Factors Influencing Crop Water Productivity in Pakistan: An Empirical Analysis

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CERTIFICATE

This is to certify that this thesis entitled: **"Factors Influencing Crop Water Productivity in Pakistan: An Empirical Analysis."** submitted by Rameesha Zahid is accepted in its present form by the Department of Environmental Economics, Pakistan Institute of Development Economics (PIDE), Islamabad as satisfying the requirements for partial fulfillment of the degree in **Master of Philosophy in Environmental Economics**.

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Dedicated to My Beloved Parents

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List of Abbreviations

WP= Water Productivity

CWP= Crop Water Productivity

ET= Evapotranspiration

CWR= Crop water requirement

WPS= Water Productivity of Sugarcane

WPW= Water Productivity of Wheat

WPM= Water Productivity of Maize

WPR= Water Productivity of Rice

WPC= Water Productivity of Cotton

ABSTRACT

The study estimates the impact of different factors on water productivity of wheat, rice, maize, cotton and sugarcane in Pakistan during the time period of 1983-2014. To this end the ordinary least square and autoregressive distributed lag models have been employed. The findings show that impact of temperature and precipitation varies across the crops and their respective growth stages. Temperature has positive impact on water productivity of cotton at vegetative stage, while it effects the water productivity of cotton negatively in flowering stage. Temperature impacts negatively the water productivity of rice in sowing stage and positively in vegetative stage. Water productivity of wheat shows the negative response towards the temperature in vegetative stage and responds positively in maturity stage. Temperature in germination and tillering stage positively impacts the sugarcane water productivity while in vegetative growth stage it has harmful effect. Temperature is found to be negatively impacting the water productivity of maize.

The results further show that precipitation is beneficial for rice in sowing and maturity stages, while this adversely impact the cotton at sowing and vegetative stage. Precipitation has positive impact on the water productivity of maize. Precipitation in vegetative and has positive and in maturity stage has negative impact on water productivity of sugarcane. CO_2 emission also found to be positively impacting the water productivity of rice.

Furthermore fertilizer consumption positively impacts the water productivity of cotton wheat and sugarcane except for maize and rice. Distribution of improved seeds shows the positive impact on water productivity of rice. Water availability shows the positive and significant impact on water productivity of wheat. Technological improvement and availability of tractors positively impacted the water productivity of maize. On the premise of the outcomes, the study suggest the development of heat resistant and high yielding varieties, balanced use of fertilizer and adoption of improved technology. Easily accessibility of agriculture credit to farmer is also recommend to enhance the water productivity.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Agriculture sector has very decisive role in economic growth of Pakistan; it provides the food security and livelihood to the people. The share of agriculture in Gross domestic product (GDP) of Pakistan is 20.9%, and the major crops produced by this sector are cotton, rice, wheat, maize and sugarcane. The contribution of these major crops is 25.6 percent in agriculture and 5.3 percent of overall Gross domestic Product. Pakistan is blessed with two cropping seasons namely Kharif and Rabi. The major crops of Kharif or summer season are rice cotton sugarcane and corn; covers the months of May to November. While the Rabi or winter season starts from November/December through April, with the major crops being wheat, barley and millet (Pakistan, 2014). As agriculture is the major consumer of water so for its sustainability enough water is needed (Kang, Khan, & Ma, 2009).

In 21st century the challenges faced by agriculture sectors worldwide are; change in climatic conditions, water availability depletion and reduction in productivity of crops. Global patterns of temperature, distribution of water and rainfall may change and which may results in unsure situation of resources of water and production (Sun et al., 2016). Climate is one of the key influencing factors of agriculture productivity. The climate change is described by change in seasons, increase in temperature, uncertain, higher intensity of rainfall and occurrence of extreme events floods and droughts. These changes have created serious threats for agriculture sector as almost 60% percent of agricultural production depends upon the weather situation (Deshmukh and Lunge, 2012).

Unfortunately Pakistan is also the victim of climate change, facing growing frequencies and intensities of flood and droughts, depletion in fresh water availability and agriculture yield (Piracha & Majeed, 2011).For instance in 1987 the fragile monsoon rainfall resulted in lower crop production in Pakistan, India and Bangladesh (World Food Institute, 1988). This problem is likely to increase, with the growing world population that is expected to rise in 2025 to 7.8 billion, this increment in population will put pressure on agriculture sector to meet the food demand under depleting water resources(Ximing Cai & Rosegrant, 2003). Water is a vital renewable natural resource and timely availability of water is also crucial to fulfill the water need of the crops. In Pakistan water resources (ground and surface water) are becoming insufficient to fulfill the rising demand of agriculture sector(Ashraf, Nasir, & Saeed, 2010). The water accessibility is diminishing, in 1951 the per capita water availability was 5600 m^3 which is reduced to 1032 m^3 in 2017 (Wasif, 2017).

In future the gap between the demand and supply of water availability will further rise, water shortage will increase from 28 million acre feet (MAF) in 2015 to 41 MAF in 2025 (Pakistan, 2010). Shortage and low storage capacity of dams and inefficient irrigation systems are the major reasons behind the growing water scarcity. In Pakistan efficiency of irrigation system is weak due to the improper management and maintenance of irrigation infrastructure. However, this situation of shortage of water resources can be met through either by increasing the storage capacity which is by building new storage reservoirs or by enhancing water use efficiency. Both are critically essential but, huge financial investment is needed for the building of new storage reservoirs. Besides the limited availability of potential sites, migration of population, socio political and environmental issues constrained building of new reservoirs. Therefore, under these conditions proper management of the prevailing water resources, sensibly use of water and improvement in water productivity is necessary (Ashraf et al., 2010).

To cope up with these challenges improvement in water productivity is crucial. Water productivity is defined in terms of physical and economic water productivity and it can be assessed for crops, trees, livestock and fish. *Physical water productivity is define as the ratio of agricultural output to the amount of water consumed, and economic water productivity is expressed as the ratio of value derived to the unit of water used*(Molden, Murray-Rust, Sakthivadivel, & Makin, 2003). Maximizing the water productivity of crops implies that either to produce the same yield with minimum resources of water or to get the more yield of crops with the same amount of water (Zwart & Bastiaanssen, 2004). The concept of crop water productivity varies from location to location and it depends on several factors. Like climatic variable that is temperature, precipitation and Carbon dioxide (CO_2) affects the crop water productivity. Increase in temperature reduces the CWP by increasing the crop evapotranspiration, decline in precipitation reduce the soil moisture and ultimately crop yield(Kang et al., 2009). Moreover, Increase in temperature affects crop yields by impacting its crop growth and development process (physiological processes) (Rasul, Chaudhry, Mahmood, & Hyder, 2011). The change in weather conditions affects the yield of crops and this effect varies across the different growth stages. Moreover, the influence of temperature and rainfall on crops growth vary according to their rainfall and temperature requirement (M. Ahmad, Nawaz, Iqbal, & Javed, 2014).

Increase in CO_2 has positive effect on CWP as it reduces the consumptive use of water (Delphine et al., 2016). Increase in the concentration of carbon dioxide raise the photosynthesis process important for crop growth and restrains the transpiration rate in crops. (Janjua, Samad, & Khan, 2014). However, water management practices and irrigation efficiency plays crucial role in crop water productivity (Cai and Rosegrant 2003). In situation of water shortage, fully utilization of the other inputs of production (improved seeds, land formation and tillage, energy, mechanization labor and fertilizers) is also critical for the improvement in water productivity (Sharma, Molden, & Cook, 2015)

1.2 Significance of the Study

Due to increase in water scarcity and changes in climatic pattern it has become necessary to improve the crop water productivity. Pakistan being the agriculture based economy relies on crop production, so improvement in crop water productivity is necessary to meet the challenges of water scarcity and food requirement of growing population. In past studies have been conducted on the topic of water productivity but in case of Pakistan the literature is very limited. None of the study till now in Pakistan has been conducted that had empirically tested the impact of different factors on crop water productivity covering the time period of 1983-2014. This study empirically estimate the long run effect of different factors (both climate and non-climate) on water productivity of wheat, rice, cotton maize and sugarcane in Pakistan.

1.3 Research Questions

- Does water productivity vary across time under consideration (1983-2014)?
- How much climatic and non-climatic factors impact crop water productivity in Pakistan?

1.4 Objectives of the study

This study aims:

- To calculate the crop water productivity of wheat, cotton, rice, maize and sugarcane.
- To estimate the impact of influencing factors on Crop Water Productivity.

1.5 Organization of the study

Introduction of the study has been given in Chapter 1. Chapter 2 provides the brief literature; Data sources and Methodology is presented in Chapter 3, detailed discussion of the empirical results is provided in the Chapter 4. In Chapter 5 conclusion and Policy recommendations are given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Availability of water is very crucial to produce crops. Globally changes in climate, such as decline in rainfall pattern have poses serious threats to the water availability in different countries (Kang et al., 2009). Shortage of Water and lack of nutrients availability in soil both hinders the growth and production of crop. On the other side, too much use of water results in leaching of the fertilizer and pollutes the environment. During these scenarios proper management of water and improvement of water productivity of crop is very critical (Ali & Talukder, 2008).

This section is divided into three sub sections. Section 2.2 is about the accounting method of water productivity. In Section 2.3 literature about the models of water productivity is given. Section 2.4 is presenting the literature on different factors (climatic and non-climatic) affecting CWP.

2.2 Accounting of Water Productivity

Molden(1997) proposed a conceptual framework for water accounting. The framework aims to develop terminologies and indicators that identify the opportunities to save water, and to improve water productivity. This structure examines the use of water resources at different level, the first one involves the usage of water for irrigation filed and domestic purpose, second level incorporates the services such as water supply system, and third level is related to water basin. Water productivity is defined in two ways, one is Physical water productivity which is the ratio of agricultural output to the amount of water consumed, and economic water productivity is defined as the value derived per unit of water used (Molden et al., 2003). The definitions of water productivity vary across the stakeholder (Agriculturist, irrigation specialist and water resource specialist) and its indicators depend of the scale (crop, field, farm, irrigation system and basin). The concern of agricultural researchers is at field level management of the varieties of crop. The focus of irrigation specialist is the management of water resources for set of fields. Whereas, the emphasis of water resources specialist is on the use of water by several users (agriculture, municipal, industrial and environment).At field scale water productivity is termed as yield per unit of water depleted through evapotranspiration (ET)[1]. Different indicators are used to illustrate the productivity of water, however, the most commonly used indicators are physical mass of production per unit of gross water inflow, water depleted through evapotranspiration, or water available. Whereas, the water productivity (WP) describe as mass per unit of evapotranspiration (ET) is a fundamental determinant that can be used at any level (Molden, 1997; Molden et al., 2003; Sakthivadivel, De Fraiture, Molden, Perry, & Kloezen, 1999).

2.3 Water Productivity Models

Climatic changeability affects the local and world's crop production. Most of the studies conducted in past have used crop growth models mostly simulation models to analyses the crop water productivity. Soil Water Atmosphere Plant (SWAP), GEPIC, Aqua-Crop and IMPACT-WATER models have been utilized as a part of the examinations to assess the

[1]Evapotranspiration is a process in which water is lost from the soil(evaporation) and from the plants (transpiration) (Allen, Pereira, Raes, & Smith, 1998).

conceivable effects of climate changeability and different factors on crop development and water necessity.

IMPACT-WATER is basically integrated water and food model developed by International Food Policy Research Institute (IFPRI) in which water is included in the agricultural supply functions with water simulation model (WSM). IMPACT-Water explores the relationship between availability of water and food production at regional and global level. Moreover, it simulates the water use by crops, demand, supply and trade for food at the global level. Ximing Cai and Rosegrant (2003)In their study uses the IMPACT-WATER model to access the water productivity at regional and global scale and also forecasted the water productivity for 2025.

Soil Water Atmosphere Plant (SWAP) model is used to analyze the Water balance and crop growth, it is an agro hydrological model which includes physically based modules for simulation of crop growth and irrigation practices. It incorporate both simple and comprehensive crop growth module. In the first module growth of a crop is explained on the basis of its development stages, root depth, height and leaf area index. While in second module crop growth is simulated on the basis of photosynthetic characteristics of leaf, water and salt stress of the crop, and absorption of photo-synthetically active radiation by the crop. Moreover, SWAP model also accounts for weeds and pest, disease and nutrient deficiency(Singh, Van Dam, & Feddes, 2006).

Liu, Wiberg, Zehnder, and Yang (2007) developed the GEPIC Model in which they Integrated the crop growth model with a Geographic Information System (GIS) to explore the variability in crop evapotranspitation (ET) and crop yield due to change in climate, management practices and soil. GEPIC is GIS based EPIC model to simulate the crop yield, ET (evapotarnspiration) and crop water productivity. Further, in order to conduct the simulation and visualization of results this model uses Graphical User Interface to access GIS data. The EPIC model is different from other models as it uses an integrated approach to simulate more than 100 types of crops. By considering the different combinations of climatic condition, crops, soil properties and management practices this model has been effectively used all across the globe in simulation of crop yields. So this study used this model to estimate crop yield and water productivity with 30 degree resolution of global coverage, and by assuming the optimal supply of water and fertilizer holding other variable as constant.

