JAZULI ABDULLAHI

VIRTUAL WATER TRADE IN THE SEMI-ARID REGIONS OF NIGERIA

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**A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY**

**By
JAZULI ABDULLAHI**

**In Partial Fulfillment of the Requirements for the Degree of Master of Science
in
Civil Engineering**

NICOSIA, 2016

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Jazuli Abdullahi: VIRTUAL WATER TRADE IN THE SEMI-ARID REGIONS OF NIGERIA

Approval of Director of Graduate School of Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my Mum and Dad

ABSTRACT

With continuous growth in the world population, the demand for water increases and hence water scarcity rises. Adequate measures have to be put in place in order to make proper utilization of the available water. Virtual water trade is defined as the water volume conveyed within the imported or exported food. Hence, this research was aimed to determine the volume of virtual water required to produce 25 different crops in the semi-arid regions of Nigeria in 2013. In the meantime, the virtual water imports and exports, the volume of virtual water produced, water balance, and water footprint, contributions of green, blue, and grey water for crop productions, imports costs, exports income and productions value of the selected crops were distinguished. CROPWAT 8.0 software was used in conducting this research. The results obtained were presented and comparisons were made with previews studies for Nigeria.

Keywords: Virtual water trade, semi-arid regions, crop productions, water footprint, water balance, Nigeria

ÖZET

Dünya nüfusunun sürekli yükselmesi ile birlikte su talebi ve dolayısıyla da su kıtlığı artar. Mevcut su kaynaklarının doğru kullanılabilmesi için gerekli önlemlerin alınması kaçınılmazdır. Sanal Su Ticareti (Virtual Water Trade) ithal veya ihraç edilen ürün içerisinde transfer edilen su miktarı olarak tanımlanır. Bu nedenle bu araştırmada 2013 yılında Nijerya'nın yarı kurak bölgelerinde yetiştirilen 25 farklı bitki türü için, sanal su hacmi, sanal su ithalatı ve ihracatı, üretilen ürün sanal su hacmi, su balansı ve su ayak izi, hesaplanması amaçlanmıştır. Buna bağlı olarak, yetiştirilen ürün bazında ekonomik getiri ve yeşil, mavi ve gri su kullanımı dağılımları etüt edilmiştir. Bitkilere ait su ihtiyaçlarının hesaplanmasında COPWAT 8,0 yazılımı kullanılmış ve elde edilen sonuçlar önceki çalışmalar dikkate alınarak kıyaslanmış ve sunulmuştur.

Anahtar kelimeler: Sanal su ticareti, yarı kurak bölge, bitki türleri, su ayak izi, su balansı, Nijerya

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LIST OF ABBREVIATIONS

VWC:	Virtual Water Content
VWT:	Virtual Water Trade
WB:	Water Balance
VWD:	Virtual Water Demand
WP:	Water Footprint
VWI:	Virtual Water Import
VWE:	Virtual Water Export
CT:	Crop Trade
CWR:	Crop Water Requirements
CY:	Crop Yield
NVWI:	Net Virtual Water Import
NVWE:	Net Virtual Water Export
GVWI:	Gross Virtual Water Import
GVWE:	Gross Virtual Water Export
QP:	Quantity Produced
GVWC:	Gross Virtual Water Content
GVWD:	Green Virtual Water Demand
BVWD:	Blue Virtual Water Demand
GRVWD:	Grey Virtual Water Demand

CHAPTER 1
INTRODUCTION

1.1 Globalization of Trade

With the diversification of communications and information systems, the crackdown of barriers in the international trade and rise in economic power global corporations, the global trade is getting momentum speedily for more than one-fourth of the past century. However with the crossing of Columbus, European colonialism of 450 years got optimism, and the modern global economy is as a result of the foundation laid by the colonial empire (Ellwood, 2006). Global trade advanced drastically at the time of colonialism as raw materials were imported by European powers from their controls including furs, fish and timbers from Canada, gold and slaves from Africa, fruits and sugar rum from the Caribbean, spices and tea from Asia, silver, meat, coffee and gold from Latin America. European powers gathered a lot of wealth from colonies countries though some where taken back for investment in to dams, ports, cities, roads, and railways (Ellwood, 2006). In globalization history there exist numerous diverse landscape as illustrated by Rennen and Martens (2003) based on context chosen, including political viewpoint (America discovery in 1492), the technological viewpoint (steam engine invention in 1765), the economic viewpoint (United East Dutch Foundation East India in 1602), and the environmental viewpoint (Growth limits to Rome's club in 1972).

Globalization process is difficult which extend from culture to political domain, to environment and to economy. Globalization perspectives are in numerous moments biased with figures often followed to maintain the philosophy desired. Protect itself not refuse the phenomenon, rather a concentrated in the directed and defined process (Rennen and Martens, 2003).

In many places in the globe, interactions intentionally other than seclusion had been the principle behind the economic progress. The benefits of globalization of trade have reached some and some are yet (Watkins and Fowler, 2002). The strong globalization opposition believes that the notion competitions that the winner take-it-all and been an expanded gap between the poor and the rich. They highly imagine that environmental degregation, as well as poverty rise, are fueled by culpable global trade and agricultural large scale industries (Cavanagh and Mander, 2002).

Subsidies in agriculture, barriers in trade and export dumping are among the primary reasons by World Trade Organization (WTO) (Oxfam, 2003; Watkins and Fowler, 2002).

Uncertainties may arise in globalized markets, however, it gives way to the emergence of fresh opportunities (Daveri et al., 2003). Focusing on one direction of globalization to in-accurate perceptions. The face off, in a nutshell, is to provide the global community with the material required in a way that gives optimism in equality and that does not damage the environment (Dicken, 1992).

1.2 Globalization of Water

Even though global government does not exist, many establishments of regional and global organizations to check the issues of water trans-boundary which comprise global government for emergent system exhibiting a rise in the coordination of politics between governments, social movements and inter-government organizations. At this juncture, aims and goals are achieved through consensual agreements in values, rules and principles. Right now, the river basins internationally stood at 261 in number, and 145 countries shared territorial basins that spanned around 50% of global land surface involving over 40% population of the world (UNESCO – WWAP, 2003).

With commission invention of Mekong River in 1957, water regime introduced internationally. Water globalization issues were evident with the invention numerous international commissions to take care of water issues. For instance, Botswana, Namibia and Angola corroborate permanent water commission named Okavango River Basin in 1994 to organize and participate in the distribution of water resources of the basin. Nile Basin was established in 1999 with the ambition of maintaining the socio-economic development via fair management and contributions from water resources of Nile Basin can be another great example of affiliations in cross-border for the river basin management. Moreover, all these accomplishments, are downward steps in water resources managements spanning the regimes borders between national and basin scale. Solutions were demanded in basin boundary.

There exist many schemes for water transfer ranging between surplus regions and deficit regions, usually occurring between political or national borders. Transfer of bulk water proposals was delivered at both global and international levels (Gleick et al., 2002). Many of these transfer projects of large scales whether being implemented or conceptions are India's Link Projects of Water Transfer for Inter Basin, the China's Projects of Water Transfer for South-North and Lesotho's Projects of Highland Water and South Africa. Bulk trading of large scale fresh water is now a debatable issue for negotiations and arguments at international trade. Many of those transfer from China and India are implemented individually on the national scale, even though the Indian project has consequences on the distributed basins.

In addressing the current and probably the future water shortage problems, the peak use of water resources globally has become the main point of deliberations in the water resources sector. Efficiency could be assessed either using physical sense or economic sense. Economic efficiency in the use of water implied that marginal benefit should always be higher than marginal cost, in another word, marginal cost should be less than or equal to the marginal benefits. Therefore, the water distributions to places of uses should be considered in accordance with the economic return, while the used water volume for a given water used should be in a way that marginal cost equal to marginal benefits (Chapagain, 2006).

A research by Hoekstra and Hung (2002; 2005) differentiate water use in three (3) distinct levels where efficiency in water use can be enhanced through decision making, including global level, basin level and local level. Using different crop or reducing wasteful agricultural water use or employing better efficient water technology to get similar output, hence, enhancing the efficiency of locally used water. Efficiency could be elevated by distributing water for uses at a greater marginal benefit at basin level. Efficiency could be elevated at the global level through production at more preferred sites. In all the levels, increasing the physical efficiency should be the main focus point, implying that to obtain the same output by using little or less water (small meter cube per kg of water or production dollar) or way of increasing economic efficiency by optimizing the overall output with the full given set including water resources. Water resources maintainability management required systematic, desegregated decision making, which identifies all the three levels interdependence decision making (Gallopin and Rajisberman, 2000).

1.3 Virtual Water Trade

The phrase "Virtual Water" was initially introduced by Allan (1993; 1994), which was described as the water volume needed for the production of a commodity and or services (Allen, 1998a; Allan, 1999b; Hoekstra, 1998). While product and or services are transferred from one position to another, little physical water transfer was involved (with the exception of water content in quantitative measures of product that is negligible). However, there is essential virtual water transfer. From a nation's point of view, Haddadin (2003) defined virtual water with the phrase "exogenous water". Virtual water is however called ultraviolet water whereas different forms of water are classified as grey, green, white, deep blue and blue water (Savenije, 2004).

Virtual water is defined more specifically in two different perspectives; from the production perspective and from the use perspective (Hoekstra, 2003). The production perspective appraises virtual water to be the water (real water) responsible for commodity production. The efficiency of water used and production time are among the production conditions upon which the production site depends on. In the water used perspective, the term 'Virtual Water Content' referred to as the quantity of water which could have been needed for the production of a product at the region or point in which the product was used. The former definition is important if interest is placed in knowing the quantity of water actually used in producing a project, example for forecasting the production impact to the environment. The latter definition is important when interested in knowing the quantity of water saved by a country through importation of commodity rather than domestically producing it.

In the second perspective definition of the virtual water, trouble awakens when products could not be produced in a region where it is imported, for some reasons such as owing to conditions of the climate. Renault (2003) determined to substitute the virtual water content of the product in consideration by devising a means of nutritional equivalent that determined food products comparison owing to nutritional values.

As water productivity, trend increases generally with time, therefore, commodity virtual water content depends on time (Renault, 2003). It is, however, essential whether considering the virtual water of the past or the future. Consequently, virtual water differs in both time and space.

Research by Allen (1998a) gives explanations why in the Middle East there was no conflict over water, although a lot of economics possesses only half of the water they required in the arid zones. He further clarified problems of water supply was solved by the economics system for the regions through virtual water trade. When water-intensive products are exported to another country, then such water exported is in virtual form. Based on this, some countries gets the water they needed by the support of other countries. For countries that are water-scarce, water security is achieved by the importation of products that are water-intensive instead of domestically producing the entire products of water demanding. Meanwhile, countries that are water rich benefit from their water resources availability by the production of products that are water-intensive for exports. Due to associated costs and large distance, it is practically impossible to have real water trade between regions that are water-poor and water-rich, but virtual water trade is realistic with water intensive trade for products. For a country with different zones of climate, the trend is as well applicable for efficiency improvement between country's regions itself.

Allen (1998a) described how watershed water scarcity problem can be accurately solved by opting to the international economic viewpoint. The economic system globally developed to be heavily essential with regards to filling local periodic scarcity (Allan, 1999a). Allan resolved why in spite twice available water was needed to meet the Middle East demand by 1990 and in spite driven trend of demography which suggest that the region will require four times the currently available water by 21st century, 3rd decade, it had been observed that the water budget of the region can be balanced through importation of virtual water. Currently, the region of the Middle East and North Africa (MENA) each year import water of volume equivalent to Nile annual flow to the region (Allan, 2001).

Virtual water advantage is likely to rise dramatically at the global level due to extrapolation by International Food Policy Research Institute (IFPRI). Rosegrant and Ringler, (1999) estimated that food trade would speedily increase: Cereals will double while meat will triple within 1993 to 2020. Whereas the food and water self-sufficiency trend sound fascinating and give strength optimism to national feelings, this gives rise to non-authentic perception of water need which is non-sustainable and irrational in many arid regions. It needed a strong economy that brings about adequate exports cash income to take care of virtual water imports or required food cost

(Shuval, 1998). The land, capital and labor incarnate in the product should be taken in to considerations for countries in which one or many of the resources scarce (Wichelns, 2001).

In the majority of countries that are in arid and semi-arid regions, the managements of water resources are often significance and disputatious (Garrido et-al., 2010). The view of many water resources professionals attributes water scarcity to the miserable management of the water rather than natural scarcity (Garrido and Dinar 2009, Benoit and Comeau 2005).

The semi-arid region covered a huge part of Northern Nigeria and it includes Sahel savanna and Sudan bioclimatic regions. Rain-bearing dominated the climate, the dry, tropical continental North-easterly, and tropical maritime South Westerly air masses (Tarhule and Woo, 1998). In some regions of Nigeria, most especially the northern regions, there is an insufficiency in annual precipitation. However, in many other areas, low-rainfall dependability, space, and time distributions are the main problems (FAO AQUASTAT, 2005).

This research was aimed to determine the volume of virtual water required to produce 25 different crops in the semi-arid regions of Nigeria in 2013, virtual water imports and exports, volume of virtual water produced, water balance, and water footprint, contributions of green, blue, and grey water for crop productions, imports costs, exports income and productions value of the selected crops. The results obtained was compared with the old studies to be a guidance to the scientists, and agencies dealing with the sector. The result showed that in the 7 regions of the semi-arid zone, the sum of the volumes of virtual water produced of the crops selected was approximately 35.9 Gm^3 yr^{-1} , virtual water imports volume was 8.6 Gm^3 yr^{-1}, virtual water exports volume was 27.5 Mm^3 yr^{-1}, water balance was 8.6 Gm^3 y^{-1} and water footprint was 44.5 Gm^3 yr^{-1}. Total production value was \$2.6 billion, import cost \$794.6 million and export income \$1.1 million. The suitable region to grow crops in the semi-arid regions of Nigeria is Gusau as it has more percentage of rainfall water used than others, which can, therefore, reduce cost of production and scarcity of water.

CHAPTER 2
LITERATURE REVIEW

2.1 Previous Studies for Nigeria

Hoekstra and Hung (2002) study showed that between 1995 – 1999, Nigeria was ranked 24th out of 30 top world virtual water import countries with net virtual water import (water balance) of 24 Gm^3/yr. It was the 4th in the top African countries with the highest imports of virtual water, behind Egypt, Algeria, and Morocco that were 8th, 14th, and 21st positions respectively in the top 30. The research however, revealed that within the said period (1995 – 1999) Nigeria's production capacity was approximayely 124 million tons, water withdrawal was 4.6 Gm^3/yr, water availability was 280 Gm^3/yr, gross virtual water export was 934.4 Mm^3/yr, gross virtual water import 5.8 Gm^3/yr, net virtual water import 4.9 Gm^3/yr, and water footprint 77 Mm^3/yr per capita. Moreover, Hoekstra and Hung (2002) revealed that in 1995 Nigeria was among the world countries that were 70 – 90% self – sufficiency of water.

According to a study by Hoekstra (2003), between the period 1995 – 1999 the Net virtual water import (water balance) of Nigeria was between 10 – 50 Gm^3/yr. moreover, the regional net virtual water imports (water balance) of Africa within the same period was 242 Gm^3/yr.

Chapagain and Hoekstra (2003) and Zimmer and Renault (2003) conducted a research in Nigeria on virtual water trade for 2003. The result by Chapagain and Hoekstra (2003) revealed that the gross virtual water import of Nigeria was 6.4 Gm^3/yr, gross virtual water export was 1.0 Gm^3/yr and net virtual water import 5.4 Gm^3/yr. While research by Zimmer and Renault (2003) showed that the gross virtual water import of Nigeria in 1999 was 8 Gm^3/yr, gross virtual water export was 0.3 Gm^3/yr and the net virtual water import was 7 Gm^3/yr.

Yang et al.(2006) stated that between 1997 to 2001 Nigeria was among the world countries with total net virtual water import of 487.1 Gm^3/yr and total net virtual water import percentage of 68.1%. However, Nigeria within the said period had water availability per capita larger than 2500m^3.

According to Mekonnen and Hoekstra (2011), Nigeria was the seventh (7) largest crop production water footprint country in the world after India, China, USA, Brazil, Russia, and

Indonesia from 1996 to 2005. Nigeria had a total water footprint of $192Gm^3$/yr. green water contributes 99.3% of the total water footprint at $190.6Gm^3$/yr, blue water 0.6% at $1.1Gm^3$/yr, and grey water 0.3% at $0.6Gm^3$/yr.

2.2 Global Virtual Water Trade

Shiklomanov (1997), stated that irrigated water use for agricultural global withdrawal of water in 1995 was 2500 Gm^3/yr and in 2000 was 2600 Gm^3/yr.

Allen (1998a) disclosed that through virtual water imports an armed conflict was averted in the Middle East owing to its water resources scarcity. He forecasted that North Africa and the Middle East by 2000 were importing grains annually of 50 million tons of virtual water.

Yang and Zehnder (2001) considered analysis in the plain of North China on water scarcity and stated that importation of virtual water should be considered as supplementary measures in addition to conservation intelligent of economizing and initiation of new sources of water resources use in order to attain the gross in water demand.

Hoekstra and Hung (2002, 2005) estimated that wheat water productivity is usually beyond $1kg/m^3$ for countries of major exports in Western Europe and North America when compared to less than $0.6kg/m^3$ in a lot of Central Asia and African countries. The productivity of water is beyond $1.5kg/m^3$ for maize in the Australia, EU countries, and the USA. In a nutshell, the value in major countries Central Asia and Africa is less than $0.9kg/m^3$. It is realized that poor countries possess lower water productivities. The condition is predicted because the material input is related closely to water productivity level, water management and agronomic practices at both farm and regional level.

A study by IHE which Chapagain and Hoekstra (2003) and Hoekstra and Hung (2002, 2003) reported revealed that in the given period 1995 – 1999, global virtual water trade was 1040 Gm^3/yr between nations, out of which crops related international trade constituted 67%, trade of livestock products and livestock 23% and industrial products trade 10%. The estimate was in accordance with the products of exporting countries virtual water content.

Study by Food and Agricultural Organization of United Nations (FAO) and World Water Council (WWC) which Zimmer and Renault (2003) and Renault (2003) reported revealed that by the year 2000, the global virtual water trade was 1340 Gm^3 between nations, out of which trade related to vegetable products constituted 60%, seafood, and fish trade 14%, animal products trade 13% and meat trade 13%. The estimate was in accordance with the products of importing countries' virtual water water content.

Oki et al., (2003) revealed that global virtual water trade with respect to exporting countries viewpoint was 683 Gm^3/yr. The estimated value was lesser compared to that of IHE research group and it could perhaps be as a result of fewer products considerations by Oki et al. (2003). The global virtual water trade with respect to importing countries viewpoint was 1138 Gm^3/yr. This estimate value was lesser compared to that of research by FAO-WWC, perhaps again as a result of fewer products considerations. The results showed that the world water saving as a result of global food trade accounts for 455 Gm^3/yr. The world total crops water used was forcasted by Rockstrom and Gordon (2001) as 5400 Gm^3/yr, meaning about 8% of water was saved. The study forcasted that the international virtual water content in relation to food trade flows was 683 Gm^3/yr by exporting countries perspectives. Production of food products traded within the importing countries will amount to 1138 Gm^3/yr. The global water saving is their difference.

According to Fraiture et al. (2004), water use potentially reduced by virtual water trade in both global and national levels. Because for 1kg of cereal produced, crop water from 500 up to 4,000 liters of water is involved. By food importation rather than domestic production, a country's water use is reduced. From the global point of view, a country's water saving is possible via trade when the importer is less water efficient than the exporter. Water use by irrigation reduces via trade under rain-fed cultivation situations by the exporting country, whereas irrigated agriculture would have been relied upon by the importing country.

Hoekstra and Hung (2005) computed international crop related volume of virtual water trade between 1995 – 1999, the result showed that export of water in virtual form constitutes crop water used of 13% of the production. Also the research revealed that the average international virtual water trade global volume in relation to crops betwen 1995-1999 was 695Gm^3/yr. More results stated that with consideration of the said period, the top five largest net virtual water exports countries in ascending order were India, Argentina, Thailand, Canada, and the United States of America. While the top five largest net virtual water imports countries in ascending order were Indonesia, China, Republic of Korea, Netherlands, and Japan. It was further revealed that the result showed developing countries generally have less stability in virtual water balance than the developed countries. For instance, virtual water exports optimum years found for Syria, Guatemala, vietnam, India and Thailand. The occurance of optimum years with large virtual water import founded in Jordan. Moreover, the research clarified that comparably close countries with respect to development level and geography can have varied virtual water balance. Where as countries in Europe such as Germany, Belgium, Italy, Netherland and Spain are virtual water imports of crops, but France is large virtual water exports. Regarding the Middle East, Syria was seen having net virtual water trade export of crops but Israel and Jordan possess net import of virtual water. In Southern Africa, Zambia and Zimbabwe between 1995-1999 had net export, but the country of South Africa had net import. In the former Soviet Union regions, countries like Ukraine and Kazakhstan possess net virtual water export, however, net import was possessed by Russian Federation.

Chapagain et al. (2005, 2006), clarified that 6% of agricultural world water used is saved through virtual water trade, which is equivalent to 28% of the overall sum of virtual water trade in reference to trade in international agriculture.

