Macro Determinants of Water Footprint of Agriculture sector in Pakistan

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Dedicated to My Beloved Parents

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List of Abbreviations

WF= Water Footprint

Blue WF= Blue Water Footprint

Green WF= Green Water Footprint

Grey WF= Grey Water Footprint

ARDL= Autoregressive Distributive Lag

ANOVA= Analysis of Variance

ABSTRACT

Conventional techniques of measuring water footprint only tell about the changes in the water use but do not investigate into factors which influence such changes. This study is therefore an attempt to know about the driving factors behind changes in water footprint of Agriculture sector of Pakistan during 1980-2013. Auto regressive distributive lag approach (ARDL) and ANOVA are employed for this purpose. Study explores that population, per capita income, consumption patterns, fertilizer, temperature, precipitation and technological improvements are the main determinants of changes in agricultural water footprint. The results reveal that increase in population, per capita income, meat diet, fertilizer consumption and temperature have positive and precipitation and technological improvements have negative impact on agricultural water footprint. It is also found that meat diet results in a higher water footprint as compared to a vegetable diet. Pakistan's agricultural water footprint has shown an increasing trend over time. It is recommended to make people aware of water shortages owing to increased production of livestock products. Farmers should be given education regarding fertilizer use and its run off to nearby water sources and also efficient water technologies should be used to reduce water footprint of agriculture sector.

CHAPTER-1

INTRODUCTION

1.1.Background and Problem statement

Water is imperative for human life on earth. Use of water is increasing at a higher rate because of human activities like using it for domestic, industrial and agricultural purposes (Hoekstra, 2008). Because of anthropogenic activities unsustainable use of water has become a serious issue. Water is becoming scarce because of many reasons. Like changes in climate around the globe are affecting not only the surface water but also the groundwater resources (Hanjra & Qureshi, 2010). Water resources are also polluted due to the development process of cities and the poor water management especially in less developed countries. Globally, only 20% of waste water is treated and reused while remaining 80% is left untreated (Sato et al, 2013). Wasting of water or overuse of this resource is also a serious issue because its price is usually underestimated in many parts of world (Savenije & Van der Zaag, 2008).

Agriculture sector has the biggest share in the world’s total water consumption. According to Hoekstra and Chapagain (2007a), 86 percent of world fresh water is used to produce agricultural commodities. As far as developing nations are concerned almost 90 percent of water is taken up by their agriculture sector (Gleick & Ajami, 2014). Fresh water resources are polluted by agriculture sector through its use of fertilizers and pesticides for production. This pollution of water also leads to shortage of water resources if this waste water is not carefully treated and reused (Winpenny, Heinz, & Koo-Oshima, 2010)

Water footprint (WF) idea was first floated by Hoekstra (2003). Then different studies were carried out to calculate the water footprint around the globe [Chapagain and Hoekstra (2004, 2008), Chapagain et al. (2006) and Hoekstra and Chapagain (2007a, 2008) and Mekennon and Hoekstra (2011)]. “*The water footprint is an indicator of direct and indirect* *appropriation of freshwater resources"*(Mekonnen, Hoekstra, Chapagain, Mathews, & Richter, 2012). The term "freshwater appropriation" accounts for both types of water consumption i.e. directly used water in consumption or production of goods and services (the green and blue WF) and the indirect utilization of water in terms of polluted water as a result of consumption and production (the grey WF).

According to Water Footprint Network (WFN), Water footprint of a country can be calculated from production as well as consumption point of view. Total amount of water required to produce goods and services within the domestic boundaries is termed as WF of production. While, WF computed for the consumption of both, local or imported commodities and services consumed by the inhabitants of a country is known as water footprint of consumption. Three components of water footprint are blue, green and grey water footprint (Hoekstra and Chapagain, 2007). "*Sum of fresh ground and surface water resources consumed*" accounts for Blue water footprint whereas Green WF usually refers to "*the volume of water taken up by the crops from soil*". Grey WF refers to the "*amount of fresh water needed to dissolve the pollutants in any consumption and production process*" (Mekonnen and Hoekstra, 2011).

WF of humans has surpassed sustainable level in many parts around the globe (WWF, 2015). Consumption and production of water intensive goods such as meat, rice, sugar and cotton is rising over time due to rapid increase in population of world. Currently, world has population of 7.5 billion and this figure is likely to increase by 30% in near future which will put downward pressure on water resources. Rapid development taking place around the world is threatening sustainability of fresh water resources (Sebri, 2015). As when people become rich they tend to demand water intensive goods like dairy and meat products etc (Cazcarro, Duarte, & Sánchez-Chóliz, 2013). According to UN-HABITAT (2016), demand of water at global level will get increased by almost 50% till 2030.

Estimates of world water footprint calculated for time period 1996-2005 show that on average per person water footprint is1385 m^3/year (Mekonnen and Hoekstra, 2011). But there are huge variations among the water footprints of different nations. Per capita water footprint of USA, China, India, Pakistan, UK, Canada is 2842, 1071, 1089, 1331, 1258, 2333 m^3/year respectively. Reasons behind these huge differences are consumption patterns (more use of water intensive products), population, climatic conditions, GDP growth, technology and higher consumption level (Ercin and Hoekstra, 2012).

Pakistan is one of the water scarce countries (Briscoe, Qamar, Contijoch, Amir, & Blackmore, 2006). It is at 31st number in the list of water scarce countries having water stress index of 4.1 (WRI, 2015). The situation is getting worst day by day due to increased demand owing to rise in population and economic expansion and due to mismanagement of water resources in Pakistan because of which economic growth may be halted further (Kahlown & Majeed, 2003). Agriculture sector is the second largest sector of Pakistan and it requires huge amount of water to produce food (Government of Pakistan, 2013). Growing population and rapid urbanization have put burden on the agriculture sector to increase supply of food for which it is essential to ensure sufficient amount of water to this sector (Ahmed, Scholz, Al-Faraj, & Niaz, 2016). Also, from last two to three decades production of livestock in Pakistan has increased because of which water demand in agriculture sector has gone up as livestock requires more water to produce as compared to vegetables (Pakistan Economic Survey 2013-14).

1.2. Significance of the study

Knowing the water footprint of a nation helps to assess the situation of water resources so that these resources can be well managed to ensure future food security (WFN, 2010). Pakistan is an agricultural country and because of agricultural dependency on water it has become crucial to know the status of agriculture sector in terms of water footprint analysis and analyze the factors responsible for changes in WF of this sector. Therefore this study will be an attempt to analyze the driving forces behind the changes in agricultural water footprint during 1980-2013. Literature does provide the theoretical justification behind the changes in water footprint and many studies have empirically tested it at global level. But no attempt has been made to know the magnitude and precision of the link between driving forces and the agricultural water footprint in Pakistan. Considering the problem of water scarcity in Pakistan, there is an instant need to know the quantitative association between driving forces and agricultural water footprint to help the policy makers to devise effective policies from the consumption and production perspective so that water resources can be better managed.

Research Questions

- Which are the main influencing factors behind the changes in the agricultural water footprint of Pakistan?
- Does the agricultural WF changes by changing diet from meat to vegetable consumption?
- Which component of agriculture sector of Pakistan has more WF?

Objectives:

This study aims:

- To estimate the macro determinants of agricultural WF of Pakistan.
- To find out the relationship between blue, green and grey WF of Wheat, rice, cotton, maize and sugarcane and their influencing factors.
- To calculate the Water footprint of agriculture sector specifically for cereals, cash crops, crop processed products, vegetables, fruits and livestock in Pakistan.

1.3.Organization of Study

Introduction of this study has been given in Chapter 1. Chapter 2 gives detailed literature on WF. Chapter 3 tells about the data and methodology of research while chapter 4 deals with results and discussion. Conclusion and policy recommendations are presented in chapter 5.

CHAPTER-2

LITERATURE REVIEW

2.1. Introduction

Importance of water cannot be denied. All animals, plants, humans need water to survive. It cannot be separated from our daily lives. Humans are heavily dependent on agriculture sector for food. Water plays an essential role in production of agricultural products. Agriculture is a major user of water, almost 85 percent of fresh water resources are used by agriculture sector around the globe (Hoekstra & Chapagain, 2007a). And this requirement of agriculture sector for water is increasing with the passage of time. Water footprint (WF) is a concept developed in the recent past. WF *is "the amount of total water used for consumption and production of goods and services"*(Mekonnen & Hoekstra, 2011b).

At national and international level, much work has been done on WF calculation for crops, derived crops, and animal production, because agriculture sector requires more water than any other sector so it has remained main focus of the researchers. (Chapagain & Hoekstra, 2004; Chapagain, Hoekstra, Savenije, & Gautam, 2006; Mekonnen & Hoekstra, 2011; Gerbens-Leenes, Hoekstra, & van der Meer, 2009). But few studies have also focused on calculating WF of industrial and commercial sector (Gu et al., 2015; Linstead, Sayed, & Naqvi, 2015). Literature on the topic of WF is vast. Besides calculating water footprint some studies have also put focus on the factors and driving forces affecting the changes in water footprint (Xu, Huang, Yu, & Wang, 2015; Zhao & Chen, 2014; Zhao, Chen, Hayat, Alsaedi, & Ahmad, 2014; Zhi, Yang, & Yin, 2014).

In this chapter existing studies on the topic of water footprint are reviewed. Section 2.2.reviews studies conducted at the national and international level regarding calculation of

WF. While studies regarding driving forces behind WF are presented in section 2.3. Section 2.3 is further divided into 3 subsections.

2.2. Literature on Calculation of Water footprint

The calculation of water footprint can be done by two approaches: bottom up approach and top down approach (A. Hoekstra & Chapagain, 2008; Van Oel, Mekonnen, & Hoekstra, 2009). Bottom up approach estimates WF at product level taking into account the amount of water used at each particular phase over whole supply chain of a good. In this method, WF is calculated by multiplying all the products and services consumed by residents of a country with their respective water requirements. In contrast to it, the top down approach also known as input-output approach estimates WF as the total amount of water used by the people of a country adding the virtual water coming into the country subtracting the virtual water going out of the country (Chapagain & Hoekstra, 2004). This approach estimates WF at sectoral, country or region level. Using bottom up and top down approaches different studies have been carried out at international and national level to find out the WF of nations, products and activities (Cazcarro et al., 2013; Xu et al., 2015; Zhao & Chen, 2014; Zhi et al., 2014). Current study is using bottom up approach to calculate WF of agriculture sector in Pakistan as this approach is simple and provides more detailed information regarding a commodity.

Concept of water footprint is not so old. It was first introduced in 2002 when Hoekstra and Hung first calculated consumptive use of water at world level for different crops using bottom up approach. Time span of their study was from 1995 to 1999. But they did not make a distinction between three components of water footprint i.e., blue, green and grey water footprint. After that many studies have been carried out for estimating water footprint at global level for different crops and animal products (Chapagain & Hoekstra, 2004; Hoekstra & Chapagain, 2007a; Mekonnen & Hoekstra, 2010; Mekonnen & Hoekstra, 2011a).

Chapagain and Hoekstra (2004), using top down approach, calculated water footprints at world level and provided estimate of consumptive use of water for production of crops in time period of 1997-2001. They found that animals have a higher content of virtual water than crops because animals also need feed. For e.g, virtual water content of wheat, maize and rice is 1300, 900 and 3000 m3 per ton respectively while that of poultry meat, pork and beef was 3900, 4900 and 15500 m3 per ton respectively. They also stated that virtual water content of crops is different at different places for the reason that climate, technologies used for irrigation and yield level differ from one place to another (Chapagain & Hoekstra, 2003; Gerbens-Leenes, Mekonnen, & Hoekstra, 2013; Hoekstra, 2003; Hoekstra & Hung, 2002; Palhares & Pezzopane, 2015).