Aqua crop is a dynamic crop simulation model that simulates yield response of crops towards water consumption. *Aqua-Crop requires information on* small number of parameters and input variables by generally using simple methods. The Input variable are comprise of climate information, managing practices, for example, mulching and fertilization, characteristics of crop and soil (water and salt balance) all these variables classify the environment needed for the development of the crop will develop. Although Aqua crop model allows the simulations of crop yield under different environment condition and management practices also by including different scenarios of climate change scenario, but it does not investigate the effect of pest and diseases attacks on crop growth (Steduto, Hsiao, Fereres, & Raes, 2012).

2.4 Factors Impacting Crop Water Productivity

The changing climate and growing water shortage problem has drawn the attention of many researchers towards improving the crop water productivity. Enhancing water productivity implies either to create a similar yield with less water or to acquire higher yields with a similar resources of water (Zwart & Bastiaanssen, 2004). The components which impact crop yield (numerator of the CWP equation), and water needed or applied (denominator of the CWP equation) clearly effects the CWP (Ali & Talukder, 2008). So the current study focuses on the factors that impacts both numerator and denominator.

2.4.1 Climatic Factors and Water Productivity

Intense climatic events will make agriculture more susceptible and thus diminishes the WP of agriculture (Xueliang Cai, Molden, & Sharma, 2011). In past, studies have been conducting on assessing the impact of climatic variables that is change in temperature rainfall and CO2 on the crop yield and crop water productivity. Kang et al. (2009) reviewed the literature of different studies that uses the Global climate models (GCM) and crop growth models to see the impact of climate change on availability of water, WP and yield of crops. Review concludes that projected rise in temperature and changes in the pattern of the precipitation, will affect the water availability and crop yield. Climate change influence crop yield through evaporation and transpiration. Increase in temperature reduces the crop growth, while Increase in precipitation raise the crop yield through increase in irrigation application in crop growing stages. However, climate change positively effects the crop production through increase in CO_2 concentration. Similarly increase in temperature in higher latitudes have positive effect on crop yield through increase in crop growing period. Singh et al. (2006) Found the similar results that increase in temperature decrease the water productivity. The results show that water productivity of Rabi crops (wheat) is higher than that of Khairf (cotton and rice) crops, the value of average WP expressed as (Yield/ET) for wheat was 1.39kgm^{-3}, 0.94 kgm^{-3} and 0.23 kgm^{-3} for rice and cotton respectively. The study mentions that increase in temperature during Kharif season is the reason for low WP.

Increment in temperature influences the physiological procedures fundamental for crop development and eventually affects the yields (Rasul et al., 2011). The changes in climatic conditions amid different phases of crop development have distinctive impact on its yield. Moreover the impact of temperature and rainfall on crops vary according to their rainfall and temperature requirement. Raza and Ahmad (2015) investigates the effect of change in environment on different phonological stages of cotton production. The results indicate that climatic change influences cotton production significantly. However, the impacts differ across crop's growth cycle. Temperature normal in Punjab during the sowing and maturity stage has positive and significant impact on cotton, while in second stage (vegetative) and third (flowering) stage cotton is responding negatively towards temperature. While in case of Sindh temperature was found negatively and insignificantly affecting the cotton production, vegetative growth stage also shows negative response toward temperature. Cotton production in third stage (flowering) indicates the positive influence of temperature. Furthermore, the insignificant impact of precipitation on cotton production was due to irrigated nature of cotton crop in Punjab and Sindh.

M. Ahmad, Nawaz, et al. (2014) examined the response of different growth stages of rice towards climate change and their evidence suggests that the effect of temperature on rice differs in extent and vary over the development stages. Siddiqui, Samad, Nasir, and Jalil (2012) also examined the impact of climatic variables on crop growth stages and their result reveals that impact of climate change on crops vary. The results showed the negative impact of increase in temperature on wheat in short run and positive effect in long run, while the impact of increase in rainfall on wheat was negative in both cases. At first increment in temperature has positive impact on rice yield, however, additionally rise in temperature after specific point was discovered unsafe for the rice production, while increment in precipitation has no impact on the rice. The discoveries proposed that the changes in climatic factors have a critical negative effect on production of cotton. At last, in long run increment in temperature can influence the sugarcane adversely.

A study by Shakoor, Saboor, Baig, Afzal, and Rahman (2015) finds the positive response of rice production towards mean minimum temperature and negative effect of mean maximum temperature on rice production. Furthermore, the simulation result for 2030 shows that in much increase in rainfall and temperature will negatively impacts the rice production in long run. Besides these climatic variables the others factors such as fertilizers use and water availability also found to effect rice production in future, whereas too much use of fertilizers will have negative impact on rice production. Likewise, timely availability of water will raise the rice production.

Zwart and Bastiaanssen (2004) reviewed different studies conducted on measuring the value of water productivity of different crops. The study concludes that, the difference in the value of CWP is due to climatic conditions, soil nutrient and water management practices. The areas having higher latitudes have favorable conditions for CWP because of low vapor pressure deficit. In areas having marginal soil can improve CWP through fertilizer application, while CWP increase more when less than 80 Kg/ha nitrogen is applied.

Rising atmospheric CO_2 concentrations regardless of specifically contributing to environmental changes can possibly raise CWP. CO_2 increase CWP by upgrading photosynthesis and decreasing transpiration in leaf of plants. Delphine et al. (2016) by combing the results of different field experiment and global crop models presents the viewpoint on CWP. Increase in CO_2 and associated projected increase in climate change (due to greenhouse gas emissions) the research finds the 10% increase in global CWP by

2080 that depends on the crop type. Furthermore increase in CO_2 could reduce the world yield loss by decreasing consumptive use of water. In contrary to this Anwar, O'leary, McNeil, Hossain, and Nelson (2007)projected the negative impact of elevated CO_2 on rain fed wheat in Australia. The study explains that the effect of elevated CO_2 is to minimize the negative impact of temperature rise and low precipitation, but CO_2 is unable to compensate for these negative effects.

2.4.2 Non Climatic Factors and Water Productivity

Growing water shortages and increasing water demand for production has raised the importance of efficient management of water. Water management practices and irrigation efficiency plays also crucial role in crop water productivity (Cai and Rosegrant (2003). Sarwar and Perry (2002) found the increase in productivity due to deficit irrigation when availability of water was low. While, in case of abundant water highest productivity is also achieved when irrigation is accurately scheduled to fulfill the crop water needs. Moreover, as long the 80% of the total crop water requirement are meet soil salinity will not occur.

Ashraf et al. (2010) Evaluates the crop water productivity of farms located in Lower Bari Doab Canal (LBDC) command and find the gap between the actual and potential yield and water productivity. The authors gave the multiple reasons for the low yield and CWP, which includes the lack of cropping zone, cost of water, small and fragmented lands traditional irrigation system and improper irrigation scheduled. Thus, efficiently utilization of available water is critical for CWP. Bekchanov, Karimov, and Lamers (2010) examined the effect of temporal and spatial water availability on CWP in Khorezm locale, where the rural jobs mostly rely upon agriculture, and because of agro climatic condition it relies on irrigation water availability. The results show the increase in water productivity when water availability is low due to decrease in water extraction rate, farmers achieves higher water productivity without additional incentives.

Ximing Cai and Rosegrant (2003)explores the role of technological improvement, investment and water management on water productivity at world and global level through an integrated water and food model. The study projected that mean WP of rice and other cereals for 2025. The results reveal that the water productivity of rice will increase from 0.39 kgm^{-3} to 0.52 kgm^{-3} and of other cereals will raise from 0.67 kg m^{-3} to 1.01 kg m^{-3}. Furthermore, the study recommends that CWP depends upon other factors such as technology use for irrigation, labor**,** and machinery, use of fertilizer, land and infrastructure. Sharma et al. (2015) Likewise suggests that in situation of water shortage, fully utilization of the other inputs of production (improve seeds, land formation and tillage, energy, mechanization labor and fertilizers) becomes very critical for the improvement in water productivity.

Fertile land is the most essential assets for crop production. The utilization of manure (fertilizer), pesticide and farming apparatus will likewise add to the improvement of crop growth (Evenson and Gollin, 2003). Physical productivity of water can be improved by the use of input such as labor and fertilizer (Barker et al. 2003). M. D. Kumar, Singh, Samad, Purohit, and Didyala (2008)Examine the yield and water productivity responses of crops toward fertilizer usage at field level for the period of two year 2002-03. The findings reveal the strong response of water productivity towards the increase in fertilizer dosage in normal year (2003) while its shows the weak response in dry year (2002). This means the farmers in normal years optimally utilize the fertilizer along with irrigation water. Laamari, Faiz, and Lakhyar (2014) also clarify that nitrogen is basic input for the development and advancement of crops. However, their examination finds the negative impact of nitrogen manure on economic WP for wheat and alfalfa, implying that utilization of fertilizers crossing the ideal level will lessen the WP. Moreover, their study finds the positive response of economic water productivity towards weed control chemicals, tillage technologies and improved seeds rate. On premise of the outcomes the author proposes that the water system method can add to the diminishment of water amount utilized by the crops, yet fertilizer consumption, seed rate, crop protection are likewise factors that can enhance the effective utilization of water and consequently increment the economic WP.

According to Kijne, Barker, and Molden (2003) improvement in WP can be achieved by investing in agricultural Research and infrastructure, instead of spending on system of irrigation . Like spending in improved seed enhance the productivity of agriculture and hence has exclusive place among the other inputs of production. Therefore, effectiveness of other inputs depend upon the improved variety of seeds (Shah, Mohy-ud-Din, Akhter, & Ansar, 2007). Improved seeds (hybrid and treated) are less sensitive to the change in climate and environment as they are designed to adjust with local conditions and can be resistant towards the pest attacks and different diseases (Smale, Cohen, & Nagarajan, 2009).Farm mechanization is beneficial to increase land and labor productivity by productive utilization of the inputs (Verma & Tripathi, 2015). Tractor is also an important part of modern agricultural production system. To emphasize the significance of tractor, Dauda, Musa and Ahmad (2012) stated that agricultural mechanization is synonymous with tractorization, they find that use of tractors increases the crop production and reduces the manual labor.

Salam (1981) Conducted a study to highlight the importance of tractor use along with fertilizer usage on wheat production and found out the high response of yield on the farms having the tractor application than the farm using bullock. Results reveal the greater use of fertilizer on tractor farms. Moreover the study also analyses the response of wheat yield toward the presence and absence of tube wells on farm, but result didn’t show any significant effect on yield. Similarly the use of tractors and tube wells have positive effect on cropping intensity relative to bullock and canal irrigation (Agarwal, 1984).Tube wells is an important source of irrigation. Its application results in high fertilization consumption, multiple cropping and increase in crop value (Mohammad, 1964). Muhammad and Sohail (2014) Investigated the response of maize water productivity in District Buner of the Khyber Pakhtunkhwa under tube well irrigation system, by relating it with different depths of water availability. The finding of the study shows the positive response of CWP towards the optimum depth of water. While CWP of maize decreases due to over irrigation that is when water depth is apply beyond its optimum level. The study suggests the application of deficit irrigation system and farmers training to enhance CWP. However, contrary to this Nangraj, Mangan, Laghari, and Nizamani (2016)in their study discuss that canal water is better source of irrigation than tube wells because tub well irrigation results in soil degradation (soil become hard and saline).

To adopt the modern technologies, purchase of fertilizers and improved seeds timely availability of credit is crucial .Credit is required for executing different farm operations in the agriculture sector. Therefore, agricultural credit is a necessary part for modernization in agriculture sector (Machethe, 2004). In this regard a recent study conducted byA. Ahmad, Jan, Ullah, and Pervez (2015) finds the positive impact of agriculture credit on wheat productivity however the result shows the low value of coefficient, the author gave the reason that mostly credit were utilizes for other purposes and less was used for the purchase of seed and fertilizer.

From above literature, it can be conclude that improvement of crop water productivity is the focus of many researchers in order to cope with the water shortage conditions and to save water. There are many factors that influence the water productivity of crops like climatic factors (temperature, precipitation, CO_2,) and non-climatic factors that includes many factors (water availability fertilizer consumption, labor, pesticides, improve seeds, water management practices, and mechanization). So, in order to enhance the CWP effective utilization of the inputs and water management is necessary.

In context of Pakistan the literature on crop water productivity is limited, and no study till now in Pakistan has empirically estimated the impact of climatic and non-climatic factors on crop water productivity for important crops (wheat, maize, cotton, rice and sugarcane). Furthermore, most of the studies conducted have used crop growth simulation model for water productivity analysis like Ximing Cai and Rosegrant (2003), Liu et al. (2007) and Singh et al. (2006). It is difficult to apply these models in our case because these models used field level data on (daily mean min/max temperature, rainfall, quality of soil nutrition, water and salt stress and etc) which is not available at national level. Therefore, the present study considered the econometric approach for the exploring the impact of different variables on water productivity of major crops (maize, wheat, cotton rice and sugarcane**)** in Pakistan.