A study by Yang et al. (2006) revealed that the global virtual water export for the total volume in conncetion to the considered crops amounts to 644 Gm^3/yr. Equivalent import volume was 981 Gm^3/yr. The difference between import and export was 337Gm^3/yr. The food trade resulting volume was the global water saving. In another way, if the food imported were produced domestically within the countries that imported them, more water would be otherwise required. Their study also stated that the main exporting countries at the global level achieved water saving through reflections of a relatively higher productivity of water. However, according to the study, South America, Oceania, and North America are the regions of net virtual water export. The regions of West and North Africa, Central America, Middle East Asia are net virtual water import and these regions are the virtual water main destinations. The research also showed that virtual water volumes differ greatly in importing and exporting parts. For instance, North

America's virtual water of 73 Gm^3 exported worth 149 Gm^3 of East Asia virtual water. These correspond to volumes of 55 Gm^3 and 17 Gm^3 respectively in the Middle East. The only exception is the import of virtual water to Western Europe from South America. The virtual water imported to Western Europe worth more than in South America due to lower productivity of water in the latter region than in the former. The results explained that the importance of water saving is limited with respect to country level due to the reason that many available (abundant) water resources countries are net importers. It, however, clarified the negative effect of usually subsidized and cheap food to the ordinary food prices from the main exporting countries and production of food in the importing countries, most especially the poor countries. Moreover, irrigation intensity is totally low for major exporting food countries. The irrigated areas of production proportion of food are judge small. Green water dominated virtual water trade globally. Water use opportunity cost is efficient with regards to such trade. Moreover, partly a results of large inputs of pesticides and chemical fertilizers, main exporting countries have the high water productivity. The results further revealed that the global food trade of current time is fundamental between the countries surpassing the low-level income country classification of the World Bank. The countries with the low level of income are the least in the global food trade participation. Part of the reasons are shallow income and subsequently lower natural resources exploitation ability and agricultural investment are hugely responsible. Financial resources limitation also obstruct the choice of food purchase in the international market by poor countries when there is a shortage in the supply of domestic food.

Hoekstra and Chapagain, (2006) revealed that between 1997 and 2001, the virtual water of about 6.3 Gm^3/yr was imported in to Morocco while 1.6 Gm^3/yr was exported. The agricultural water use in Morocco stands at 37.3 Gm^3/yr. Cereals virtual water import was 3.0 Gm^3/yr. The main cereals sources were the USA, Canada, and France. The second largest virtual water imports crops to Morocco were oil crops at 1.7 Gm^3/yr. The majority of the oil crops imported were from France, Ukraine, Brazil, the Netherlands, Argentina, and the USA. Stimulants and sugar at 0.7 Gm^3/yr and 0.6 Gm^3/yr respectively were among the significant agricultural commodities of Morocco's virtual water import. The result also stated that the Morocco's virtual water export was related specifically to the oil crops exports at 0.54 Gm^3/yr, with livestock products at 0.23, cereals at 0.25 and fruits 0.32. The major destinations of Morocco's virtual water exports of the oil crops are Spain and Italy. Russian federation and France are the major importers of fruits while Libya was the largest destinations for cereals. Exports constitute 4% of the agricultural sector water use in Morocco while 96% of the crops produced are consumed domestically in Morocco. Furthermore, the results showed that with 28 million people population, the agricultural water footprint of Morocco was 42.1 Gm^3/yr, where as with a population of 16 million people, Netherlands water footprint was 9.9 Gm^3/yr. Morocco's external water footprint was 6.1 billion m^3/yr. The Morocco water dependency (dependence on external water resources) explained as the import ratio to the total water footprint was 14%, while Morocco's self water sufficiency explained as the domestic water ratio to the total water footprint was 86%. The major virtual water imports to Morocco were Argentina, Canada, Brazil, the USA and France.

Shuval (2007) stressed that out of 100% of the total food consumption at the national level, 80% were imported from abroad in Israel while caloric intake of greater than 65% was imported by Palestinians.

Liu et al. (2007) indicated that a lot of crops that transform water to have greater economic value in water intensity are down but can be more efficient in irrigation water saving, thereby reshupling to crops with a greater value that can ascend the incomes of farmers without water consumption increase of agriculture.

Liu et al. (2007), and Liu et al., (2008) studied that China's virtual water trade under the effects of both macro and micro-economic situations and weather variability, has unnoticely developed and based on their given suggestion, a significant role of active strategy could be played by virtual water insecurity of food and sustainability of water use, owing to liberalization of markets commodity by China's agriculture.

Novo et al. (2009) revealed that Spain's virtual water imports in connection with trade of grain are harmonious with respect to water scarcity, but the exports involvement in grain did not coincide with the difference in scarce resources, thus recommend other conditions inclusively products specifications, quality, and standardized products demands likewise instigate virtual water trade.

Research by Jiang (2009) and Liu et al. (2013) showed that, in terms of per capita water resources, China is termed water-scarce country and could face increase severety trend of unbalance water between North and South that are water-scarce and water-abundance regions respectively.

Hoekstra (2010) research revealed that water use of 5% is reduced currently in agriculture via international trade of virtual water.

El-Sadek (2010) showed that Egypt's net virtual water imports accounted for 24% of their available water resources.

According to Mekonnen and Hoekstra (2011), the crop production of the world water footprint within 1996 to 2005 period was 7404 Gm^3/yr (10% grey, 12% blue and 78% green). The crop with highest total volume share was wheat with 1087 Gm^3/yr consumption (11% grey, 19% blue, and 70% green). The next crops in terms of large volume of water footprint were maize which consumed 770 Gm^3/yr and rice 992Gm^3/yr. The average world green water footprint in relation to the production of crops stands at 5771 Gm^3/yr, out of which 4701 Gm^3/yr was rain-fed crops, and 1070 Gm^3/yr irrigated crops. In continuation, the study revealed that for the majority of crops, green water footprint contributions in accordance with water footprint total consumption (green and blue) is beyond 80%. With respect to the main crops, date palm has the lowest green water contributions to the total water footprint consumption with 43% and 64% cotton. However, the study further showed that the average global blue water footprint in relation to the production of crops was 899 Gm^3/yr. 202 Gm^3/yr rice, and 204 Gm^3/yr wheat, with both the two occupied 45% of the global water footprint of blue water. In relation to nitrogen fertilizer use, grey water footprint for crops cultivation consumed 733 Gm^3/yr, rice 111Gm^3/yr, and maize 122 Gm^3/yr together account for huge grey water footprint of 56% out of the total grey water footprint of the globe. Moreover, the research revealed that green water contributed 86.5% of the global crop production water consumed. The important contributions of green water can also be traced in irrigated agriculture for total water consumption. The regions of arid and semi-arid are the regions with the largest blue water footprint share. The locations of the regions having huge blue water congruity, for instance, USA western part, around the west cost of of Peru-Chile (South America) in Southern Europe, Northern India, and Pakistan, North Africa, parts of Australia, Central Asia, Northeast China and Arabian Peninsula. Also stated by the results, the average per ton water footprint of primary crop varies between crops significantly and among production areas. Crops with crop biomass of large fraction or high yield crops that are generally harvested, the water footprint per ton are smaller compared to low yield crops or harvested crop biomass of small fraction. When product per ton considered, huge water footprint commodities are spices, cocoa, fibers, rubbers, tea, nuts, and tobacco. Moreover, the study revealed that at the country level for water footprint, the highest green water footprint in ascending order where computed for Indonesia, Brazil, Russia, USA, China, and India. At the province or state level (sub-national level) green water footprints of largest amount were determined from India which are Madhya pradesh 60 Gm^3/yr, Andhra pradesh 61 Gm^3/yr, Karnataka 65 Gm^3/yr, Maharashtra 86m^3/yr and Uttar pradesh 88Gm^3/yr. The blue water footprints of the largest value were determined for Pakistan, USA, China, and India. Those four (4) countries together contributed 58% to the overall blue water footprint in relation to the production of the crop. At the state level (sub-national level) blue water footprints of largest values were computed in California in the USA 20 Gm^3/yr, Punjab in Pakistan 50 Gm^3/yr, Madhya pradesh in India 24 Gm^3/yr and Uttar pradesh in India 59 Gm^3/yr. Grey water footprints of large values were obtained from India, USA, and China.

Dalin et al. (2012) introduced evolution analysis through network approach in between 1986 to 2007 of virtual water trade globally. Their results stand by the debate that the world virtual water trade with respect to the trade of international food give rise to efficiency in water used globally and as such help in saving water used worldwide, even though patterns of virtual water trade for both national and regional changed quite a lot.

Ozkaynak et al. (2012) state that even though there are improvements in efficiency, usually regional as well as global water withdrawals persistently increase in flawless terms owing to the combination of affluence increase and growth population effect.

Ercin, Mekonnen, and Hoekstra (2012) study showed that France national production of total water footprint between 1996 and 2005 was 90 Gm^3/yr, and this represented 1% of the world production of the total water footprint. Green water took the largest portion with 76% of the water footprint, the second was grey with 18% and then blue with 6%. Crop production covered the largest portion with 82% of the France national production of water footprint, the second was industrial activities with 8%, grazing with 6%, domestic water supply with 3%, lastly livestock production with 1%. Between the crops, 47% of the overall water footprint was contributed by cereals, 15% fodder crops, 9% oil seed crops, fruits and nuts 6% were the other significant groups of crops with large share to the overall water footprint. Crop production covered 50% to the overall France water footprint of blue water. However, their research stated that the France agricultural production of water footprint (crop production, livestock water supply, and grazing) between 1996 and 2005 was 80 Gm^3/yr, meaning 89% of the overall France water footprint. Sugar beet 2%, sunflower 4%, grapes 5%, rapeseed 7%, barley 9%, maize 14%, fodder crops 18%, and wheat 29% were together provided 88% of the entire agricultural water footprint. The main huge water footprint vegetables were artichokes, tomatoes, califlower, lettuce, carrots, onions, asparagus, and cabbages. Grapes has the largest water footprints among the fruits.

Shi et al. (2014) state that import of virtual water surpasses to a larger extent the export of virtual water of china and a yearly average of 97% of the import virtual water of China are grains. However, 53% of export of virtual water are grains, even though not a dominant crop in comparison with import. Vegetables and fruits exports of virtual water are minor, though significant are cash crops, having 46% share of which tea exports of water is the utmost significant source. The research also revealed that China imports virtual water from abundant-water regions of South America and North America and there by regarded as Net Virtual Water Import country. Moreover, China exports virtual water to water scarce regions of Africa, Europe, and Asia. Import of virtual water is higher than export, and the chain of supply is controlled by few trade partners. Grain crops contribute the majority of virtual water trade. However, the most important grain crops imported usually from Brazil, Argentina, and U.S.A are soy beans. The study further presented that poor water-abundant countries can lessen their water scarcity through virtual water importation of commodities that are water-intensive rather than domestically producing them, whereas countries that are water-abundant economically gain through virtual water export from their water-rich resources. According to the result, the net virtual water imports of China has drastically raised in 2009 to 137.14 Gm^3 from 1986 of 7.02 Gm^3. The virtual water trade pattern of the trend are identical historically, where as virtual water trade values are insignificantly smaller. In continuation, the result showed that grain being the largest contributor of exports of virtual water may later loss it position and replace by cash crop.

CHAPTER 3
STUDY LOCATION

3.1 Study Country

Nigeria is situated in West African region of the tropical zone, it has latitudes between 4^0N to 14^0N and longitudes of $2^0$2’E to $14^0$30’E with an area of 923,770 km^2. The distance from North to South of Nigeria is 1,050 km while the optimum distance from east to west is 1,150 km. Nigeria is surrounded by Benin to the West, to the North and Northwest by Niger, to the Northeast by Chad, and to the East by Cameroon, while bordered by Atlantic Ocean is Southern Nigeria. Nigeria’s Land constitutes of dense rain forests and thick mangrove forests at south, and the close-to-desert situation at the northeastern part of the country (FAO AQUASTAT, 2005).

Nigeria is incomparably the most populous in African continent and the most populous blacks’ country in the world, with a population of 127 million people in 2004 which stood about one-seventh of the total population of 53 countries in Africa (FAO AQUASTAT, 2005). Nigeria has a population of 140,431,790 according to 2006 population and houses census (www.population.gov.ng) out of which 71,345,488 were males, and 69,086,302 were females. Kano State had the highest population in Nigeria with 9,401,288 people. In 2013 the population was 172,816,500, by 2015 it was estimated to be 182,202,000 people and by 2016 it would be 186,987,600 (FAOSTAT, 2015a). According to United Nations report (2015), Nigeria will overtake United States of America and become the 3rd world most populous country in the world by 2050. Nigeria is divided in to six geo-political zones, namely; North-East, North-West, North-Central, South-East, South-West, and South-South. The major spoken languages are Hausa, Igbo, and Yoruba. The official language is English. The two major religions are Islam and Christianity. The Northern Nigerian people are mainly Muslims, while Southern Nigeria are predominantly Christians. The Nigeria’s federal capital territory (F.C.T) is Abuja, and is surrounded by 36 states that form up the country (as shown in Fig. 1)

Figure 3.1: Map of Nigeria showing 36 states and capital

(FAO AQUASTAT, 2005/Nigeria. Accessed 02-02-2016)

Nigeria consists of three ecological zones that are broadly prominent (FAO AQUASTAT, 2005), these are;

i. The Sudan Savannah in the North
ii. The Guinea Savannah in the Central also called Middle belt
iii. The rain forest zone in the South.

Due to difference in temperature and rainfall, the agro-ecological zones in Nigeria are grouped in to eight (8) according to FAO AQUASTAT (2005) as shown in Table 1 below;

Table 3.1: Agro-ecological zones in Nigeria
(FAO's AQUASTAT 2005. Accessed 15 April, 2016)

Zone Description	Percentage of Country Area	Annual Rainfall	Monthly Temperature		
			Minimum	Normal	Maximum
	(%)	(mm)	(^{0}C)	(^{0}C)	(^{0}C)
Semi-arid	4	400 - 600	13	32 - 33	40
Dry sub-humid	27	600 - 1000	12	21 - 31	49
Sub-humid	26	1000 - 1300	14	23 - 30	37
Humid	21	1100 - 1400	18	26 - 30	37
Very humid	14	1120 - 2000	21	24 - 28	37
Ultra humid (Flood)	2	> 2000	23	25 - 28	33
Mountainous	4	1400 - 2000	5	14 - 29	32
Plateau	2	1400 - 1500	14	20 -24	36

In some regions of Nigeria, most especially the northern regions, there is an insufficiency in annual precipitation. However, in many other areas, low-rainfall dependability, space, and time distributions are the main problems. The mean annual rainfall of Nigeria as a whole stood at 1,150mm. About 1,000mm and 500mm mean rainfall annually in the Central and the Northeastern country respectively. Mean pan evaporation annually is 2,450mm, 2,620mm and 5,220mm in the southeast, central and north of Nigeria respectively. The total area of cultivation represents 66% of the total land area of Nigeria which was estimated as 61 million ha. There was 33 million ha of cultivated area in 2002, with arable land covering the larger area of 30.2 million ha and 2.8 million ha of permanent crops. The Northern part has the majority of the cropped area which is about two-thirds of it, and one-third distributed equally between South and Middle belt and Central (FAO AQUASTAT, 2005).

3.1.1 Nigeria's economy

Nigeria depends hugely on oil revenues for her economy, which is arises to about 70% of revenues gain by government and 90% of Nigeria's total export. In 2003, GDP for Nigeria was estimated to be US$50.2 billion. In 2002, agricultural sector contributed 37.4% of the GDP in which smallholder sector has the majority of the agricultural output with about 90%. Agricultural sector economically provides 30% occupation to active population, female constitutes 38% of agricultural employees (FAO AQUASTAT, 2005).

3.1.2 Agriculture and food security

Nigeria is among the countries listed that are technically incapable of attaining the food demands through rain-fed crop production at outputs level by FAO. This prediction may likely be sustained at an average inputs level at a given period of time within 2000 to 2025. The system of farming in Nigeria largely smallholder based, also landholdings of agriculture are speed. Inexperience technology of low inputs is adopted, thus, arise to low output in productivity of labor. Average sizes of farms are 0.5 ha in Southern part where there are high rainfall intensity and 4 ha in the Northern part (dry north).

Diversification activities of crop production is possible due to wide agro-ecological zones in Nigeria (FAO AQUASTAT, 2005), which are;

- The Northern Savannah (Dry northern savannah) is convenient for cotton, groundnuts, maize, sorghum and millet. Millet and sorghum are more significant crops.
- In the South and Middle belt, the majority of the crops grown are maize, plantain, sorghum, cassava and yam.
- The South major cash crops include rubber, cocoa and palm oil.
- Seasonally flooded and low-lying areas mainly produce rice.

3.1.3 Water resources

Nigeria has streams and rivers in an enclosed network that is well drained some of which are seasonal especially the ones in the North which are smaller. Generally, Nigeria comprises of four main water basins, which are;

- **The Niger Basin:** has 584,193km^3 area which stood at 63% of the entire area of Nigeria. It passes via a large area of central and Northwestern Nigeria. The most significant rivers in this basin comprise the Niger and minor Kaduna, Benue and Sokoto.

- **The Lake Chad Basin:** it is located in the Northeastern Nigeria with 179,282km^2 area, which stood at 20% of the entire country area. This is Nigeria's only internal drainage basin, high-ranking rivers Komadougou of Yobe and minors Hadejia, Komadougou Gena and Jama'are.
- **The Littoral Southwestern Basins:** Possessed 101,802km^2 area, which stood at 11% of the entire country area. The origin of the rivers is hilly areas west of Niger river to the south.
- **The Littoral Southeastern Basins:** Imo and Cross rivers are the main watercourses of this basin which have 58,493km^2 area, which stood at 6% of the entire country area. Mountain and Plateau areas are the main sources of this basin runoff adjacent to Cameroon border (FAO AQUASTAT, 2005).

Nigeria encompasses comprehensive groundwater resources, situated in the main eight (8) hydrological locations in succession with local shallow Fadama (alluvial) groundwater aquifers close to main rivers (FAO AQUASTAT, 2005);

- The zone of Sokoto Basin: Consist of northwest sedimentary rocks in Nigeria. Have yields between less than 1.0 up to 5.0l/s.
- The Zone of Chad Basin: consist of sedimentary rocks. Three dissimilar aquifers are present in this zone; the lower, middle and upper aquifers. Yields for borehole at middle aquifer are 1.5 up to 2.1l/s and at the unconfined upper aquifer are 1.2 up to 1.6l/s.
- The zone of Middle Niger Basin: consist of sandstone aquifers which yield from 7.5 up to 37.0l/s.
- The Zone of Benue Basin: In Nigeria, this basin is the fewest utilized extend through Cameroon border and linked to Niger-Benue junction. The by sandstone aquifers in the location is from 1.0 up to 8.0l/s.
- The Zone of Southwest: Consists of sedimentary rocks bordered by costal alluvium at the south and Basement Complex at the north.
- The Zone of South Central: comprises centered tertiary sediments and cretaceous in Niger-Delta. Yields range between 3.0 up to 7.0l/s.

- The Zone of Southeast: Consist of cretaceous sediments in Cross river basin and Anambra basin. Due to sufficient resources of surface water, boreholes are few in numbers.
- The Zone of Basement Complex: Involves more than 60% area of the country. Have rocks of low permeability and weathered mantle with fracture zones is where there is ground water occurrence, that have yield from 1.0 up to 2.0l/s.

In the Sahel semi-arid corridor, the significant wetland lying is Lake Chad. Having 3.9m mean depth, it has highly fluctuating surface area, starting in 1907 by 2,000km^2 minimum up to 22,000km^2 maximum in 1961.

In the wet season, flooded areas of low lying also Called Fadama areas are spread within Sahel, Sudan Savanna and Guinea Savanna ecological zones. Those diversified wetlands are essential for agriculture municipal uses and grazing, and are of international value as procreation ground for migration birds, and thus, have biodiversity of global importance (FAO AQUASTAT, 2005).

The annual renewable total water resources of Nigeria were approximated at 286.2km^3. Annual resources produced, internationally stood at 221km^3, which comprises of surface water of 214km^3 and groundwater of 87km^3, while out of the latter's 87km^3, 80km^3 was predicted to be an overlap between groundwater and surface water. 65.2km^3/year of resources by external water are focused due to a surface water source from Benin, Cameroon and Niger. 80% of the utilized resources of surface water are considered natural flow, which contains around 96km^3/year. Annual resources of extractable groundwater are around 59.51km^3, divided into; 10.27km^3 North, 25.48 km^3 Middle belt and 23.76 km^3 South. 45.6km^3 is predicted dam capacity.

Nigeria has been a member of water resources management by two regional water authorities, they are;

- The Niger Basin Authority (NBA): It was founded in 1964. It has nine (9) member countries that are involved in Niger Basin. The countries are; Cameroon, Niger, Chad, Benin, Algeria, Burkina-Faso, Mali, Cote d'Ivore and Guinea. The authority is responsible for ensuring the Basin development harmoniously.
- The Lake Chad Basin Commission (LCBC): Involves representations from Nigeria, Central African Republic, Niger, Cameroon and Chad. It has the aim of making sure the

natural resources development involving water in the region of Lake Chad are impartial and impersonal.