Mekonnen and Hoekstra (2010a) and Aldaya, Chapagain, Hoekstra, and Mekonnen (2012) studied the WF of a large number of products and processes assessing agriculture at a high spatial resolution. For example, among crops, maize has the lowest WF (1222 m3/t) while wheat (1827 m3/t) has the highest and rice stands near the average (average for crops: 1644 m3/t). The result on rice is similar to Chapagain and Hoekstra (2011), where it was 1675 m3/t. Sugar crops and vegetables show low WF (200 and 300 m3/t, respectively). Fruits have 1000 m3/t and oil crops 2400 m3/t. Pulses, spices and nuts required higher volumes, varying between 4000 and 9000 m3/t, respectively.

Blue, green and grey WF were separately calculated by Mekonnen and Hoekstra (2010a). They calculated WF of primary and derived crops. This study was carried out for almost all the countries of world. Based on requirements of crops for water, soil moisture balance and yield of crops, they estimated blue and green WF of crops. WF of most of the crops is estimated by using “Grid based dynamic water balance model” while for some crops

“CROPWAT model” is used. Blue and green water requirements of crops (m3/year) were divided with total production which is accounted for blue and green WF while grey WF (m3/ton) is computed by multiplying amount of nitrogen fertilizer (kg/ton) used for crops with the amount of nitrogen that leaks to the nearby water resources. Then it is divided by the “maximum allowable concentration” of nitrogen fertilizer in water subtracting the “natural concentration of nitrogen in water (kg/m3). At the end it is divided by the total yield of crop (ton/ha) to get an estimate of Grey WF.

Crop produced around globe are found to have average WF of 7404 billion m3 per year. In this, share of green, blue and grey WF is 78%, 12% and 10% respectively. Wheat, rice and maize are at first, second and third number related to their global average WF.

Water footprints of livestock production are also quantified by Mekonnen and Hoekstra (2010b). They find three main factors of “feed conversion efficiency, feed origin and feed composition” in determining WF of livestock production. They also made distinction in different systems (grazing, industrial and mixed) used to raise animals. According to this study global average WF related to raising of livestock is 2242 billion meter cubic per year. Cattle meat has more WF as compared to sheep, goat and chicken. Cattle meat requires 15400 m3 water per ton while sheep, goat and chicken require 10400, 5500 and 4300 m3 water per ton respectively.

With regard to WF calculation, some studies have also been conducted in Pakistan (Ghufran, Batool, Irfan, Butt, & Farooqi, 2015; Linstead et al., 2015). Calculating WF for 20 main crops of Pakistan, Ghufran et al. (2015) reported that WF of all the concerned crops differ substantially from the global average estimate of WF of these crops. Wheat, potato and tobacco are found to use low water as compared to the global average WF because of high yield of these crops than the global production. All other crops have a greater WF than global average.

Another research conducted by Linstead et al. (2015) investigated that how much water is required by key industrial sectors of Pakistan to keep their production process going. Industries of “textile, leather tanning, sugar processing and paper manufacture” are examined. It is found that cotton and sugar industries require more blue WF as compared to other two industries examined in the study. Almost 58% and 38% of blue water is used by cotton and sugar industries respectively. Green WF is high for leather industry as compared to blue WF. It is also observed that cotton is more water polluting industry as this industry has the largest grey WF among the other sectors.

2.3.Literature on determinants of WF

Section 2.2 reviews studies related to the quantification of WF. It can be seen from literature that there are large variations in the water footprints calculated for different nations. These differences are mainly attributed to climate change, high level of consumption, agricultural practices, patterns of consumption and technology (Mekonnen & Hoekstra, 2011b).

2.3.1. Economic growth, population, urbanization, technology and WF.

Anthropogenic factors like population, urbanization and economic growth are blamed to bring changes in WF. With the passage of time as the population is growing, demand for different products is increasing because of which need for water has gone up. Urbanization process is also linked with the water use changes. Economic growth has also found to bring substantial changes in the consumption of water (Cazcarro et al., 2013; Duarte, Pinilla, & Serrano, 2013; Jin, Huang, Yu, & Zhang, 2016; Sebri, 2015). In an attempt to find out the relation of changes in Spanish economic growth with the water consumption Cazcarro et al. (2013) explored that economic growth driven by technological improvements, structural changes and demand forces plays an important role in influencing consumption of water. By using Input output model, their research found that demand driven growth is the main cause of rising water consumption in Spain. While the technological effect leads to offset this increase in water consumption. Production at a large scale has remained dominant in bringing changes in Spanish water consumption. Development of agriculture sector has played an important role in increasing pressure on Spanish water resources during 1962 to 2008 (Duarte, Pinilla, & Serrano, 2014). But initiatives (building of damns, construction of wells and utilizing modern technology for water withdrawal etc) taken by Spanish government regarding agricultural water use efficiency have proven to be vital in saving water (Duarte et al., 2014)

Hubacek and Sun (2005) in finding the socio economic determinants of water use changes in China reached to the similar conclusion. Achieving water efficiency through improved technology and coping with the production is thus necessary for bringing down WF. Decomposing the driving factors behind variations in WF of Haihe River Basin in China, Zhi et al. (2014) also discovered technology as the key contributor in bringing down the WF. Increase in WF of Haihe River basin is mainly due to the scale effect (increase in the demand of final commodities) and structural changes in economy reinforcing the importance of economic growth in changing water consumption (Zhi et al., 2014).

In finding out the due causes behind variations in WF of agricultural sector of Beijing, China Jin et al. (2016) explored the negative relation of changes in WF with population, per capita GDP and technological development in rural areas, whereas urbanization and Engel coefficient are responsible for bringing upward change in WF. Behind negative relationship of population, they gave reason that due to rise in Beijing population the area under cultivation has reduced because of which demand for water has reduced within the city. Engel coefficient that shows level of living standards affects WF significantly. But their research found that economic development and water use are not following an inverted U-shaped association showing no evidence of existence of Environmental Kuznets curve (EKC) because China has not yet achieved higher levels of economic growth. Sebri (2015) found similar results related to economic growth and WF. Conducting a panel analysis at world level, study discovered an N-shaped EKC instead of usual EKC. It shows that as the per capita income raises the demand for water increases first. Then at higher levels of economic development water use decreases as people start saving the water resources and after reaching threshold level of development it again starts increasing. But in assessing the nature of the link between per capita income and per capita use of water for 65 countries Duarte et al. (2013) confirm the existence of inverted U-shaped EKC. But the downward trend in water us at high levels of income dominates the relationship. It is concluded that at high levels of income water use per person decreases but at a decreasing rate. Katz (2008) has demonstrated an inverted U-shaped link between income and water withdrawal in case of OECD countries but findings of his study are highly dependent on the econometric technique and data set used.

Zhao et al. (2014) analyze the determinants of WF changes of agricultural sector of China from 1990 to 2009. Calculation of WF is done through bottom up approach while in order to find the factors causing changes in WF an extended STIRPAT[1] model is employed. Study reveals a positive relationship of population changes, diet structure, urbanization and economic activity with WF of Chinese agriculture sector. But their study ignores the fact that water saving technology is an important factor in accelerating the process of conservation of water. Empirically investigating the driving factors behind variations in the WF of crop production in Beijing city of China, Xu et al. (2015) found technology to be affecting WF significantly. Employing Log-mean Divisia Index (LMDI) method of decomposition study quantified the five potential factors of population, production scale, urbanization, plant structure and technology in affecting WF. Among these population and production scale were

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[1] Stochastic impacts by regression on population, affluence and technology (STIRPAT)

found to increase WF of crops while plant structure, urbanization and technology lead to decrease WF. It is also reported that WF of crop production increased from 1978 to 1992 while decreased in 1993-2003 and remained unchanged from 2004 to 2012. It is suggested to give focus on water saving technologies and improving plant structure so that less water is used in production of crops. Using similar methodology of decomposition analysis Zhao and Chen (2014) also attempted to find influencing factors of WF of Chinese agricultural sector. Covering the time period of 20years from 1990 to 2009 their study also establishes that WF of agricultural sector is influenced by many factors like population, agricultural efficiency, economic activity and diet structure of Chinese people. The only factor negatively affecting WF is the efficiency in using water while other three factors show a positive change in the WF of Chinese agricultural sector. Results also disclose the fact that Chinese agricultural WF has been on an increasing trend just because of rising demand for livestock items.

2.3.2. Consumption Patterns and WF

As the time is passing by, people are shifting their consumption patterns from plant-based food to meat based food all over the world. This increase in the demand for meat based food is putting pressure on the world water resources creating the problem of water scarcity. The water footprint of consuming cattle meat is higher than that of a crop product of equal dietary value (M Jalava, Kummu, Porkka, Siebert, & Varis, 2014; Mekonnen & Hoekstra, 2012). In California, 1kg of meat production requires 13.5 m3 water whereas for producing same amount of cereal only 1 to 2 m3 water is used in general (Rijsberman, 2006; Yang, Reichert, Abbaspour, & Zehnder, 2003). Considering the amount of energy produced by one unit of water the crop items produce more energy than animal products using same amount of water (Liu & Savenije, 2008). Per capita water requirement for food items has been increased from 255 m3/cap/year to 860 m3/cap/year during 1961-2003 in China largely due to the shifts in consumption patterns from cereals and vegetables to livestock products (Liu & Savenije, 2008). Chinese future total water requirements for food (TWRF) under low, medium and high scenarios regarding food consumption patterns and population increase are also projected by Liu and Savenije (2008) from 2003 to 2030. Their study projected an increase in TWRF in all the three scenarios and it was shown that in each scenario consumption patterns will lead to raise the TWRF more than population change in 2030. Technological changes were supposed to reduce the TWRF in 2030 under each scenario.

Similar scenario analysis was carried out by Vanham, Mekonnen, and Hoekstra (2013). In quantifying the effects of dietary changes on WF of European countries study reveals that diet high in meat substantially raises the WF of consumption while healthy, combination and vegetarian diets are likely to decrease WF by 974 liter/cap/day, 1292 liter/cap/day and 1611 liter/cap/day respectively. European countries will become net virtual water exporter if they shift consumption from current and healthy diets (i.e. high in meat) to combination and vegetarian diets. But this study did not split EU countries into different regions having different characteristics regarding climatic conditions and preferences for consumption of food items because of which WF of consumption may differ. Secondly, region to region the recommended healthy diet may also differ. Taking care of these weaknesses Vanham, Hoekstra, and Bidoglio (2013) divided EU countries into 4 regions and found that in all 4 regions consumption patterns based on vegetarian diets will result in significant reduction in WF of consumption. Similar relation exists between agricultural WF and diet structure changes for a single country Austria, but in all the three scenarios related to diet structure its virtual water imports will remain higher than virtual water exports (Vanham, 2013).

Keeping in view the importance of link between consumption behavior and WF Mika Jalava et al. (2014) also suggested to limit the contribution of animal based products in the diets of people to save water all over the world except for the South and Southeast Asia regions mainly due to the fact that in these regions, diets have already limited part of animal products. But dietary changes alone are not enough in explaining the variations in WF rather food losses will also impact WF considerably (Mika Jalava et al., 2016). Reduction in the food losses along with shift from animal to vegetarian diets will reduce agricultural blue WF by 23% and green WF by 28% globally. When the combined effect is considered the regions of North America and Oceania have the greatest potential to decrease both types of WF while Africa is less likely to reduce blue WF among other regions as it has to become self-sufficient in producing food to meet food needs of its inhabitants. South and Southeast Asian regions are found to have the minimum potential for reducing green and blue WF because their diets are already vegetarian (Mika Jalava et al., 2016).

