_0 + \beta_{21} \ln(IA)_{W,t-1} + \beta_{22} \ln(WP)_{i,t-1} + \beta_{23} \ln(BP)_{i,t-1} + \beta_{24} \ln(GP)_{i,t-1} + \beta_{25} \ln(RMP)_{i,t-1}$$
$$+ \beta_{26}(PST) + \beta_{27}(PSP) + \beta_{28}(SST) + \beta_{29}(SSP) + \beta_{30}(PSVT) + \beta_{31}(PSVP) + \beta_{32}(SSVT) + \beta_{33}(SSVP)$$
$$+ \beta_{34} \ln(PUrea)_{i,t-1} + \beta_{35} \ln(PDAP)_{i,t-1} + \beta_{36} \ln(EY_I)_{it} + e_{it}$$

The empirical model for total area is given below:

$$\ln TA_{W,it} = \beta_0 + \beta_{41} \ln(TA)_{W,t-1} + \beta_{42} \ln(WP)_{i,t-1} + \beta_{43} \ln(BP)_{i,t-1} + \beta_{44} \ln(GP)_{i,t-1} + \beta_{45} \ln(RMP)_{i,t-1}$$
$$+ \beta_{46}(PST) + \beta_{47}(PSP) + \beta_{48}(SST) + \beta_{49}(SSP) + \beta_{50}(PSVT) + \beta_{51}(PSVP) + \beta_{52}(SSVT) + \beta_{53}(SSVP)$$
$$+ \beta_{54} \ln(PUrea)_{i,t-1} + \beta_{55} \ln(PDAP)_{i,t-1} + \beta_{56} \ln(EY_T)_{it} + e_{it}$$

Where A_{it}, $WP_{i,t-1}$, $GP_{i,t-1}$, $Bp_{i,t-1}$, EY_{it}, SST and PSP are independent variables respectively representing area under wheat, lagged wheat price, lagged competing crop prices, expected yield, temperature normal—twenty years moving average, and precipitation normal—twenty years moving average.

The subscripts *i* and *t* respectively denote district and year identifications of the panel data set; *βs* are parameters to be estimated and e_{it} is the error term. For climatic factors linear as well as variation terms are included in wheat acreage response model.

4.3 Econometric Model for Wheat Acreage

This study uses panel data for 30 years from four districts of Barani Punjab. Panel data is the combination of time series and cross-sectional data. It is also called a pooled data. The advantage of using panel data is that it controls the individual heterogeneity and is more informative. Moreover, the panel data helps yield such estimates/effects that are not easily measurable in pure cross section or pure time-series data. There is less collinearity among variables in panel data. Pooling cross-sectional and time series observations provide more degrees of freedom and thus better estimates can be obtained. The problem of omitted variables, which may cause biased estimates in a single individual regression, might not occur in panel context.

4.3.1 Generalized Method of Moments (GMM)

Generalized method of moments is used to estimate dynamic panel model. Arellano and Bond (1991) developed a most efficient estimator called Difference Generalized Method of Moments (GMM). The GMM is a large-sample estimator. These estimators are asymptotically efficient in a large class, and this method is suitable for estimation of reduced equations involving lagged dependent variable. Moreover, it provides a useful framework for estimators' comparison and evaluation (Johnston and DiNardo, 1997). The model can be written as:

$$y_{it} = \gamma y_{i,t-1} + x'_{1it}\beta_1 + x'_{2it}\beta_2 + z'_{1i}\alpha_1 + z'_{2i}\alpha_2 + u_{it} \qquad \text{..........4.1}$$

$$y_{it} = \delta' w_{it} + u_{it} \qquad \text{..........4.2}$$

where

$$w_{it} = (y_{i,t-1}, x'_{1it}, x'_{2it}, z'_{1i}, z'_{2i}) \qquad \text{..........4.3}$$

In $Equation\ 4.1$ the set of right hand side variables now include the lagged dependent variable, $y_{i,t-1}$. The lagged dependent variable is correlated with the disturbance term.

$$COV[X_t, \varepsilon_s] = 0 \text{ if } s \geq t \ldots\ldots 4.4$$

$$\neq 0 \text{ if } s < t$$

In several studies, crop acreage response models assumed log linear functional form mainly for convenience of interpretation (e.g., Lee and Helmberger, 1985; Haile, *et al.* 2015; Trabulsi, 2013). Linear functional form is used for our acreage model. Endogeneity problem may arise due to inclusion of lagged acreage, input and output price variable because of the presence of independent variables in the acreage model. Due to the inclusion of lagged dependent variable as independent as well as noticing its correlation with disturbance term, the endogeneity is observed; it can be seen in Equation 4.4. Therefore, the study uses dynamic GMM technique to overcome the problem of endogeneity as well as lagged dependence (Greene, 2006). In addition, lagged dependent as an independent variable may create the problem of autocorrelation. Arellano-Bond difference GMM estimator is introduced in model to control for the problem of autocorrelation (Mythili, 2006). In the “Arellano-Bond GMM estimation” the instrumental variables that are used include: lagged temperature and precipitation at different stages, prices of different competing crops, yields of competing crops and price of fertilizer due to their influence on price expectations and therefore on crop acreage decisions.

4.4 Empirical Yield Model

The detailed empirical production function being followed in present study for yield under un-irrigated conditions can be written as:

$$\ln Y_{U,it} = \beta_0 + \beta_{11}TEMP_{ND} + \beta_{22}TEMP_{JF} + \beta_{33}TEMP_{MA} + \beta_{44}PREC_{ND} + \beta_{55}PREC_{JF} + \beta_{66}PREC_{MA}$$
$$+ \beta_{77}(TEMP_{ND})^2 + \beta_{88}(TEMP_{JF})^2 + \beta_{99}(TEMP_{MA})^2 + \beta_{111}(PREC_{ND})^2 + \beta_{221}(PREC_{JF})^2 +$$
$$\beta_{331}(PREC_{MA})^2 + \beta_{441}VTEMP_{ND} + \beta_{551}VTEMP_{JF} + \beta_{661}VTEMP_{MA} + \beta_{771}VPREC_{ND} + \beta_{881}VPREC_{JF}$$
$$+ \beta_{991}VPREC_{MA} + \beta_{112}(TEMP_{ND} \times PREC_{ND}) + \beta_{222}(TEMP_{JF} \times PREC_{JF})$$
$$+ \beta_{332}(TEMP_{MA} \times PREC_{MA}) + \beta_{442}\ln(UAREA) + \beta_{552}T + \beta_{662}\ln(F) + \mu_{it}$$

The yield model under irrigated conditions can be written as:

$$\ln Y_{I,it} = \beta_0 + \beta_{101}TEMP_{ND} + \beta_{202}TEMP_{JF} + \beta_{303}TEMP_{MA} + \beta_{404}PREC_{ND} + \beta_{505}PREC_{JF} + \beta_{606}PREC_{MA}$$
$$+ \beta_{707}(TEMP_{ND})^2 + \beta_{808}(TEMP_{JF})^2 + \beta_{909}(TEMP_{MA})^2 + \beta_{110}(PREC_{ND})^2 + \beta_{220}(PREC_{JF})^2 +$$
$$\beta_{330}(PREC_{MA})^2 + \beta_{440}VTEMP_{ND} + \beta_{550}VTEMP_{JF} + \beta_{660}VTEMP_{MA} + \beta_{770}VPREC_{ND} + \beta_{880}VPREC_{JF}$$
$$+ \beta_{990}VPREC_{MA} + \beta_{117}(TEMP_{ND} \times PREC_{ND}) + \beta_{223}(TEMP_{JF} \times PREC_{JF})$$
$$+ \beta_{335}(TEMP_{MA} \times PREC_{MA}) + \beta_{447}\ln(IAREA) + \beta_{555}T + \beta_{666}\ln(F) + \mu_{it}$$

For climatic factors linear as well as quadratic terms are included in the model to capture possible non-linear relationship between wheat yield and climatic variables. Similarly, interactions of temperature and precipitation are also included to capture the joint impact of these climatic factors.

4.5 Econometric Model for Wheat Yield Models

The literature on panel data basically proposes two different approaches to estimate the country specific effects, the random effects model (REM) and the fixed effects model (FEM). The motivation behind these techniques is the problem of omitted variables' effects which lead to unobserved effects in the panel data.

4.5.1 Fixed Effects Model (FEM)

The unobserved effects could be time-wise or cross section wise that depend upon the objectives of the study. In agriculture, these are usually time invariant because of the agroecological characteristics of the specific region in different time horizons. The FEM can be written as

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.5$$

$$U_{it} = \alpha_i D_i + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.6$$

By substituting equation 4.6 in 4.5 would result in

$$Y_{it} = \beta_0 + \beta_i X_{it} + \alpha_i D_i + \varepsilon_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.7$$

Where X_{it} are explanatory variables like cropped area, fertilizer and climatic factors etc., β_i, is the vector parameters of X_{it} conditional on Y_{it} and effects are denoted by $\alpha_i D_i$, where α_i is called as individual heterogeneity and dummy (D) captures characteristics that are specific to soil qualities, district climatic variables other than temperature and precipitation, and knowledge of farm practices that make a district different than others (Bell and Jones, 2015). A fixed effect model also shows that fixed term in the model is correlated with explanatory variables: cross-section specific characteristics. In agriculture, the fixed effects model is used when sample is not chosen randomly (Wooldridge, 2002).

4.5.2 Random Effects Model (REM)

Fixed or random effects model is determined on the basis of unobserved effects. If unobserved effects are determined as random variable then the random effects model is applied for study (Wooldridge, 2002). The REM can be written as

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.8$$

$$U_{it} = v_i + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.9$$

$$Y_{it} = \beta_0 + \beta_i X_{it} + v_i + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 4.10$$

The REM assumes zero correlation between explanatory variables and random effects, which is a very strong assumption (Wooldridge, 2002). Due to measurement or sample selection error, endogeneity problem may arise. It may happen due to omitted variable problem. If endogeneity problem exists, then model will be estimated through instrumental approach (Mundlak, 1978).

In order to check the existence of fixed or random effect in the model, Hausman[4] specification test is applied. This test is based on the hypothesis that explanatory variables and the error term have no correlation; under this condition if chi-square statistic is significantly different than the critical value then we reject the null hypothesis that validates the fixed effects model and it is considered more appropriate for study analysis.

4.6 Unit Root Test

Panel unit root or stationary tests have been widely used over the last decade. This is largely due to the availability of panel data with long time span, and the growing use of cross-country and cross-region data over time to test for many important economic inter-relationships, especially those involving convergences/divergences of various economic variables[5]. The panel unit root tests are used to check whether the variables are stationary or non-stationary. The standard errors of non-stationary variables are biased; that may create spurious regression. Panel unit root tests would be checked to avoid any spurious regression.

There are many tests for panel unit root. Levin and Lin (1992) (LL) and Im, Pesaran and Shin (1997) (IPS) tests are commonly used to check stationarity of variables through panel unit root.

[4] Hausman (1978)
[5] Mahadeva and Robinson (2004)

4.6.1 The Levin and Lin (LL) test

The first panel unit-root test was introduced by Levin and Lin (1992)[6]. LL test has a following form

$$\Delta Y_{i,t} = a_i + \rho Y_{i,t-1} + \sum_{k=1}^{n} \phi_k \Delta Y_{i,t-k} + \delta_i t + \theta_t + u_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

Where, $\delta = (\rho - 1)$

$\Delta Y_{t-1} =$ lagged of dependent variables

t= time or trend variable

u= white noise error term

ρ = coefficient of unit root

ϕ_k = vector of parameters

Equation 4.11 allows two-way fixed effects, one from a_i and other from θ_t. It also allows fixed effects, individual deterministic trends and heterogeneous serial correlation.

The null and alternative hypotheses of this test are:

$H_o : \rho = 0$

$H_a : \rho \prec 0$

Under null hypothesis ρ are equal to zero indicating panel series contain unit root. Alternatively, if the ρ parameter for any cross-section is less than zero then the panel series is said to be stationary.

4.6.2 The Im, Pesaran and Shin (IPS) test

Im, *et al.* (1997) extended the LL test, which is written as:

[6] Asteriou and Hall (2007)

$$\Delta Y_{i,t} = a_i + \rho_i Y_{i,t-1} + \sum_{k=1}^{n} \phi_{ik} \Delta Y_{i,t-k} + \delta_i t + u_{it} \quad \text{.......................................} \; 4.12$$

IPS test allows separate estimations for each i, allowing different specifications of the parametric values, the residual variance and the lag lengths.

The null and alternative hypotheses of this test are:

$H_o : \rho_i = 0$ for all i

$H_a : \rho \prec 0$ for at least one i

The null of this test is that all series are not stationary, and under the alternative that fractions of the series in the panel are to be stationary.

Chapter 5

Trends of Climatic Variables in Sampled Districts

Climate change is a global phenomenon and Pakistan is no exception. There has been general argument that temperature is on the rise and the rainfall has declined and became more erratic over time. However, the trends may vary from country to country and from region to region (even from district to district) within a country. Therefore, this chapter is devoted to analyzing the trends in climatic variables—temperature and precipitation. As discussed previously, climate change is a long-term phenomenon, and we took 20 years moving average of these variables (called climate normal) to evaluate the impact on area cultivated under wheat and wheat yield. The climate change impacts vary among different growth stages of the crop (Ahmad, et al., 2014). Since this study deals with area and yield responses to climate change in rain-fed (barani) region, trends in climate variables—temperature and precipitation, across phenological stages of wheat crop season, are discussed. In this regard, we rely on graphical exposition just to get better picture of the trends and climatic behavior.

