Examining the Water Footprint Concept in Relation to Sustainable Water Management, Libya

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DEDICATION

To spirit of my Mother and Father

ABSTRACT

Despite widespread enthusiasm for the development and use of the water footprint concept, some concerns have been raised about the concept itself and its usefulness. A variety of methodologies have been developed for determining the water footprint of a country, each of which varies with respect to how individual countries deal with different forms of water use.

Following an extensive review of the literature related to water footprints, this thesis focuses on critically examining the concept of the water footprint in the specific conditions and circumstances of Libya, an arid and water-scarce country. In addition, it explores how the water footprint concept can be applied to existing water resource management to meet the increasing water demand to attain food security and attempts a critical evaluation of the water footprint concept as a tool for water management policy makers in Libya.

Two philosophical paradigms (positivism and interpretivism) were utilized to gather data related to the water management system in Libya. Data were collected through semi-structured interviews conducted with selected participants, questionnaires distributed to farmers, critical analysis of pertinent official documents, literature review and the researcher`s own non-participant observation. Direct field observation of agricultural practices in selected study areas in Libya was conducted based on the experience of the researcher and was used to augment the data collected by other methods and to gain an in-depth understanding of the effectiveness of current water policies. The water footprint was calculated according to national statistical information. As the agricultural sector is responsible for more than 85% of the total water use in the study area, Libya, this study focuses on agricultural water use.

This research has identified a number of key issues in relation to current water and agriculture management practices and the potential use of the water footprint as a tool to develop water management. Although the current water management seems to be theoretically well drafted, it is not implemented and water polices require review, revision and reformulation. The national water footprint of Libya has been estimated and analysed for the period of 2001–2009. The internal water footprint (internal water use) in the agricultural sector was between 1.9-2.5 Gm^3/year (a total of 19 G m^3 over the study period), while the external water footprint (imported products) was between 6-12

G m3/year of water in virtual form. As the internal water footprint represents only water used to produce products consumed by a country’s inhabitants and excludes water for exports, in countries which have negligible exports, such as Libya, the water footprint concept would not add value for water resource management because, in that case, internal water footprint would be as same as actual water withdrawal.

Despite the potential value of the water footprint concept as a tool for water management, the authorities of a region or a country already know the amount of water consumed and required to be withdrawn from domestic water resources. Thus, this knowledge is already available to the decision-makers and little new information is contributed by the water footprint concept. Furthermore, the concept considers only the volume of water consumed and there is no mention of other inputs of crop production, such as the water used in the production of fertiliser and pesticides, nor does it take into account opportunity costs.

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LIST OF ABBREVIATIONS AND ACRONYMS

ELP	Economic Land Productivity
EWP	Economic Water Productivity
GAI	Libyan General Agency of Information and Documentation
GDP	gross domestic product
GEA	General Environmental Authority
GMMRWUA	Great Man-Made River Water Utilisation Authority
GMRA	Great Man-Made River Authority
GWA	General Water Authority
GWP	Global Water Partnership
IWRM	Integrated Water Resource Management
MENA	Middle East and North Africa
TRSW	total renewable surface water
WDM	Water Demand Management
WF	Water Footprint
WFA	Water Footprint Assessment
WFe	External water footprint
WFi	Internal water footprint
WFn	The total water footprint of a nation
WTO	World Trade Organisation
WWC	World Water Council

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CHAPTER 1 INTRODUCTION

2.1 THE CONTEXT OF STUDY

Water issues have become a crucial issue the world over and in arid and semi-arid areas in particular. The problem of water around the world is not one of overall shortage but that water resources are not distributed evenly across the world. Therefore, it can be seen as abundant in some parts and as scarce in others. The concept of water footprint introduces a new clear and accurate indicator of water consumption within a country by adding the volume of water in the form of virtual water (the volume of water required to produce a commodity or service Hoekstra and Chapagain (2007)) to the volume of water used inside the country from domestic sources. This indicator, as Hoekstra and Chapagain (2007) claim, is able to contribute to developing water management policies and help decision-makers draw up a suitable water strategy in the face of growing demand.

This "water footprint" is defined as the total quantity of freshwater used to produce the products and services consumed within a country. It is divided into two parts: internal water footprint – water used to produce products within the country that are then consumed by inhabitants – and external water footprint – water used to produce products outside of a country which are then imported to be consumed within that country (Hoekstra, 2003).

The water footprint focuses on both water demand and supply. It includes all of what the inhabitants consume with a country either produced domestically or imported from another country in virtual water form (Chapagain, 2007). Hoekstra and Chapagain (2008) pointed out that total water use is traditionally estimated based on the water supply (production side) which is important but it does not reflect the actual use of water because it excludes virtual water in imported products. It shows how much water is withdrawn from domestic resources for different sectors. However, this does not reflect the actual water consumption by the people of a country (which includes virtual water). For this reason, the concept of water footprint includes virtual water in imported food, in addition to the water withdrawn, as a new indicator to reflect the actual water use in terms of both production and consumption.

Increasing pressure on water resources to produce potable water and food is causing intense problems of water shortage and pollution, with growing risks for economic development and food security worldwide. The OECD (2010) pointed out that by 2050 over 40% of the global population will suffer from severe water shortage problems, and at least 20% of groundwater resources will be overexploited. Furthermore, surface water is expected to be contaminated and polluted because of the use of chemical substances such as pesticides. These problems are linked with the water consumption by populations in other parts in the world as a result of virtual water importation through international trade.

UNESCO-WWAP (2003) has pointed out that the water crisis is expected to be exacerbated in the next two decades. Alongside increasing demand associated with population growth is the increasing pollution of water resources. Water management has become the main challenge for water management policy-makers in the light of global climate changes, particularly in arid and semi-arid regions. For example, this problem can be seen in the Middle East and North Africa (MENA) region where water resources are limited with scarce renewable surface water resources. The challenge has become more acute with the increase in population and improvement in living standards at the end of the last century. It may be necessary to triple the amount of water presently used, which is estimated at 3,400 million m^3/year, by the year 2050 (Falkenmark and Rockstrom, 2004).

Bigas, et al. (2012) point out that the world faces a real water crisis due to the growing number of issues that threaten the water supply and quality. They also claim that these issues can be overcome by developing and reforming policies and changing society attitudes to the use of water.

The problem is not solely the physical shortage of water; in most arid and semi-arid countries, the mismanagement of water resources and inadequate polices have also contributed to aggravating the water deficit (Foster and Louck, 2006). Moreover, the weakness in enforcement of regulations has led to the limited effectiveness of water resources management measures (UNEP, 2002).

Libya is situated in North Africa, which has severe shortages in water resources. The country is largely dependent on groundwater for its water use and the lack of water supply is limiting development (Salem, 2007). Additionally, the mismanagement of water demand has led to an ineffective water strategy for the future, and this has made any suggested solutions to overcome water deficits ineffective or only partly effective (Wheida and Verhoeven, 2007a). Local water resources for the agricultural industry are limited and are becoming scarcer because of the depletion of water resources (GWA, 2007). Management of water resources in Libya is further complicated by seawater intrusion in the coastal area, which represents most of the arable land in the country (Ekhmaj et al., 2014).

Another aspect is that the food self-sufficiency policy adopted in the 1970s has largely led to over-exploitation of underground water resources in order to meet food demand. This has led to a significant number of water problems, such as decreasing levels of groundwater and the intrusion of seawater in the coastal areas where the high-density populations are living and carrying out their different activities (Salem, 2007b).

The current point of view of the Libyan authorities on the topic of food security is still to hold on to the goal of national food self-sufficiency as far as possible (WAEA, 2008). The image of colonisation at the beginning of the 19th century is still carved into the minds of Libyans and the Libyan authorities. In order to reduce the pressure on the groundwater resources, the Libyan authorities have accepted the idea of water transfer as the solution for water scarcity in the northern region of the country where intensive farming activities take place (Wheida, 2007a).

Whether the water transfer would have provided enough water to completely solve the water deficit and what the side effects of the project would have been had it not been interrupted by conflict are still unclear. Therefore, it is useful to see to what extent another strategy, the application of the water footprint concept as a tool, can help to reduce the water scarcity in the drier regions.

Water footprint has been estimated in several countries by Hoekstra and Chapagain, (2007 and 2008). Other researchers, such as Kampman (2007), have estimated water footprint for several countries, such as India and China, based on more detailed and accurate data related to interstate trade and production at the national level. These studies have produced a clearer picture of water use in terms of production and consumption by inhabitants than the international study of Hoekstra and Chapagain, (2007, 2008; Bulsink, et al., 2010).

As the agricultural sector is responsible for more than 85% of the total water use in the study area, Libya (Algheriane, 2007), this study will focus on agricultural water use.

In addition, this study considers the application of the water footprint concept in four countries with different climate conditions related to water abundance: India, the Netherlands, Morocco and Tunisia. The water footprints of these countries are explored to gain a better understanding of the water footprint concept and explore the extent to which it helps in developing water management strategies.

2.2 GAPS IN CURRENT RESEARCH

After developing and refining the water footprint concept as a method for quantifying water use, several concerns and limitations have been identified. According to Ridoutt et al. (2010) and Ridoutt and Pfister (2010), the main concern is the fact that water footprint represents only the quantity of water used, regardless of the environmental impacts. According to Hastings & Pegram (2012), reviewing previous case studies, particularly in developing countries, highlighted several cases where a water footprint has potentially contributed in informing policy and planning, and raising awareness and understanding between different sectors such as agriculture, trade and economic development. However, other researcher such as Wichelns (2011) claim that the water footprint concept does not illustrate how a water footprint for a nation can be used to inform policy or that there is no link between water footprint and policy.

To gain fuller understanding of the concept of water footprint, it has to be analysed in the local context with consideration of the environmental, social and economic implications of water use and its connection to the economic, social and environmental indicators (Kuiper.et.al, 2010).

From the review of water footprint literature, all the conducted studies were focused on estimation of water use in terms of quantity. There is no critical examination of water footprint in specific conditions and circumstances and this can be considered a gap in the literature. Therefore, this research will focus on filling this gap in the literature.

2.3 RESEARCH AIM

The aim of this study is to examine critically the concept of the water footprint in the specific conditions and circumstances of Libya. It will also explore how existing water resource management needs to be developed to meet the increasing water demand to attain food security and illustrate whether this concept can be a helpful tool in developing water management policy in Libya.

2.4 OBJECTIVES

The objectives of the study are designed to achieve the above aims and are as follows:

(1) To define and critically evaluate the concept of the water footprint.

(2) To investigate how the concept of water footprint might be applied in Libya.

(3) To investigate and explain the social and cultural context of Libya and how this influences water use.

(4) To critically evaluate the current national water resources management policy.

(5) To examine the water footprint concept as a tool for the assessment of the consequences of current water management practices.

2.5 RESEARCH QUESTIONS

The main research question is the extent to which the concept of the water footprint could contribute to the development of a water management strategy in Libya.

This question generates other questions:

(1) To what extent is the concept of the water footprint of value in the development of successful water management strategies?

(2) Is the current water resources management approach in Libya effective for balancing the water needs of the present and for the future (sustainable water use)?

(3) How far will applying the concept of the water footprint successfully tackle water limitations and protect water resources in Libya?

(4) What components should be included and excluded in calculating national water footprint for Libya?

2.6 OVERVIEW OF RESEARCH METHODOLOGY

This research aims to examine critically the concept of the water footprint and to apply the concept to water management in Libya as a case study. To achieve the objectives of this research, two philosophical paradigms (positivism and interpretivism) are utilized to gather data related to the water management system in Libya. Thus data have been collected through interviews with key water institutions, questionnaires distributed to farmers, the examination of documents, and non-participant observation. The interpretivism side of this study is based on the interviews, while the positivism side is based on the questionnaire.

It was considered that the use of one methodology, either quantitative or qualitative, alone is inadequate for this study in view of the problem under consideration. Therefore, both qualitative and quantitative methods have been employed to achieve the aims and objectives of this research.

The methods used in this research have to reflect both the facts and the quality of people’s meanings, understandings and interpretations. For this reason, a combination of the two research paradigms is more useful for gathering and analysing the data. Thus, mixed methods have been employed to avoid the weakness of each paradigm.

2.7 THE SIGNIFICANCE OF STUDY

This study is not just an application of existing theory or a technical framework for improving polices but it seeks to examine critically the concept of the water footprint in the specific conditions and circumstances of Libya as a case study. Thus, the estimation of the water footprint of Libya is not the main purpose of this study but it is nevertheless a key issue in this research. Therefore, the contribution to knowledge of this study might be validating or modifying this concept depending on the outcome of this research. Also, the outcomes might be of significance to some other countries in developing their water resource management system depending on the circumstances and conditions of the country under study.

The data collection and analysis covers the period up to 2011 after which, due to the conflict in Libya, no further data collection was possible.

2.8 STRUCTURE OF THE THESIS

This section outlines the structure of the thesis including a summary of all the chapters. It provides guidance to the reader in understanding the direction of the study and knowing the sequence and placement of various concepts.

2.8.1 Chapter One: The Introduction

The author provides the reader with an introduction to the research focus, the objectives/aims and the context of the study as well as the author's personal and academic motivation to carry it out. This chapter summarises the potential contribution to knowledge of this research as well as the processes that were undertaken through the implementation of this research'

2.8.2 Chapter Two: Literature Review

The aim of this chapter is to review the literature on water footprints and other related aspects. It starts with food security, water scarcity, virtual water and water management. Finally, it explores the applications of the water footprint as a tool of water resources management. It also explores and addresses the gaps in the literature on water footprints.

2.8.3 Chapter Three: Development Of The Water Footprint Concept: Selected Case Studies

This chapter considers four places with different climate conditions related to water abundance: the Netherlands, Morocco and Tunisia. The water footprints of these countries were explored to gain a better understanding about the concept and explore the extent to which it helps in developing water management.

2.8.4 Chapter four: Water Resource in Libya

This chapter focuses on the availability of water resources and agricultural sector related water use and food security in Libya. The objective of this chapter is to discuss the background of agricultural development related to water consumption in Libya within the last fifty years and its present performance. It also examines the current agricultural state in Libya in terms of food production and water use through irrigation and its effects on the natural water resources.

2.8.5 Chapter five: Research Methodology

This chapter deals with the methodology used for collecting and analysing data related to water resources management and strategy and major agricultural products (major crops) in order to calculate the water footprint of Libya. This chapter shows the research philosophy and the strategy of this research and also the methods that have been used to collect the required data and then the ways of analysing it.

2.8.6 Chapter six: Analysis

This chapter focuses on the analysis of collected data pertaining to the current water and agricultural management. It also calculates the national water footprint based on the primary data gathered via questionnaires and interviews. The chapter is divided into three sections. The first is quantitative analyses of the data gained from the questionnaire survey over the country. The second is qualitative analyses of the interviews conducted with official and non-official water and agricultural organisations over the country. The third represents a calculation of the water footprint and analysis of its application with reference to national water scarcity, national water dependency and national water self-sufficiency.

2.8.7 Chapter Seven: Discussion

The discussion focuses on the most important findings from the analysis in terms of the current water and agricultural management situation in Libya, the extent to which the formal water policies are implemented on the ground, and the measures and tools of water management and, in particular, water footprint. This chapter discusses the key findings of the primary research within the context of the literature reviewed in chapters 2 and 3. The chapter is in two main sections. The first section provides an overview of the characteristics of Libyan water and agricultural management. The second section addresses and analyses the water footprint of Libya including virtual water and the extent to which the water footprint as a tool is helpful in developing water management in Libya.

2.8.8 Chapter eight: Conclusion and Recommendation

The purpose of this chapter is to summarise the insights developed in the previous chapters regarding water management in Libya. It also brings together the overall conclusion of this in-depth study focusing on the extent to which the concept of water footprint as a tool can contribute in developing water management strategies. It also explains the contribution to knowledge of this thesis. Finally, the limitations of the study are discussed and further research is proposed.

CHAPTER 2 LITERATURE REVIEW

3.1 INTRODUCTION

The aim of this chapter is to review the literature on water footprints and other related aspects which provide background information for water footprint. It starts with food security, water scarcity, virtual water and water management. Finally, it explores the applications of water footprints as a tool for water resources management. This chapter also explores and addresses the gaps of the literature on water footprints.

3.2 FOOD SECURITY AND SELF-SUFFICIENCY

The concept of food security has been defined in many different ways. However, most definitions define food security in terms of the availability of food to the population of a country. For instance, the World Bank (1986) cited in Maxwell & Slater (2003:532) defines food security as "Access by all people at all times to enough food for an active, healthy life. The essential elements of food security are the availability of food and ability to acquire it". Similarly, the European Community has identified key elements of food security as the absence food shortage for people and the availability of sufficient healthy food (Maxual, 1990).

The World Food Summit (1996) claimed that food security means all people, at all times, having access physically and economically to satisfactory quantities of safe and nutritious food that meets their needs for an active and healthy life. Therefore, four main dimensions of food security can be generated as follows: physical availability of food, which deals with the supply side of food security and is measured by the level of food production, stock levels and net trade; economic and physical access to food, which means enough supply of food either nationally or internationally (which does not necessarily guarantee food security at household level; accordingly, a greater policy focus on incomes, expenditure, markets and prices is required in achieving food security objectives); food utilization, which means the most of various nutrients in the food in which adequate energy and nutrient consumption by individuals, is the result of good care and feeding practices, food preparation, diversity of the diet and intra-household distribution of food; stability of the other three dimensions over time (as opposed to cases where even with guaranteed food intake today, there is still concern about the accessibility of food on a periodic basis, risking a deterioration of an individual's nutritional status). Furthermore, several factors can have a significant impact on food security status such as unemployment, rising food prices, and political instability.

From those definitions it can be seen that food security can be achieved by either producing the required food domestically (self-sufficiency based on what a country can grow internally) or importing food from other countries. In turn, this means that food security focuses on providing food for the population in a country rather than on achieving self-sufficiency. By this definition, food security is based on the degree to which a country can afford to import the food it can no longer find the resources for growing (Ohlsson, 1999; Wichelns, 2001).

In this context, the FAO (2000) claims that food self-sufficiency is becoming difficult to achieve in many countries. It claims that food self-sufficiency is not a big challenge for countries that have enough financial resources to import their food. However, it is an essential challenge for countries which do not have enough foreign currency to import food. Thus, Chapagain (2006) argues that countries such as Yemen will never achieve food security because it does not have sufficient foreign currency to import the requisite volume of food. Therefore, it is necessary for Yemen to put more pressure on its domestic water resources despite all the environmental impacts and consequences that could appear as a result of this over-exploitation of domestic water resources.

Self-sufficiency may be achieved if a country has an abundance of water. However, even with water abundance, it is difficult to achieve self-sufficiency without strong water management to avoid depletion of these resources (Wheida, 2007b). Attempts to achieve food self-sufficiency by producing all food requirements using domestic water resources have been adopted in the second half of 20th century in several regions, including the Middle East and North Africa (MENA). This has been an aim of a number of governments in order to satisfy a national political desire to achieve full independence. To achieve this aim, a huge expansion in irrigated land in MENA started in the early 1970s, despite constraints on domestic water resources due to reasons such as climatic conditions, in order to meet the increased food demand of rapidly expanding populations (Richard & Waterbury, 1996).