2.3.3. Climate change and WF

Climate change has become a serious threat nowadays for the survival of human being on earth. Climate change is recognized as the rise in temperature and changing patterns of precipitation. It is a global phenomenon which is affecting each and every country on earth. All sectors of economy are affected by this phenomenon but agriculture sector which is more dependent on nature is likely to have more adverse effects due to changes in climate. Climate change has serious implications for agriculture sector in terms of rising water requirement, putting water and food security under question. With the increasing temperature and reduction in rain fall, agricultural demand for water is increasing (Chaowiwat, Boonya-aroonnet, & Weesakul, 2016; Papadopoulou, Charchousi, Tsoukala, Giannakopoulos, & Petrakis, 2015). Water demand in Thailand is on an increasing trend from 1979 to 2006. And this demand will keep on rising till 2039 under low and medium climate change scenarios (Chaowiwat et al., 2016). Estimate of Chaowiwat et al. (2016) study shows a 15% increase in water demand in major river basins of Thailand. Similarly, examination of climate change effect on WF and crop yield is performed by Papadopoulou et al. (2015) for plains of

Messara and Chania in Greece. Their study yielded the results in consistent with that of presented by Chaowiwat et al. (2016). But this study developed a climate change scenario till 2100 and found that both in the past and future WF of agricultural sector has been and will be substantially affected by rainfall patterns and temperature changes.

Climate change has led to changes in both blue and green WF of agriculture sector. In Chinese Lake Dianchi basin, climate change has led to an annual 50.42 m3/ton increase in total agricultural WF. Whereas it brings 5.87 m3/ton reduction in green WF and 56.29 m3/ton/year increase in blue WF occurred during 1961-2010 (Y. Zhang, Huang, Yu, Hu, & Wei, 2015). Rise in rate of crop evapotranspiration (ET) is significantly caused by increased temperature and reduction in precipitation creating situation of drought. When impact of climate change variability is seen related to WF of a single crop like wheat in an irrigated area climate change is noticed to bring negative change in the WF. In contrast to previous study Sun, Wu, Wang, and Zhao (2012) showed that only temperature and wind speed are the main climatic factors which are responsible for varying level of WF of Wheat in the Hetao irrigation district of China. Both irrigation water requirement and ET reduce due to increase yield and reduced precipitation. Wind speed reduces WF by 20.33% while temperature increases it by 9.88%, bringing a net reduction in total WF of wheat production. Their findings suggested that climate change does not significantly affect the WF in the concerned area rather WF is mainly influenced by the yield of wheat but in the long run it may produce adverse effects.

After reviewing existing literature on topic of WF and its influencing factors it is evident that over time WF of agriculture sector is subject to change. And these changes in WF are mainly attributed to the factors of population, economic growth, urbanization, consumption patterns, technology and climatic conditions. Briefly concluding the literature review it can be observed that WF analysis has gained much fame in the field of water management. It not only shows the relation between consumption and misuse of water resources but also gives a complete picture of how the sustainability of water can be ensured by focusing on not only blue WF but also on green and grey WF. Existing literature lacks in terms of finding out factors bringing changes in agricultural sector of Pakistan. WF studies carried out for Pakistan in order to calculate WF are few and they did not focus on the influencing factors of changes in agricultural sector of Pakistan. Given the importance of agriculture sector in Pakistan and situation of water shortage it has become important to analyze the driving factors of agricultural WF changes so that policy implications related to better management of water resources can be made.

CHAPTER-3

DATA AND METHODOLOGY

The chapter is divided into 4 sections. Section 3.1 deals with the collection of data and measurement of variables and section 3.2 contains detailed methodology adopted to achieve the objective of study. Section 3.3 provides details on analytical tools used in this study while estimation technique is given in section 3.4.

3.1. Data and Measurement of Variables

Agricultural products are divided into six categories.

Table 3.1. Major Categories of Agricultural products

Serial no.	Categories	Items
1.	Cereals	Rice, Wheat, Maize, Barley and Sorghum
2.	Cash crops	Soybean, Cotton, Groundnut, Sugarcane, Coconut
3.	Crop processed products	Cottonseed oil, Rape and Mustard seed oil, Sunflower oil, Sesame seed oil
4.	Fruits	Apples, Bananas, Oranges, Dates, Lemon, Grapes
5.	Vegetables	Onions, Tomatoes, Potatoes, Peas and other primary vegetables
6.	Livestock	Beef, Mutton and Goat meat, Poultry meat and Milk

The research utilized annual data on population, average temperature, average precipitation, fertilizer consumption, production, imports and consumption. Time span of study is 1980-2013. Average total WF of crops and livestock production were taken from (Mekonnen and Hoekstra (2010a), (2010b)). Average WF is expressed in m3/ton (1996-2005). In order to calculate Water footprint of agricultural consumption the data on production, consumption and imports was extracted from food balance sheets of Food and

Agriculture Organization (FAO). FAO has made a distinction between the quantities fed to livestock, used for seed, used for food consumption and used for others. The part of food consumption apart from the agricultural products fed to livestock is selected to compute the water footprint for cereals, cash crops, fruit, and vegetables so that double accounting is avoided. Because WF of livestock products already includes WF of crops that are used as feed to these animals.

Data on fertilizer has been taken from National Fertilizer Development Centre. Data on agriculture GDP, population are taken from World Development Indicators.

Table 3.2. Data sources and abbreviations

Variables	Unit	Source	Abbreviations
Population	Million	World Development Indicator (WDI)	POP
Fertilizer	1000 N/tones	National Fertilizer Development Centre (NFDC)	FER
Real per capita GDP	Thousands	WDI	RPCG
Average annual Temperature	Degree Celsius	Economic Survey of Pakistan (various issues)	TEMP
Average annual Precipitation	Millimeter (mm)	Meteorological department of Pakistan	PRE
Meat consumption	Kcal/capita/year	Food and Agriculture Organization (FAO)	MC
Vegetable Consumption	Kcal/capita/year	FAO	VGC
Total WF of agriculture sector	Billion meter cubic (GM3)	Calculated	WF
Blue water footprint of wheat, rice, cotton, sugarcane	GM3	Calculated	BF_{it}

and maize			
Green water footprint of wheat, rice, cotton, sugarcane and maize	GM3	Calculated	GF_{it}
Grey water footprint of wheat, rice, cotton, sugarcane and maize	GM3	Calculated	GRF_{it}
Precipitation for wheat, rice, cotton, sugarcane and maize	MM	Meteorological department of Pakistan	$PREC_{i}$
Temperature for wheat, rice, cotton, sugarcane and maize	Degree Celsius	Economic Survey of Pakistan (various issues)	TMP_{i}
Blue water use efficiency for wheat, rice, cotton, sugarcane and maize	GM3	Calculated	$BWUE_{i}$
Green water use efficiency for wheat, rice, cotton, sugarcane and maize	GM3	Calculated	$GWUE_{i}$
Grey water use efficiency for wheat, rice, cotton, sugarcane and maize	GM3	Calculated	$GRWUE_{i}$
Fertilizer use for wheat, rice, cotton, sugarcane and maize	1000 N/tonnes	National Fertilizer Development Centre (NFDC)	FR_{i}

3.2. Methodology

In this study WF of national consumption of agricultural products was calculated based on bottom up approach. In which consumption of agricultural goods was multiplied by the water required to produce these goods. This approach of national WF accounting is extensively used because of its being a simple approach as compared to top down approach (Mekonnen & Hoekstra, 2011b; Zhao & Chen, 2014). The 'top down approach' usually measures WF of nation by summing total water used by a country minus the imports of water plus the export of water in virtual terms (Chenoweth, Hadjikakou, & Zoumides, 2014). Bottom up approach provides more detailed information regarding a product. It incorporates data on water used at every stage of production and consumption of a good and service. It does not allow for overestimation of WF estimates by not including water consumed by primary commodities when processed commodities are under consideration (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2009). It is more stable and reliable approach as data required to calculate WF through this approach, is easily available (Van Oel et al., 2009). But top-down approach lacks these benefits.

Formula for calculating WF of consumption of agricultural products based on bottom up approach will be as following Mekonnen and Hoekstra (2011b).

$$\mathrm{WF_{pak,agri}} = \sum_{n} \mathrm{CONS_A} \times \mathrm{WF_{pro}(A)} \qquad (3.1)$$

Here, CONS(A) is consumption quantity of commodity (A) by inhabitant within Pakistan, WFpro(A) refers to the water footprint for product A. Since the consumption of a commodity A is the sum of both production within the country and imports outside the country. WFpro(A) is therefore calculated by utilizing the average water footprint, which can be expressed by following formula:

$$\mathrm{WF_{pro}}\ (\mathrm{A}) = \frac{\mathrm{Q(A)\times WF_{pro.Pak}[A]+IMP[A]\times WF_{pro.Global}[A])}}{\mathrm{Q[A]+IMP[A]}} \qquad (3.2)$$

Where, Q[A] is the production quantity of commodity A in Pakistan. $\mathrm{WF_{pro.Pak}[A]}$ refers to the average production related WF of commodity A (m3/ton) when produced in Pakistan. IMP[A] is the import quantity of commodity A. WFpro,global[A] presents the average global WF of commodity A (m3/ton). Here it is assumed that the WF of commodity A depends on its production and import quantities.

Blue and green WF will be calculated by using following formula

$$BWF_{pro}\ (A) = \mathrm{Q[A]xBlueWF} \qquad (3.3)$$

$$GWF_{pro}\ (A) = \ \mathrm{Q[A]xGreenWF} \qquad (3.4)$$

$$GRWF_{pro}\ (A) = \mathrm{Q[A]xGreyWF} \qquad (3.5)$$

Where, Q[A] is the production quantity of commodity A (wheat, rice, sugarcane, cotton and maize) in Pakistan. $\mathrm{BWF_{pro}[A]}$, $\mathrm{GWF_{pro}[A]}$, $\mathrm{GRWF_{pro}[A]}$ are the blue, green and grey water footprint of product A(m3/ton) respectively when produced in Pakistan[2].