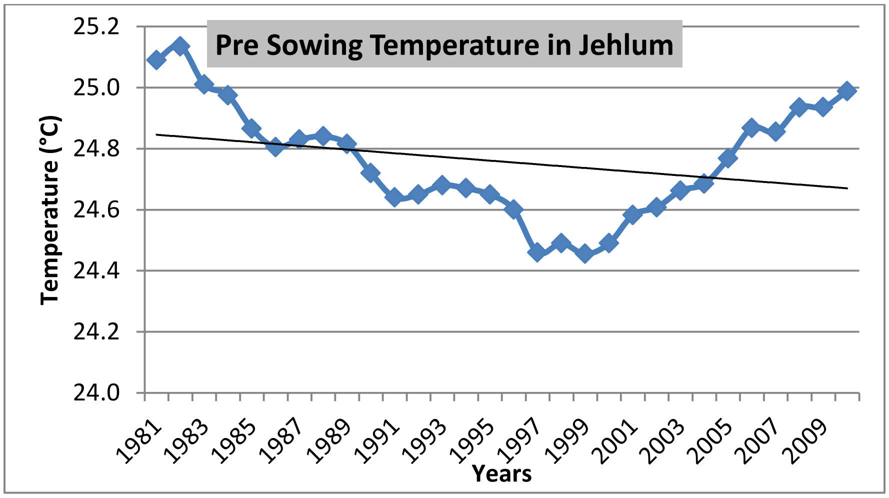
5.1 Temperature Normals during Phenological Stages

a) Pre Sowing Stage Temperature (PST)

The pre-sowing period in barani areas of Punjab is October month. The graphs represents 20 year moving averages of temperature and precipitation during the various crop growth stages in selected wheat growing districts of Barani Punjab.

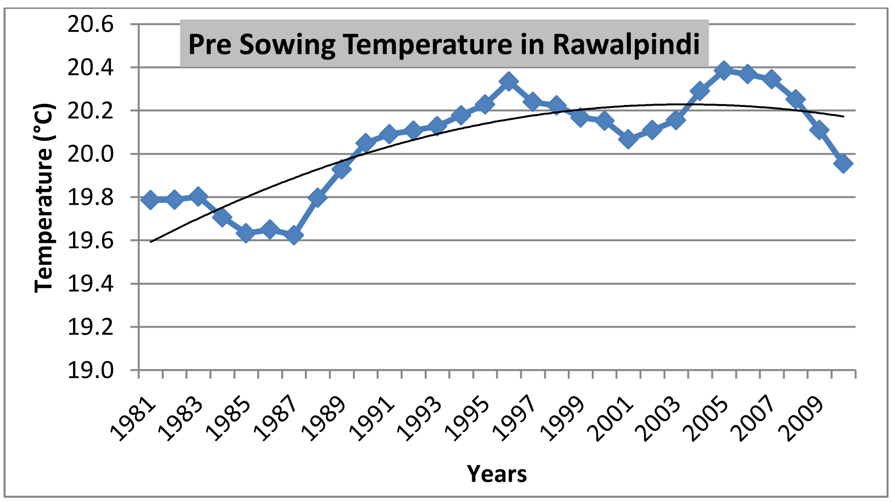
Graph 1 shows the temperature for pre-sowing stage of wheat in Jehlam district. It indicates that temperature declined till 1999. However, it continued to rise since then till recently.

Graph 1 Pre Sowing Temperature for Jehlam



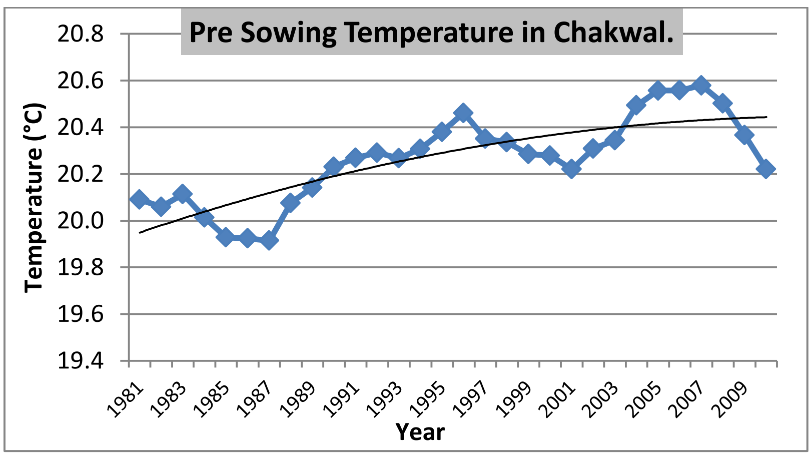
Graph 2 shows the temperature trend for pre sowing stage of wheat at Rawalpindi district. The graph shows that first temperature increased from year 1987 to 1996 then it declined till 2001. It has again shown increasing trend till 2005. It has however experienced decreasing trend during the last at least one decade. The Graph 2 however clearly shows that the temperature has been rising over the last three decades in district Rawalpindi.

Graph 2 Pre Sowing Temperature for Rawalpindi



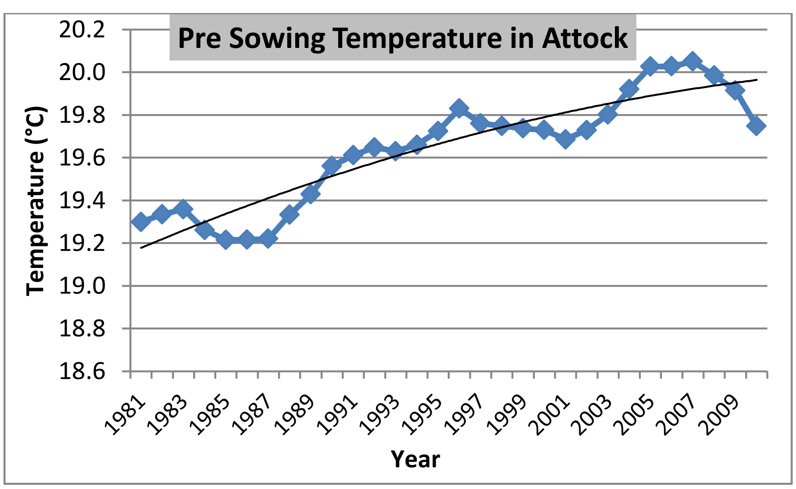
Graph 3 presents the trend of temperature for Chakwal district and shows mixed trends: declined till the end of 1980s; then increased till the mid of 1990s; declined in second half of the 1990s; and rose again during the first half of the 2000s followed by declining trend till recently. However, the overall temperature trend shows that it has risen over the last three decades in Chakwal. The similar trend is observed in Attock district over the same period.

Graph 3 Pre Sowing Temperature for Chakwal



Graph 4 shows temperature of district Attock. It has increasing and then decreasing trend in temperature. It shows decreasing after mid of 2000s till recently.

Graph 4 Pre Sowing Temperature for Attock

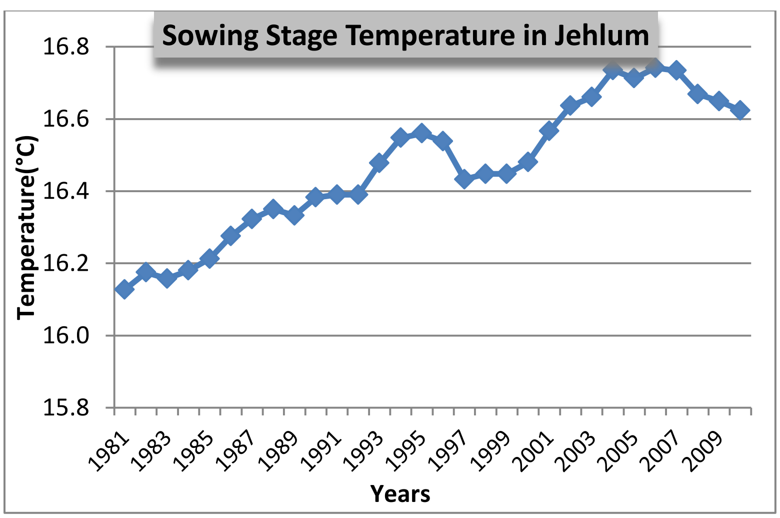


b) Sowing Stage Temperature (SST)

Sowing/Germination is the second phenological stage of the study. November to December is the sowing stage of wheat in Barani area of Punjab. It is believed that temperature has increased and precipitation declined over the time. Some evidence from literature[7] as well as current study shows that temperature has increased over time during November-December months.

Graph 5 shows increasing trend of temperature in district Jehlam during the sowing period of wheat. However, it is evident from the graph that after reaching at peak in 2006, the temperature show declining trend in recent years. It can however be concluded that long term temperature trend shows a sustained upward movement during the sowing period of wheat in Jehlum district.

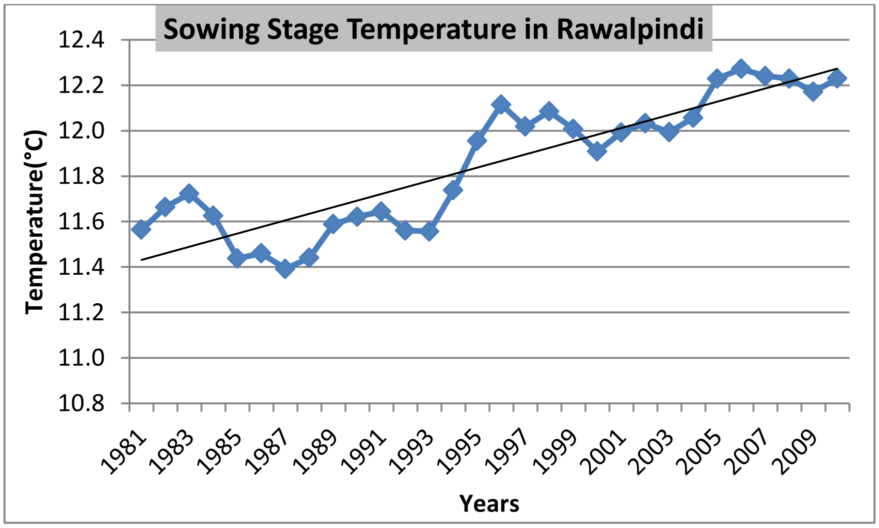
Graph 5 Sowing Stage Temperature for Jehlam



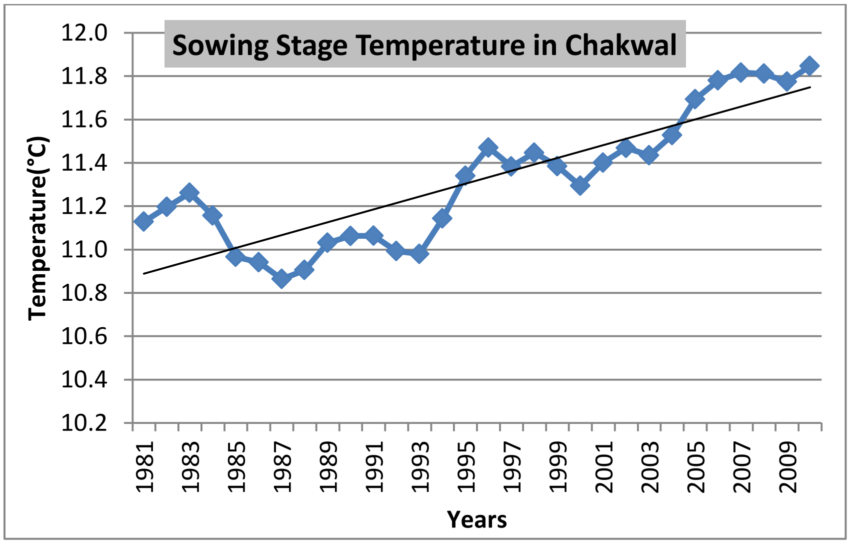
[7] Ahmad et al. (2014)

The similar trend is observed in Graphs 6 and 7 for Rawalpindi and Chakwal districts where the long term temperature during the sowing period of wheat has continued to rise till recently.

Graph 6 Sowing Stage Temperature for Rawalpindi

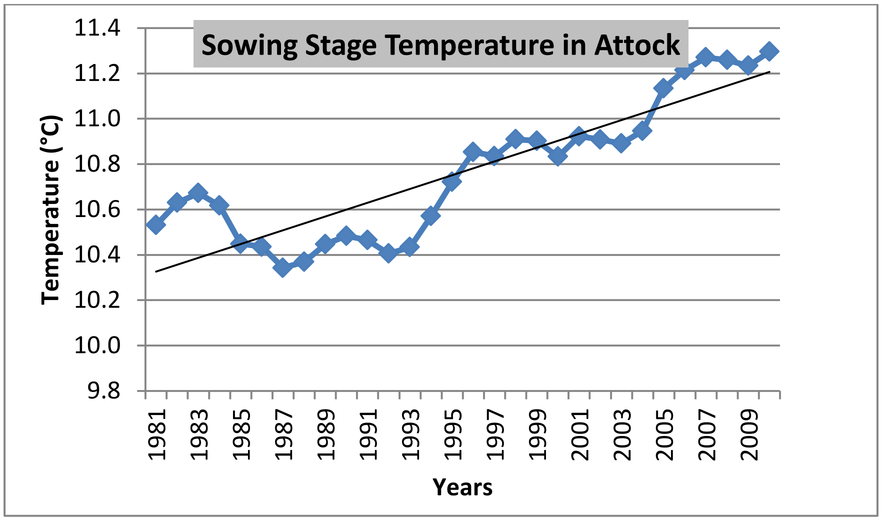


Graph 7 Sowing Stage Temperature for Chakwal



Graph 8 shows increasing trend of temperature after 1990s till recently in Attock district of Barani Punjab for sowing stage of wheat area.