This desire to achieve food self-sufficiency has led to undesirable environmental issues such as soil degradation and deteriorating water quality. Furthermore, achieving food self-sufficiency is unrealistic and difficult to achieve because food self-sufficiency has resulted in increasing the pressure on the domestic water resources which are already limited. Therefore, this trend towards self-sufficiency should be assessed in order to develop an understanding of the impact on scarce water resources of a country and to what extent the country is able to achieve self-sufficiency without depleting its domestic water resources. Israel, in contrast, adopts a policy of importing food from other countries; as a result, it imports about 85.5% of the required food (Astrow, 2014).

According to Wichelns (2001), food self-sufficiency as a national aim can be secured by other means, such as importing food needed from other countries where there is an abundance of water. Many regions such as the MENA, which have real water scarcity, have changed from attempting to develop self-sufficiency to importing most of their requirements of food from water-rich countries, despite the risk of dependency and its effects that may appear in the future, such as political and economic subordination (El-Naser, 2005). This policy involves the production of low-water intensity produce and importing the remainder with high water requirements. Jordan, for example, imports up to 7 Gm^3/year in the form of virtual water to relieve the pressure on its domestic water resources. Jordan, therefore, is able to use only 1Gm^3/year from domestic resources (Chapagain & Hoekstra, 2008). Thus, Hoff, El-Fadel and Haddadin (2006) point out that the MENA region is already very highly dependent on virtual water with only countries such as Iraq, Syria and Lebanon in a position to achieve self-sufficiency.

However, arguably virtual water dependency on other countries causes a loss of independence, as importing countries are at the mercy of exporting countries, which undermines the sovereignty of the importing countries. Furthermore, depending on imports from other countries can affect the national security of the state as a large number of workers lose their income, driving down standards of living, which in turn may encourage a high rate of crime (Wichelns, 2001). Therefore, governments face a delicate balance between the limitations of water resources, producing food internally and importing food from water-rich countries when drawing-up their water policy (Robert, 2008).

Egypt, for instance, which adopted a policy of self-sufficiency in the 1950s, now imports up to 20 Gm^3/year as virtual water from other countries (Chapagain & Hoekstra, 2008).

3.3 WATER SECURITY

The magnitude of the global freshwater problem and the issues related to it have been significantly underestimated. Around one billion people on our planet have unreliable water supplies; in addition, more than two billion people lack access to basic sanitation (Bigas, et al. 2012). In the historical perspective, national security in many countries was understood to mean military security but now this understanding has been developed to add the water element to the human security equation. This is because water can play a vital role in either international or national conflicts. As long as the underlying institutions and capacity are in place for such cooperation to happen, water tensions can also offer the chance for cooperation between countries (Prud'homme, 2011).

Water security is essential for social and economic development in general and it is closely linked to food security Schmidhuber, and Tubiello. (2007). While water has an essential role in enhancing health, well-being and economic progress, particularly in developing countries, the most developed countries in the world face uneven water supply and quality problems that are also threatening their security (Bigas, et al. 2012). For instance, water availability in the USA is already considered as one of the inputs in the national security equation, where there is concern about the availability of sufficient water to meet the country's water, food and energy needs.

Furthermore, the problem has become more complicated as a result of water stress, which is expanding at the international level and particularly in mid-latitude countries that are already considered to be water scarce (Frank, 2006). This circumstance combined with increasing numbers of environmental migrants moving within and beyond national boundaries threatens and hinders important development progress in those countries.

All cumulative and compounding water problems, affecting either quantity or quality, and their environmental impacts will eventually converge internationally. These impacts are exacerbated by increasing population growth, which causes competition for limited water resources. In light of all of these problems, particularly water contamination, high standards of treatment with intensive and comprehensive monitoring are required (Dinar, 2004).

Due to legislative congestion (Solomon 2010), along with rapid increase of population which have led to increase demand on the water, the world still faces a growing global water problem and this inactivity in the face of water crisis cannot be ignored. Therefore, to fill the gap in international water leadership, considerable urgency in creating new forms of hydro-diplomacy are required to address the root causes of the global water crisis and to address the lack of political will and effective governance (Solomon 2010).

3.4 WATER SCARCITY

3.4.1 Overview

The simple definition of water scarcity is a shortage in the supply of water in relation to the corresponding demand (Chatterton et al, 2010). Thus it can be defined as insufficient water to meet the normal needs of population within a country. Utilisateur (2006:23) attributes different meanings to the water scarcity as: an imbalance between supply and needs; demand exceeding water availability; and increasing consumption of water above the available supply. Furthermore, scarcity is the result of limited natural supply relative to population need. Therefore, dealing with water scarcity depends on understanding the causes of the scarcity (Utilisateur 2006:24).

However, Orr et al. (2009) argue that despite the many attempts to understand the issue of water scarcity, it is still difficult to find specific conclusions that show if water is scarce around the world or if it is just unevenly distributed and is therefore a matter of management.

Elhance (1999) defines water scarcity as human life and civilization depends on continuously available fresh water of the highest quality for numerous uses (e.g. drinking, cooking, washing the body and washing clothes).

Water is not allocated equitably across regions and within countries. Thus, it is logical to describe the water problem as one of allocation rather of water shortage. Yang and Zehnder (2002) summarise this by stating that the net water capacity of the world is arguably enough to meet global demand, but that water is not evenly apportioned; some regions have over-abundance of water, while others are arid and drought-stricken, and the general availability and quality of potable water is in decline. According to this argument, limited water resources are a result of the lack of management, an effective planning system and cooperation between those requiring water and those with surplus capacity.

Warner (2003) and Kluge and Liehr (2005) point out that water scarcity in any country can be attributed to social, political and technical reasons (see Table 2.1).

Table 3-1 Types of Water Scarcity (Warner, 2003) (abridged cited in Horlemann & Neubert, 2007)

Type of Water Scarcity	Limiting Factor
Absolute	Physical absence
Technical	Technological (and economic) limits to generation
Economic	Macroeconomic policy decisions
Social	Absence of social ingenuity, institutional / political maturity
Induced	Political strategy, exploitation of resources

Each type of scarcity can be found in arid and semi-arid countries such as those in the MENA where real water scarcity exists due to climate conditions but is exacerbated by technical, economic, social and induced scarcity.

3.4.2 Water Scarcity Indicators.

One of the simplest indicators of water scarcity, the 'Water Stress Index' is proposed by Falkenmark et al. (1989). The authors argue that 'Water Stress' is experienced when levels fall below 1700m^3/capita/year of renewable water: this includes use in different sectors, such as household, industrial, agricultural and environmental. When the level falls below 1000m^3/capita/year then countries are considered to have 'Water Scarcity' and any country that has less than 500m^3/capita/year is considered as 'Absolute Scarcity'.

Falkenmark et al.'s Water Stress Index has been developed by Ohlsson (1998 cited in Frank, 2006) to account for a society's adaptive capacity. He also used UNDP's Human Development Index to weight the Falkenmark's indicator, to become a 'Social Water Stress Index`.

Water availability per capita is an important water scarcity indicator of a nation. For example, in North Africa, Morocco has the highest at over 1000 m^3/capita/year, while in Egypt it is 880 m^3/capita/year, but other countries have less than 500 m^3/capita/year (Falkenmark & Widstrand, 1992; Postal, 1999). However, Mehta (2007:656) argues that water scarcity should not only be considered in volumetric terms (limited as it is by the natural availability of surface and groundwater), but there is also the need to link water scarcity with socio-political and institutional processes and management. Water scarcity often results in high levels of emigration, for example, which, as will be discussed in Section 2.3.4, may lead to local or national conflicts and wars (Homer-Dixon, 1994 cited in Mehta, 2007).

3.4.3 Causes of Water Scarcity

Water scarcity is caused by a number of factors, natural and socio-economic: physical; economic; environmental; and social and political. These reasons are discussed in the following sections.

3.4.3.1 Physical reasons

The physical reasons for water scarcity refer to a natural limitation on water resources within a country (quantity shortage). The International Water Management Institution (IWMI) has categorised countries depending on their capability to meet their estimated water demand. Thus any country that could not meet its demand for water due to a natural shortage is considered to be in physical water scarcity. This kind of scarcity takes place in arid and semi-arid regions such as Central and West Asia and North Africa (IWMI, 2007).

3.4.3.2 Economic Reasons

However, water scarcity may not arise just because of physical water shortage but because of economic reasons such as a lack of sufficient financial resources or poor service delivery. This type of shortage is more apparent in poor countries such as Sudan and Egypt. It occurs as a result of lack investment in water infrastructure and effective technology (Rijsberman, F. 2006).

3.4.3.3 Environmental Reasons

This kind of water scarcity means water is abundant within a country but the population are not able to access it due to environmental problems such as pollution by pesticides or contamination by salt water (Rijsberman, 2006). Increased populations are leading to the depletion of existing water resources, which in turn make them unusable or high costly to treat. This can be clearly seen in the Arab region in Asia where irrigated farming is expanding which in turn increases use of chemical fertilizer and pesticides and therefore raises the levels of contamination (UN, 2003).

3.4.3.4 __Social and political reasons__

Social and political reasons for water scarcity occur in places where there may be an abundance of water. However, people are not able to access the water as a result of political issues or socio-cultural reasons or poor water management and policy. This can be clearly seen where the water is abundant but the scale of development projects presents major challenges its management (Youkhana & Laube, 2006).

Appelgren and Klohn (1999) pointed out that water scarcity is partly a social construct which is determined by water availability and consumption patterns. Therefore, it may be more beneficial to define water scarcity as a particular mix of availability and demand at which water stress occurs, rather than an absolute per capita figure.

Water scarcity is also associated with population increases. Cosgrove and Rijberman (2000:5) point out that during the 20th century the population of the world has increased by three times; usage of water has increased up to six times. Lutz et. el. (2004:17) have mentioned that 2 billion were added to the world population in the past decades and that it is expected that significant world population growth will add at least 2 another billion, with the world's population thus to approach 8 billion.

This increasing of the world's population leads to increased food demand which is resulting in increased pressure on water resources. In West Asia and North Africa, for example, cereal imports are expected to increase up to 83 million tonnes by 2025, where they were 38 million tonnes in 1998 (Rosegrant, 2002). Water use has increased as the average income has increased, affecting patterns of consumption, and thus creating water scarcity. For more illustration, consumption patterns contribute to drawing the picture of future resources use. For instance, consumption patterns for meat are rapidly increasing every year to exceed 465 million tonnes in 2025 where the figure was 229 million tonnes in 1999 (FAO, 2006). This rapid increase in meat consumption may affect water use depending on the country producing livestock, water used in the production of beef ranging between 11,000 l/kg in Japan and 37,800 l/kg in Mexico (Hoekstra & Chapagain, 2007).

Chatterton et al (2010) pointed out that the source of water use is important to judge if the meat production affects the environment. For example, if livestock are fed on foodstuffs produced under irrigation in water-scarce areas, this water use may have a significant impact. However, if animals eat rain-fed grass, the impact of water use may be low or negligible. UK livestock production, for example, is very different to that in drier regions, such as parts of North America where much of the diet is sourced from crops grown in dry areas and irrigation is more common than in the wetter UK (Chatterton et al, 2010).

3.4.4 Water Scarcity and Conflicts

Water scarcity is an important issue not just for the individuals affected but in certain parts of the world it is behind conflict and war. For instance, conflict between African tribes in Darfur is mostly related to water scarcity as a result of physical and environmental problems exacerbated by climate conditions. This conflict has caused a significant number of victims, either through death or homelessness (Selby, 2005)

3.4.5 How to Compensate for Water Scarcity

Overcoming or reducing water scarcity can be achieved in two main ways (UN, 2003). The first is by developing additional water supply resources through the import of water from abroad, by developing non-conventional water sources, such as desalination and the reuse of waste water and by collecting rainwater, from large-scale dams to small-scale dishes on buildings. The second is focusing on water demand management by rationalising consumption through shifting to consuming low water-use products from high water-use products. Another element in reducing demand is by importing food from water-rich countries. This trend has been effective in alleviating water scarcity in different parts of the world, such as the MENA region (Yang & Zehnder, 2002).

Raising awareness of water scarcity should play a vital role in sustainable water management. Thus, Allan (2002) argues that although politicians and environmental researchers are aware of water scarcity, it is noticeable that the public discourse is still weak around water issues. However, authors such as El-Naser (2005) claims that in some circumstances raising public awareness is not the only way to help in improving water management. Therefore, he argues that, if other solutions such as improving water productivity are applied along with raising public awareness, it would be more effective in developing water management in some regions. Historically the political priorities of MENA have been firmly entrenched in security and defence considerations, impervious to the increasingly serious environmental challenges facing the region. However, there is a growing consensus that the productive efficiency of water infrastructure must be addressed and improved, which has become an important part of the normative political discourse as part of general economic development planning (E-Naser, 2005).

3.5 WATER MANAGEMENT

3.5.1 Overview

The scale of the water problem means that it must now be treated as a global concern and not just a national concern. The imbalance in the supply and use of water is related, most importantly, to food security, which often cause or exacerbate different kinds of conflict Hoekstra and Chapagin (2007). In light of the rapid increase in the world's population, which has exploded from less than 2 billion in 1910 to a projected 10 billion by 2050, (Figure 2.1), water management, in all its aspects, has become a significant global challenge. Thus, UNESCO (2003) highlights that more than 1 billion people do not have access to the clean water and about 7 billion will be under the threat of real scarcity by 2050.

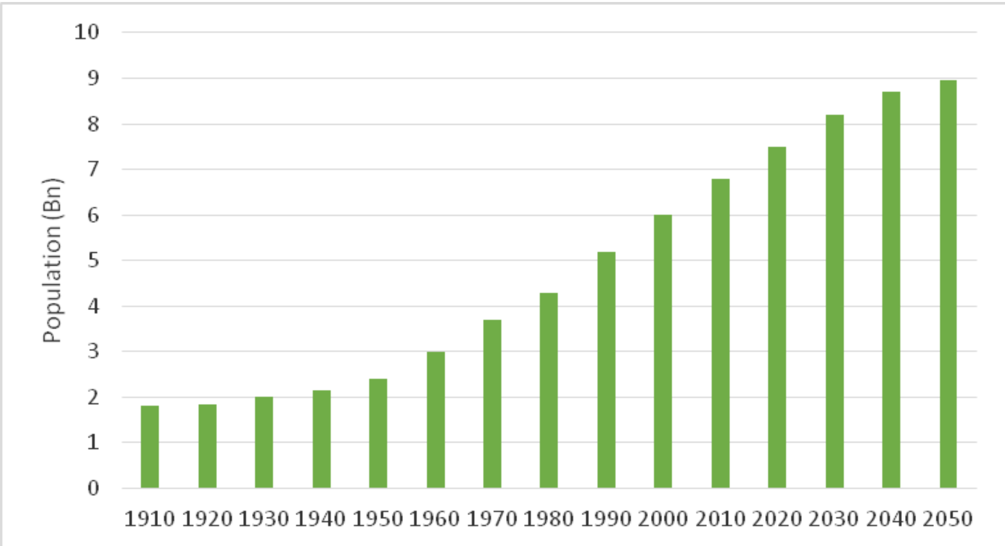


Figure 3-1Historical and Projected World Population (UN Population Division, 2017)

It is useful to review the current approaches of water management across the world, which mostly focuses on water supply management, such as finding additional water supplies. Improving water efficiency could be made on three levels of water use: local; national; and global. The aim of water management should be using less water to gain the same output. Therefore, systematic and integrated decision-making is required to achieve sustainability in water resources management, recognising the relationship between decision-makers on all three levels (Gallopin & Rijsberman, 2000).

At each level – local, national and global – water resource management has to focus on the two sides of the equation: supply and demand. While water supply management focuses on increasing quantity, water demand management focuses on reducing water demand (Savenije, 2000). These aspects are discussed in the following two sections.

3.5.2 Water Supply Management

The rapid increase in population experienced since the beginning of 20th century has imposed additional pressures on water resources in order to meet increased demand. The extra population has resulted in increases in domestic, agricultural and industrial use, impacting on both quantity and quality, and resulting in attempts to improve supply (Al Radif, 1999). The response of water resource management to increasing demand for water (due to the essential increase of population relative to available water capacity and infrastructure as well as aspiration lifestyles) has generally been met by channelling water from legacy sources (e.g. reservoirs) toward new settlement areas, as part of general urban planning rather than a comprehensive water strategy (Figure 2.2) (Al Radif, 1999).

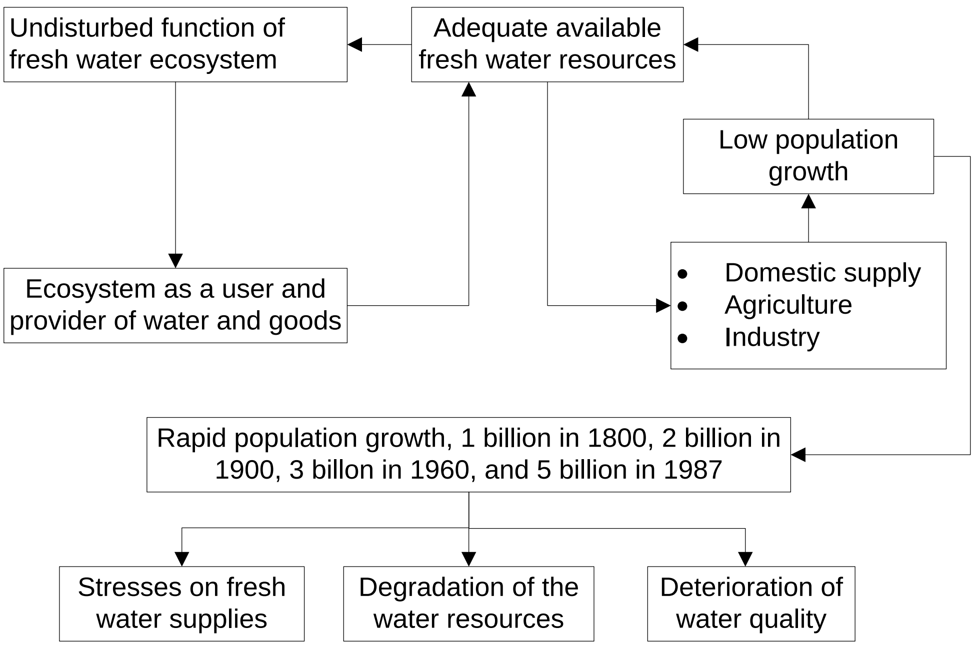


Figure 3-2 The Main Components of Supply Driven Management Alradif (1999:148)

As stated above, water supply management focuses on managing the existing water resources more efficiently as well as searching for additional supplies. This includes, in Libya, for example, the widespread construction of dams in high-water areas, with the contents used in short periods of drought and transferred to where it is needed. However, this solution is only effective where runoff is high and there is a strong systemic enforcement of regulations. Developing countries, particularly those in arid or semi-arid areas such as Saudi Arabia, have a noticeable weakness in the enforcement of regulations that has led to ineffective water resource management (Postel, 1992; UNEP, 2002).