The impact of climate change and anthropogenic factors on WF is analyzed by many researches internationally (Chaowiwat et al., 2016; Sun et al., 2012; Zhao & Chen, 2014; Zhao et al., 2014). These studies have shown that changes in water footprint are linked with the changes in Climate change, population, technology, diet structure and economic activity. Concerning the factors changing the agricultural WF many studies have been conducted for developed and developing countries but no such study has been conducted for Pakistan. So given research adds to the literature by exploring the relationship between agricultural WF and its determinants in case of Pakistan. The main objective of the study is to find out the

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[2] Average values of blue, green and grey WF of crops for Pakistan and at global level will be taken from (Mekonnen & Hoekstra, 2010a)

influencing factors of changes in agricultural WF for Pakistan and in order to achieve this objective following Log-log model for time period 1985-2013 will be applied as also proposed by (Zhao et al., 2014):

$$\mathbf{lnWF_t = \alpha_0 + \alpha_1(POP_t) + \alpha_2(RPCG_t) + \alpha_3(MC_t) + \alpha_4(VGC)_t + \alpha_5(PRE_t) + \alpha_6(TEMP_t) + \alpha_7(FER_t) + \alpha_8(T_t) + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.6)}$$

Dependent Variable $=WF_t$

Independent Variables= $POP_t, RPCG_t, MC_t, VGC_t$ $PREC_t$, $TEMP_t$, FER_t,T_t

Where,

ln= Natural Log

$\mathbf{WF_t}$= Total water footprint of agriculture sector (Billion m3)

$\mathbf{POP_t}$= Population (million)

$\mathbf{RPCG_t}$ = Real per capita GDP (Thousands)

$\mathbf{MC_t}$**=** Caloric consumption from meat (kcal/per capita/year)

$\mathbf{VGC_t}$ = Caloric consumption from Vegetables (kcal /per capita/year)

$\mathbf{PRE_t}$**=** Average annual Precipitation (Milimeter)

$\mathbf{Temp_t}$**=** Average annual Temperature (Degree Celsius)

$\mathbf{FER_t}$**=** Fertilizer Consumption (1000 N/tonnes)

$\mathbf{T_t}$ = Time trend (Proxy for technological improvement)

$\boldsymbol{\alpha_0}$= Intercept term

$\boldsymbol{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6, \alpha_7, \alpha_8}$ =Slope Terms

$\boldsymbol{\mu_t}$ = Error Term

t = 1, 2, 3 . . ., 29

In order to find out relationship among blue, green and grey WF and their determinants following three different models will be applied for major crops i.e. wheat, rice, cotton, maize and sugarcane for time period 1980-2013.

$$\mathbf{lnBF_{it} = \beta_0 + \beta_1(lnPREC_{it}) + \beta_2(lnTMP_{it}) + +\beta_3(lnBWUE_{it}) + \mu_{it}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.7)}$$

$$\mathbf{lnGF_{it} = \beta_0 + \beta_1(lnPREC_{it}) + \beta_2(lnTMP_{it}) + +\beta_3(lnGWUE_{it}) + \mu_{it}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.8)}$$

$$\mathbf{lnGRF_{it} = \beta_0 + \beta_1(lnFR_{it}) + \beta_2(lnGRPREC_{it}) + \beta_3(lnGRWUE_{it}) + \mu_{it}}\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.9)}$$

Here,

ln= Natural Log

$\mathrm{lnBF_t}$, $\mathrm{lnGF_t}$, $\mathrm{lnGRF_t}$ are natural log of blue, green and grey WF.

$\mathrm{BWUE_t}$= Blue Water use efficiency (blue agricultural water footprint/agricultural GDP)

$\mathrm{GWUE_t}$ = Green Water use efficiency (green agricultural water footprint/agricultural GDP)

$\mathrm{GRWUE_t}$= Grey water use efficiency (grey agricultural water footprint/agricultural GDP)

$\mathrm{PRE_t}$= Average annual Precipitation (Milimeter)

Tmp_t= Average annual Temperature (Degree Celsius)

FR_t= Fertilizer Consumption (1000 N/tonnes)

$\boldsymbol{\beta_0}$ = Intercept term

$\beta_1, \beta_2, \beta_3$= Slope Terms

$\boldsymbol{\mu_t}$ = Error Term

t = 1, 2, 3 . . ., 34

i refers to crop (wheat, rice, cotton, maize and sugarcane)

3.3.Theoretical Justification of variables

The expected relationship between agricultural WF and independent variables mentioned in above models is discussed as follows:

3.3.1. Population and WF

Population change is an important influencing factor in determining WF of agriculture sector (Jin et al., 2016; Zhao & Chen, 2014). Population is expected to increase agricultural WF. The agriculture sector plays an important part in fulfilling the basic needs of people in terms of providing food items. With the increase in population, demand for agricultural commodities increases and in order to produce more agricultural products more water is needed (Zhao et al., 2014). So this variable is expected to affect consumption of WF of agriculture sector positively.

3.3.2. Technological Changes and WF

Technological development plays a critical role in bringing changes in water requirements of any sector. Application of water-saving technologies make it possible to produce more output by using less water (Xu et al., 2015). So the more advance an agriculture sector is in terms of technology the less will be its WF. A negative relation between technology and WF is expected therefore.

3.3.3. Per capita GDP and WF

Agricultural water consumption is also affected by per capita GDP/ per capita income (Duarte et al., 2013; Jin et al., 2016; Zhao et al., 2014). Rise in income level translates into a better living standard. As the income of people increases due to increased economic activity they tend to have more sophisticated food items (Zhao et al., 2014). Because of which agricultural production increases which leads to a rising trend in WF. But the relationship between income growth and water use is not so simple. Because when the income rises, initially people start consuming more without taking care of natural resources. But there comes a point when every increase in income does not translate into exploitation of resources like water. Rather consumption of water starts decreasing at higher levels of income (Duarte et al., 2013; Sebri, 2015). But keeping in view the weak economic conditions of Pakistan it is expected that per capita GDP will be linearly related with agricultural WF. A positive relation between per capita GDP and WF is expected therefore.

3.3.4. Diet Structure and WF

Diet structure is also a potential factor which affects agricultural WF (Vanham, Hoekstra, et al., 2013; Zhao & Chen, 2014; Zhao et al., 2014). Diets that are high in calories from meat tend to increase the demand for livestock products. A rise in demand will eventually increase the production of dairy products. And livestock products require more water to produce than crops and vegetables (Mekonnen & Hoekstra, 2012; Rijsberman, 2006; Yang et al., 2003). So with the shift in the diets of people from plant based food to animal based food demand for water will increase by agriculture sector resulting in a higher WF.

3.3.5. Climatic factors and WF

Climatic factors like temperature and precipitation also have significant impact on WF of agricultural sector (Papadopoulou et al., 2015; Y. Zhang et al., 2015). Climate change is associated with a rise in temperature and decreased precipitation (Chaowiwat et al., 2016). Rise in temperature affects green WF positively by increasing the rate of evapotranspiration of crops.

This will also lead to an increase in the blue WF by shifting source of water from rainfall to Fresh surface and ground water resources (Bocchiola, Nana, & Soncini, 2013; Papadopoulou et al., 2015). Reduction in precipitation will also affect evapotranspiration rate positively which will eventually increase the green and blue WF of crops (Papadopoulou et al., 2015). So the effect of temperature is positive on WF of crops while it is negatively affected by rainfall.

3.3.6. Efficiency and WF

Efficiency in using water also plays an important role in bringing changes in the WF (Xu et al., 2015; Z. Zhang, Shi, & Yang, 2012; Zhao & Chen, 2014; Zhi et al., 2014). Better management practices and awareness among farmers to use less water can make agriculture sector more efficient (Zhao & Chen, 2014). So, the more efficient is an agriculture sector in using water the less will be its WF. So variable of water use efficiency is expected to bring negative changes in agricultural WF.

3.3.7. Fertilizer use and Grey WF

Use of fertilizer is expected to influence WF of agriculture sector in a positive way. Due to excessive use of fertilizer water will be polluted more because of drainage and surface run over causing grey WF to increase (Brueck & Lammel, 2016).

3.3.8. Precipitation and grey WF

It is well clear that grey WF of crops is mainly caused by fertilizer application on crops. The rate of runoff of nitrogen into ground and surface water is influenced by precipitation (Franke, Hoekstra, & Boyacioglu, 2013) as these can easily be moved in moist soil. So, higher the precipitation higher is the chance that nitrogen will run off to nearby water resources.

3.4.Estimation Technique

For estimating eq (3.6) ‘Auto Regressive Distributive Lag’ or *ARDL bound testing approach to co integration* given by Pesaran, Shin, and Smith (2001) is used. ARDL approach test for the long run association among variables. It also tells about short run dynamics of the model. There are few other techniques like Engle and Granger (1987) *technique of cointegration*, *fully modified OLS procedure of* Phillips and Hansen (1990)*, maximum likelihood based* (Johansen, 1988, 1991) *and Johansen and Juselius (1990) technique of co integration* through which long run relationship can be assessed between time series. But these techniques have some weaknesses in terms of sample size and order of integration. They are appropriate to use only when variables are either of same order or I(1) and sample size is large enough. But ARDL technique dose not suffer from these weaknesses as it can be opted where all the variables are either I(1) or I(0) and even if the model to be estimated is the mixture of variables that are integrated of order 1 and 0. But a pre requisite for this technique is that none of the variable should be integrated of order 2 (Pesaran & Shin, 1998). If this is the case ARDL approach cannot be utilized. ARDL model make a distinction among regressors and regressand and also allows including a large number of variables in the model. So ARDL model does not possess issues that may be present due to endogineity and autocorrelation problems (Afzal, Malik, Butt, & Fatima, 2013). This approach can also be used where sample size is small (Pattichis & Pattichis, 1999).

3.4.1 Unit Root Test

In order to check the order of integration of time series variables Unit root test is used. For determining that the none of the variable is I(2), it is important to check order of integration before applying ARDL co integration analysis. The order of integration of each variable is checked by using Augmented Dickey Fuller unit root test (Dickey & Fuller, 1981).The ADF test is based on the following regression:

$$\Delta Y_t = \alpha + \beta_t + \gamma_t Y_{t-i} + \sum_{i=1}^{m} \varphi_i \Delta Y_{t-1} + \varepsilon_t$$

Where

ΔY_t = variable under consideration

t = time subscript

Δ = first difference operator

ε_t = random error term

m = maximum lag length

By determining the optimal length it is made sure that the error term is white noise error term, while α, β, γ and φ are the parameters to be estimated.

3.4.2. Lag Length Criteria

Selection of appropriate lag length is the second important step in the ARDL co-integration technique of estimation. In order to select lag length, two information criterions are used namely Akaike Information Criterion (AIC) and Schwarz Information Criteria (SIC) (Hasan & Nasir, 2008).

The equation (3.6) will be transformed into following ARDL equations. Here equation (3.10) represents long run relationship while equation (3.11) is presenting short run dynamics of model (3.6).

$$\mathbf{lnWF_t = \varphi_0 + \varphi_1(lnWF_{t-i}) + \varphi_2(POP_{t-i}) + \varphi_3(RPCG_{t-i}) + \varphi_4(MC_{t-i}) + \varphi_5(VGC_{t-i}) + \varphi_6(PRE_{t-i}) + \varphi_7(TEMP_{t-i}) + \varphi_8(FER_{t-i}) + \varphi_9 T_{t-i} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.10)}$$

$$\mathbf{\Delta lnWF_t = \delta_0 + \textstyle\sum_{i=1}^{k} \delta_1 \Delta lnWF_{t-1} + \sum_{i=1}^{k} \delta_i \Delta POP_{t-i} + \sum_{i=1}^{k} \delta_i \Delta RPCG_{t-i} + \sum_{i=1}^{k} \delta_i \Delta MC_{t-i} + \sum_{i=1}^{k} \delta_i \Delta VGC_{t-i} + \sum_{i=1}^{k} \delta_i \Delta PRE_{t-i} + \sum_{i=1}^{k} \delta_i \Delta TEMP_{t-i} + \sum_{i=i}^{k} \delta_i \Delta FER_{t-i} + \sum_{i=i}^{k} \delta_i \Delta T_{t-i} + ECM_{t-1} + \upsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.11)}$$

$\varphi_0,\ldots,\varphi_9$ are long-run coefficients while $\delta_0, \ldots, \delta_i$ represent short-run coefficients. In equation (3.11) Δ is the first difference operator and ECM is error correction term which shows that in how much time a disturbance in dependent variable caused by independent variables will be corrected. This term must be negative and significant (Hasan & Nasir, 2008).