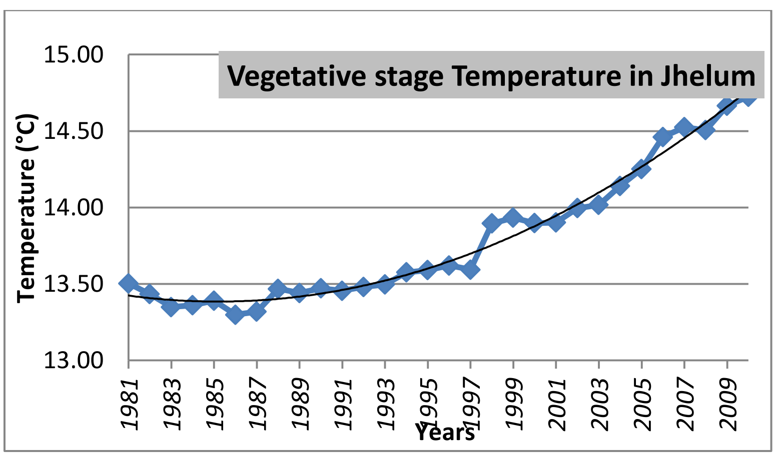
Graph 8 Sowing Stage Temperature for Attock



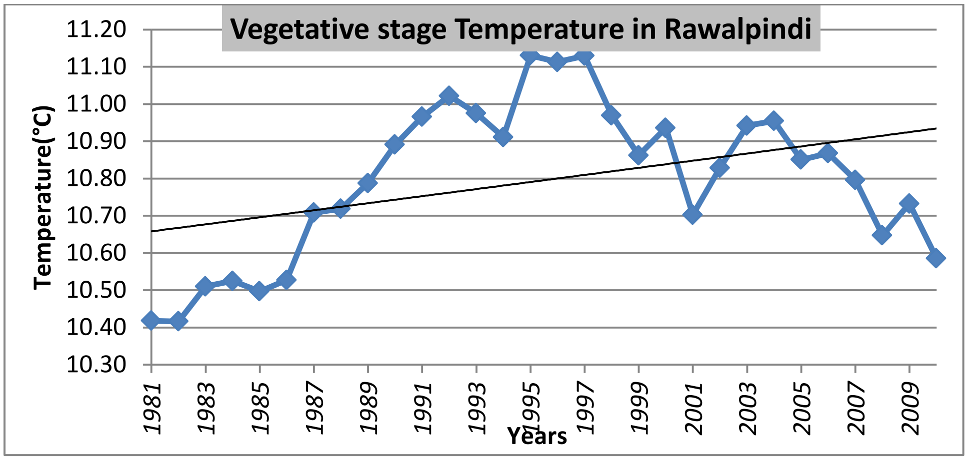
c) Vegetative Stage Temperature (VST):

Vegetative growth/flowering stage is phenological stage of wheat yield. The vegetative stage covers the months of January to February. Trend lines in Graphs 10-12 show that temperature declined in all districts of barani Punjab during the last 15 years except district Jehlam (Graph 9) where rising trend is observed.

Graph 9 Vegetative Stage Temperature for Jhelum

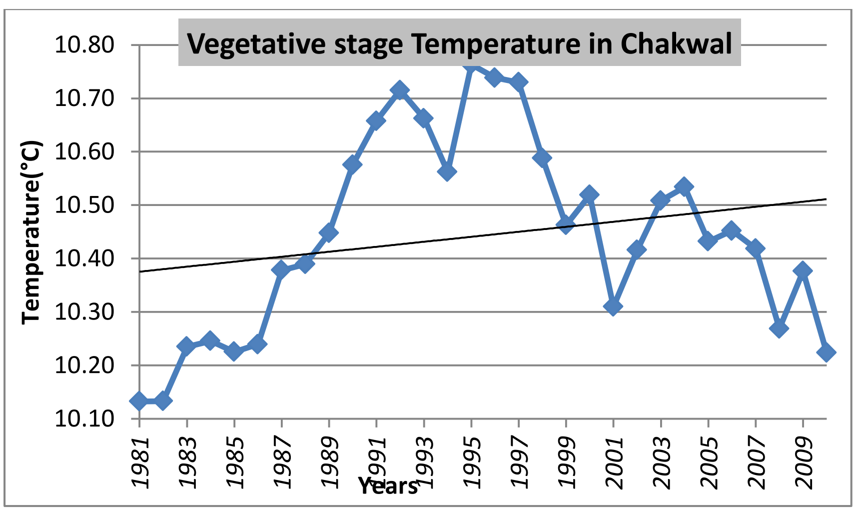


Graph 10 Vegetative Stage Temperature for Rawalpindi



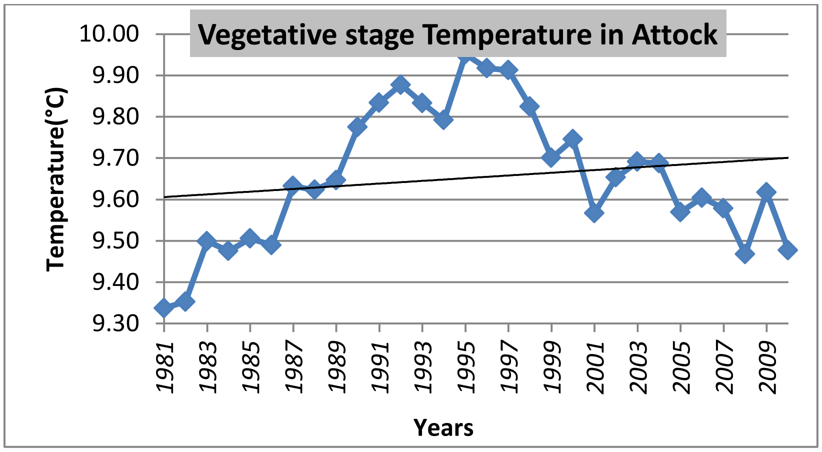
Graph 11 for district Chakwal has almost same trend line as district Rawalpindi. The temperature increases year by year and then starts decreasing after year 1995.

Graph 11 Vegetative Stage Temperature for Chakwal



The temperature for month of January to February for Attock is shown in Graph 12.

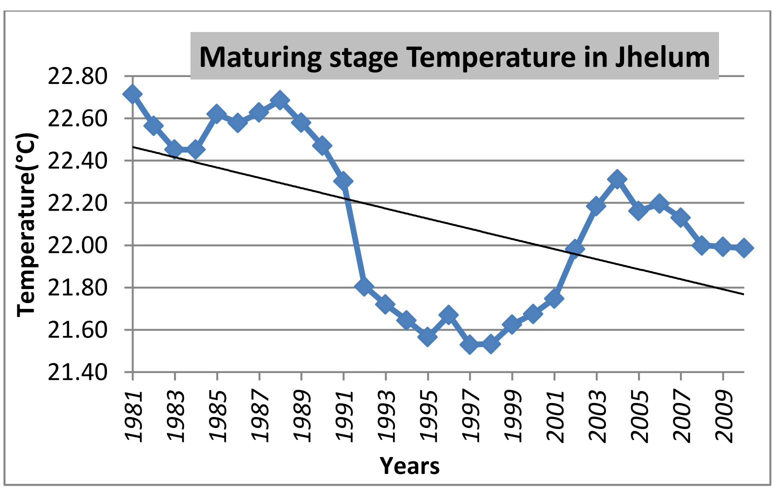
Graph 12 Vegetative Stage Temperature for Attock



d) Maturity Stage Temperature (MST)

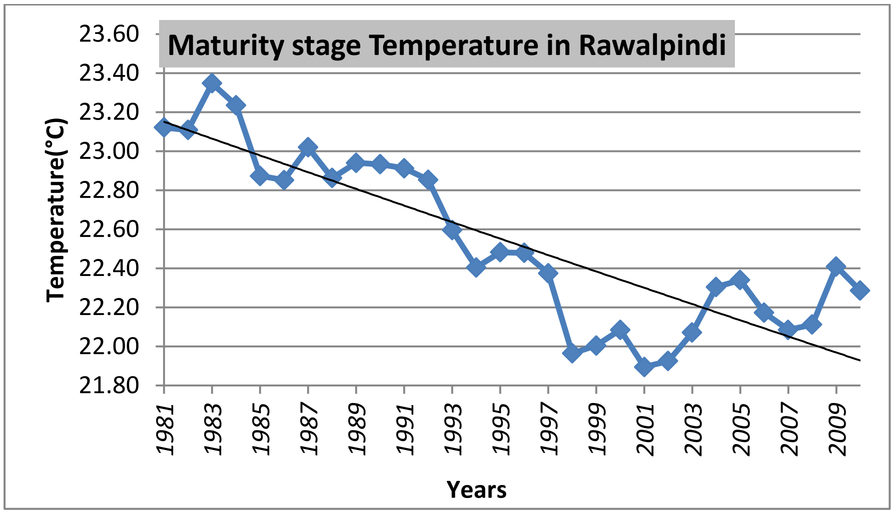
The last stage for wheat crop is grain formation/ maturing stage. This stage covers the months of March to April. Graph 13 shows that the mean temperature declined from 1981 to 1997 and then increased till the year 2003. After that a declining trend in temperature was observed till 2010—the last year of the data used in this thesis.

Graph 13 Maturing Stage Temperature for Jhelum



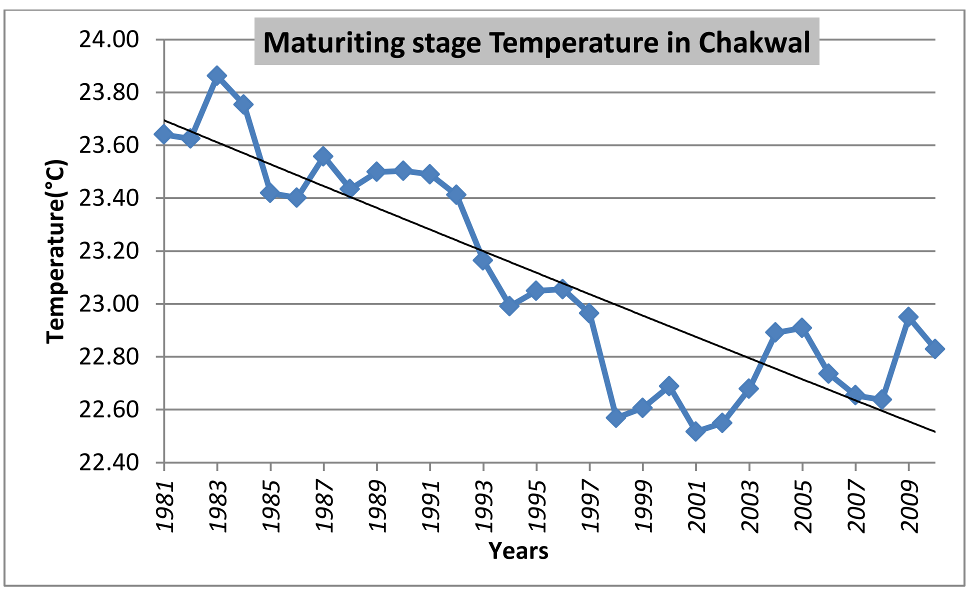
Graph 14 shows that the temperature during the wheat maturity and harvest period declined till 2001 and started rising since then.

Graph 14 Maturing Stage Temperature for Rawalpindi

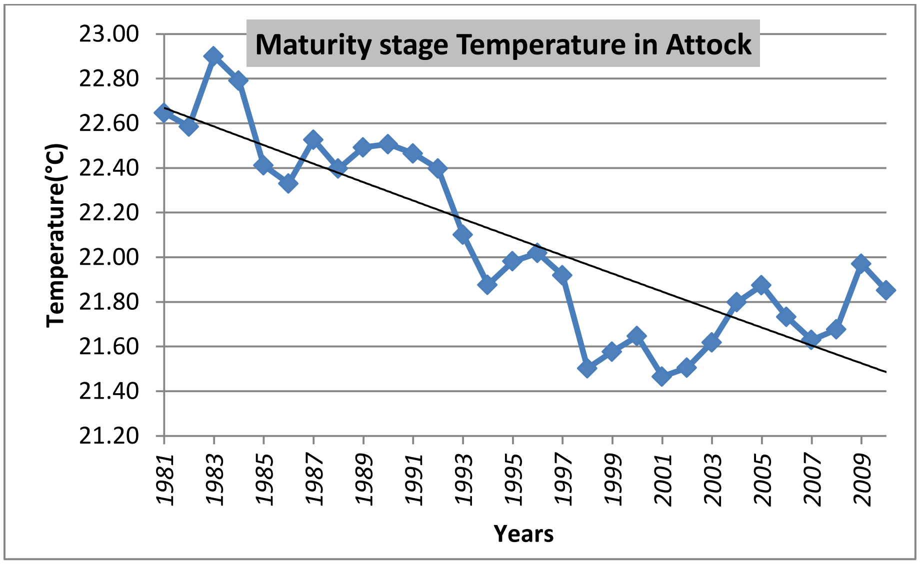


Next two graphs relate to districts of Chakwal and Attock, which also exhibit the same trend as observed in Rawalpindi.