Furthermore, there is a lack of awareness among both people and decision-makers about the need to conserve supplies. In countries, such as China, water transfer from high-water areas to the population centres has been successful as a part of the solution to water shortages. However, in countries such as Yemen no alternative solutions are available, which has resulted in increased pressure on local water resources and has led to depletion of its water resources (Chapagain and Hoekstra (2007).

Water supply as Utilisateur (2006) mentioned could be increased from existing sources – even it is difficult – in several ways, as follows:

- Storing water in new distribution systems as a warranty against unpredictable supply problems
- Aquifer recharge, strategic use of groundwater
- Increased pumping from strategic aquifers (traditionally used for droughts)
- Targeting water supply for specific uses (e.g. higher quality for residential areas and poor quality for industrial zones)
- Reusing water from sewerage in non-domestic applications (e.g. agriculture)
- Importing water (e.g. by barge)
- Desalinization

While some regions, such as the Arab region including Libya and the Gulf Arab countries, have used new technology such as power plants (Sea water desalinisation) to increase water supply resources, poor countries, due to financial shortages, are not able to afford this technology.

3.5.3 Water Demand Management (WDM)

According to Utilisateur (2006:34) 'The term "water demand" is defined as the volume of water requested by users to satisfy their needs'. Water demand management refers to the implementation of policies or measures which serve to control or influence the amount of water used (Utilisateur, 2006). It focuses on reducing demand for water by means such as raising awareness and shifting consumption patterns to lower water requirement products.

The traditional approach to meeting the rising demand was by increasing the use of existing water resources. This has created serious problems of unbalanced water resources in terms of water availability and withdrawal, water shortages, and the degradation of water quality (Chapagain and Hoekstra (2007).

Until the recent past, for most developing countries in particular, water resource management was oriented towards supply-driven approaches which involved looking for solutions through new water supply projects. Shifting towards water demand management has become indispensable for the sustainability of water resources, the environment, economic efficiency and social development (Hoekstra, 2007).

WDM can be achieved by the control of several types of factor, which are: technical, economic, administrative, financial and social measures to regulate the use of water with the aim of amount, manner and price in which water is accessed, used and disposed, with the ultimate goal of easing pressure on freshwater resources supplies (Brooks et al., 2003). In the simple way, the International Development Research Centre (IDRC) defines the water demand management as "To get the most from the water we have" (Abu Qdais, 2003).

According to Fang et al. (2007) water demand management refers to that supplying water is only one side of the supply-and-demand paradigm of water utilisation, and many initiatives have been undertaken to reduce demand by improving behaviour and technologies to utilise water more efficiently.

The management of water demand uses different methods to control demand such as licensing, penalties and water pricing, which have improved water use by up to 95% in the US, Israel and Cyprus (Plaut, 2000). A further method is improving crop productivity efficiency by using the water efficiently in agriculture. Importing water-intensive goods instead of producing them locally is referred to as importing 'virtual water'. This expression is used to describe the amount of water which has already been used to produce crops in the exporting country. It reduces demand in the importing country as the crops are produced abroad, thus freeing up supply (Allen, 1999).

On the demand side, according to FAO (2000), several meetings about water management and environmental issues, such as the Global Water Partnership (GWP) and the World Water Council (WWC), have emphasised the important role of water users in improving water management. The FAO (2000) states that while water strategy was traditionally dominated by policy makers and water suppliers (and other industries where appropriate), modern approaches attempt to involve all stakeholders in water strategy, including end users.

Overall, water demand management seeks to find an acceptable equilibrium between limited water resources and competing, usually increasing, demands for water, using policy and technical means.

3.5.4 Integrated Water Resource Management (IWRM)

The failure of water supply to keep up with demand has resulted in IWRM being adopted to balance water supply management and water demand management against a background of population growth (Frank, 2006). The aim is to produce sustainable development in water management UN (2003).

As a response to the world's fresh water resources coming under increasing pressure due to growth in population and increased economic activity leading to increased competition for and conflicts over the limited freshwater resources, IWRM, using a participatory process World Bank (2006), focuses on working out solutions that are acceptable to all stakeholders, taking account of differing interests, particularly among the various sectors. This approach is concerned with the decentralisation of water management by involving all the stakeholders concerned in keeping with the principle of subsidiary. The subsidiarity principle, which states that management decisions

should be taken at the lowest appropriate level, with central government retaining regulatory and support roles, implies all aspects of life, such as education curriculum of children and international agencies and post-graduation studies, support water management (WBI, 2006). In other words, it promotes all levels of societies to participate in managing water resources. Bouchouata et al (2012) pointed out that environmental education in general, and water education in particular, provide a means to address the challenges of water management in water-scarce regions. This is emphasised by Jardiouia et al (2015) as they also pointed out that, as it is difficult to train people how to be aware of the need to improve water management and thus be able to manage water rationally, the role of education is crucial indeed.
Okpala (2009) pointed out that the necessity for a broad and comprehensive approach supports international cooperation and postgraduate and continuing professional education targeted to ensuring the adoption of best practices.

. In many countries, such as Ghana and Burkina Faso, reforms and measures are already being implemented in accordance with IWRM (Youkhana & Laube, 2006).

Demand-driven approaches consider all aspects relevant to water such as environmental and socio-economic issues in the integrated framework presented in a comprehensive strategy such as that shown in Figure 2.3. In other words, these are new programme considering socio-economic and cultural benefits which ensure sustainable water resources for future. These programmes may need to impose some changes in consumption patterns which are leading to unsustainable water use (Al Radif, 1999).

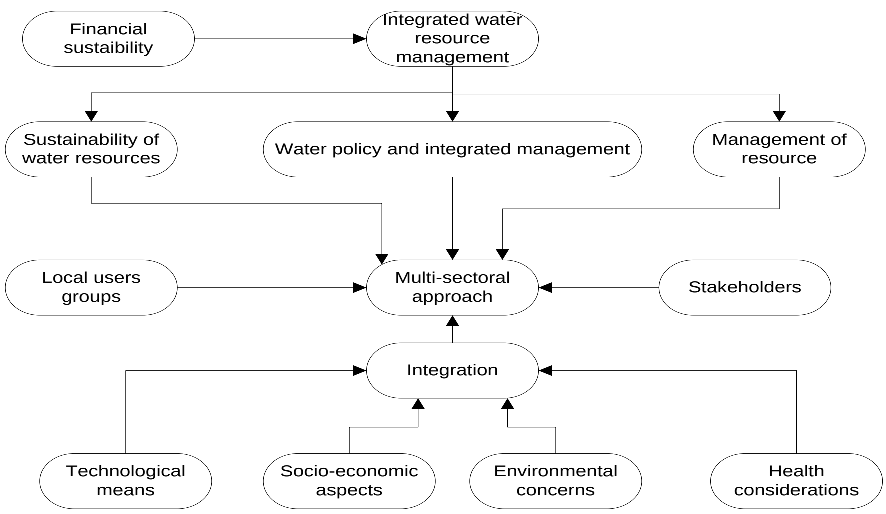


Figure 3-3 Integrated Water Resource Management (Aradif, 1999:149)

3.6 VIRTUAL WATER

3.6.1 Overview

As noted previously, authors such as Yang and Zehender (2002) believe that the water problem is not one of water sufficiency but of uneven distribution around the world. While some parts of the world can be seen as water abundant others are water scarce. Many attempts have been made to overcome the problem of water deficit in the regions where it is scarce. However, these attempts have only been partially successful because most of the effort has focused on searching for additional physical supply which is only part of the problem. Thus, the transfer of water from water-abundant areas to water-scarce areas may be a more successful and effective solution.

One effective way to mitigate the water crisis in water-scarce regions is importing food products and services in virtual water form from water-rich regions instead of producing them domestically. Virtual water is similar to the concept of water transfer but is not in the form of water but food, which is the focus of this thesis, and other products. Thus, virtual water transfer in the form of food (and other products) can save water at the domestic and regional levels. The concept of virtual water was introduced in 1993 by Allan as an alternative solution for water scarce-countries. It is defined by Chapagain and Hoekstra (2007a) as the volume of water required producing a commodity or service. The definition of virtual water has been expanded to include both the volume of water which is needed to produce particular products depending on site conditions and the volume of water needed if these products are grown where they are consumed. This highlights how much water can be saved by importing these products. Allan (1999) cited in Wichelns (2001) gives an example to illustrate this concept: "If $1000m^3$ of water are required to produce 1 tonne of wheat, then importing 1 million tonnes of wheat is equivalent to importing 1 Gm^3 of water" However, it is a quite difficult to work out how much water will be saved if the importing country cannot grow this product because of natural conditions (Hoekstra, 2003).

3.6.2 Virtual Water Trade

According to Horlemann & Neubert (2009), agricultural goods account for 80% of virtual water trade across the world, the remaining 20% by all other goods. An increase in levels of trade has been encouraged in order to help mitigate the water crisis in several parts over the world, particularly in arid areas. Global agricultural exports amounted to about US$783bn in 1990 with the largest exporters being European and Asian countries, and the lowest exporters being Middle Eastern countries (See Figure 2.4) (Chapagain et al, 2005; WTO, 2004).

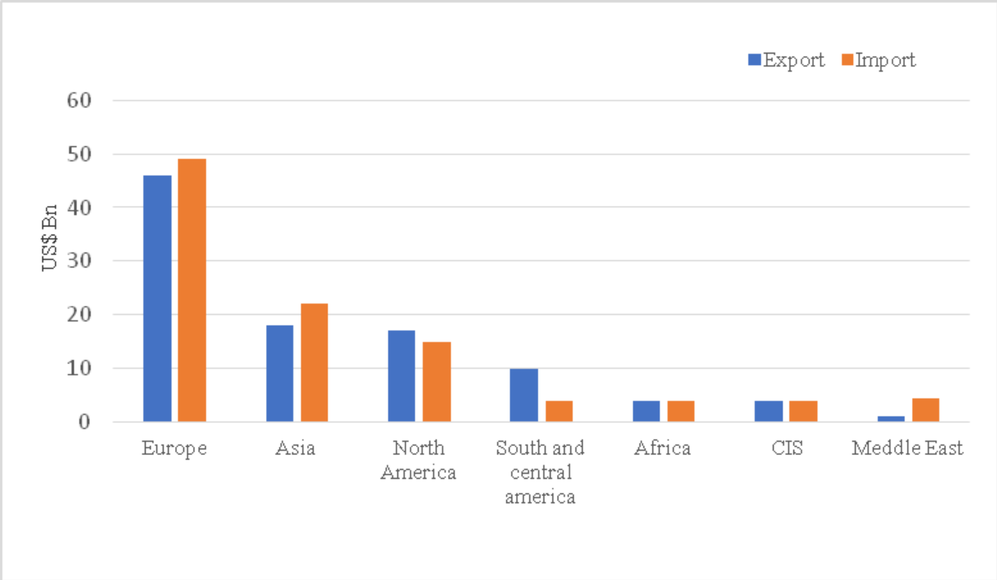


Figure 3-4 Regional Shares in World Trade in Agricultural Products, 2004 (WTO, 2004)

Horlemann and Neubert (2007) point out that the Virtual Water Trade was in place before the concept was developed. Between 1997 and 2001, approximately 987 km^3 of virtual water was traded globally each year in the form of agricultural products (Horlemann and Neubert, 2007). Oki et al (2003) state that as a result of this global trade in food, up to 455 km^3 of water is saved each year. However, Virtual Water Trade as a strategy is only likely to be successful if the following are in place in the importing countries:

Sufficient foreign exchange reserves are held to import the required food;

The social capacity to overcome any negative effects such as shifting the agricultural workers who lose their jobs into other sectors, and;

Acceptance by the political decision-makers and the public of the abandonment of food sovereignty.

Undesirable impacts could happen when applying this strategy; for example, political blackmail by the exporting countries and environmental issues in exporting countries such as soil degradation and depletion of local water resources (Horlemann & Neubert, 2007).

Trading water in virtual form between countries can physically save the domestic water resources in importing countries. Chapagain and Hoekstra (2007b) estimates that large nations are saving their domestic water resources through food trading. For example, Japan saves 94 Gm^3/year from its domestic water resources, Mexico 65 Gm^3/year, and Italy 59 Gm^3/year.

It also can be seen that how much water would be lost if Mexico moved to growing wheat, maize and sorghum instead of importing them from US. These products require 7.1 Gm^3/year of water in the US whereas they need 15.6 Gm^3/year in Mexico. Therefore, from national point of view, it saves the full 15.6 Gm^3/year as it grows nothing, while internationally it saves 8.5 Gm^3/year. However, countries such as Japan do not have the option of using that volume of water to expand crop and livestock production due to the lack of arable land. Therefore, their policymakers import this level of food to sustain their population rather than save water (Wichelns, 2010).

In the MENA region, Horlemann and Neubert (2007) show how in the global context the Virtual Water Trade can save water. In Egypt, producing 1 kg of maize requires 1,100 litres of water whereas it needs nearly half the amount in France which means a global saving of water if Egypt imports maize from France. A further example is highlighted by Mekonnen and Hoekstra (2010), who point out that Morocco saves 3.77 Gm^3 of domestic water resources by importing 906,000 tons of wheat from France each year. As the wheat is produced in France using only 600 Mm^3 of water/year, the annual volume trade in wheat between Morocco and France saves 3.17 Gm^3 on the global scale.

However, saving water either globally or nationally is not just about the domestic water deficit but other factors also play a vital role in water resource allocation. One such factor is crop productivity. For example, Japan imports maize from the USA despite maize in Japan requiring 367 Mm^3 during the growing period compared with 411 Mm^3 in the USA. However, productivity in growing maize in the USA is about three times as high as in Japan (Chapagain, et al., 2005).

Another example to illustrate this has been given by Wichelns (2010), who says That the importance of agricultural water efficiency is easily demonstrable due to the importance of the agricultural economy and the dedicated studies of agricultural phenomena. For instance, in the SADC, South Africa exports the most maize in the other countries in the region despite having relatively less water; indeed, Zambia and Zimbabwe are major importers of this maize, both of which have significantly higher rainfall.

De`Fraiture et al. (2004) point out that the researchers in the International Water Management Institute have clarified the national and international impacts of the virtual water trade. They illustrated that 178 km^3 of irrigation water would be added to the 433 km3 of water used to produce 215 million tonnes of grain in 1995 if the grain were produced in the importing countries.

3.6.3 Virtual Water Trade Prevents Conflicts

The concept of water conflict or water wars has appeared as a security issue since the 1970s. In 1979, after the peace agreement with Israel, Egyptian President Anwar Sadat stated that water is the only reason that could return Egypt to war (Starr, 1991). In addition, Cosgrove (2003) quotes UN Secretary General Kofi Annan in 2001 stating that: "If we are not careful, future wars are going to be fought over water and not about oil".

Since the 1990s, the global freshwater problem has become worryingly clear, and it has produced much academic debate and in the popular media. This debate is about to what extent international water supply pressures will reach a critical point that may lead to conflicts and fights over regional water security. Prud'homme (2011) and Wolf (1999) claim that the possibility of war over water is less likely to happen compared with other resources such as oil. However, Dinar (2004) points out that the rapid increasing of populations combined with changing circumstances of water supply resources in different places over the world is rather likely to aggravate existing tensions over water security and generate new sources of potential war in regions that are seem stable today.

Armed conflicts are only one of the possibilities of water war. Fighting over water may take different forms such as armed conflicts inside a country, national violence and develop to occupation of a region. Tignino (2010) has pointed out that water scarcity is a massive threat to human security of the most immediate kind, but it also contributes to international political insecurity. For instance, some major water resources are already hotly contested, such as the Golan Heights and the River Jordan, which are potential sources of major conflict in MENA.

On the other hand, Thomas (1998) rejects the analysis of water war. Thomas mentions that the side of cooperative and shared water resources has been increasingly recognized. However, there are other elements related to water management policies that can cause violence. For instance, the privatization of water services and developing hydroelectric installations caused the violence in Cochabamba, Bolivia, during the spring of 2000 (Postal et. el., 2001)

Fluharty (2010) illustrates that the idea of water wars is based on the theory of increasing population resulting in increasing water demand in water-scarce areas, in turn leading to conflicts over the water rights. Importantly, it is not just water shortage that can be a cause of conflict; it can happen because of mismanagement of water resources and lack of cooperation. For example, Burkina Faso has witnessed conflict between farmers and cattle breeders in rural area in the south (Youkhana & Laube, 2006). Furthermore, inequality in water distribution exacerbated by drought conditions caused around 50 violent clashes over water in 2009 between local families in the Indian state of Madhya Pradesh (Fluharty, 2010).

In MENA countries such as Egypt, Jordan and Iraq are dependent to a greater or smaller degree for their water on rivers that pass through other countries. In order to mitigate the risk of potential conflict over scarce resource, virtual water has been proposed as part of the solution (Hummel et al, 2006). Thus arguably, the absence of war over water between or within water-poor Middle Eastern countries is due, at least in part, to the importing of their required products in virtual water form (Figure 2.5) (Allan, 1998). Thus, countries such as Jordan, which uses more water than it can regenerate, has led to competition but not conflict among water uses and users. Iraq, as another example, has dampened the likely conflict with its neighbours by adopting this strategy when it shifted towards importing more agricultural products (Horlemann & Neubert, 2007).

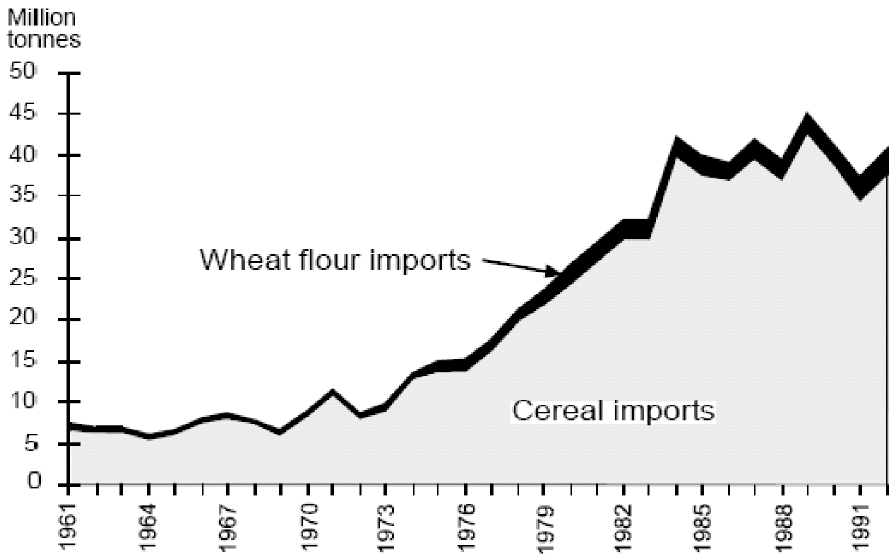


Figure 3-5 Imports of Grain and Wheat Flour by the Middle East (1961-1992) Jobson (1999) cited in Horlemann & Neubert (2007)

The lack of conflict has led Wolf (1999) to argue that conflict is very rare because a significant number of international agreements manage the use of shared water resources. He goes on to state that negotiations between countries on cross-border waterways often encourage cooperation rather than causing conflicts. A good example is the case of Turkey, Syria and Iraq where the competitive situation over using water from the Euphrates and Tigris has been mitigated by bilateral agreements between the countries.

