Impact of Climate Change on Wheat Production:

A Case Study of Pakistan

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بسم الله الرحمن الرحيم

Allah will exalt in degree those of you who believe and those who have been granted knowledge.

(Chapter: 58, Verse: 11)

Dedicated to my

Grandfather

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Acronyms, Chemical Symbols & Scientific Units

AAAS	American Association for Advancement of Sciences
APSIM	Agricultural Production System Simulator
ARDL	Auto Regressive Distributed Lag
C-CAM	Conformal Cubic Atmospheric Model
CDM	Clean Development Mechanism
CERES	Crop Estimation through Resource and Environment Synthesis
CGE	Comparable General Equilibrium
CO_2	Carbon Dioxide
CH_4	Carbon Tetrahydride (Methane)
CSIRO	Commonwealth Scientific and Industrial Research Organization
DSSAT	Decision Support System for Agro-technology Transfer
ECM	Error Correction Model
EPIC	Erosion Productivity Impact Calculator
ET	Emission Trading
FACE	Free Air Carbon dioxide Enrichment
FAO	Food & Agriculture Organization
GCMs	General Circulation Models
GDP	Gross Domestic Product
GEPIC	Geographic Information System (GIS) based Environmental Policy Integrated Climate
GHGs	Greenhouse Gases
GSL	Growing Season Length
HadCM	Hardley Centre Model

HFCs	Hydroflorocarbon
IEA	International Energy Agency
IPCC	Inter-governmental Panel on Climate Change
JI	Joint Implementation
Kg per ha	Kilogram per hectare
Km	Kilometer
MAF	Million Acre Feet
Mg ha^{-1}	Mega gram per hectare (10^6 of a gram)
M/s	Meter per second
N_2O	Nitrous Oxide
OLS	Ordinary Least Square
PARC	Pakistan Agriculture Research Council
PFCs	Perflorocarbons
PNNL	Pacific Northwest National Laboratory
PPM	Parts Per Million
RCM	Regional Climate Model
SF_6	Super Hexafluoride
SWOPISM	Static World Policy Simulation Model
TSI	Terminal Spikelet Initiation
UKMO	United Kingdom Meteorological Organization
UN	United Nations
UNFCCC	United Nation Framework Convention on Climate Change
USA	United States of America
UK	United Kingdom
WOFOST	World Food Stu

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Abstract:

Climate change is an emerging issue of agricultural production and geographical location of Pakistan makes it vulnerable to climate change. Climate change is basically due to the increase in the concentration of greenhouse gases (GHGs) like carbon dioxide, methane and nitrous oxide through anthropogenic activities. These gases trap the sunlight and increase the earth's overall temperature. This higher temperature may negatively affect the growth process of wheat and hence decreases the productivity of wheat. The objective of this study is to look at the impact of climate change on wheat production which is the main food crop of Pakistan. The study uses Autoregressive Distributed lag (ARDL) model to evaluate the impact of global climate change on the production of wheat in Pakistan. The study considers annual data from 1960 to 2009. On the basis of this historical data the study tries to capture the impact of climate change on wheat production up to now. The results of estimation reveal that global climate change doesn't influence the wheat production in Pakistan. However, on the basis of the results some appropriate adaptative measures are proposed to confront any adverse shock to wheat production in Pakistan.

1. INTRODUCTION

1.1 What is Climate Change

Atmospheric condition that prevails for a short period of time such as for a hour, day or week is termed as weather, whereas, if such atmospheric condition prevails for a long period of time like for season, decade or a century then such atmospheric condition is known as climate. Man is massively using fossil fuels in order to meet with the growth requirements because of which the concentration of some gases is increasing which in turn disrupt the atmosphere and this change is going to alter the climate. According to the forth assessment report of Inter-governmental Panel on Climate Change; "change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity" (IPCC 2007: 30). Whereas, article 1 of United Nation Framework Convention on Climate Change (UNFCCC) defines climate change as; "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Naomi Oresker (2004) in his essay responded to different critical aspects about the uncertainties among science community on the issue of climate change as an anthropogenic activity. He said that Inter-governmental Panel on Climate Change (IPCC) reports, which were based on the findings of World Meteorological Organization and United Nations Environmental Programme, unequivocally stated that climate change is subjected to anthropogenic activities. Besides these scientific research centers other bodies like National Academy of Sciences, American Meteorological Society, American Geophysical Union and American Association for Advancement of Sciences (AAAS) also urged that human activities for the last 50 years are intensifying the atmospheric constituent particles, which are ultimately causing to increase the land surface and oceanic surface temperature. They also urged that the IPCC reports are fair and realistic. Thus, according to Oresker most of the scientists hold the consensus of IPCC regarding the climate change as a man-made activity.

Earth gains energy from sun in the form of solar energy and atmosphere which is composed of different gases called Greenhouse Gases (GHGs), holds energy rays which are used by the earth and then let them to go back into the space. So the atmosphere plays a vital role to maintain the earth average temperature at an average level of 15°C which is required for the living creature. In the absence of the atmosphere it is said that the earth average temperature would be -19°C which is not suitable for living organism (Edwards 1999).

GHGs are comprised of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapors. These gases are produced by a number of anthropogenic activities. Higher concentration level of GHGs originates the problem of Global Warming (Motha & Baier, 2005). The unsympathetic outcome of global warming is articulated as global climate change (Cerri *et al.* 2007). Some of the consequences of global warming will be in the form of more frequent floods, more frequent drought, food shortage, non supporting weather conditions, new born diseases, sea level rise etc (Tisdell 2008).

Carbon dioxide (CO_2) is mainly produced during the combustion of wastes, carbon, wood and fossil fuels. Methane (CH_4) is produced during the mining of coal, gas and oil and during their transportation. Nitrous oxide (N_2O) is produced during agriculture and industrial activities and also from burning of fossil fuels. Man is the ultimate creator of this newly emerging CO_2 enriched world because since the pre industrial time CO_2 concentration has increased from 280ppm to 380ppm due to deforestation and massive use of fossil fuels[1]. Presently, concentration of GHGs as a result of anthropogenic activities is increasing at a rate of 23ppm per decade (Stern 2006). Percentage contribution of different sectors in GHGs in atmosphere is as follows; agricultural contributes 13%, industrial sector 3%, land use change and forestry 18%, waste contributes 3% and large contribution of energy sector 63% (Rosegrant *et al.* 2008).

Three important GHGs, namely N_2O, CH_4 and CO_2, differ from each others according to their intensity in global warming. One kg of N_2O is equivalent to 310 kg of CO_2. Similarly, one kg of NH_4 is equal to 21 kg of CO_2. Utilizing one liter of gasoline creates 2.32kg of carbon dioxide, one liter of diesel generates 2.67 kg of CO_2 and one kg of coal or wood creates 2 kg of CO_2 in atmosphere (Motha & Baier, 2005). According to

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[1] There is consensus that modern industrialization started in the second half of 19^{th} century in United Kingdom that later on expanded to other parts of transatlantic region. Thus, modern industrialization has a history of about 150 years. (Ballance & Ansari 1982)

2008 statistic of International Energy Agency (IEA), global emission of CO_2 was about 29,888,121 thousand of metric tons. According to their report China was holding first rank regarding this emission. China emitted 7,031,916 thousand of metric tons which was 23.33% of the global emission. USA which came 2nd in rank emitted 5,461,014 thousand of metric tons, which was reported as 18.11% of global emission. Contribution of Pakistan towards this emission was 163,178 thousand metric tons, which was about 0.54% and held 31st rank towards global emission. At global level per head concentration of CO_2 is about 22 ton.

Climate change is an externality which is mainly caused by the economic activities like land use, deforestation, use of fossil fuels by industries, transport and household etc. The impact of climate change is highly inequitable because developed countries, which are mainly relying on industries and geographically most of them are lying on the polaric (colder) part of the world, are playing major role towards greenhouse gases (GHGs) emission and consequently any increase in temperature is benefiting this region. Whereas, the effect of these GHG are geographically different and would affect the developing countries on most because most of developing countries are lying on tropical and subtropical (warmer) region of the world and agriculture is the main pillar of their economy. Any increase in temperature would affect them badly and these countries are technologically not developed to an extent to combat such types of externalities (Stern 2006). In consequence of climate change the countries would be considered as looser because of receiving adverse effect in its agricultural output, natural resource availability, increase in natural calamities (frequent floods, droughts, temperature hike etc). Whereas, a winner is one which would get positive impact in all the said terms due to climate change (O'Brien & Leichenko, 2000).

In tropical region two major sources of increase in GHGs are deforestation and agricultural intensification. In moderate regions major sources of increase in GHGs are burning of fossil fuels. According to the IPCC prediction, in the absence of any policy to abate the GHGs emission, GHGs would mount to 550-700ppm[2] at the mid of current century and this level of GHGs would cause to accelerate the temperature from 3°C to 6°C since the pre industrial era (Cerri *et al.* 2007).

Climate change would further mount the surface temperature because of diminishing soil ability to absorb CO_2 and methane. Rise in temperature would also lead to increase the evaporation, which is also one of the constituents of GHGs. It would cause to accelerate the earth surface temperature (Stern 2006). Plants and oceans have the natural ability of absorbing CO_2 which is produced through natural processes, namely emission of CO_2 by human and animals, and thus maintaining the CO_2 at equilibrium level. However, CO_2 produced by anthropogenic activities by massive use of fossil fuels and deforestation reduces the natural absorbing ability and thus this additional CO_2 remain in the atmosphere, which intensify the GHGs and cause to increase the atmospheric temperature (World Bank Report 2009).

[2] ppm is abbreviation of parts per million, used to measure the level of pollution in air, it is a ratio between pollutant components and the solution.

In order to forecast the future warming at different levels of GHGs, scientists use climate models based on physical laws which cover a lot of aspects like temperature at different levels, wind speeds, snows etc. (Stern 2006). The historical data of fifty years about CO_2 concentration shows an increasing trend. If this concentration level is stabilized up to 550ppm by the mid of this century, even then it would cause to 3.2°C to 4.0°C increase the global temperature (Tisdell 2008). Whereas, a part of scientist body has a strong view that up to 2100 concentration of greenhouse gases would cause to increase temperature from 1.5°C to 5.8°C along with change in precipitation pattern (Mendelsohn *et al.* 2006). If GHGs emission rates continue with the current proportion then it is expected that this would hike the global mean surface temperature by 1.5°C to 4.5°C in the 21st century. This high level of temperature could shorten the time period for phenological development and overall biomass (Rosenzweig & Tubiello, 1996). Due to diminishing natural sinking ability of plants to absorb CO_2, the temperature would increase from 1°C to 2°C by the end of current century (Stern 2006).

It means that by the end of 21^{st} century the level of CO_2 emission would double from pre-industrial level of 280ppm to 560ppm. However, research also suggests that it could even be 3 times as much as the pre-industrial era and this high concentration would lead to hike the temperature from 3°C to 10°C (Stern 2006).

Knowing the aftermath of climate change United Nations (UN) form a treaty called United Nation Framework Convention on Climate Change (UNFCCC). The objective of this treaty was to curtail the anthropogenic emission of greenhouse gases and to stabilize the greenhouse gases. Under the treaty of UNFCCC an agreement called Kyoto Protocol was signed among the countries[3].

1.2 Effects of Climate Change on Agriculture Sector

Change in climate will affect almost all the sectors but agriculture is the most vulnerable in all of these and one fifth of these damages will be experienced by this sector (Rosegrant *et al.* 2008). Climate change will affect the agriculture productivity in number of ways, like changing rainfall pattern, temperature hike, changing sowing and harvesting dates, water availability, evapotranspiration[4] and land suitability. All of these are outcomes of climate change which may affect the yield of agriculture productivity. However, increased emission of CO_2 may enhance the photosynthesis response creating positive impact on agriculture production (Pearce *et al.* 1996). Carbon dioxide concentration may have dual effects. CO_2 enrichment can increase the photosynthesis, biomass and water-use-efficiency[5], and in this way may have a direct positive impact on crops production. However, increased CO_2 emission can increase temperature and the increased temperature may negatively affect the production of crops.

Increase in the level of atmospheric CO_2 is a continuous process and with every passing day this concentration is becoming higher as compared to the previous day. Being the global effect of CO_2, this high level of concentration would affect all global

[3] Kyoto Protocol detail at Appendix1

[4] Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere.

[5] Water use efficiency means the amount of water gained per unit water lost per unit leaf area.

crops (Warrick 1988). Impacts of climate change on agriculture are manifold like diminishing the agricultural output and shortening the growth period for crops. Countries lying on the tropical and sub-tropical regions would face callous results whereas countries situated in temperate regions would be on the beneficial side (Harry *et al.* 1993).