Graph 15 Maturing Stage Temperature for Chakwal



Graph 16 Maturing Stage Temperature for Attock

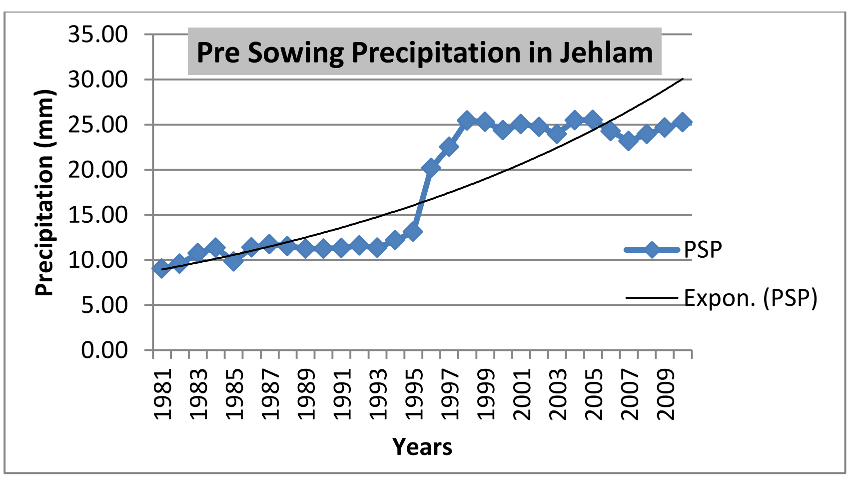


5.2 **Precipitation Normals during Phenological Stages**

a) Pre Sowing Stage Precipitation (PSP)

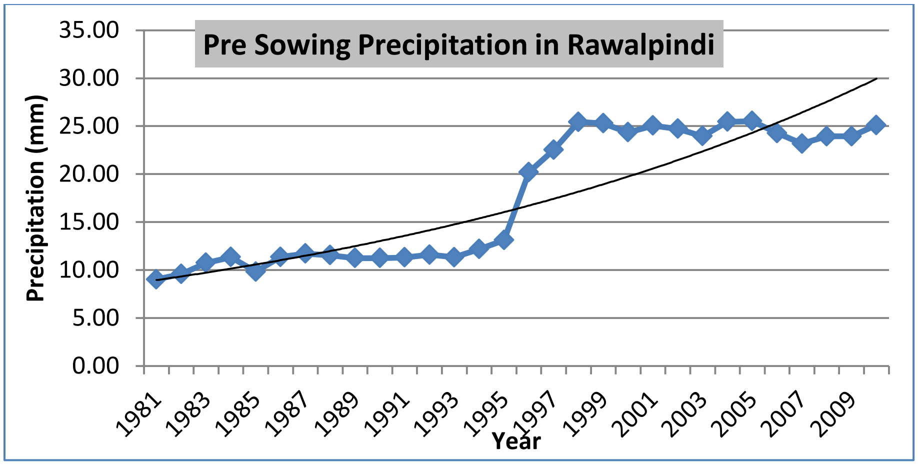
Precipitation is also showing different trends over the years just like temperature. The selected districts are near to each other but still trends of precipitation vary from district to district. Graph17 shows the increase of precipitation during October month in district Jehlam.

Graph 17 Pre Sowing Stage Precipitation for Jehlam



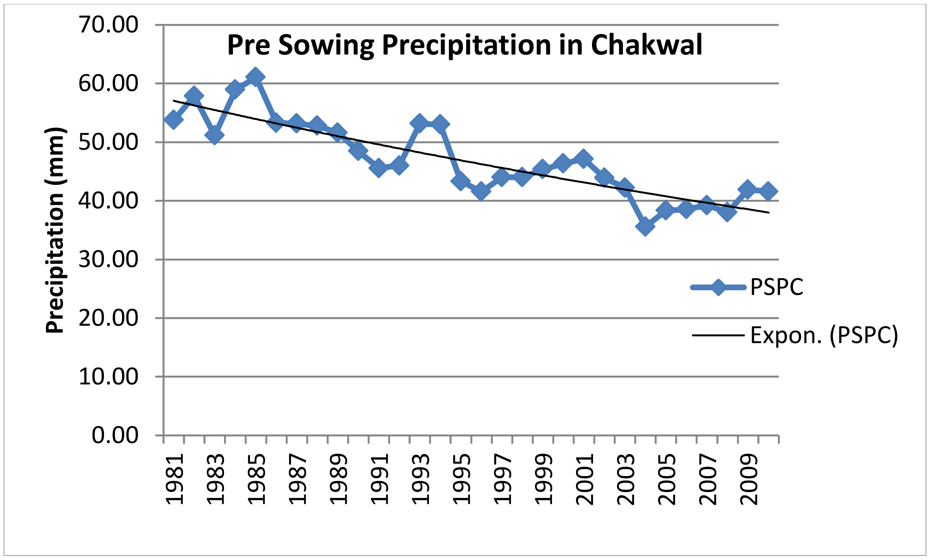
Graph 18 also shows almost the same pattern in Rawalpindi as in Jhelum. However, since 1999 the quantity of precipitation stagnated.

Graph.18 Pre Sowing Stage Precipitation for Rawalpindi



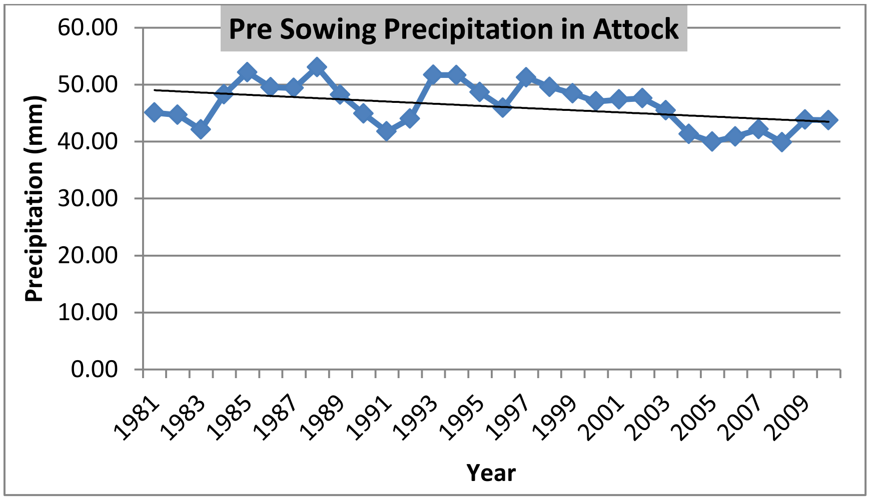
The graph 19 indicates that precipitation during pre-sowing stage has been declining since 1981 in Chakwal.

Graph.19 Pre Sowing Stage Precipitation for Chakwal



Graph 20 shows that district Attock is experiencing declining trend in pre-sowing precipitation.

Graph 20 Pre Sowing Stage Precipitation for Attock

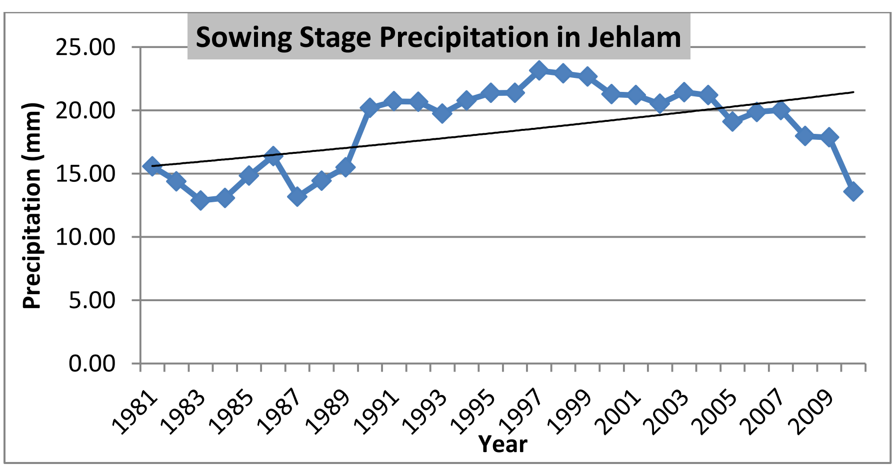


b) Sowing Stage Precipitation (SSP)

As mentioned earlier, November-December is the sowing stage for wheat crop. Graphical presentations of precipitation for selected districts during sowing stage are reported in this section.

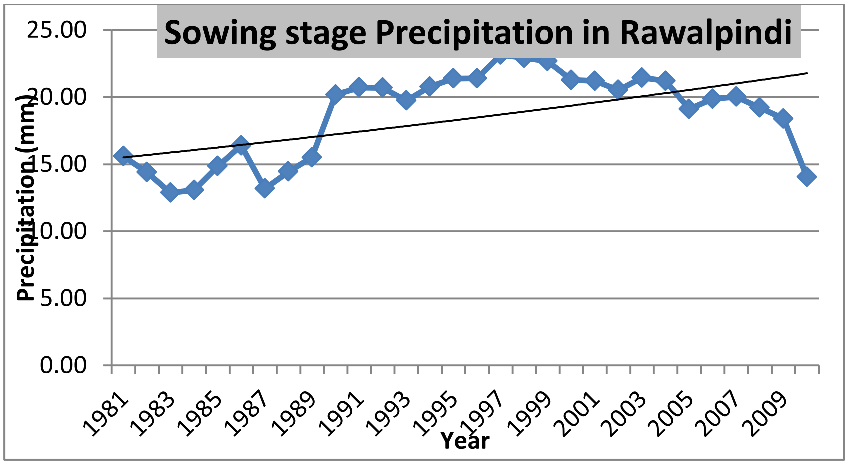
Graph 21 shows that precipitation during November-December in district Jehlam increased till 1997 and since then the precipitation has continuously been declining in the district.

Graph 21 Sowing Stage Precipitation for Jehlam



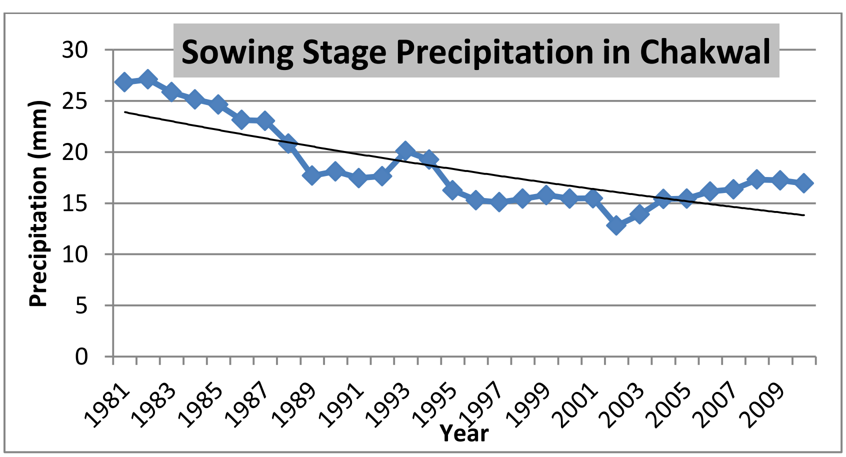
Graph 22 presents the sowing stage precipitation for Rawalpindi district. It shows almost the same trend as observed in district Jehlum. The precipitation rose till 1997 and the district has been experiencing declining trend since then till recently.

Graph 22 Sowing Stage Precipitation for Rawalpindi



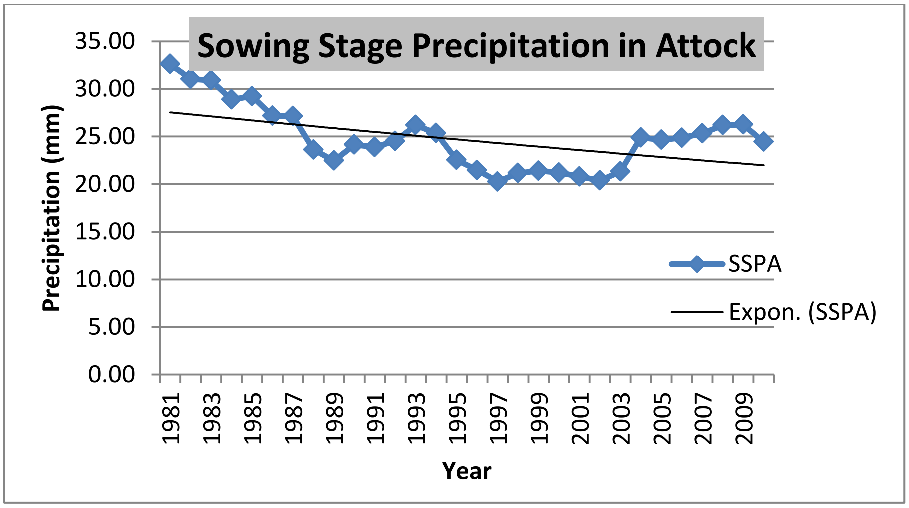
The precipitation trend in district Chakwal is presented in Graph 23. It shows that the precipitation during the wheat sowing months has continuously been declining since 1981. However, a slight increase in rainfall is being experienced during the sowing stage of wheat in this district since the early 2000s.