3.6.4 Virtual Water Trade Supports Other Sectors

The Virtual Water Trade can be used as a tool to save money to fund other projects or activities which support the development of the national economy. For example, in the case of imported food, there would be no need to construct dams to save additional water which in turn would save money to invest in more effective ways such as developing irrigation systems, desalination of sea water and other industrial activities to create new jobs (Horlemann & Neubert, 2007).

3.6.5 Problems associated with Virtual Water Trade

There are a number of problems associated with the virtual water trade. First, not all virtual water trade results in saving resources. For example, in 1995 India exported 2.3 million tons of grain, which consumed 17.4 km^3 of water, to Indonesia, which would have consumed 16.7 km^3 of water if it was grown in Indonesia. Thus, in this case it can be considered as water loss of 0.7 km^3 (De Fraiture et al. 2004 cited in Horlemann &

Neubert, 2007). Furthermore, Richards and Waterbury (1996) and Turton (2002) point out those political issues such as virtual water dependency and the failure to achieve self-sufficiency may appear. Therefore, decision-makers need to find the balance between these issues and achieving food security. In the water exporting countries, soil and water depletion may also arise (Hoekstra, 2009). The following sections look in more detail at the issues of water dependency, social risks and environmental risks.

Although the role of virtual water is to mitigate the pressure on the water resources particularly in the regions of scarcity, there are several issues that have to be considered before changing a strategy from virtual water importer to exporter, or the reverse. Authors such as Belloumi and Matoussi (2008) emphasise that the arid areas have to continue to import their required food to meet domestic demand, in the Middle East and North Africa in particular. Under that strategy, farmers should look for other opportunities to increase their incomes. However, climate changes and energy prices may impact on the trade patterns more than just the water scarcity issue. El Fadel and Maroun (2003) cited in Wichelns (2010) illustrated that point by giving Lebanon's water management as an example. They pointed out that although Lebanon is considered as a potential exporter of virtual water to other Middle Eastern countries, at the same time it imports a considerable volume of virtual water. The authors suggested that there are several issues not related to water scarcity such as national security, food security and life quality have to be considered while drawing up a water strategy.

China, for example, has conducted a water transfer project from south to the north to improve its food security and save jobs for farmers who are mainly dependent on the agricultural sector in the north. However, the volume of virtual water trade from the north to the south in China is bigger that the reverse. Ma et al. (2006) mention that 52 Gm^3 of virtual water was sent to the south in 1999 while the proposed amount of annual water transferred from the south to the north is 38 Gm^3/year. Therefore, these authors suggest environmental implications and other considerations should be considered during the taking of decisions to move so much water from the south.

3.6.5.1 <u>Water dependency</u>

Hoekstra and Hung (2002) state that water dependency is measured as "the ratio of net virtual water imports to total national water appropriation". Chapagain and Hoekstra (2007) give a slightly different version, as "as the annual volume of water resources used in other countries to produce the goods consumed by the inhabitants of the country concerned".

The dependency on external water resources is already substantial for many countries and is projected to increase further. Countries such as Saudi Arabia and Israel have a high-water dependency combined with high degree of water scarcity. Positively, these countries have sufficient foreign currency to ensure that water needs can be met, through the import of food. However, water dependency creates its own problems in that importation becomes vulnerable to breakdowns in the political or security relationship with the exporting country. Therefore, it is crucial for the importing countries to carefully choose its trading partners and verify food suppliers and establish strong contracts in order that imports will not be affected by any future political or security tensions (Horlemann & Neubert, 2007).

Some authors such as Roth and Warner (2008) and Neubert et al. (2006) have raised their concerns that virtual water trading may place the importing countries at risk of political blackmailing by water-rich exporting countries. Therefore, these authors have recommendations to exclude developing countries from any virtual water trading strategy.

Importantly, countries such as Yemen have a high degree of water scarcity but combined with low water dependency. This is because Yemen lacks the financial resources to import the food needed (Chapagain & Hoekstra, 2008). This creates its own set of socio-economic problems.

According to the World Bank (2008) depending on global market for food importing leads to susceptibility to price increases and the volatility of food markets. Egypt, for example, is struggling substantially to maintain its decreasing foreign exchanges reserves. Egypt's large annual food imports cause the country to run out of fiscal reserves and leads to the country`s dependency on the price fluctuations of food in the international markets (James, 2013).

3.6.5.2 Social risks associated with the virtual water trade

Although this strategy could be a solution to the water shortage in water scarce-countries, it would be a risk in terms of the social aspect. Depending on the level of development the country concerned has reached, a large proportion of the population may be affected. In some water-scarce regions, such as sub-Saharan Africa, up to 90% of population is employed in agriculture (El-Naser, 2005). Even in the MENA agricultural employment is lower but much of the population is dependent on agricultural activities for their income. In these countries, the social effects of expanding the virtual water trade would lead to many workers losing their jobs. Therefore, they tend to migrate to the cities looking for other jobs, but these are difficult to be gain due to their lack of education and skills to help them to compete in the market. Furthermore, the cities may have not sufficient infrastructural capacity to absorb the additional workers leading to the problem of growing slums (Jong and Fawcett, 1981)..

Thus, Kluge and Liehr (1995) raise the question of how agricultural workers in the farming sector can meet their basic needs, including food. Therefore, they call for "a regionalized examination of the purpose of Virtual Water Trade and its socio-economic requirements".

Rich countries, such as Saudi Arabia, are able to offer subsidies to those affected and create alternative economic activities to provide jobs. However, in poor developing countries, which cannot afford to import food, the virtual water trade is virtually ruled out because it is accompanied only by disadvantages through generating social problems, so food security cannot be achieved (Horlemann & Neubert, 2007). Therefore, the virtual water trade strategy is a realistic option only for countries that have sufficient foreign exchange.

Researchers such as El-Naser (2005) discuss the impact of replacing agricultural products with imported products on social life in rural areas. He argues that in the MENA countries there are several constraints against adopting the virtual water trade concept as a policy to compensate for water shortage. The most important of these constraints are that the old farmers will rule out new policies for water allocation and also the rural lives of those old farmers' families have a historical, economic and cultural value.

As mentioned above, there is also the problem of populations migrating from the rural areas to the cities to seek job opportunities instead of agricultural activities as alternative income. Agriculture employs about one-fifth of the MENA population; the use of virtual water would dispossess rural communities of their traditional industries and throw them into an already overcrowded labour market in the cities, for which they are uneducated and economically unequipped (El-Naser, 2005).

In the developed counties, greater attention has been given to the social capacity than has occurred in developing countries as Kluge and Liehr (2005:13) illustrate (see Figure 2.6).

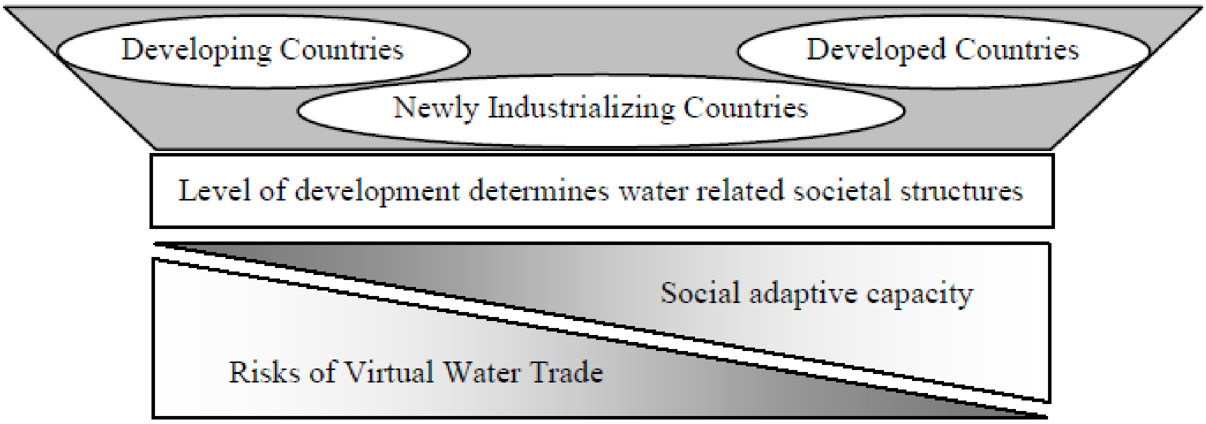


Figure 3-6 Potential of Society to Adapt in Water-Scarce Countries (Kluge and Liehr, 2005)

In this figure, Kluge & Liehr point out that sustainable use of water grows with the level of development and, based on this observation, formed the water scarcity index for developing, newly industrializing and industrialized countries.

3.6.5.3 Impact on water resources of the virtual water trade

(a) Background

Although the aim of adopting virtual water trade is to protect water resources and therefore, in theory, the environment, it can lead to problems in the eco-system in exporting and importing countries, which can suffer from a depletion of their local resources that impacts negatively on the local eco-system. A clear example is given by Partzsch and Schepelmann (2005). The over-exploitation in Ogallala aquifer in the USA for agriculture and cattle-breeding means the level of the water table is declining by up to 1.5m a year. This example illustrates that any virtual water trade should be introduced as a part of a comprehensive water resource management strategy that avoids simply shifting the water problem from one country to another. Furthermore, Partzsch and Schepelmann (2005) insist that a full analysis should be undertaken to assess for any potential ecological problems in exporting countries.

Attempts to increase the output of crop production have resulted in the over-use of pesticides and fertilizers, for example in South Africa, Botswana, Kenya and Ethiopia (Horlemann and Neubert, 2007). Mekonnen. et al. (2012) point out that there is a concern about the environmental impacts of commercial farms in Kenya raised by some studies such as Kitaka et al. (2002) and Gitachi (2005). Those studies showed large amounts of nutrients in the upper catchment of Lake Naivasha Basin in Kenya as a result of commercial farms of flowers produced for exportation. Because of that, vegetation on the riverbank could be lost.

It is mentioned by Gawel and Bernsen (2013) that when a country attempts to increase agricultural production for short-term economic gain (i.e. cash crops), without appropriate sustainability practices, it inevitably inflicts numerous environmental pressures, including increased water use, which is evaded (indeed, on the macro-economic level, outsourced) by the importing country.

In relation to importing countries, the virtual water trade is seen as a tool to protect water resources from depletion but also environmental impacts such as caused by pollution from agro-chemicals. However, the switch from an agricultural economy to an industrial one can see pollution caused by industrial wastewater. Therefore, the virtual water trade does not inevitably protect the environment (Horlemann & Neubert, 2007).

As the trade in virtual water of the Netherlands is well-characterised (Witmer and Cleij, 2012), it is helpful to use the country as an example in considering the impacts of the trade in virtual water in the following case studies.

(b) China

Agricultural products have significant impacts on the water resources in China. The northern part of China has a significant water problem in which rivers are contaminated, which poses restrictions on irrigation and risks to public health (Mu, X. and Khan, S., 2009). The most important basin impacted by the production of cotton and groundnuts is the basin of Huang He (the Yellow River); this historic river gets dry for at least three months a year as it is a water provider to the most important farming region in China. Smakhtin et al. (2004a) pointed out that this river basin has a withdrawal-to-availability ratio of 94%. In addition, the groundwater extracted by farmers in the northern plain of China is 30 Gm^3/year more than is replaced by rain (Smakhtin et al. 2004).

Since more than 40% of the water used for agricultural products, particularly cereals, comes from groundwater resources, groundwater has come under pressure from over-exploitation (FAO, 2007b). This hinders the development of irrigation and most old irrigation projects will not be worked in an effective way, which clearly affects the stability of agricultural development in the country (FAO, 2007b).

(C) India

An increasing number of problems are expected in the near future, related to the challenges of water management, including civil unrest (Fraiture et al., 2008). The World Bank (2007) has identified India as particularly vulnerable in this regard, with its large population and uneven allocation of water between administrative regions, along with deteriorating irrigation infrastructure.

After oil crops, cotton (cultivated in northern and central India) and coffee (grown mainly in southern India) are the most important crops grown in India for export. All of these crops are produced in water scarce areas. For example, castor oil crops produced in the Tapti basin have a withdrawal to availability ratio of about 128%, and cotton production in the Indus basin has a withdrawal-to-availability ratio of 1292% (Smakhtin et al., 2004)

The Krishna basin, representative of coffee production, has a withdrawal to availability ratio of 157%. According to IWMI (2008), increasing tensions are rising between states that share the Krishna basin due to the influence of severe water problems on land use and water allocation.

(D) Spain

To overcome water scarcity in Spain in the past, particularly in the Segura, Jucar, Guadiana and Gualdaquivir river basins, water transfer infrastructures have been established between basins to meet the escalating water demand and water shortage problem (Müller&Hennings, 2000).

Crops produced in Spain that contribute to the external water footprint of countries importing Spanish agricultural product include citrus fruits, almonds, grapes and wine, olive oil and various livestock products. Citrus crops are mainly produced in Valencia,Andalucía and Murcia. The main citrus is orange. Olives and grapes are mainly produced in the Castilla and La Mancha regions, respectively (INE, cited in Oel. (2008).

(E) South Africa

According to the FAO (2007a) water resources in South Africa are expected to be placed under great stress by 2025 as a result of over-exploitation of basins, particularly in the north of the country. Therefore, it is expected that in the near future irrigation farming will decrease in order to save some water for municipal and industrial use. Although internal water transfers between basins are planned, the high cost of these projects hinders using this water for irrigation, so it would be used mainly for public and industrial usage (FAO, 2007a). The economic distance between fertile soil and water supply also makes it costly to use water from other basins and limited water availability restricts any new irrigation development on a large scale.

For example, Leff et al. (2004) pointed out that fruit is responsible for about half of the external water footprint of the Netherlands, for example, in South Africa, the most important crops being groundnuts and sunflower seeds, which account for 32%. These crops are evenly distributed across the country. It is pointed out that as a result of heavy use of groundwater, the Limpopo and Orange river basins have withdrawal-to-availability ratios of 45% and 56%, respectively (Smakhtin et al., 2004a).

In order to increase water supply, discussions are taking place between South Africa and Namibia about re-allocation of Orange River water and between South Africa and the other three countries in the Limpopo River basin (Botswana, Zimbabwe and Mozambique) about sharing Limpopo River water (FAO 2007).

(F) Mexico

Mexico, according to Van Oel et al. (2009), faces large water problems, especially in Mexico City in which the over-extraction of groundwater aquifers beneath the city led to noticeable declining water levels in these aquifers, with a drop of 9 metres since the 1990s. It is estimated that one-third of the city’s water requirements are brought from nearby areas, while a million people in Mexico City are dependent on water trucks (Van Oel et al. 2009). Although severe water scarcity is not experienced in any basins due to coffee production, producing other crops has been limited by coffee production (Van Oel et al. 2009). Coffee production is located in the regions of Chiapas, Oaxaca and

Veracruz in the south, which account for 99% of coffee production (Müller & Hennings, 2000). Coffee is the major contributor to the external water footprint of the Netherlands, for example, in Mexico, followed by sunflower seeds and oil, with 66% and 12% respectively (Müller & Hennings, 2000).

3.6.6 Critique of the Concept of Virtual Water

Although the concept of virtual water has been the subject of substantial debates and authors such as Allen and Hoekstra have agreed that it has a significant contribution to make in helping water-short countries to ensure their food security, some criticism has appeared from some writers,such as Wichelns (2010) and Ramaswamy R. Iyer (2012).

One of the questions is: does virtual water trade generate national and global water savings? In this context, Whichelns (2010) claims that the notion of water saving made by trading virtual water sounds misplaced; for instance, the conclusion that has been made by Chapagain (2006), which claims that Japan saves 94 Gm^3 of water each year through the virtual water trade, is not clear. Whichelns claims that there is no choice for Japan of using that volume of water because the strategy of Japanese leaders determined a long time ago is towards an industrialised country and would not return to its agrarian past.

Hoekstra and Chapagain (2008) gave statements that Jordan managed its local water resources through international trade by importing 4.6 Gm^3 a year while its local water resources are only 0.9 Gm^3. Given that, Jordan does not have the choice of using its domestic water resource because it is limited, and Jordan is a water-scarce country. Whichelns (2010) argues that the notion of global saving by virtual water trade might be not helpful in this case.

While the notion of virtual water trade seems to be attractive and has convinced many readers, the virtual water analyses fall short of developing our understanding of important water resource issues and also does not provide a legitimate conceptual framework to support its analyses; there is no theory that suggests that a country or region should always import water-intensive products from water-rich countries (Garrido et al. 2010).

Another criticism has been raised by Garrido et al. (2010), which is their concern that the notion of virtual water is concerned only with water and ignores other valuable inputs in producing products, such as labour, energy, seeds, nutrients and land that we should also be concerned about. The opportunity cost should also be considered.

Gawel and Bernsen (2011) pointed out that the cons of the virtual water concept are summarised by the vagueness in which it merely offers quantitative measures of water use and does not gives specific information about whether virtual water trade actually leads to an over use of water resources in the place of origin. By other word, purely quantitative measures, including increasingly detailed analyses of water footprint, cannot give an accurate perspective on the ways in which virtual water trade affects real-world water resources. "An ever more refined water footprint analysis would not change this fact [that the virtual water trade actually leads to an overuse of water resources in the place of origin]. Since no information about costs and benefits are given, the "right" direction of virtual water trade flows cannot be assessed" (Gawel and Bernsen, 2011). Furthermore, in terms of Inconsistency: even if water use could be economically assessed in a sound way, the normative framework of water footprint analysis is argued by Gawel and Bernsen (2011) to be contradictory and does not show clear "guideline" as to which trade relations could be justified from a moral standpoint.

3.7 THE CONCEPT OF WATER FOOTPRINT

3.7.1 The Traditional Way to Estimate Water Use

Traditionally, national water use was based on the volume of water extraction in the country. While this is useful, it does not reflect the actual water needs of the population in terms of agriculture (the focus of this thesis) because some of those needs are fulfilled through imported virtual water. Hoekstra (2003), cited in Chapagain (2006), developed a measure of water withdrawal that includes the virtual water in imported goods which are consumed within a country. Consequently, this measure shows both direct and indirect water use in a country. Chapagain (2006) pointed out that the prevailing method of calculating the withdrawal from the source relative to demand at the destination does not reflect the whole lifecycle implications of products' water footprints.

3.7.2 What is the Water Footprint?

The water footprint is defined by Hoekstra (2003) as an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. The water footprint of a nation breaks down into two main components: the internal water footprint and the external water footprint (See figure 2.7) (Hoekstra, 2008). The internal water footprint refers to the domestic fresh water used to produce the goods and services consumed inside the country by the inhabitants of a particular area. The external water footprint refers to the freshwater used out of the area to produce goods and services and then imported for consumption inside the particular area. It is closely related to the virtual water concept discussed above. Distinguishing between internal and external water footprints is essential when analysing the footprint of a delineated area, such as a country. Before the concept of the water footprint was introduced, there was only limited awareness among policy makers about the characteristics of the agricultural production and supply chain, which have strong influences on the volume of water consumption and pollution.