CHAPTER 3

DATA AND METHODOLOGY

This chapter is organized as follows: section 3.1 presents the Data Sources and description; section 3.2 presents the construction of variables; section 3.3 presents the methodology; the expected relationship of the explanatory variables with the dependent variable is given in section 3.4; Section 3.5 represents the Estimation technique applied to achieve the objective of the study.

3.1 Data Sources and Description

The study is conducted for Pakistan and covers the time period of 1983-2014. The study focuses on the water productivity of major crops (wheat, cotton, rice, maize and sugarcane). The selection of these major crops is based on their contribution to total GDP. The value added of major crops is 36.3 percent in overall agriculture. The major crops such as wheat, cotton, rice and sugarcane contributes 88.7 percent of the value added in the major crops (Pakistan, 2015). The information about the data sources and units is given in Table 3.1.

<table>
<tr><th colspan="6">Table No3.1. Data Sources and Units</th></tr>
<tr><th>Notation</th><th colspan="2">Construction/Description of Variables</th><th>Units</th><th>Source</th><th>Expected sign</th></tr>
<tr><td rowspan="2">CWP</td><td rowspan="2">Crop Water Productivity

CWP= (Yield)/10× (evapotranspiration)</td><td>(Numerator) Yield(wheat, Rice, cotton, maize and sugarcane)</td><td>Kg/ha</td><td>Economic Survey of Pakistan</td><td rowspan="2"></td></tr>
<tr><td>(Denominator)Crop water requirement</td><td>mm</td><td>Pakistan Council of Water Resources (PCWR) report (2003)[2]</td></tr>
<tr><td>PRE</td><td colspan="2">Precipitation</td><td rowspan="5">mm</td><td rowspan="5">Pakistan Metrological Department</td><td rowspan="5">Uncertain</td></tr>
<tr><td>FP</td><td colspan="2">First stage Precipitation[3]</td></tr>
<tr><td>SSP</td><td colspan="2">Second stage Precipitation</td></tr>
<tr><td>TSP</td><td colspan="2">Third stage Precipitation</td></tr>
<tr><td>FSP</td><td colspan="2">Fourth stage Precipitation</td></tr>
<tr><td>TEMP</td><td colspan="2">Temperature</td><td rowspan="5">Degree Celsius</td><td rowspan="5">Pakistan Metrological Department</td><td rowspan="5">Uncertain</td></tr>
<tr><td>FT</td><td colspan="2">First stage temperature</td></tr>
<tr><td>SST</td><td colspan="2">Second stage temperature</td></tr>
<tr><td>TST</td><td colspan="2">Third stage temperature</td></tr>
<tr><td>FST</td><td colspan="2">Fourth stage Precipitation</td></tr>
</table>

[2](khalown, Ashraf, Rauf, & Haq, 2003)

[3] Months of specific stage for crops are given in table 3.3.

CO_2	Carbon dioxide(Total emissions)	Kilo tonnes	Word Development Indicators (WDI)	Positive
FC(w,r,c,m,s)	Fertilizer consumption for wheat, rice, cotton, maize and sugarcane (total nutrient)	Thousands nutrient tonnes	National Fertilizer Development Center (NFDC)	Positive
ACR	Agriculture Credit disbursement	Million rupees	Pakistan Economic Survey	Positive
WA	Water availability	Million acre feet	Pakistan Economic Survey	Positive
ISR	Distribution of Improved seeds for rice)	Thousands tonnes	Agriculture Statistics of Pakistan	Positive
TR	No of Tractors	Total production in thousands	Agricultural Statistics of Pakistan	Positive

Table No3.2 Average Crop Water Requirement in Pakistan

Crop	Crop Water Requirement (mm)	Crop water requirement(m^3/ha)
Wheat	480	4800
Sugarcane	1800	18000
Rice	1500	15000
Cotton	620	6200
Maize	550	5500

Source: Pakistan Council of Water Resource (PCWR) research report 2 (2003)

3.2 Construction of Variables

3.2.1 Calculation of Crop water Productivity (Dependent Variable)

Distinctive indicators are utilized to depict the physical WP. Most basic are physical mass of production per unit of gross inflow, water drained through evapotranspiration, or water available. While, the productivity of water expressed as mass per unit of water evapotranspirated (ET) is a fundamental measure of WP, substantial at any scale (Molden, 1997; Molden et al., 2003; Sakthivadivel et al., 1999). Liu, Zehnder, and Yang (2009)in their article give the formula for calculating crop water productivity at global, national and grid level. They calculated the national average crop water productivity by taking ratio of sum of the yield (irrigated and rain fed) of all grids to the evaporation (rain fed and irrigated) in all grid cells. However, due to non-availability of the grid wise information, this study utilizes the following formula for calculating the CWP:

$$CWP_i = \frac{Yield_i(kg/ha)}{ET_i(\frac{m3}{ha})}$$

Where CWP is crop water productivity (in kgm^{-3}) of crop i. Y is the yield of crop i in (kg/ha) and ET is the crop evapotranspiration of respective crop i (in mm). The constant 10 is used to convert mm into m^3/ha. This component ET is replaced by crop water requirement (CWR), as actual crop evapotranspiration is also known as CWR(Naheed & Mahmood, 2009). Basically, the crop water requirement is calculated by multiplying the reference crop evapotranspiration (*ETo*) by the crop coefficient (*Kc*): $CWR = Kc \times ETo$. It is assumed that the crop water requirement is completely met, so actual crop evapotranspiration (ETc) will be equivalent to the crop water requirement: ETc= CWR (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2009).

<u>3.2.2</u> Climatic Independent Variables

Temperature and Precipitation

Temperature and precipitation are two important climatic variables. Climatic factors (temperature and precipitation) play a critical role in crop yield. The changes in environment amid different phases of product development have distinctive impact on crop yield (Siddiqui et al., 2012); (M. Ahmad, Nawaz, et al., 2014). Therefore, this study would analyze the yield responses by incorporating phonological stages of the crops. The data on temperature and Precipitation is attained from the Pakistan Meteorological Department (PMD), Islamabad. The division of crops according to their stages of growth is given in table 3.3.

Table No.3.3 Growth Stages of Crops

Crops	**First Stage(F)**	**Second Stage(SS)**	**Third Stage(TS)**	**Fourth Stage (FS)**	**Source**
Cotton	Sowing and germination (May)	Vegetative growth (June to July)	Flowering (Aug to Sep)	(Boll Opening) October	Riaz (2016)
Wheat	Germination (Nov to Dec)	Vegetative growth (Jan to Feb)	Grain formation/maturity (March to April)		M. Ahmad, Siftain, & Iqbal (2014).
Rice	Growing/tillering (May to July)	Vegetative growth(July to Sep)	Maturity and Harvesting (Sep to Nov)		M. Ahmad, Nawaz, et al., (2014)
Sugarcane	Germinantion(Feb-March)	Tillering(April-June)	Vegetative growth(July-sep)	Maturity (Oct- Dec	(Siddiqui et al., 2012)

Non Climatic Independent Variables

Data on fertilizer consumption (thousand nutrient tonne) is taken from National Fertilizer Development Centre (NFDC), Islamabad. Water availability (million acre feet) and agriculture credit disbursement (million rupees) is taken from Pakistan Economic Survey (various issues). The data on distribution of improved seeds (Thousand tonne) and Total number of tractors is taken from Agricultural Statistics of Pakistan (various issues).

3.3 Econometric Models

In order to accomplish the goal of the study following models are built. The general equation of study including climatic variables and non-climatic variables is:

Crops (s, w, m, r, c) = f(FT, SST, TST, FST, FP, SSP, TSP, FSP, CO_2 , FC, WA,

IS, TR, ACR, T)………………………. (A)

The crop wise econometric models are given under.

Model 1 for water productivity of Sugarcane (WPS)

$\ln WPS_t = \alpha_{0t} + \alpha_1 (\ln FT)_t + \alpha_2(\ln SST)_t + \alpha_3(\ln TST)_t + \alpha_4(\ln FST)_t + \alpha_5(\ln FP)_t +$

$\alpha_6(\ln SSP)_t + \alpha_7(\ln TSP)_t + \alpha_8(\ln FCS)_t + +\alpha_9(\ln ACR)_t + \mu_t$…. (3.1)

Model 2 for water productivity of Wheat (WPW)

$\ln WPW_t = \alpha_{0t} + \alpha_1 (\ln FT)_t + \alpha_2(\ln SST)_t + \alpha_3(\ln TST)_t + \alpha_4(\ln FP)_t +$

$\alpha_5(\ln SSP)_t + \alpha_6(\ln TSP)_t + \alpha_7(\ln WAR)_t + \alpha_8(\ln FCW)_t + \mu_t$…………….............. (3.2)

Model 3 for water productivity of Maize (WPM)

$\ln WPM_t = \alpha_{0t} + \alpha_1 (\ln TEMP)_t + \alpha_2(\ln PRE)_t + \alpha_3(\ln FCM)_t + \alpha_4(\ln TR)_t +$

$\alpha_5(T)_t + \mu_t$ ……………………………………………………………………… (3.3)

Model 4 for water productivity of Rice (WPR)

$\ln WPR_t = \alpha_{0t} + \alpha_1 (\ln FT)_t + \alpha_2(\ln SST)_t + \alpha_3(\ln TST)_t + \alpha_4(\ln FP_t + \alpha_5(\ln SSP)_t +$

$\alpha_6(\ln TSP)_t + \alpha_7(\ln FCR)_t + \alpha_8(\ln ISR)_t + \alpha_9(\ln CO_2)_t + \mu_t$………………………. (3.4)

Model 5 for water productivity of cotton (WPC)

$$\ln WPC_t = \alpha_{0t} + \alpha_1 (\ln FT)_t + \alpha_2(\ln SST)_t + \alpha_3(\ln TST)_t + \alpha_4(\ln FST)_t + \alpha_5(\ln FP)_t + \alpha_6(\ln SSP)_t + \alpha_7(\ln TSP)_t + \alpha_8(\ln FSP)_t + +\alpha_9(\ln FCC)_t + \alpha_{10}(T)_t + \mu_t \ldots\ldots\ldots\ldots (3.5)$$

Where from model 1 to 5;

FT and SP refers to first stage temperature and precipitation for wheat (Nov to Dec); Cotton (May to June); Rice (May to July); Sugarcane (Feb to March)

SST and SSP=second stage temperature and precipitation, for wheat (Jan to Feb); Cotton (June to July); Rice (July to Sep); Sugarcane (April to June)

TST and TSP = Third stage temperature and Precipitation for wheat (March to April); Cotton (Aug to Sep); Rice (Sep to Oct); Sugarcane (July-Sep)

FST and FSP= Forth stage temperature and precipitation for cotton (Oct); Sugarcane (Oct-Dec)

FC= Fertilizer consumption (thousand nutrient tonnes)

WA= Water availability for Rabi and Kharif(million acre feet)

IS= improved seeds (Thousand tonnes)

TR= No of Tractors (total production)

ACR= agriculture credit (million rupees)

T= Time trend proxy for Technological improvement

CO_2= Carbon dioxide (Killo tonnes)

α_0= Intercept term; $\alpha_1 \ldots. \alpha_{11}$ = Slope terms

μ_t=error term

t= 1, 2, 3……..31 [for the models 3.1, 3.2 and 3.3 the study has same time period (1985-2014), for models 3.4 and 3.5 time period is (1983-2014)].

3.4 Theoretical Justification of Variables

The theoretical justification of the variable is given below as:

3.4.1 Temperature and Precipitation

Crops are totally dependent on weather conditions as their growth cycle relies on temperature and precipitation. The water required for crop is specifically identified with the evaporative demand of the air in which the crop is developed. Increment in temperature influences the physiological procedures vital for crop growth and eventually affects yield (Rasul et al., 2011). Rise in temperature increases the soil evaporation and plant transpiration (ET) and hence reduces the water productivity. Increase in precipitation raises the crop in crop growing stages. While decrease in precipitation reduces the soil moisture and decreases the crop yield (Kang et al., 2009). However, sometime heavy rainfall results in excess soil moisture and floods which damages the crops.

Furthermore, Impact of temperature and rainfall on crops vary according to their rainfall and temperature requirement. The climatic changeability amid different phases of crop development have distinctive impact on its yield (M. Ahmad, Nawaz, et al., 2014). Siddiqui et al. (2012) finds the negative impact of increase in temperature on wheat in short run and positive effect in long run, while the impact of increase in rainfall on wheat was negative in both cases. In case of rice, at first increment in temperature has positive impact on rice yield, however, additionally rise in temperature after specific point was discovered unsafe for the rice production, while increment in precipitation has no impact on the rice. At last, in long run increment in temperature has negative impact on the sugarcane. So the expected sign of temperature and precipitation is uncertain.

3.4.2 Carbon Dioxide

Rising atmospheric CO_2 concentrations despite directly contributing to climate change have the potential to increase crop water productivity. CO_2 increases the crop water productivity by enhancing photosynthesis and reducing leaf level transpiration of plants, hence reducing the consumptive use of water by crops (Delphine et al., 2016). So the expected relation is positive.