However, Nigeria and Niger signed an agreement in 1990 where by a joint commission was established to oversee and evaluate the development of water resources in particular, in the main sub-basins similar to the countries. Moreover, the agreement implantation was yet to be effective.

3.1.4 Irrigation and drainage

Potential estimates of irrigation in Nigeria differ between 1.5 – 3.2 million ha. A total of almost 2.1 million ha was the recent estimates, out of which surface water has around 1.6 million with groundwater 0.5 million ha. Moreover, with regards to ground water, in Nigeria, 0.5 million ha is enough for water resources extractions.

Table 3.2: Areas good enough for irrigation by the use of surface water, whereas for groundwater is yet to be verified
(FAO's AQUASTAT 2005. Accessed 15 April, 2016)

Zone	Uplands	River valleys	Inland swamps	Delta swamps	Total	
	(ha)	(ha)	(ha)	(ha)	(ha)	(%)
North	343,000	578,500	154,100	-	1,075,600	68
Middle Belt	82,000	28,000	28,000	-	138,000	9
South	180,000	11,000	93,400	78,000	362,400	23
Total (ha)	605,000	617,500	275,500	78	1,576,000	100
%	38	39	18	5	100	

During oil flourishing in the 1970s, a programme for investment was lunched primarily to support public irrigation. Nigeria's circumstances in public irrigation refer to practices by either the states of RBDAs (River Basin Development Authorities) as seen in Fig. 3.2 below. The programme consists of large dam constructions and also pumping stations specifically within the dried areas of northern Nigeria. A total of 162 dams have been constructed by 1990, the entire storage capacity of the dams, if developed, will be capable of irritating 725,000 ha. However, a lot of the dams were erected with small or without infrastructure with chosen sites does not consistently have required close by irrigable areas. The practiced developed were not fully implemented in to production rather, they were actualized with undeserved infrastructure.

Only around 20% of the schedules area of the public irrigation sector was developed. However, 32% only was irrigated out of the area developed.

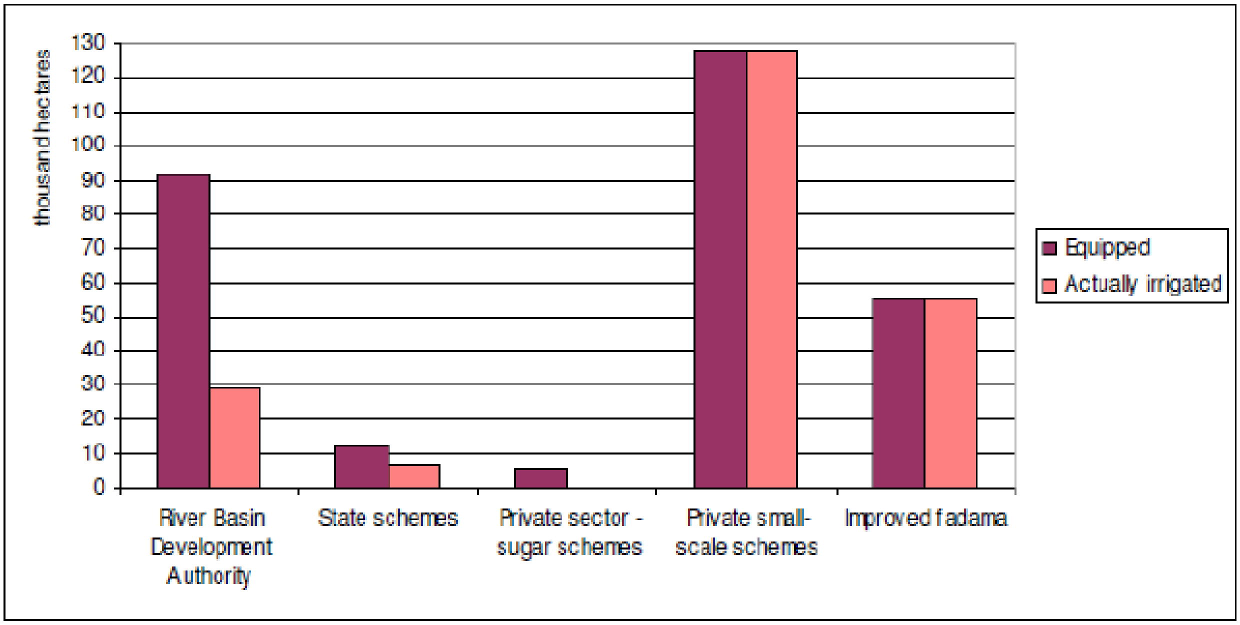

Figure 3.2: Structure of the irrigation sub-sector in Nigeria in 2004

(FAO AQUASTAT, 2005. Accessed 02-02-2016)

As cultivated area of less than 1% was irrigated, the irrigation agriculture contribution is small with respect to the total production of crops. The irrigation effect is felt only by some certain specific individual crops including sugarcane, wheat and sometimes vegetables and rice. In the season of 2003 – 2004, production of irrigated grains provided 0.9% of total production of grain and irrigated production of vegetables provided 2.3% of total production of vegetables. In 1999, maize, wheat, sugarcane, and vegetables were the major irrigated crops in Nigeria (as in Fig. 3.3). Other crops irrigated were potatoes, rice, cashew nuts, citrus, cowpeas, rubber, cotton, palm oil and taro (FAO AQUASTAT, 2005).

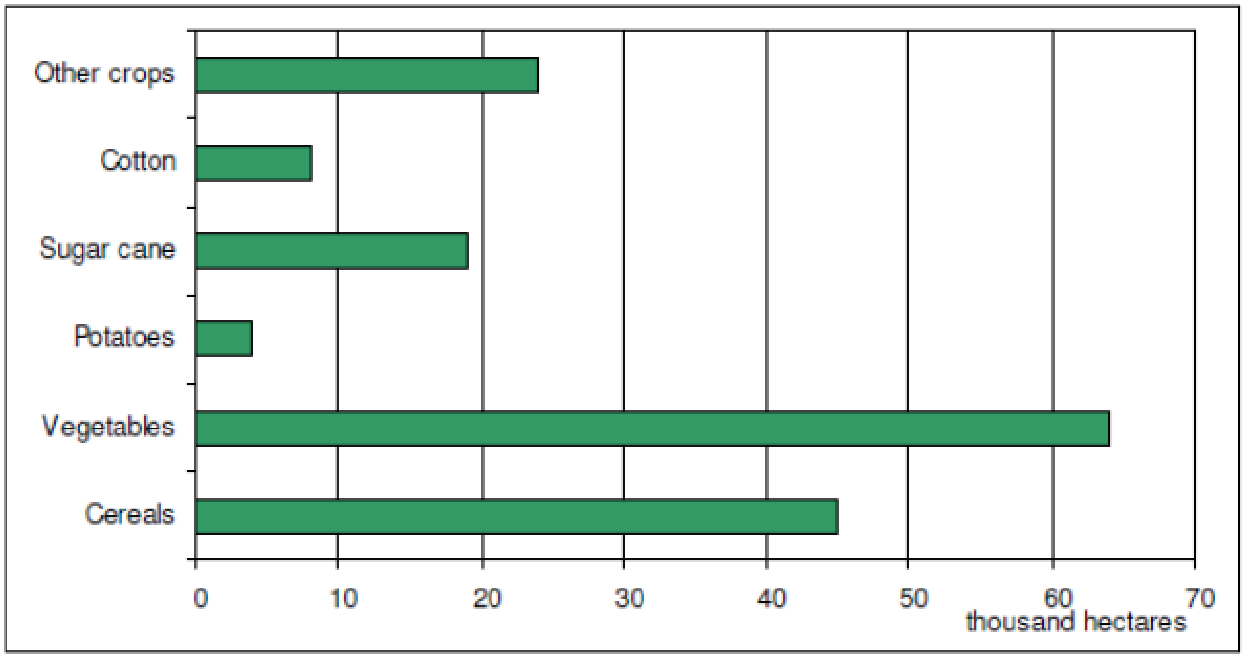

Figure 3.3: Main irrigated crops in equipped schemes in 1999

(FAO AQUASTAT, 2005. Accessed 02-02-2016)

3.2 Study Regions

The semi-arid region covered a huge part of Northern Nigeria and it includes Sahel savanna and Sudan bioclimatic regions. Rain-bearing dominated the climate, the dry, tropical continental North-easterly, and tropical maritime South Westerly air masses (Tarhule and Woo, 1998). Humidity discontinuity called Inter-tropical Discontinuity of a quasi-frontal zone formed by the air masses meeting which travelled over West Africa in reaction to the relative intenseness of the St. Helena and the Azores-Libyan system for tropical pressure (Anyadike, 1993). The rainy season begins at any moment, whenever the Inter-tropical Discontuinity migrates beyond Northward bound while retreatinged at the end Southward. Within June to September, the Inter-tropical discontuinity invade the North and the Northern Nigeria subsequently influenced by tropical maritime.

The aridity zones in Nigeria are categorized in to four (as in Fig.3.4) they are;

- Humid

- Moist sub-humid
- Dry sub-humid and
- Semi-arid

Among the four zones, the semi-arid zone has the highest rate of water scarcity. Therefore, this research was conducted in the semi-arid zone in the northern part of Nigeria.

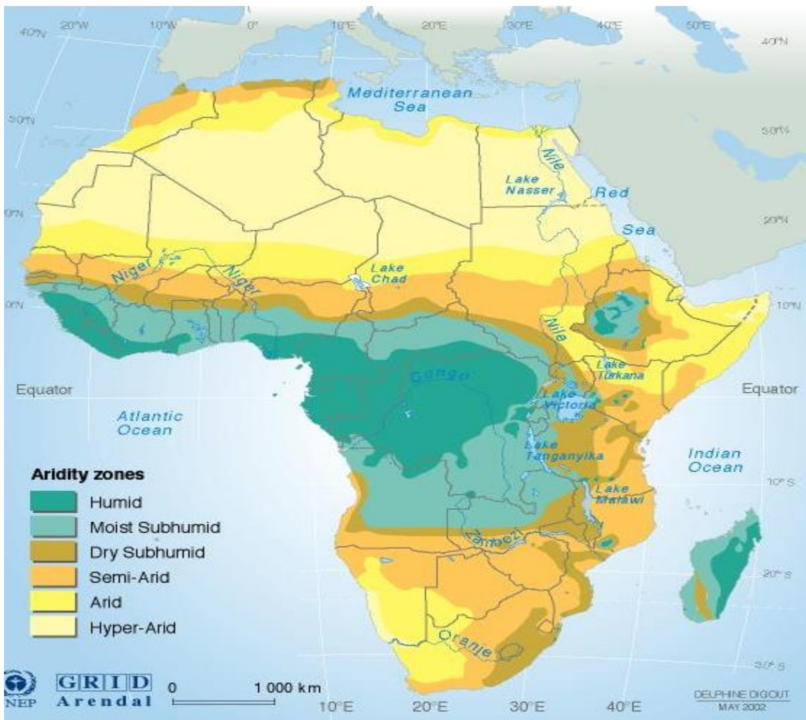

Figure 3.4: Aridity zones in Africa

(World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), climate change 2001. Accessed 23-02-2016)

The semi-arid zone has 7 regions. These are; Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum, and Sokoto.

In each of the regions, 25 crops were selected. The crops are; Banana 1, Banana 2, Barley, Beans dry, Beans green, Cabbage, Citrus, Dates, Groundnut, Maize, Mango, Millet, Pepper, Potato, Pulses, Rice, Sorghum, Soybean, Sugarcane, Sugarbeet, Tobacco, Tomato, Vegetables fresh nes, Spring wheat and Winter wheat. They were grouped into; Cereals, Vegetables, Fruit and Nuts, Oilseed crops and Other crops.

3.3 Background of the Crops Used for the Study

Nigeria is situated in West African region of the tropical zone, it has latitudes between 4^0N to 14^0N and longitudes of $2^0$2'E to $14^0$30'E with an area of 923,770 km^2. The distance from North to South of Nigeria is 1,050 km while the optimum distance from east to west is 1,150 km (FAO AQUASTAT, 2005). Due to diversification of agro-ecological condition in Nigeria, agricultural production to a wide scope is possible. Thus, agriculture serve as one of the highly significant sectors of Nigeria's economy. Agriculture contributes to export earnings of revenue, employment generation and GDP (gross domestic product) in Nigeria.

Despite the huge agricultural resources in Nigeria, however, the rate of agricultural growth is very low. The area of land under cultivation is below 50% of the cultivable land of the country's agriculture. Moreover, majority of the agricultural productions are done by traditional and smallholder farmers whom use local and unsophisticated tools consequently, result in low yield (Manyong et al., 2005).

25 crops are chosen and the related information and results obtained are given in appendices 1, 2, 3, 4, 5, 6 and 7 for each region of the semi-arid zone.

3.4 Cereal Crops

3.4.1 Wheat

The sole most essential source of food for developing world after rice is wheat. The contributions of calories to diets of all the rest of the cereals put together is less than that of wheat. It has a greater content of protein than virtually the rest of the cereals. Within wheat, clarification is possible between bread wheat and durum, likewise between spring wheat and facultative between winters. Wheat production of developing country grounds to 5% by durum wheat, while North Africa – West Asia grown 70% (FAO, 1994).

In 1989, global wheat production stands for 42% of developing countries about 538 million tons and global wheat area of 226 million ha which was 44%. Developing world contributed 70% of the increase in wheat production in the 1980s and 50% in 1970s. Asia provides 71% of wheat production by developing world in 1989 Sub-Saharan Africa 2%, the Caribbean and the Latin

America 10%, and North Africa – West Asia 17%. In the North Africa – West Asia region, in terms of calorie provision wheat is of greatest benefit (FAO, 1994).

Production of wheat in developing countries rises by 5% yearly in the 1970s, but in 1980s by 4.3%. The five (5) biggest wheat producers in the world in ascending order; Argentina, Pakistan, Turkey, India, and China annually raised an average wheat production of 5.4% during the 1970s and during 1980s by 4.3% (FAO, 1994).

3.4.2 Rice

Rice is regarded as an essential crop in the world, with respect to its beneficence to production value and diet. In 1989, out of harvested 147 million ha globally, developing countries produced over 142 million ha, and in which paddy rice of over 460 million tons was produced. The major producer was Asia, which produced 91% of the developing countries production. The Caribbean and Latin America produced 4%, North Africa – West Asia 3%, 2% from Sub-Saharan Africa. About 2.7 billion Asian people consumed calories provided by rice between 60% to 35%, and 1 billion people in the Caribbean, Latin America and Sub-Saharan Africa 8% food energy. Globally, the trade of rice is only 4% in the international market. Many countries depend on domestic rice production in order to meet their countries demands. Some protective measures and subsidies bulkily determine international markets price structure. Consumption per capita of rice in West Africa was multiplied in recent decades, whereas around 25% was increased in Latin America (FAO, 1992).

The stages of rice growth were classified into two, namely; Vegetative stage and reproductive stage. Nursery period: have a duration of roughly of roughly 25 – 30 days from sowing up to transplanting. Vegetative stage: have a duration between 45 and 90 days starting with transplant up to panicle initiation. Mid-season stage: have a duration of roughly 30 days between panicle initiations up to flowering. This latter stage comprises of stem elongation, extension panicle and lastly flowering. The Late season also called ripening stage: have duration roughly 30 days, it is the period of full maturity attainment from flowering. Cumulative leave number (CLN) also was introduced by Counce et al., (2000) to clarify rice growth. Based on the method the growth stage of rice was separated into three phases, namely; the seedling phase, the vegetative phase, and the reproductive phase.

3.4.3 Maize

The 10th largest maize producer in the world is Nigeria and it is the largest maize production county in the whole Africa, with South Africa as second (FAO, 2003). Both white and yellow varieties of maize are grown in the entire country with North Central Nigeria as the largest producing area. Smallholder farmers constitute 70%, with 5 ha average area of cultivated production land representing 90% of the aggregate sum of farm input (Cadoni and angelucci, 2013). Maize is a predominant food crop that impacts positively on socio-economic developments in Sub-Saharan Africa, with Nigeria inclusive having per capital of 40kg/year (FAOSTAT, 1997). Intercropping is usually the main maize cropping pattern in Nigeria, with soybeans, guinea corn, yam, groundnut, cowpea, and cassava.

According to National Bureau of Statistics of Nigeria (2005/2006), the major maize producing state is Kaduna. When the figures are analyzed annually, 31% average maize production in Nigeria is from the north central area. Between 2006 – 2007, 58% in 2008 and 44% in 2009.

On average, Maize is the 5th highest agricultural commodity produced in Nigeria between 2005 and 2010, and by quantity, 3rd highest crop produced between 2009 – 2010, following cassava and also yams. The majority of the maize productions were directed towards domestic markets, as formal export of the maize production is of negligible proportion (FAOSTAT, 2012). Moreover, though detailed quantity may not be ascertained, but neighboring countries were engaged in informal trade.

3.4.4 Millet

In sub-Saharan Africa and Asia, an essential crop is pearl millet in lowland tropic of semi-arid and subtropic summer rainfall areas, with sorghum (mostly sub-Saharan Africa), or Wheat (mostly in Asia) which are together regarded as staple food. Poorest people and poorest countries are among the beneficiaries or consumers of millet. Millet can grow under the condition that is unfavorable or very dry to sorghum, and it has a valuable straw that is used as a livestock feed (FAO, 1992).

As statistics are combined for millet and sorghum in many countries, the data are sometimes over predicted for millet, more specifically sub-Saharan Africa data. It is observed that harvested crop in developing countries is the amount for around 40 million ha, in which around 45% came from India and 32% West Africa. Sahelian zone in Africa uses millet as it main staple cereal. In West Africa semi-arid regions, millets account for around half of everyday calorie intake, and also a protein of about one-third (FAO, 1992).

FAO (2002a) suggest that efforts have to be intensified for millet in order to increase it level over a short period, given greater considerations to sub-Saharan Africa need. The suggestion was in accordance with importance of the crop in meeting the demand of poor people in India and sub-Saharan Africa, based on the reality that people living in the tropics of semi-arid driest areas depend on largely millet for their survival, management practices of crop and continue improvement in varieties development is required (FAO, 1992).

3.4.5 Sorghum

Sorghum donates 1.6% of total world GDP and 5.4% of GDP of the agricultural sector, it is the 6^{th} world highest essential products after maize, rice, fruits, yams and cassava (IFPRI, 2010).

Nigeria is undoubtedly the biggest producer of sorghum in the West Africa, providing around 71% of the aggregate sum of sorghum regional output (Ogbonna, 2011). Sorghum production in Nigeria also represents 35% of its (sorghum) production in the year 2007. After United States alongside India, Nigeria stood as the 3^{rd} largest sorghum producer in the world (FAOSTAT, 2012). Moreover, 90% of India and United States sorghum productions are directed towards animal feed, and thus, Nigeria became the leading world country producer of sorghum for food crop.

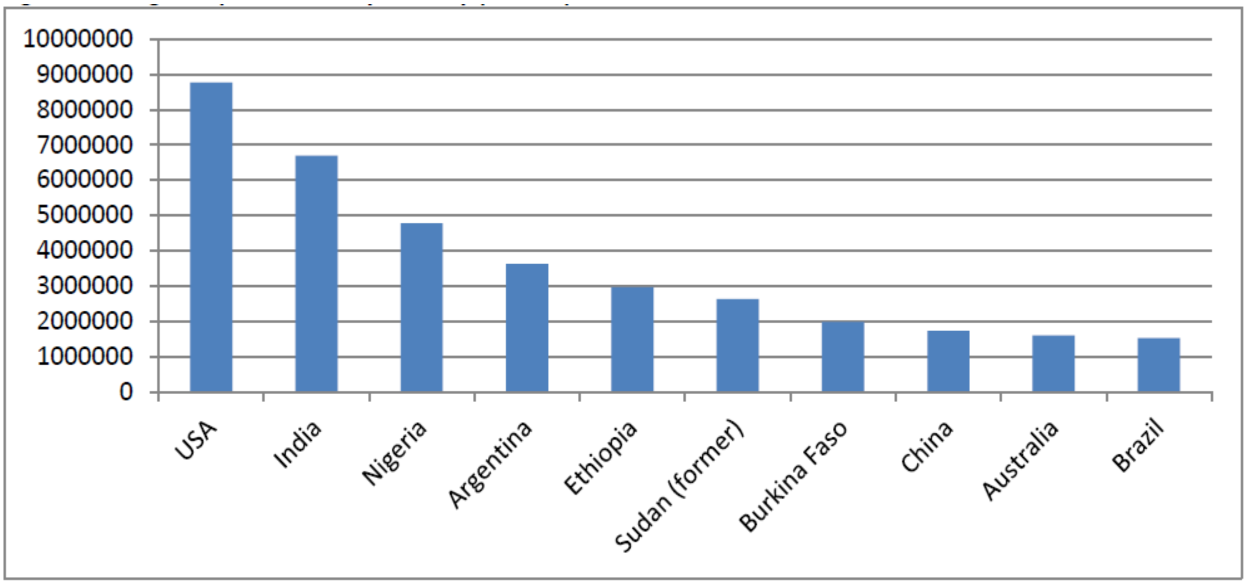

Figure 3.5: Sorghum country's production (tons), 2012

(FAOSTAT, 2012. Accessed 12/03/2016)

Sorghum is the 3rd largest cereal crop in Nigeria with respect to production, behind maize alongside millet (FAOSTAT, 2012). Sorghum accounted for 25% of the entire production of cereal in 2010 where by over 4.5 million tons was harvested (FAOSTAT, 2012). In the almost whole of northern Nigeria, sorghum is considered principal food crop (USAID, 2009).