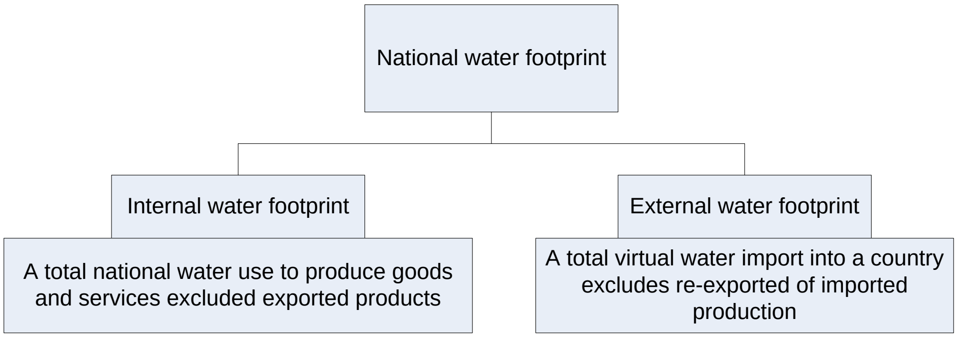


Figure 3-7 The National Water Footprint (After Hoekstra, 2008)

The concept of water footprint develops our understanding of the total water use from the perspective of consumption. It is analogous with the concept of ecological footprint and creates awareness of how and where this precious resource is used. The water footprint is an accurate indicator of water use that shows both the direct and indirect usage of a consumer or a producer Hoekstra et al. (2011). A water footprint can be estimated for an individual, a family, a village, a city, a province or a nation. It not only includes the volume of water used but where this water is used. Developing this understanding can assist in forming a basis for a better management of the globe`s freshwater resources (Hoekstra & Hung, 2005).

The water footprint of a country is normally different from the actual domestic use of domestic water either because the country is importing and/or exporting water in virtual form. For example, while the water resource of European Union is up to 559 Gm^3/year, it consumes 744 Gm^3/year. (Chapagain & Hoekstra, 2008).

In conclusion, Hoekestra et al. (2011) point out that the concept of the water footprint aspires to encompass the whole impact of consumer choices and production, but it remains essentially a volumetric measurement, and not an indicator of local environmental impacts or broader issues such as pollution.

3.7.3 The Components of Water Footprint

Hoekstra and Chapagain (2008) point out that the two elements – internal and external – of the water footprint include three components: green water, blue water and grey water. They are defined more clearly by Hastings and Pegram (2012) as among the subtypes of water footprint, the green footprint is particularly concerned with rainwater temporarily stored close to the point of precipitation (i.e. before it enters the soil and general water table system); once water recharges groundwater and it is used in production it is known as blue water; and grey water footprint is concerned with freshwater used to assimilate or dilute pollutants in relation to conventional expectations and standards of quality.

For the purposes of this thesis, the terms green, blue and grey water are used as defined by Hoekstra and Chapagain (2008) as follows:

The blue water footprint is the volume of freshwater that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community.

The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture).

The gray water footprint is the volume of polluted water that associates with the production of all goods and services for the individual or community.

3.7.4 The Importance of the Water Footprint

The importance of water footprint is that it introduces a new clear and accurate indicator of water consumption within a country by adding the volume of water in the form of virtual water to the volume of water used inside the country from domestic sources. This indicator is able to contribute to developing water management methods and help decision-makers draw up a suitable water strategy in the face of growing demand. Hoekstra and Chapagain (2007) point out that analysis of water footprints gives new data and perspectives that provide a more optimistic viewpoint about the threat of a water shortage. Because of the new knowledge, traditional water and food security concepts are likely to change in the minds of most policy-makers.

In conclusion, policy and infrastructure planning should consider water footprint for its intrinsic worth, and it is also a useful tool to increase public awareness and promote collaborative efforts that bring stakeholders together (e.g. agriculture, government and economy) (Hastings, & Pegram, 2012).

3.7.5 Major Determinants of a Water Footprint

According to Hoekstra and Chapagain (2008) to determine the water footprint of a country, there are four factors that contribute. These are: consumption volume; consumption pattern; climate; and agricultural practice.

3.7.5.1 Consumption volume

This is generally related to the national income of a country. It partially explains the high-water footprints of nations such as the USA (2,480 m^3/year per Capita). In Europe, two south European countries Italy (2,300 m^3/year per Capita), Spain (2,400 m^3/year per Capita) have high water footprints, despite not being wealthy compared to other European nations (Smil, 2008). In rich countries, where the income of people is high, consumption of goods is more than others which immediately increases water footprint. Therefore, it explains the large water footprint of countries such as the USA and Canada as a result of high meat consumption, where 1 kg of beef require 15,000 litres of water (15m^3/water) to 30,000 litres (30m^3/water). However, soybeans (for protein) and corn require an average of between about 500 and 1,900 litres (0.5 – 1.9m^3/ of water per kilogram of harvested grain (Smil, 2008).

3.7.5.2 Consumption pattern

Hoekstra and Chapagain (2008) point out that consuming large volumes of meat significantly increases the water footprint. This is one of the factors that contribute to the large water footprints of different nations such as the USA, Canada, France and Spain. For instance, the consumption rate of meat in the USA is up to 124 kg/Capita/year, which is more than three times the world average consumption rate of meat (38kg/Capita/year) (Speedy, 2003).

3.7.5.3 Climate: evaporation demand at place of production

Areas with a high evaporative demand will have a larger water requirement per unit of crop production than areas with low evaporative demand because more water is lost to evaporation. This contributes to the large water footprint of nations such as Iran, where its water footprint is relatively high (1,624 m^3/Cap/year) as a result of low yields of crops (Hoekstra and Chapagain, 2008).

3.7.5.4 Agricultural practice: water use efficiency

This refers to the efficiency with which water is used in crop production. It includes poor agricultural practice such as using inefficient technology for irrigation systems and water pricing. The awareness of farmers and decision-makers about water use efficiency has a significant effect on the water footprint of a nation. Hoekstra and Chapagain (2007) argue that this is an acceptable explanation for the high-water footprints of nations such as Thailand, Sudan, and Nigeria. For example, although the global productivity average of rice yields is 3.9 tonne/ha in the period 1997–2001, Thailand, where water efficiency is low, has rice productivity of 2.5 tonne/ha in the same period (Hoekstra and Chapagain, 2007).

3.7.6 Calculation of National Water Footprint

The total water footprint of a nation (WFn) is the total water used in the industrial, domestic and agricultural sectors to produce food and services consumed in the nation. It has two components: internal (WFi) and external (WFe) water footprint. It calculated as the follows:

$$WFn = WFi + WFe \tag{2.1}$$

Water footprint is calculated by two methodological approaches, either the bottom-up or top-down approaches which have been are developed by Chapagain & Hoekstra (2004) and Hoekstra & Chapagain (2008) with goal of calculating the water footprint of national consumption. The first considers the total of all products consumed multiplied with their respective product water footprint. The second considers the water footprint of national consumption as the total use of local water resources and the gross virtual water import excluding the gross virtual water export (Hoekstra et al., 2009).

3.7.6.1 Internal water footprint

This is defined as the volume of water that is used to produce products and services consumed within a country. It includes agricultural water use (WUa) domestic water uses (WUd) and industrial water use (WUi) but excludes the volume of virtual water that is exported to other countries (Ve,d)(.

$$WFi = WUa + WUi + WUd - Ve,d \tag{2.2}$$

- Agricultural water use

Agricultural water use is defined as the volume of water that is used to produce crops (m^3/y). It is called indirect water use

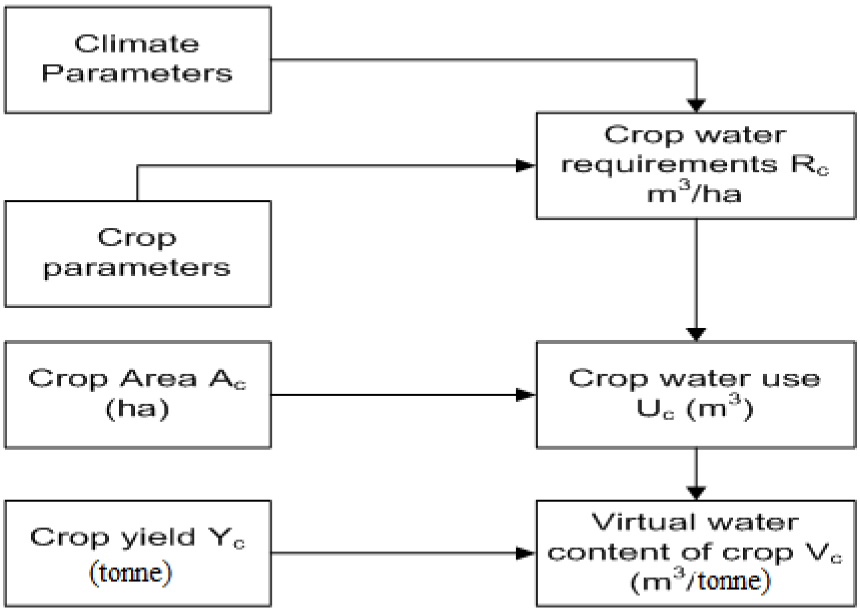


Figure 3-8 Calculation of Virtual Water Contents of a Crop (Chapagain, 2006)

The virtual water content of crops can be defined in terms of the production side as the volume of water used to produce a particular crop at the place of production and in terms of consumption side as the volume of water required to produce the same product in the place of consumption (Chapagain, 2006). The virtual water content of a crop (Vc) is calculated as the ratio of total amount of water used to produce the crop (Uc) (m^3) to the total crop production (Yc) (Figure 2.8).

$$Vc = Uc / Yc \tag{2.3}$$

Uc is calculated as water requirement of a crop, Rc m^3/ha multiplied by the total harvest area Ac (ha) of a crop in the country.

$$Uc = Rc \times Kc \tag{2.4}$$

Crop water requirement (Rc) is calculated by using CROPWAT software (FAO, 2006) which is based on the Penman Equation to estimate total evaporation (mm/day). The length of the growing period of a crop, the totals for evapo-transpiration, evaporation coefficient (Kc), max-temperature and min-temperature, humidity, and total precipitation are fed into the CROPWAT software.

Virtual water contents can also be divided between the types of water resource used to produce a crop; Vg green (rain water) and Vb blue (irrigation water).

The total water footprint of crops is the sum of the water footprints of the individual crops.

$$WFtotal = WFC1 + WFC2 + WFC3 + \cdots \tag{2.5}$$

- Domestic water use

Domestic or municipal water use is the volume of water that is used for drinking, cooking, washing, etc. It is sometimes called direct water use.

- Industrial water use

Industrial water use is the volume of water that is used in the industrial sector.

3.7.6.2 External water footprint

This is defined as the volume of water that is used to produce products and services to be consumed outside the country of production. It equals the virtual water (Vi) that is imported into a country minus the volume of imported virtual water (Vi) that is re-exported to other countries (Ve,r)

$$WFe = Vi - Ve,r \tag{2.6}$$

The virtual water content of products can be described either in terms of the production side or the consumption side; the first is the volume of water that is used to produce this product in the exporting country; the latter, is the volume of water that is needed to produce this product in the same country in which it will be consumed (Hoekstra et al., 2009).

3.7.7 The Applications of National Water Footprint

The water footprint concept has several applications in terms of estimating water scarcity from the demand perspective, water dependency, and water self-sufficiency. Methods for calculating the water footprint and its applications are shown in Figure2 .9 (Chapagain (2006; Hoekstra, 2008).

3.7.7.1 Water scarcity

Before the development of the concept of the water footprint of a nation, water scarcity was estimated in terms of volume of water withdrawn in relation to the available renewable water. This meant it was only estimated from the supply side. However, the demand side is now included in estimating water scarcity. Therefore, water scarcity (Ws) is re-defined as the percentage of national water footprint (WFn) to the total renewable water resources(WA).

$$Ws = WFn / WA \times 100 \tag{2.7}$$

3.7.7.2 Water dependency

Water dependency (WD) is defined as the percentage of external water footprint (WFe) (m^3/yr) to the total water footprint of nation (WFn) (m^3/yr).

$$WD = WFe / WFn \times 100 \tag{2.8}$$

3.7.7.3 National self-sufficiency

National self-sufficiency (WSS) is defined as the percentage of internal water footprint (WFi) to the national water footprint (WFn)

$$WSS = WFi / WFn \times 100 \tag{2.9}$$

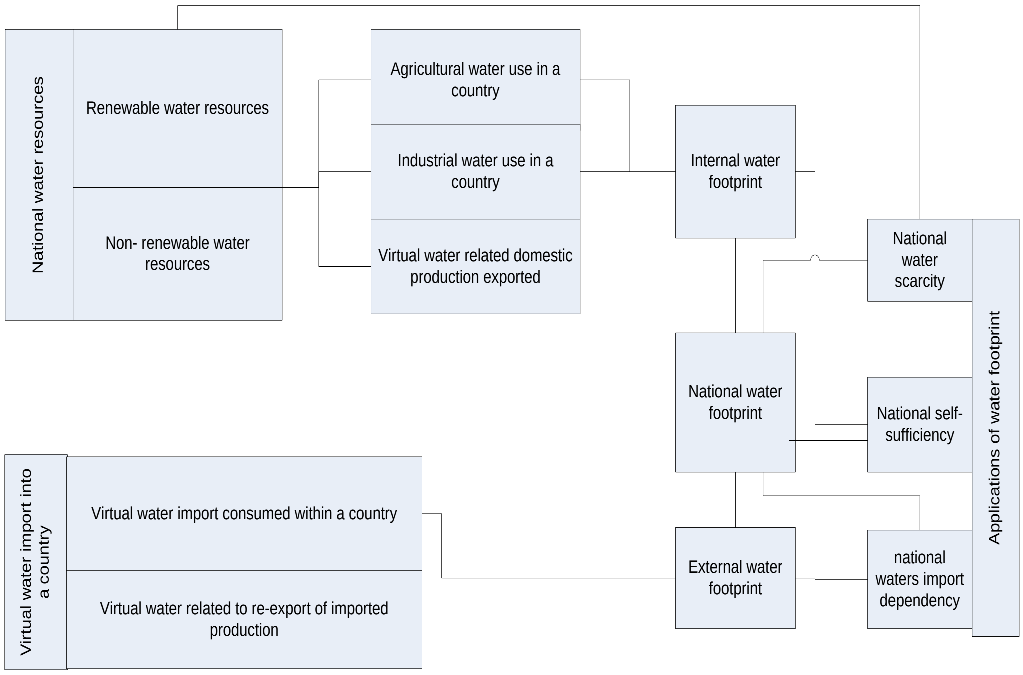


Figure 3-9 Calculation of Water Footprint Steps and its Applications (After Chapagain, 2006)

3.7.8 How to Reduce the Water Footprint

The water footprint of a country can be reduced by taking into consideration the factors described in Section 2.6.5 (Chapagain et al, 2005). The first possible way is adopting production that requires less water per unit of output and therefore gives more products per unit of water used. For instance, applying modern technology to an irrigation system and improving the rain water storage to use in supplementary irrigation.

A second way is shifting from consuming highly water-intensive products to less water-intensive products, such as by reducing meat consumption. To achieve this requires raising the awareness of consumers and planners and changing consumption behaviour. Water pricing could be an effective way to make people change their consumption behaviour.

A third way is to shift production from countries with low water-productivity to countries with high water-productivity (Chapagain et al., 2005). Jordan is a good example where it has succeeded in externalising its water footprint by depending on imports of rice and wheat from the USA which has higher water productivity.

3.8 SUMMARY

This chapter presented more insight and understanding of water management and factors that affect water resources. The food security issue and its consequences were explored, along with ways in which nations can achieve food security, including food self-sufficiency, which was explained with its environmental impacts on local water resources in arid and semi-arid countries. Importing goods in virtual water form from other countries as a means to reduce the pressure on the local water resources in water scarce countries was reviewed and the possible consequences were addressed.

Water scarcity was discussed in depth and its various definitions were explored with reference to the causes of water scarcity. It was concluded that water scarcity should not only be considered in volumetric terms; rather there is a need to link water scarcity with socio-political and institutional processes and management. Water scarcity is caused by a number of physical, economic, environmental, social and political factors. Overcoming or reducing water scarcity can be achieved in two main ways: by developing additional water supply resources; and by focusing on water demand management by rationalising consumption through shifting to consuming low water-use products from high water-use ones. This trend has been effective in alleviating water scarcity in different parts of the world, including within the MENA region.

The problem of the imbalance in the supply and use of water is related to various aspects such as food security, which often causes or exacerbates different kinds of conflict. In light of the rapid increase in the world's population, water management, in all its aspects, has become a significant global challenge. The aim of water management should be using less water to gain the same output. At the local, national and global levels, water resource management has to focus on the two sides of the equation: supply and demand. While water supply management focuses on increasing quantity, water demand management focuses on reducing water demand. Therefore, systematic and integrated decision-making is required to achieve the sustainability of water resources management, which recognises the relationship between decision-makers on all three levels. However, the failure of water supply to keep up with demand has compelled the adoption of IWRM in order to balance water supply management and demand management against a background of population growth. The aim is to produce sustainable development in water management. Virtual water trade as a concept to mitigate water shortage in the water scarce countries was explained and its advantages and disadvantages were discussed in detail.

This chapter outlined the novel concept of water footprint and explained its development. The framework of the water footprint was deeply reviewed, and the formula of water footprint calculation was addressed and identified. The application of the water footprint and the factors that determine it were explained. Finally, this chapter focused identified the gaps in existing literature concerning water footprint.

CHAPTER 3 DEVELOPMENT OF THE WATER FOOTPRINT CONCEPT: SELECTED CASE STUDIES

4.1 Introduction

To better understand the water footprint, this study considers four places with different climate conditions related to water abundance: the India, Netherlands, Tunisia and Morocco. The water footprints of these countries were explored to gain a better understanding about the concept and explore the extent to which it helps in developing water management strategies. In this chapter, the case studies were chronologically presented with consideration of the development of water footprint concept. Therefore, the presented data of each case study will be slightly different from case to another.

4.2 India case study

4.2.1 Overview

Indian was the country in which the concept of the water footprint was first assessed (Kampman, 2007). India is a large country located in South Asia bordering with Pakistan, China, Nepal, Bhutan, Myanmar and Bangladesh. It covers about 3,287,263 Mkm^2, which forms 2.4% of the world's land area. India is considered the world's second largest population with over one billion people (1,326,802,000) (United Nations, 2015), representing 18% of world population, 2% of world's land and 4% of world's water resources. India is divided into thirty-six administrative governorates (Figure 3.1).

Water scarcity in India is not new but is the natural condition for large parts of the country. Historically, the Harappan civilisation, for example, was destroyed because of prolonged drought (Sivasami, 2000). Drought is common in India, with 25 years of widespread drought recorded over the past 123 years. Sivasami (2000) attributed the present day rural water crisis in India to the lack of sustainability and equity in natural resource access.

Although India has large rivers such as, the Ganges, Godavari and the Brahmaputra, some regions of the country have historically been water scare

Because of the growing human population and over-exploitation of water resources during the last century, Sinasami (2000), recognition of this water scarcity has become more important as a policy driver (Figure 3.1). Long before, when the lifestyle was simple, and population was low, water was available in plenty. However, because of the growing population and changing lifestyle the available water resources in India have become vulnerable and depleted (Hegde, no date). As a result of that the demand on water has become growing for crop production to meet the food demand, which finally lead to identification of some Indian regions as water scarce where the water availability is less than 1000m^3/year/Capita (Hoekstra & Chapagain, 2007).