Climate change is having manifold impact on crop growth, productivity and its water use. Most of the studies on agricultural growth related with the tropical and sub-tropical region show that increase in temperature in these regions will create catastrophic impact on the agricultural productivity (Attri & Rathore, 2003).

The crops which exhibit high positive responses to enhanced CO_2 are characterized as C3 crops[6]. These include wheat, rice soybean, cotton, oats, barley and alfalfa. Whereas, the plants which show low positive response to enhanced CO_2 are called C4 crops[7] which includes maize, sugarcane, sorghum, millet and other crops (Motha & Baier 2005). Carbon dioxide enriched atmosphere positively affect the plants by two ways. First, it increases the photosynthesis process in plants. This effect is termed as carbon dioxide fertilization effect. This effect is more prominent in C3 plants because this higher level of CO_2 increase rate of fixed carbon and also suppresses photorespiration[8]. Second, increased level of CO_2 in atmosphere decreases the

[6] Dark reaction which is independent of sun light is the 2nd stage of photosynthesis. This reaction occurs in stroma of plastid. It has named as C3 because during carbon fixation 3 carbon molecules are produced. So plants where this kind of reaction occurs during photosynthesis are called C3 plants.

[7] In contrast to C3 plants, 4 carbon molecules are produced during photosynthesis. On the basis of which plants such plants are characterized as C4 plants.

[8] Photorespiration means a process that displaces newly fixed carbon.

transpiration[9] by partially closing stomata and hence declining the water loss by plants. Both of the factors enhance the water use efficiency of plants causing increase in growth (Motha & Baier, 2005 and Warrick 1988).

Double level of CO_2 concentration will create a positive impact on C3 and C4 crops, resulting C3 yield to increase from 10% to 50% and that of C4 crops yield increase from 0% to 10% (Warrick 1988). This positive impact of CO_2 is offset by higher temperature which increases the process of evaporation in plants (Motha & Baier, 2005). Carbon fertilization[10] shows a very small effect on C3 crops and even having no impact on C4 crops (Zhai & Zhuang, 2009).

Increasing level of CO_2 in atmosphere is going to alter the climate having havoc impact on agriculture and it will produce results in the form of decline in agriculture yield and economic losses. Frequency, duration and intensity of these extreme climatic change events create catastrophic impact on agriculture yield as compared to change in mean value of climate (Motha & Baier, 2005). A lot of research has been conducted regarding the possible negative effects of climate change on land fertility, its potential and production, which shows change in all features of agricultural lands (Schnidhuber & Tubiello, 2007).

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[9] Transpiration is loss of water by plant during exchange of gases.

[10] Carbon fertilization means the development of plant in consequence of increased atmospheric CO_2 concentration, as the photosynthesis mechanism of C3 plants becomes more active in presence of enhanced level of elevated CO_2.

1.3 Effects of Climate Change on Wheat Production

Nowadays wheat is cultivated throughout the world. It was originally cultivated in Middle East and Asia Minor regions about 7000 years ago. Stalk of a wheat plant is normally 2 to 4 feet high. It has grass like leaves each of which is normally 8 to 15 inches in length. The top of each stalk is having a spike which is normally 2 to 8 inches in length. It is the grain rich part of wheat plant. Each spike contains 20 to 100 grains (kernels) whereas some spike contains up to 300 kernels depending upon the climate conditions.

A kernel is basically having three parts;

- Bran: This covers the entire kernel.
- Endosperm: It consists of food, endosperm cells are filled with starch and protein.
- Embryo: The part of kernel which take part in reproduction.

Each kernel contains 71.7% of carbohydrates, 11.7% protein, 2.1% fat, 12.8% water and 2% of fiber and mineral. Wheat is largely used in bread, cake, pastries, cookies, etc.

Cool moist springs for sowing and drier warmer period during harvesting along annual rainfall of 9 to 30 inches are ideal conditions for wheat cultivation. Usually in winter season wheat is cultivated during September and October whereas in spring it is cultivated during March and April in certain wetter regions of the world. In precipitation rich regions it is cultivated at a depth of 1 ½ inches whereas in dried region at a depth of 2 to 3 inches in ground. Globally 9 regions are ranked as most suitable for the cultivation of wheat. These regions are Central America, Canada, South Russia, Danube (Donau) River region, north Western India, North Central China, Argentina, Australia and Mediterranean region.

Effect of temperature on wheat productivity is quite distinct regarding the phenological development and growth rate. Wheat production is subjected to temperature. Besides this, temperature also affects plants by a number of ways mainly through cold hardening, winterkill (expiry of plant due to long cold season), vernalization, leaf appearance, carbohydrate fixation, respiration, grain filling, water stress and evapotranspiration (Rosenzweig and Tubiello 1996). Winter plants require minimum temperature of 5 to 10°C in order to come out of the dormancy period and hence wheat, which is a winter crop, also requires long cold season in order to hasten plant development before flowering occurs (Chouard 1960).

Wheat plant requires different levels of temperature (lethal, optimum, minimum and maximum) at different stages. It was observed that the lethal temperature range of minimum and maximum for wheat production was -17.2°C to 47.5°C. Minimum and maximum temperature requirement for leaf initiation is -10°C to 24°C, whereas, shoot growth phase of wheat requires 3°C minimum and more than 20.9°C of maximum temperature. Root is much sensitive to temperature as compared to shoot in the sense that the variation around mean temperature for root is less than in case of shoot. For root the optimal soil temperature requirement is below than 20°C. Temperature requirement for development of under ground part of wheat plant is 2°C minimum and 35°C maximum. The best range of temperature for enzymes working is 17.5°C to 23°C for wheat plant. However, temperature range for best working of photosynthesis operation in wheat plant is greater than that for enzymes process, the temperature requirement here for photosynthesis case is 15 to 30°C. Beyond these levels of temperature range, functioning of photosynthesis would be disrupted (Porter & Gawith, 1999).

Effects of temperature on the four different phases of phenological development of wheat are as follows (Porter & Gawith 1999):

a) Sowing

Minimum level of temperature required for sowing is about 2.4 to 4.6°C, whereas, maximum range of this temperature is from 31.8°C to 33.6°C. However, optimum temperature considered for this stage is about 20.4°C to 23.6°C and temperature required during vernalization phase is -1.3°C to 15.7°C.

b) Terminal Spikelet Initiation (TSI)

TSI is an important phase of wheat production. Productivity of wheat plant is subjected to number of spikelets and number of kernels per spikelet. So it is the phase from where productivity can be judged. Higher level of temperature during the early phase of spikelet initiation creates negative impact and reduces number of spikelets. Temperature required for this phase of wheat should be greater than 1.5°C and maximum limit of temperature for this phase is 25°C. Beyond this level of temperature it would create negative impact. Optimum temperature requirement for this phase is from 9.3°C to 11.9°C.

c) Anthesis

If temperature increases above 31°C before the start of anthesis phase, in such situation pollen sterility become active, this ultimately causes to reduce grain yield. Minimum temperature required for anthesis phase is considered to be 9.5°C, whereas its maximum temperature requirement is 31°C. However, optimum level of temperature for anthesis phase is around 18°C to 24°C. After one week of anthesis phase, higher level of temperature can not harm the wheat yield.

d) Grain Growth

Wheat plant becomes temperature tolerant with its development. Hence, greater range of temperature is then needed during grain growth phase as compared to anthesis phase. Synthesis of different research reveals that 12°C of minimum temperature and 33.4°C to 37.4°C of maximum temperature is required for grain growth phase. However, optimal temperature needed for this phase is 19.3°C to 22.1°C. Temperature during this phase also creates important impact regarding protein deposit in grains. Higher level of temperature reduces grain quality by reducing protein accumulation in grains.

The global wheat production is about 690 million tons per year. China is the world largest wheat growing country in the world having a share of 112 million tons in the total wheat production followed by the India which is producing about 79 million tons of wheat. Pakistan's share in global wheat production is 21 million tons which is almost 3% of the total wheat production (Food & Agriculture Organization 2008).

Warrick study for USA, UK and Western Europe regarding the impact of increase in temperature on the wheat productivity indicates that impact of increase in temperature is catastrophic in term of yield losses because higher temperature accelerates the evapotranspiration process creating moisture stress, it also shorten the growth period duration of wheat crop and this becomes more severe regarding yield losses if it occurs during the canopy formation because less time will be available for the formation of kernels (Warrick 1988).

It was evaluated that temperature increase by 1.7°C fasten the phonological development and growth rate of plant due to which the required growth period dropped by 3 days for the development of food, this ultimately create negative impact on wheat yield. Wheat, which was cultivated late, faced shortage of water due to low rainfalls and high temperature, both of which adversely affected the yield (Asseng *et al.* 2004). Subtropical winter regions are expected to experience decline in wheat productivity, warmer winter will sabotage the winter season wheat production of this subtropical region. In order to offset the losses emerging from decline of wheat production, farmers have to shift to other crops suitable to that weather conditions (Gbetibouo & Hassan, 2005).

Wetter conditions are beneficial for wheat yield whereas drier are harmful and cause to decrease the productivity. If temperature increases in wetter region then warmer conditions cancel the opposite effect of wetter condition creating end result with no effect. Whereas, in drier situation, the increase in temperature creates a multiplier effect and may cause the productivity loss (Warrick 1988).

Increase in temperature also increases the water requirement for agriculture production. The maximum winter temperature required for cereal crops production is 14.7°C along with 290mm of rainfall, whereas, in summer season the temperature requirement is 22°C and 570mm of rainfall. Beyond these values of temperature and rainfall the agricultural productivity will decline (Gbetibouo & Hassan, 2005).

South Asia is severely susceptible to the natural calamity and according to the survey of the World Bank for the last 28 years 900 such events have been recorded causing damages of infrastructure, life losses, health issue, food crises etc. Because of these calamities numbers of deaths recorded were 230000 and damages of worth US $45 billion (World Bank Report 2009).

Pakistan is lying in Arid Asia region along with Afghanistan, Kazakhstan, Kyrgyz Republic and Uzbekistan. Agriculture of this region would face both the positive and negative effect of climate change. Summer monsoon rainfall of Pakistan would be increased by 17% to 59% causing catastrophic impact on irrigation system and agricultural system of this region resulting in the food shortage. Wheat yield in Pakistan would decline mainly due to the effect of high temperature causing to shorten the time period for wheat growth (Luo & Lin 1999).

Up till now the temperature of Himalayan mountainous region increased by more than 1°C and similar conditions are of the Hindukush and Karakarum regions. Future disasters relating to these regions are floods, droughts, land erosion, loss of biodiversity, changing in rainfall and monsoon patterns and change in rivers flow, etc. (Sheikh *et al.* 2005).

1.4 Climate Change and Wheat Production in Pakistan

Pakistan is located to the north of the tropic of cancer between latitudes 24° and 37° N, and having an extreme climate condition, the mean temperature during June is 38°C (100°F) which sometime exceed 47°C (117°F) and in winter with minimum mean temperature of about 4°C (40°F). The total geographical area of Pakistan is 79.6 million hectares. About 27% of the area is currently under cultivation. Of this area, 80 % is irrigated. Most of the area of Pakistan is classified as arid to semi-arid because rainfall is not sufficient to grow agricultural crops, forests, fruit plants and pastures. About 68% of the geographical area has annual rainfall of 250 mm, whereas about 24% has annual rainfall of 251 to 500 mm. Only 8% of the geographical area has annual rainfall exceeding 500 mm.

Pakistan is an agricultural economy, having two main cropping seasons. In summer (Kharif) season the cultivation starts normally in April and ends in June, whereas the crops harvesting period is from October to December. Main crops of this season are rice, sugarcane, cotton, maize, mong, mash, bajra and jawar. In winter (Rabi) season the sowing period is from October to December, whereas the harvesting starts in the month of April and May. Major crops of this season include wheat, gram, lentil (masoor), tobacco, barley and mustard.

Total area under agricultural production in Pakistan has increased from 14.70 Mha in 1947 to 23.5 Mha in 2008. Summer crops use 84% of the total available water for agriculture in a year, whereas, winter crops use rest of the 16% agricultural water. The river flows during June to September is nearly 81% and for the rest of eight month river flow is about 19%. Our agricultural sector yield is not efficient as compared to China, Egypt and USA. The favorable temperature for wheat is 15 to 20°C. However, the prevailing temperature available for wheat in Pakistan is 0 to 40°C. Hence, negative impact of climate change on agriculture and wheat production in the form of rise in temperature is inevitable. Therefore, research is needed how to cope with this emerging threat in order to meet the future demand of wheat in Pakistan (Bhatti *et al.* 2009).