Graph 23 Sowing Stage Precipitation for Chakwal



Graph 24 portrays the precipitation trend in district Attock during the sowing period of wheat. First it declined till 1989 and then increased up to 1993. It again started declining (till 1994); however, the precipitation has slightly been increasing since 1994 till recently.

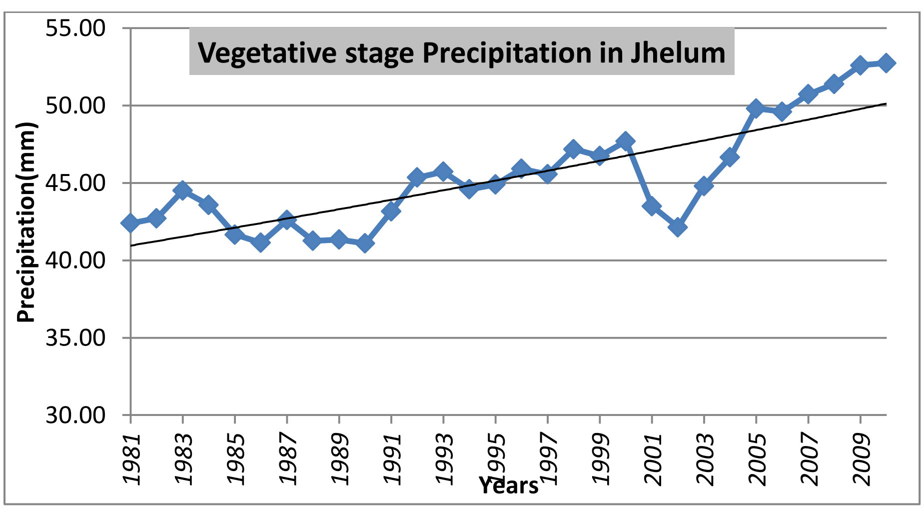
Graph 24 Sowing Stage Precipitation for Attock



c) Vegetative Stage Precipitation (VSP)

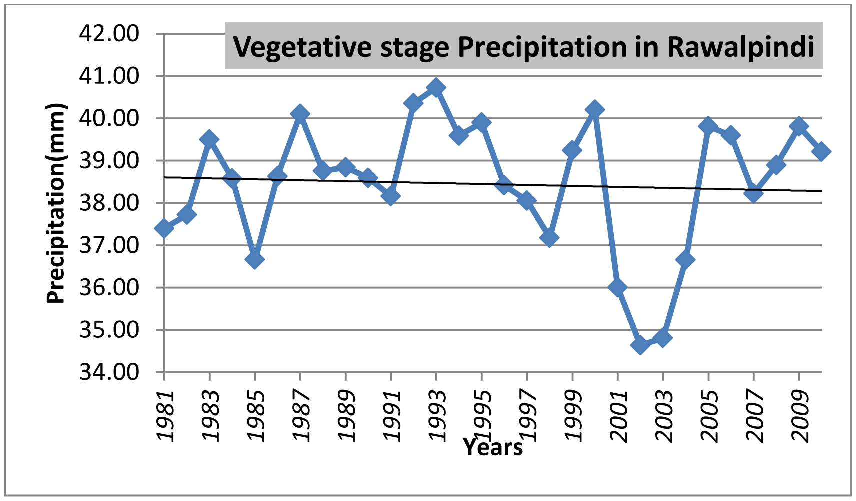
Precipitation for the months of January-February for selected districts of Punjab is discussed. Graph 25 shows that vegetative stage of wheat growth has been experiencing a reasonable increase in precipitation in district Jehlam.

Graph 25 Vegetative Stage Precipitation for Jhelum



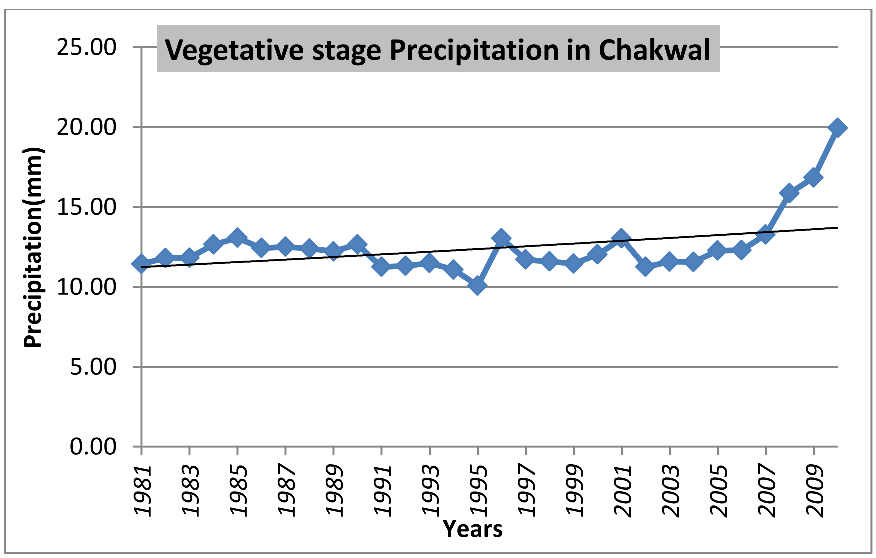
Graph 26 shows that vegetative stage precipitation in district Rawalpindi exhibits wide-ranging fluctuations during the 30 years period, and however no significant increase is observed.

Graph 26 Vegetative Stage Precipitation for Rawalpindi

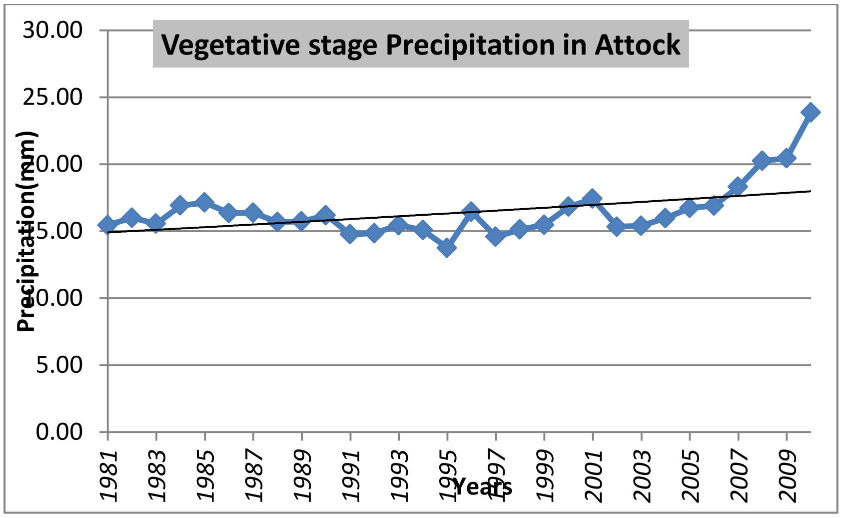


Graphs 27 and Graph 28 show no significant increase in precipitation in Chakwal and Attock districts till the end 1990s; however, precipitation increased during the 2000s.

Graph 27 Vegetative Stage Precipitation for Chakwal



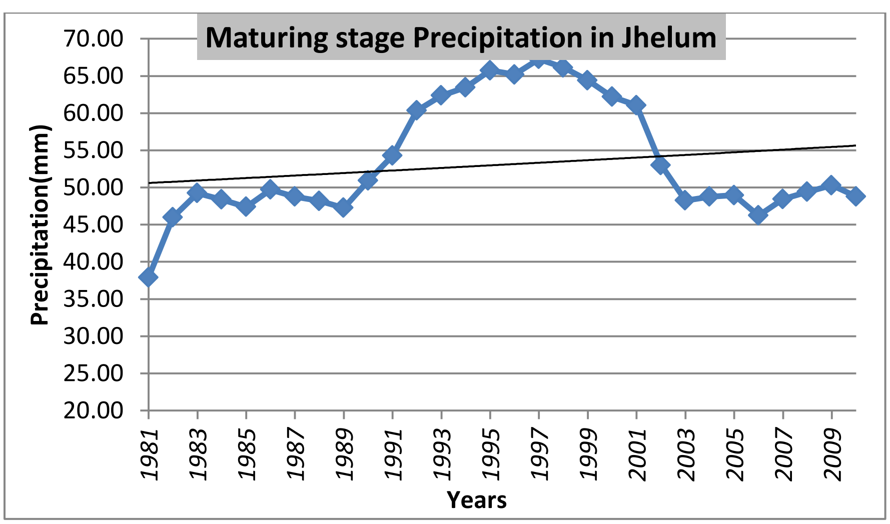
Graph 28 Vegetative Stage Precipitation for Attock



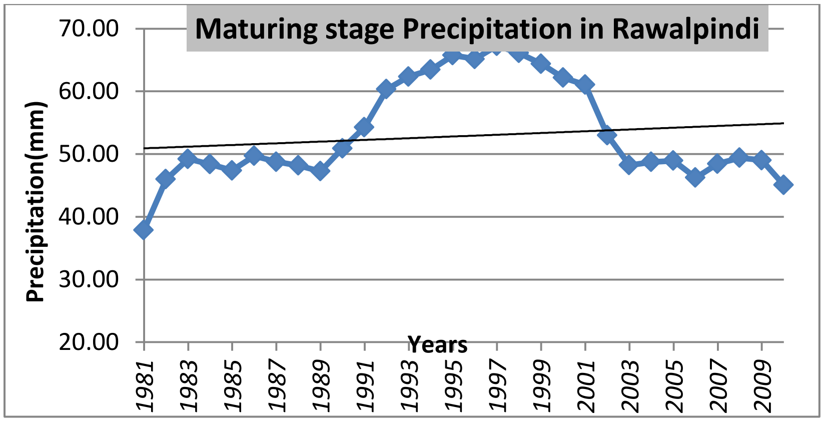
d) Maturing Stage Precipitation (MSP)

Increasing trend in precipitation was observed during March-April months till 1997. However, after this period the occurrence of precipitation during maturity and harvest stage of wheat declined significantly till 2006 in both the districts of Jhelum and Rawalpindi (Graph 29, Graph 30).

Graph 29 Maturing Stage Precipitation for Jhelum

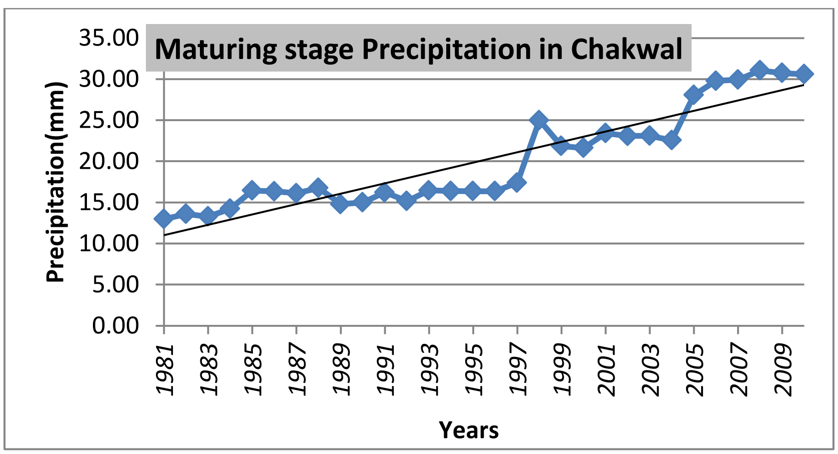


Graph 30 Maturing Stage Precipitation for Rawalpindi

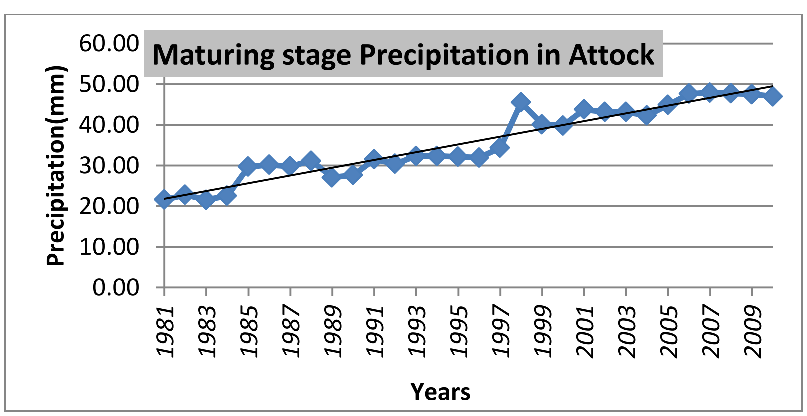


Graphs 31 and 32 shows that precipitation has increased in districts of Chakwal and Attock during the study period.

Graph 31 Maturing Stage Precipitation for Chakwal



Graph 32 Maturing Stage Precipitation for Attock



5.3 Conclusion

Climatic variables (Temperature and Precipitation) show unique trends for each selected district. Overall change of temperature in pre-sowing (October) and sowing stage (November-December) for wheat crop increased with the study period. While, vegetative and maturity stage temperature indicate decreasing trend. Precipitation for all stages of wheat has upward trend except pre-sowing stage where precipitation declined with given years.

Chapter 6

Results and Discussions

6.1 Introduction

The empirical models are estimated using fixed effect estimation techniques and generalized method of moments (GMM) as described in Chapter 4. Acreage response and yield of wheat crop are regressed on climatic (precipitation and temperature) and non-climatic variables. The detailed discussion and interpretation of the results in the subsequent sections are preceded by unit root tests for all variables of study.