For finding out presence of long run relation among variables usually Bound test is applied and F-statistic value of this test is compared with critical value of F-statistic given by Pesaran et al. (2001). If F-stat calculated > F-stat critical then there exists a long run relationship among variables otherwise not. Also different tests are applied to check the robustness of the model. These include test for hetroscadesticity, serial correlation and normality. At the end model is tested for stability by using Cumulative Sum (Cusum) and cumulative sum of squares tests (Pesaran & Shin, 1998). The null hypothesis of this test is that

Ho= the long run and short run estimated coefficients are stable.

H1=the long run and short run estimated coefficients are not stable.

If the solid line of CUSUM graph remains within the limits of critical bound lines (broken lines) then Ho is accepted and if it goes beyond red lines Ho is rejected and model is not stable (Ahmad & Riaz, 2011).

In order to the significance of the relationship among the variables in model (3.7), (3.8) and (3.9) One Way Analysis of Variance (ANOVA) is used. ANOVA makes use of F-test which also shows whether there is statistically significant relationship among variables in a multivariate regression (Sow, 2014).

Chapter-4

RESULTS AND DISCUSSION

This section presents the results of estimation and their discussion. This chapter is further split into 7 sub sections. Section 4.1 gives Descriptive statistics while section 4.2 presents Unit root test results. Section 4.3 presents results of Lag length criteria while section 4.4 presents bound test result. Short and long run results are given in section 4.5. Results of ANOVA estimates are given in section 4.6 while section 4.7 gives category wise WF of agriculture sector of Pakistan.

4.1.Descriptive Statistics

The mean, minimum value, maximum value, and standard deviation for all explanatory variables and dependent variable are given in table 4.1. Population has minimum value of 92.16 and maximum value of 181.1 million. Minimum value of fertilizer consumption in Pakistan is 1253.26 while maximum value is 4360 1000N/tones. It is showing that during 1985-2013 fertilizer consumption has increased a lot. Factually, soil of Pakistan lacks in essential nutrients and chemicals (like nitrogen and phosphorus) important for crop growth (Ishaq, 2002). Growing population of Pakistan has put pressure on agriculture sector to increase production which has caused fertilizer consumption to get increased (Government of Pakistan). Fertilizer industry has flourished much during last three decades because of agricultural support prices specified by the Government to increase the output. Agriculturalists when receiving higher prices for their produce they increase the production and use more fertilizer to increase the yield (Quddus, Siddiqi, & Riaz, 2008). With the passage of time awareness among farmers is also growing regarding benefits of fertilizer use that is why fertilizer consumption has grown up in Pakistan (Raza & Siddiqui, 2014).

On average each person consumes 19.23 calories from meat each year. Its minimum and maximum values are 16 and 23.67 kcal/cap/year, while SD value is 2.16. Vegetable caloric intake per person every year is 12.62 on average while values are dispersed from mean by 1.57. Minimum and maximum values are 9 and 15 Kcal/cap/year respectively. It is showing a higher caloric intake from meat consumption than vegetables. The reason behind increased caloric consumption from meat is that people have shifted their consumption patterns from vegetables to meat. Income per person per year is 44758.69% during 1985-2013. Minimum and maximum values are 33718.67 thousands and 55922.67 thousands respectively. SD value is 6799.185 showing that per capita GDP data is dispersed around the mean.

Mean value of temperature is 15.54 degree Celsius while its minimum and maximum values are 14.72 and 16.28 respectively. Values are dispersed from mean by very low value of 0.42. Precipitation takes value of 42.88 mm on average. Its minimum value is 27.1mm and maximum value is 68.6. SD is 8.3.

WF of agriculture sector is 76.1 Billion M3 in 1985 and 173.23 billion m3 in 2013. Its average value is 122.8 Billion M3 on average during 1985-2013. It is showing that WF of agricultural consumption has increased by more than 100% from 1985 to 2013. It has increased at an average annual growth rate of 3percent. In comparison Chinese agricultural WF has increased at annual growth rate of 2.21 percent (Zhao & Chen, 2014). During 1985-2013 not only population has increased but also people have started consuming livestock products more as production of cattle and buffalo has grown by 70.4% and meat consumption by 96% during 1999-2013 (Pakistan Economic Survey 2013-14) which has become reason for increase in WF of agriculture sector.

Table.4.1 Descriptive Statistics (Dependent and Explanatory Variables)

Variables	Unit	Mean	Minimum	Maximum	Standard Deviation
Population	Million	135	92.16	181.19	26.63
Fertilizer	1000 N/tonnes	2720.704	1253.26	4360	866.5846
Meat caloric intake	Kcal/cap/year	19.22	16	23.67	2.16
Vegetable caloric intake	Kcal/cap/year	12.62	9	15	1.57
Temperature	Degree Celsius	15.54438	14.72	16.28	0.42
Precipitation	Millimeter	42.8848	27.1	68.6	8.3
Real GDP per capita	Thousands Rupees	44758.69	33718.67	55922.67	6799.19
Total agricultural Water Footprint	Billion M3 (GM3)	128	76.10	173.23	29.03
Water Footprint of Wheat	Billion M3 (GM3)	43.20	27	62	11.02
Water Footprint of Cotton	Billion M3 (GM3)	13.99	4.2	20.78	4.13
Water Footprint of Rice	Billion M3 (GM3)	19.43	13.5	32.16	4.84
Water Footprint of Sugarcane	Billion M3 (GM3)	15.16	9.4	23	3.43
Water Footprint of Maize	Billion M3 (GM3)	5.84	2.71	14.43	3.4

WF for five major crops of Pakistan is presented in figure 4.1. For all five crops WF is on increasing trend (Figure 4.1). Among these five crops Wheat has largest WF. Wheat is the main staple crop of Pakistan and its production on average is 17.05 million tons during 1980-2013 (FAO) which is lower than sugarcane production (43 million tons). But wheat has higher average WF value than sugarcane. One ton of wheat is produced with 2532 m3 of water while of sugarcane is produced with 348 m3 of water (Mekonnen & Hoekstra, 2011a). At world level wheat is at second among most water consuming crops. Rice is the second largest staple crop in Pakistan (Government of Pakistan). And at international level it consumes 21% of the total water used for crop production. More water is needed in Pakistan to produce rice as it requires almost 4524 m3 water to produce one ton of rice in Pakistan while globally one ton of rice is produced by using only 2414 m3 of water (Mekonnen & Hoekstra, 2011a). After Wheat, Rice has the largest blue WF because almost all rice production is irrigation based in Pakistan. Sugarcane is on third number when it comes to national WF accounting. Its production is higher among all three major crops. Among all crops grey WF of Wheat is high because its fertilizer use is at highest among other crops (Figure 4.2). Almost 1270 thousands N/tonnes fertilizer is used for wheat production on average. Grey WF of cotton is largest after wheat as consumption for cotton is 602 thousands N/tonnes which is at second (NFDC). N-fertilizer added to the field is partly taken up by the plant, is partly transformed through de-nitrification into N2 that leaves the soil to the atmosphere and partly leaches to the groundwater or gets washed away through surface runoff (Chapagain, 2006). Out of the total nitrogen applied for cotton production about 20% leaves the field through leaching to the groundwater, surface runoff or de-nitrification to the atmosphere (Silvertooth et al. (2001).

Figure 4.1. Water Footprint of Major Crops of Pakistan(1980-2013)

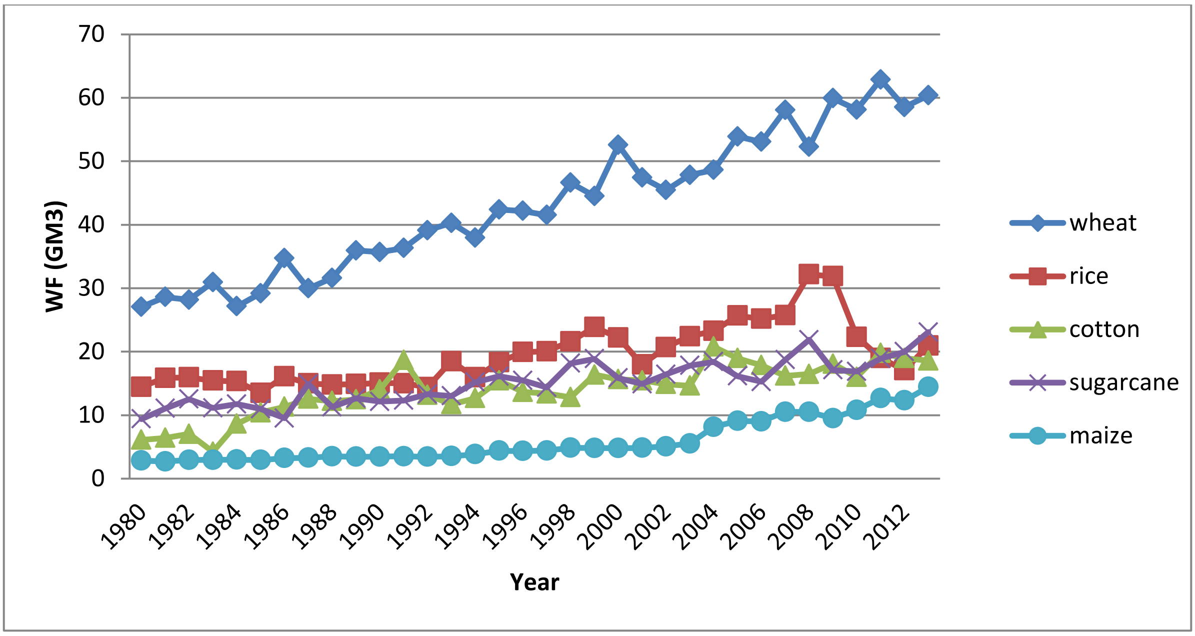
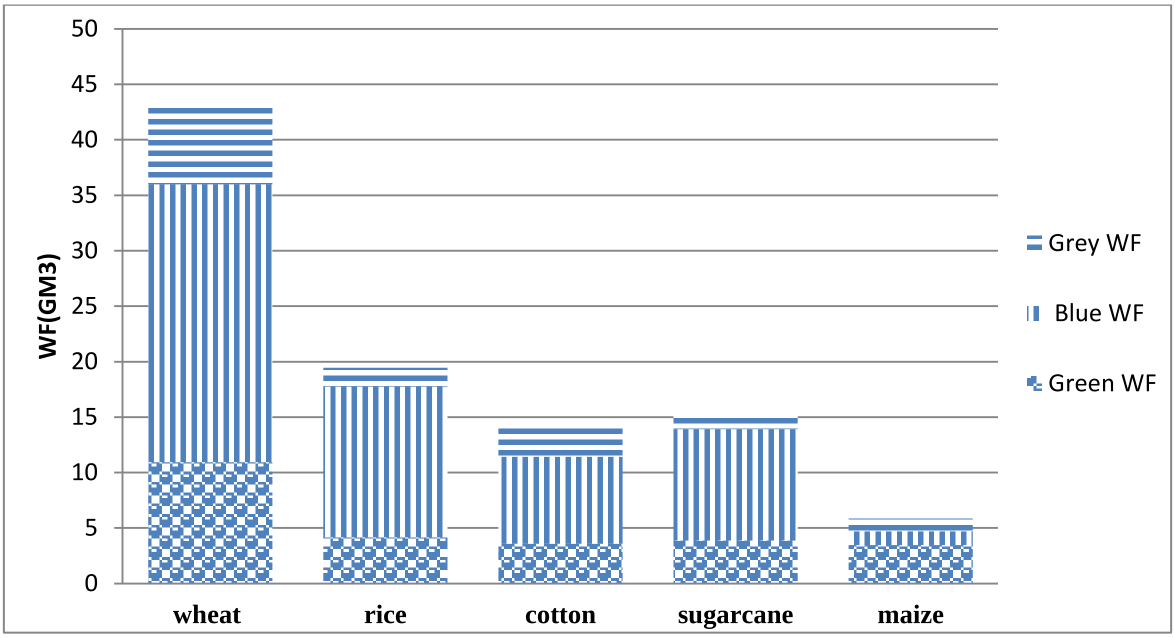


Figure 4.2. Blue, Green and Grey WF of Major Crops of Pakistan(1980-2013)



4.2. Unit root test

The results of ADF test are presented in table 4.2.