Although Pakistan's contribution to CO_2 emission is small and it comes on 35^{th} regarding the CO_2 emission but it suffers disproportionally from climate change and hence it is the 12^{th} most vulnerable country in the world. Pakistan among this region has to face the consequences of the climate change which includes the temperature hike, glacier melting, drought, floods and raising the sea level. According to the World Bank Report 22.8% of area and 49.6% population are prone to the consequences of the climate change. (World Bank Report, 2009)

The major crops of Pakistan's agriculture sector are wheat, cotton, sugarcane, and rice, whereas minor crops are oil seed, chili, pulses (masoor) and potatoes. There are many threats to the agriculture sector and water is one of the main important inputs of it which is deteriorating day by day. Besides water scarcity, water salinity, land erosion, agricultural diseases and climate change are newly emerging threats to our agriculture sector. According to the 4^{th} IPCC Report (2007) cereal yield could decrease up to 30% by 2050 in South Asia along with the decline of gross per capita water availability from $1820m^3$ in 2001 to $1140m^3$ in 2050. Water supply is scarce in many parts of the country and in near future a dramatic decline in the water availability would cast a sharp decline towards the production of agricultural productivity. According to the IPCC report the average temperature could rise by $2^{o}C$ in this century which could further destabilize our agriculture sector. Similarly, the sea level rise by average of 10 cm exhibit further pressure of coastal areas which may give birth to further soil erosion, floods etc.

Agriculture is the second largest sector of Pakistan economy having 21% share in GDP and 45% of the total labor force is engaged with this sector (Economic Survey 2010). Main crops (i.e. wheat, cotton, rice and sugarcane) of the agriculture sector have a share of 33.1% in the total value added of agriculture, whereas these four crops collectively have a share of 7.1% in GDP and their share in GDP at single crop level is 3.1% for wheat, 1.8% for cotton, 0.8% for sugarcane and 1.4% for rice.

After the inception of Pakistan agricultural sector couldn't grow rapidly because focus was given to the development of industrial sector. During the 1st Five Year Plan (1955-60) agricultural growth was just 1.7 percent against 7.72 percent of industrial growth. Key factor behind this lethargic agricultural growth was inauspicious agricultural policies.

However, during 2nd and 3rd Five Year Plan (1960-70) constructive agricultural policies boosted the agricultural sector. 1960s was the golden era of Green Revolution. New technologies were introduced in the mid of 1960s which were in the form of high yield varieties of wheat and rice. Wheat was the main constituent regarding the success of Green Revolution. Semi-dwarf, rust-resistant wheat seeds played vital role in this regard. Investment for agriculture and infrastructure development was improved. This policy initiation resulted substantial increase in agricultural output in Pakistan. Initiation of favorable policies during this period mounted the agricultural growth to 5.1 percent along with the comprehensive growth in industrial sector as well. It was the success of this high yield breed that during 1970 about 40% of the area of wheat was under the cultivation of this modern seeds. In 1994 more than 90% of the area was under the cultivation of high yield seeds in Asian region. Later on policies were not made in accordance with the requirement of Green revolution. Hence, intensified inputs caused lower marginal returns which restricted the positive effects of Green revolution for short-run only (Zia Khan *et al.* 2003).

During 4th Five Year Plan (1970-75) agricultural sector couldn't sustain the pace of growth as in the 1960s. Major reasons behind this were several natural calamities in the form of drought, floods, oil price hike, political instability and 1971's war. These factors slowed down the performance of agricultural sector and restricted its growth to 2.4 percent.

During the 5th and 6th Five Year Plan agricultural policies and development programs flourished the agricultural sector performance and once again Pakistan became self-sufficient in all basic foodstuffs. During this era agricultural growth was almost 5.4 consequently the effect was also experienced in industrial sector which flourished with 8.2 percent growth rate. However, in the subsequent periods agriculture sector was not focused as earlier.

The agricultural performance since the inception of Pakistan is shown in the table-1.1

Table 1.1: Agricultural Growth Rate

Sector	1950 to 1960	1960 to 1970	1970 to 1980	1980 to 1990	1990 to 2000	2000 to 2010
GDP (fc)	3.1	6.8	4.8	6.1	4.6	4.9
Agriculture	1.7	5.1	2.4	5.4	4.4	3.2
Industry	7.7	9.9	5.5	8.2	4.8	7.4

Source: Economic Survey of Pakistan

In Pakistan more than four million farmers (i.e. 80% of total farmers) are engaged with the cultivation of wheat. It is being cultivated on 40% of cropped area. It is also one of the main sources of income for the farmers. During 1975-76 about 20% of the farmers' income was generated with the cultivation of wheat.

According to a survey conducted by the Agricultural Price Commission of Pakistan (APCOM) during 1998 in Punjab 55% of the wheat production is sold during post harvest 4 months. According to the survey Punjab farmers, having more than 25 acre of land, sold 67% of their wheat production, whereas they used 20% of the production as payments for harvesting and threshing and the rest 13% was used by them for their own consumption. However, farmers of the rest of provinces use major portion of the wheat production for their own consumption. According to the survey at national level farmers use 30% of the wheat production for their own consumption.

According to another survey, namely Pakistan Integrated Household Survey (PIHS) in 2001-2002, 67% of total wheat sale was subjected to top 20% of the farmers engaged with the production of wheat, whereas the remaining farmers were either fully or partially fulfilling their wheat requirement through wheat cultivation.

Net consumption of wheat in rural areas is higher than in the urban areas. In rural areas wheat consumption is about 10.3 kgs/person/month. However, in urban areas consumption is about 7.2 kgs/person/month. During 1990s average wheat consumption was 131 kgs/person/year, however during 2003-2005 this consumption decreased to 113 kgs/person/year mainly as a result of 21% increase in wheat prices (Darosh & Salam 2006).

Wheat production in Pakistan is being affected because of water scarcity and little rainfall or delay in cycle of rainfall during the time of cultivation. The water available for the cultivation of wheat in Pakistan is 26 million acre feet (MAF) which is still 28.6% lesser than the normal requirement of water.

Qureshi and Iglesias (1994), by using GCMs and Dynamic Crop Model, estimated the impact of climate change on agriculture production in Pakistan. They concluded that wheat is highly influenced by extreme climate conditions (high temperature level). Their simulation results showed that the wheat yield would decline significantly almost in all major wheat growing areas even in fully irrigated conditions due to rise in temperature and shortening of phenophase duration of wheat plant.

1.5 Objectives of Study

The primary purpose of this study is to find out whether the global warming negatively affects the wheat production in Pakistan. More specifically, what has been the impact of change in temperature, precipitation and carbon dioxide on the wheat production in Pakistan? How far possible future changes in these factors may affect the level of wheat production in Pakistan? Moreover, along with core variables of temperature, precipitation carbon dioxide and water availability, the study also aims to investigate the role of a number of explanatory variables on the wheat production of Pakistan.

1.4 Scope and Limitation of Study

The study uses the data of last 50 years (1960-2010). This study assumes Pakistan as a homogenous region. It considers two basic variables of climatic change, namely temperature and precipitation. It does not consider the impact of climatic change on wheat production through humidity due to non-availability of wide range of time series data about the level of humidity in Pakistan. In context of dependent variable, scientists sometimes consider yield (per unit output) in place of total output to investigate the impact of various independent variables. However, this study does not consider yield due to non-availability of data on various factors (including different features of soil, etc.) that may influence yield.

2. LITERATURE REVIEW

2.1 Positive Effects of Climate Change

The following literature review is relating to the positive effects of climate change on agriculture production of wheat in different regions.

Warrick (1988) carried out investigation regarding the impact of CO_2 and climate change on agriculture. He used the techniques of crop impact analysis, marginal spatial analysis and agriculture system analysis. According to his study, at higher level of CO_2 in the atmosphere C3 crops especially wheat would show improvement in water use efficiency through less transpiration. At $2\times CO_2$ concentration level (680ppm) wheat production would increase 10% to 50% for mid and high latitude region of Europe and America. However, 2°C increased in temperature would decrease the production by 3% to 17%. This level of increase might be offset by higher level of precipitation caused by increased CO_2 emission. He further examined that in this case if precipitation decrease then agriculture losses would increase. He analyzed that for each 1°C increased in temperature would cause to shift the geographical location for crops production to several hundred kilometers towards mid and high latitude regions. According to his finding adverse shock to agriculture system could be reduced through better management policies.

Rosenzweig and Tubiello (1996) used the CERES-wheat simulation model in order to check the impact of change in mean minimum and maximum temperature on wheat yield for US central region. Their areas of investigation were four sites of US namely Fargo, North Platte, Dodge city and San Antonio. Their aim was to check the effect of change in minimum and maximum temperature along with prevailing (330ppm) level of CO_2 and elevated level of CO_2 (550ppm) on the phenological development of wheat plant. They considered two scenarios for their study. In scenario one, they considered equal increase in minimum and maximum temperature, whereas, in second scenario they increased minimum temperature three times as much as maximum temperature. The increased mean temperature (1 to 4°C) shortened the growth period and consequently lessened the potential yield of wheat. The results revealed that increased in mean minimum temperature over maximum lead to increase the wheat yield. They also found that elevated CO_2 and 1 to 2°C increase in temperature would create positive impact on wheat yield. Moreover, negative impact with 3 to 4°C increase in temperature might be offset by the elevated CO_2 fertilization affect. They regarded it as minimum and maximum limit of temperature for wheat yield in Central US region.

Wang and Connor (1996) used wheat model in order to study the impact of present and future climate on the agricultural production of wheat in two counties of Australia which were Mildera and Wagga Wagga. They found that an increase in CO_2 concentration would be having positive impact on wheat by increasing wheat productivity from 10-30%. They also revealed that yield would be declined up to 50% if temperature increased up to 3 °C. They found that the short-season genotypes are more sensitive to warming and increase in temperature would negatively affect the productivity of wheat in this region.

Harrison and Buterfield (1996) used Euro-Wheat and Euro-Sunflower models for three different climate scenarios UKHI, UKTR31-40 and UKTR66-75 in order to assess the impact of climate change on the wheat and sunflower productivity in Europe. The results presented for current climate (1961-1990) under the UKHI and UKTR31-40 scenarios indicated decrease wheat productivity. However, under the scenario UKTR66-75, it showed a slight increase in sunflower productivity. By applying Euro-Wheat model under these three climate change scenarios simulation results showed positive impact on wheat production, whereas for UKTR66-75 the productivity was very high. According to their study UKTR31-40 and UKTR66-75 scenarios would be realized in 2023 and 2064 which would exhibit increase in wheat production of 2 ton per hectare per decade from 1990 to 2023 and 0.36 ton per hectare per decade from 2023-2064 across Europe.

Zalud *et al.* (1999) used CERES-Maize and CERES-Wheat simulation model. The purpose of their study was to find the climate change impact on the agricultural productivity of maize and wheat. Their area of investigation was Czech Republic. They used double level of carbon dioxide scenario. The results of their study showed that the positive effect of carbon fertilization on wheat productivity was dominating over the negative effect of increase in temperature on wheat production. The results also showed that the maize productivity would increase by 14% and that of wheat by 31% for $2\times CO_2$ scenario.

Ghaffari *et al.* (2002) used the dynamic crop grain model in order to assess the impact of climate change on wheat production for South Eastern England. They used CERES-WHEAT simulation model for the period of 2025 and 2050. They considered cultivars, planting and harvesting dates, temperature and soil nutrition as factor inputs. They used six different scenarios for their simulation study. In each scenario they used increased level of temperature and CO_2 concentration and different level of precipitation. According to them for dry scenario increase in temperature would result in reduction of wheat yield. In areas having water stress condition, CO_2 fertilization could play its role to improve yield. They also revealed that sowing on early days will generate greater yield as compared to sowing on later dates. Cultivation made on modest soil would produce potential wheat yield as compared to cultivation made on sandy or clay type lands. According to them nitrogen and other fertilizer would enhance the wheat yield in water stress areas.

Southworth *et al.* (2002) applied the CERES-Wheat model to assess the impact of climate change, climate variability and CO_2 concentration level on the production of wheat. Their areas of investigation were five states of US, namely Indiana, Illinois, Ohio, Michigan and Wisconsin. Along with CERES-Wheat they used Decision Support System for Agrotechnology Transfer (DSSAT) software in order to categorize and maneuver the data in different ways before applying the model. The study was made for the period of 2050-2059 and it used six climate scenarios. They concluded that at 555ppm level of CO_2 concentration would employ positive effect on the production of Northern areas of the study and would increase the yield from 60% to 100%. For Southern areas production would increase by 0.1% to 20% or a slight decrease in production of wheat of Southern region from -0.1% to 15%. However, the overall impact of climate variability and CO_2 concentration on the study areas would be positive by producing greater yield. Early planting or sowing would create positive impact on yield. They concluded that in order to cope with the future high level of climate variability soil quality would play important role.