6.2 Tests of the data and Model

It is essential to see the nature of data prior to estimation of models. This is done by using appropriate technique for estimation. A researcher needs to know whether the data being used for the study is having unit root or is it stationary. If there exist individual effects, it is necessary to know that: Is the data cross section specific, period specific or both? Are un-observed individual effects randomly distributed or fixed constant independent of the explanatory variables?

6.2.1 Panel Unit root tests

This study utilizes Levin, Lin and Chu (LLC) and Im, Pesaran and Shin (IPS) unit root tests to determine the order of integration among the variables included in the model. The unit root tests are used to check the stationarity of variables because in case of large panel data sets, there is likelihood of presence of unit root in variables. The unit root tests are applied with individual trends and intercepts. Table 6.1 shows the results of unit root tests for variables of wheat acreage response model. The results show that all variables are stationary at level i.e. I (0)

or become stationary after the first difference. The variables like wheat price (*ln*WP), expected yield of wheat (under total and un-irrigated area) are non-stationary at levels but stationary at first difference i.e. *I* (1).

Table 6.1 Unit Root Tests for Wheat Acreage Response Models

Variable	LLC test		IPS test	
	t statistic at level	t statistic at 1st difference	t statistic at level	t statistic at 1st difference
*ln*UA	-3.351* (0.000)	_	-3.966* (0.000)	_
*ln*WP	2.427 (0.992)	-5.942* (0.000)	-1.217*** (0.101)	_
*ln*BP	-4.812* (0.000)	_	-3.662* (0.000)	_
*ln*GP	-4.769* (0.000)	_	-3.381* (0.000)	_
*ln*RMP	-4.403* (0.000)	_	-2.124** (0.01)	_
*ln*PUrea	-0.897*** (0.143)	_	-3.283* (0.000)	_
lnPDAP	1.192*** (0.115)	_	1.689 (0.954)	-5.935* (0.000)
lnEY_U	-0.141 (0.443)	-3.676* (0.000)	-1.885** (0.031)	_
lnEY_I	-1.048*** (0.147)	_	-2.518* (0.005)	_
lnEY_T	0.162 (0.564)	-3.291* (0.000)	0.306 (0.620)	-4.530* (0.000)
*ln*IA	-0.848*** (0.135)	_	-1.680** (0.046)	_
*ln*TA	-3.266* (0.000)	_	-3.833* (0.000)	_
SST	-4.381* (0.000)	_	-4.762* (0.000)	_
SSP	-1.747** (0.040)	_	-3.697* (0.000)	_
PST	-1.076*** (0.140)	_	-1.304*** (0.091)	_
PSP	-0.988*** (0.154)	_	-5.299* (0.000)	_
SSVT	-3.924* (0.000)	_	-4.726* (0.000)	_
SSVP	-6.167* (0.000)	_	-3.478* (0.000)	_
PSVT	-2.478*	_	-3.934*	_

	(0.006)		(0.000)	
PSVP	-4.690* (0.000)	–	-4.072* (0.000)	–

Note: (***) (**) (*) denotes statistical significance at the 10 %, 5% and 1% level.

The results of the Levin-Lin and Chu and Im-Pesaran-Shin panel unit root tests reported in Table 6.2 show that all variables are stationary at level.

Table 6.2 Unit Root Tests for Wheat Yield Models

Variable	**LLC test**		**IPS test**	
	t statistic at level	t statistic at 1st difference	t statistic at level	t statistic at 1st difference
*ln(*UA)	-4.419* (0.000)	–	-5.680* (0.000)	–
ln(IA)	-6.705* (0.000)	–	-3.935* (0.000)	–
*ln(*TA)	-5.296* (0.000)	–	-6.660* (0.000)	–
$In(Y)_{UA}$	-3.774** (0.051)	–	-1.968* (0.000)	–
$In(Y)_{IA}$	-3.454* (0.000)	–	-3.948* (0.000)	–
$In(Y)_{TA}$	-6.586* (0.000)		-4.713** (0.0419)	
*ln(*Fert)	-5.890* (0.000)	–	-3.198* (0.000)	–
$(Temp)_{ND}$	-3.435* (0.000)	–	-3.991*** (0.120)	–
$(Temp)_{JF}$	-5.912* (0.000)	–	-4.527* (0.000)	–
$(Temp)_{MA}$	-5.895** (0.0162)	–	-3.171* (0.000)	–
$(Precp)_{ND}$	-6.908* (0.000)	–	-4.103* (0.000)	–
$(Precp)_{JF}$	-5.298* (0.000)	–	-6.856* (0.000)	–
$(Precp)_{MA}$	-4.014* (0.000)	–	-2.323* (0.000)	–
$(VTemp)_{ND}$	-6.339* (0.000)	–	-4.482* (0.000)	–
$(VTemp)_{JF}$	-3.858* (0.000)	–	-5.412* (0.000)	–
$(VTemp)_{MA}$	-3.894* (0.000)	–	-2.122* (0.000)	–
$(VPrecp)_{ND}$	-13.747* (0.000)	–	-11.366* (0.000)	–

$(VPrecp)_{JF}$	-16.922* (0.000)	_	-15.946* (0.000)	_
$(VPrecp)_{MA}$	-7.942* (0.000)	_	-14.88* (0.000)	_
$(Temp)_{ND}^2$	-16.891* (0.000)	_	-11.091* (0.000)	_
$(Temp)_{JF}^2$	-17.419* (0.000)	_	-20.702* (0.000)	_
$(Temp)_{MA}^2$	-12.16* (0.000)	_	-14.88* (0.000)	_
$(Precp)_{ND}^2$	-6.993* (0.000)	_	1.909* (0.000)	_
$(Precp)_{JF}^2$	-3.125* (0.000)	_	-2.632* (0.000)	_
$(Precp)_{MA}^2$	-2.730* (0.000)	_	-2.335* (0.000)	_
$(Temp*Precp)_{ND}$	-4.419* (0.000)	_	-12.89* (0.000)	_
$(Temp*Precp)_{JF}$	-6.705* (0.000)	_	-5.679* (0.000)	_
$(Temp*Precp)_{MA}$	-5.296* (0.000)	_	11.567* (0.000)	_

Note: (***) (**) (*) denotes statistical significance at the 10 %, 5% and 1% level.

6.3 Empirical Results of Climate change and Wheat Acreage

GMM is applied to analyze the impact of climate change on wheat acreage during different phenological stages of crop. The model includes linear and variation of temperature and precipitation, prices of competing crops, fertilizer prices, and area of wheat to capture the effect of climatic and non-climatic variables on wheat acreage. The variation of temperature and precipitation from long run norms are used to capture the impact of weather shocks.

The study estimates three regression equations under the irrigated, un-irrigated and total area of wheat acreage response in Barani Punjab. The majority of the area of Barani region of Punjab is rainfed and it shares 10 percent of the wheat in Punjab. It is also observed that irrigation in Barani Punjab increased over time (Ahmad and Ahmad, 1998). The results obtained by estimating the irrigated, un-irrigated and total area are different from each other.

6.3.1 Estimation of Model under Un-irrigated Conditions:

The empirical results for Model 1 are shown in Table 6.3. Model 1 is estimated for un-irrigated area; where the dependent variable is un-irrigated area under wheat.

Table 6.3 GMM Estimates for Model 1 (Dependent Variable: .Un-irrigated area of Wheat)

Explanatory Variables	**Coefficient**	**Std. Error**
$ln\text{UA}^{-1}$	0.347*	0.080
$ln\text{WP}^{-1}$	0.211***	0.121
$ln\text{BP}^{-1}$	0.835	0.093
$ln\text{GP}^{-1}$	-0.146**	0.059
$ln\text{RMP}^{-1}$	-0.191**	0.085
$ln\text{PUrea}^{-1}$	-0.145	0.205
$ln\text{PDAP}^{-1}$	-0.606	0.118
$ln\text{EY}_U$	-0.110	0.111
SST	-0.129*	0.035
SSP	0.005*	0.001
PST	0.063**	0.032
PSP	-0.002*	0.009
Constant	1.908*	0.366
No. of observations	116	**Prob>chi2=0.000**

Note: *** (**) (*) denotes statistical significance at the 10 %, 5% and 1% level

The study also used the Sargan test to check validity of the results. Sargan test was proposed by John Denis Sargan in 1958. It is also called J-statistics. Sargan test is used for testing over identifying restrictions of the model. It evaluates the validity of instrumental variables [8] used during GMM estimation. The hypothesis under the Sargan test technique suggests that if the instrumental variables are uncorrelated with the model residuals then instruments of model are acceptable.

[8] GMM model is used due to the presence of endogeneity and endogeneity is the cause of causality; when x causes y and y causes x. Due to this x variable replace with other variable z, z is correlated with x, but not with y. So x will no more exogenous, z variable is called instrumental variable (Soderbom, 2009). Instruments used for model are lag of *ln*UA, lag of *ln*BP, lag of *ln*WP, lag of *ln*GP, lag of *ln*RMP, SST, SSP, PST, PSP)

Table 6.4 shows that null hypothesis was not rejected which implies that instruments used for model are valid. Higher the p-value of Sargan test indicates that there is no endogeneity present any more in model (Mileva, 2007).

Table 6.4 Sargan Test Result for Un-irrigated Area of Wheat

Null Hypothesis	**Chi-square statistic**	**P-value**	**Summary**
Instruments are valid	71.75	0.64	Not rejected

Changes in climatic variables (temperature, precipitation) indicate significant impact on crop area. Results reported in Table 6.3 for wheat acreage response under un-irrigated conditions show that precipitation at sowing stage of wheat has significant positive impact on area allocation to wheat under un-irrigated conditions—10mm increase in precipitation at sowing stage will increase wheat crop area under un-irrigated conditions by 5 percent. Whereas, temperature at sowing stage of wheat has significant negative impact on un-irrigated area allocation to wheat crop. A 1°C increase in temperature would reduce un-irrigated area by 13 percent.

Pre sowing stage temperature of wheat crop indicates significant positive impact on un-irrigated area of wheat. A 1°C increase in temperature will increase un-irrigated area allocation of wheat by 6.3 percent—it could be due to early harvest of groundnut crop making land available for wheat. But, pre sowing precipitation of wheat shows significant negative effect on un-irrigated area of wheat by 0.2 percent. Major reason appeared to be sowing of other competing crops like rapeseed, gram and barley early having relatively higher temperature—not suitable for wheat, and availability of reasonable moisture available through rainfall for sowing of these crops. These results are consistent with the findings of Boussios and Barkley (2012) that increase in precipitation in the presence of high temperature reduced wheat acreage. The variation variables of temperature and precipitation are omitted from Model 1 because these variables had no impact on area allocation.

Economic variables—prices of wheat, competing crops and fertilizer, and expected yield, included in the model show different effects on wheat acreage. Lagged un-irrigated area of wheat indicates highly significant and positive impact on wheat acreage. The significant influence of the lagged dependent variable on acreage allocation also seems to contributing to better performance of crops in term of acreage (Khan and Zaman, 2010). Lagged price of wheat also shows significant positive effect on wheat under un-irrigated conditions. Lagged competing crops prices and lagged fertilizer prices (urea and DAP) show negative significant impact (except barley price) on area allocation to wheat under un-irrigated conditions. Expected yield of wheat from un-irrigated area and barley price had no significant influence on area allocation under rainfed conditions. Haung and Khanna (2010) study estimated that crop acreage was positively related to the lagged acreage of crop. The acreage of wheat showed positive response to own price and negative to prices of competing crops. Fertilizer prices also showed negative relationship with wheat crop acreage. Higher fertilizer prices incentivize producers to plant less input-intensive. Abler (2001) also found that the crop acreage responds positively to own price and negatively to the price of other crops. This suggest that higher output price of own crop induce producer to increase acreage and to invest in improving crop yield.

A study Ahmad and Ahmad (1998) analyzed wheat output growth in Barani Punjab. This study takes wheat output as the dependent variable and rainfall as input variable. Its results showed wheat output increased with increase in wheat acreage, and rainfall input variable indicated that wheat output increased by 2.1 percent with a 10 percent increase in rainfall. The current study take the wheat area as dependent variable and analyses the effect of prices and climate change on wheat acreage response, besides taking rainfall as an input variable, the precipitation and temperature both taken as climate change variable and determine the temperature and precipitation in different phenological stages of wheat crop. The current year area depends on previous year wheat area, prices of competing crops and prices of wheat crop. The study results showed that precipitation at pre sowing stage has negative impact on wheat acreage, while at sowing stage precipitation increased wheat area.

6.3.2 Area Response Model: Irrigated Conditions:

Table 6.5 shows the empirical results for wheat acreage response under irrigated conditions.

Table 6.5 GMM Estimates for Model 2 (Dependent Variable irrigated area of Wheat)

Explanatory Variables	**Coefficient**	**Std. Error**
$ln\text{IA}^{-1}$	0.632*	0.070
$ln\text{WP}^{-1}$	0.144***	0.215
$ln\text{BP}^{-1}$	-0.029***	1.700
$ln\text{GP}^{-1}$	0.126	0.108
$ln\text{RMP}^{-1}$	-0.130	0.154
$ln\text{PUrea}^{-1}$	-0.022	0.380
$ln\text{PDAP}^{-1}$	0.005	0.221
$ln\text{EY}_{I}$	-0.403	0.344
SST	-0.106***	0.060
SSP	0.013*	0.004
PST	0.130**	0.062
PSP	-0.002***	0.001
SSVT	-0.015	0.013
SSVP	0.001**	0.001
PSVT	0.022***	0.012
PSVP	-0.001*	0.000
Constant	-1.238***	0.687
No. of observations	116	**Prob>chi2=0.000**

Note: (***) (**) (*) denotes statistical significance at the 10 %, 5% and 1% level.