Table 4.2 **Augmented Dickey Fuller (ADF) Test**

Variables	Level	1st Difference	Order of Integration
	t-statistic	t-statistic	
$LPOP_t$	-4.94***	-	I(0)
LWF_t	-10.76***	-	I(0)
$LTEMP_t$	-4.61***	-	I(0)
LPRE_t	-5.39***	-	I(0)
$LRPCG_t$	-	-3.8**	I(1)
$LVGC_t$	-	-4.22***	I(1)
LMC_t	-	-6.03***	I(1)
$LFER_t$	-	-6.22***	I(1)

Note: *** ,** denote the significance at 1 and 5 percent level of significance respectively.

From this table it is clear that Population, WF, temperature, precipitation are integrated of order zero (stationary at level), while real GDP per capita, vegetable consumption, meat consumption and fertilizer are integrated of order 1 as these are stationary at 1st difference. The main reason behind selecting this estimation technique is that the model 1 is the mixture of I(0) and I(1) this suggests to apply ARDL model.

4.3. Lag length Selection

Results of AIC and SIC are presented in table 4.3

Table 4.3 VAR Lag Order selection Criteria

Lag	SIC	AIC
0	-16.50	-16.87
1	-26.22	-29.52
2	-25.78*	-32.01*

Note: *denotes the minimum value according to Schwarz and Akiake Information Criterions

According to AIC and SIC criteria's the appropriate lag length that can be selected is 2 as * is appearing on values of AIC and SIC at Lag 2.

4.4. Results of Bound test

As discussed above that in order to find out long run association among variables bound test is applied. The results of this test are presented in table 4.4.

Table 4.4 ARDL Bounds test

Order of lag 2	F-statistic: 6.87
99% Lower Bound: 3.31	99% Upper Bound: 4.63
97.5% Lower bound: 2.98	97.5% Upper bound: 4.16
95% Lower bound: 2.69	95% Upper bound: 3.83
90% Lower bound: 2.38	90% Upper bound: 3.45

Ho: There is no long run association among variables

H1:There exists long run association among variables

From above table it is clear that F-statistic value is greater than 1% level of significance upper bound value of 4.63. So Ho of no long run relationships is rejected and it is concluded that variables are having long run relationship.

4.5.ARDL Model Results of Determinants of Agricultural WF:

Long and short run results of ARDL models are presented in table 4.5.

Results of ARDL show that in long run all the independent variables have significant effect on dependent variable of agricultural water footprint.

Long run results of ARDL show that climatic variables of temperature and precipitation both have significant impact on agriculture WF of Pakistan. In long run, 1 percent increase in temperature increases the WF of agriculture sector by 0.53% keeping all other factors as constant. While every one percent rise in precipitation brings negative changes of 0.47 percent in WF when all other factors do not change. These results are in line with the results of Papadopoulou et al. (2015) and Bocchiola et al. (2013). When temperature increases it raises the rate of evapotranspiration (Green WF) i.e. water evaporation and transfer of water from soil to crop increases. In order to provide sufficient water to crops also irrigation water (blue WF) demand increases. In case of increase in precipitation level WF will reduce as rate of evapotranspiration will be less in humid atmosphere caused by rainfall (Papadopoulou et al., 2015).

It is also evident from results present in table 4.5 that real per capita GDP (RPCG) has significant long run effect in bringing changes in agricultural WF of Pakistan. With 1percent increase in RPCG, WF will increase by 8.23 percent. Higher per capita GDP/ per capita income shows that people have better living standards so as the per capita GDP increases people will have more money to consume more sophisticated food products like when they have more income they would consume more meat and other dairy products whose WF is higher than simple diets like vegetables etc. So with this WF of agriculture sector will increase. These findings are in line with the results of Zhao et al. (2014) and Zhao and Chen (2014). Both of these researches find that agricultural related WF are positively affected by the changes in real per capita GDP.

It is also confirmed from the results of the ARDL model that vegetable and meat caloric consumption play significant role in bringing changes in agricultural WF of Pakistan in the long run. Their coefficients are significant at 1% level of significance. Both changes WF of agriculture sector positively but the change in WF caused by meat consumption is greater than that of vegetable consumption. As coefficient of meat consumption is 1.46 and that of vegetable consumption is 1.22. It shows that with every 1 percent increase in meat and vegetable consumption agricultural WF raises by 1.46% and 1.22% respectively. As people tend to shift their diets to meat products from vegetables, agricultural WF gets increased because livestock production requires more water than vegetable consumption (Vanham, Hoekstra, et al., 2013; Zhao et al., 2014).

Results show that population growth has positive impact on WF of agriculture sector of Pakistan in the long run and this impact is also statistically significant. When all other variables are kept constant, with every 1percent increase in population growth there will be 23.47 percent increase in agricultural WF in the long run. As population grows need for more food and other agricultural related products increases. So in order to produce more food more water in agriculture sector is needed which results in increased agricultural WF. The finding is in line with the findings of Jin et al. (2016), Zhao and Chen (2014) and Zhao et al. (2014). These studies also confirmed a positive significant impact of population on WF of agriculture sector.

It is also evident from results present in table 4.5 that trend variable capturing effect of technological development has significant long run effect in bringing changes in agricultural WF of Pakistan. With 1 percent increase in technology, WF will decrease by 0.70 percent.

Fertilizer also brings significant variations in agricultural WF of Pakistan in long run. These variations are significant at 10% level of significance. When all other variables remain unchanged with every 1 percent rise in fertilizer consumption WF of agriculture sector will get changed by 0.51% and this change is positive. When fertilizer is applied on fields nearby surface and ground water resources are polluted due to drainage and surface run over causing grey WF to increase (Brueck & Lammel, 2016).

Speed of correction of any disturbance in agricultural WF from its equilibrium level in the long run is 0.73 which is negative and significant at 1% level of significance. It is showing that if WF of agriculture sector gets out of equilibrium due to any shock, 73percent of the disturbance will be corrected each year. F-stat value is highly significant showing that overall model is significant. Also value of adjusted R^2 is high indicating that 99.8 percent variations in WF of agriculture sector are explained by explanatory variables.

Short run results of the model show that all variables have significant impact on agricultural WF of Pakistan.

Table 4.5	**Long and short run ARDL results for the determinants of WF (2,2,2,2,2,1,1,2)**				
Long run results			**Short run results**		
Dependent Variable: LWF_t			Dependent Variable: ΔLWF_t		
Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
$LTEMP_t$	0.53**	3.19	$LTEMP_t$	2.42***	4.73
$LPRE_t$	-0.47**	-3.02	$\Delta LTEMP_t$(-1)	0.95**	3.09
LMC_t	1.46**	3.16	$LPRE_t$	-0.97***	-3.40
$LVGC_t$	1.22***	3.56	$\Delta LPRE_t$(-1)	0.53**	2.44
$LPOP_t$	23.47**	3.06	ΔLMC_t	0.35***	3.54
$LFER_t$	0.51*	2.47	$\Delta LVGC_t$	0.21**	2.34
LT_t	-0.70**	-3.32	$\Delta LVGC_t$(-1)	-0.25**	-2.04
$LRPCG_t$	8.23**	3.29	$\Delta LPOP_t$	30.92***	4.27
C	169.75***	3.75	$\Delta LPOP_t$(-1)	24.83***	4.74
R-squared: 0.999 **Adjusted R-squared: 0.998** **AIC: -5.38** **F-statistic: 7253*** **			$\Delta LFER_t$	0.35***	3.58
			$\Delta LFER_t$(-1)	0.195**	2.07
			ΔLT_t	-0.51***	-4.83
			$\Delta LRPCG_t$	5.2***	8.98
			ΔECM_t	-0.73***	-4.2

Note: ***indicates significance at 1% level of significance.

** indicates significance at 5% level of significance.

* indicates significance at 10% level of significance.

C: intercept term

Results of tests for checking robustness of model are given in table 4.6.

Table 4.6	**Robustness tests**		
Problems	**Tests**	**Chi square**	**Probability**
Serial Correlation	Breusch Godfrey LM test	1.98	0.161
Normality test	Jarque Bera Normailty test	0.45	0.798
Hetroscadesticity test	White test	19.04	0.64

It is evident from this table that the model does not suffer from any statistical problem like serial correlation, non normality of the residuals and hetroscadesticity. As probability values of these tests are greater than 0.1 showing acceptance of desired null hypotheses (no serial correlation, no hetroscadesticity and normal residuals).

At the end CUSUM and CUSUM square tests are applied to check the stability of the parameters of models (3.11) and (3.12). It is evident from Graphs (4.3 and 4.4) that model is stable as solid lines are within the limits of broken lines (critical bounds).

Figure4.3 Graph of Cumulative sum of Recursive Residuals

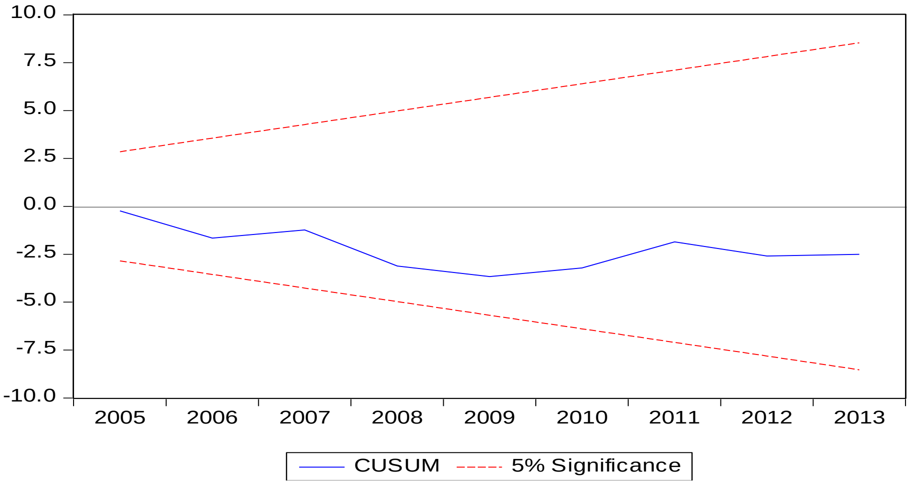
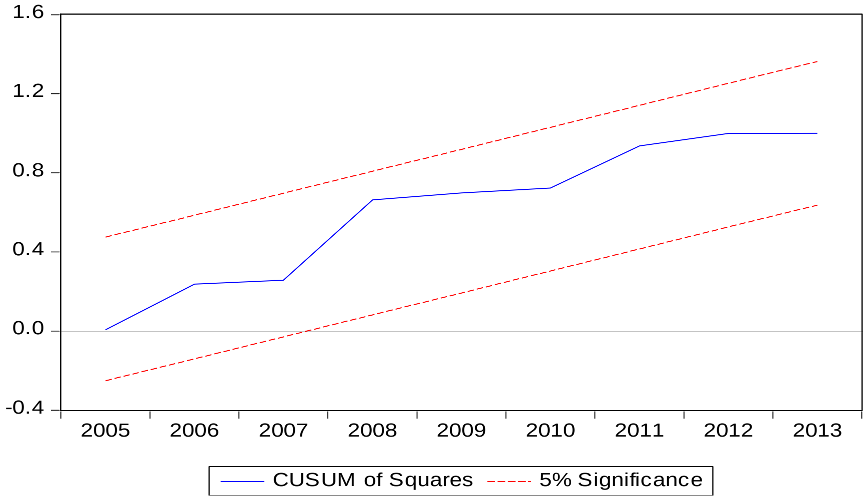


Figure4.4 Graph of Cumulative sum of Squares of Recursive Residuals



4.6.Results of OLS and ANOVA estimates

This section presents the estimates of Analysis of Variance which is used to see whether independent variables in equation (3.7), (3.8) and (3.9) for five major crops (wheat, rice, sugarcane, cotton and maize) have statistically significant relationship with the blue, green and grey WF respectively. The results of OLS estimates are also presented in Appendix (A1 to A5).