Thomas *et al.* (2002) used Erosion Productivity Impact Calculator (EPIC V.7270) in their study to check the impact of climate change on wheat production for the region of U.S Pacific North-West. To address the climate pattern of the complex topology of this region they used Pacific Northwest National Laboratory Regional Climate Model (PNNL-RMC) to simulate the methodology for the EPIC model. By using double level of CO_2 concentration in PNNL-RCM it predicted warmer and wetter climatic condition. The input data used in EPIC model was regarding soil, cultivars, tillage, fertilization, minimum and maximum temperature, precipitation, solar radiation, surface pressure and winds. EPIC simulation model predicted 1Mg ha^{-1} increase in wheat yield under climate change alone scenario. However, at double level of CO_2 the model predicted increase in winter wheat yield for dry land was 1.4 Mg ha^{-1} and 1.2 Mg ha^{-1} for irrigated land, considering the beneficial effect of CO_2 on wheat crop (water use efficiency and evapotranspiration) and also adequate water availability for irrigation purpose. From the results it was also concluded that areas located at high altitude would take benefit due to climate change.

Attri and Rathore (2003) used the Crop Estimation through Resource and Environment Synthesis-Wheat (CERES-wheat) V3-5 model in order to check the impact of temperature, precipitation, radiation on phenology of wheat. They also investigated water and nitrogen stress on growth and development of wheat under three different scenarios. In scenario-I they considered present climate, in scenario-II maximum daily temperature was increased by 1°C and concentration of CO_2 was increased up to 460ppm. In scenario-III minimum day time temperature was increased by 1.5°C and concentration of CO_2 at 460ppm. They used these three scenarios in order to simulate the wheat yield in India. According to the simulation result for scenario II & III wheat yield showed 29-37% and 16-28% increase under rain fed and irrigated conditions, respectively. The study revealed that further increase in temperature keeping CO_2 level at 460ppm wheat yield would be decreased. However, in this case productivity would still be higher as compared to present. Temperature increase by 3°C or beyond would decrease the wheat yield in Indian region.

Lobell *et al.* (2005) used CERES-Wheat simulation model for the climate trend effect on wheat production in the Mexico region (Yaqui and Mayo valleys of Southern Sonora and Mexicali and San Luis Rio Colorado valleys of Northern Sonora and Baja California). They studied the climate trend and wheat yield from 1988 to 2002. They found that the climate had favored during the last two decades resulted in a 25% increase in wheat production. However, 25% increase was less as compared to the previous studies which predicted higher increase in wheat production for this region.

Xiao *et al.* (2008) carried out the investigation in order to check the effect of climate variability on high altitude crop production. They incorporated statistical analysis (GLM analysis) in order to check the impact of enhanced temperature and rainfall on the productivity of crops. For this they selected two sites, Tonguei Metrological station 1798m above the sea level and Peak of Lulu Mountains 2351m above the sea level. They investigated the effect for the time period from 1981 to 2005. Their results showed that yield of both the sites increased during this period bearing positive change of temperature and precipitation. Initially up to 1998, yield of two altitudes was high but after that yield of high altitude showed as increasing trend as compared to low altitude regions. The simulation results up to 2030 also showed that the agriculture production of wheat for low altitude would increase by 3.1% and that of high altitude would show 4.0% increase.

Hussain and Mudasser (2006) used Ordinary Least Square (OLS) method to assess the impact of climate change on two regions of Pakistan which were Swat and Chitral, 960m and 1500m above the sea level, respectively. They investigated that increase in temperature up to 3°C would decrease the Growing Season Length (GSL) of the wheat yield of these regions. Increased in temperature would create positive impact on Chitral district as its location is on high altitude and negative impact on Swat because of its low altitude position. They said that temperature increased up to 1.5°C would create positive impact on Chitral and would enhance yield by 14% and negative impact on Swat by decreasing its productivity by 7%. They found that further increase in temperature up to 3°C would decrease the wheat yield in Swat by 24% and increase in Chitral district by 23%. They presented the adaptation strategy that high yield cultivars of warmer region should be tested in mountainous areas of Northern Region of Pakistan because of expecting future increase in temperature.

Crimp *et al.* (2008) used Agricultural Production System Simulator (APSIM) model embedded with 350-750ppm level of CO_2 concentration, -30% to +20% change in rainfall and 0 to 4°C of temperature in order to study the effect of these factors on wheat yield for different transect of Australia. Their simulation results for Dalby showed that keeping other factors constant at 650ppm level of CO_2 wheat yield would increase 34%. However, keeping all factors constant except temperature each degree increase would create 8% decline of wheat in this region. Whereas, keeping all factors constant except CO_2 concentration, at 650ppm level wheat yield showed +34% for Dalby , 23% for Coolamon and 30% for Wongan Hill. Their results indicated that while keeping rainfall and CO_2 concentration at current level each degree increase in temperature would reduce the potential wheat yield of Dalby by 8% and of Coolamon by 2%. Based on Commonwealth Scientific and Industrial Research Organization (CSIRO) 2007 best estimation of climate change by 2050 at 550ppm CO_2, 2 to 2.5°C and -5% to -10% rainfall would create impact on wheat yield from -5% to 6%, for Dalby, whereas, for Coolamon small decrease in rainfall -2 to -5%. They also found that 550ppm level of CO_2 and 2 to 2.5°C of temperature would create positive effect of 7% to 11% on the wheat production for this region.

Jamieson and Cloughley (2001) incorporated Sirius CLIMPACTS model in order to assess the effects of climate change factors, namely temperature amplification, CO_2

concentration, droughts and types of soil effects on the production of wheat in New Zeeland region. They used common variety of wheat for two different season autumn and spring. The model was used for deep soil, medium soil and shallow soil. They revealed that for the last two scenarios the model predicted earliness of wheat in order to avoid it from drought risk and to get high productivity. They also said that CO_2 concentration have positive impact on agriculture productivity in all cases.

2.2 Neutral Effects of Climate Change

Following studies are related with neutral impact of climate change on production of wheat for different global regions.

Tobey *et al.* (1992) used General Circulation Model (GCMs) and Static World Policy Simulation Model (SWOPISM) for their study. The model used by them was static in nature, in the sense that it presented only on spot effect of doubling of CO_2 on global agriculture. The model used 20 agriculture commodities. According to their study climate change would affect the agricultural productivity on regional level, but as a whole it would not disrupt the global agricultural productivity. The negative impact of climate change in one region would be compensated by another region and hence there would be no major threat to global agricultural productivity. For the study they divided the world into four regions, namely northern, northern mid latitude, tropics and southern mid latitude regions. Although climate change would create negative impact on the major agriculture producing countries lying on tropic, mid northern latitude but this negative impact would be counter balanced by the regions of southern and northern latitude. So they were having the strong view that global agricultural productivity would not be disturbed by climate change.

Wolf *et al.* (1996) incorporated five wheat models (AFRCWHEAT2, CERES-Wheat, N-WHEAT, SIRIUS-WHEAT, and SOILN-wheat). The models were applied for two European regions, for Rothamsted (UK) and Sevelle (Spain). Both of the regions are having different climatic conditions. They used different agronomic conditions for their models and then compared the results. They concluded that almost all the models predicted the same results. Their results showed that temperature increase would result in yield reduction. Whereas, increased level of precipitation and CO_2 fertilization would create positive impact on the production of wheat for Europe.

Zhang and Nearing (2005) used Hardley Centre Model (HadCM3) for their study about the wheat productivity in Central Oklahoma. They used three scenarios A2a, B2a and GGa1 for the current time period (1950-1999) and future time period (2070-2099). The simulations model projected that annual future precipitation would decrease by 13.6%, 7.2% and 6.2% for the three said scenarios, respectively, whereas temperature would increase by 5.7°C, 4°C and 4.7°C, respectively. They said that the short of rainfall would be in summer not in winter to affect the yield, whereas the increase in temperature was in large offset by the carbon fertilization. According to their estimation in scenario B2a wheat yield was expected to decrease by 5%, whereas, in scenario GGa1 yield was expected to increase by 5%. In GGa1 scenario they used historical trend of greenhouse gas emission from 1860-1990 and then used this trend for 2099. According to them scenario A2a was less environmental conscious as compared to scenario B2a.

2.3 Negative Effects of Climate Change

Among others the following studies relate to the negative impact of climate change on wheat production:

Tubiello *et al.* (1995) used the changed version of CERES-wheat v-2.10 to assess the impact of higher temperature and CO_2 concentration on wheat. They found that infertile environment slow down the ability of wheat to gain benefit from enriched CO_2 condition, whereas higher level of temperature not only negatively affect the canopies of wheat but also reduce the positive impact of CO_2 fertilization on wheat at a $2\times CO_2$ level. Yield losses would occur if the minimum and maximum temperature enhance equally in rain fed areas, whereas gain would occur for the irrigated regions.

Winters *et al.* (1996) analyzed the impact of global warming on the archetype structure of Africa, Asia and Latin America. They used Comparable General Equilibrium (CGE) model for their study. They concluded that these entire three regions will face agriculture losses in cereal and export crops and hence income losses. They said that Africa would be the most negatively affected regions by this climate change because its economy is relying very heavily on agriculture output. They investigated that higher substitution possibility for increase in import cereal could do more to reduce income losses. For Asia and Latin America domestic prices of export crops could increase because of the increase in the demand for these crops.

Luo and Lin (1999) made a theoretical study of the Asia Pacific region in which they reviewed different papers regarding the impact of climate change on the agriculture production of this region. They divided this region into three sub-regions namely Temperate Asia, Tropical Asia and Arid Asia. According to them most of the studies made for this region were on the agricultural products including wheat, rice, soybeans and maize. Most of the studies used General Circulation Models (GCMs) to check the impact of climatic change. Almost all the results of the studies indicated negative impact of climate change on agriculture production specially wheat. Their study revealed that the agriculture production of this region is under threat.

Reyenga *et al.* (1999) used the I-wheat model to assess the climate change impact on the wheat cropped land area. Their study areas were South Australia and North New Wales. Their results for South Australia showed that double level of CO_2 concentration would create positive impact on all regions of South Australian wheat yield, expanding the area towards North. However, the temperature increase would offset this expansion. Whereas, for the dry scenario when summer rainfall decreases by 15% and winter by 20%, then it would create negative impact on wheat yield and would decline the wheat productivity by 10% to 35% and causing contraction of the agricultural land for wheat. Their results for South New Wales showed that $2\times CO_2$ concentration level would create 20% to 28% increase in wheat yield expanding the boundary by 150km towards the

West. Similarly, the temperature increase offsets this expansion. However, in the dry scenario, where rainfall declines by 20%, it would cause 5% to 53% decline in wheat yield and also a substantial retreat of agricultural land.

Wassenaar *et al.* (1999) showed the response of winter wheat yield to soil and climate change variability for 63 different sites of South France. They used Euro-ACCESS simulation model for their study for current climate 1976-1984 and for future climate 2047-2054. They used three different climate scenarios for their study which were low, mid and high. The impact of low and mid scenario for the time period 1976-1984 showed slight increase and slight decrease in wheat yield, respectively. Whereas, high scenario exhibit a prominent decrease in wheat yield and on average the wheat production declined about 0.8 ton per hectare. The results also suggested that the effects of soil are more explicit than temperature for the entire three scenarios discussed in the study.

Amthor (2001) carried out investigation in order to check the impact of CO_2 on wheat. He performed 156 experiments in laboratory chambers, glasshouse, closed top field chamber, open top field chamber and free air fields CO_2 enrichment system. The results showed average increase in wheat productivity up to 31% in the fields where concentration of CO_2 was increased from 350 to 700ppm and also provided ample nutrient and water. According to the author when concentration of CO_2 was increased at double level and temperature increased from 1.6 to 4°C, wheat productivity decreased.

He concluded from his experiments that increased in both temperature and CO_2 simultaneously would decrease the wheat yield.

Tubiello *et al.* (2002) analyzed the effect of climate change on the agriculture of USA at regional level. They tested two different climate scenarios HCGS and CCGS. According to their study climate change had shown positive impact on winter wheat under HCGS scenario. Whereas, under CCGS scenario it shown 30% to 40% decline. The study revealed that in the Northern Plain region under CCGS scenario negative impact of climate change could cope through early cultivation otherwise productivity could decline from 20% to 25%. They also revealed that US agriculture sector is not under threat up to the end of this century due to climate change. However, climate change has a positive impact on the northern areas and negative on the southern areas in USA.