Sargan test for Model 2 is shown below in Table 6.6. The probability value of Sargan test is 0.261 which is greater than the significance level implying that instruments used in Model 2 are valid.

Table 6.6 Sargan Test Result for Irrigated Area of Wheat

Null Hypothesis	Chi-square statistic	P-value	Summary
Instruments are valid	88.52	0.261	Not rejected

The results reported in Table 6.5 show that climatic variables under irrigated conditions have significant impact on wheat acreage allocation. The rise in temperature at sowing stage impacts acreage wheat allocation even under irrigation conditions negatively. A 1°C increase in temperature at sowing stage of wheat will decrease irrigated area by 10 percent, which is lower by 3 percentage points than the impact of 1°C rise in temperature under un-irrigated conditions. This implies that the use of irrigation by any source for wheat growing substantially moderates the impact of climate change on wheat production.

Precipitation at sowing stage of wheat crop shows significantly positive effect on wheat area allocation under irrigated conditions. A 10mm increase in precipitation at sowing stage will increase wheat irrigated area by 1.3 percent. Pre-sowing temperature has significant positive impact, whereas precipitation significantly reduces area under wheat. Deviations of temperature and precipitation from their respective normals at different phenological stages influence area allocation under wheat significantly. Boussios and Barkley (2012) analyzed the impact of climate and weather on crop acreage. The study results showed that climate had significant impact on acreage of wheat and soybean allocation.

Lagged dependent of wheat irrigated area, wheat own price, and barley crop price play a significant role in allocating the area under wheat in Model 2. A 10 percent increase in price of wheat will increase irrigated area of wheat by 14 percent, whereas 10 percent increase in price of competing crop like barley here will reduce wheat irrigated area by 2.9 percent. Lagged dependent variable has significant positive impact on current year wheat acreage. However, fertilizer, gram and mustard oil prices and expected yield of wheat under irrigated area show insignificant results. Haile *et al.* (2015) found that acreage of crop respond significantly positive to its own price and lagged acreage of crop. The study showed that higher output prices encouraged the farmer to increase acreage for respected crop and also indicted that 10 percent increase in own price increased wheat area by 1 percent. Ali (1998) showed that 1 percent increase in competing crop reduced acreage of crop by 0.4 percent.

6.3.3 Estimation of Aggregate Model—Using Total Area:

Total area is the sum of irrigated and un-irrigated area. Table 6.7 shows the results of aggregate model—where impact analysis has been conducted of both climate change and other variables on wheat area cultivation in Barani Punjab.

Table 6.7 GMM Estimates for Model 3 (Dependent Variable: Total area of Wheat)

Explanatory Variables	**Coefficient**	**Std. Error**
$ln\mathrm{TA}^{-1}$	0.298*	0.083
$ln\mathrm{WP}^{-1}$	0.179***	0.102
$ln\mathrm{BP}^{-1}$	-0.125***	0.080
$ln\mathrm{GP}^{-1}$	-0.081**	0.051
$ln\mathrm{RMP}^{-1}$	-0.151	0.070
$ln\mathrm{PUrea}^{-1}$	0.226	0.173
$ln\mathrm{PDAP}^{-1}$	-0.018***	0.100
$ln\mathrm{EY}_T$	-0.122	0.109
SST	-0.107*	0.030
SSP	0.005*	0.001
PST	0.052**	0.027

PSP	-0.002*	0.008
Constant	1.676**	0.323
No. of observations	116	**Prob>chi2=0.000**

Note: (***) (**) (*) denotes statistical significance at the 10 %, 5% and 1% level

The Sargan test result reported in Table 6.8 highlights the fact that the model fits the data well and instruments of model are valid.

Table 6.8 Sargan Test Result for Total Area of Wheat

Null Hypothesis	Chi-square statistic	P-value	Summary
Instruments are valid	77.10	0.475	Not rejected

Results for total area of wheat crop shown in Table 6.7 reveal that temperature and precipitation variables show significant impacts on total area of wheat. Temperature at sowing and precipitation at pre-sowing stages show negative relation with total area under wheat. Whereas temperature at pre sowing stage and precipitation at sowing stage have significant and positive relation with area allocation under wheat, respectively. Deviations of climatic variables from their respective long-term mean have insignificant role in wheat area allocation.

Lagged dependent of total area and own price of wheat shows significant positive impact on wheat crop area. All competing crops prices—barley, gram, rapeseed mustard oil have significant negative role on wheat area. Increase in price of competing crop will decrease wheat area in Barani Punjab. Fertilizer price (DAP) shows negative impact on wheat crop. A 10 percent increase in fertilizer price will reduce wheat total area (1.8 percent). Expected yield does not have any influence on wheat area allocation.

6.4 Empirical Results of Climate change and Wheat yield

The Hausman (1978) test was applied to investigate either random effects or a fixed effect is appropriate for estimation of models. Hausman test shows that the estimators of fixed effects model are consistent in situation where cross section specific effects are correlated with the independent variables. The random effects model in such cases provides inconsistent results. The Hausman test's null hypothesis states that there is no significant difference between the coefficients of the estimators of random and fixed effects models.

6.4.1 Yield of Un-irrigated Area:

Results of Hausman test statistics for un-irrigated yield model are shown in Table 6.9.

Table 6.9 Hausman Test for Un-irrigated Yield

Null Hypothesis	**Chi-Sq. Statistic**	**P-Value**	**Test Summary**
Random is appropriate	21.67	0.0519	Rejected

Table 6.9 shows that null hypothesis is rejected which implies that the fixed effect is appropriate for un-irrigated yield model. Fixed effect estimates for un-irrigated yield are reported in Table 6.11. The Wald tests were applied to choose the final model that best suits the data. On the basis of the specification tests Model C[9] is selected as a final model. The specification tests results are stated in Table 6.10.

Table 6.10 Specification Results for Un-irrigated Yield

Null Hypothesis		**χ^2 value (Prob.)**	**Result**
$\beta_{TPND} = \beta_{TPJF} = \beta_{TPMA} = 0$	Interaction Terms	1.27 (0.735)	Not Rejected
$\beta_{VPND} = \beta_{VPJF} = \beta_{VPMA} = 0$	Precipitation Variations	6.01 (0.051)	Rejected
$\beta_{VTND} = \beta_{VTJF} = \beta_{VTMA} = 0$	Temperature Variations	1.56 (0.0371)	Rejected

[9] Three Models have been calculated in this Fixed effect approach. Final model C selected and results are reported in table 6.7.

$\beta_{2PND} = \beta_{2PJF} = \beta_{2PMA} = 0$	Precipitation Square	5.67 (0.0146)	Rejected
$\beta_{2TND} = \beta_{2TJF} = \beta_{2TMA} = 0$	Temperature Square	6.33 (0.0965)	Not Rejected
$B_{PND} = \beta_{PJF} = \beta_{PMA} = 0$	Precipitation normal	14.99 (0.0511)	Rejected
$\beta_{TND} = \beta_{TJF} = \beta_{TMA} = 0$	Temperature normal	8.19 (0.0422)	Rejected

The first hypothesis tested was that βTPND = βTPJF = βTPMA = 0 which states that temperature and precipitation combined have no influence on wheat productivity. The null hypothesis was accepted which implies that interaction term has no significant impact on wheat un-irrigated yield. The second hypothesis tested was that βVPND = βVPJF = βVPMA = 0 which states that variation of precipitation is equal to zero. The estimate implies that precipitation shocks have significant influence on wheat un-irrigated yield. Based on these results the variations of temperature restriction 'βVTND = βVTJF = βVTMA = 0' was tested which was rejected. Given the outcome of these tests square terms of both temperature normal β2TND = β2TJF = β2TMA = 0 and precipitation normal β2PND = β2PJF = β2PMA = 0 were also tested one by one. The null hypotheses were not rejected and rejected. Another null hypothesis which tested was that BPND = βPJF = βPMA = 0, which states that the impacts of precipitation normal are equal to zero. The null hypothesis was rejected. The last hypothesis which was tested is that βTND = βTJF = βTMA = 0 which states that wheat productivity is not impacted by the temperature normals. This null hypothesis was also rejected.

Based on specification tests, Model C is the most suitable specification for the analysis. The results reported in Table 6.11 reveal that parameter estimates of non-climatic variables including un-irrigated area under wheat, fertilizer and technology represented by time trend are all statistically significant and carry positive signs. These results imply that larger farmers are more productive than the smaller ones—as indicated by the positive sign and statistically significant coefficient of area under wheat. Use of higher fertilizer also significantly encourages the yield of wheat under barani conditions. The coefficient of time variable indicates that yield of wheat increased by over 1 percent every year over the last 30 years due change in technology. The coefficient of first stage (Nov-Dec) temperature is statistically significant and carries a negative sign. The impact of rise in temperature during November-December months on wheat yield under rainfed conditions is negative. Sivakumar and Stefanski (2011) and Ahmad, et al. (2014) reported that an increase of 1°C in mean temperature would reduce wheat yield by 5 to 7 percent in Pakistan. The results of a Rapid Rural Appraisal (RRA) conducted in Punjab, Sindh and KP provinces highlighted the facts that wheat sowing has generally been delayed 2-3 weeks throughout the country to avoid higher temperature level from mid-October to early-November (Ahmad *et al.*, 2013).

The coefficient of temperature normal (Stage 2), is highly significant and positive. The coefficient at the mean temperature is calculated to be 0.057 which implies that 1^0C increase in average temperature during vegetative growth period would increase wheat yield by 5.7 percent—this result is again consistent with Ahmad, et al. (2014). Farmers' perceptions survey has highlighted the fact that the temperature has generally increased and frost incidence has declined in most areas of Pakistan during the vegetative growth stage (January-February). However, in certain areas frost may occurs in late winter months, i.e. February, impacting the wheat yield adversely (Ahmad *et al.*, 2013). There is no significant impact of temperature normal during the stage-3 (March-April). This non-significance impact of temperature could have been mainly due to the non-rising temperature trend—that might have actually helped sustain the duration of crop stand in the field and avoided yield losses (Ahmad *et al.,* 2014).

The linear parameter estimate of November-December precipitation is statistically non-significant. The response coefficients evaluated at mean of the data indicate positive impact of precipitation during the remaining two stages of growth. Temperature and precipitation deviations from their respective long term trend have also been used to estimate the impacts of climatic shocks. The precipitation variation variables of all stages were included in the model. The results show that the coefficients of deviations from the long-term mean precipitation during the second and third stages of wheat growth are statistically significant and carry positive signs implying that the weather shocks have influenced wheat productivity positively. However, the variations variable relating to the wheat growth Stage 1 shows statistically non-significant impact on wheat yield. Any deviation from long-term temperature trends influence wheat yield negatively under barani conditions.

Table 6.11 FEM Estimates for Un-Irrigated Yield (Dependent Variable: natural logarithm of Un-Irrigated yield)

		Model A		Model B		Model C	
Variables		**Coef.**	**Std.**	**Coef.**	**Std.**	**Coef.**	**Std.**
Constant	β_0	67.30*	40.658	8.359*	23.72	-4.007**	1.909
Time	β_t	0.016***	0.003	0.013***	0.003	0.011***	0.002
Temperature (Nov-Dec)	β_{TND}	-0.228**	0.367	-0.168	0.358	-0.079**	0.058
Temperature (Jan-Feb)	β_{TJF}	-0.604*	0.771	-0.362*	0.549	0.057*	0.085
Temperature (Mar-Apr)	β_{TMA}	2.775	3.436	0.763*	2.148	0.065	0.059
Precipitation (Nov-Dec)	β_{PND}	0.087*	0.057	0.033	0.038	0.037	0.032
Precipitation (Jan-Feb)	β_{PJF}	0.054**	0.058	0.019**	0.022	0.0021**	0.017
Precipitation (Mar-Apr)	β_{PMA}	-0.233	0.136	0.003*	0.013	0.003*	0.010
Temperature (Nov-Dec)2	β_{2TND}	0.014	0.014	0.008	0.013		
Temperature (Jan-Feb)2	β_{2TJF}	0.025	0.040	0.013	0.023		
Temperature (Mar-Apr)2	β_{2TMA}	0.115*	0.072	0.018	0.047		
Precipitation (Nov-Dec)2	β_{2PND}	-0.001*	0.001	-0.007*	0.002	-0.000	0.001
Precipitation (Jan-Feb) 2	β_{2PJF}	-0.002*	0.000	-0.003**	0.001	0.003**	0.002
Precipitation (Mar-Apr)2	β_{2PMA}	0.000	0.000	0.000	0.000	0.001*	0.000
V Temperature (Nov-Dec)	B_{VTND}	-0.009*	0.015	-0.009*	0.015	-0.010*	0.015
V.Temperature (Jan-Feb)	B_{VTJF}	0.013	0.011	0.009	0.010	-0.009**	0.010
V Temperature (Mar-Apr)	B_{VTMA}	0.003	0.006	-0.002	0.006	-0.003	0.006
V Precipitation (Nov-Dec)	B_{VPND}	0.001**	0.000	0.001	0.000	0.000	0.000
V Precipitation (Jan-Feb)	B_{VPJF}	0.000	0.000	0.001*	0.000	0.001**	0.000
V Precipitation (Mar-Apr)	B_{VPMA}	0.000	0.000	0.000	0.000	0.002*	0.001
Temp x Precip	β_{TPND}	-0.002	0.002				
Temp x Precip	β_{TPJF}	-0.003	0.007				
Temp x Precip	β_{TPMA}	0.008*	0.005				
Un-irrigated wheat area	β_{IA}	0.621***	0.191	0.628***	0.189	0.553***	0.179
Fertilizer	β_F	0.072**	0.099	0.089**	0.099	0.106**	0.097

Note: ***, **,* indicate the 1%, 5% and 10% level of significance.