3.4.3 Fertilizer Consumption

Fertilizer is amongst the essential inputs for crop production (Evenson and Gollin, 2003). Physical productivity of water can be improved by the use of nutrient input labor and fertilizer (Barker et al. 2003). So the expected sign of this variable is positive.

3.4.4 Water Availability

Water availability is key influencing factor of crop yield and crop water productivity. Water availability is necessary to meet the crop water requirement during growing stages. The shortage of water results in moisture stress necessary for crop growth (Davoren, 1993). On the other hand, it is fundamental to plan for water system legitimately and coordinate the amount of water required and water gave to crops (Carr, Yang, & Ray, 2016). Shakoor et al. (2015) finds the positive effect of water availability on crop production. So the expected sign of this variable is positive.

3.4.5 No. of Tractors

Tractor are used for ploughing, tilling and landscape maintenance, moving or spreading fertilizer and clearing bushes. The use of tractors increases the cropping intensity by preparing land after harvesting for sowing the next crop. Moreover, farm machinery reduces the evaporative losses by faster conservation of rain water on large areas under dry land farming (Riaz, A. 2001). The services of tractors also vary from crop to crop, like Sugarcane is a deeply rooted crop and requires proper land arrangements for attaining higher growth (Nazir, Jariko, & Junejo, 2013). To significance of tractor, Dauda, Musa and Ahmad (2012) stated that agricultural mechanization is synonymous with tractorization. They find that use of tractors increase the crop production and reduces the manual labor. Salam (1981) Conducted a study to highlight the importance of tractors use along with fertilizer use on wheat production and found out the high response of yield on the farms having the tractor application than the farm using bullocks. So the positive response of CWP towards tractors is expected.

3.4.6 Distribution of Improved Seeds

Seed is a key input for crop and enhancing accessibility of affirmed seed gives sound base to agricultural sustainability and food security (Pakistan, 2014). Improved seeds enhance the productivity of agriculture. Improved seeds (hybrid and treated) are less sensitive to the change in climate and environment as they are designed to adjust with local conditions and are resistant towards the pest attacks and different diseases (Smale et al., 2009). The expected sign of the improve seeds is positive.

3.4.7 Agriculture Credit

In order to adopt the modern technologies, purchase of fertilizers and improved seeds timely availability of credit is crucial. Credit is required for executing different farm operations in the agriculture sector. Therefore, agricultural credit is a necessary part for modernization in agriculture sector (A. Ahmad et al., 2015; Machethe, 2004). So for this reason present study has incorporated agriculture credit as a potential determinant of CWP, and the expected sign is positive.

3.4.8 Technological Change

Growing water shortages and increasing water demand for production has raised the importance of efficient management of water and technological improvement. Water management practices and irrigation efficiency plays also crucial role in improving crop water productivity (Cai and Rosegrant, 2003). So the expected sign of this variable is positive.

3.5 Estimation Technique

The purpose of this study is to estimate the impact of climatic and other non-climatic factors like fertilizer consumption, distribution of improved seeds, water availability, supply of agriculture credit, number of tractors and technological change on water productivity of crops.

Before selecting the estimation technique the data was tested for stationarity. The Augmented Dickey Fuller test of unit root was performed to check the stationarity of the variables. All the dependent variables of the 5 models presented in section 3.2 were found stationary at level. While among the independent variables mentioned in table 3.1 all were stationary at levels except supply of agriculture credit, water availability, total number of tractors, fertilizer consumption for sugarcane and wheat. The results of unit root test are given in appendix 3.A. So on the basis of the unit root results two techniques ordinary least square and auto regressive distributed lag model have been selected. For models of water productivity of rice and cotton ordinary least square technique is employed as all the variables in the models are stationary at levels, while for maize, wheat and sugarcane water productivity ARDL approach was used.

3.5.1 Ordinary Least Square Method

To examine the effect of climatic and non-climatic factors on water productivity of rice and cotton Ordinary least square (OLS) technique has been employed. To apply the ordinary least square method certain assumption must hold. These assumptions include homoscedasticity or equal variance of error term, no autocorrelation between the disturbances and no multicollinearity among the independent variables (Gujarati & Porter, 2003). To check the OLS assumption of homoscedasticity, Breusch Pagan Godfrey for heteroskedasticity is applied. The null hypothesis of there is no heteroskedasticity is tested against the alternative hypothesis of there is heteroskedasticity; the null hypothesis is rejected when the probability value of chi square is less than 0.1. The presence of relation among the explanatory variables is verified by variance inflation factor (VIF). If the VIF is larger than 10, it indicates that a severe multicollinearity existed. The Durbin Watson statistic and Breusch Godfrey LM Test is used to detect the autocorrelation or serial correlation. The null hypothesis of no serial correlation is tested against the alternative hypothesis of there is serial correlation. The null hypothesis is rejected when the probability value of chi square is less than 0.1 (Gujarati & Porter, 2003).

3.5.2 Auto Regressive Distributed Lag (ARDL) model.

For the analysis of water productivity of sugarcane, wheat and maize ARDL approach has been used. The ARDL cointegration technique is employed to see the long run relationship between the variables with different order of integration. The ARDL approach also provides the short-run dynamics of the variables. The ARDL can be employed when the variable are integrated at level, at fist difference, or mixture of both. However if the variables are integrated of order 2 ARDL cannot be employed. So for this purpose, first step to employ the ARDL approach is to conduct Unit root test. In second step appropriate lag length is selected for the variables included in the regression. The lag length can be selected by Akaike Information Criterion (AIC) or by the Schwarz Information Criteria (SIC). After selecting the lag length the model is tested for the long run relationship. For this purpose bound test is performed, long run relationship exists when the calculated value of F statics is appear to be greater than the critical values. To explore the short run relationship the Error Correction method (ECM) is used. ECM term should be negative and significant. Further, the model is tested for autocorrelation, normality and stability (Pesaran & Shin, 1998)

The equation 3.1, 3.2 and 3.3 will be transformed into following ARDL equations. Here equation B C and D represents long run relationship.

$\mathrm{lnWPS_t} = \varphi_0 + \varphi_1(\mathrm{lnFT_{t-i}}) + \varphi_2(\mathrm{lnSST_{t-i}}) + \varphi_2(\mathrm{lnTST_{t-i}}) + \varphi_3(\mathrm{lnFST_{t-i}}) +$

$\varphi_4\ (\mathrm{lnFP_{t-i}}) + +\varphi_5(\mathrm{lnSSP_{t-i}}) + \varphi_6(\mathrm{lnTSP_{t-i}}) + \varphi_7(\mathrm{lnFSP_{t-i}}) + \varphi_8(\mathrm{lnFCS_{t-i}}) +$

$\varphi_9(\mathrm{lnACR_{t-i}}) + \varepsilon_t$……………..…………………………………………………………B

$\mathrm{lnWPW_t} = \varphi_0 + \varphi_1(\mathrm{lnFT_{t-i}}) + \varphi_2(\mathrm{lnSST_{t-i}}) + \varphi_2(\mathrm{lnTST_{t-i}}) + \varphi_3\ (\mathrm{lnFP_{t-i}}) +$

$+\varphi_{54}(\mathrm{lnSSP_{t-i}}) + \varphi_5(\mathrm{lnTSP_{t-i}}) + \varphi_6(\mathrm{lnFCW_{t-i}}) + \varphi_7(\mathrm{lnWAR_{t-i}}) + \varepsilon_t$ ………………C

$\mathrm{lnWPM_t} = \varphi_0 + \varphi_1(\mathrm{lnTEMP_{t-i}}) + \varphi_2(\mathrm{lnPRE_{t-i}}) + \varphi_3(\mathrm{lnFCM_{t-i}}) + \varphi_4\ (\mathrm{lnTR_{t-i}}) +$

$+\varphi_5(\mathrm{T_{t-i}}) + \varepsilon_t$ ……………………………………………………………………..……D

Equations E, F and G is presenting short run dynamics of models 3.1, 3.2 and 3.3 respectively.

$\Delta\mathrm{lnWPS_t} = \delta_0 + \sum_{i=1}^{k} \delta_1 \Delta\mathrm{lnFT_{t-i}} + \sum_{i=1}^{k} \delta_i \Delta\mathrm{ln}SST + \sum_{i=1}^{k} \delta_i \Delta\mathrm{lnTST_{t-i}} +$

$\sum_{i=1}^{k} \delta_i \Delta\mathrm{lnFST_{t-i}} + \sum_{i=1}^{k} \delta_i \Delta\mathrm{lnFP_{t-i}} + \sum_{i=1}^{k} \delta_i \Delta\mathrm{lnSSP_{t-i}} + \sum_{i=1}^{k} \delta_i \Delta\mathrm{lnTSP_{t-i}} +$

$\sum_{i=1}^{k} \delta_i \Delta\mathrm{lnFSP_{t-i}} + \sum_{i=i}^{k} \delta_i \Delta\mathrm{lnFCS_{t-i}} + \sum_{i=1}^{k} \delta_i \Delta\mathrm{lnACR_{t-i}} + \mathrm{ECM_{t-1}} + \varepsilon_t$………….... E

$$\Delta \ln WPW_t = \delta_0 + \sum_{i=1}^{k} \delta_i \Delta \ln FT_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln SST + \sum_{i=1}^{k} \delta_i \Delta \ln TST_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln FP_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln SSP_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln TSP_{t-i} + \sum_{i=i}^{k} \delta_i \Delta \ln FCW_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln WAR_{t-i} + ECM_{t-1} + \varepsilon_t \qquad \text{F}$$

$$\Delta \ln WPM_t = \delta_0 + \sum_{i=1}^{k} \delta_1 \Delta \ln TEMP_{t-i} + \sum_{i=1}^{k} \delta_i \Delta \ln PRE + \sum_{i=1}^{k} \delta_i \Delta \ln TR + \sum_{i=i}^{k} \delta_i \Delta FCM + \sum_{i=1}^{k} \delta_i \Delta T_{t-i} + ECM_{t-1} + \varepsilon_t \qquad \text{G}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Literature shows that not just the climatic factor but non-climatic factors also effect the crop yield and water productivity. Timely and optimal availability of water, balanced use of fertilizer and pesticides, improvements in seeds variety and management practices, mechanization, and agriculture credit, all these factors have critical role in determining the crop growth and water productivity.

This Chapter is devoted to analyze the determinants of water productivity of major crops. Section 4.2 represents the descriptive statistics of the study; section 4.3 discusses the impact of climatic and non-climatic factors on water productivity of sugarcane in Pakistan. The results for water productivity of wheat are presented in section 4.4. Section 4.5 shows the results of water productivity of maize. While, sections 4.6 and 4.7 represents the estimated results of the water productivity of rice and cotton respectively.

4.2 Descriptive Statistics

Table No 4.1.

Variables	**Units**	**Mean**	**Median**	**Maximum**	**Minimum**	**Std. Dev.**
Temperature	Degree Celsius	18.16	18.23	19.06	17.40	0.41
Precipitation	Millimeter	42.54	41.96	68.62	27.09	8.09
Water availability	Million acre feet(MAF)	51.99	53.04	59.74	41.14	5.18
No of Tractors	Production in numbers	35803.91	31434.00	83659.00	10077.00	19909.50
Supply of Agriculture Credit	Million Rupees	106354.4	40118.40	515874.8	8310.510	133345.1
Fertilizer consumption for maize	Thousand Nutrient Tonnes	76.59	70.88	124.88	53.72	20.55
Fertilizer consumption for Cotton	Thousand Nutrient Tonnes	602.68	573.83	1090.0	180.45	287.00
Fertilizer consumption for Rice	Thousand Nutrient Tonnes	200.21	214.48	279.00	120.30	41.52
Fertilizer consumption for Sugarcane	Thousand Nutrient Tonnes	246.34	275.38	348.80	96.24	77.02
Fertilizer consumption for wheat	Thousand Nutrient Tonnes	1270.39	1182.00	2180.00	597.12	467.37
Distribution of improved seeds for Rice	Thousand tonnes	9.88	2.3	49.62	1.32	13.56
Carbon dioxide	Killo tonnes	98144.35	94711.28	163060.5	34400.13	44250.39

Water Productivity of sugarcane	kg/m^3	2.63	2.64	3.19	1.97	0.33
Water Productivity of wheat	kg/m^3	0.46	0.46	0.59	0.30	0.08
Water Productivity of Maize	kg/m^3	0.42	0.31	0.76	0.22	0.19
Water Productivity of Rice	kg/m^3	0.12	0.12	0.16	0.10	0.019
Water Productivity of Cotton	kg/m^3	0.09	0.09	0.13	0.03	0.02

Source: Author's own calculations

Table 4.2 demonstrates the descriptive statistics of the study variables. The average value of water productivity of Sugarcane (2.63kg/m^3) is greater than the water productivity of wheat maize rice and cotton. During 1983-2014 water productivity of sugarcane has maximum value of water productivity, as in 2013-14 production of sugarcane was more than the expected production; the reasons behind this raise in productions were increase in sown area, favorable weather, use of fertilizer (Pakistan, 2014). While the average value of water productivity of cotton is 0.09 kg/m^3 which is quite low as compared to other water productivity of other crops. In 2008-09 the production of cotton was affected by the less use of pesticides, pest attack and shortage of irrigation water (Pakistan, 2009), similarly in 2012-13 per hectare yield of cotton declined due to the pest attacks and change in monsoon pattern also affected the production of cotton crop (Pakistan, 2013).