Tsvetsinskaya *et al.* (2003) carried out investigation regarding the impact of climate change on maize, wheat and rice production for south-eastern United States region. They incorporated version 3.1 of CERES-Maize, CERES-Wheat and CERES-Rice models in the study in order to check the phenological development of these three crops, production of biomass, effect of CO_2 on plants regarding CO_2 fertilization, water use efficiency and effect of temperature on plants. General Circulation Model (GCM) and Regional Climate Model (RCM) were used to generate the values for climate change scenarios of controlled and double level of CO_2. They adopted three cases in each scenario, climate change alone in case one, climate change and effect of CO_2 in second case and in case three they considered climate change with adaptation strategies. The results of their study showed that on dry land condition among the three crops maize yield would affect badly whereas, wheat yield would be less affected. Moreover, the results from General Circulation Model showed large wheat reduction and less reduction in case of the results from Regional Climate Model.

Asseng *et al.* (2004) employed APSIM-N wheat version 1.55s simulation model. The model was calibrated with soil water, nitrogen, crop growth and also daily climatic data on minimum and maximum temperature and precipitation in order to check the impact of increase in temperature, water scarcity and concentration of CO_2 on wheat yield. Their study for the Obregon (Mexico) region showed that 1.7°C increase in temperature would shorten the flowering time by 11 days which would be resulted in decline of wheat yield. They also reported that Lincoln (New Zeland) would face productivity losses from 10 ton per hectare to 4 ton per hectare due to water scarcity. They found that Western Australia would also face the yield shortage when production fall to 0.5 ton per hectare during water deficiency conditions. They revealed that Free Air Carbon dioxide Enrichment (FACE) showed positive impact on Arizona (USA) region where wheat yields increased substantially. The impact of elevated CO_2 along with increase in temperature had on average positive impact on Mediterranean environment of Western Australia.

Gbetibouo and Hassan (2005) employed Ricardian model on wheat, sorghum, maize, sugarcane, ground nut, sunflower and soybean for the South African region. They found that temperature increase would be having positive impact on the agriculture production of maize, sorghum, sunflower and soybean, whereas it would be having negative impact on sugarcane and wheat productivity. They said that this region is already having threshold level of temperature and any further increase in temperature in future due to climate change would havoc the wheat productivity. They suggested that in order to avoid losses wheat should be replaced by maize and sorghum or other heat tolerating crops.

According to the study made by Howden and Crimp (2005), 2°C increase in temperature along with rainfall would deteriorate the wheat productivity of Australia. They revealed that subtropical regions where temperature already remained very high and if temperature of this region further increases then what so ever adaptation applied to the wheat in this region, wheat yield would decline. Their study about Southern region showed that temperature increase up to 1°C would be beneficial. However, incorporating adaptation strategies up to 3°C increase in temperature would still be beneficial for this region's wheat productivity. They further investigated that 2°C increase in temperature with no change in rainfall would negatively affect the wheat production in this region.

In order to check the impact of climate change in Iran for 2025 and 2050 Nassiri *et al.* (2006) used United Kingdom Meteorological Organization (UKMO) climate model. They applied this model to 12 rain fed wheat areas of north-west and western Iran. They used World Food Study (WOFOST, v 7.1) crop simulation model. The crop simulation model was calibrated with 425 and 500ppm level of CO_2. They also used 2.7 to 4.7°C level of air temperature. Their results revealed that wheat yield would be declined by

18% for 2025 and 24% for 2050. They founded that this decline would be the outcome of 8.3% to 17.7% of rainfall scarcity and 8 to 36 days shortening of the growth period of wheat. They also revealed that at this level of change in climate, area under wheat production would be declined by 15% to 40%. They suggested that in future this loss could only be decreased by early sowing and by using new breeds of wheat.

Timsina and Humphreys (2006) used CERES-Rice and CERES-Wheat simulation model in order to assess the impact of climate change on Asian region. The results showed that agriculture output of both crops would be decreased with increase in temperature. They also found that increase in temperature would decrease growth period of wheat. The results showed that CO_2 concentration would have some level of positive impact on yield. Increase in temperature could lead to extend geographical region for cultivation of rice and wheat. Simulation results revealed that there would be strong negative impact of climate change in Pakistan and India regarding wheat yield and Bangladesh regarding rice yield.

Rajin *et al.* (2007) carried out a study for South-East Australian region. According to them temperature is consistently increasing and this increase in temperature would create strong negative impact on wheat production. They incorporated CropSyst version 4 embedded with new model, which took the response of elevated CO_2, relative humidity in percentage, dew point in degree centigrade and wind speed in meter per second as input variables. They used three climate change scenarios for their simulation study which were low, mid and high daily climate change scenario for 2000-2070. These scenarios were generated by Australian Commonwealth Scientific and Industrial Research Organization (CSIRO's) atmosphere models, followed by the IPCC requirements. Their results showed that for all the three scenarios the medium wheat yield declined by 29%. However, elevated CO_2 created positive impact to some extent and trimmed down this decline in production from 29% to 25%. CO_2 fertilization effect slightly compensated low rain fall and higher temperature. They suggested that higher yield productivity could be made through better agronomic strategies and breeds of wheat.

Cerri *et al.* (2007) used four General Circulation Models (GÇMM2, CSIRO m2, DOEPCM and Had CM3) for their simulation study. The models were embedded with climatic variables which were cloud cover, daily temperature range, precipitation and vapors pressure. They used four different climatic scenarios (A1F1, A2, B2 and B1). In order to generate the values of variables for their simulation study they used TYN CY 3.0 data set. The model was integrated for region of Brazil up to 2050. They revealed that 3°C to 5°C increase in temperature and 11% increase in precipitation would cause to decrease the production of wheat by one million ton. They said that in Brazil wheat was being cultivated at the threshold level of temperature and any further addition to this level of temperature would cause to decline in the production of wheat. They further added that most of the developing countries which were lying on the tropical belt and whose economies are relying on agriculture, would face agriculture yield losses.

Magrin *et al.* (2009) made a study on agriculture productivity of wheat for Pergamino (latitude 33.54°S, longitude 60.35°W) a temperate-humid region located in Pampus region of Argentina. They used CERES-Wheat model calibrating with minimum and maximum temperature, precipitation and solar radiation as inputs. According to the results of their study Central and Northern Pampus would face 20% to 30% yield losses due to climatic change. They analyzed that increase in temperature during the period from 1930 to 2000 was 2.5°C for the months of October and November, and each °C increase in temperature caused a 7% reduction of wheat productivity and further increase in temperature would cause further decline in yield. They concluded that in future if carbon dioxide concentration work at 550ppm level then this could offset the negative impact of increase in temperature. According to them by the end of the current century 4 to 5°C increase in temperature and precipitation could decrease the wheat productivity.

Qunying *et al.* (2009) incorporated the Agriculture Production System Simulator-wheat (APSIM-wheat) model version 4.1 to investigate the climate change impact on the agricultural production of wheat in the region of Keith which is located in southeast of South Australian. They used historical data from 1906 to 2005, and used CSIRO Conformal Cubic Atmospheric Model (C-CAM) to generate the values of the variables for the simulation study up to 2080. The principal objectives of their investigation were to reckon the impact of climate change on wheat production and extent of adaptation policies to curtail the negative effect of climate change on wheat production. According to their findings wheat yield would decline by 10% under low water availability condition for plants and 15% under high water availability conditions for plants. They also found that 75kg per hectare of nitrogen-application under current circumstances would be suitable for land under wheat production. From the results of their simulation study they found that under the assumed climatic conditions for 2080 application of nitrogen and wheat cultivars collectively or alone could not be able to attain the wheat yield of the current level. According to them adaptation strategies of early sowing by two weeks and different level of nitrogen-application might be useful in order to cope with the future negative impact of climate change on wheat yield up to some extent in South Australia.

Zhai *et al.* (2009) used global Comparable General Equilibrium (CGE) model in order to examine the impact of climate change on agriculture and trade sector of China. To check the impact in future they incorporated simulation study up to 2080. Their results showed that agriculture share in GDP would decline by 1.3%. Thus, in 2080 agriculture output would become slow which ultimately leads to output losses. The simulation results also showed that China agriculture productivity would decline by 7.2% which is less as compared to the global productivity loss of 15.9%. Their simulation results also indicated that agriculture productivity losses for Asia alone would be 19.3%.

Zhai and Zhuang (2009) made a study on Southeast Asian region. They used CGE model to investigate the economic impact of climate change on the said region. According to them impact are not consistent throughout the world and developing countries would face large losses. According to the simulation results made by them up to 2080 Southeast Asia would face 1.4% decline in GDP. Crop productivity would fall up to

17.3%, whereas the agriculture productivity of paddy rice would fall 16.5% and that of wheat up to 36.3%. In future the Southeast Asian countries dependency on import of these agricultural products would increase creating more welfare losses and hence weakening the term of trade of this region.

From the literature review we can infer that the effect of climate change is subjected to the geographical positioning of each region. On that basis climate change effect can vary among three categories of regions, which are as follows:

Category one include tropical region countries situated on the equator of the earth which is the nearest path way of sun to the earth. Most of the countries situated on this belt are developing countries. Temperature of this region is already at threshold level and any further increase in temperature might create havoc results on these countries.

Second region can be called as the moderate region. Most of the countries lying on the Tropic of Cancer and Tropic of Capricorn are part of the moderate category. Temperature of this region is mostly cool or favorable to the agricultural crops. Any moderate increase in the temperature will be beneficial for most of the countries of this group.

Third category includes the countries which are lying very next to the tropical region which can also be called as countries of sub-tropical region. Pakistan is amongst this category. The historical temperature data of this region shows that the temperature didn't create havoc results on the agriculture crops of this region up till now. However, some studies for this region show that in future any further increase in temperature might create catastrophic impact on agricultural crops and climate related sectors. Repeated climate change events like frequent droughts, floods, glacier retreats and changing rainfall pattern are some evidences for this changing behavior of climate for this region.

From the literature review it can also be observed that most of the studies used double level of CO_2 for their simulation study. For all the regions CO_2 showed positive impact on wheat production. Carbon dioxide concentration is not bounded to geographical positioning. All the regions will be benefitted with the enhanced level of CO_2.

The subject case of our research is wheat, which belongs to the C3 crops category. This category exhibits high response to enhanced level of CO2. Enhanced level of CO_2 in atmosphere in consequence of anthropogenic activities will create positive impact on wheat as compared to crops of C4 category.

3. METHODOLOGY

3.1 Variables and Data

The variables used in this study and data sources are mentioned below:

Wheat Production

Wheat production data is collected from different editions of Economic Survey of Pakistan. The unit of measurement used for wheat production is in thousand tons.

Carbon Dioxide

The direct impact of carbon dioxide on the production of wheat is positive, as it enhances the water use efficiency of plants. The data regarding the CO_2 is gathered from the website of Carbon Dioxide Information Analysis Center and all emission estimates are expressed in thousand metric tons of carbon.

Average Temperature

Temperature is assumed to be having negative impact on wheat productivity for the regions which lie on the tropical or near to the tropical regions. The temperature is considered in Celsius degree centigrade. Data source is Metrological Department of Pakistan.

Average Precipitation

Precipitation assumed to be having positive impact on the production of wheat. Our source of data for precipitation is Metrological Department of Pakistan. The gauge of precipitation is millimeter.

Water Availability

Data regarding water availability has been collected from different editions of Economic Survey of Pakistan. Unit of measurement is Million Acre Feet (MAF).

Agriculture Credit

Data for agriculture credit is generated form different publications of Economic Survey of Pakistan. Unit of measurement is billion rupees.

Explanatory Variables

Values of other explanatory variables namely fertilizers offtake and technology (tractors, threshers and tube wells) are also collected from different editions of Economic Survey of Pakistan.

3.2 The Model

Up to now a number of models have been applied to find out the relationship between climate related variables and wheat production. Most of them were agronomic in nature. Some of these models have been discussed here;

Crop Estimation through Resource and Environment Synthesis (CERES-Wheat), basically yield simulation model which was created under the support of USDA-ARS Wheat Yield Project and the US government multi agency AGRI STARS program. The purpose of this model is to check the impact of temperature, precipitation, quality of soil and crops management factors on the production of wheat. In this model temperature, precipitation, soil quality, crops management (plant population, planting depth and date of plantation) and plant characteristics are used as input factors (Bannayan et al. 2003).