Figure 4-1 Map of the Indian States, Union Territories and river basins (Amarasinghe, 2007)

India has an average rainfall of 1170 mm a year distributed over 5-6 months in the year. This rainfall varies from regions. Although the total available fresh water in India is 4000 Gm^3/year, only 18% of the rainwater is used effectively while 48% enters the river, most of which reaches the ocean. In 2006 India consumed about 829 Gm^3 of water and it is expected to increase to 1093 Gm^{3}by 2025 (Ministry of Water Resources, 2012). Amarasinghe, et al. (2007) illustrated that 8.56% (395 Gm^3) of total annual rainfall of the country contributes to replenishing groundwater. The available groundwater resource for irrigation is 361 Gm^3, of which usable is 325 Gm^3. Kampman (2007) pointed out that water availability per capita varies from place to another whereas it is about 300 m^3 per annum for the Sabarmati basin and it is 13,393 m^3 for the Brahmaputra–Barak basin.

Amarasinghe, et al. (2007) claims that water demand will increase by 2050 due to development of agriculture projects for intensive cash crops; development in industrialisation leads to increase in water demand from 30 Gm^3 in 2000 to 161 Gm^3 in 2050 as expected; and the primary reason is India's population which is expected to rise from 1.3 billion in 2005 to reach 1.66 billion in 2050. The study of Kampman (2007) followed the division of India was into four larger regions; North, West, East and South India and covered 94% of the total territory of India and 98% of the population.

4.2.2 Crop coverage

In the study of Kampman (2007) not all crops that are grown in India were taken into account, but the crops were selected according to the FAOSTAT database and then categorised into 12 crop categories (Table 3.1) (FAO, 2006a). As the arable land can be used or harvested more than once a year, the total gross area harvested is 178 million ha/year as is shown in Table 3.1, more than the CIA (2006) estimation of 145 million ha.

Table 4-1Water use, production value and land use per crop category in the period 1997-2001

Crop categories	Production[1]	Water use[2]		Production value[3]		Land use[1]	
	10^6 tonne/year	10^9 m^3/year	%	10^9 US$/year	%	10^6 ha/year	%
Cereals	233	581	61	30	39	101	57
Oil crops	37	154	16	10	13	35	20
Pulses	13	58	6	5	6	21	12
Sugar crops	286	46	5	5	7	4	2
Fruits	45	39	4	11	14	4	2
Spices	2	17	2	2	2	3	1
Vegetables	68	16	2	9	11	5	3
Tree nuts	1	10	1	1	1	1	1
Stimulants	1	9	1	1	1	1	0
Starchy roots	30	7	1	3	4	2	1
Vegetable fibres	2	6	1	0	0	1	0
Other	1	6	1	1	1	1	0
Total	719	949	100	77	100	178	100

1 Source: FAO (2006a), 2 Water use = production * Indian average virtual water content (source: Chapagain & Hoekstra, 2004), 3 Production value = production * producer price (US$ 1997-2001, source: FAO, 2006a).

4.2.3 Virtual water content of the primary crops

Kampman, (2007) stated that, in general, the virtual water content of the crops is lower in the northern and southern regions and higher in the western and eastern regions. This difference in virtual water contents is largely because of the difference in crop yield which is mainly due to differences in the development of the agricultural areas, such as differences in using fertiliser. The different climate between Indian regions also leads to a variation in the virtual water content of a crop. The total volume of water used in India for the production of the studied primary crops is 792 Gm^3/yr. The total blue water use is 219 Gm^3/year, the total green water use is 479 Gm^3/year and the total gray water use is 95 Gm^3/year (Table 3.2). The study of Kampman, (2007) focused, for example, on milled rice as it has the largest contribution to the water use in India. Its virtual water content varies between regions; in Punjab, for example, it is 2914 m^3/tonne while in Madhya Pradesh it is 8142 m^3/tonne. Directorate of Rice Development (2006) pointed out that the large variation between regions in the virtual water content of milled rice in India is attributed to the differences in total crop yield, which has a large correlation with the fraction of the crop area under irrigation.

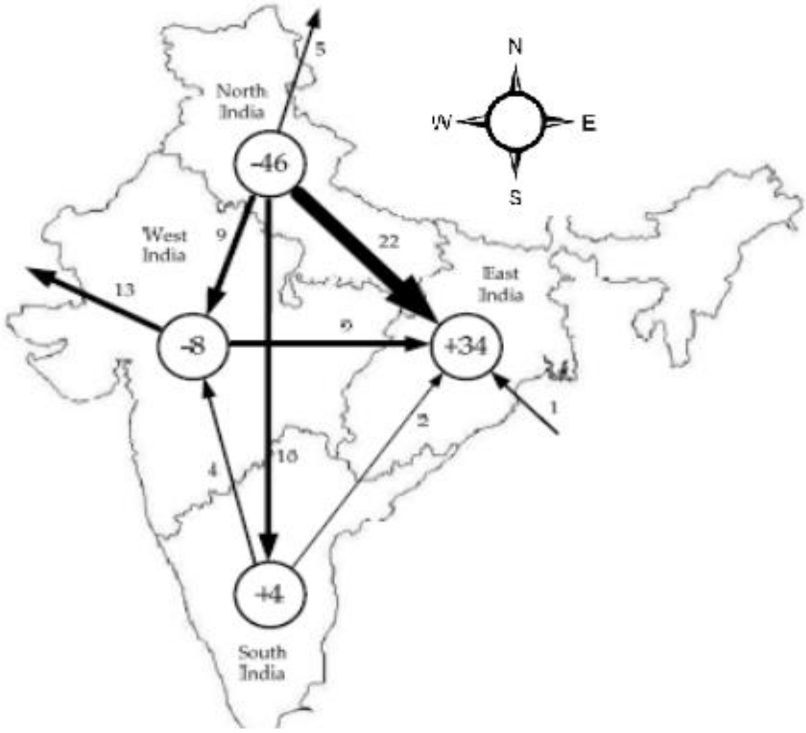


Figure 4-2 The net virtual water flows between the four regions of India in 10^9 m^3/year during the period 1997-2001 (Kampman, 2007)

The total virtual water flow because of interstate crop trade (Figure 3.2) in India constitutes 13% of the total water use (106 Gm^3/year). While the export of virtual water constitutes 4% of the total water use (29 Gm^3/year), the virtual water import is 14 Gm^3/year, which consequences in a net export of 15 Gm^3/year (Kampman, 2007).

Table 3.2 shows that the northern states Punjab, Haryana and Uttar Pradesh have a very high virtual water export and that the states Bihar, Jharkhand and Kerala have a very high virtual water import. The international export of soybean cake from Madhya Pradesh led to the largest net international export of virtual water (Chapagain & Hoekstra, 2004).

Table 4-2 Water use, virtual water flows and net import by state

States	Water Use	Virtual water export		Virtual water import		Net VW import
		Interstate	International	Interstate	International1	
Unit	10^6 m^3/year					
Year	1997-2001					
Andhra Pradesh	66652	4952	1711	569	774	-5319
Assam	17812	4	0	2304	155	2455
Bihar	38283	149	1	14469	983	15302
Chhattisgarh	27912	2835	699	2544	558	-431
Delhi	267	0	0	4026	683	4709
Gujarat	42678	3847	3120	9186	941	3160
Haryana	31956	13006	2105	638	339	-14134
Himachal Pradesh	2439	26	0	1439	212	1626
Jammu & Kashmir	4143	26	0	3101	178	3254
Jharkhand	11593	0	0	8853	430	9283
Karnataka	43358	3130	365	3699	214	418
Kerala	2897	0	2	10180	891	11069
Madhya Pradesh	64863	7671	8254	4933	162	-10831
Maharashtra	80390	5788	3949	11836	1461	3560
Orissa	37801	149	21	4552	416	4797
Punjab	43036	19351	4095	1658	914	-20874
Rajasthan	60169	9852	388	5504	512	-4224
Tamil Nadu	35496	4293	285	1397	967	-2214
Uttar Pradesh	127855	24542	2988	4777	1953	-20800
Uttaranchal	5581	1447	126	960	164	-449
West Bengal	47141	4447	1094	6238	749	1445
Total	792321	105516	29203	105516	13953	-15250

National import is blue and green water only (Chapagain & Hoekstra, 2004). Since no distinction is made between green and blue by Chapagain & Hoekstra, the total international virtual water import is contributed entirely to the blue external water footprint.

4.2.4 Water footprint of India

According to the study of Kampman (2007) and based on a population of one billion living in India between 1997-2001, the total water footprint of India related to the agricultural consumption is 777 Gm^3/year with an average of water footprint per Capita of 777 (m^3/year), which is less that the global average of 1066 m^3/Cap/year. 658 m^3/Cap/year of the Indian value is due to the internal footprint and 119 m^3/Cap/year is due to the external water footprint.

Table 3.3 shows the use of internal and external resources is divided into blue, green and gray water use. The internal water footprint represents 85% of the total average water footprint of India and the external is 15%. Chapagain & Hoekstra, (2004) pointed out that agricultural practice is one of four factors that determine the water footprint of a state. So, there is a clear relationship relation between high water footprints and poor agricultural practice in the Indian states.

An inefficient agricultural practice in the three states, Chhattisgarh and Orissa in eastern India and Rajasthan in Western India, led to low water productivity resulting in the highest water footprint per capita in those states.

Table 4-3 Composition of water footprints related to the consumption of agricultural commodities of the Indian states

States	Use of internal water resources						Use of external water resources				WFP
	Blue	Green	Gray	Total	Exp1	SC2	Blue	Green	Gray	Total	
Unit	10^9 m^3/year										
Year	1997-2001										
Andhra Pradesh	22	39	6	67	7	60	1	0	0	1	61
Assam	0	16	2	18	0	18	1	1	0	2	20
Bihar	9	24	5	38	0	38	7	6	2	15	54
Chhattisgarh	1	24	3	28	4	24	2	1	0	3	27
Delhi	0	0	0	0	0	0	3	1	1	5	5
Gujarat	12	26	5	43	7	36	3	6	1	10	46
Haryana	15	12	5	32	15	17	1	0	0	1	18
Himachal Pradesh	0	2	0	2	0	2	1	1	0	2	4
Jammu& Kashmir	1	3	1	4	0	4	2	1	0	3	7
Jharkhand	1	9	1	12	0	12	3	5	1	9	21
Karnataka	11	29	4	43	3	40	1	3	0	4	44
Kerala	0	2	0	3	0	3	6	4	1	11	41
Madhya Pradesh	14	42	8	65	16	49	2	3	0	5	54
Maharashtra	14	58	8	80	10	71	6	6	2	13	84
Orissa	3	31	4	38	0	38	2	3	1	5	43
Punjab	19	17	7	43	23	20	2	1	0	3	22
Rajasthan	21	31	8	60	10	50	3	3	1	6	56
Tamil Nadu	14	18	3	35	5	31	2	0	0	2	33
Uttar Pradesh	49	60	18	128	28	100	4	2	1	7	107
Uttaranchal	1	4	1	6	2	4	1	0	0	1	5
West Bengal	10	32	5	47	6	42	4	2	1	7	49
Total	219	479	95	792	135	658	55	51	14	119	777

Exp1 = Total use of internal water resources for export, 2 SC = Total use of internal water resources for state consumption.
(Kampman, 2007)

4.2.5 Water footprint by region

The virtual water flows within a region are considered in the calculation of the water footprint of a region as part of the internal water footprint. Table 3.4 shows the internal, external and total water footprint of the four regions of India.

Western India region has the highest water footprint either in total or per capita. This is mainly attributed to the low water productivity, a low development of agricultural practice and climatic reasons, notably variations in evapo-transpiration rate (Kampman, 2007).

Table 4-4 Water footprints of the consumption of agricultural commodities of the Indian regions

States	Total state region footprint			Water footprint per capita		
	Internal	External	Total	Internal	External	Total
Unit	10^9 m^3/year			m^3/Cap/year		
Year	1997-2001					
North	154	15	169	632	62	694
East	175	41	215	655	153	808
West	211	29	240	820	113	933
South	137	16	153	629	75	704
Total	658	119	777	658	119	777

4.2.6 *Experience from the Indian case study: relevance to this study of the water application of the footprint in Libya*

The study of Kampman (2007) shows that the total virtual water trade between Indian regions in agricultural commodities in India was 106 Gm^3/year in the period 1997-2001. Rice is responsible for 35% of the total virtual water trade; raw sugar represents 17% of interstate trade and edible oils responsible for 14% of interstate trade of water. The total virtual water flow as a result of interstate trade in agricultural commodities represented 13% of the total water use in Indian agriculture while the net international export from India represented 15 Gm^3/yr. For comparison, Ma et al. (2006) pointed out that a total virtual water flow as a result of interstate trade in agricultural commodities in China was 128 Gm^3/year in the year 1999. This represented 10% of the total agricultural water use in China.

As a result of the application of food self-sufficiency policy in Indian regions; the Rajasthan, Punjab, Uttar Pradesh, Tamil Nadu and Haryana, the water scarcity is high, and the water resources are nearest to be exhausted. Therefore, the interstate trade was helpful in alleviating water scarcity in those regions whereas the wheat trade alone saved about 23 Gm^3/year. Currently, to overcome the water scarcity in some regions, the Indian authorities consider linking those regions by transfer of water from East (abundant regions) to North (scarce regions) through the connection of rivers. However, Kampman, (2007) claims that improving water productivity in the water scare states has a better chance of reducing the national water scarcity than the proposed water transfer since implementing the concept of river interlinking project mainly reduces local water scarcity, while water scarcity needs to be reduced significantly at a national level in order to remain food self- sufficient as a nation (Verma, et al., 2009).

Although the water footprint of India was studied academically and demonstrated to be an effective way to raise awareness among the general public, businesses and governments about the global scale of water appropriation, it has not been applied in practice. Moreover, since the water footprint of India was estimated, the water footprint concept has been developed further and updated to include economic water productivity (EWP), such as in Tunisia and Morocco water footprint estimation, discussed later in this chapter.

4.3 The Netherlands case study

4.3.1 Overview

The water footprint of the Netherlands was first estimated and analysed by Van Oel et al. (2009) based on data for the period of 1996-2005. The Netherland is situated in the delta of the three major North-West European Rivers. It has a land area of 38,400 km^2 with population of which 17.3 million (Kalpakian, 2012). Netherlands is a flat country and about half of its land is threatened by sea or river floods (Figure 3.3) (Mostert, 2006). It is abundant water country with an average precipitation of which is 800mm/year.

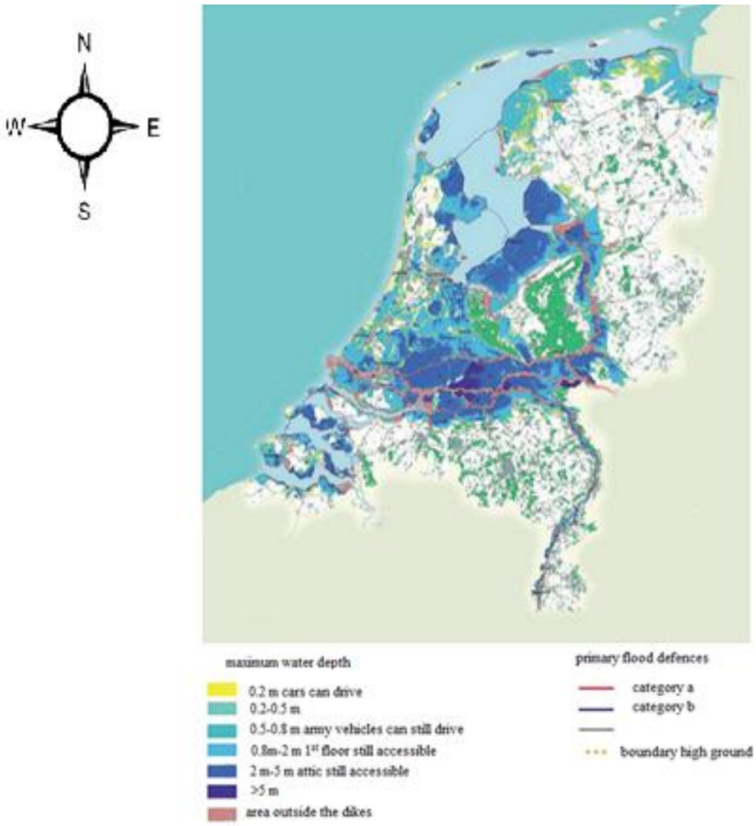


Figure 4-3 Netherlands flood risk map (Keessen, et al, 2013)

Due to growing awareness of the problem of water scarcity, the Dutch Parliament in 2012 issued a decision proposing that the government publishes the water footprint of Dutch companies importing into the Netherlands to reduce the water footprint in water shortage areas. As a result of that, the Netherlands Environmental Assessment Agency was asked to examine the extent to which water footprint would be a suitable tool for Dutch policy making.

Van Oel et al. (2009) stated that most products consumed in the Netherlands are produced abroad; some of those products, agricultural products in particular, have high water requirements during their production, with major impacts on water systems in production areas. The impacts were clearly observed in the reduced water level of rivers, lakes and groundwater tables accompanied by salt intrusion in the coastal areas and contamination of freshwater bodies (Section 2.5.5.3) (Van Oel et al. 2009).

The external water footprint of the Netherlands was identified by Van Oel et al. (2009) related to imported goods and partner countries, and the results of countries and products were compared with water scarcity indicators to identify the most significant impacts in order to identify:

- How water use outside the Dutch borders affects Dutch consumption;
- The countries in which the external footprint is concentrated;
- The main products related to this external footprint, and external water use related to total imports into the Netherlands;
- The most serious 'hotspots' (Van Oel et al, 2009) for the impact of the external water footprint; and
- The impact of the external water footprint on local water systems in the identified hotspots.

In that study of the Netherlands' external water footprint by Van Oel et al. (2009), the trade analysis covers all agricultural and industrial categories based on the information presented in the trade database of ITC (2006) and consumption analysis presented in the FAO (2007) food balance sheet (Table 3.5).

Table 4-5 Variables derived from the literature by Van Oel et al. (2009)

Input variable	Source
Agricultural water use Crop water requirement per crop per country Agricultural yield per crop per country Livestock feed composition in the Netherlands Livestock feed composition in other countries Consumption per product Agricultural production Use of fertiliser for important crops in hotspots	Hoekstra & Chapagain (2008) FAOSTAT (FAO, 2007b) CBS (2007), Elferink et al. (2007), LEI (2007) PDV (2005) Hoekstra & Chapagain (2008) FAO's food balance sheets, which are part of FAOSTAT (FAO, 2007b); data available for 1996-2003; average for this period assumed for 2004-05. FAO PRODSTAT (FAO, 2007b) FAO FERTISTAT (FAO, 2007c)
Domestic water use Domestic water withdrawal in the Netherlands	AQUASTAT (FAO, 2007a); Vitens (2008)
Industrial water use Industrial water withdrawal per country Added value in the industrial sector per country	AQUASTAT (FAO, 2007a) UN Statistic Division (2007)
Import and export of agricultural and industrial products. Precipitation and renewable water resources per country.	ITC (2006) (FAO, 2007a)

4.3.2 The Netherlands Water footprints

According to the calculated water footprint indicator (Mekonnen & Hoekstra, 2011; Hoekstra & Mekonnen, 2012), the Netherlands is the ninth largest net water importer, with about 71 Gm^3 of virtual water. This reflects the important characteristic of the Netherlands as a place of re-export for agricultural goods. The character of net virtual water imported is illustrated in Table 3.6.