Means value of fertilizer consumption for wheat is high as compared to the fertilizer consumption of other crops. The high level of fertilizer consumption can be attributed to many factors like decline in the prices of fertilizer and increase in the support prices of the wheat. After wheat fertilizer consumption of cotton has mean value of 602.8 thousand nutrient tonnes. In 2013-14 important reason behind the surge in fertilizer off take was due to the trend in its prices of phosphates and high market prices of agriculture produce especially cotton (Pakistan, 2014). Mean value of improved seeds for rice is 9.88 thousand tonnes with maximum seeds distribution 49.62 thousand tonnes in 2014. Government of Pakistan is engaged in the provision of certificates to public and private sectors for producing the high quality seeds (Pakistan, 2014). Carbon dioxide emissions has showed the mean value of 98144.35 killo tonnes with maximum value of 163060.5, which was recorded in 2012. Pakistan's total emissions has grew 87% from 1990-2012. Major contributor of emission are energy and agriculture sectors. Mean value of Supply of agriculture credit is 106354.4 million rupees, in 2014 maximum value of 515874.8 agriculture credit was witnessed, while in 1983 there was minimum supply of agriculture credit. The mean value of the temperature is 18.16 degree Celsius. With the standard deviation of 0.41 maximum temperature reaches to 19.06. However, precipitation varied 8.099 millimeter with mean value of 42.54mm.

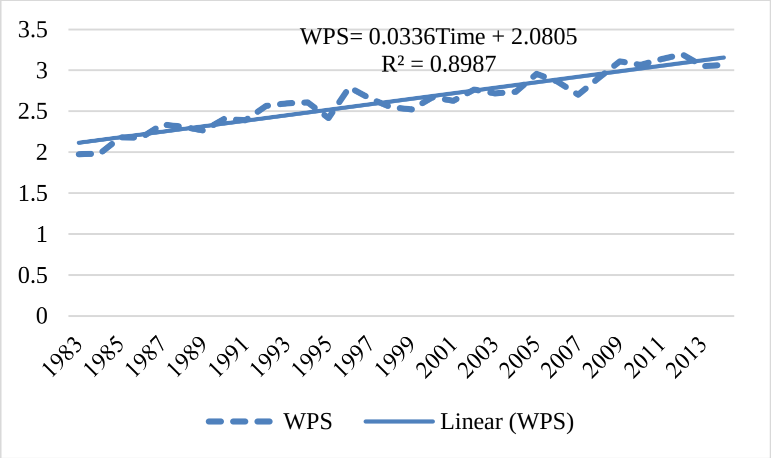


Fig 4.1 [Water Productivity of Sugarcane (Kg/m^3)]

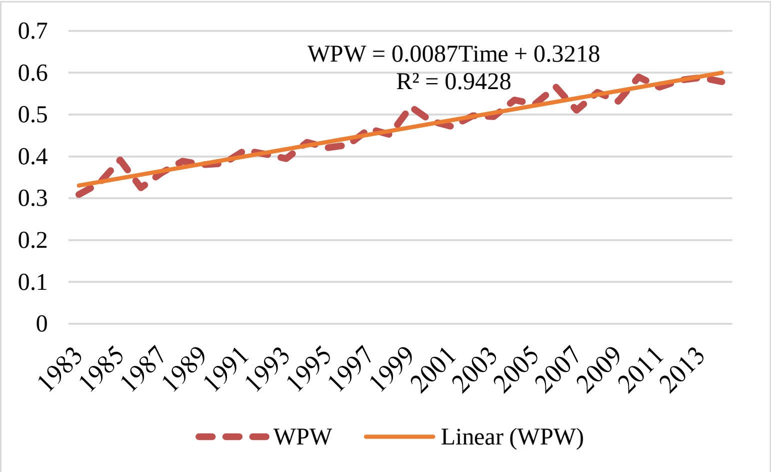


Fig 4.2. [Water Productivity of Wheat (Kg/m^3)]

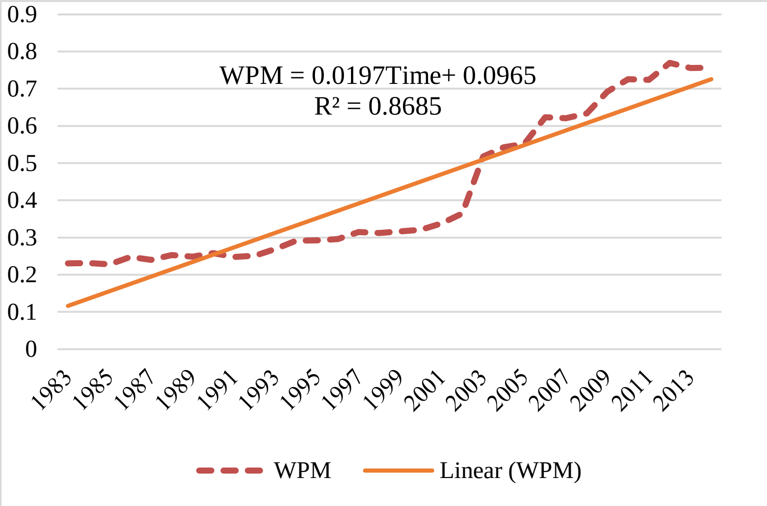


Fig 4.3 [Water Productivity of Maize (Kg/m^3)]

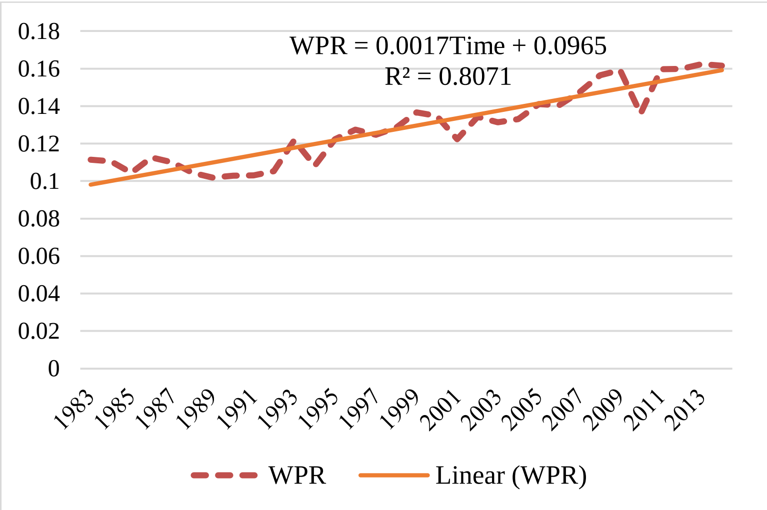


Fig 4.4 [Water Productivity of Rice (Kg/m^3)]

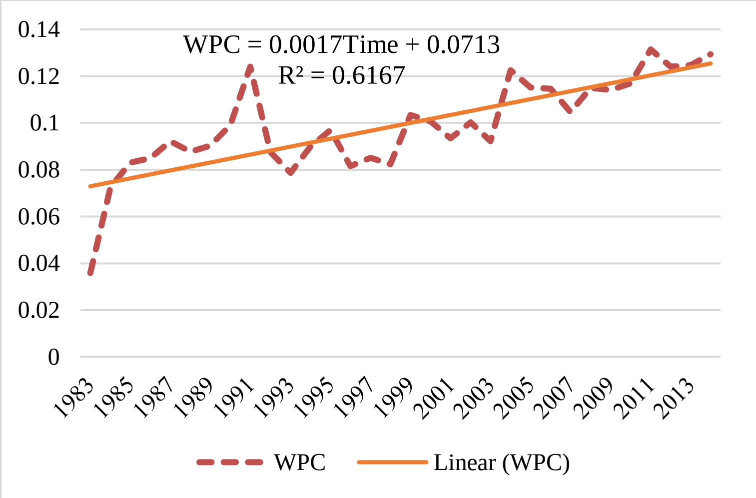


Fig 4.5: [Water Productivity of Cotton (Kg/m^3)]

The fig 4.1 is showing the water productivity of sugarcane. The graph is showing fluctuations over the time. In 2013-14 WPS reaches to its maximum value, as in 2013-14 production of sugarcane was more than the expected production; the reasons behind this raise in productions were increase in sown area, favorable weather, use of fertilizer and increase in the soil fertility due to the floods of 2010 and 2011 (Pakistan, 2014). In 2008 WPS decline because of low production due to shortage of irrigation water, improper application of pesticides and on time non-payments of dues by sugar mills to farmers. However, overall the trend line of WPS is showing the increasing trend.

Water productivity of wheat and maize is also showing increasing trend as can be seen from figures 4.2 and 4.3 respectively. In 1987 WPW increases due favorable weather conditions in growing areas, and provision of input which includes irrigation water, fertilizer, improved seeds and machinery (Pakistan, 1987). Similarly, in 2013 wheat production also rise which result in higher WPW (Economic Survey of Pakistan, 2014). The figure 4.2 is showing increment in WPM with the time period. In 2013 maximum WPM reaches which is attributed to the increase in improved seeds and area sown.

Figure 4.4 is showing the trend for rice water productivity, trend line is showing that overall water productivity of rice is increasing. The figure 4.5 is depicting the fluctuation in water productivity of cotton. In 1992-93 the production of cotton was adversely effected by the heavy rains, floods and leaf curl virus in Punjab (Pakistan, 1993). Overall the trend lines of water productivity for crops are showing increment with the time period.

4.3 Regression Analysis of the determinants of Water Productivity of Sugarcane (WPS)

In Pakistan the season of sugarcane crop is from Feb to December. Sugarcane is divided into four stages. First stage of germination (Feb-March), second stage of tillering (April-June), Vegetative growth is third stage (July-Sep) and forth stage of maturity (Oct-Dec).[4]

This section is further divided in subsections. 4.3.1 Represents the appropriate lag length of the selected model. 4.3.2 Represents results of bond test. Short run and long results of the model are presented in section 4.3.3.

4.3.1 Lag length Selection

Table 4.2 is showing the lag length for the model. The lag length criteria SIC and AIC shows that the appropriate lag length for the model is one as the * appears on lag one.

Table No. 4.2. VAR Lag Order selection Criteria

Lag	SIC	AIC
0	40.60746	41.10128
1	35.04720*	40.97308*

*Note: * indicates the selected lag order*

`

[4] Information about the stages of sugarcane is taken from the study conducted by Siddiqui et al. (2012)

4.3.2 Results of Bound test

The table 4.3 shows that the value of F-statistics is greater than the critical value at 1%, 5% and 10% level of significance. So we are rejecting the null hypothesis means there exists long run association among the variables.

Table 4.3. ARDL Bounds test		
Order of lag 0	F-statistic: 5.04	
Level of Significance	Lower Bound	Upper bound
1%	2.54	3.86
5%	2.06	3.24
10%	1.83	2.94
Ho: There is no long run relationship *H1:There exists long run relationship*		

4.3.3 Regression Results of the Determinants of Water Productivity of Sugarcane (WPS)

The long run regression results of climatic variables in table 4.4 indicates that temperature has positive impact on water productivity of sugarcane in first (germination) and third (vegetative) stage. This may be attributed to the fact that sugarcane requires high temperature. In vegetative growth stage cane formation and elongation take place, and for leaf production and growth warm conditions are required(Srivastava & Rai, 2012). A 1% increase in temperature during germination and vegetative stage will increase the WPS by 0.09% and 0.87% respectively.

In second stage (tillering) temperature has negative and insignificant effect on WPS. While Temperature in forth stage (maturity and harvesting) shows the negative and significant impact on WPS. The maturity stage requires the low temperature as the sweetness starts in this stage of production. A 1% rise in temperature during maturity stage results in decline of the WPS by 0.31%.

Precipitation has insignificant impact on WPS in first two stages. The reason could be as Sugarcane in Pakistan is cultivated primarily in irrigated areas. In third (vegetative) stage, precipitation has positive and significant impact on the WPS. A 1% increase in precipitation during vegetative growth stage will increase the WPS by 0.05%. This stage demands moist conditions for the leaf production and growth. Moreover, in forth stage (maturity) precipitation has negative and significant impact on WPS. A 1% rise in precipitation will reduce the WPS by 0.02%. This stage requires the dry weather conditions as accumulation of sugar in this stage take place (Srivastava & Rai, 2012).

Siddiqui et al. (2012) found the insignificant impact of temperature in first three stages of sugarcane. While in forth stage temperature shows the positive and significant effect on sugarcane. Moreover, their study also found the insignificant impact of precipitation in all the stages of sugarcane production.