Conformal Cubic Atmospheric Model (C-CAM) was developed under the supervision of Commonwealth Scientific and Industrial Research Organization (CSIRO). The basic purpose of this model is also to simulate the effect of climate change, management practices, changing N-application rate on the wheat growth.
The input factors used in this model are mean climatic change factors, i.e. mean rainfall, mean temperature and mean solar radiation, and changes in climate variability, i.e. wet spells, dry spells and temperature variability (Luo et al. 2009).

Erosion Productivity Impact Calculator (EPIC) is also crop-soil-climate interaction model. Purpose of this model is also to simulate the impact of climate and soil on wheat growth. This model requires data on daily basis. The variables used in this regard are precipitations, maximum and minimum temperature and solar radiation. For the missing values sub-models are used to generate the missing figures (Moulin & Beckie 1993).

It is difficult to apply these agronomic models in our case because of following reasons:

First, the agronomic models are basically used at farm level from where data regarding the soil nutrition, soil water etc is obtained through different experiments.

Beside this temperature, precipitation and solar radiation data can also be arranged for farm level experiment. In our case we are applying model on the production of wheat at national level so the problem arises in this case is regarding the data availability of soil quality, soil water, soil nutrition, minimum and maximum temperature, precipitation, solar radiation and crop management for every region. Data for each region, where wheat is being cultivated, is not available. Due to the absence of any proper mechanism regarding data collection, one has to perform experiments at every region to collect data.

Second, agronomic models are prepared and used by international research institutions with copyrights. Hence, the models are not easily accessible.

Third, the software is difficult to run without proper training. At national level there is no such institution which is providing training regarding such software.

Beside agronomic models *Computable General Equilibrium model* (CGE) is also used in some studies. CGE is an input-output model. The model is calibrated to Social Accounting Matrix (SAM). Features of this model are needed to be updated but the model for Pakistan has not been updated for last decade. Therefore, applying the old structure of CGE model would generate spurious results which can ultimately mislead the facts.

Why ARDL is a better technique in case of our study?

In this study will apply Auto Regressive Distributed Lag (ARDL) model. Some of the variables in our study are stationary at level whereas, some of them are integrated of order 1. So in this case ARDL model is a better econometric technique as compared to other econometric techniques. Beside this as our objective is to check the impact of different variables on a single dependent variable (wheat production) in short-run as well as in long-run so in our case this technique becomes more suitable than others.

3.3 Unit Root Test

In order to ascertain the Auto Regressive Distributed Lag (ARDL) model we first check the stationarity of the data. Stationary data have the property of uncorrelated error term and have constant variance. In the absence of this property data is considered to be unit root. To make it stationary we perform unit root test.

In time series analysis unit root test has widely been used to check the stationarity of the data. For this purpose numbers of unit root tests have been introduced in econometric literature like Phillip-Perron (PP) unit root test, Dickey Fuller (DF) GLS test, Augmented Dickey Fuller (ADF) test, Ng Perron test etc.

We are using Augmented Dickey Fuller and Phillips-Perron unit root testing approaches for our study. ADF test was established by Dickey & Fuller. The general form of the test is as follows:

$$\Delta Yt = \beta_1 + \beta_2 t + \delta Y_{t-1} + \alpha_i \sum_{t=1}^{m} \Delta Y_{t-i} + \varepsilon_t \quad (1)$$

ε is error term whereas, Δ is difference operator.

$$\Delta Y_{t-1} = (Y_{t-1} - Y_{t-2}), \qquad \Delta Y_{t-2} = (Y_{t-2} - Y_{t-3})$$

The null hypothesis in this regard is $\delta = 0$ for unit root and $\delta < 0$ for stationarity. The calculated values of δ are checked with τ critical values from Fuller table. If the calculated value is less than critical value then variable is said to be stationary or otherwise (Gujrati 2003).

The other unit root test we are using for our study is Phillips-Perron (PP) unit root test. This test was developed by Phillips and Parron during 1984. PP test is non-parametric in nature. As compared to ADF test, PP test ignores any serial correlation in the test regression. General form of the PP test is as follows:

$$\Delta Y_t \quad = \quad \alpha_1 t + \theta Y_{t-1} + u_t \tag{2}$$

Where u_t is I(0) and may be heteroskedastic. The null hypothesis in this case is that $\theta=0$. The PP tests correct for any serial correlation and heteroskedasticity in the errors u_t of the test regression by directly modifying the test statistics.

The Phillips-Perron (PP) unit root tests differ from the ADF tests mainly in how they deal with serial correlation and heteroskedasticity in the errors. Beside this PP test is independent of lag length selection (Virmani, 2004).

3.4 Auto Regressive Distributed Lag (ARDL) model

In econometrics literature extensive work has been done especially for the last two decades regarding the generation of univariate and multivariate cointegration models. Some of the prominent univariate cointegration models are Engle and Granger (1987) and the fully modified OLS procedures of Phillips and Hansen (1990). Whereas, some of the well known multivariate cointegration models are Johansen (1988), Johansen and Juselius (1990), and Johansen's (1996) approach to cointegration analysis.

For the last couple of years researchers are extensively using a new single cointegration technique in their research work. This new cointegration approach is Autoregressive Distributed Lag (ARDL) of Pesaran et al. (2001) also known as bound testing cointegration technique. Pesaran cointegration technique has some econometric advantages over the other cointegration techniques (Ferda, 2009) which are as follows:

1. ARDL model is more efficient for small sample data as compared to other cointegration techniques e.g. Engle & Granger (1987), Johansen & Juselius (1990) and Philips & Hansen (1990) which requires large sample data. The model could use limited sample data (30 to 80 observations) in which the set of critical values were developed by Narayan (2004) by using Gauss (Duasa, 2010).
2. ARDL models evade making extensive specification in the standard cointegration test. These comprise choice concerning the insertion of exogenous and endogenous variables (if any) to be integrated (Duasa, 2010).
3. The model generates the short run and long run coefficient simultaneously, eliminating the problems connected with omitted variables and autocorrelations.
4. As compared to other cointegration techniques e.g. Johansen & Juselius (1990), the model use OLS procedure to find the cointegration among the variables under consideration after selection of lag level (Frimpong et al., 2006).
5. It permits that the variables may have different optimal lags (Ozturk & Acaravci, 2010).

6. ARDL provide flexibility regarding the order of integration of the variables. This technique does not require the pre-testing of the variables integrated in the model for unit roots unlike other methodologies like the Johansen cointegration technique. It is appropriate irrespective of whether the regressors in the model are purely I(0), purely I(1) or mutually cointegrated (Frimpong et al., 2006).

7. ARDL procedure collapse in the presence of any variable of second order difference. So we can't apply this procedure in the presence of any variable of I(2) series (Frimpong et al., 2006).

3.4.1 General form of ARDL model[11]

Simple example of ARDL having two variables and one lag is as follows;

$$Y_t = \alpha_0 + \alpha_1 Y_{t-i} + \beta_0 X_t + \beta_1 X_{t-1} + U_t \qquad (3)$$

This is termed as ARDL(1,1) model because both the variables have one lag. U is expressed as error term.

However, introducing n lags for variable Y and m lag for variable X the equation (3) will become in the following format;

$$Y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=1}^{m} \beta_j X_{t-i} + U_t \qquad (4)$$

In the above equations βs are expressed as short term impact of variables X_t on Y_t.

In order to obtain the long run coefficient of ARDL, the lag variables in equation (4) have to be replaced by the following (a) & (b) equations;

$$Y_t = Y_{t-1} = Y_{t-2} = Y_{t-3} = \ldots\ldots = Y_t^{*} \qquad (a)$$

[11] For detail see Johnston & DiNardo Econometric Methods 4th edition

$$X_t = X_{t-1} = X_{t-2} = X_{t-3} = \ldots\ldots = X_t^* \quad \text{(b)}$$

$$Y^*_t = \alpha_o + \alpha_1 Y^*_t + \alpha_2 Y^*_t + \alpha_3 Y^*_t + \ldots\ldots + \alpha_n Y^*_t + \beta_o X^*_t + \beta_1 X^*_t + \beta_2 X^*_t + \beta_3 X^*_t + \ldots\ldots + \beta_n X^*_t + U_t \quad (5)$$

Parameterizing the coefficient will generate the equation in the following form;

$$Y^*_t = A + BX^*_t + U_t \quad (6)$$

$$A = \alpha_o / (1-\alpha_1-\alpha_2- \ldots\ldots -\alpha_n)$$

$$B = (\beta_o+\beta_1+ \ldots +\beta_n) / (1-\alpha_1-\alpha_2- \ldots\ldots -\alpha_n)$$

In the equation (4) coefficient "B" is termed as long-run multiplier.

The Error Correction representation of the ARDL model can be found by writing equation (2) in terms of the lagged levels and the first differences of $Y_{t-n} \ldots Y_t$ and $X_{t-n} \ldots X_t$.

To generate the Error Correction Model (ECM) we incorporated successive substitution of the following equations in (4):

$$Y_{t-n} = Y_{t-(n-1)} - \Delta Y_{t-(n-1)} \quad , \quad X_{t-n} = X_{t-(n-1)} - \Delta X_{t-(n-1)} \quad \text{(i)}$$

$$Y_{t-(n-1)} = Y_{t-(n-2)} - \Delta Y_{t-(n-2)} \quad , \quad X_{t-(n-1)} = X_{t-(n-2)} - \Delta X_{t-(n-2)} \quad \text{(ii)}$$

$$\ldots \quad \ldots \quad \ldots\ldots\ldots \quad , \quad \ldots \quad \ldots \quad \ldots\ldots\ldots$$

$$Y_t = Y_{t-1} - \Delta Y_{t-1} \quad , \quad X_t = X_{t-1} - \Delta X_{t-1} \quad \text{(iii)}$$

After the successive substitution of the above equations in equation (4) the final result would be in the following form;

$$\Delta Y_t = \alpha_o + \sum_{j=1}^{n=1} a_j Y_{t-i} + \sum_{j=1}^{m=1} \beta_j X_{t-j} + \gamma Y_{t-1} + \theta X_{t-1} + \varepsilon_t \quad (7)$$

Or

$$\Delta Y_t = \alpha_o + \sum_{j=1}^{n=1} a_j Y_{t-i} + \sum_{j=1}^{m=1} \beta_j X_{t-j} + \Psi ECM_{t-1} + \varepsilon_t \quad (8)$$

In the above equation Ψ shows the speed of adjustment parameter. In order to look for the significant model the sign of ECM parameter Ψ must be negative. Error Correction Term specifies that any divergence from the long-run equilibrium between variables is corrected in each period and how much time it will take to come again to the long-run equilibrium position. ECM_{t-1} is the residuals that are acquired from the estimated cointegration model.

Combined parameters of equation (8) are as follows:

$$a_j = -\sum_{i=j+1}^{n} \alpha_i$$

$$\beta_j = -\sum_{i=j+1}^{m} \beta_i$$

$$\gamma = \sum_{i-1}^{n} \alpha_i - 1$$

$$\theta = \sum_{i=1}^{m} \beta_i$$

3.4.2 Specific form of ARDL model for the study

The relationship of wheat production with variables is specified as follows:

Wheat Production = f (CO_2, T_{emp}, P_{recip}, W_{ater}, A_{rea}, A_{gr}. C_{redit}, $F_{ertlizers}$, $T_{echnology}$) (I)

This linear combination is transformed into log-linear model which would present suitable and proficient outcomes as compared to the simple linear model.

$$L_nWheat = \beta 1 + \beta_2 L_nCO_2 + \beta_3 L_nT_{emp} + \beta_4 L_nP_{recip} + \beta_5 L_nW_{ater} + \beta_6 L_nA_{rea} + \beta_7 L_nA_gC_r + \beta_8 L_nF_{rt} + \beta_9 L_nT_{ech} \qquad \text{(II)}$$

The specific form of ARDL model for our study to find out the long-run relationship among the variables is as follows:

$$L_nWheat_t = \alpha_o + \sum_{i-1}^{p} \alpha_1 L_nWheat_{t-i} + \sum_{i-0}^{q} \alpha_2 L_nPrecip_{t-i} + \sum_{i-0}^{q} \alpha_3 L_nTemp_{t-i} + \sum_{i=0}^{q} \alpha_4 L_nCO2_{t-i} + \sum_{i=0}^{q} \alpha_5 L_nWater_{t-i} + \sum_{i=0}^{q} \alpha_6 L_nArea_{t-i} + \sum_{i=0}^{q} \alpha_7 L_nAgCr_{t-i} + \sum_{i=0}^{q} \alpha_8 L_nTech_{t-i} + \sum_{i=0}^{q} \alpha_9 L_nFrt_{t-I} \quad (9)$$