This result of assessing the water footprint of the Netherlands is important for consumers, government and businesses to address the sustainability of consumer behaviour and supply chains. Moreover, the results of this study can be helpful in encouraging the cooperation between the Netherlands and its trade partners to reduce the negative impacts of Dutch consumption on foreign water resources (Hoekstra & Mekonnen, 2012a)

Table 4-6 The characteristic of net virtual water imported. (Hoekstra & Mekonnen, 2012a)

The Total Dutch imported virtual water in period 1995-2005 71 Gm^3		
Green	Blue	Grey
80% 56 Gm^3	7% 4.9 Gm^3	15% 10.6 Gm^3

The Netherlands, as a trade nation, mainly imports for purposes other than domestic consumption; thus it only consumed 30% (22 Gm^3) of total imported virtual water during the period of 1996–2005, which is called the external water footprint of national consumption. The remaining 70% (49 Gm^3, with 4 Gm^3 of virtual water produced and processed within Netherlands, totalling 53 Gm^3 annual total virtual water exportation) was re-exported after processing.

Ercin (2012) pointed out that 95% of the Netherlands' water footprint was external, and that the country has the highest ratio between external and total water footprint of all EU members of states. The Netherlands produced agricultural goods for internal consumption containing about 1.3 Gm^3 of water which, added to the imported virtual water value of 22 Gm^3, gives a total water footprint of 23.3 Gm^3.

As can be seen in Figure 3.4, the EU represents the highest contribution (48%) to the Netherlands' water footprint in terms of agricultural products, with 52% being located in other countries (Latin America 20%, Asia14%, North America 9% Africa 8%) of the external Dutch water footprint.

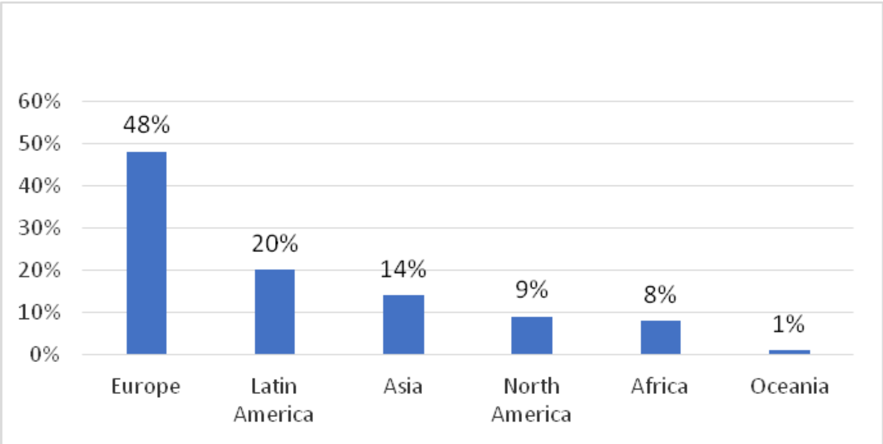


Figure 4-4 Distribution of the external water footprint of Dutch consumption due to the consumption of agricultural products, 1996-2005 after (Van Oel et al, 2009)

In relation to the sustainable use of water, many countries from which the Netherlands imports agricultural goods for domestic consumption have become blue water scarcity regions. Smakhtin et al. (2004) and Van Oel et al. (2009) gave examples ('hotspots') of countries that have water resources the sustainable use of which is at risk as a result of irrigated agriculture in order to produce products to be consumed in the Netherlands, including China (mainly for cotton), India (cotton, coffee and castor oil), Spain (fruit), Turkey (cotton, fruit and tobacco), Pakistan (cotton and sugar molasses), Sudan (sesame), South Africa (fruit and oil crops) and Mexico (coffee).

4.3.3 Experience from the Netherlands case study: relevance to Libya

According to Witmer & Cleij, (2012) the analysis of the water footprint of the Netherlands shows that the large water footprint is as a result of the large net external virtual water footprint associated with agricultural products.

From the aforementioned, the water footprint of the Netherlands can be summarised as being twice that of the average water footprint of the world, with the average Dutch per Capita water footprint estimated at 2300 m^3/year (Van Oel et al. 2009).

The external water footprint of the Netherlands comprises nearly 90% of its total water footprint, 48% of which is manifest in European countries (mainly Germany, France and Belgium) (Witmer and Cleij, 2012).

According to water scarcity indicators (Van Oel et al, 2009), China, India, Spain, Turkey, Pakistan, Sudan, South Africa and Mexico are 'hotspots' in part due to the impacts of the external water footprint of the Netherlands. Although these countries are not the main locations of the external water footprint of the Netherlands, they have the most serious water scarcity problems.

Witmer and Cleij (2012) also point out that Dutch food consumption mostly depends on using the water resources of other countries, with significant negative impacts at those countries. In considering the application of the water footprint concept, it would be inappropriate to compare its application in the Netherlands with its potential application in other countries, such as Libya, which may be different in water resources and climate conditions.

4.4 The Tunisia case study

4.4.1 Overview

The water footprint of Tunisia was first assessed by Chouchane, et al. (2013). Tunisia is classified as one of the most arid countries in the Mediterranean Sea, suffering from high water scarcity and limited food production (Benabdallah, 2003).

Tunis is situated in North Africa on the Mediterranean lies on the area of which 164,420 km^2 with population of which 9.84 million (Jagannathan (2009); Kalpakian, 2012). It is classified as one of the least water resources endowed countries in the Mediterranean basin with a rainfall variation from 1500mm in the north to less than 55mm in the south with the average 230 mm/year of rainfall.

The water resources of Tunis are limited due to the semi-arid to arid climate found in most of the country (Benabdallah, 2003). According to the Tunisian Ministry of Environment (2009), water resources are limited to an estimated 4.87 Gm^3/year in 2005, of which 4.26 Gm^3/year are renewable and the remainder is fossil ground water in the southern region. This groundwater is expected to run out within fifty years at the current rate of withdrawal (FAO, 2003).

According to Chouchance, et al. (2013) the Total Renewable Surface Water (TRSW) was estimated at 2.70 Gm^3/year. The far northern part of Tunisia accounts for about 3% of the national total (960 Mm^3/year), while the southern region represents the largest land area of Tunisia but the smallest availability of surface water, estimated by Tunisian Ministry of Environment (2009) at 190 Mm^3/year.

The total groundwater resources are 750 Mm^3/year from shallow aquifers (depth less than 50 m) and 1420 Mm^3/year from deep aquifers (deeper than 50 m). 50% of the shallow aquifer resources are situated in northern Tunisia, 33% in central and 17% in southern. Conversely, for deep aquifers the southern region has the biggest share (55%), followed by central (23%) and northern (22%) (Tunisian Ministry of Environment, 2009).

Therefore, wise management of available resources, choices in agricultural production and adopting the policy of importing water in virtual form through international trade appears to be helpful in alleviating the water scarcity (Chouchance, et al. 2013).

The study by Chouchane et al. (2013) analysed water footprint (green, blue and grey) in light of the availability of blue water. Land and water productivity were economically assessed with respect to crop production through irrigated and rain-fed farming. In addition, the economic return of exports and the economic costs of imported crops were assessed and water dependency was also analysed by Chouchane et al. (2013) related to Tunisian consumption.

The scope of analysis covers the period 1996-2005 following the methodology described in The Water Footprint Assessment Manual (Hoekstra et al., 2011).

Chouchane et al. (2013) differs from the previously conducted studies by adding the economic dimension in a comprehensive national water footprint assessment (WFA).

The notion of water productivity (WP) is closely related to water footprint. The optimisation of water is essential for all human activities, the agricultural sector in particular. Although there is no common definition of the term WP, generally it refers to the ratio of the net benefits from crop, forestry, fishery, livestock or mixed agriculture systems to the amount of water used to produce those benefits (Rodrigues & Pereira, 2009). Despite WP mostly being expressed in terms of agricultural output to the total water consumption (‘crop per drop’), it would be useful to express WP in the form of ‘dollar per drop’ because expressing WP in only physical terms does not demonstrate the economic dimension of water use. (Cook et al. 2006).

4.4.2 Tunisian virtual water import

The total imported virtual water in the period 1996-2005 was 8100 Mm^3/year (71% blue, 18% green and 11% grey, (Table 3.7) with an economic value of $10330 M/year (Chouchance, et al. 2013). Crop products have the largest contribution (94%) followed by industrial products (4%) then animal products (2%). Conversely, industrial products account for 80% of the total economic value of imported virtual water followed by crop products (18%) and animal products (2%). The large virtual water imports are largely due to cotton, wheat, soybean, maize, sugar and barley imports from France, Belgium, Italy, France, Canada and Spain. Those crops together account for 53% of the total virtual water imported (Chouchance, et al. 2013).

Table 4-7 Tunisia`s virtual water import. Period (1996-2005) (ITC, 2007cited in Schyns (2014) and Hoekstra and Mekonnen, 2012).

	Related to crop products	Related to animal products	Related to industrial products	Total virtual water imported
Green (Mm^3/year)	5610	140	-	5750
Blue (Mm^3/year)	1400	20	30	1450
Grey (Mm^3/year)	600	10	280	890
Total (Mm^3/year)	7610	170	310	8100
Economic value of imports (Million US$/year)	1840	150	8330	10330
Value per unit of imported virtual water (US$/$m^3$)	0.24	0.85	27.00	1.28

4.4.3 Tunisian virtual water export

The total exported virtual water for all products in the period 1996-2005 was 9760 Mm^3/yr (88% blue, 5% green and 7% grey) (Table 3.8) (Chouchance, et al. 2013). Agricultural products had the largest contribution to this exportation, crops accounting for 95% of total virtual water export and animal products for 3%, while industrial products represented only 2%.

On the other hand, industrial products accounted for 67% of the total economic value of exported virtual water, followed by 32% for crop products and 1% for animal products. Hence, Tunisia generated a foreign exchange averaging \$1.00/m^3.

Olive oil is the largest contributor to virtual water exports (68%), followed by cotton (26%), with both products being considered to be the main crop products related to Tunisian agricultural virtual water export (Table 3.8), with the virtual exports estimated at 6360 Mm^3/year for olive oil and 2380 Mm^3/year for cotton. Olive oil exportation is responsible for 73% of the total green water exported (6110 Mm^3/year).

Table 4-8 Tunisia`s virtual water export. Period:(1996-2005). (ITC, 20072007cited in Schyns (2014)and Hoekstra and Mekonnen,2012)

	Related to crop products	Related to animal products	Related to industrial products	Total virtual water exported
Green (Mm^3/year)	8320	260	-	8580
Blue (Mm^3/year)	400	40	10	460
Grey (Mm^3/year)	570	20	130	730
Total (Mm^3/year)	9300	320	150	9760
Economic value of exports (million US\$/year)	3120	20	6620	9760
Value per unit of exported water (US\$/m^3)	0.35	0.05	50	1.00

Tunisia is a net virtual water exporter related to the cotton trade, whereby the water footprint of imported cotton (2210 Mm^3/year) is less than the water footprint of exported cotton (2380 Mm^3/year), which means that most exported cotton from Tunisia is re-exported imported cotton (after processing), with value added. By contrast, virtual water related wheat import, which is 1850 Mm^3/year, exceeds the virtual water related wheat export, which is 190 Mm^3/year (Chouchance, et al. 2013).

Most of the crop-related virtual water export (about 85%) goes to Italy, Spain and France, with the rest distributed among Latin America, North America and Africa, with only 1% to Asia. On the other hand, the biggest part of animal products goes to Africa, mainly Libya (Chouchance, et al. 2013).

4.4.4 Water saving through virtual water trade

Although the total Tunisian virtual water export in the period 1996-2005 was 9760 Mm^3/year, the country saved more water than if Tunisia had produced the imported commodities domestically.

In this regard, Tunisia has a gross virtual water import of 8100 Mm^3/year, which would require more water, estimated at 10700 Mm^3/year, due to relatively lower water productivities in Tunisia (Chouchance, et al. 2013).

Thus, while Tunisia lost 9760 Mm^3/year related to virtual water export, it saved 10700 Mm^3/year, of water used in other countries to produce commodities for Tunisian consumption (imported virtual water by trade).

According to Mekonnen and Hoekstra (2011). This water saving was estimated at 940 Mm^3/year, comprising 62% green, 3% blue and 35% grey. Crop product imports account for 58% of total water saving, followed by animal and industrial products.

4.4.5 Water footprint of Tunis

In this study, Tunisia was divided into three provinces with respect to the climate: the north has a Mediterranean climate, the south has a Saharan climate and the central region has a climate in between the previous two (Figure 3.6).

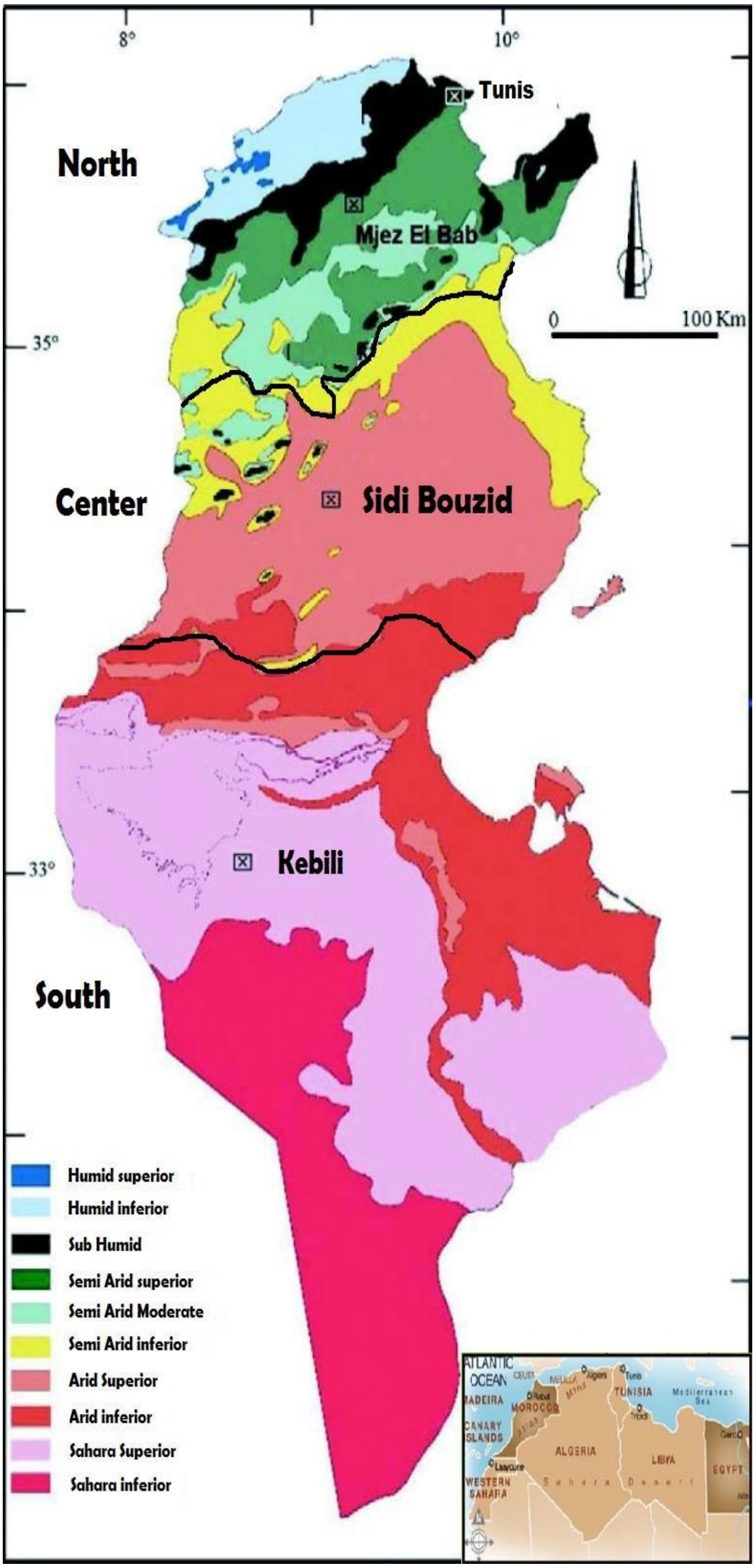


Figure 4-5 Bioclimatic map of Tunisia (Chelbi et al., 2009)

Tunisia has a total WF from production of about 19 Gm^3/year over the period 1996-2005, comprising 89% green, 8% blue and 3% grey (Table 3.9). The largest contribution to the total WF is the crop production water footprint (87%).

Table 4-9 The national water footprint of Tunisia and its components (Mm^3/year), 1996-2005 (Mekonnen and Hoekstra (2011a)

	Water footprint of crop production	Water footprint of grazing	Water footprint of animal water supply	Water footprint of industrial production	Water footprint of domestic water supply	Total water Footprint
Green	14820	-	-	-	-	16820
Blue	1330	-	60	10	40	1440
Grey	450	-	-	50	220	750
Total	16600	2000	60	60	260	19000

The water footprints of the main crops in terms of total national production represent 86% of the total blue water footprint of crop production. Almonds have the largest water footprint per unit of weight at about 20,820 m^3/tonne, which is double the global average of almonds' water footprint. However, almonds in Tunisia use four times more rain water and the average amount of blue water (Mekonnen and Hoekstra (2011a).

Tomatoes have the smallest WF with 120 m^3/tonne, which is below the global average (210 m^3/tonne). Dates, figs and grapes are the biggest blue water users, higher than the global average, especially for grapes, which use ten times the global average amount of blue water. Dates and olives together account for about 47% of the total blue WF while the production of olives accounts for 79% of the total green water footprint in Tunisia (Mekonnen and Hoekstra (2011a).

4.4.5.1 Water footprint of crop production at sub-national level

The crop production water footprint of Tunisia accounts for about 16.6 Gm^3/year, of which green water represents the biggest share (89%), and the blue and grey water account for 11%. In this total, northern Tunisia has the biggest contribution to the total WF of crop production (70%), while the South takes the smallest share (4%) (Chouchance, et al. 2013).

The Kairouan Governorate in Central Tunisia represents 13% of the crop-related WF in the whole country, and half of the Central Tunisian WF. The governorates Beja, Jandouba, Kef and Siliana surrounding the Medjerda basin take the largest WF in the north of the country (Figure 3.5), both representing about 7 Gm^3/year, accounting for 43% of the total WF of crop production in Tunisia (Mekonnen and Hoekstra, 2011b).

The blue water in northern Tunisia represents 49% of the total blue WF of crop production in the country, followed by the south with 28% and central with 23%. The governorates Gabes and Tozeur in the south, which is the driest part of the country, have the biggest blue WF, mainly because of the production of dates. The blue water footprint contributes to 68% of the total water footprint in southern Tunisia Table.3.10).