Fertilizer Consumption shows expected result, it has positive and significant impact on the sugarcane water productivity. A 1 percent increase in the fertilizer consumption result in 0.09% increase in WPS. Fertilizer nutrient is vital for sugarcane production, and its shortage in the soil will results in shortening and thinning of stalk , paleness of plants and decline in the quantity and quality of juice in sugarcane (Srivastava & Rai, 2012).

The importance of agriculture credit for agriculture sector growth cannot be ignored. The results shows the positive and significant impact of agriculture credit on WPS. A 1%

increase in agriculture credit leads to 0.05% increase in WPS. Availability of Agriculture credit to farmers helps them to purchase the inputs. Shakoor et al. (2015) found that fertilizer consumption and agriculture credit has a positive role in accelerating the crop growth.

The results of ECM shows that speed of adjustment due to any disturbance in water productivity of sugarcane from its equilibrium level in the long run is 1.0, which is negative and significant. It means that WPS diverge from its equilibrium due to any shock, 100percent of the disturbance will be corrected each year.

Short run results of the model shows that temperature has significant impact on WPS in all stage except second stage. While precipitation has insignificant impact in all stages. Moreover, fertilizer consumption and supply of agriculture credit has positive and significant impact on WPS.

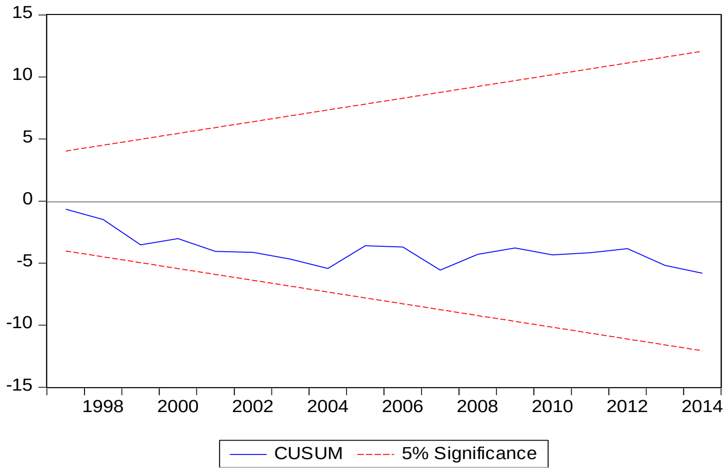
The value of F statistics favors that overall model is significant and value of R2 shows that 92% of the total variation in WPS is due to the included explanatory variables. In addition the probability value of hetroscedasticity test is 0.39 which suggest to accept the null hypothesis of equal variance, means this model is not having the problem of hetroscedasticity. Moreover, the probability value of LM test and normality test also shows that model has no issue of serial correlation and non-normality of residuals.

Table No. 4.4			**ARDL(1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)**		
Long run results			**Short run results**		
Dependent Variable: $lnWPS_t$			Dependent Variable: $\Delta lnWPS_t$		
Variable	Coefficient	Probability	Variable	Coefficient	Probability
lnFT	0.096*	0.1	$\Delta lnFT$	0.09*	0.1
lnSST	-0.34	0.24	$\Delta lnSST$	-0.34	0.27
lnTST	0.87*	0.09	$\Delta lnTST$	0.89*	0.1
lnFST	-0.31*	0.1	$\Delta lnFST$	-0.32*	0.1
lnFP	-0.02	0.16	$\Delta lnFP$	-0.02	0.17
lnSSP	0.0009	0.97	$\Delta lnSSP$	0.0009	0.97
lnTSP	0.052*	0.1	$\Delta lnTSP$	0.053	0.19
lnFSP	-0.020*	0.1	$\Delta lnFSP$	-0.02	0.16
lnFCS	0.099***	0.01	$\Delta lnFCS$	0.10*	0.02
lnACR	0.054***	0.0001	$\Delta lnACR$	0.05***	0.002
C	-1.41	0.38	ECM_{t-1}	-1.0***	0.002
F-statistic	19.81***	0.000	Jarque Bera Normailty test		0.34
R-squared	0.92		White Hetroscadesticity test		0.39
			Breusch Godfrey LM test		0.19

NOTE ****denotes significance at 1% level of significance*

** denotes significance at 10% level of significance.*

The figures 4.6 and 4.7 demonstrate that the CUSUM and CUSUM square lines are within the critical band of 5% significance level over time. The graphs confirm that ECM model is stable.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2000
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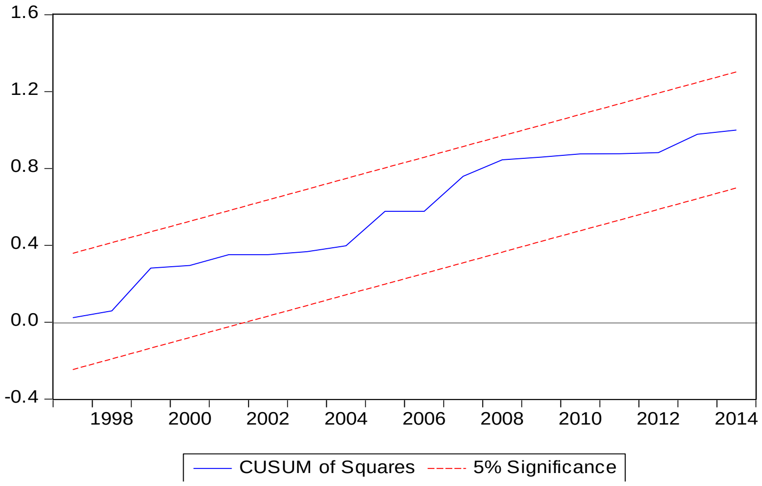
CUSUM
5% Significance

Fig (4.6)


1.6
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0.0
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1998
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2012
2014
CUSUM of Squares
5% Significance

Fig (4.7)

4.4 Regression Analysis of the Determinants of Water Productivity of Wheat (WPW)

Wheat in Pakistan has been divided into three stages, first stage of sowing or germination comprises of the months of Nov and Dec. Vegetative growth stage(second stage) extended from Jan to Feb, and third stage of grain formation and maturity (March to April) (M. Ahmad, Siftain, & Iqbal, 2014).

This section is further divided in subsections. 4.4.1 Represents the appropriate lag length of the selected model. 4.4.2 Represents results of bond test. Short run and long results of the model are presented in section 4.4.3

4.4.1 Lag length Selection

The lag length criteria both AIC shows that the appropriate lag length for the model is two while SIC shows that appropriate length is 0.

Table No. 4.5. VAR Lag Order selection Criteria

Lag	AIC	SIC
0	25.82953	26.23767*
1	22.86146	26.94284
2	19.62997*	27.38460

*Note: * indicates the selected lag order*

4.4.2 Results of Bound test

The table 4.6 shows that the value of F-statistics is greater than the critical value at 10 and 5%. So we are rejecting the null hypothesis means there exists long run association among the variables.

Table No.4.6. ARDL Bounds test

Order of lag 1	F-statistic: 3.61	
Level of significance	Lower Bound	Upper bound
10%	1.95	3.06
5%	2.22	3.39
1%	2.79	4.1

Ho: There is no long run relationship

H1:There exists long run relationship

4.4.3 Regression Results of the Determinants of Water Productivity of Wheat

The long run results of the regression in table 4.7 shows that in first stage temperature has negative impact on water productivity of wheat however the impact is insignificant. While the temperature in second stage (vegetative growth) has negative and significant impact on WPW. This stage requires low temperature, increase in temperature during this stage will affects the tillering and may results in poor development of the seeds and low production (M. Ahmad, Siftain, et al., 2014). Moreover, rise in time temperature also increases the crop water requirement. A 1% increase in temperature in vegetative stage will reduce the WPW by 0.21%.

In third stage (maturity) temperature shows the positive and significant impact on WPW. A 1% increase in temperature during maturity stage will raise the WPW by 0.94%. As maturity stage of wheat needs high temperature (Imran, Ayaz, & Noureen, 2015). Siddiqui et al. (2012) found the negative and insignificant impact of temperature in second stage and positive and insignificant effect of temperature in third stage of wheat production.

In first and third stage Precipitation has insignificant impact on the WPW. In second stage precipitation has positive and significant impact on WPW. A 1% increase in precipitation will increase the WPW by 0.04 kg/m^3, it means that during vegetative growth stage precipitation is beneficial for grain formation and to meet the crop water requirement. The results of first and second stage precipitation are in accordance with the study conducted by M. Ahmad, Siftain, et al. (2014). Siddiqui et al. (2012) also found the insignificant impact of precipitation on wheat production in third stage (maturity).

The other non-climatic variables such as water availability and fertilizer consumption are positively and significantly affecting the water productivity of wheat. As Pakistan agriculture is mostly irrigated, so timely availability of water is important to meet the crop water requirement and hence for crop growth. So the positive and significant coefficient of water availability shows that 1% increase in water availability raises the wheat water productivity by 0.64%. However, timely and optimum level of water availability is very crucial, excess water supply also harmful for crop production, excess water supply result in leaching of nutrients and pesticides that can stunt the growth process and infect the crop by diseases (Singh et al., 2006). Further, fertilizer consumption shows the positive and significant impact on raising the water productivity of wheat. A 1% increase in fertilizer consumption will raise the WPW by 0.22%. M. Ahmad, Siftain, et al. (2014) Also finds the positive impact of fertilizer on wheat productivity.

The short run results of temperature and precipitation are almost same as in the long run. In first stage temperature has insignificant impact on WPW. While temperature increases in second stage has negative and significant impact on WPW. Temperature in third stage also shows the positive impact on WPW. The estimation results of precipitation for first two stage are same as in the long run, while in third stage wheat shows the negative response toward the precipitation. A 1% increase in precipitation during maturity stage will decline the WPW by 0.09%. Precipitation at the time of maturity negatively affects the crop growth and ultimately reduce the yield. Moreover, heavy rains also poses the threat of pests attack on wheat crop(Imran et al., 2015) . Water availability also shows the positive impact on WPW which means an adverse shock on water productivity of wheat can be curtailed by the availability of water. Unlike long run fertilizer consumption shows the negative impact on WPW in short run. This could be the unbalanced use of fertilizer.

The results of ECM shows that speed of adjustment due to any disturbance in water productivity of sugarcane from its equilibrium level in the long run is 0.86 which is negative and significant. It means that WPW diverge from its equilibrium due to any shock, 86 percent of the disturbance will be corrected each year.

The estimation finding also reveals that overall model is good fit and value of R^2 shows that 97% of total variation in dependent variable is due to independent variables. The diagnostic tests also representing that there is no concern of hetroscadasiticty, serial correlation and non-normality of residuals.

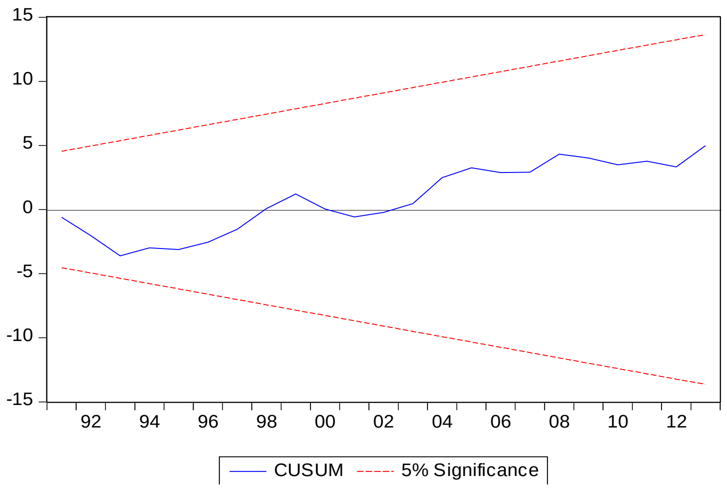
Table No. 4.7		**ARDL(1, 1, 1, 1, 0, 0, 1, 0, 1)**			
Long run results			**Short run results**		
Dependent Variable: $lnWPW_t$			Dependent Variable: $\Delta lnWPW_t$		
Variable	Coefficient	Probability	Variable	Coefficient	Probability
C	-6.76		C	-5.86	
ln(FT)	-0.14	0.41	ΔlnFT	0.04	0.64
ln(SST)	-0.21***	0.01	ΔlnSST	-0.07**	0.04
ln(TST)	0.94**	0.04	ΔlnTST	0.38*	0.1
ln(FP)	-0.017	0.28	ΔlnFP	-0.01	0.27
ln(SSP)	0.04**	0.02	lΔnSSP	0.034**	0.04
ln(TSP)	-0.02	0.46	ΔlnTSP	-0.09***	0.00
ln(WAR)	0.64***	0.01	Δln(WAR)	0.560***	0.01
ln(FCW)	0.22***	0.01	Δln(FCW)	-0.15*	0.1
R-squared	0.97		ECM_{t-1}	-0.86	0.000
F-statistic	35.92***	0.000	Durbin-Watson stat		2.14
White Hetroscadesticity test		0.71	Breusch-Godfrey LM Test		0.53

NOTE: ****denotes significance at 1% level of significance*

*** denotes significance at 5% level of significance.*

** denotes significance at 10% level of significance.*

The figures 4.8 and 4.9 demonstrate that the CUSUM and CUSUM square lines are within the critical band of 5% significance level over time. The graphs confirm that ECM model is stable.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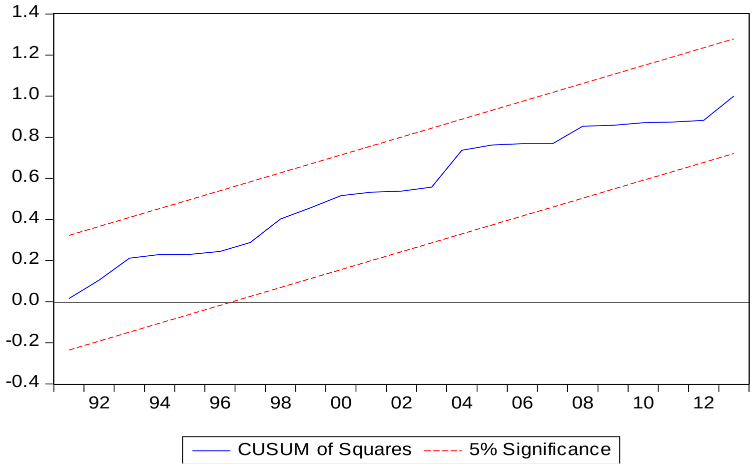
CUSUM
5% Significance

Fig (4.8)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CUSUM of Squares
5% Significance

Fig. (4.9)

4.5 Regression Analysis of the Determinants of Water Productivity of Maize (WPM).

This section is further divided in subsections. 4.5.1 Represents the appropriate lag length of the selected model. 4.5.2 Represents results of bond test. Short run and long results of the model are presented in section 4.5.3

4.5.1 Lag length Selection

Table 4.9 is showing that appropriate lag for the model is four.