Whereas, the short-run dynamics of ARDL model can be found via the following equation;

$$\Delta L_nWheat_t = \beta_o + \sum_{i=1}^{p} \beta_1 \Delta L_nWheat_{t-i} + \sum_{i=0}^{q} \beta_2 \Delta L_nPrecip_{t-i} + \sum_{i=0}^{q} \beta_3 \Delta L_nTemp_{t-i} + \sum_{i=0}^{q} \beta_4 \Delta L_nCO_{2t-i} + \sum_{i=0}^{q} \beta_5 \Delta L_nWater_{t-i} + \sum_{i=0}^{q} \beta_6 \Delta L_nArea_{t-i} + \sum_{i=0}^{q} \beta_7 \Delta L_nAgCr_{t-i} + \sum_{i=0}^{q} \beta_8 \Delta L_nTech_{t-i} + \sum_{i=0}^{q} \beta_9 \Delta L_nFrt_{t-i} + \Psi_i ECM_{t-I} \quad (10)$$

Whereas, error correction model (ECM) for our study can be defined as follows;

$$ECM_t = -\alpha_o + L_nWheat_t - \sum_{i=1}^{p} \alpha_1 L_nWheat_{t-i} - \sum_{i=0}^{q} \alpha_2 L_nPrecip_{t-i} - \sum_{i=0}^{q} \alpha_3 L_nTemp_{t-i} - \sum_{i=0}^{q} \alpha_4 L_nCO2_{t-i} - \sum_{i=0}^{q} \alpha_5 L_nWater_{t-i} - \sum_{i=0}^{q} \alpha_6 L_nArea_{t-i} - \sum_{i=0}^{q} \alpha_7 L_nAgCr_{t-i} - \sum_{i=0}^{q} \alpha_8 L_nTech_{t-i} - \sum_{i=0}^{q} \alpha_9 L_nFrt_{t-I} \quad (11)$$

3.4.3 Bound Testing Procedure:

ARDL or Bound testing approach consists of two steps. In first step long-run relationship among the variables is checked. In this step the null hypotheses of no cointegration H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$ among the variables under consideration are checked against the alternate hypotheses H_1: $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$ of cointegration among the variables.

The fundamental statistics employed for this methodology is the well-known Wald or F-statistic in a generalized Dickey-Fuller sort of regression, which is used to check the significance of lagged levels of the variables in a conditional unrestricted equilibrium error correction model (ECM) (Pesaran, *et al.*, 2001). F-stat distribution is non-standard irrespective of whether the variables are I(0) or I(1) partially distributed.

Pesaran et al., (2001) established two sets of critical values. One set presumes that all the variables are I(0), whereas, other presume all variables I(1). These two sets of critical values form a band which wraps all expected categorization of I(0), I(1) or even partially integrated.

The computed Wald or F-statistics values are reconciled with the critical values proposed by Pesaran et al., (2001). If the computed value is greater than the critical values then null hypothesis of no-cointegration $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$ is rejected. And conclusive inference is drawn that long-run relationship among the variables exists. However, if computed values falls inside the critical values band then inference of inconclusive test is drawn. If the computed value falls below the lower critical value band then inference of no-cointegration $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$ among the variables is accepted.

Akike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC) are used for appropriate lag selection. In this stage the long-run elasticities δ_2, δ_3, δ_4, δ_5, δ_6 are obtained.

3.4.4 CUSUM & CUSUMSQ Stability Tests

After confirmation of the long-run relationship among the variables, stability test is incorporated. Brown et al., (1975) developed a pair of test to check the stability of the long run coefficient of the model. This test is known as cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests. These tests are used to check the goodness of fit for ARDL as suggested by Pesaran *et al.,* (1999, 2001). These tests are incorporated on the residuals of the error correction model and fabricate results in graphical form. For existence of the stability the plots of CUSUM and CUSUMQ have to stay within the 5% critical band. These tests also confirm about the long-run relationship among the variables.

4. ESTIMATIONS, RESULTS AND ANALYSES[12]

4.1 Unit Root Test Results:

Before incorporating ARDL bound testing approach we test stationarity of each variable of the study. All the variables for ARDL bounding approach must be stationary either at level or at first difference. Bound testing approach necessitate all the variables to be integrated of I(0) or I(1) or of both nature for computation of F-statistics. One must not be worried whether the variables are integrated of order zero or one. But the condition which binds the researcher applying unit root test is that none of the variable used in the study has to be integrated of order two. So in order to look that none of the variable is integrated of order (2) we apply unit root test. Variables integrated of level (2) in bound testing procedure would yield spurious results.

To check the order of integration of each variable we incorporated Augmented Dickey Fuller (ADF) and Phillips Perron (PP) unit root tests. The results of both the tests are reflected in table 1.

[12] PC application Eviews5 and Microsoft Excel worksheet have been used for the purpose of estimation.

Table.1 Unit Root Test

Variables	ADF test statistics		PP test statistics		5% Level of Significance	10% Level of Significance
	Levels	1st Differences	Levels	1st Differences		
L_nArea	-1.250507	-11.90007*	-1.007293	-20.26158*	I(1)	I(1)
L_nAgr. Credit	-0.161646	-5.435241*	-0.213200	-5.460654*	I(1)	I(1)
L_nCO_2	1.405041	-4.903619*	1.405041	-7.434342*	I(1)	I(1)
L_nFertilizer	1.015808	-7.194808*	2.311983	-7.373736*	I(1)	I(1)
L_nPrecipitation	-2.65204**	-14.01685*	-5.649812	-15.09729*	I(1)	I(0)
L_nTechnology	0.988138	-7.038518*	1.410809	-7.038518*	I(1)	I(1)
L_nTemperature	-0.911447	-9.745926*	-3.32828**	-13.00892*	I(1)	I(0)
L_nWater	-0.026193	-10.06023*	-0.036929	-10.41614*	I(1)	I(1)
L_nWheat	0.634517	-7.833288*	1.646709	-20.42502*	I(1)	I(1)

*Significance at 5% level
**Significance at 10% level

The results in table-1 reveal that none of the variable of our study is integrated of order 2. From the results we can see that precipitation is stationary at 10% significance level. Similarly, PP test shows that temperature is also stationary at 10% significance level. Beside temperature and precipitation all the variables of our study are integrated of order I(1). From the results it can be seen that the essential condition for bound testing accomplishes as none of the variable is integrated of order two.

4.2 Bound Testing Approach for Cointegration Analysis

After verifying the absence of I(2) variables in the study we proceed towards Bound Testing approach to check the existence of long-run relationship among the variables. In this regard we use equation (9) to check the long-run relationship. For the selection of lag length we used Akike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC). We used truncated lag length one as recommended by AIC and SBC. Moreover, we eradicated the insignificant variables by following the general to specific methodology

For equation (9) the null hypothesis of no cointegration $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$ is tested against the alternative hypothesis $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$ of cointegration among the variables. The results are reported in table 2. The results clearly indicate that the calculated value of F-stat 4.640689 is greater than the upper bond values (F_u) of 4.05, 3.39 and 3.08 at 1%, 5% and 10% respectively. The $F_{cal} > F_u$ deduce the existence of long run relationship among the variables.

Table.2 Result of the F-test for Cointegration

Wald Test:					
F-Statistic	Degree of Freedom	Critical Value	Pesaran *et al* (1999)[a]		Conclusion
			Lower Bound Value	Upper Bound Value	
4.640689	(9, 37)	1%	2.76	4.05	Cointegration
		5%	2.24	3.39	
		10%	1.98	3.08	

[a]Critical values are obtained from Pesaran et al (1999), Table C1 (ii)

In order to check the stability of the ARDL-bound testing procedure we applied cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) test. The output of the test is in the graphical form. From the figure 1 and figure 2 it can be seen that the CUSUM and CUSUMSQ lines are overtly in between the critical bound of 5%

significance level over time. The output of CUSUM and CUSUMSQ shows that model is stable.

Fig.1: Plot of CUSUM for Coefficients Stability for ARDL Model

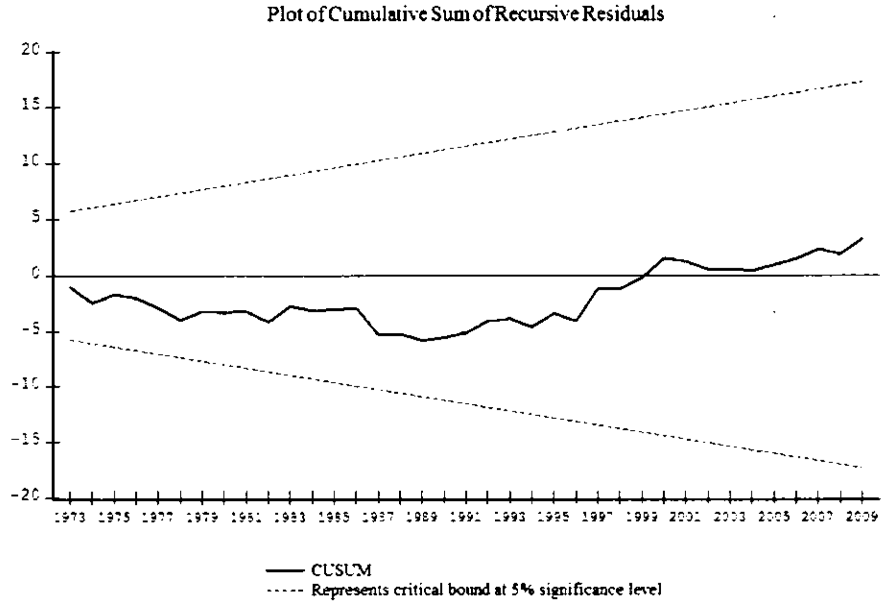
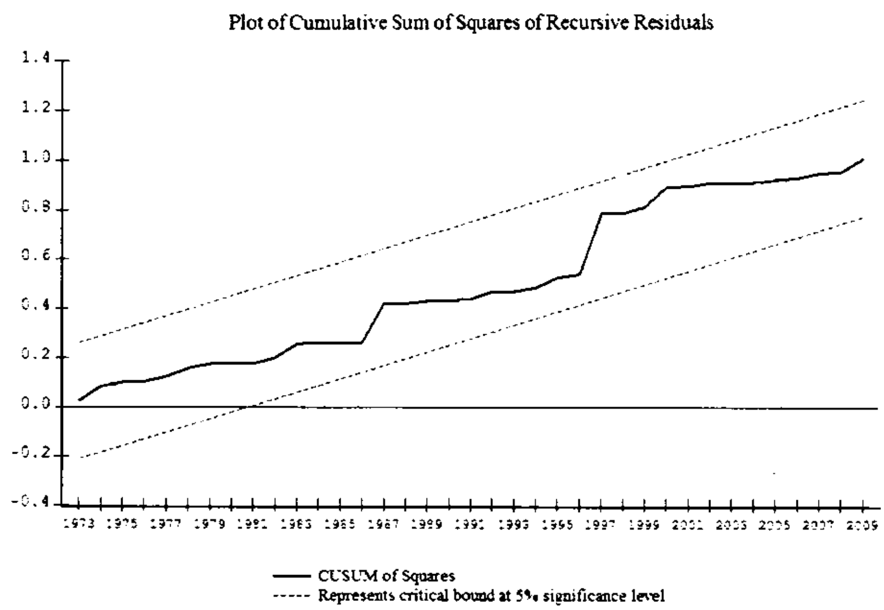


Fig.2: Plot of CUSUMSQ for Coefficients Stability for ARDL Model



4.3 Short-run and Long-run Elasticities for Wheat Production

The results of the short-run and long-run elasticities are demonstrated in table 3. The short-run values of area under wheat production and fertilizers are statistically significant. In short-run area under the wheat cultivation and fertilizer will play an important role towards increase in wheat production. The results show that 1% increase in area can increase the wheat production by 0.37%, whereas, 1% increase in fertilizer can increase the wheat production by 0.32%.

From the results we can deduce that in short-run area under wheat production and fertilizers can be the better remedies to increase the wheat production. In short run to give an instant response to any adverse shock to wheat production, one must have to pay emphasize on area under wheat production and fertilizers. However, in short-run we can't use barren land by converting it to arable land for cultivation of wheat, as this whole process will require long span of time. In short run we haven't enough time to cope with any adverse shock to wheat production. For this purpose we have to utilize the area under the cultivation of other cereal crops for wheat production. In this regard in short-run area is having significant importance to increase the wheat production. Similarly, another factor which can also play significant role to cope with any adverse shock to wheat production in short-run is fertilizers. Fertilizers, which are having the ability to enhance the soil nutrition and soil fertility, can also create considerable positive impact on wheat production through enhancing the per acre wheat yield. Therefore, in short-run any adverse shock to wheat production can also be curtailed through effective use of fertilizers. Therefore, in short-run both the factors are having significant positive impact as compare to other variables, i.e. CO_2, precipitation, temperature, water and agricultural credit. In short-run we do not perceive any significant role of temperature and CO_2 on wheat production.