3.4.6 Barley

Barley is timely maturing and short-season crop, it is one of the most grown family of grains and it can grow under different climatic conditions including sub-tropical and subarctic areas. A moderate climate is the perfect weather for barley (not freezing or over-heating climate). Barley accord to divergent soil varieties for instance, when compared to wheat, barley is less disturbed to dryness and miserable land (FAOSTAT, 2009).

Barley is mostly planted between mid-Septembers till October with regards to winter barley while planted between March till April in the case of spring barley. The crop density ranges between 180 and 200mm/m^2 during planting period, but this, however, is subject to cropping pattern and what crop should be intended for. Meanwhile, different planting time and crops variety determine huge growing season for barley. The development cycle of winter varieties is accomplished by a collective temperature 1900 to 2000^{0}C, however, spring varieties require less with 1500 – 1700^{0}C. Late june to mid-july is the harvesting period for winter barley while spring barley is august (FAOSTAT,2009).

FAOSTAT (2009) stated that global yield averaged barley stand at 2.4tons/ha. Moreover, barley yield was believed to range between 0.8 and 7.5ton/ha based on variety, climate, technology etc.

3.5 Vegetables

3.5.1 Tomatoes

After potato, tomato is the next most important vegetable crop. The current world production of tomato is around 100 million tons from cultivated land of 3.7 million ha (FAO, 2001b).

Tomato crop which is growing rapidly has a period of growing between 90 – 150 days. The crop is all day neutral plant. Maximum daily mean temperature for development is between 18 – 25^{0}C and temperature at night from 10 – 20^{0}C. Having larger temperature between night and day, hence, yield is adversely affected. Tomato is very conscious to frost. Yield reduced when strong wind and high humidity are accompanied by temperature greater than 25^{0}C. Tomato can grow on different varieties of soil, but preferably well-drained bright loamy soil of PH value 5 – 7 (FAO, 2001b).

3.5.2 Cabbage

Cabbage is originated from West and Southern coast of Europe. Cabbage global production annually stood at around 55 million tons from harvested area of 2.6 million ha (FAO, 2001c). For optimum production, cabbage needed humid and cool climate. The growing periods differs between 90 – 200 days, but depending on planting date, variety and climate. For better production, cabbage growing period is in between 120 – 140 days. In general, the most suitable soil for cabbage production is loamy but, preferably, sandy loam soil under heavy rainfall condition due to improved drainage.

3.5.3 Vegetables fresh ness

In developing countries, a lot of vegetables grow, and the varieties differ greatly from one place to another, with high social favoritism controlling the choice of used species. Vegetables are valuable income source to producers close to big urban areas. Being a group, vegetables are suitable for operations in small-scale farming due to cold storage availability, transportation and improved infrastructure. Vegetables are preferred by entire income group as supplementary foods while there is expected demand increase in developing countries by 3.4% per year in the entire 1990s (FAO,2001a).

Out of the prevailing 252 million tons production in developing countries, sub-Saharan Africa provides 4%, the Caribbean, and Latin America 8%, North Africa – West Asia 18% and Asia 70%. There is an increase in the production of vegetables by 3.2% for two decades ago. The four vegetables that have the greatest significance with regards to harvested area in developing regions in ascending order are; cabbage 0.8 million ha, peppers 0.9 million ha, onion 1.3 million ha, and tomato 1.6 million ha (FAO, 2001a).

By including the vegetable initiative in to the system of CGIAR portfolio of the commodity could be complete with respect to nutrition. The main limitations are insect pests and diseases, and more rooms are available for varieties improvement. Among the limitations also are pathetic marketing facilities due to the destruction of several vegetables. Reasonable production increase can result in temporary burden, and several areas required main research for production period extension (FAO, 2001a).

3.5.4 Potato

Potato productions started in South America in the tropical highland areas. It was brought in to Europe in the ending period of 16th century. The potato was initially produced as a temperate climate crop and thereafter, shared all over the world mainly due to European countries expansion through colonialization. Potato varieties with late maturing of temperate zones mostly grew flourishingly in high altitude of tropics (1200m and more) descending to regions of cool seasons at sea level. Potato is now recognized as an essential crop in different climates as well as varieties condoning in high temperature (FAO, 1994).

Potatoes in tropic regions are mostly cultivated around four (4) months thereafter planting and thus, give rise to high yield in comparisons to regions of temperate climates to which the growing season of major crop advanced to six (6) months. Major potatoes crop should be allowed to mature fully before harvesting, it should be around two (2) weeks after dying off of the tops during which the tuber skin would have been set well and less susceptible to damage when harvesting. Early harvested potatoes in the stage of immaturity in antecedent to skin set up, are vulnerable to damage and cannot be stored for longer periods (FAO, 1994).

3.6 Fruit and Nuts

3.6.1 Banana

Global trade of Banana approached a new height in 2013, traced by full supply owing to recovery production in the main area producing banana and higher demand in main markets. Consequently, banana exports exceeded 17 million tons, which was 6.1% more than its exports level in 2012 and marked a third straight year for an increase in banana exports (FAO, 2015a).The driven force for these increase are the Caribbean and Latin America, where by about 829,000 tons grew in 2013, representing 6.6%. Ecuador is the world largest exporter of banana, it was stroked by some hitches in exports as a result of floods in 2012, but bounced back in 2013 by making 5.3 million tons supply of banana in to the global markets. Based on information from sources in Ecuador industry, destructive conditions of weather in many producing nations involving Colombia was the major reasons why companies focus their imports from Ecuador. In 2013, the export by Columbia slumped by 10.5%, which was around 1.6 million tons, this was the fewest amount since 2006 (FAO, 2015b).

The Russian Federation, the United States and the European Union were the largest three importers of banana in the world. All the three increases by imports growth in 2013 with 5.3, 7.6, and 7.0% respectively. As the consumption demand increases, United States grabbed 4.4 million tons while the European Union imports 4.8 million tons (FAO, 2015b).

3.6.2 Mango

Mango is a fruit with greatest economic importance in poison ivy family or cashew. Pistachio and cashew are other family members of great importance. After banana, mango is the 2nd most significant foodstuff for dwellers of tropic regions (FAO, 2002a). About 150 mangoes cultivars are produced across the globe. Mango areas production are divided in to 6 regions, they are;

- Florida (USA), Central America and Mexico.

- Caribbean Islands (West Indies)
- Arabian/Africa Peninsula
- Pacific/Indonesia/Indochina (China)
- South America
- Indian subcontinent

Figure 3.6: Mango producing areas in the world

(FAO, 2002 accessed 21-03-2016)

3.6.3 Citrus

Citrus varieties have perennial growth habit. The major species of citrus cultivated are lime, citrus (Shaddock), citrus (citron), citrus (Seville orange or sour), citrus (lemon), citrus (sweet orange), citrus (Tangerine, mandarin) and citrus (grapefruit). World citrus production of fresh fruit is currently around 98.7 million tons, out of which orange account for 62%, tangerine and mandarin 17%, citron 5%, grapefruit 5%, and lemon and lime 11% (FAO, 2001a). Only banana exceeded the fresh fruit quantity pouring in to international trade. South East Asia is the origin of citrus in the wet tropical areas, but for commercial production of large scale citrus is established through irrigation in the subtropical area. However, for juice and the fresh fruit, citrus is produced for citric acid and oil extraction (FAO, 2001a).

3.6.4 Dates (Date palm)

Dates are exclusive as it comprises of different characteristics and properties, which separated them from the rest of the primary fruits. The consumption of dates can be traced in to three major maturity stages: fresh, crisp and succulent. The ripened date for a full tree is for month self-preserving and may be transported or stored as a gathered food source. Dates is important as desert fruit and as staple food, whereas their utilization in industrial applications and date products has risen. Date palm excel where the rest (Fruit products) marginalized at their best, which may give contributions of special affection to the producer for the date palm with the habitation created by it (FAO, 1994).

3.7 Oilseed Crops

3.7.1 Groundnut

Groundnut, also Peanut, is ordinarily referred to as man's nut. It is currently an essential food crop and oilseed. Groundnut is South America inhabitant and at no time discovered uncultivated. Groundnut is annual plant that is principled or prostrate. It is normally spread in the warm temperate, sub-tropical and tropical zones. The Ethnological studies carried out of the main Indian tribes, document of South America the outspread agrology of groundnut and gave complicated testimony for its adaptation for a long time before the later Spanish conquest. The Spaniard take away the groundnut when returning back to Europe. Groundnut was later spread to Africa and Asia by traders in which currently groundnut grow within 40^0S and 40^0N (Pattee and young, 1982).

In major developing countries, the level of productivity is fewer compared to that of the United State of America, largely as a result of constraints in some productions (FAO, 2002).

Table 3.3: Groundnut (in-shell) area, yield and production in various developing countries in Africa, Asia, and Latin America

(FAOSTAT, database1990-1998. Accessed 06/-3/2016)

Countries	Areas	Yield (t/ha)	Production ('000 t)
Africa			
Nigeria	1,798	1.1	1,917
Sudan	960	0.69	663
Senegal	829	0.83	684
Mozambique	279	0.39	109
Niger	207	0.37	83
Uganda	191	0.73	141
Zimbabwe	181	0.5	95
Mali	174	0.9	155
Tanzania	113	0.62	70
Egypt	38	2.7	107
Asia			
China	3,658	2.6	9,737
India	7,740	0.98	7,609
Indonesia	661	1.7	1,159
Myanmar	393	1	506
Vietnam	239	1.2	302
Thailand	97	1.5	143
Pakistan	98	1	99
Turkey	30	2.4	75
Syria	13	2.2	28
Latin America and Caribbean			
Argentina	214	2.2	464
Brazil	93	1.7	164
Mexico	82	1.3	112
Paraguay	32	1	35

More than half of worldwide harvested groundnut is punched for oil, however, a considerable amount of the produced groundnut by developing countries is being traded in native markets. International groundnut trade is mostly in the likes of the meal (cake), shelled (kernels) and shell (pods). Developed countries such as France, Germany, Japan, Canada, Holland and England provided 65% of demand for groundnut worldwide. Moreover, the main groundnut suppliers are Argentina, China and the United States of America (FAO 2002b).

Table 3.4: Major exporting countries of cake and their values groundnut in-shell, and shelled

(FAOSTAT database 1990 to 1998. Accessed 06/03/2016)

Countries	Groundnut in-shell		Groundnut shelled	
	Export (Mt)	Value (1000 $)	Export (Mt)	Value (1000 $)
China	49,078	30,849	289,213	202,412
India	4,394	2,303	86,494	50,276
Argentina	75	39	16,068	115,541
South Africa	4,378	3,370	25,406	16,722
Netherlands	6,089	5,564	81,335	79,868
Indonesia	1,992	1,874	206	110
Brazil	2,100	1,679	558	440
Sudan	144	73	7,170	3,666
Senegal	120	79	9,823	5,324
Myanmar	55	20	130	132
Nigeria	18	15	1,277	624

Developing countries provide export trade for around 90% groundnut meal. Between 1995 and 1997, India became first in the world as it exports groundnut cake of about 50%, then Sudan, Senegal, the Netherland and Argentina contributed 35% export in the globe. Imports of groundnut cake of over 65% were accounted by Thailand, Indonesia and France. There was a sudden increase in groundnut imports in the 1990s by developing countries, these include; Malaysia, China and Thailand as a result of meal demand by livestock sector which was rising (FAO, 2002b).

3.7.2 Soybean

Soybean was originated domestically in China, but currently cultivated in the entire South-East and East-Asia, the America (specifically Brazil and the USA) with West Asia and sub-Saharan Africa to some limited extent. Soybean cultivation in Northern hemisphere currently from tropics expands to 52^0N (FAO, 1994).

Soybean has content of fat 18% and protein 38%. The primary uses of this crop is for protein products and oil in food industries. After oil extraction, the residue left are used for animal feed, protein products and flour. Even though soybean is a cheap protein source, essential crop in East

Asia for vitamin B and significant food crop, limited success recorded in efforts made in presenting it elsewhere as a food crop. Moreover, its importance increases in several areas in the sub-Saharan Africa. It is indigestible, non-flamboyant flavor, thereby needed a lot of labor in its processing, unlike rest of the legumes preparation (FAO, 1994).

In developing countries, global area of about 40% is harvested. Subtropical and South America account for 49% share of developing countries (Brazil has a huge trade export and 75% of the value), moderate South America 13%, Asia 5%, and China 28%. Almost 5% of South Asia and China protein consumption was provided by soybean. The contribution of the crop to diet by fat is 4-5% in Indonesia, 6-7% in Thailand, India and China and 20% in Brazil. Annually, combine efforts by the Caribbean and Latin America produces soybean that amount to 26 million tons. There was increase area of the regions by around 1.4% a year for the past decade and 2% yield increase, approach 1.8 tons/ha. Among the limiting factors in crop production in the Caribbean and Latin America are photoperiodic, aluminum toxicity, pests and diseases, and acid soils. Variations in yields range between 1.8tons/ha in the sub-Saharan Africa (FAO, 1994).

3.8 Other Crops

3.8.1 Pepper

Pepper origin was thought to be tropical America. The current world pepper production is around 19 million tons from harvested area of 1.5 million ha. Pepper succeed to grow in climate at a temperature between 18 – 27^{0}C during day hours and 15 – 18^{0}C during night hours. There are more flowers and greater branching when the temperature is low at night, but the warm temperature at night result in an increase in light intensity (FAOSTAT, 2011).

Pepper is grown considerably by attaining high yield and under rain-fed conditions, with 600 – 1250mm of rainfall evenly shared across the growing season. Huge rainfall could cause the poor setting of fruit and flower shedding at a period during flowering, as well as a period of ripening of fruits rotting (FAOSTAT, 2011).

Soils that are light-textured with moderate drainage and holding a capacity of water are more favored. Maximum PH value is between 5.5 – 7.0 linings for acid soil need. Flooding for even smaller periods results in leaf shedding. Requirements for fertilizer are 550 – 100 kg/ha K, 25 – 50kg/ha P and 100 – 170kg/ha N (FAOSTAT, 2011).

3.8.2 Sugarcane

Sugarcane currently have an area of around 13 million ha and the world commercial production of sugarcane of around 1254.8 million ton/year with sucrose 55 million ton/year (FAOSTAT, 2001).

Asia and may be New Guinea are the origin of sugarcane. Majority of commercial irrigated and rain-fed sugarcane grow in equator of 35^0N and S. Sugarcane succeeded in a growing season that is warm, and long with great radiation incidence and enough moisture, in a fairy cool, sunny and dry harvesting period with frost-free ripening (FAOSTAT, 2001).

Maximum temperature for germination (sprouting) cuttings of stem is between 32 and 38^0C. Successful growth minimum temperature is nearly 20^0C. However, for ripening, lower temperatures between 20 and 10^0C are relatively desired, as this has observable influence on the sugarcane sucrose enrichment and growth rate of vegetation reduction (FAOSTAT, 2001).

3.8.3 Sugarbeet

Sugarbeet provides around 16% of sugar production in the world. Currently, production of beets in the world is around 234 million tons from 5.9 million ha of harvested area (FAOSTAT, 2001). Asia is the origin of sugarbeet. A biennial crop with harvesting period during the first year. Sugarbeet grow under rainfall as well as in the tropical areas under irrigation which is perceived to tolerate alkali soils and high saline.

Sugarbeet required moderately long period to grow, usually between 140 – 160 and up to 200 days. Leaves formed huge sugar amounts. The higher part is utilized during the period of vegetation for growth processes, whereas when growth of vegetation slow down huge part is for late period hoard inside the root of growth. Furthermore, sugar concentration and sugar size determined sugar yield. With sudden development of the hoarding root concentration of sugar attain a constant value that is basically climate determinant, level of soil nitrogen and water supply and at a given point influence by plant spacing and variety. Usually the root contain higher than 15% sugar of the weight of fresh root. Crop harvesting is close to the end of first growth period of the season, when optimum sugar amount is possessed by the root (FAOSTAT, 2001).

3.8.4 Beans

Beans is the world's most significant food crop for straight consumption. Within the main crops, it possessed one among the different level of growth habit, color, shape, size of seed (seed characteristics), adaptation and maturity. Beans also possessed immense variability (greater than 40,000 varieties). Beans of Germplasm collection correlate with the rest of the essential commodities worldwide (Gumaraes et al., 2009).

Beans are produced in crop system series and regions of the environment as distinct from Africa, Europe, China, United States, Canada and Latin America. The major producer and consumer of the bean is Latin America, whereby bean serves as essential traditional food, particularly in Andean zone, the Caribbean, Central America, Brazil and Mexico. Beans are produced in Africa mostly for livelihood (subsistence), in which the highest world consumption per capita is Great Lake regions. Beans serve as the main dietary protein source in Uganda, Zambia, Kenya, Malawi and Tanzania. Dry beans are mostly less beneficial compared to the rest legumes in Asia, but China is increasing in export (Gumaraes et al., 2009).

3.8.5 Tobacco

People used tobacco for centuries, however, smoking of cigarette and manufacture of cigarette in bulk scale was only introduced in 19^{th} century. Cigarette smoking was since diffused worldwide, one for each three adults which is around 1.1 billion people to 1.2 billion globally smoked in the year 2000. It is assumed that cigarette smoking is the rationale behind the deaths of four million people each year worldwide (WHO, 1994). A number of people smoking are predicted to rise by 1.6 billion by the year 2025 due to adult population growth and rise in the consumption of tobacco (Montiel and World Bank, 1999).

Tobacco consumption and products of tobacco by smoking specifically is regarded to compel to the society the net-social-cost. Tobacco use and smoking are persistently regarded to reach a level of an epidemic. Based on numerous studies conducted, for 25years to come death related to tobacco will suddenly increase unless the present smokers of tobacco stop making (Montiel and World Bank, 1999).

As every product, tobacco products and tobacco are legitimately produced, consumed and traded and also the rules laid down for their trade and production are same as every product. Hence, even though a lot of countries take strict measures in curling down tobacco use and smoking, as measures to curtail the social costs that are tobacco related, dissimilar countries economies rely hugely on manufacturing and growing tobacco and tobacco-related products for income and employment (FAO, 2003).

3.8.6 Pulses

Pulses are leguminous plants of eatable dry seeds. They have unique economic and nutritional significance owing to the diets contributions worldwide to millions of people. The major pulses advantages lie mainly to their protein content which is high (twice or thrice greater than many bowls of cereal) and are also valuable energy sources. Moreover, iron and calcium are minerals of nutritional importance and a significant amount of them are contain in pulses. Developing countries lead in pulses use as food, providing around 90% of human consumption of pulses globally. In many countries of low income, the pulses contributions to daily protein are about 10% and around 5% of diet energy intakes of people (FAO/WHO, 2001).

The World pulses production indicated an ascending trend in the contemporary years with Asia and North America as leading forces for the majority of the increase. However, in 2000, there was almost 2 million tons drought in the pulses production from the earlier year to about 55 million tons, with India, France and Australia as the main victims of the decrement. In 2001, global production was predicted to account for the earlier year and meet 58 million tons. Pulses utilization globally was also expected to rise and by 2011, was expected to attain 57 million tons. Pulses trade was expected to expand in 2001 worldwide, geared by the Indian subcontinent, Central America, North Africa, and the Middle East higher demand (FAO/WHO, 2001).

Table 3.5: Crop productions, Imports and Exports percentage for semi-arid regions of Nigeria in 2013

Crop Category	Crop Type	Production (%)	Import (%)	Export (%)
Grains	Wheat	0	55	0
	Winter wheat	0	0	0
	Rice	11	27	1
	Maize	20	0	28
	Millet	2	0	7
	Sorghum	13	0	15
	Barley	0	0	0
Vegetables	Tomato	4	0	0
	Cabbage	0	0	0
	Vegetables fresh nes	15	0	0
Fruit and Nuts	Banana 1	0	0	0
	Banana 2	0	0	0
	Mango	2	0	0
	Citrus	9	0	0
	Dates (Date palm)	0	0	0
Oilseed Crops	Groundnut	6	0	5
	Soybeans	1	0	33
Other crops	Pepper	0	0	0
	Sugarcane	3	17	0
	Sugarbeet	0	0	0
	Potato	3	0	8
	Beans Dry	0	0	0
	Beans Green	0	0	0
	Tobacco Unmanufactured	0	0	0
	Pulses	11	0	2

3.9 The Colors of Water

Virtual water is classified in to three types, namely; the green water, the blue water and the Grey water respectively. It is, therefore, important to differentiate them as they also differ in their characteristics (Hoekstra, 2007).

3.9.1 The green water: The green water as virtual water content is defined as the volume of rain-fed water which evaporated in the process of production (Chapagain and Hoekstra, 2008).

This specifically concerned products from agriculture, whereby referred to the aggregate sum of rained water hoard inside soil as soil water and disappeared by evaporation from the portion at the time of crop development.