Table No. 4.9 VAR Lag Order selection Criteria

Lag	SIC
0	-6.444219
1	-7.906328
2	-6.908250
3	-7.037211
4	-11.09255*

*Note: * indicates the selected lag order*

4.5.2 Results of Bound test

The table 4.10 shows that the value of F-statistics is greater than the critical values at 1, 5 and 10%. So we are rejecting the null hypothesis means there exists long run association among the variables.

Table 4.10. ARDL Bounds test		
Order of lag 4	F-statistic: 12.13	
Level of significance	Lower Bound	Upper bound
1%	4.4	5.72
5%	3.47	4.57
10%	3.03	4.06
Ho: There is no long run relationship *H1:There exists long run relationship*		

4.5.3 Regression Results of the Determinants of Water Productivity of Maize

The estimation results in presented in table 4.11 shows that temperature has negative and significant impact on the WPM. This means that increase in temperature will adversely affect the WPM by increasing the evapotranspiration of the plant hence increasing the water requirement of the crop. Moreover, growing season of crop also reduce due to increment in temperature. The results are in accordance with the Rowhani et al., (2011) they also found that increase temperature will decrease the maize production. Precipitation shows the positive and significant impact on WPM. A 1% increase in Precipitation will raise the WPM by 0.17%, as rainfall very important for the moisture of soil and helps in the growth of the plant. Huang and Khanna, (2010) also found that increase precipitation has beneficial impacts on maize yield.

The non-climatic variables like fertilizer, tractors and technological change also affect the water productivity of maize crop. Application of nutrient is important for crop production. Increase in fertilizer leads to the increase yield and hence water productivity of crop. However, unexpectedly the fertilizer consumption is found to be negatively and significantly affecting the water productivity of maize.

A 1% increase in fertilizer consumption of maize leads to 0.71% decrease in WPM. Balanced application of fertilizer during different phonological stages of crop is important to meet the nutrient requirement of the crop. Fertilizers nutrients are very important for the soil but at the same time balance and timely application of fertilizer has significant role in enhancing crop growth. The result coincides with the study conducted by Laamari et al. (2014) in which they also find the negative impact of fertilizer on economic productivity of the crops. They gave the reason that increase in use of fertilizer than the optimal requirement may act as pollutant and harm the crop yield.

Technological improvement has positive and significant impact on WPM. A 1% increases in the use of improved technology will increase the WPM by 0.02%. However, the coeffiecient of technological improvement is low, this may be due to the financial constraint of the farmers to have access on these inputs. The results are in concordance with the study by Amin, Ahmad, and Iqbal (2013) indicating the positive influenece of tractor mechanisation and technolgical improevment on agriculture in Pakistan.

Water productivity of maize also shows positive and significant response towards the number of tractors. A 1% increase in the number of tractors will raise the WPM by 0.31%. As, farm machinery reduces the evaporative losses by faster conservation of rain water on large areas under dry land farming (Riaz, A. 2001). The results are in accordance with the study by Gul (2015), which suggests that availability of tractors enhance the maize production through important operations such as, timely tillage, ridge making, and shelling etc.

The results of ECM shows that speed of adjustment due to any disturbance in water productivity of sugarcane from its equilibrium level in the long run is 0.63 it is negative and significant. Which means that WPM diverge from its equilibrium due to any shock, 63 percent of the disturbance will be corrected each year

The short run results of the model shows that current fertilizer consumption has insignificant impact on WPM. The reason could be the unbalance use of fertilizer. While use of fertilizer with one year lag has positive and significant impact on current year water productivity of maize. This means application of fertilizer in previous year makes the soil fertile for current year production of maize. Temperature and precipitation has the significant impact on the WPM in short run, the sign are same as in the long run. Tractor also has the positive and significant impact on the WPM. The impact of technological change captured by time trend is also positive and significant like the long run results.

The value of F statistics favors that overall model is significance and value of R^2 is specifying that 99% of the total variation in the WPM is due to included explanatory variables. In addition the probability value of hetroscedasticity test is 0.40 which suggest to accept the null hypothesis of equal variance, means this model is not having the problem of hetroscedasticity. Moreover, durbin Watson and the normality test also shows that model has no issue of autocorrelation and non-normality of residuals.

Table 4.11		**ARDL(1,4,1,0,4)**			
Long run results			**Short run results**		
Dependent Variable: $lnWPM_t$			Dependent Variable: $\Delta lnWPM_t$		
Variable	Coefficient	Probability	Variable	Coefficient	Probability
lnFCM	-0.71***	0.000	$\Delta lnFCM$	-0.06	0.17
lnAVT	-2.15**	0.048	ΔlnFCM(-1)	0.06*	0.1
lnPRE	0.17***	0.009	ΔlnFCM(-2)	-0.12**	0.02
lnTR	0.31***	0.000	ΔlnFCM(-3)	0.30***	0.00
TREND	0.02***	0.000	$\Delta lnAVT$	-0.81**	0.05
C	4.01	0.1	$\Delta lnPRE$	0.10**	0.003
			$\Delta lnTR$	0.14***	0.000
			$\Delta lnTR$(-1)	-0.02	0.48
			$\Delta lnTR$(-2)	0.008	0.80
			$\Delta lnTR$(-3)	-0.109***	0.001
F-statistic	467.17***	0.000	$\Delta @TREND$	0.013***	0.001
R-squared:	0.99		ECM_{t-1}	-0.63	0.000
Jarque Bera Normailty test		0.49	Durbin-Watson stat		2.2
White Hetroscadesticity test		0.40			

Note: ****denotes significance at 1% level of significance*
*** denotes significance at 5% level of significance.*
** denotes significance at 5% level of significance.*

The figures 4.10 and 4.11 demonstrate that the model is stable as CUSUM and CUSUM square lines are within the critical band of 5% significance level over time.

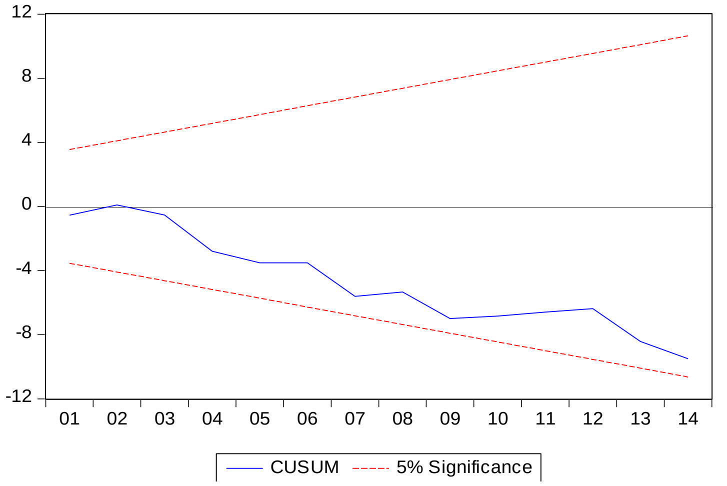

Fig (4.10)

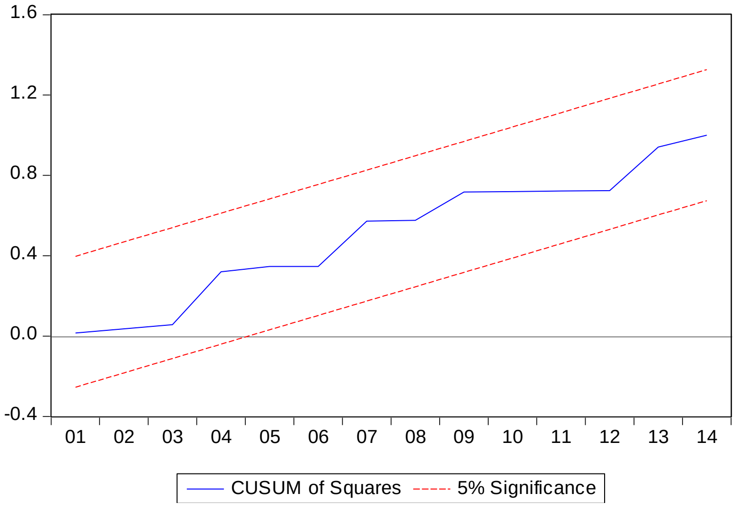

Fig. 4.11

4.6 Regression Analysis of the Determinants of Water Productivity of Rice (WPR)

Rice is important crop in Pakistan, it is a Kharif crop and divided into 3 phonological stages. Stage one (Sowing/tillering) extended from May to July, second stage is vegetative (July-Sep). Third stage is of maturity and extended from Sep-Oct (M. Ahmad, Nawaz, et al., 2014).

Table No.4.12. Ordinary Least Square Regression

Dependent Variable: ln(WPR)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-5.55	1.89	-2.93	0.007
ln(FP)	0.10**	0.04	2.11	0.04
ln(SSP)	-0.09**	0.04	-2.00	0.05
ln(TSP)	0.052**	0.02	2.26	0.03
ln(FT)	-1.05**	0.44	-2.39	0.02
ln(SST)	2.14***	0.74	2.88	0.00
ln(TST)	-0.53	0.43	-1.23	0.23
ln(FCR)	-0.10**	0.05	-2.03	0.05
ln(ISR)	0.07***	0.01	4.58	0.00
ln(CO2)	0.17***	0.04	3.70	0.00
R-squared	0.93	Durbin-Watson stat		2.09
Adjusted R-squared	0.90	BG-LM test		0.32
F-statistic	34.91***			
Prob(F-statistic)	0.000	White hetroscdasiticity test		0.58

***Note**: ***denotes significance at 1% level of significance*
*** denotes significance at 5% level of significance.*

The results reported in table 4.12 shows that the precipitation in first stage has positive and significant impact on WPR. A 1% increase in precipitation leads to 0.10% increase in WPR, as in the rice growth in the beginning stage needs standing water in the field (M. Ahmad, Nawaz, et al., 2014). While in second stage (vegetative growth, flowering and milking) precipitation has negative and significant effect on rice water productivity. A 1% increase in precipitation reduces the water productivity of rice by 0.09%. This outcome could be due to the irregular and intense rains, resulted in floods that may have causes the runoff of nutrients pivotal for vegetative growth, and submergence of recently transplanted rice. Furthermore, increment in precipitation can also cause pest and diseases attack (M. Ahmad, Nawaz, et al., 2014). In third stage of maturity precipitation shows the positive and significant effect on WPR. A 1% increase in precipitation enhance the water productivity of rice by 0.05%.

Temperature impact on rice water productivity shows that, in first stage (germination/tillering) has negative effect on WPR. A 1% increase in temperature in first stage leads to 1.05% decrease in water productivity of rice. Rise in temperature will increases the soil evaporation and plant transpiration (ET) and hence will reduce the water productivity. The water required for crop is directly related to the evaporative demand of the atmosphere in which the crop is grown (Rasul et al., 2011).

In second stage temperature has positive effect on WPR, with 1% rise in temperature, WPR increases by 2.14 %. While in third stage temperature has negative effect on the water productivity of rice however, the impact is insignificant. Siddiqui et al. (2012) also found the insignificant impact of temperature (maturity stage) on rice production.