Table.3 Results of Short-run and Long-run Elasticities

Dependent Variable: D(L_nWheat)
Method: Least Squares
Sample (adjusted): 1961 2009
Included observations: 49 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.254926	2.578881	0.098851	0.9218
D(L_nA_{rea})	0.388396	0.191196	2.031398	0.0494
D(L_nF_{rt})	0.301153	0.079613	3.782706	0.0005
L_nW_{heat}(-1)	-0.868308	0.149706	-5.800073	0.0000
L_nCO_2(-1)	0.106141	0.101231	1.048497	0.3012
L_nP_{recip}(-1)	0.010148	0.044386	0.228639	0.8204
L_nT_{emp}(-1)	0.621299	0.457294	1.358641	0.1825
L_nW_{ater}(-1)	0.430669	0.292390	1.472925	0.1492
L_nA_{rea}(-1)	0.212342	0.274700	0.772996	0.4444
$L_nA_gC_r$(-1)	0.003805	0.034275	0.111029	0.9122
L_nF_{rt}(-1)	0.174262	0.036908	4.721479	0.0000
L_nT_{ech}(-1)	-0.019566	0.036479	-0.536359	0.5949

R-squared	0.673376	Mean dependent var	0.037064
Adjusted R-squared	0.576271	S.D. dependent var	0.097734
S.E. of regression	0.063619	Akaike info criterion	-2.462904
Sum squared resid	0.149755	Schwarz criterion	-1.999601
Log likelihood	72.34115	F-statistic	6.934546
Durbin-Watson stat	2.152737	Prob(F-statistic)	0.000003

The long run elasticities for wheat production are presented in the following equation:

$$L_n W_{heat} = 0.293589 + 0.122239 L_n CO_2 + 0.011687 L_n P_{recip} + 0.715528 L_n T_{emp} + 0.495986 L_n W_{ater}$$

$$+ 0.244547 L_n A_{rea} + 0.004382 L_n A_{gcr} + 0.200691 L_n F_{rt} - 0.02253 L_n T_{ech} \quad (12)$$

After re-parameterization of the long-run coefficients the results are incorporated in the long-run wheat production equation.

We observe from the table 3 that t-stat value for CO_2 is insignificant for long-run. From the results we can deduce that the impact of CO_2 on wheat production in long-run is insignificant. In long-run we don't see any major shift in wheat production due to climate change. The scientific studies show that the impact of CO_2 on wheat production is positive but the extent of this positive impact is still a question mark.

The long run t-stat value for precipitation is also insignificant. We can infer from this that in long-run the impact of precipitation may be insignificant. The geographical rainfall pattern may change in consequence of the climate change However, this shift in rainfall is uncertain and this uncertainty in rainfall pattern may influence the pattern of production, but it may create insignificant impact on the overall level of wheat production.

Temperature t-stat value is also insignificant. In long-run a small increase in temperature may create insignificant impact on wheat production in this region. As Pakistan is located next to the tropic region where any increase in temperature due to climate change may not have significant impact on agricultural production of wheat as compared to the tropical regions where temperature is already at threshold level.

Similarly, water t-stat value is also insignificant in long-run. This insignificance might be due to the limited availability of water reservoirs in long-run, until water reservoir management is significantly improved. Agricultural credit is also having insignificant t-stat value for long-run. This insignificance may also be due to the ineffective mechanism and distribution of agricultural credit to the farmers.

Area's long-run t-stat value is also insignificant. We can infer that area under wheat cultivation is also substantial as compared to other major crops and any major increase in area under wheat cultivation may not be possible in future. Thus, we do not expect any visible contribution of area towards increase in wheat production in long-run.

In long run fertilizers is only variable having significant t-stat value which is 4.721479. After re-parameterization the coefficient value of fertilizers becomes 0.200691. From this we can infer that 1% increase in fertilizers may cause to increase the wheat production by 0.20%. Fertilizers have dual effect. First they enhance the land fertility and second they increase the growth of plants. Fertilizers in long-run would increase the available land fertility causing to increase the agricultural production. Farmers of this region use natural as well as chemical fertilizers to increase the fertility of land to make it suitable arable land. Hence for this region fertilizers may play important role to increase the wheat production and to create significant positive impact on the wheat production.

The t-stat value for technology is insignificant. The insignificance of the technology shows that the technology adaptation is not frequent for this region. Farmers here are not well equipped regarding new technology. They mostly rely on old method of cultivation because of which it may have insignificant long-run impact on the wheat production. Lack of education and farmer's poor condition are also major reason for adopting new technology. Besides these factors lack of technology transfer is also a reason to create any significant impact on wheat production in long-run.

In long-run we do not observe any significant positive or negative impact of climate change factors, e.g. temperature, CO_2 and precipitation on the production of wheat in Pakistan.

4.4 ARDL-Error Correction Model (ECM)

The dynamic results of the error correction model are reported in table 4. The coefficient sign of ECM term is negative and significant. The higher value of ECM shows fast adjustment process. From the results we can infer that the value of ECM term necessitates that change in wheat production from short run to long span of time is corrected by almost 87% each year with high significance. Thus, disequilibrium occurring due to a shock, will take slightly more than a year to attain the equilibrium. The results show that any negative shock to wheat production in short-run will be adjusted by area and fertilizers. Consequently, area and fertilizers will play an important role to absorb any negative shock to wheat production.

Table.4 ECM Results

Dependent Variable: D(L_nWheat)

Method: Least Squares

Sample (adjusted): 1961 2009

Included observations: 49 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.002382	0.010081	0.236246	0.8143
D($L_n A_{rea}$)	0.379902	0.119316	3.183994	0.0026
D($L_n F_{rt}$)	0.296373	0.055634	5.327232	0.0000
ECM(-1)	-0.874946	0.123992	-7.056457	0.0000

R-squared	0.669919	Mean dependent var	0.037064
Adjusted R-squared	0.647914	S.D. dependent var	0.097734
S.E. of regression	0.057992	Akaike info criterion	-2.778908
Sum squared resid	0.151339	Schwarz criterion	-2.624473
Log likelihood	72.08324	F-statistic	30.44342
Durbin-Watson stat	2.117215	Prob(F-statistic)	0.000000

To check the stability of the ECM we incorporated CUSUM and CUSUMSQ tests. The results of the tests are presented in graphical form. The figure 3 and figure 4 demonstrate that the CUSUM and CUSUMSQ lines are within the critical band of 5% significance level over time. The graphical results confirm that ECM model is stable in our case.

Fig.3: Plot of CUSUM for Coefficients Stability for ECM

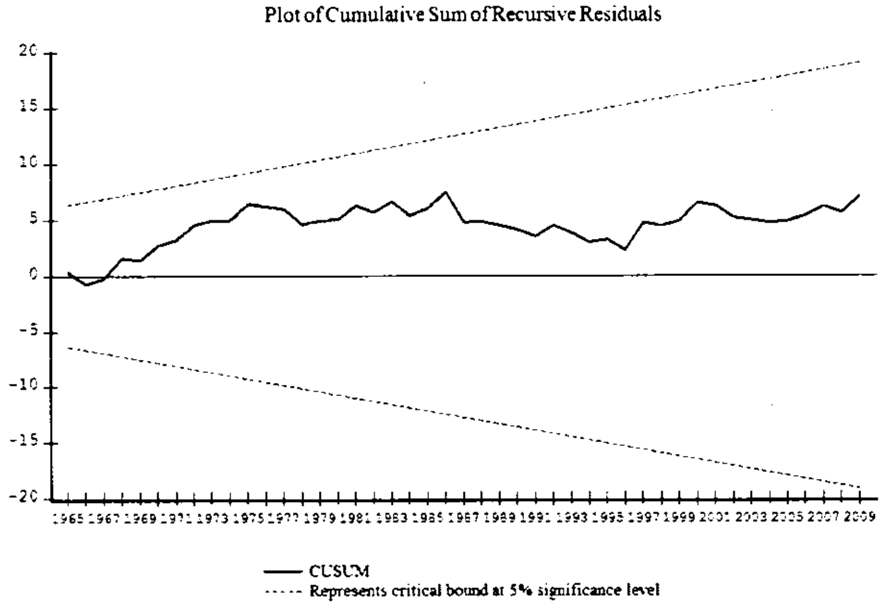
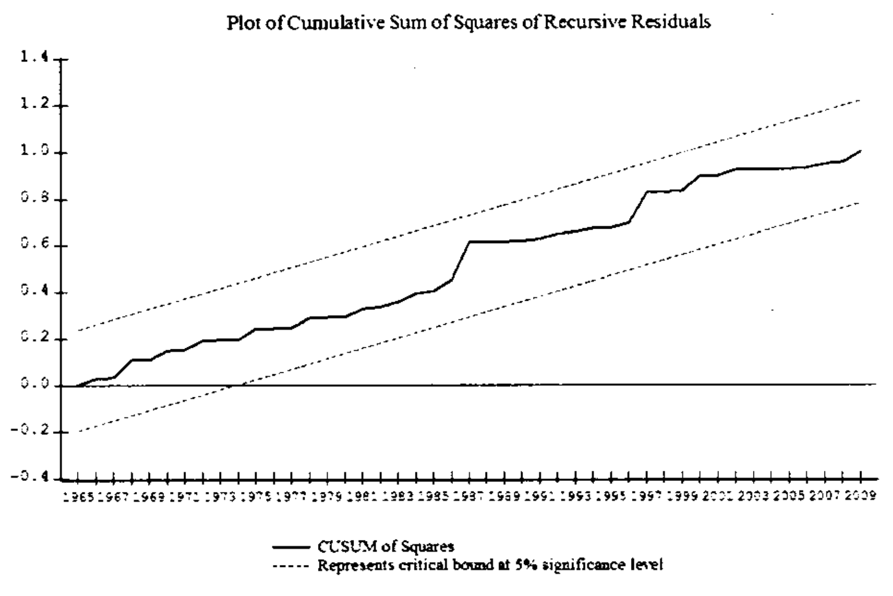


Fig.4: Plot of CUSUMSQ for Coefficients Stability for ECM



5. CONCLUSION AND RECOMMENDATIONS

Wheat is main food crop of Pakistan. The objective of this study is that whether the newly emerging threat of climatic change is influencing the level of wheat production in Pakistan or not. For this purpose the Autoregressive Distributed Lag (ARDL) model is used in this study in order to check the impact of climate change on wheat production in Pakistan. The study used data of the last half century. The results of historical data estimation revealed that up to now there is no short-run and long-run impact of climate change variables on wheat production in Pakistan. However, in short run land under wheat cultivation and fertilizers could play important role to offset any kind of negative shock to wheat production. Whereas, the long-run results revealed that fertilizers would be the only remedy to counter any deficiency of wheat production.

Keeping in view the results following adaptation strategies are suggested in case of any adverse shock to wheat sector;

1. Government is required to promote the culture and mechanism of research and development to secure food for its population. In this regard new fertilizers are needed to be produced.

2. In order to avoid the problem of food insecurity of wheat in future due to any adverse shock, the government may have to promote farmers by offering them fertilizers at subsidized prices.

3. Government is required to increase the arable land area by offering the government owned free land area to the deserving farmers on lease basis.

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APPENDIX-1

Kyoto Protocol

To cope with the global warming as a globally emerging threat UN formed a body known as UNFCCC (United Nation Framework Convention on Climate Change) in March, 1994. Most of the countries are members of this body. Purpose of this body is to share information regarding emission among signatories' countries. It does not impose penalty on the countries, rather it provides a platform for the member countries to negotiate and to formulate policies. It was the success of this body that Kyoto agreement was first negotiated in 1997, which was ultimately ratified in 2005 (Tisdell 2008). The protocol consists of 28 articles. The basic motive of this protocol was to bring back the emission of GHGs at 1990 level. The GHGs, which were considered to be abated, were Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydroflorocarbon (HFCs), Perflorocarbons (PFCs) and Super hexafluoride (SF6). For this purpose the protocol proposed different mechanism to abate the CO_2 emission. These include Clean Development Mechanism (CDM), Emission Trading (ET) and Joint Implementation (JI). (Kyoto Protocol 1998)