3.9.2 The blue water: The blue water as virtual water content is defined by Hoekstra and Chapagain (2008) as the surface water volume that disappeared through evaporation owing to its production. With regards to crop production, the content of blue water is established as the evaporation of soaked water from soil and water supplied evaporation from the soaked watercourse and unnatural hoarding reservoirs (Garrido et-al., 2010). In the domestic supply of water and industrial production, the content of blue water product and or services is equivalent to the portion of the withdrawn water from the ground or evaporated surface water and hence irreversible to the former system. Water that evaporated is regarded as unobtainable for other purpose use, although it may, however, return as rainfall water (mostly of several kilometers away). Rainfall is also received by numerous irrigated crops, in order for the mixture of artificial and natural sources mostly satisfied the overall water demand. Moreover, due to significant variation in weather conditions, the quantity demanded blue water irrigation also varies. An Andalusia evaluation which was technically carried out (of irrigated land which was about 900,000 ha) showed that the blue water evapotranspiration demand of crop varies between 3.4 and 5 billion m^3, owing to the condition of the weather at growing season period.

The difference between blue and green water was initiated by Falkemark (1995). Both blue and green water differs in basis in their areas of applications as well as opportunity cost (Chapagain and Orr, 2009). It is impossible for green water to automatically re-positioned to uses in any form apart from natural vegetation and optional rain-fed crops, whereby unlike green water, blue water is usable for soaked (irrigation) crops likewise for the rest of industries, agriculture and urban water uses (Fraiture et-al., 2004; Hoekstra 2007). However, green water used in the production of crops is regarded as better withstanding than the blue water (Yang et-al., 2006). Despite being not necessarily the issue, if the sources of blue water are utilized lower than their yield withstanding ability. In the world regions of sub-humid and semi-arid, the food production obstacle is water, owing to utmost rainfall fluctuations, recurrent deficiency, dry seasons are long, dry spells and floods. The main face off is to limit the water-related dangers caused by extreme variability of rainfall other than enduring the complete insufficiency of water (CAWMA, 2007). Altogether there is adequate rainfall to double as well as sometimes quadruple the yields of the crop in rainfall system of farming, even in regions of water limitations (CAWMA, 2007), but usually, it is accessible at the unscheduled time, resulting in dry spells with a lot of this achievement wasted. The concentration of rainfall management for 50 years back in the field of farmers via conservation of water and soil by itself cannot limit the danger caused by the usual dry spell. In the management of water resources, there is a need for investments in the smallhold farming system of rainfall which utilizes rainfall in composition with extra irrigation (CAWMA, 2007).

Within the component of blue water, it is however extremely significant to differentiate between the systems of groundwater and surface water. Groundwater perform an important role different with surface water. In view with currently available data, irrigated agriculture for groundwater gave greater productivity if compared to irrigation by surface water (Hernandez-Mora et al., 2001). This greater productivity is due to farmers' ability to control supply and used water guarantee and also groundwater security provided in contrast to dry spells. With the two circumstances, farmers are given room for investments, without being afraid of possible dry periods, and in better techniques of irrigation as well as more cost cash crops equipment. Farmers that utilizes groundwater, generally, bear all operating, financial costs and maintenance. Mostly, the users of groundwater pay more price per water volume than surface water irrigations, because surface water is mostly densely subsidised (Hernandez-Mora et al., 2001).

3.9.3 The grey water: The grey water is defined as the volume of water needed to mix the quantity of toxic waste (pollutants) ejected into the pure water scheme to a point that the perfection or pureness of the surrounding area of the water kept beyond the quality standard of water agreed (Chapagain and Hoekstra, 2008).

CHAPTER 4

METHODOLOGY

The research was conducted in accordance with the following procedure;

4.1 Virtual Water Content (VWC) Calculations

Crop evapotranspiration ETc (mm day^{-1}) was used to calculate the crop water requirements (m^3 ha^{-1}). Reference crop evapotranspiration ETo was multiplied by crop coefficient Kc, in order to obtain crop evapotranspiration ETc (as in Fig. 4.1). Thus,

$$ETc = Kc \ x \ ETo \tag{1}$$

Where ETo called reference crop evapotranspiration (mm/day) and Kc is crop coefficient.

Penman Monteith equation was used for ETo calculations (Allen et al., 1998b).

$$ETo = \frac{0.408 \, \Delta(Rn - G) + \gamma \frac{900}{T+273} \mathcal{U}2 \, (\mathrm{e}s - \mathrm{e}a)}{\Delta + \gamma \, (1 + 0.34\mathcal{U}2)}, \tag{2}$$

Where by

ETo = Reference evapotranspiration [mm day-1],

Rn = net radiation at the crop surface [MJ m-2 day-1],

G = soil heat flux density [MJ m-2 day-1],

T = mean daily air temperature at 2 m height [°C],

$\mathcal{U}_2$ = wind speed at 2 m height [m s-1],

$\mathrm{e}s$ = saturation vapour pressure [kPa],

$\mathrm{e}a$ = actual vapour pressure [kPa],

$\mathrm{e}s - \mathrm{e}a$ = saturation vapour pressure deficit [kPa],

γ = slope vapour pressure curve [kPa °C-1],

Δ = psychrometric constant [kPa °C-1].

CROPWAT 8.0 (2005) software developed by Food and Agricultural Organization of the United Nations (FAO, 2015a) was used for the calculations of crop evapotranspiration and reference evapotranspiration.

The Virtual Water Content was then calculated using,

$$VWC[n,c] = \frac{CWR[n,c]}{CY[n,c]} \tag{3}$$

VWC represent virtual water content in (m^3 ton^{-1}) in Nigeria n, and for crop type c grown. CWR represent crop water requirements in (m^3 ha^{-1}). CY represent crop yield in (ton ha^{-1}).

4.2 Virtual Water Trade (VWT) Calculations

The virtual water trade calculations were done by multiplying the Virtual Water Content of each crop by their corresponding crop trade. Thus;

Virtual Water Trade Import was calculated using;

$$VWI\ [ni, c, t] = CT\ [ni, c, t]\ x\ VWC\ [n, c, \mathrm{t}] \tag{4}$$

Virtual Water Trade Export was calculated using;

$$VWE\ [n\mathrm{e}, c, t] = CT\ [n\mathrm{e}, c, t]\ x\ VWC\ [n, c, \mathrm{t}] \tag{5}$$

Where

VWI represents virtual water import in (m^3 y^{-1})

VWE represents virtual water export (m^3 yr^{-1})

VWC signifies virtual water content in (m^3 ton^{-1})

CT implies crop trade (ton y^{-1})

ne, ni, t implies, Nigeria export, Nigeria import, at time t (2013) respectively.

4.3 Water Balance (WB) Calculations

The water balance is defined as the difference between the total volume of virtual water import and the total volume of virtual water export of Nigeria in 2013. When the value obtained is positive then it referred to as net virtual water import, indicating that there are more imports than exports. When the water balance value is negative then it is regarded as net virtual water export, implying that a country is a large exporter of virtual water.

The Water Balance was calculated using;

$$NVWI = GVWI - GVWE \tag{6}$$

$NVWI$ represent Net Virtual Water Import ($m^3\ yr^{-1}$).

GVWI and GVWE represent Gross Virtual Water Import and Export respectively.

$$GVWI\ [ni, c, t]\ =\ \sum VWT\ [ni, c, t], \tag{7}$$

$$GVWE\ [ne, c, t]\ =\ \sum VWT\ [ne, c, t] \tag{8}$$

$\sum VWT$ represents summation of Virtual Water Trade for both import and export.

4.4 Virtual Water Demand (VWD) Calculations

The virtual water demand (also virtual water produce) of crops is the total volume of crops virtual water (including export volume) produced in Nigeria for the given year.

The Virtual Water Demand was calculated using;

$$VWD\ [c, t] =\ QP\ [c, t]\ x\ VWC\ [c, t] \tag{9}$$

Where

VWD = Virtual Water Demand ($m^3\ yr^{-1}$), QP = Quantity produced ($ton\ yr^{-1}$), VWC = Virtual water content ($m^3\ ton^{-1}$).

4.5 Green, Blue and Grey Water Calculations

The Green and Blue virtual water for CROPWAT were computed on the basis of Aldaya et al., (2012) using irrigation schedule option, while Grey water was obtained by subtracting blue and green water from virtual water produced.

4.6 Water Footprint (WP) Calculations

The water footprint is a water use indicator that focused on the producer or consumer water used both directly and indirectly. The water footprint of a community or an individual is expressed as the total volume of water utilized in the production of goods and services that community or an individual consumed.

The water footprint of the crops selected of the semi-arid regions of Nigeria was calculated using,

$$WP = VWD + NVWI \tag{10.1}$$

Or

$$WP = VWD - GVWE + GVWI \tag{10.2}$$

Where,

WP represents water footprint (m^3 yr^{-1}), VWD represents virtual water demand (m^3 yr^{-1}), $NVWI$ represents Net Virtual Water Import (m^3 yr^{-1}).

4.7 Generated Data

4.7.1 Climate data

CLIMWAT 2.0 for CROPWAT is a database software developed by FAO to provide a climate data that can be used as an input to cropwat (FAO, 2015b). It provided data on temperatures, relative humidity, solar radiation, sunshine hours and wind speed. The software is available and can be downloaded from FAO's website. There are data for over 100 countries in the CLIMWAT database, and the data for Nigeria (as a case study) is inclusive.

4.7.2 Crop parameters

The crop parameters for which includes crop coefficient in the initial stage, middle stage, and late stage, and also root depth were adopted from crop water information of FAO database, planting date from FAO crop calendar. Crop yield data was taken from FAOSTAT database and is accessible via FAO's website (FAOSTAT, 2015b). The regional cultivated lands owing to the lack of the data is obtained by generating an equation considering the population distributions in the country.

4.8 Calculations Procedure

The step by step procedure of the virtual water trade calculated in the semi-arid regions of Nigeria were summarized in Figure 4.1 below

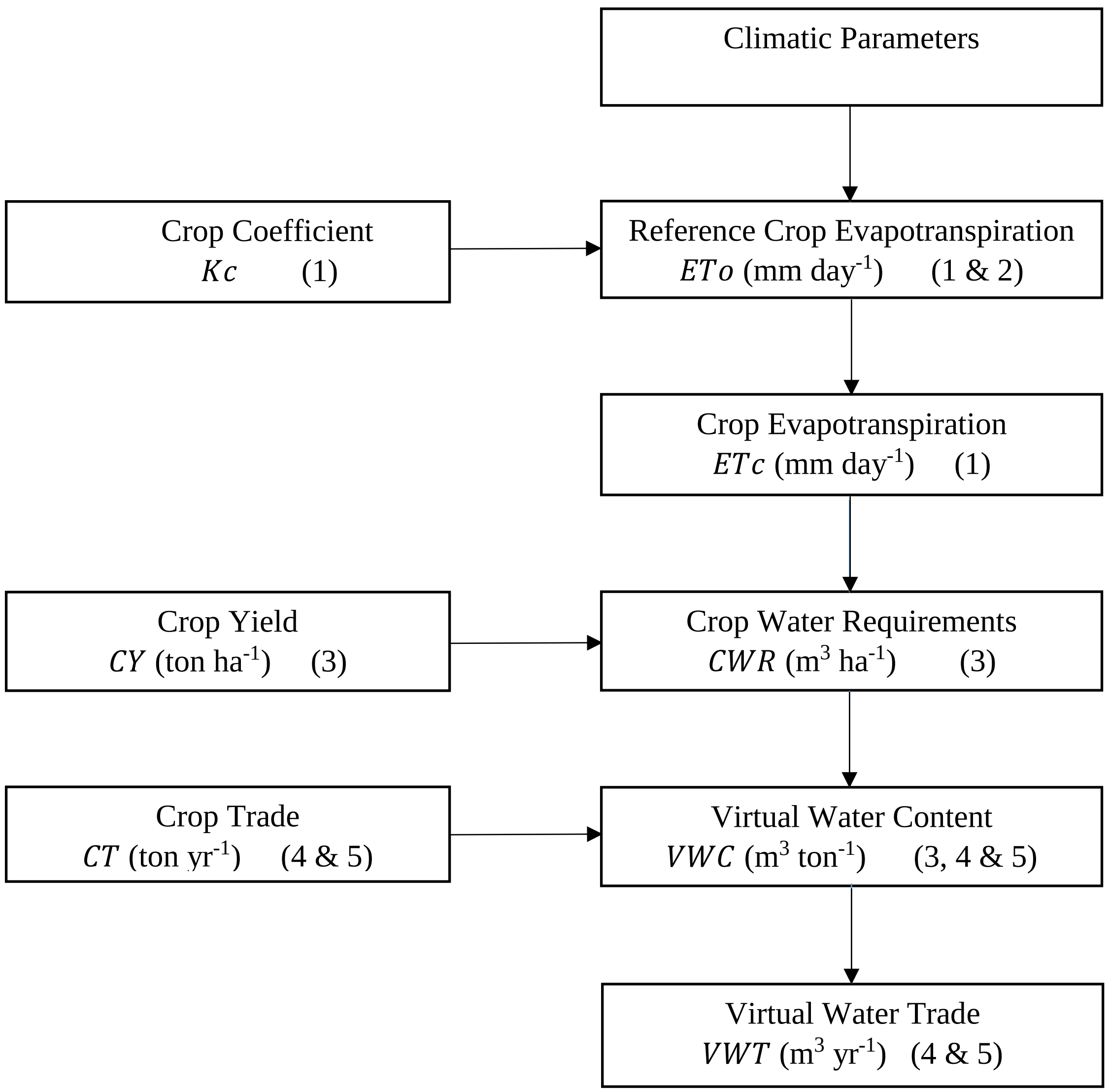

Figure 4.1: Flow chart showing the overall procedure for virtual water trade calculation

CHAPTER 5

RESULTS AND DISCUSSION

Owing to the methodology and procedure explained, the results were obtained and presented. According to the results obtained in table 5.1, crops grew in Kano have the highest virtual water content with 1.19 x 10^{-4}Gm3/ton, consequently, consumed/required more water than any production area of the semi-arid regions. The next in terms of water consumption by crops is Maiduguri, then followed by Sokoto, Potiskum, Gusau, Katsina, and lastly Nguru which has 8.6 x 10^{-5} Gm^3/ton.

The volume of Virtual water import in the semi-arid regions of Nigeria in 2013 was far larger than that of virtual water export with 2.9 x 10^{-1} Gm^3/yr import and 9.2 x 10^{-4} Gm^3/yr export, from Nguru which was the least region in terms of virtual water. Being the highest crop virtual water content region, Kano also had the largest volume of virtual water for both imports and exports with 3.1 Gm^3/yr and 9.3 x 10^{-3} Gm^3/yr, respectively (as in Table 5.1).

Even though Maiduguri was the second highest virtual water content region, but it was the third with regards to crops' virtual water volume for both imports with 1.4 Gm^3/yr and exports with 4.4 x 10^{-3} Gm^3/yr (Table 5.1). The average volume of gross virtual water imports between the seven regions can be calculated from table 5.1 as approximately 1.2 Gm^3/yr for 2013 while for export as 3.9 x 10^{-3} Gm^3/yr

Table 5.1: Gross virtual water content, import, and export for semi-arid regions of Nigeria.

Regions Name	GVWC (m^3/ton)	GVWI (m^3/yr)	GVWE (m^3/yr)
Gusau	96,386	674,513,830	2,724,064
Kano	118,802	3,077,852,660	9,345,039
Katsina	95,103	1,601,205,587	5,473,175
Maiduguri	118,085	1,443,105,299	4,400,463
Nguru	86,151	291,952,092	919,609
Potiskum	97,831	363,139,277	1,078,763
Sokoto	110,620	1,158,870,692	3,513,415
Total	722,978	8,610,639,437	27,454,527

Based on the result obtained and shown in Figure 5.1, the volume of virtual water produced was incomparably larger than both volumes of imports and exports in each region by providing more than two-third of the total virtual water volume of production, imports, and exports.

The result further clarified that there was an increase in virtual water imports and decrease in virtual water exports in the whole Nigeria when this research is compared to the study by Zimmer and Renault (2003). Their study revealed that the gross virtual water import of Nigeria in 1999 was 8 Gm^3/yr whereas the total gross virtual water import for semi-arid regions by this research was 8.6 Gm^3/yr (Table 5.1). Moreover, the gross virtual water export was 3 x 10^{-1} Gm^3/yr for the entire country against the value by this research which was 2.7 x 10^{-2} Gm^3/yr (Table 5.1). These huge differences could be due to a population increase of Nigeria between 1999 and 2013, varied study location(s), different types and quantities of crops used or all of the three. This significantly indicated that as the population of Nigeria increases, foreign food dependence by Nigeria rise and the food exports become short. This assertion could be backed by the research conducted by Hoekstra and Hung (2002) which revealed that between 1995 – 1999, the gross virtual water import of Nigeria was 5.8 Gm^3/yr and the gross virtual water export of Nigeria was 9.3 x 10^{-1} Gm^3/yr which was short of research by Zimmer and Renault (2003) with regards to import and in excess amount in export perspectives.

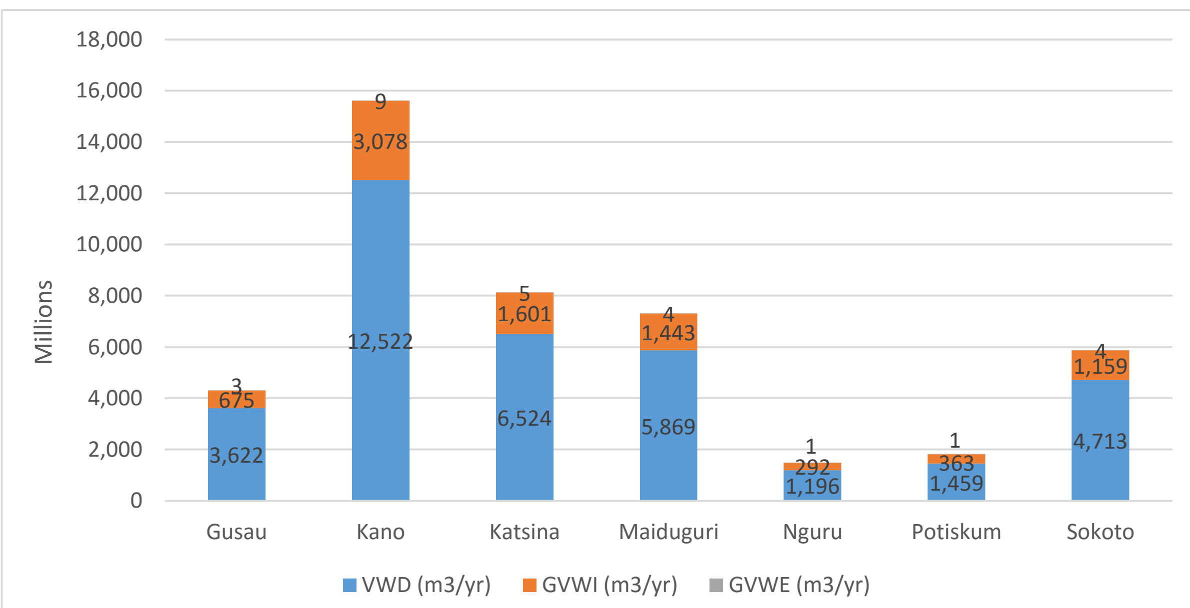

Figure 5.1: Variations in production, Imports, and Exports of virtual water

Kano was by far the largest Green water region between the semi-arid regions with 3.6 Gm^3/yr (Table 5.2). Gusau came second with regards to Green water availability with a difference of over 2 Gm^3 of water when compared to Kano. The third was Katsina, then Maiduguri, Sokoto, Potiskum, and the highest Green water scarce region was Nguru with 2.5 x 10^{-1} Gm^3/yr (As seen in Table 5.2 and Figure 5.2).

The region which consumed the largest Bluewater was Kano which happens to be the biggest consumer of crops virtual water with approximately 9 Gm^3/yr. The next in Bluewater consumption was Katsina, followed by Maiduguri, Sokoto, Gusau, Potiskum and Nguru the lowest Green water region had the lowest Bluewater demand with 9.4 x 10^{-1} Gm^3/yr (As seen in Table 5.2 and Figure 5.2).

Table 5.2: Summary of Green, Blue, and Grey water of each region of semi-arid zone

Regions Name	GVWD (Gm^3/yr)	BVWD (Gm^3/yr)	G_RVWD(Gm^3/yr)
Gusau	1.5	2.1	1.6 x 10^{-4}
Kano	3.6	9	6.1 x 10^{-4}
Katsina	1.2	5.3	4.2 x 10^{-5}
Maiduguri	1.2	4.7	1.1 x 10^{-4}
Nguru	0.25	0.94	9.7 x 10^{-6}
Potiskum	0.46	1	9.9 x 10^{-6}
Sokoto	1.2	3.5	2.2 x 10^{-4}
Total	9.4	26.5	1.2 x 10^{-3}

Grey water was less significance in crop productions. Only a few crops mostly with year-long development span utilized little Grey water such as Mango, Sugarcane etc. As a result, less than 0.01% of Greywater was used for the entire produced selected crops. Kano region has the highest virtual water volume of Greywater with 6.1 x 10^{-4} Gm^3/yr, followed by Sokoto, Gusau, Maiduguri, Katsina, Potiskum, and the fewest Nguru with 9.7 x 10^{-6} Gm^3/yr (as shown in Table 5.2).