Tables 4.7, 4.8, 4.9, 4.10 and 4.11 present F-stat value for blue, green and grey WF of wheat, sugarcane, cotton, maize and rice. F-stat values are significant at 1% level of significance for all three models of each group other than for rice. For rice F-stat values are significant at 10% level of significance for blue and green WF models while grey WF model is significant at 5% level of significance. Hence it is cleared that all the three models for each crop have statistically significant relationship among dependent and independent variables.

Table 4.7 The relationship between blue, green and grey WF of Wheat and their determinants

Dependent variable[3]	Independent variables	F-stat	Probability value
$\mathrm{LBF_W}$	$\mathrm{LPREC_W}$,$\mathrm{LTMP_W}$,$\mathrm{LBWUE_W}$,	24.255	0.000***
$\mathrm{LGF_W}$	$\mathrm{LPREC_W}$,$\mathrm{LTMP_W}$,$\mathrm{LGWUE_W}$	24.255	0.000***
$\mathrm{LGRF_W}$	$\mathrm{LPREC_W}$,$\mathrm{LFR_W}$,$\mathrm{LGRWUE_W}$	36.83	0.000***

Note: ****showing significance at 1% level of significance

Table 4.8 The relationship between blue, green and grey WF of Sugarcane and their determinants

Dependent variable[4]	Independent variables	F-stat	Probability value
$\mathrm{LBF_S}$	$\mathrm{LPREC_S}$,$\mathrm{LTMP_S}$,$\mathrm{LBWUE_S}$	4.427	0.011****
$\mathrm{LGF_S}$	$\mathrm{LPREC_S}$,$\mathrm{LTMP_S}$,$\mathrm{LGWUE_S}$	4.427	0.011***
$\mathrm{LGRF_S}$	$\mathrm{LPREC_S}$,$\mathrm{LFR_S}$,$\mathrm{LGRWUE_S}$	25.25	0.000***

Note: ***showing significance at 1% level of significance

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[3] $\mathrm{LBF_W}$, $\mathrm{LGF_W}$, $\mathrm{LGRF_W}$= log of blue, green and grey WF of Wheat.

[4] $\mathrm{LBF_S}$, $\mathrm{LGF_S}$, $\mathrm{LGRF_S}$= log of blue, green and grey WF of Sugarcane

Table 4.9 The relationship between blue, green and grey WF of Cotton and their determinants

Dependent variable[5]	Independent variables	F-stat	Probability value
$\mathrm{LBF_C}$	$\mathrm{LPREC_C}$,$\mathrm{LTMP_C}$,$\mathrm{LBWUE_C}$	4.14	0.014***
$\mathrm{LGF_C}$	$\mathrm{LPREC_C}$,$\mathrm{LTMP_C}$,$\mathrm{LGWUE_C}$	4.14	0.014***
$\mathrm{LGRF_C}$	$\mathrm{LPREC_C}$,$\mathrm{LFR_C}$,$\mathrm{LGRWUE_C}$	448.6	0.000***
Note: ***showing significance at 1% level of significance			

Table 4.10 The relationship between blue, green and grey WF of Maize and their determinants

Dependent variable[6]	Independent variables	F-stat	Probability value
$\mathrm{LBF_M}$	$\mathrm{LPREC_M}$,$\mathrm{LTMP_M}$,$\mathrm{LBWUE_M}$	22.82	0.000***
$\mathrm{LGF_M}$	$\mathrm{LPREC_M}$,$\mathrm{LTMP_M}$,$\mathrm{LGWUE_M}$	22.82	0.000***
$\mathrm{LGRF_M}$	$\mathrm{LPREC_M}$,$\mathrm{LFR_M}$,$\mathrm{LGRWUE_M}$	30.52	0.000***
Note: ***showing significance at 1% level of significance			

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[5] $\mathrm{LBF_C}$, $\mathrm{LGF_C}$, $\mathrm{LGRF_C}$= log of blue, green and grey WF of cotton

[6] $\mathrm{LBF_M}$, $\mathrm{LGF_M}$, $\mathrm{LGRF_M}$= log of blue, green and grey WF of Maize

Table 4.11 The relationship between blue, green and grey WF of Rice and their determinants			
Dependent variable[7]	Independent variables	F-stat	Probability value
LBF_M	$LPREC_M$,$LTMP_M$,$LBWUE_M$	2.23	0.12*
LGF_M	$LPREC_M$,$LTMP_M$,$LGWUE_M$	2.23	0.12*
$LGRF_M$	$LPREC_M$,LFR_M,$LGRWUE_M$	2.93	0.05**
Note: **showing significance at 5% level of significance *showing significance at 10% level of significance			

4.7.Category wise WF of agriculture sector of Pakistan

Agriculture sector is divided into six categories namely Cereals, Livestock, cash crops, vegetables, processed crops and fruits (see chapter-4 for detail). Average values of WF of these categories are given in table 4.12. Total WF of agriculture sector has risen from 76.11 Gm3 to 173.29 Gm3 from 1985 to 2013.The WF of each category has increased from 1985 to 2013. It is clear from figure 4.12 that in 1985 cereals had the largest share in total WF but in 2013 livestock WF has the highest contribution in total agriculture related WF. It can also be seen that Livestock WF has been on increasing trend. It has increased from 27.9 Gm3 in 1985 to 84.32 Gm3 in 2013 (Fig 4.5). It has increased more than doubled from 1985 to 2013. Other categories have also experienced growth in terms of WF but the rate of growth of these categories is slower than livestock.

Livestock is an important sub sector of agriculture sector. From 1999 to 2014 population of Pakistan has increased by 37.8% while production of cattle and buffalos has

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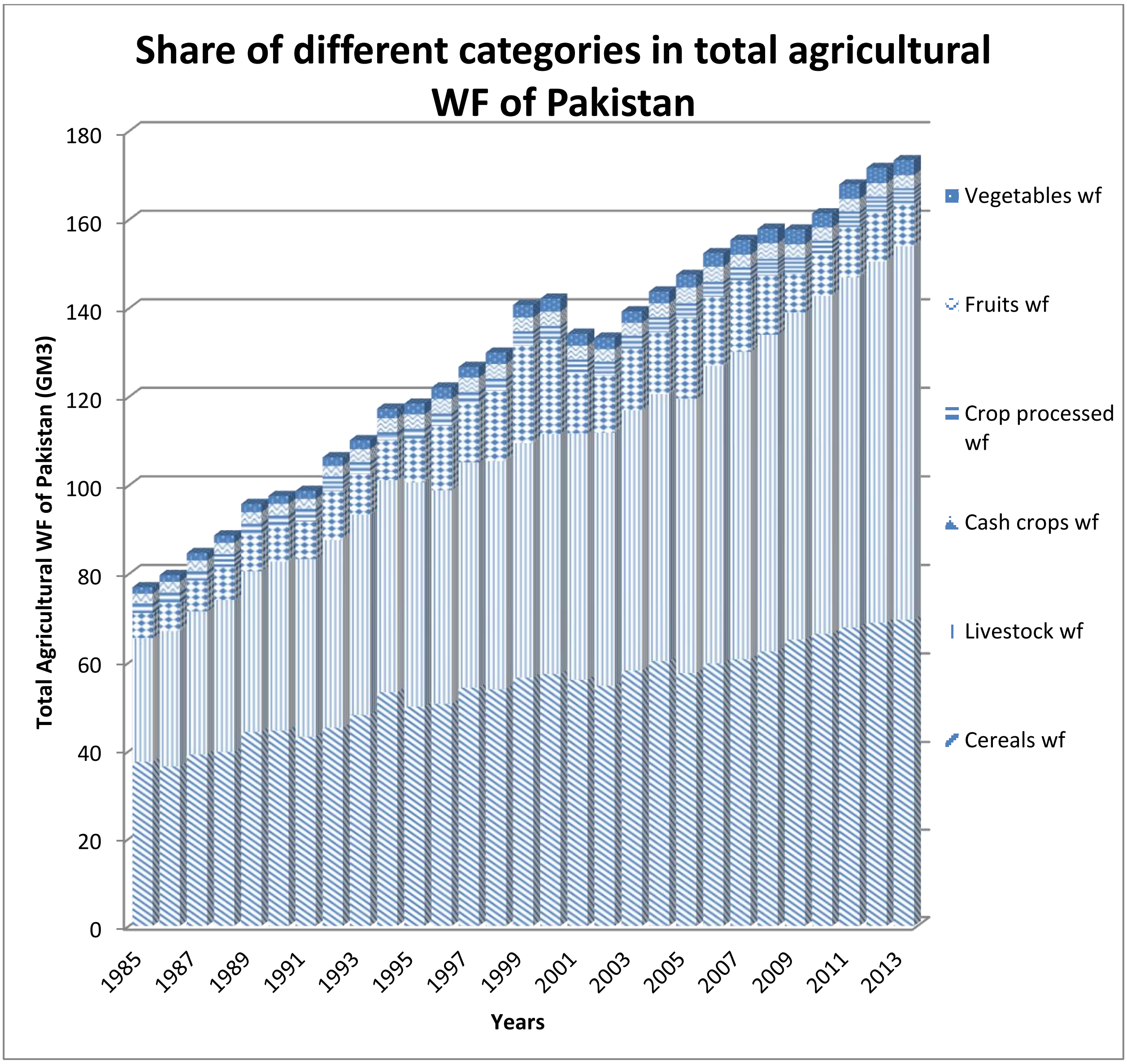
[7] LBF_R, LGF_R, $LGRF_R$= log of blue, green and grey WF of Rice

risen by 70.4% and meat consumption experienced growth of 96% in this time period (Pakistan Economic Survey 2013-14). It confirms that production and consumption of livestock products is increasing with the passage of time and this sector experienced growth of 4.1% in 2014-2015 (Pakistan Economic Survey 2014-15). It shows that in our country people has started preferring consuming more meat than vegetables. WF of Cereals has increased from 37.59 Gm3 to 69.72 GM3 from 1985 to 2013. While WF of cash crops, crops processed products and fruits and vegetables has experienced growth of 64%, 175%, 35% and 135% respectively from 1985 to 2013.