M. Ahmad, Nawaz, et al. (2014) in their study investigated the effect of climate change on productivity of basmati and coarse rice, who found that in first stage temperature has negative impact on rice (basmati) productivity and positive impact on coarse rice, while in second and third stage temperature is harmful for coarse rice however impact was insignificant. Their result of precipitation shows that in first and third stage coarse rice responds positively, and in second stage precipitation has negative influence on basmati rice.

Moreover, the results shows that increase in CO_2 emissions has beneficial effects on the WPR. With 1% increase in CO_2 emissions, WPR will increase by 0.17%. Increase in CO_2 will improve the photosynthesis and reduces the transpiration rate of leafs, which results in decline in the consumptive use of water by crops (Delphine et al., 2016). U. Kumar, Quick, Barrios, Cruz, and Dingkuhn (2017) Finds that CO_2 increase the production of rice and improves the water use efficiency of rice.

The regression results indicates that fertilizer consumption has negative and significant impact on WPR. The reason could be the improper timing and unbalanced application of fertilizer. The result are in accordance with the study conducted by M. Ahmad, Nawaz, et al. (2014) who also find the negative impact of fertilizer consumption on rice yield.

Distribution of improved seeds has positive and significant impact on WPR. 1% increases in distribution of improved seed increase the WPR by 0.07%. Adaption of improved seeds technology by farmers will raise the crop productivity and will the make agriculture products more competitive in the global markets (Ahmed et al., 2013). The result improved seeds are supported by the study conducted Wasim (2007) in Pakistan to see the impact of high yielding variety seeds on crop production, their findings reveal that adoption of high yielding verities has raised the yield of rice.

The results of F statistics favors the overall significance of the model; the value of R^2 shows that 93% of the total variation in WPR variable is due to included independent variables. Moreover the test results for detection of the autocorrelation, hetroscedasticity and multicollinearity also depicting that model is not having these issues. The result of multicollinearity are given in appendix 4.1.A

4.7 Regression Analysis of the Determinants of Water Productivity of Cotton (WPC).

Cotton crop in Pakistan has been divided into four stages. 1st stage of sowing and germination cover the month of May. Second stage is of Vegetative (June to July) and third stage of flowering and fruit formation covers the month of August and September. Fourth and final stage is maturity and ball opening comprises the month of October (Riaz, 2016) . The regression results of ordinary least square are given in table 4.13.

The regression results in table 4.13 shows that in first stage (sowing and germination) temperature has negative and insignificant impact on WPC. As in first fortnight cotton crop does not react to the changes in temperature and become responsive in second fortnight (Sankaranarayanan, Praharaj, Nalayini, Bandyopadhyay, & Gopalakrishnan, 2010).

In second stage (vegetative) temperature has positive and significant effect on water productivity of cotton. A 1% increase in temperature raises the WPC by 4.32% in vegetative growth stage of cotton crop. It is the most important stage and has crucial effects on the production of cotton, this stage requires favorable temperature for photosynthesis and optimal growth (Raza & Ahmad, 2015). Riaz (2016) also find the negative and insignificant impact of temperature on cotton in first stage and positive and significant effect in second stage.

In third stage (Flowering and fruit formation) temperature has negative and significant effect on WPC, this stage requires moderate temperature and low rainfall (Raza & Ahmad, 2015). A 1% increase in temperature in third stage will reduce the WPC by 3.53%. In forth stage (ball opening stage) temperature has the positive and insignificant impact on WPC.

Precipitation in first stage is negatively and significantly affecting the water productivity of cotton. With 1% increase in precipitation in first stage reduces the WPC by 0.22%. The reason could be erratic and excessive rainfall during this time period which has resulted in leaching of the soil nutrient and pesticides, hence affected the growth of crop.

In second and third stage precipitation is again showing the negative impact on WPC. A 1% increase in precipitation in second and third stage would result in 0.29% and 0.17% decline in WPC respectively. Increase in precipitation during these stage results in shedding of leaves, flower and ball, and also cause the attack of pest (Raza & Ahmad, 2015). In fourth stage precipitation has insignificant impact on WPC; the reason could be that cotton is grown in irrigated areas to meets its water requirements (Naheed & Rasul, 2010).

Furthermore, the result of non-climatic factor (fertilizer consumption) shows the positive and significant effect on WPC. The fertilizer coefficient indicates that 1 percent increase fertilizer consumption will increase the water productivity of cotton by 0.71 percent, this positive sign and high value of coefficient is implying that expansion in fertilizer use will raise water productivity of cotton significantly.

Time trend (proxy of technological improvement) unexpectedly showing the negative effect on WPC, however the impact is insignificant. The reason could be the poor support in rural areas for technological backup and agronomic methods (Ahmad, *et al.* (2013).

The value of F statistics favors that overall model is significant and the value of goodness of fit (R^2) shows that 68 percent of the total variation in WPC due to the included explanatory variables. Moreover, the result of diagnostic test shows that there is no problem of autocorrelation and hetroscdasticity in the model.

Table No.4.13. Ordinary Least Square Regression

Dependent Variable: ln(WPC)

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-6.94	7.89	-0.87	0.38
ln(FT)	-0.671	0.81	-0.8	0.41
ln(SST)	4.32**	2.03	2.11	0.04
ln(TST)	-3.53*	1.83	-1.92	0.06
ln(FST)	0.81	0.69	1.16	0.25
ln(FP)	-0.22**	0.10	-2.19	0.03
ln(SSP)	-0.29**	0.13	-2.25	0.03
ln(TSP)	-0.17*	0.10	-1.66	0.1
ln(FSP)	0.07	0.04	1.45	0.159
ln(FCC)	0.71**	0.32	2.18	0.04
@TREND	-0.02	0.02	-1.27	0.21
R-squared	0.68	Durbin-Watson stat		1.70
Adjusted R-squared	0.53	BG LM test for serial correlation		0.43
F-statistic	4.61***	BPG test for hetroscadasticity		0.46
Prob(F-statistic)	0.001			

Note ***denotes significance at 5% level of significance*
** denotes significance at 10% level of significance.*

CHAPTER 5

CONCLUSION AND POLICY RECOMMENDATIONS

5.1 Summary and Findings

The regression results of ordinary least square and autoregressive distributed lag model suggests that temperature in (vegetative) stage has negative effect on water productivity of wheat. This stage requires low temperature and increase in temperature will affects the tillering and may results in poor development of the seeds and low production. In third (maturity) stage temperature has positive effect on water productivity of wheat, as maturity stage of wheat needs high temperature. The regression results of temperature on cotton water productivity shows that, in first stage (sowing and germination) stage it has insignificant impact on water productivity of cotton, the reason may be that the cotton crop does not respond to temperature during the first fortnight. In second stage (vegetative) temperature has positive effect on water productivity of cotton. In third stage (Flowering and fruit formation) temperature negatively impact the water productivity of cotton; this stage requires moderate temperature and low rainfall. In forth stage (ball opening stage) temperature shows the insignificant impact on water productivity of cotton. In case of water productivity of rice increase in temperature in sowing and maturity stage has negative effect, as rise in temperature will affect the crop water productivity by increasing the crop evapotranspiration. Temperature in first stage (the germination/sowing) and third stage has positive and significant impact on water productivity of sugarcane. While in second stage tillering (April-June) it has negative and significant effect on water productivity of sugarcane. Temperature in forth stage (maturity) and harvesting shows the negative and insignificant impact on water productivity of sugarcane. Moreover, regression results shows that temperature has significant and negative impact on water productivity of maize.

The estimation results shows that precipitation plays significant role in enhancing the water productivity of rice. In first stage precipitation is beneficial for rice, as standing water at the initial stage is requirement of paddy rice. While, in 2nd stage negative effect of precipitation on water productivity of rice is found. This result could be due to the intense, uncertain rainfalls and floods that results in run over of fertilizers nutrients and may cause submergence of newly transplanted rice(M. Ahmad, Nawaz, et al., 2014). In third stage precipitation shows the negative impact on the water productivity of rice. Precipitation shows the negative effect on cotton water productivity in first and second stage, the reason could be erratic and excessive rainfall during this time period which has resulted in leaching of the soil nutrient and pesticides. Similarly in third stage precipitation is showing the negative impact on water productivity of cotton, during this stage cotton crop is more sensitive towards the attacks of pest and increase in rainfall during this stage will lead to shedding of flower and the pests attacks. In fourth stage precipitation has insignificant impact on water productivity; the reason could be that as cotton is grown in irrigated areas and rely on irrigated water resources. The effect of precipitation on water productivity of maize was found positive and significant. For water productivity of sugarcane precipitation in first two stages has insignificant impact. In third (vegetative) stage, precipitation has positive and significant impact. This stage demands moist conditions for the leaf production and growth. Moreover, in forth stage (maturity) precipitation has negative and significant impact on water productivity of sugarcane. This stage requires the dry weather conditions as accumulation of sugar in this stage take place.

Further the results found positive and significant impact of precipitation in second (vegetative) stage on the water productivity of wheat, precipitation in this stage is beneficial for grain formation and to meet the crop water requirement.

In nut shell for all crops the impact of temperature and precipitation is varying across crop and their respective growth stages, and the change in temperature and rainfall would certainly affect crop water requirement and potential yields of the crops in Pakistan. The results also suggested that that increase in CO_2 emissions has beneficial effects on the water productivity of rice. Increase in CO_2 reduces the consumptive use of water by crop by improving the photosynthesis and reducing the transpiration rate of leafs.

Among the non-climatic variables a significant positive relation is documented for fertilizer consumption and water productivity of cotton, wheat and sugarcane. Unexpectedly fertilizer consumption carries the negative sign for water productivity of maize and rice. The plausible explanation for this result may be improper timing and unbalanced application of fertilizer. Water availability exerts a positive and significant effect on water productivity of wheat, showing the importance of water to meet the crop water requirement. Moreover, the study finds the positive and significant relationship between water productivity of rice and distribution of improved seeds, improved seeds that are designed to resist the impact of climate change will increase the crop yield and hence crop water productivity. A significant and positive relation is found between mechanization and water productivity of maize, employing that increase in number of tractors will raise the water productivity of maize by reducing the evaporative losses by faster conservation of rain water, plus they are important for timely operation of tillage, ridge making, and shelling of maize. The results also suggest the positive and significant role of agriculture credit in improving the water productivity of sugarcane. Supply of agriculture credit to farmer will make them able to purchase agriculture inputs such as fertilizer, pesticides, improved seeds and modern machinery for higher crop growth. The result of time trend variable used as a proxy for capturing the technological improvement confirms that adoption of water efficient technologies and improved seeds has a critical and significant role in boosting the water productivity of maize.

5.2 Policy Recommendations

Keeping in mind the importance of water productivity to deal with the challenges of rapidly changing climate and growing water scarcity following measure should be taken

- Water productivity can be enhanced through non-water management interventions, such as balanced use of fertilizer, use of tractors for timely operations (for example, land leveling and tillage).
- Awareness campaigns and training program should be arranged at local levels to educate the farmers regarding the adoption of improved technology to improve water productivity of crops.
- Government should develop heat resistant and high yielding varieties, which also have the potential to resist the attacks of pest and diseases.
- Most importantly easily and timely supply of agriculture credit to farmers is also important.

5.3 Limitation of the study

Impact of climate change varies across regions so does the response of crop growth also varies. This study does not explore the response of crop water productivity at provincial level due to time constraint which is the limitation of the study. Moreover, soil characteristic and application of pesticides also effects the water productivity of crops, due to unavailability of data these important variables are not examined in this study.

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APPENDICES

Table No. 3.A. Augmented Dickey Fuller (ADF) Test

Variables	Level t statics	1st Difference t statics	Order of Integration
lnWPS	-4.41**		I(0)
lnWPM	-2.49**		I(0)
lnWPR	-3.33*		I(0)
lnWPC	-4.61**		I(0)
lnWPW	-7.20**		I(0)
lnTEMP	-4.61**		I(0)
lnPRE	-5.35**		I(0)
LnFCC	-3.24**		I(0)
LnFCR	-2.72*		I(0)
LnFCM	-3.35**		I(0)
LnISR	-1.92**		I(0)
LnCO2	-2.91**		I(0)
LnWA		-4.80**	I(1)
lnFCW		-5.74**	I(1)
LnACR		-5.05**	I(1)
LnTR		5.02**	I(1)
LnFCS		-6.65**	I(1)

Note: *,** denotes the significance at 10 and 5%

Table No.4.1.A	
Variable	**VIF**
C	NA
ln(FT)	1.83
ln(SST)	2.97
ln(TST)	3.00
ln(FP)	2.52
ln(SSP)	2.58
ln(TSP)	1.73
ln(FCR)	1.98
ln(ISR)	5.68
ln(CO2)	6.03

Table No.4.2.A	
Variable	**VIF**
C	NA
ln(FT)	1.67
ln(SST)	2.42
ln(TST)	1.83
ln(FST)	2.42
ln(FP)	2.09
ln(SSP)	2.26
ln(TSP)	1.61
ln(FSP)	2.06
ln(FCC)	3.35