Considering the number of years passed, the population increase, and the regions selected, the result obtained in this research is similar to the result unveiled by Mekonnen and Hoekstra (2011) for crop productions water footprint between 1996 – 2005. The total virtual water produced was found to be 192 Gm^3/yr compared to the result of this research which was approximately 36 Gm^3/yr (as seen in Table 5.3 and can be calculated from Figure 5.1).

Based on the Mekonnen and Hoekstra (2011) study, green water contributed 190.6 Gm^3/yr, blue water 1.087 Gm^3/yr, and grey water 6.1×10^{-1} Gm^3/yr against this researche's 9.4 Gm^3/yr, 26.5 Gm^3/yr, and 1.2×10^{-3} Gm^3/yr, respectively (Table 5.2). This implies that the majority of crops produced in Nigeria grows in other regions that are green water-abundance rather than water scarce regions of the semi-arid zone, as over 99% of the crops produced was green water. Having said that, owing to the two results obtained, it can be observed that the utilization of grey water is significantly lower in semi – arid regions than the other regions based on the study result by Mekonnen and Hoekstra (2011).

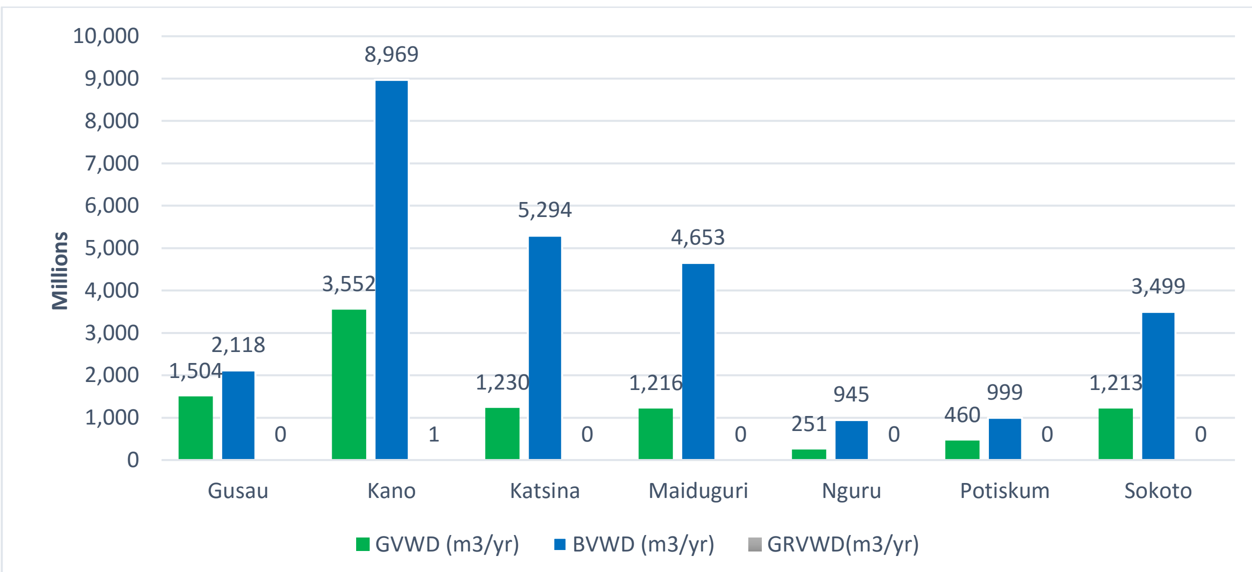

Figure 5.2: Chart showing the contributions of Green, Blue and Grey water of semi-arid regions of Nigeria in the year 2013

Considering the result obtained, Bluewater had the highest virtual water contributions to crop productions in the semi-arid regions of Nigeria in 2013 (Figure 5.3). The overall Blue and Green water contributions for all the regions were 74% and 26%, respectively (Figure 5.3), while the Blue water contributions for each region were Gusau 58%, Kano 72%, Katsina 81%, Maiduguri 79%, Nguru 79%, Potiskum 68% and Sokoto 74%. However, Green water contributions were

42%, 28%, 19%, 21%, 21%, 32% and 26%, respectively. Grey water remained 0% throughout the regions (as seen in Figure 5.3).

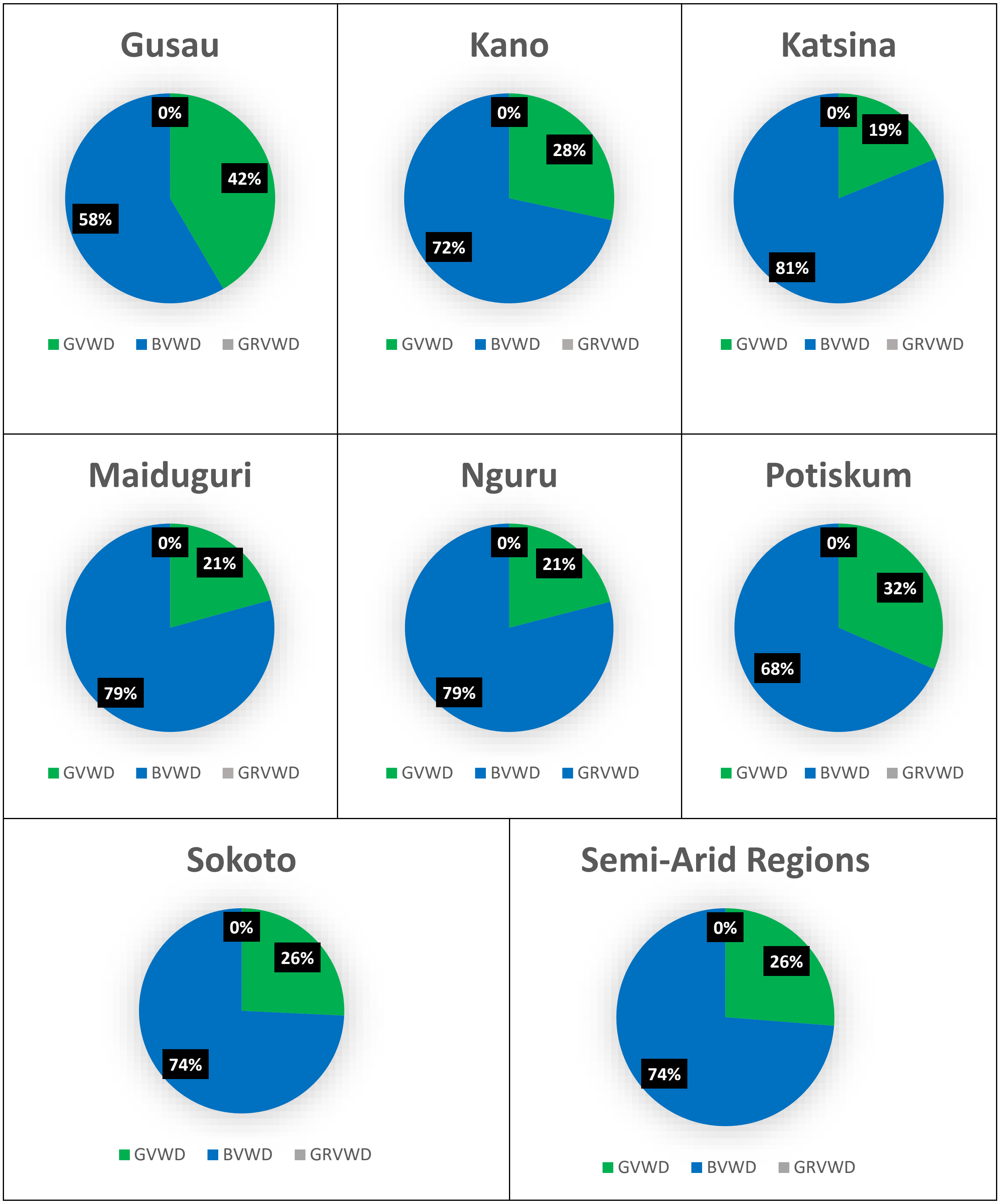

Figure 5.3: Zonal and regional percentage contributions of Green, Blue, and Grey water.

The water balance for all the regions were positives (NVWI), implying that there were more imports than exports (Table 5.3). It can be calculated from Table 5.3 that the total volume of virtual water demand (virtual water produced) in the semi-arid regions to be 81% of total water used (water footprint) while the water balance to be 19%. The region with a maximum volume of virtual water used was Kano with 15.6 Gm^3/yr and the minimum was Nguru with 1.5 Gm^3/yr (Table 5.3).

By inspection of the data, the water footprint of the whole Nigeria increased when compared with a result by Mekonnen and Hoekstra (2011) between 1996 and 2005. According to their study, Nigeria was the seventh largest crop production water footprint country in the world with 192Gm^3/yr while for this research it was 35.9 Gm^3/yr for crop productions and 44.5 Gm^3/yr for water footprint in the semi-arid regions (Table 5.3), signifying that when the other aridity zones are considered, the result may surpass the said result.

However, comparing the result with that by Hoekstra and Hung (2002) which was conducted between the period 1995 – 1999, it was revealed that the net virtual water import (water balance) of Nigeria was between 10 – 50Gm^3/yr, the result of this research was not within the given range because one-fourth of the Nigerian aridity zones was selected which was 8.6 Gm^3/yr (Table 5.3).

Comparison was made between the result of this research and that of Zimmer and Renault (2003), which revealed that the net virtual water import of Nigeria in 1999 was 7 Gm^3/yr which was slightly fewer than that of this research of 8.6 Gm^3/yr (Table 5.3), and this could be attributed to population increase after 14 years of the former research.

Owing to the concentration of this research to semi-arid regions (and possibly a different number of crops used), the result of this study gave varied outcome to that by Hoekstra and Hung (2002) between 1995– 1999. Their result ranked Nigeria as the 24th out of 30 top world virtual water import countries with net virtual water import of 24 Gm^3/yr, whereas 8.6 Gm^3/yr was obtained in this study (Table 5.3).

By vividly looking at table 5.3, it can be distinguished that production value is higher than import cost which in turn greater than export income. As may be predicted owing to its superior production quantity, Kano region had the highest production value which stood at $842 million.

Katsina reclaimed the next position with \$511.9 million, Maiduguri \$375.5 million, Sokoto \$326.7 million, Gusau \$292.2 million, Potiskum \$109.9 million, and Nguru \$100.1 million. Furthermore, Kano led in import cost with \$261.5 million, joined behind by Katsina, Maiduguri, Sokoto, Gusau, Potiskum, and Nguru \$31.1 million. The export income goes in a similar manner with \$364.3 thousand, \$221.4 thousand, \$162.4 thousand, \$141.3 thousand, \$126.4 thousand, \$47.5 thousand, and \$43.2 thousand, respectively. The total production value was \$2.6 billion, import cost \$794.6 million, and export income \$1.1 million (Table 5.3).

Table 5.3: Virtual water demand, water balance, water footprint, production value, import cost and export income of the semi-arid regions of Nigeria for the year 2013

Regions Name	VWD (m^3/yr)	NVWI (m^3/yr)	WP (m3/yr)	Production Value (\$)	Import Value (\$)	Export Value (\$)
Gusau	3,622,385,651	671,789,766	4,294,175,417	292,209,166	90,761,786	126,448
Kano	12,521,544,086	3,068,507,622	15,590,051,708	842,028,048	261,539,746	364,333
Katsina	6,523,754,007	1,595,732,412	8,119,486,418	511,886,141	158,995,364	221,399
Maiduguri	5,869,013,385	1,438,704,836	7,307,718,221	375,456,645	116,619,529	162,381
Nguru	1,196,000,272	291,032,483	1,487,032,756	100,100,560	31,091,845	43,247
Potiskum	1,459,134,481	362,060,514	1,821,194,996	109,901,608	34,135,493	47,483
Sokoto	4,712,629,262	1,155,357,277	5,867,986,539	326,694,329	101,473,382	141,259
Total	35,904,461,145	8,583,184,910	44,487,646,054	2,558,276,497	794,617,145	1,106,550

The crops production values, import costs, and export income in \$/m^3 where determined for each crop in each region and were presented in appendix 1.4 to 7.4. For Gusau region, tobacco unmanufactured had the largest production value of 0.46 \$/m^3, vegetables fresh ness the biggest in terms of import and export with 14.08 \$/m^3, and 2.07 \$/m^3 (appendix 1.4). Kano was also in the same order, with tobacco 0.38 \$/m^3, and vegetables 11.66 \$/m^3 & 1.72 \$/m^3 (appendix 2.4). Katsina had the largest production value of 0.37 \$/m^3 tobacco, then vegetables 11.77 \$/m^3 and 1.73 \$/m^3 (appendix 3.4). Maiduguri was similar with tobacco 0.33 \$/m^3, vegetables 10.58 \$/m^3, and 1.56 \$/m^3, respectively (appendix 4.4). In Nguru tobacco was 0.35 \$/m^3, vegetables 11.67 \$/m^3 and 1.72 (appendix 5.4). In Potiskum, vegetables had the largest value in all the 3 with 0.33 \$/m^3, 11.87 \$/m^3, and 1.75\$/m^3 respectively (appendix 6.4). In Sokoto, tobacco was highest for production value with 0.36 \$/$m^{3,}$ but vegetables led in imports cost and export income with 11.26 \$/m^3 and 1.66 \$/m^3 (appendix 7.4).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The virtual water content of crops varied in each region of the semi-arid zone of Nigeria due to the difference in climatological parameters. It was observed that some crops have high water requirements but due to their large crop yield, they possessed less virtual water content.

Based on the results obtained, it was deduced that the circumstances surrounding the virtual water trade volume could be classified in to regulated and unregulated circumstances. The regulated circumstances include the types of crops and the quantities of their imports and exports. While, the unregulated circumstances are temperatures (max. and min.), humidity, wind speed, sunshine hours and solar radiation.

With the advancement in technology and improved awareness in the agricultural production techniques, Nigeria may soon be self-sufficient in food production, as of 2013, production was averagely 81% of virtual water consumed with only 19% imported through virtual water trade. By immense contributions in food productions, the country within the semi-arid zone was able to domestically produced food crops which was consumed that amount to approximately $2.6 billion and also received internal income of $1.1 million but spent $794.6 million for food importation. As production capacity increases, there will be a rise in income generation and drought in food expenditure through import, and consequently, result in developmental growth.

As the world population continues to increase, and the global warming continues to be experienced, the scarcity of water tends to be ascending due to increasing water demand and drying of surface water. Hence, a care should be given to the regions necessitating the minimum blue water for cultivation of the crops in order not to depleting the water resources. Consequently, among the seven (7) regions of the semi-arid zone of Nigeria, Gusau is the preferable region to grow crops due to it higher percentage of green water and minimum blue water used and therefore, reduced cost of blue water provision.

6.2 Recommendations

Upon completion of this research and the results obtained, the following recommendations were drawn;

- This research was limited to semi-arid regions of Nigeria, similar researches should be conducted in other climatic regions to determine how the degree of aridity influence productions, imports, and exports of virtual water in Nigeria.
- The research was specifically conducted for 2013, more researches should be carried out earlier and later than 2013, to figure out how a change in population (and possibly climate) affects the virtual water trade in Nigeria.
- The study was based on 25 most populous crop products in Nigeria, more crops should be added for future researches.
- The research was focused on crop products, similar research should be conducted on livestock products to know the virtual water trade of livestock products in Nigeria.
- Crop productions in the regions should be stopped or reduce to the barest minimum. For the vulnerable people that cannot afford it or whose, their survival is dependent on farming, government should devise a means of supporting and empowering by enrolling them in to skills acquisition programs, give them loans to start trade, and a lot of other initiatives that can provide for their daily needs. By so doing, the regions will continue to be comfortable areas for its dwellers by utilizing the little available water in the regions for consumptions and other day-to-day activities.
- As the nation continue to experience a tremendous growth in population, the demand for food is also on the rise. Therefore, modern sophisticated means through advanced farming machines and equipments should be employed to enhance the current production capacity, so that the country could be self-reliable in crop productions and the money that could have been used for food imports will then be channeled in to other infrastructural works for the benefits of the citizens.

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APPENDICES

APPENDIX 1

GUSAU REGION

Table 1.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	1,882	3,888	1	3,888
	Winter wheat	0	14,601	1	14,601
	Rice	68,783	7,390	1.65	4,479
	Maize	135,741	6,361	1.46	4,357
	Millet	35,084	6,070	0.61	9,951
	Sorghum	128,570	4,590	0.97	4,732
	Barley	0	4,257	2.69	1,583
Vegetables	Tomato	6,404	7,667	5.75	1,333
	Cabbage	0	8,366	14.78	566
	Potato	6,206	7,993	4.55	1,757
	Vegetables fresh nes	17,415	4,027	8.35	482
Fruit and Nuts	Banana 1	0	15,817	20.51	771
	Banana 2	0	17,220	20.51	840
	Mango	3,058	20,838	6.54	3,186
	Citrus	18,706	14,295	4.78	2,991
	Dates (Date palm)	0	20,432	2.7	7,567
Oilseed Crops	Groundnut	63,983	6,604	0.91	7,257
	Soybeans	16,036	2,490	0.76	3,276
Other crops	Pepper	0	7,957	1	7,957
	Sugarcane	1,747	24,031	19.6	1,226
	sugarbeet	0	10,092	14.34	704
	Beans Dry	0	3,978	0.84	4,736
	Beans Green	0	4,252	7.84	542
	Tobacco Unmanufactured	433	3,489	0.95	3,673
	Pulses	87,667	4,954	1.26	3,932

Table 1.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	1,882	102,562	2	7,318,771	398,761,056	9,331
Winter wheat	0	0	0	0	0	0
Rice	113,492	51,468	3	508,306,146	230,513,359	15,228
Maize	198,182	28	177	863,447,368	122,863	772,034
Millet	21,402	5	46	212,962,467	48,759	460,723
Sorghum	124,713	1	91	590,136,300	3,312	429,662
Barley	0	7	0	0	11,394	0
Tomato	36,824	1	1	49,100,401	1,867	933
Cabbage	0	0	0	0	57	0
Potato	28,235	6	52	49,601,220	10,540	90,646
Vegetables fresh nes	145,413	7	2	70,128,927	3,472	723
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	20,000	0	3	63,725,089	0	8,603
Citrus	89,412	0	0	267,395,152	0	0
Dates (Date palm)	0	93	0	0	701,499	0
Groundnut	58,225	184	29	422,544,240	1,331,686	209,006
Soybeans	12,187	300	207	39,929,771	983,550	678,525
Pepper	0	35	0	0	277,699	0
Sugarcane	34,236	32,740	0	41,975,168	40,141,333	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	4	0	0	20,364	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	412	423	0	1,512,390	1,553,890	1,469
Pulses	110,460	7	12	434,302,239	27,129	47,181

Table 1.3: Eff. Rainfall, Act. Irriga. req., Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	3,888	0	3,888	0	7,318,771	0	0
Winter wheat	1,974	12,620	1,974	12,620	0	0	0
Rice	3,779	3,611	2,290	2,188	259,930,842	248,375,304	0
Maize	1,938	4,423	1,327	3,029	263,065,713	600,381,655	0
Millet	75	5,995	123	9,828	2,631,332	210,331,135	0
Sorghum	3,327	1,263	3,430	1,302	427,752,390	162,383,910	0
Barley	3,611	647	1,342	241	0	0	0
Tomato	2,621	5,045	456	877	16,785,203	32,308,794	6,404
Cabbage	1,003	7,363	68	498	0	0	0
Potato	110	7,883	24	1,733	682,614	48,918,606	0
Vegetables fresh nes	2,220	1,807	266	216	38,660,595	31,468,332	0
Banana 1	3,990	11,820	195	576	0	0	0
Banana 2	2,144	15,070	105	735	0	0	0
Mango	6,993	13,840	1,069	2,116	21,385,428	42,324,371	15,291
Citrus	4,118	10,170	862	2,128	77,029,258	190,234,956	130,939
Dates (Date palm)	6,156	14,270	2,280	5,285	0	0	0
Groundnut	2,184	4,420	2,400	4,857	139,739,040	282,805,200	0
Soybeans	2,490	0	3,276	0	39,929,771	0	0
Pepper	151	7,806	308	15,931	0	0	0
Sugarcane	4,567	19,460	233	993	7,977,221	33,990,961	6,987
sugarbeet	1,024	9,068	71	632	0	0	0
Beans Dry	3,595	383	4,280	456	0	0	0
Beans Green	615	3,637	78	464	0	0	0
Tobacco Unmanufactured	3,307	182	3,481	192	1,433,497	78,892	0
Pulses	2,283	2,671	1,812	2,120	200,143,725	234,158,515	0

Table 1.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	207,064	36,922,320	600	0.03	0.09	0.06
Winter wheat	0	0	0	0	0	0
Rice	29,961,862	37,020,789	2,102	0.06	0.16	0.14
Maize	23,781,792	35,250	8,258	0.03	0.29	0.01
Millet	20,010,403	303	2,449	0.09	0.01	0.01
Sorghum	21,450,619	1,167	5,512	0.04	0.35	0.01
Barley	0	2,585	0	0	0.23	0
Tomato	13,624,769	4,603	45	0.28	2.47	0.05
Cabbage	0	520	0	0.00	9.19	0
Potato	3,642,367	5,882	3,689	0.07	0.56	0.04
Vegetables fresh nes	27,337,569	48,881	1,500	0.39	14.08	2.07
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	11,980,060	0	1,010	0.19	0.00	0.12
Citrus	40,414,360	0	0	0.15	0.00	0.00
Dates (Date palm)	0	21,228	0	0	0.03	0
Groundnut	30,102,118	150,562	20,635	0.07	0.11	0.10
Soybeans	3,363,722	169,883	72,961	0.08	0.17	0.11
Pepper	0	49,418	0	0.00	0.09	0.00
Sugarcane	1,095,536	14,110,854	0	0.03	0.35	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	7,822	0	0.00	0.38	0.00
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	694,913	2,197,116	675	0.46	1.41	0.46
Pulses	64,542,012	12,603	7,012	0.15	0.46	0.15