6.5.2 Yield of Irrigated Area:

Based on Hausman test, random effects technique was selected. The result of Hausman test is given in Table 6.12.

Table 6.12 Result of Hausman test for Irrigated Yield

Null Hypothesis	**Chi-Sq. Statistic**	**Prob.**	**Test Summary**
Random is appropriate	17.13	0.4237	Not rejected

The Wald specification tests were applied to check that either climatic variable have affected the wheat irrigated yield in selected districts of Punjab or not. The results of specification tests presented in Table 6.13 imply that climatic normals—temperature and precipitation, not only significantly influence wheat yield under irrigated conditions but their impacts are also non-linear. Furthermore, the climatic variables also have combined effect on wheat yield—higher the temperature with increased rainfall would negatively impact wheat productivity. However, deviations in temperature from their respective historical means have not impacted the wheat yield significantly.

Table 6.13 Specification Results for Irrigated Yield

Null Hypothesis		**χ^2 value (Prob.)**	**Result**
$\beta_{TPND} = \beta_{TPJF} = \beta_{TPMA} = 0$	Interaction Terms	12.66 (0.0054)	Rejected
$\beta_{VPND} = \beta_{VPJF} = \beta_{VPMA} = 0$	Precipitation Variations	8.25 (0.041)	Rejected
$\beta_{VTND} = \beta_{VTJF} = \beta_{VTMA} = 0$	Temperature Variations	3.96 (0.265)	Not rejected
$\beta_{2PND} = \beta_{2PJF} = \beta_{2PMA} = 0$	Precipitation Square	12.15 (0.0069)	Rejected
$\beta_{2TND} = \beta_{2TJF} = \beta_{2TMA} = 0$	Temperature Square	13.23 (0.0042)	Rejected
$B_{PND} = \beta_{PJF} = \beta_{PMA} = 0$	Precipitation normal	13.43 (0.0038)	Rejected
$\beta_{TND} = \beta_{TJF} = \beta_{TMA} = 0$	Temperature normal	12.76 (0.0052)	Rejected

Based on the specification tests Model B (Table 6.14) is selected as a final model which suggests non-linear impact of climatic variables on wheat yield. It is obvious from the results that temperature and precipitation normal make a significant joint impact across various stages of the crop growth. It shows the fact that the impact of temperature and precipitation is not independent.

In order to know the marginal impact of climatic variables on wheat yield we calculated compare the differences in coefficient estimates of climate models, we calculate their marginal effects ($\frac{\partial lny_{it}}{\partial x_{it}}$), at the sample mean and the results are reported in the following table.

Table 6.14 Marginal Impacts of Climate Change on Wheat Irrigated Yield

Variables	**Marginal Impacts**
Temperature (Nov Dec)	-0.1098
Temperature (Jan feb)	0.1891
Temperature (march april)	-0.0745
Precipitation (Nov Dec)	0.0054
Precipitation (jan feb)	0.0091
Precipitation (march april)	0.0269

The coefficient of the average temperature during the sowing stage is statistically significant and carries a positive sign, while the coefficient of its square term is negative and statistically significant. This estimate is supported by the existing literature that temperature affect wheat yield in first stage in Pakistan (Siddiqui et al., 2014; Ahmad, et al. 2014). Our results in *Table 6.14* of marginal impacts show that 1°C increase in temperature during the germination stage of wheat would reduce yield by 10 percent. Higher temperature tends to have negative effect on wheat crop because wheat is a cold loving plant and grown in the cold winter season.

The coefficient of average temperature and square terms of temperature for second stage of wheat crop have significant positive and negative signs, respectively. The magnitude of the marginal impact indicates that 1°C increase in temperature during vegetative stage would encourage yield wheat by 19 percent. Warming weather during the vegetative growth helped to enhanced wheat productivity (Ahmad *et al.*, 2014). We found no significant impact of temperature normal during the maturity stage (March-April) in *Table 6.16* but value of marginal impact shows negative sign.

The impact of higher precipitation on wheat yield also depends strictly on geographical area. Overall, higher precipitation in arid and semi-arid regions affects wheat production positively. However, in regions with already high rainfall, more precipitation can reduce wheat production by nutrient leaching and water logging (Ludwig and Asseng, 2006). The results have shown that the 10mm increase in precipitation during the vegetative growth and maturity stages would increase wheat yield by 0.1 and 0.3 percent, respectively. The combine impact of temperature and precipitation has also been included in the model but their coefficients show insignificant impact on irrigated yield of wheat. The precipitation variation variables were included in the irrigated yield model. The results show that the coefficients of variations from the long-term mean precipitation during the first and third stages of wheat growth are statistically significant and carry positive signs implying that the weather shocks have influenced wheat productivity positively.

Table 6.15 REM Estimates for Irrigated Yield (Dependent Variable: natural logarithm of Irrigated yield)

		Model A		**Model B**	
Variables		**Coef.**	**Std.**	**Coef.**	**Std.**
Constant	β_0	-21.619**	18.076	-25.167**	17.927
Time	β_t	0.005***	0.001	0.005***	0.001
Temperature (Nov-Dec)	β_{TND}	0.118**	0.162	0.070**	0.158
Temperature (Jan-Feb)	β_{TJF}	-0.982***	0.350	0.092***	0.347
Temperature (Mar-Apr)	β_{TMA}	1.316	1.525	1.575	1.512
Precipitation (Nov-Dec)	β_{PND}	0.050	0.025	0.054	0.024
Precipitation (Jan-Feb)	β_{PJF}	0.089***	0.025	0.00095***	0.025
Precipitation (Mar-Apr)	β_{PMA}	0.069*	0.060	0.00035*	0.059
Temperature (Nov-Dec)2	β_{2TND}	-0.008*	0.006	-0.007**	0.006
Temperature (Jan-Feb)2	β_{2TJF}	-0.050***	0.018	0.053***	0.018
Temperature (Mar-Apr)2	β_{2TMA}	-0.026	0.032	-0.030	0.031
Precipitation (Nov-Dec)2	β_{2PND}	0.000	0.000	-0.000	0.000
Precipitation (Jan-Feb) 2	β_{2PJF}	0.000**	0.000	0.001*	0.000
Precipitation (Mar-Apr)2	β_{2PMA}	0.00**	0.000	0.002***	0.000
V Temperature (Nov-Dec)	B_{VTND}	-0.006	0.006		
v.Temperature (Jan-Feb)	B_{VTJF}	0.007*	0.004		
V Temperature (Mar-Apr)	B_{VTMA}	-0.001	0.002		
V Precipitation (Nov-Dec)	B_{VPND}	0.000**	0.000	0.000**	0.001
V Precipitation (Jan-Feb)	B_{VPJF}	-0.000	0.000	-0.000	0.000
V Precipitation (Mar-Apr)	B_{VPMAA}	0.000**	0.000	0.000**	0.000
Temp x Precip	β_{TPND}	0.002	0.001	0.002	0.001
Temp x Precip	β_{TPJF}	-0.010***	0.003	-0.010***	0.003
Temp x Precip	β_{TPMA}	-0.002	0.002	-0.003	0.002
N logarithm of Irrig. Area	β_{IA}	0.019*	0.057	0.013*	0.057
N logarithm of fertilizer	β_F	0.072**	0.045	0.057**	0.044

Note: ***, **,* indicate the 1%, 5% and 10% level of significance.

Chapter 7

Conclusion and Policy Recommendations

Agriculture is extremely susceptible to climate change, and Pakistan is one of the worst hit countries due to climate change. Changing rainfall trends, erratic weather patterns and extreme weather events including floods badly affected the agriculture. Agriculture and climate change have a strong relationship, since it depends on weather conditions. The major objective of this study has been to evaluate that 'how sensitive is area allocation and yield of wheat to changes in climate'. Most of studies in literature use only economic variables to examine the acreage response of crops. This study analyzes the wheat acreage response and wheat yield under the climate change scenario as well as economic variables.

The results show that the impacts of climate change are not the same across different phenological stages. Wheat acreage response is also determined by the lagged dependent area, own price of crop, competing crops and fertilizer prices. The study divides the area into irrigated, un-irrigated and total area. Climatic variables (temperature, precipitation) significantly impact area allocation to wheat crop whether sown under irrigated or un-irrigated conditions. Both economic and climatic variables show significant impact on un-irrigated area allocation. Temperature at sowing stage has negative correlation with wheat under un-irrigated area and precipitation at sowing stage has positive significant impact on un-irrigate area allocated to wheat. Results suggest that variables of variation in temperature and precipitation only affects irrigated area. Price of wheat crop has positive and significant influence on wheat acreage allocation. Increase in competing crops prices reduces wheat acreage both under irrigated and un-irrigated conditions.

The current study also reveals that climate change is affecting the wheat yield significantly in barani Punjab and that the impacts varies across different growth stages. The increase in long run mean temperature during germination and tillering stage affects wheat yield negatively. Moreover, an increase in temperature at vegetative stage enhances wheat productivity whereas no such evidence was found during maturity stage. Precipitation normals during vegetative and maturity stages and their variations from mean have impacted the wheat yield positively.

7.1 Policy Recommendations

On the policy front, not only changing sowing time of wheat is needed, but also ensuring continues guidelines for farmers are also required. Government should take appropriate measures to support public and private sector research to develop new seeds resistant of climate stresses (drought resistant verities, tolerant to heat and water stress and less prone to viral attack) and to educate farmers regarding other adaptations to climate change.

In order to reduce the adverse impacts of climate change there is dire need to scale up the adaptation strategies. Therefore, instead of centralized adaptation framework there should be decentralized framework because climate change is not uniformly affecting the all parts of the Pakistan.

Government should also announce proper price policies before the sowing period of crop, so that farmers can allocate agricultural area in rational manner.

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Appendices

Appendix 1

Table A.1: List of Variables for Wheat Acreage Model

Variables	Definition
Dependent Variable	
UA_{it}, IA_{it}, TA_{it}	Wheat acreage under un irrigated area(UA), irrigated area(IA), Total area(TA) in district i at year t
Independent variables	
UA^{-1}	Lagged wheat un irrigated area
IA^{-1}	Lagged wheat irrigated area
TA^{-1}	Lagged wheat total area
WP^{-1}	Lagged wheat price
BP^{-1}	Lagged barley price
GP^{-1}	Lagged gram price
RMP^{-1}	Lagged rapeseed-mustard price
$PUrea^{-1}$	Lagged urea price
$PDAP^{-1}$	Lagged DAP price
EY_U	Expected yield of wheat under un irrigated area
EY_T	Expected yield of wheat under irrigated area
EY_I	Expected yield of wheat under total irrigated area
SST	Sowing stage temperature of wheat
SSP	Sowing stage precipitation of wheat
PST	Pre sowing stage temperature of wheat
PSP	Pre sowing stage precipitation of wheat
SSVT	Variation in sowing stage temperature of wheat
SSVP	Variation in sowing stage precipitation of wheat
PSVT	Variation in pre sowing stage temperature of wheat
PSVP	Variation in pre sowing stage precipitation of wheat

Appendix 2

Table A.1: List of Variables for Wheat Yield Model

Variables	Definition
Dependent Variable	
$Y_{U,it}$ $Y_{I,it}$	Wheat Yield under un irrigated (U), irrigated (I) in district i at year t
Independent variables	
$Temp_{ND}$	Temperature (Nov-Dec)
$Temp_{JF}$	Temperature (Jan-Feb)
$Temp_{MA}$	Temperature (Mar-Apr)
$Precp_{ND}$	Precipitation (Nov-Dec)
$Precp_{JF}$	Precipitation (Jan-Feb)
$Precp_{MA}$	Precipitation (Mar-Apr)
$Temp_{ND}^2$	Square of Temperature (Nov-Dec)
$Temp_{JF}^2$	Square of Temperature (Jan-Feb)
$Temp_{MA}^2$	Square of Temperature (Mar-Apr)
$Precp_{ND}^2$	Square of Precipitation (Nov-Dec)
$Precp_{JF}^2$	Square of Precipitation (Jan-Feb)
$Precp_{MA}^2$	Square of Precipitation (Mar-Apr)
$VTemp_{ND}$	Variation in Temperature (Nov-Dec)
$VTemp_{JF}$	Variation in Temperature (Jan-Feb)
$VTemp_{MA}$	Variation in Temperature (Mar-Apr)
$VPrecp_{ND}$	Variation in Precipitation (Nov-Dec)
$VPrecp_{JF}$	Variation in Precipitation (Jan-Feb)
$VPrecp_{MA}$	Variation in Precipitation (Mar-Apr)
$Temp_{ND}*Precp_{ND}$	Interaction of Temp. & Precp. (Nov-Dec)
$Temp_{JF}*Precp_{JF}$	Interaction of Temp. & Precp. (Jan-Feb)
$Temp_{MA}*Precp_{MA}$	Interaction of Temp. & Precp. (Mar-Apr)
UArea IArea	Un-irrigated Area Irrigated Area
T	Time Trend
F	Share of fertilizer