Table 4.12: Descriptive Statistics of Category wise WF of Agriculture sector

Categories	Mean	Minimum	Maximum
WF of Cereals	54.51 GM3	36.55 GM3	69.68 Gm3
WF of Livestock	55.44 GM3	30.52 GM3	84.32 GM3
WF of Cash crops	12.15 GM3	6.47 GM3	22.04 GM3
WF of Processed Crops	2.49 GM3	1.29 GM3	3.7 GM3
WF of Fruits	2.93 GM3	2.27 GM3	3.54 GM3
WF of Vegetables	2.56 GM3	1.53 GM3	3.46 GM3
Total Water footprint	130 GM3	78.72 GM3	173.29 GM3

Figure: 4.5


Share of different categories in total agricultural WF of Pakistan
Total Agricultural WF of Pakistan (GM3)
180
160
140
120
100
80
60
40
20
0
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
Years
Vegetables wf
Fruits wf
Crop processed wf
Cash crops wf
Livestock wf
Cereals wf

CHAPTER-5

CONCLUSION AND POLICY RECOMMENDATIONS

Water plays an important role in our daily livings. It is necessary for life on earth. Water footprint (WF) analysis is significant in terms of knowing how much water is being consumed today and how important is to save this natural resource in order to survive in future. WF has three components namely green, blue and grey WF. Ground and surface water resources consumed account for blue WF; green WF usually refers to the volume of water taken up by the crops from soil. And grey WF refers to the amount of fresh water needed to dissolve the pollutants in any consumption and production process. Keeping in view the significance of water this research is an attempt to know about the factors bringing changes in the agricultural WF of Pakistan. Pakistan is an agricultural country and agriculture sector is considered backbone of the economy. WF of this sector are mainly affected by real per capita GDP, population growth, climatic factors of temperature and rainfall, consumption patterns and fertilizer which causes grey WF.

Study used ARDL bound testing approach in order to examine the relationship among different factors and agricultural WF. In long run impact of all explanatory variables is significant. In long run both population and per capita GDP has positive and significant impact on agricultural WF. Among all variables population has the largest impact on WF. Second largest determinant of WF of agriculture sector is per capita GDP. Temperature is observed to affect agricultural WF positively while precipitation tends to reduce WF in the long run. Increase in meat consumption impact WF more as compared to vegetable consumption. Fertilizer consumption also increases the agricultural WF in the long run. The result of technological changes (time trend variable) shows that adoption of water efficient technologies leads to reduce WF of agriculture sector. Error correction term is negative and significant showing that if due to any reason WF of agriculture sector changes it comes back to its equilibrium soon as 73% of disturbances are adjusted each year. Results of ANOVA also show that blue, green and grey WF of major crops have significant relationship with temperature, precipitation, fertilizer consumption and water use efficiency.

Analyzing the estimates of water footprint of agriculture sector and investigating different factors that potentially affect the WF of agriculture sector is very important to help government of Pakistan making necessary decisions regarding water resources management. In this regard following recommendations are given:

- Consumption patterns are influenced by pricing, awareness raising, labeling of products or introduction of other incentives that make people change their consumption behavior. Government should start educating people regarding pressure on water resources that is put by production of livestock products. So that people of Pakistan change their consumption patterns by shifting their diets from meat and livestock products to vegetables and grains because livestock requires more water to produce. Rising livestock production will thereby threaten Pakistan’s water resources as Pakistan is already a water scarce country. Also some sort of pricing policy should be introduced that will incorporate price of water in more water consuming products.
- Also different measures should be taken at field level to make sure that less amount of fertilizer runs off to the nearby water resources. In this regard there is an instant need to educate the farmers.
- In Pakistan it is needed to use efficient water technologies to control the increasing water footprint of agriculture sector. Water footprint of agriculture can be reduced for instance by applying advanced techniques of irrigation.

Limitations:

Grey WF accounting used in this research makes use of only nitrogen related pollution of water resources. Due to non-availability of pesticides related data, grey WF related to pesticides consumption are not calculated. Further field level research can be conducted by incorporating phosphorus and pesticides related grey WF. It will give more precise information regarding actual water pollution taking place in our country.

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Appendices

A-1

ANOVA and OLS regression results for Sugarcane

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.521	3	.174	4.427	.011[b]
	Residual	1.178	30	.039		
	Total	1.699	33			

a. Dependent Variable: lbf

b. Predictors: (Pattichis & Pattichis), ltmp, lprec, lbue

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	21.857	5.471		3.995	.000
	lbue	-.518	.198	-.437	-2.615	.014
	Lprec	.174	.181	.154	.963	.343
	Ltmp	1.659	1.562	.181	1.062	.297

a. Dependent Variable: lbf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.521	3	.174	4.427	.011[b]
	Residual	1.178	30	.039		
	Total	1.699	33			

a. Dependent Variable: lgf

b. Predictors: (Pattichis & Pattichis), lgue, lprec, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	21.393	5.595		3.824	.001
	Lprec	.174	.181	.154	.963	.343
	ltmp	1.659	1.562	.181	1.062	.297

	lgue	-.518	.198	-.437	-2.615	.014

a. Dependent Variable: lgf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.217	3	.406	25.246	.000[b]
	Residual	.482	30	.016		
	Total	1.699	33			

a. Dependent Variable: lgrf

b. Predictors: (Pattichis & Pattichis), lfr, lprec, lgrue

Coefficientsa

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	15.227	1.676		9.084	.000
	lsrf	.024	.112	.021	.210	.835
	lsgre	.383	.186	.323	2.059	.048
	lsf	.554	.082	1.072	6.786	.000

a. Dependent Variable: lgrf

A-2
ANOVA and OLS regression results for Cotton

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.297	3	.432	4.141	.014[b]
	Residual	3.133	30	.104		
	Total	4.430	33			

a. Dependent Variable: lbf

b. Predictors: (Pattichis & Pattichis), lbwue, lprec, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	-6.062	10.055		-.603	.551

	Lprec	.402	.230	.274	1.748	.091
	ltmp	6.991	2.842	.396	2.460	.020
	lbwue	.794	.279	.465	2.843	.008

a. Dependent Variable: lbf

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.541[a]	.293	.222	.32315

a. Predictors: (Pattichis & Pattichis), lgwue, lprec, ltmp

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1.297	3	.432	4.141	.014[b]
	Residual	3.133	30	.104		
	Total	4.430	33			

a. Dependent Variable: lgf

b. Predictors: (Pattichis & Pattichis), lgwue, lprec, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	-7.472	10.179		-.734	.469
	Lprec	.402	.230	.274	1.748	.091
	ltmp	6.991	2.842	.396	2.460	.020
	lgwue	.794	.279	.465	2.843	.008

a. Dependent Variable: lgf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.334	3	1.445	448.606	.000[b]
	Residual	.097	30	.003		
	Total	4.430	33			

a. Dependent Variable: lgrf

b. Predictors: (Pattichis & Pattichis), lgrwue, lprec, lfr

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	11.157	.543		20.549	.000
	Lprec	.014	.042	.009	.326	.747
	Lfr	.582	.017	.970	33.752	.000
	lgrwue	.922	.048	.540	19.267	.000

a. Dependent Variable: lgrf

A-3

ANOVA and OLS regression results for Wheat

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1.605	3	.535	24.255	.000[b]
	Residual	.662	30	.022		
	Total	2.266	33			

a. Dependent Variable: lbf

b. Predictors: (Pattichis & Pattichis), ltmp, lprec, lbue

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	42.104	2.508		16.790	.000
	lbue	-1.946	.239	-.862	-8.129	.000
	Lprec	.021	.077	.028	.270	.789
	Ltmp	-.277	.420	-.067	-.660	.514

a. Dependent Variable: lbf

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1.605	3	.535	24.255	.000[b]
	Residual	.662	30	.022		
	Total	2.266	33			

a. Dependent Variable: lgf

b. Predictors: (Pattichis & Pattichis), ltmp, lprec, lbue

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	42.104	2.508		16.790	.000
	lgwue	-1.946	.239	-.862	-8.129	.000
	Lprec	.021	.077	.028	.270	.789
	Ltmp	-.277	.420	-.067	-.660	.514

a. Dependent Variable: lgf

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	6.588	3	2.196	30.526	.000[b]
	Residual	2.158	30	.072		
	Total	8.747	33			

a. Dependent Variable: lgrf

b. Predictors: (Pattichis & Pattichis), lmf, lmrf, lmgre

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	12.961	2.535		5.112	.000
	Lprec	.516	.245	.195	2.108	.044
	lgrwue	1.386	.256	.593	5.417	.000
	Lfr	-.825	.235	-.389	-3.508	.001

a. Dependent Variable: lmgr

A-4
ANOVA and OLS regression results for Maize

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.082	3	2.027	22.828	.000[b]
	Residual	2.664	30	.089		
	Total	8.747	33			

a. Dependent Variable: lbf

b. Predictors: (Pattichis & Pattichis), lprec, lbwue, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	-7.257	6.147		-1.181	.247
	lbue	1.639	.265	.701	6.189	.000
	ltmp	4.640	2.245	.241	2.067	.047
	Lprec	.505	.276	.190	1.831	.077

a. Dependent Variable: lbf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6.082	3	2.027	22.828	.000[b]
	Residual	2.664	30	.089		
	Total	8.747	33			

a. Dependent Variable: lgf

b. Predictors: (Pattichis & Pattichis), lgwue, lprec, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	-4.502	6.192		-.727	.473
	ltmp	4.640	2.245	.241	2.067	.047
	Lprec	.505	.276	.190	1.831	.077
	Lgwue	1.639	.265	.701	6.189	.000

a. Dependent Variable: lgf

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	6.588	3	2.196	30.526	.000[b]
	Residual	2.158	30	.072		
	Total	8.747	33			

a. Dependent Variable: lgrf

b. Predictors: (Pattichis & Pattichis), lmf, lmrf, lmgre

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	12.961	2.535		5.112	.000
	Lprec	.516	.245	.195	2.108	.044
	lgrwue	1.386	.256	.593	5.417	.000
	Lfr	-.825	.235	-.389	-3.508	.001

a. Dependent Variable: lmgr

A-5
ANOVA and OLS regression results for Rice

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	.266	3	.089	2.229	.116[b]
	Residual	.796	30	.040		
	Total	1.062	33			

a. Dependent Variable: lbf

b. Predictors: (Pattichis & Pattichis), ltmp, lprec, lbwue

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	8.773	7.038		1.246	.227
	lbwue	.582	.247	.506	2.352	.029
	lprec	.127	.229	.110	.555	.585
	ltmp	3.437	1.857	.396	1.851	.079

a. Dependent Variable: lbf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.266	3	.089	2.229	.116[b]
	Residual	.796	30	.040		
	Total	1.062	33			

a. Dependent Variable: lgf

b. Predictors: (Pattichis & Pattichis), lgwue, lprec, ltmp

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	6.893	7.247		.951	.353
	Lprec	.127	.229	.110	.555	.585
	Ltmp	3.437	1.857	.396	1.851	.079
	Lgwue	.582	.247	.506	2.352	.029

a. Dependent Variable: lgf

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.407	3	.136	2.930	.050[b]
	Residual	1.388	30	.046		
	Total	1.795	33			

a. Dependent Variable: lgrf

b. Predictors: (Pattichis & Pattichis), lprec, lfr, lgrwue

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Pattichis & Pattichis)	20.384	2.949		6.911	.000
	lgrwue	.069	.213	.069	.324	.748
	Lfr	.516	.200	.525	2.574	.015
	Lprec	-.051	.162	-.055	-.316	.754

a. Dependent Variable: lgrf