APPENDIX 2

KANO REGION

Table 2.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	5,424	7,142	1	7,142
	Winter wheat	0	16,566	1	16,566
	Rice	198,205	9,097	1.65	5,513
	Maize	391,150	7,704	1.46	5,277
	Millet	101,099	6,580	0.61	10,787
	Sorghum	370,487	5,587	0.97	5,760
	Barley	0	8,449	2.69	3,141
Vegetables	Tomato	18,454	9,240	5.75	1,607
	Cabbage	0	9,244	14.78	625
	Potato	17,882	8,707	4.55	1,914
	Vegetables fresh nes	50,182	4,862	8.35	582
Fruit and Nuts	Banana 1	0	17,864	20.51	871
	Banana 2	0	18,916	20.51	922
	Mango	8,812	23,607	6.54	3,610
	Citrus	53,902	16,087	4.78	3,365
	Dates (Date palm)	0	23,175	2.7	8,583
Oilseed Crops	Groundnut	184,373	8,005	0.91	8,797
	Soybeans	46,209	3,035	0.76	3,993
Other crops	Pepper	0	8,701	1	8,701
	Sugarcane	5,033	27,375	19.6	1,397
	sugarbeet	0	7,815	14.34	545
	Beans Dry	0	7,774	0.84	9,255
	Beans Green	0	4,576	7.84	584
	Tobacco Unmanufactured	1,249	4,246	0.95	4,469
	Pulses	252,621	6,043	1.26	4,796

Table 2.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	5,424	295,542	7	38,739,636	2,110,763,107	48,566
Winter wheat	0	0	0	0	0	0
Rice	327,038	148,309	10	1,803,067,853	817,679,159	54,031
Maize	571,079	81	511	3,013,419,600	429,524	2,694,289
Millet	61,671	14	133	665,232,607	153,174	1,437,892
Sorghum	359,372	2	262	2,069,909,199	11,520	1,506,762
Barley	0	21	0	0	65,016	0
Tomato	106,111	4	2	170,515,924	6,428	3,375
Cabbage	0	0	0	0	188	0
Potato	81,363	17	149	155,698,574	32,914	284,748
Vegetables fresh nes	419,020	21	4	243,985,117	12,170	2,504
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	57,632	0	8	208,031,093	0	28,155
Citrus	257,650	0	0	867,115,887	0	0
Dates (Date palm)	0	267	0	0	2,291,750	858
Groundnut	167,780	529	83	1,475,907,360	4,652,576	730,126
Soybeans	35,119	865	597	140,244,954	3,454,309	2,382,874
Pepper	0	101	0	0	875,321	0
Sugarcane	98,653	94,343	0	137,786,755	131,767,048	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	12	0	0	113,834	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	1,187	1,219	1	5,303,031	5,449,182	4,916
Pulses	318,302	20	35	1,526,586,497	95,441	165,943

Table 2.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	G_RVWD (m3/yr)
Wheat	1,753	5,388	1,753	5,388	9,508,623	29,225,590	5,424
Winter wheat	1,349	15,210	1,349	15,210	0	0	0
Rice	3,305	5,792	2,003	3,510	655,066,423	1,148,001,429	0
Maize	1,461	6,243	1,001	4,276	571,470,150	2,441,949,450	0
Millet	22	6,558	36	10,751	2,224,182	663,008,425	0
Sorghum	2,587	3,000	2,667	3,093	958,449,096	1,111,460,103	0
Barley	689	7,760	256	2,885	0	0	0
Tomato	2,423	6,817	421	1,186	44,714,295	125,801,629	0
Cabbage	932	8,312	63	562	0	0	0
Potato	53	7,721	63	9,192	0	0	0
Vegetables fresh nes	1,871	2,991	224	358	93,890,612	150,094,505	0
Banana 1	3,916	13,940	191	680	0	0	0
Banana 2	2,189	16,720	107	815	0	0	0
Mango	6,311	17,290	965	2,644	55,614,192	152,364,027	52,874
Citrus	5,897	17,270	2,184	6,396	0	0	485,115
Dates (Date palm)	1,547	6,458	1,700	7,097	285,225,320	1,190,682,040	0
Groundnut	2,908	126	3,826	166	134,376,384	5,822,361	0
Soybeans	428	8,273	873	16,884	0	0	46,209
Pepper	4,871	22,500	249	1,148	24,517,234	113,249,388	0
Sugarcane	4,345	3,470	303	242	0	0	20,133
sugarbeet	98	8,609	22	1,892	1,752,436	153,946,138	0
Beans Dry	742	3,834	95	489	0	0	0
Beans Green	4,328	11,750	905	2,458	233,286,353	633,344,419	0
Tobacco Unmanufactured	4,011	235	4,222	247	5,009,528	293,503	0
Pulses	1,886	4,157	1,497	3,299	476,442,517	1,050,143,979	0

Table 2.4: Production Value, Import Cost, and Export Income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	596,662	106,395,228	1,700	0.02	0.05	0.04
Winter wheat	0	0	0	0	0	0
Rice	86,337,953	106,678,951	6,057	0.05	0.13	0.11
Maize	68,529,480	101,750	23,794	0.02	0.24	0.01
Millet	57,661,918	879	7,052	0.09	0.01	0
Sorghum	61,812,001	3,333	15,879	0.03	0.29	0.01
Barley	0	7,431	0	0	0.11	0
Tomato	39,261,107	13,152	135	0.23	2.05	0.04
Cabbage	0	1,560	0	0	8.31	0
Potato	10,495,840	16,861	10,639	0.07	0.51	0.04
Vegetables fresh nes	78,775,779	141,890	4,300	0.32	11.66	1.72
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	34,521,688	0	2,917	0.17	0	0.10
Citrus	116,457,755	0	0	0.13	0	0
Dates (Date palm)	0	61,143	100	0	0.03	0.12
Groundnut	86,742,053	433,962	59,470	0.06	0.09	0.08
Soybeans	9,692,844	489,504	210,217	0.07	0.14	0.09
Pepper	0	142,450	0	0	0.08	0
Sugarcane	3,156,890	40,661,747	0	0.02	0.31	0.00
sugarbeet	0	0	0	0	0	0
Beans Dry	0	22,374	0	0	0.20	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	2,002,219	6,331,184	1,856	0.38	1.16	0.38
Pulses	185,983,859	36,347	20,217	0.12	0.38	0.12

APPENDIX 3

KATSINA REGION

Table 3.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	3,298	6,156	1	6,156
	Winter wheat	0	12,201	1	12,201
	Rice	120,493	7,779	1.65	4,715
	Maize	237,788	6,514	1.46	4,462
	Millet	61,460	4,317	0.61	7,077
	Sorghum	225,227	5,302	0.97	5,466
	Barley	0	5,227	2.69	1,943
Vegetables	Tomato	11,219	8,022	5.75	1,395
	Cabbage	0	6,668	14.78	451
	Potato	10,871	5,508	4.55	1,211
	Vegetables fresh nes	30,507	4,818	8.35	577
Fruit and Nuts	Banana 1	0	12,962	20.51	632
	Banana 2	0	14,424	20.51	703
	Mango	5,357	18,095	6.54	2,767
	Citrus	32,768	12,485	4.78	2,612
	Dates (Date palm)	0	17,367	2.7	6,432
Oilseed Crops	Groundnut	112,084	6,853	0.91	7,531
	Soybeans	28,092	4,183	0.76	5,504
Other crops	Pepper	0	6,638	1	6,638
	Sugarcane	3,060	20,338	19.6	1,038
	sugarbeet	0	7,571	14.34	528
	Beans Dry	0	4,862	0.84	5,788
	Beans Green	0	4,127	7.84	526
	Tobacco Unmanufactured	759	4,368	0.95	4,598
	Pulses	153,573	5,233	1.26	4,153

Table 3.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	3,298	179,666	4	20,299,410	1,106,025,127	25,240
Winter wheat	0	0	0	0	0	0
Rice	198,813	90,160	6	937,312,454	425,064,833	27,816
Maize	347,171	50	310	1,548,951,567	220,851	1,384,894
Millet	37,491	9	81	265,324,235	61,570	573,241
Sorghum	218,470	1	159	1,194,150,876	6,559	869,091
Barley	0	13	0	0	24,483	0
Tomato	64,507	2	1	89,995,818	3,348	1,814
Cabbage	0	0	0	0	90	0
Potato	49,462	11	91	59,876,560	12,711	109,555
Vegetables fresh nes	254,731	13	3	146,981,255	7,328	1,500
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	35,036	0	5	96,937,737	0	13,004
Citrus	156,631	0	0	409,107,592	0	0
Dates (Date palm)	0	162	0	0	1,043,950	0
Groundnut	101,997	322	51	768,112,857	2,421,142	380,304
Soybeans	21,350	526	363	117,507,075	2,893,976	1,996,282
Pepper	0	61	0	0	405,582	0
Sugarcane	59,973	57,353	0	62,231,271	59,512,412	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	8	0	0	43,411	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	721	741	1	3,316,461	3,407,960	3,219
Pulses	193,502	12	21	803,648,838	50,253	87,217

Table 3.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	1,074	5,082	1,074	5,082	3,541,515	16,757,895	0
Winter wheat	1,020	11,180	1,020	11,180	0	0	0
Rice	63	7,716	38	4,676	7,591,038	929,721,416	0
Maize	1,045	5,469	716	3,746	248,488,546	1,300,463,022	0
Millet	3	4,314	5	7,072	184,381	265,139,854	0
Sorghum	2,720	2,582	2,804	2,662	612,616,066	581,534,810	0
Barley	3,524	1,703	1,310	633	0	0	0
Tomato	1,778	6,244	309	1,086	19,946,717	70,049,101	0
Cabbage	853	5,815	58	393	0	0	0
Potato	50	5,458	11	1,200	543,542	59,333,018	0
Vegetables fresh nes	1,327	3,491	159	418	40,482,384	106,498,871	0
Banana 1	3,371	9,590	164	468	0	0	0
Banana 2	3,871	10,550	189	514	0	0	0
Mango	4,630	13,460	708	2,058	24,803,632	72,107,319	26,786
Citrus	3,685	8,800	771	1,841	120,749,818	288,357,774	0
Dates (Date palm)	5,245	12,120	1,943	4,489	0	0	0
Groundnut	1,183	5,670	1,300	6,231	132,595,580	635,517,277	0
Soybeans	3	4,180	4	5,500	84,275	117,422,800	0
Pepper	381	6,256	778	12,767	0	0	0
Sugarcane	4,083	16,250	208	829	12,493,376	49,722,596	15,299
sugarbeet	3,638	3,933	254	274	0	0	0
Beans Dry	2,821	2,042	3,358	2,431	0	0	0
Beans Green	3	4,124	0	526	0	0	0
Tobacco Unmanufactured	3,938	430	4,145	453	2,989,978	326,483	0
Pulses	16	5,217	13	4,140	2,457,172	801,191,666	0

Table 3.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	362,725	64,679,832	1,025	0.02	0.06	0.04
Winter wheat	0	0	0	0	0	0
Rice	52,486,606	64,852,304	3,647	0.06	0.15	0.13
Maize	41,660,472	61,875	14,465	0.03	0.28	0.01
Millet	35,053,898	539	4,285	0.13	0.01	0.01
Sorghum	37,576,788	2,000	9,651	0.03	0.30	0.01
Barley	0	4,523	0	0	0.18	0
Tomato	23,867,627	7,891	84	0.27	2.36	0.05
Cabbage	0	1,040	0	0	11.53	0
Potato	6,380,637	10,293	6,471	0.11	0.81	0.06
Vegetables fresh nes	47,889,409	86,220	2,600	0.33	11.77	1.73
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	20,986,444	0	1,758	0.22	0	0.14
Citrus	70,797,076	0	0	0.17	0	0
Dates (Date palm)	0	37,167	0	0	0.04	0
Groundnut	52,732,242	263,791	36,183	0.07	0.11	0.10
Soybeans	5,892,490	297,550	127,779	0.05	0.10	0.06
Pepper	0	86,518	0	0	0.10	0
Sugarcane	1,919,139	24,719,100	0	0.03	0.42	0.00
sugarbeet	0	0	0	0	0	0
Beans Dry	0	13,643	0	0	0.31	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	1,217,194	3,848,977	1,181	0.37	1.13	0.37
Pulses	113,063,394	22,101	12,270	0.14	0.44	0.14

APPENDIX 4

MAIDUGURI REGION

Table 4.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	2,419	7,524	1	7,524
	Winter wheat	0	16,182	1	16,182
	Rice	88,379	9,617	1.65	5,828
	Maize	174,412	8,104	1.46	5,551
	Millet	45,080	6,189	0.61	10,146
	Sorghum	165,198	6,098	0.97	6,287
	Barley	0	8,473	2.69	3,150
Vegetables	Tomato	8,229	9,707	5.75	1,688
	Cabbage	0	8,893	14.78	602
	Potato	7,974	7,737	4.55	1,700
	Vegetables fresh nes	22,376	5,359	8.35	642
Fruit and Nuts	Banana 1	0	16,969	20.51	827
	Banana 2	0	17,864	20.51	871
	Mango	3,929	23,530	6.54	3,598
	Citrus	24,035	16,480	4.78	3,448
	Dates (Date palm)	0	22,810	2.7	8,448
Oilseed Crops	Groundnut	82,211	8,366	0.91	9,193
	Soybeans	20,605	3,436	0.76	4,521
Other crops	Pepper	0	8,763	1	8,763
	Sugarcane	2,244	26,878	19.6	1,371
	sugarbeet	0	8,574	14.34	598
	Beans Dry	0	5,347	0.84	6,365
	Beans Green	0	4,664	7.84	595
	Tobacco Unmanufactured	557	4,794	0.95	5,046
	Pulses	112,643	6,476	1.26	5,140

Table 4.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	2,419	131,781	3	18,197,546	991,520,244	22,572
Winter wheat	0	0	0	0	0	0
Rice	145,825	66,131	4	849,937,054	385,440,617	25,645
Maize	254,642	36	228	1,413,434,737	201,490	1,263,891
Millet	27,499	6	59	278,998,091	63,919	602,667
Sorghum	160,242	1	117	1,007,379,541	5,658	733,017
Barley	0	9	0	0	29,293	0
Tomato	47,315	2	1	79,875,105	3,039	1,519
Cabbage	0	0	0	0	120	0
Potato	36,280	8	66	61,691,097	13,093	112,909
Vegetables fresh nes	186,839	9	2	119,912,727	5,969	1,219
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	25,698	0	4	92,457,429	0	12,593
Citrus	114,885	0	0	396,088,526	0	0
Dates (Date palm)	0	119	0	0	1,006,174	0
Groundnut	74,812	236	37	687,778,973	2,167,805	340,156
Soybeans	15,659	386	266	70,796,972	1,743,770	1,202,600
Pepper	0	45	0	0	392,582	0
Sugarcane	43,989	42,067	0	60,323,008	57,687,593	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	6	0	0	35,010	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	529	544	1	2,670,006	2,743,177	2,523
Pulses	141,930	9	15	729,472,573	45,743	79,151

Table 4.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	1,194	6,330	1,194	6,330	2,887,808	15,309,738	0
Winter wheat	693	15,480	693	15,480	0	0	0
Rice	2,107	7,510	1,277	4,552	186,213,723	663,723,332	0
Maize	989	7,115	677	4,873	172,493,454	1,240,941,283	0
Millet	11	6,178	18	10,128	495,876	278,502,214	0
Sorghum	2,305	3,793	2,376	3,910	380,782,198	626,597,344	0
Barley	353	8,120	131	3,019	0	0	0
Tomato	1,530	8,177	266	1,422	12,589,771	67,285,333	0
Cabbage	1,017	7,876	69	533	0	0	0
Potato	90	7,647	20	1,681	717,616	60,973,481	0
Vegetables fresh nes	1,295	4,064	155	487	28,976,858	90,935,869	0
Banana 1	3,113	13,850	152	675	0	0	0
Banana 2	3,080	14,780	150	721	0	0	0
Mango	4,693	18,830	718	2,879	18,440,404	73,989,519	27,505
Citrus	3,917	12,560	819	2,628	94,143,128	301,873,294	72,103
Dates (Date palm)	4,852	17,950	1,797	6,648	0	0	0
Groundnut	961	7,405	1,056	8,137	79,004,972	608,774,001	0
Soybeans	2,982	454	3,924	597	61,442,541	9,354,431	0
Pepper	333	8,430	680	17,204	0	0	0
Sugarcane	4,533	22,340	231	1,140	10,173,532	50,138,255	11,222
sugarbeet	3,698	4,875	258	340	0	0	0
Beans Dry	2,523	2,823	3,004	3,361	0	0	0
Beans Green	690	3,975	88	507	0	0	0
Tobacco Unmanufactured	3,303	1,491	3,477	1,569	1,839,597	830,409	0
Pulses	1,475	5,001	1,171	3,969	166,147,629	563,324,944	0

Table 4.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	266,046	47,441,160	750	0.01	0.05	0.03
Winter wheat	0	0	0	0	0	0
Rice	38,497,721	47,567,669	2,720	0.05	0.12	0.11
Maize	30,556,980	45,375	10,611	0.02	0.23	0.01
Millet	25,711,191	390	3,142	0.09	0.01	0.01
Sorghum	27,561,693	1,500	7,078	0.03	0.27	0.01
Barley	0	3,339	0	0	0.11	0
Tomato	17,506,365	5,919	58	0.22	1.95	0.04
Cabbage	0	1,040	0	0	8.64	0
Potato	4,680,056	7,548	4,748	0.08	0.58	0.04
Vegetables fresh nes	35,125,770	63,138	1,900	0.29	10.58	1.56
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	15,393,042	0	1,309	0.17	0	0.10
Citrus	51,927,975	0	0	0.13	0	0
Dates (Date palm)	0	27,274	0	0	0.03	0
Groundnut	38,677,907	193,474	26,511	0.06	0.09	0.08
Soybeans	4,321,994	218,268	93,712	0.06	0.13	0.08
Pepper	0	63,437	0	0	0.08	0
Sugarcane	1,407,642	18,130,877	0	0.02	0.31	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	10,005	0	0	0.29	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	892,856	2,822,860	844	0.33	1.03	0.33
Pulses	82,929,407	16,256	8,998	0.11	0.36	0.11

APPENDIX 5

NGURU REGION

Table 5.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
	Wheat	645	5,608	1	5,608
	Winter wheat	0	10,392	1	10,392
	Rice	23,563	7,740	1.65	4,691
	Maize	46,500	5,858	1.46	4,012
Grains	Millet	12,019	3,276	0.61	5,370
	Sorghum	44,044	5,164	0.97	5,324
	Barley	0	5,205	2.69	1,935
	Tomato	2,194	7,413	5.75	1,289
	Cabbage	0	6,328	14.78	428
	Potato	2,126	4,782	4.55	1,051
Vegetables	Vegetables fresh nes	5,966	4,856	8.35	582
	Banana 1	0	11,701	20.51	571
	Banana 2	0	11,310	20.51	551
Fruit and Nuts	Mango	1,048	16,549	6.54	2,530
	Citrus	6,408	11,091	4.78	2,320
	Dates (Date palm)	0	15,681	2.7	5,808
Oilseed Crops	Groundnut	21,918	6,240	0.91	6,857
	Soybeans	5,493	3,305	0.76	4,349
	Pepper	0	5,587	1	5,587
	Sugarcane	598	18,007	19.6	919
	sugarbeet	0	7,570	14.34	528
Other crops	Beans Dry	0	4,994	0.84	5,945
	Beans Green	0	3,168	7.84	404
	Tobacco Unmanufactured	149	4,612	0.95	4,855
	Pulses	30,032	5,348	1.26	4,244

Table 5.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	645	35,134	1	3,616,038	197,032,033	4,486
Winter wheat	0	0	0	0	0	0
Rice	38,878	17,631	1	182,374,571	82,705,887	5,629
Maize	67,890	10	61	272,397,000	38,920	243,548
Millet	7,331	2	16	39,373,224	9,130	84,854
Sorghum	42,722	0	31	227,440,661	1,065	165,567
Barley	0	3	0	0	4,837	0
Tomato	12,615	1	0	16,262,833	645	258
Cabbage	0	0	0	0	0	0
Potato	9,673	2	18	10,165,691	2,102	18,603
Vegetables fresh nes	49,813	3	1	28,969,209	1,454	291
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	6,851	0	1	17,336,722	0	2,277
Citrus	30,630	0	0	71,069,411	0	0
Dates (Date palm)	0	32	0	0	184,107	0
Groundnut	19,946	63	10	136,770,514	431,314	67,886
Soybeans	4,175	103	71	18,155,757	447,045	308,322
Pepper	0	12	0	0	67,044	0
Sugarcane	11,728	11,216	0	10,774,709	10,303,955	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	2	0	0	8,918	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	141	145	0	685,003	703,451	485
Pulses	37,840	2	4	160,608,929	10,187	17,402

Table 5.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	785	4,823	785	4,823	506,168	3,109,870	0
Winter wheat	504	9,888	504	9,888	0	0	0
Rice	1,710	6,030	1,036	3,655	40,292,056	142,082,515	0
Maize	646	5,212	442	3,570	30,039,000	242,358,000	0
Millet	2	3,274	3	5,367	24,037	39,349,186	0
Sorghum	1,763	3,401	1,818	3,506	77,648,700	149,791,961	0
Barley	201	5,004	75	1,860	0	0	0
Tomato	1,289	6,124	224	1,065	2,827,842	13,434,991	0
Cabbage	835	5,493	56	372	0	0	0
Potato	44	4,738	10	1,041	93,536	10,072,155	0
Vegetables fresh nes	1,161	3,695	139	443	6,926,123	22,043,087	0
Banana 1	2,832	8,869	138	432	0	0	0
Banana 2	1,689	9,621	82	469	0	0	0
Mango	3,932	12,610	601	1,928	4,119,161	13,210,228	7,333
Citrus	2,846	8,245	595	1,725	18,236,727	52,832,684	0
Dates (Date palm)	3,968	11,710	1,470	4,337	0	0	0
Groundnut	690	5,550	758	6,099	15,123,663	121,646,852	0
Soybeans	2,752	553	3,621	728	15,117,895	3,037,862	0
Pepper	95	5,491	194	11,206	0	0	0
Sugarcane	3,743	14,260	191	728	2,239,670	8,532,646	2,393
sugarbeet	3,360	4,210	234	294	0	0	0
Beans Dry	2,129	2,865	2,535	3,411	0	0	0
Beans Green	2	3,165	0	404	0	0	0
Tobacco Unmanufactured	3,052	1,560	3,213	1,642	453,302	231,701	0
Pulses	1,245	4,103	988	3,256	37,389,326	123,219,603	0

Table 5.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	70,928	12,648,276	200	0.02	0.06	0.04
Winter wheat	0	0	0	0	0	0
Rice	10,263,871	12,682,050	742	0.06	0.15	0.13
Maize	8,146,800	12,125	2,829	0.03	0.31	0.01
Millet	6,854,859	105	836	0.17	0.01	0.01
Sorghum	7,348,218	333	1,888	0.03	0.31	0.01
Barley	0	898	0	0	0.19	0
Tomato	4,667,365	1,644	13	0.29	2.55	0.05
Cabbage	0	0	0	0	0	0
Potato	1,247,753	1,961	1,266	0.12	0.93	0.07
Vegetables fresh nes	9,364,882	16,973	500	0.32	11.67	1.72
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	4,103,929	0	337	0.24	0	0.15
Citrus	13,844,534	0	0	0.19	0	0
Dates (Date palm)	0	7,259	0	0	0.04	0
Groundnut	10,311,927	51,609	7,093	0.08	0.12	0.10
Soybeans	1,152,300	58,175	24,978	0.06	0.13	0.08
Pepper	0	16,992	0	0	0.12	0
Sugarcane	375,293	4,833,881	0	0.03	0.47	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	2,729	0	0	0.31	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	238,106	752,451	169	0.35	1.07	0.35
Pulses	22,109,795	4,384	2,396	0.14	0.43	0.14

APPENDIX 6

POTISKUM REGION

Table 6.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Total Imp $	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	13,886,712	6,456	1	6,456
	Winter wheat	0	12,471	1	12,471
	Rice	13,923,778	8,426	1.65	5,107
	Maize	13,250	6,862	1.46	4,700
	Millet	118	4,371	0.61	7,166
	Sorghum	500	5,433	0.97	5,601
	Barley	969	6,612	2.69	2,458
Vegetables	Tomato	1,644	8,311	5.75	1,445
	Cabbage	0	6,485	14.78	439
	Potato	2,157	5,328	4.55	1,171
	Vegetables fresh nes	18,330	4,775	8.35	572
Fruit and Nuts	Banana 1	0	12,758	20.51	622
	Banana 2	0	14,585	20.51	711
	Mango	0	17,947	6.54	2,744
	Citrus	0	12,229	4.78	2,558
	Dates (Date palm)	7,969	17,298	2.7	6,407
Oilseed Crops	Groundnut	56,615	7,159	0.91	7,867
	Soybeans	63,890	2,977	0.76	3,917
Other crops	Pepper	18,550	6,967	1	6,967
	Sugarcane	5,307,162	20,521	19.6	1,047
	sugarbeet	0	7,639	14.34	533
	Beans Dry	2,910	4,870	0.84	5,798
	Beans Green	0	3,356	7.84	428
	Tobacco Unmanufactured	826,190	5,751	0.95	6,054
	Pulses	4,749	5,787	1.26	4,593

Table 6.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Export Q. (ton/yr)	VWT Import (m3/yr)	Harvested Area(ha)	Total	Total Prod $
Wheat	708	1	249,035,035	708	80,000	77,880
Winter wheat	0	0	0	0	0	0
Rice	42,685	1	98,851,789	25,870	2,923,261	11,268,840
Maize	74,537	67	49,820	51,053	5,768,952	8,944,476
Millet	8,049	17	13,615	13,195	1,491,082	7,526,002
Sorghum	46,905	34	1,680	48,356	5,464,196	8,067,712
Barley	0	0	6,637	0	0	0
Tomato	13,850	0	723	2,409	272,174	5,124,352
Cabbage	0	0	0	0	0	0
Potato	10,620	19	2,576	2,334	263,736	1,369,916
Vegetables fresh nes	54,691	1	1,544	6,550	740,120	10,281,814
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	7,522	1	0	1,150	129,969	4,505,798
Citrus	33,629	0	0	7,035	794,979	15,200,082
Dates (Date palm)	0	0	222,952	0	0	0
Groundnut	21,899	11	542,825	24,064	2,719,264	11,321,576
Soybeans	4,584	78	442,241	6,031	681,526	1,265,101
Pepper	0	0	91,268	0	0	0
Sugarcane	12,876	0	12,892,214	657	74,235	412,038
sugarbeet	0	0	0	0	0	0
Beans Dry	0	0	9,276	0	0	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	155	0	963,141	163	18,421	261,394
Pulses	41,545	5	11,941	32,972	3,725,825	24,274,627

Table 6.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	1,480	4,976	1,480	4,976	1,047,840	3,523,008	0
Winter wheat	1,384	11,080	1,384	11,080	0	0	0
Rice	3,133	5,293	1,899	3,208	81,049,761	136,928,306	0
Maize	1,474	5,388	1,010	3,690	75,252,041	275,073,269	0
Millet	44	4,327	72	7,093	580,598	57,096,538	0
Sorghum	2,838	2,595	2,926	2,675	137,234,269	125,483,766	0
Barley	686	5,925	255	2,203	0	0	0
Tomato	2,463	5,848	428	1,017	5,932,446	14,085,645	0
Cabbage	992	5,493	67	372	0	0	0
Potato	110	5,218	24	1,147	256,735	12,178,583	0
Vegetables fresh nes	28	4,747	3	569	183,393	31,091,713	0
Banana 1	3,808	8,950	186	436	0	0	0
Banana 2	4,203	10,380	205	506	0	0	0
Mango	6,703	11,240	1,025	1,719	7,709,680	12,928,062	4,601
Citrus	4,157	8,072	870	1,689	29,245,539	56,788,546	0
Dates (Date palm)	5,589	11,700	2,070	4,333	0	0	0
Groundnut	1,573	5,586	1,729	6,138	37,853,294	134,423,714	0
Soybeans	2,928	49	3,853	64	17,659,307	295,528	0
Pepper	457	6,511	933	13,288	0	0	0
Sugarcane	4,283	16,230	219	828	2,813,712	10,662,282	5,256
sugarbeet	4,392	3,247	306	226	0	0	0
Beans Dry	2,829	2,041	3,368	2,430	0	0	0
Beans Green	815	2,541	104	324	0	0	0
Tobacco Unmanufactured	53	5,698	56	5,998	8,642	929,074	0
Pulses	1,908	3,879	1,514	3,079	62,910,697	127,898,634	0

Table 6.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	77,880	13,886,712	225	0.02	0.06	0.04
Winter wheat	0	0	0	0	0	0
Rice	11,268,840	13,923,778	804	0.05	0.14	0.12
Maize	8,944,476	13,250	3,104	0.03	0.27	0.01
Millet	7,526,002	118	920	0.13	0.01	0.01
Sorghum	8,067,712	500	2,070	0.03	0.30	0.01
Barley	0	969	0	0	0.15	0
Tomato	5,124,352	1,644	19	0.26	2.27	0.04
Cabbage	0	0	0	0	0	0
Potato	1,369,916	2,157	1,387	0.11	0.84	0.06
Vegetables fresh nes	10,281,814	18,330	600	0.33	11.87	1.75
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	4,505,798	0	374	0.22	0	0.14
Citrus	15,200,082	0	0	0.18	0	0
Dates (Date palm)	0	7,969	0	0	0.04	0
Groundnut	11,321,576	56,615	7,738	0.07	0.10	0.09
Soybeans	1,265,101	63,890	27,444	0.07	0.14	0.09
Pepper	0	18,550	0	0	0.10	0
Sugarcane	412,038	5,307,162	0	0.03	0.41	0.00
sugarbeet	0	0	0	0	0	0
Beans Dry	0	2,910	0	0	0.31	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	261,394	826,190	169	0.28	0.86	0.28
Pulses	24,274,627	4,749	2,629	0.13	0.40	0.13

APPENDIX 7

SOKOTO REGION

Table 7.1: Harvested area, crop water requirements, yield and virtual water content

Crope Category	Crop Type	Harvested Area(ha)	CWR (m3/ha)	Yield(ton/ha)	VWC (m3/ton)
Grains	Wheat	2,105	6,921	1	6,921
	Winter wheat	0	14,901	1	14,901
	Rice	76,900	8,971	1.65	5,437
	Maize	151,760	7,405	1.46	5,072
	Millet	39,225	5,614	0.61	9,203
	Sorghum	143,743	5,684	0.97	5,860
	Barley	0	7,623	2.69	2,834
Vegetables	Tomato	7,160	8,983	5.75	1,562
	Cabbage	0	7,998	14.78	541
	Potato	6,938	7,151	4.55	1,572
	Vegetables fresh nes	19,470	5,036	8.35	603
Fruit and Nuts	Banana 1	0	15,497	20.51	756
	Banana 2	0	16,554	20.51	807
	Mango	3,419	21,184	6.54	3,239
	Citrus	20,913	14,813	4.78	3,099
	Dates (Date palm)	0	20,619	2.7	7,637
Oilseed Crops	Groundnut	71,534	7,725	0.91	8,489
	Soybeans	17,929	3,142	0.76	4,134
Other crops	Pepper	0	7,950	1	7,950
	Sugarcane	1,953	24,437	19.6	1,247
	sugarbeet	0	10,508	14.34	733
	Beans Dry	0	6,728	0.84	8,010
	Beans Green	0	4,078	7.84	520
	Tobacco Unmanufactured	485	4,449	0.95	4,683
	Pulses	98,013	6,062	1.26	4,811

Table 7.2: Quantity produced, Import quantity, Export quantity, Virtual water demand, Virtual water import, and Virtual water export

Crop Type	Q.produce (ton/yr)	Import Q. (Ton/yr)	Export Q. (ton/yr)	VWD (m3/yr)	VWT Import (m3/yr)	VWT Export (m3/yr)
Wheat	2,105	114,666	3	14,565,245	793,603,386	17,995
Winter wheat	0	0	0	0	0	0
Rice	126,886	57,542	4	689,873,706	312,853,023	20,660
Maize	221,570	32	198	1,123,785,336	160,273	1,004,747
Millet	23,927	6	52	220,208,690	50,618	475,810
Sorghum	139,431	1	102	817,036,911	4,688	594,769
Barley	0	8	0	0	22,671	0
Tomato	41,170	2	1	64,317,499	2,500	1,250
Cabbage	0	0	0	0	54	0
Potato	31,568	7	58	49,613,324	10,530	90,684
Vegetables fresh nes	162,574	8	2	98,050,317	4,885	1,025
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	22,360	0	3	72,428,549	0	9,717
Citrus	99,964	0	0	309,784,765	0	0
Dates (Date palm)	0	104	0	0	791,159	0
Groundnut	65,096	205	32	552,600,659	1,741,945	273,346
Soybeans	13,626	336	232	56,331,512	1,387,441	957,070
Pepper	0	39	0	0	310,050	0
Sugarcane	38,276	36,604	0	47,721,721	45,636,846	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	5	0	0	38,446	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	460	473	0	2,156,126	2,215,134	1,873
Pulses	123,496	8	13	594,154,902	37,046	64,469

Table 7.3: Effective Rainfall, Actual Irrigation requirement, Green virtual water content, Blue virtual water content, Green virtual water demand, Blue virtual water demand, and Grey virtual water demand

Crop Type	Eff.Rain (m3/ha)	Act.Irrigat. (m3/ha)	GVWC (m3/ton)	BVWC (m3/ton)	GVWD (m3/yr)	BVWD m3/yr)	GRVWD (m3/yr)
Wheat	1,423	5,498	1,423	5,498	2,994,704	11,570,541	0
Winter wheat	1,151	13,750	1,151	13,750	0	0	0
Rice	2,757	6,214	1,671	3,766	212,014,470	477,859,236	0
Maize	1,163	6,242	797	4,275	176,497,278	947,288,058	0
Millet	19	5,595	31	9,172	745,273	219,463,416	0
Sorghum	2,533	3,151	2,611	3,248	364,101,776	452,935,135	0
Barley	554	7,069	206	2,628	0	0	0
Tomato	2,150	6,833	374	1,188	15,393,813	48,923,686	0
Cabbage	957	7,040	65	476	0	0	0
Potato	70	7,081	15	1,556	485,657	49,127,667	0
Vegetables fresh nes	1,148	3,888	137	466	22,351,423	75,698,894	0
Banana 1	3,546	11,950	173	583	0	0	0
Banana 2	3,860	12,690	188	619	0	0	0
Mango	5,835	15,340	892	2,346	19,949,990	52,447,788	30,771
Citrus	3,834	10,970	802	2,295	80,180,570	229,415,977	188,217
Dates (Date palm)	5,232	15,380	1,938	5,696	0	0	0
Groundnut	1,121	6,604	1,232	7,257	80,189,688	472,410,971	0
Soybeans	3,035	107	3,993	141	54,413,157	1,918,355	0
Pepper	339	7,611	692	15,533	0	0	0
Sugarcane	4,047	20,390	206	1,040	7,903,172	39,818,549	0
sugarbeet	584	9,924	41	692	0	0	0
Beans Dry	40	6,688	48	7,962	0	0	0
Beans Green	688	3,390	88	432	0	0	0
Tobacco Unmanufactured	3,933	516	4,140	543	1,906,056	250,070	0
Pulses	1,774	4,288	1,408	3,403	173,875,090	420,279,812	0

Table 7.4: Production value, Import cost, and Export income in dollar and dollar per cubic meter

Crop Type	Production V. ($)	Import Cost ($)	Export Income ($)	Production V. ($/m3)	Import Cost ($/m3)	Export Income ($/m3)
Wheat	231,495	41,279,760	650	0.02	0.05	0.04
Winter wheat	0	0	0	0	0	0
Rice	33,497,825	41,389,817	2,349	0.05	0.13	0.11
Maize	26,588,412	39,500	9,231	0.02	0.25	0.01
Millet	22,371,932	340	2,735	0.10	0.01	0.01
Sorghum	23,982,132	1,333	6,161	0.03	0.28	0.01
Barley	0	2,872	0	0	0.13	0
Tomato	15,232,715	5,261	52	0.24	2.10	0.04
Cabbage	0	520	0	0	9.61	0
Potato	4,072,233	6,568	4,126	0.08	0.62	0.05
Vegetables fresh nes	30,563,818	54,991	1,700	0.31	11.26	1.66
Banana 1	0	0	0	0	0	0
Banana 2	0	0	0	0	0	0
Mango	13,393,880	0	1,122	0.18	0	0.12
Citrus	45,183,864	0	0	0.15	0	0
Dates (Date palm)	0	23,724	0	0	0.03	0
Groundnut	33,654,632	168,367	23,071	0.06	0.10	0.08
Soybeans	3,760,693	189,916	81,557	0.07	0.14	0.09
Pepper	0	55,224	0	0	0.09	0
Sugarcane	1,224,826	15,776,152	0	0.03	0.35	0
sugarbeet	0	0	0	0	0	0
Beans Dry	0	8,731	0	0	0.23	0
Beans Green	0	0	0	0	0	0
Tobacco Unmanufactured	776,925	2,456,242	675	0.36	1.11	0.36
Pulses	72,158,947	14,064	7,830	0.12	0.38	0.12

APPENDIX 8

SUMMARY

Table 8.1: Summary of the entire values obtained owing to the methodology and calculations carried out 1

Regions	Harv.Area (ha)	CWR (m3/ha)	VWC (m3/ton)	Q.P. (ton/yr)	Imp.Q.(ton/yr)	Ex.Q.(ton/yr)	VWD (m3/yr)	VWI (m3/yr)	VWE (m3/yr)
Gusau	591714.92	231659	104667.87	995074.1	187870.9	624.9	3622385651	674802863.5	2724063.824
Kano	1705082.1	270397	127858.5	2867399.8	541368.1	1800.6	12521544086	3078763708	9345038.751
Katsina	1036554.6	212018	102012.23	1743151.2	329108.7	1094.4	6523754007	1601627723	5473174.782
Maiduguri	760288.6	268834	127205.37	1278560.8	241393.7	802.7	5869013385	1443513905	4400462.946
Nguru	202700.6	191785	91965.721	340877.2	64358	213.9	1196000272	292021872.6	919608.6737
Potiskum	222547.6	215374	105082.07	374253.3	70659.2	234.9	1459134481	363234270.3	1078762.994
Sokoto	430781.1	211835	86563.745	761947.9	37803.3	493.9	2884404975	52576715.9	2470013.266

Table 8.2: Summary of the entire values obtained owing to the methodology and calculations carried out 2

Regions	GVWD (m3/yr)	BVWD (m3/yr)	GRVWD (m3/yr)	Pr.Value ($)	Imp. Cost ($)	Exp. Income($)
Gusau	1504465401	2117760631	159620.069	292209166	90761786	126448
Kano	3551547344	8969386987	609755.087	842028048	261539746	364333
Katsina	1229568020	5294143902	42085.04	511886141	158995364	221399
Maiduguri	1216349109	4652553446	110830.524	375456645	116619529	162381
Nguru	251037206.2	944953340	9726.6447	100100560	31091845	43247
Potiskum	459737955.4	999386669	9856.32578	109901608	34135493	47483
Sokoto	821495665.3	2062690322	218988.494	266376597	18764305	129029

Table 8.3: Results comparison between current and previous studies

Authors	Study regions	Study year	Imports volume (Gm^3/yr)	Exports volume (Gm^3/yr)	VWD (Gm^3/yr)	GVW (Gm^3/yr)	BVWD (Gm^3/yr)	GVWD (Gm^3/yr)	NVWI (Gm^3/yr)
Hoekstra & Hung (2002)	Nigeria	1995 To 1999	5.8	0.934	-	-	-	-	10 – 50 24
Chapagain & Hoekstra (2003)	Nigeria	1995 To 1999	6.4	1.0	-	-	-	-	5.4
Zimmer & Renault (2003)	Nigeria	1999	8	0.300	-	-	-	-	7
Mekonnen & Hoekstra (2011)	Nigeria	1996 To 2005	-	-	192	190.6	1.1	0.600	
Abdullahi & Elkiran (2013)	Semi-arid	2013	8.6	0.027	35.9	9.4	26.5	0.0012	8.6

Table 8.4: Initial, Mdiddle and Late K_C values of the 25 crops used

Crope Category	Crop Type	Initial	Middle	Late
Grains	Wheat	0.30	1.15	0.30
	Winter wheat	0.70	1.15	0.25
	Rice Kc dry	0.50	1.05	0.70
	Kc wet	1.10	1.20	1.05
	Maize	0.30	1.20	0.35
	Millet	0.30	1.00	0.30
	Sorghum	0.30	1.00	0.55
Vegetables	Barley	0.30	1.15	0.25
	Tomato	0.60	1.15	0.80
	Cabbage	0.70	1.05	0.95
Fruit and Nuts	Vegetables fresh nes	0.70	1.05	0.95
	Banana 1	0.50	1.10	1.00
	Banana 2	1.00	1.20	1.10
	Mango	0.90	1.10	0.90
	Citrus	0.70	0.65	0.70
Oilseed Crops	Dates (Date palm)	0.90	0.95	0.95
	Groundnut	0.40	1.15	0.60
Other crops	Soybeans	0.40	1.15	0.50
	Pepper	0.60	1.05	0.90
	Sugarcane	0.40	1.25	0.75
	sugarbeet	0.35	1.20	0.70
	Potato	0.50	1.15	0.75
	Beans Dry	0.40	1.15	0.35
	Beans Green	0.50	1.05	0.90
	Tobacco Unmanufactured	0.50	1.15	0.80
	Pulses	0.40	1.15	0.35