Table 4-10 The total water footprint of crop production in Tunisia by governorate (1996-2005). (Mekonnen and Hoekstra, 2011b)

Governorate*	Water footprint of crop production (Mm^3 /year)			
	Green	Blue	Grey	Total
North Tunisia	10650	650	340	11640
Central Tunisia	4000	290	100	4390
South Tunisia	160	390	10	560

The water footprint differs between the three regions as a result of differences in climate conditions (shown in Figure 3.6) and corresponding crop water requirements. This difference can be clearly seen in water footprints between the northern and southern regions, particularly for olives, wheat, almonds, figs and barley. However, the difference between the northern and central regions is not considerable (Table 3.11).

For instance, growing a unit of barley in the southern region needs about 12 times as much water as a unit of barley grown in the northern region due to the different crop water requirements between both regions (Chouchance et al. 2013). Because of the domination of rain fed irrigation in the central region, almonds and figs are grown using less blue water than in the other regions.

Table 4-11The average green, blue and grey water footprint and crop water requirement of main crops in Tunisia per region (1996-2005) (after Mekonnen and Hoekstra, 2011b).

Crop		Crop water requirement(m^3/ha)
North	Almonds	9220
	Barley	4570
	Figs	7780
	Olives	8150
Central	Almonds	9550
	Barley	4710
	Figs	8030
	Olives	8420
South	Almonds	11780
	Barley	6070
	Figs	9920
	Olives	10390

4.4.6 Economic water and land productivity at national level

Due to the limitations on surface water in most Mediterranean countries and farming activities mostly depending on irrigation, the analysis of water management should focus on irrigated agriculture. Cultivated land accounts for an estimated 35% of total agricultural production in Tunisia and represents about 80% of water withdrawal in the country (Ministry of Environment, 2009).

For the main crops grown in Tunisia, the Economic Water Productivity (EWP) on average is around \$0.32/m^3 (FAO, 2009). It is noticed that the average EWP in Tunisian rain-fed agriculture (\$0.35/m^3) was slightly higher than the irrigated agriculture (\$0.32/m^3), but EWP in rain-fed and irrigated production systems are found to be very similar in general in several crops. In irrigated agriculture, carrots and potatoes have larger EWP than in rain-fed agriculture, but the reverse is true in the case of dates and tomatoes. In irrigated agriculture, the blue water applied is not always more productive than the green water. For carrots, potatoes and tomatoes, the blue EWP in irrigated agriculture was found to be higher than the green EWP, but for dates and grapes the reverse was found. Although production of dates, grapes, olives and wheat is responsible for most blue water consumption, their EWP is low compared to potatoes and tomatoes, which have the highest blue EWPs (Chouchance, et al. 2013).

The reverse was found in case of Economic Land Productivity (ELP), which is higher in irrigated agriculture than in rain-fed agriculture for all selected crops. In that case, it can be concluded that irrigation water is generally not applied to increase land productivity (\$/ha) rather than to increase water productivity (\$/m^3) (Mekonnen and Hoekstra, 2010). Therefore, expanding the irrigated farming projects for the listed crops will increase land productivity. Nevertheless, in the case of water limitation, it would be helpful to increase irrigated areas only for crops with high economic water productivity.

At a national level, the statistics on EWPs draw the basis for explaining the current cropping patterns and the data on ELPs provide a better basis for understanding that various crops with large production volumes (especially tomatoes, potatoes, oranges and dates) have a relatively high ELP, with the main exceptions being wheat, barley and olives, which have large production volumes but low ELP and also low EWP (Chouchance, et al. 2013).

4.4.7 Experience from the Tunisia case study: relevance to Libya

The Tunisian WF related to agricultural production was 19 Gm^3/year in the period 1996-2005, most of which (89%) pertained to green water. However, there are substantial regional differences, with crops in the south having a larger total WF than in central and northern Tunisia, as a result of differences in climate. Since the south is an arid region, its WF is mainly from blue water.

The country in general suffers from significant water scarcity, with a national blue WF of crop production amounting to 31% of renewable blue water resources. There are differences between Tunisian regions concerning water scarcity; southern Tunisia has severe; the central region has significant and the northern region has moderate water scarcity. In the case of groundwater, water scarcity is severe in all three regions, particularly in the south, where blue WF resting on groundwater exceeds renewable groundwater resources by an estimated 23%.

For the water productivities of different crops, 91% of the total blue WF of crop production in the country has water productivity of less than \$0.20/m^3. In contrast, tomatoes, potatoes and oranges have larger blue water productivities, and while olive production is one of the major export products of the country, it has the smallest blue water productivity (\$0.03/m^3).

While crops of oranges, tomatoes and potatoes have relatively large economic water and land productivities, low economic water and land productivities are found for wheat, barley, almonds, olives and figs. In general, it can be concluded that economic land productivity (US\$/ha) increases irrigated farming but not water productivity (US\$/m^3).

European countries are mainly responsible for the large virtual water imports arising from cotton, sugar and cereal crops. Olive oil and cotton are the crop products contributing most to virtual water export. Although the total gross virtual water export from Tunisia is more than virtual water import, the benefit per drop of water used for making export products is larger than the cost per drop of water in import products. Due to about 32% of its total WF of consumption being outside its borders, Tunisia is not water self-sufficient. However, given its water scarcity, Tunisia is less likely to be able to decrease its water dependency on external water resources.

From the results of this study, it can be seen that Tunisian water resources were further used to produce crops with low economic productivity, which may be as a result of the agricultural policy followed by the Tunisian authorities, which, according to the Ministry of Agriculture (2002), planned to guarantee a lower price for those products than the international market price. Nevertheless, the FAO (2012) points out that recently Tunisian authority have adopted integrated management of its scarce water resources and agricultural policy. Acknowledging dependency on external water resources, the Tunisian government signed a free trade agreement with the EU to encourage agricultural imports and encourage farmers to shift from low-value to high-value crops and increase the economic productivity of water in agriculture.

4.5 Morocco case study

4.5.1 Overview

Morocco is situated in north-western Africa, with shorelines on the Mediterranean and the Atlantic (Figure 3.8). It has a land area of 446,000 km2 of which 9.3 million ha cultivated land with population of which 33,655,786 (Kalpakian, 2012). Although the climate of Morocco is influenced by the Atlantic Ocean and the Mediterranean, it is mostly semi-arid with an average rainfall of 346 mm/year varying from 750mm in the northwest along the coast to less than 150mm in the southeast. The country faces water scarcity due to agricultural activities which is accounted for the largest water use, particularly for irrigation during the dry season (EMWE, 2011).

The study of Schyns and Hoekstra (2014) includes analysis of the water footprint (WF) of activities in Morocco, the country's virtual water imports and exports, and the WF in the context of water availability. The study is based on data from Mekonnen and Hoekstra (2011), who estimated the WF of nations over the period 1996-2005 related to crop production, grazing, industrial production, domestic water supply and animal water supply. Their estimates are supplemented with first time estimates of the evaporation from the Moroccan irrigation supply network and storage reservoirs.

The study of Schyns and Hoekstra (2014) evaluates the added value of understanding the WF of the economy and international virtual water trade in framing national water policy in Morocco to explore whether a thorough Water Footprint Assessment (WFA) can contribute to new understandings and response options that are presently not accounted for in the national water strategy and river basin plans.

4.5.2 Virtual water trade in Morocco

As mentioned previously, virtual water exports are less than imports. About one-third of virtual water exports are from the national water resources and the rest is from re-export of imported virtual water, which makes Morocco a net virtual water importer (Schyns, 2014)

4.5.2.1 <u>Virtual water import</u>

During the period 1996-2005, the total Moroccan virtual water import was 12,643 Mm^3/year, comprising 80% green water, 9% blue water and 11% grey water. Crop production had the largest contribution to the total virtual water import (95%), while industrial and animal production represented only 5%. The economic value of total imports over the period 1996-2005 was about 12.4 billion dollars per year, of which crop and animal products contributed 17% ($1.9 Billion per year) and industrial products contributed 83% (Table 3.12).

Table 4-12: Virtual water import in Morocco. Period: 1996-2005. Mekonnen and Hoekstra (2011)

	Related to crop cultivation	Related to animal products	Related to industrial processing of agricultural products	Total
Green (Mm^3/year)	9,964	119	-	10,083
Blue (Mm^3/year)	1,100	24	42	1,166
Grey (Mm^3/year)	888	9	498	1,394
Total (Mm^3/year)	11,951	152	540	12,643
Economic value of imports (million US$/year)	1,975	125	10,329	12,429
Value per m^3 imported (US$/$m^3$)	0.17	0.82	19.14	0.98

4.5.2.2 <u>Virtual water export</u>

During the period 1996-2005, the total Moroccan virtual water export was 4,307 Mm^3/year, including 36% green water, 57% blue water and 6% grey water (Table 3.13). Part of Morocco's virtual exportation is from local water resources, estimated at about 1,333 Mm^3/year. About 4% of the total water used in the industrial and agricultural sectors goes to export production, while the rest is used for producing products that are consumed inside the country. Blue virtual water export from domestic resources is estimated at 435 Mm^3/year, which is equal to 3.4% of Morocco's average natural runoff (Schyns, 2014).

Crop products have the largest contribution to the total virtual water export, and 91% of the total exported virtual water is for crop production, while the industrial and animal production represents only 5% each (Schyns & Hoekstra, 2014). The economic value of total exports over the period 1996-2005 was about $7.1 billion per year, of which crop and animal products represent 49% ($3.4 billion/year), with the remainder (51%) being industrial products (Table 3.13). Olives, oranges, wheat, sugar beets and mandarins are considered particularly water-demanding crop products associated with large virtual water export from Morocco.

Table 4-13 Virtual water export. Period: 1996-2005. Mekonnen and Hoekstra (2011)

	Related to crop Products	Related to animal Products	Related to industrial Products	Total
Green (Mm³/year)	1,399	171	-	1,570
Blue (Mm³/year)	2,429	21	17	2,467
Grey (Mm³/year)	78	5	186	270
Total (Mm³/year)	3,906	197	203	4,307
Economic value of imports (million US$/year)	3,418	47	3,674	7,138
Value per m³ imported (US$/m³)	0.87	0.24	18.07	1.66

4.5.3 Water savings related to trade

The national water saving is defined as the volume of water saved by importing products instead of producing them domestically. By international trade in agricultural and industrial products in the period 1996-2005, Morocco saved 27.8 Gm³/year (75% green, 21% blue and 4% grey) (Table 3.14). About 72% of the WF within Morocco was saved by this virtual water trade. The majority of the green water savings is related to trade in crop products. For example, imported wheat from France leads to a water saving for Morocco of 3.77 Gm³/year (Mekonnen & Hoekstra, 2010).

Table 4-14 National water saving of Morocco related to international trade (in Mm³/year). Period: 1996-2005. Mekonnen and Hoekstra (2011)

	Green	Blue	Grey	Total
Related to crop products	20,542	5,920	971	27,434
Related to animal products	256	15	5	277
Related to industrial products	-	8	90	98
Total	20,798	5,944	1,066	27,808

4.5.4 The Moroccan Water footprint

The whole WF within Morocco over the period 1996-2005 was 38.8 Gm³/year, in which the largest contributor was crop production (29,719 Mm³/year) (Mekonnen and Hoekstra (2011). Green water represents 78% of water consumed, 18% is blue water (28,342 Mm³/year) and 5% is grey water (1,378 Mm³/year) (Table 3.15).

Table 4-15 Water footprint of Morocco's production (Mm³/year), 1996-2005 Adapted from Mekonnen and Hoekstra (2011)

Water footprint of	Period	Green	Blue	Grey	Total	% of total
Crop production a)	1996-2005	23,245	5,097	1,378	29,719	77%
Grazing a)	1996-2005	6,663	-	-	6,663	17%
Animal water supply a)	1996-2005	-	151		151	0%
Industrial production a)	1996-2005	-	18	69	88	0%
Domestic water supply b)	1996-2005	-	125	640	765	2%
Storage reservoirs b)	-	-	884	-	884	2%
Irrigation water supply network b)	1996-2005	-	549	-	549	1%
Total water footprint	1996-2005	29,908	6,824	2,087	38,819	100%
% of total		77%	18%	5%	100%	

4.5.4.1 Water footprint of main crops

The most important water consuming crops were considered by Mekonnen and Hoekstra (2010) in an analysis of WF in the Moroccan agricultural sector over the period 1996-2005. Of the most important water consuming crops, wheat, barley and olives were responsible for the greenest water consumption (Figure 3.6).

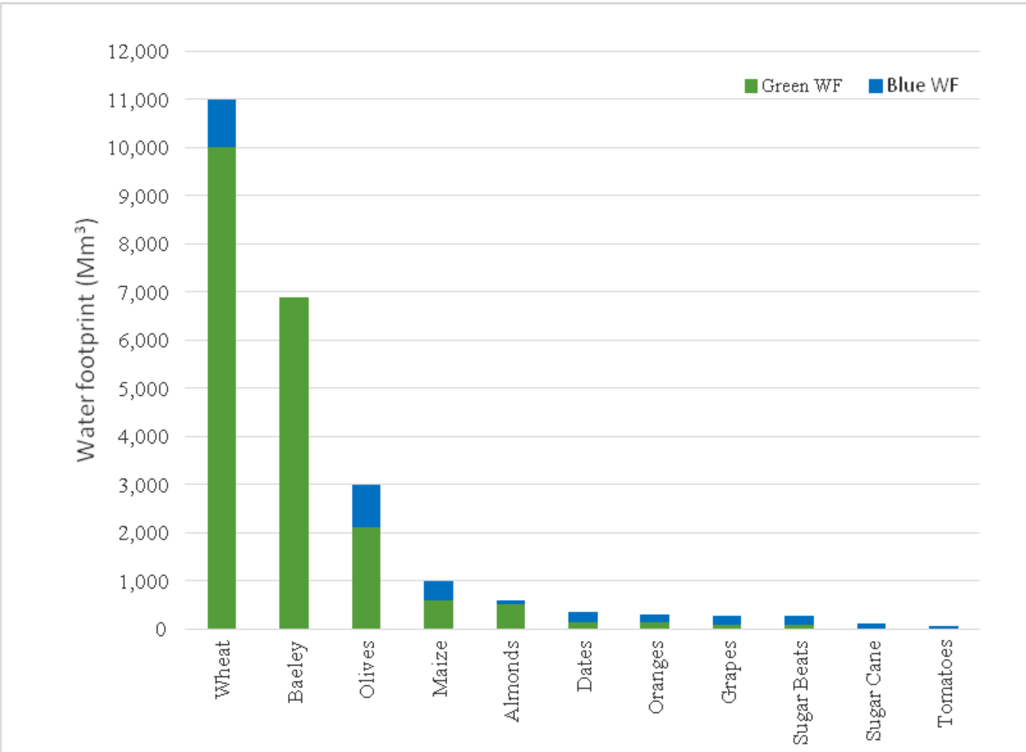


Figure 4-6 The water footprint of main crops in Morocco (in Mm³/year), 1996-2005

The difference in climatic conditions over the country means that crop water requirements (that is, the *sum* of blue and green water use) vary significantly across river basins (Figure 3.7) (Schyns and Hoekstra, 2014). Generally, crops such as barley, dates, fodder crops, maize and wheat consume less water in the basin of the Sud Atlas than the country average water consumption, while water consumption of other crops is above country average of crops in the this basin. From the analysed crops, the *ratio* of blue to green water use is above the country average in the Sud Atlas basin, reaching up to seven times more than the country average of water requirement for the production of wheat as a result of receiving relatively more irrigation water (Schyns and Hoekstra, 2014).

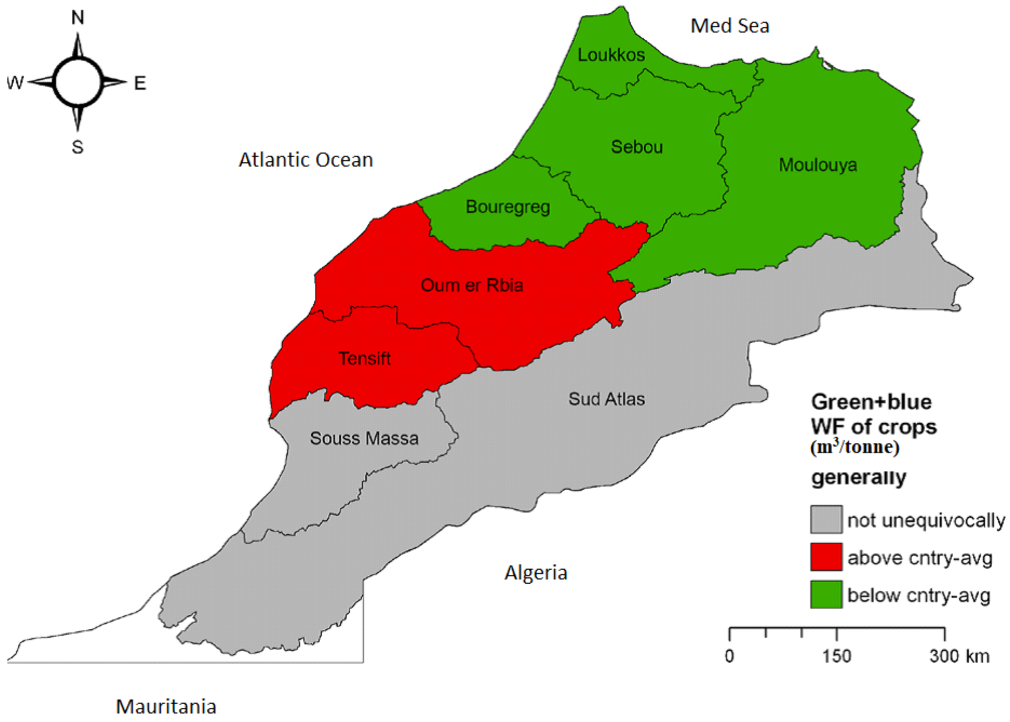


Figure 4-7 Green plus blue water footprint of main crops (in m³/tonne) compared to the national average (Schyns and Hoekstra (2014)

4.5.5 Water footprint of consumption and external water dependency

According to Mekonnen and Hoekstra (2011), the total WF of Moroccan consumption was 50.0 Gm³/year (81% green, 12% blue, 6% grey) in the period 1996-2005, of which the external component was 14.6 Gm³/year (84% green, 7% blue and 8% grey), and the internal component was 35.4 Gm³/year (80% green, 14% blue and 6% grey). About 97.5% of the WF of Moroccan consumption relates to consumed agricultural products and 1% to industrial products.

Cereals have the largest contribution to Moroccan crop production water consumption and the largest contribution to imported virtual water. Twenty-nine per cent of the WF of Moroccan consumption takes place outside the country, mainly in the US, France, Argentina, Brazil, Canada, the Russian Federation, China and the Ukraine, which means Morocco depends on the water resources in those countries (Schyns, 2014).

4.5.6 Economic water and land productivity at national level

In the study of Schyns (2014) Economic Water Productivity (EWP) was considered in analysing the amount of water used for the production of the main crops during the period 1996-2005 (Figure 3.8).

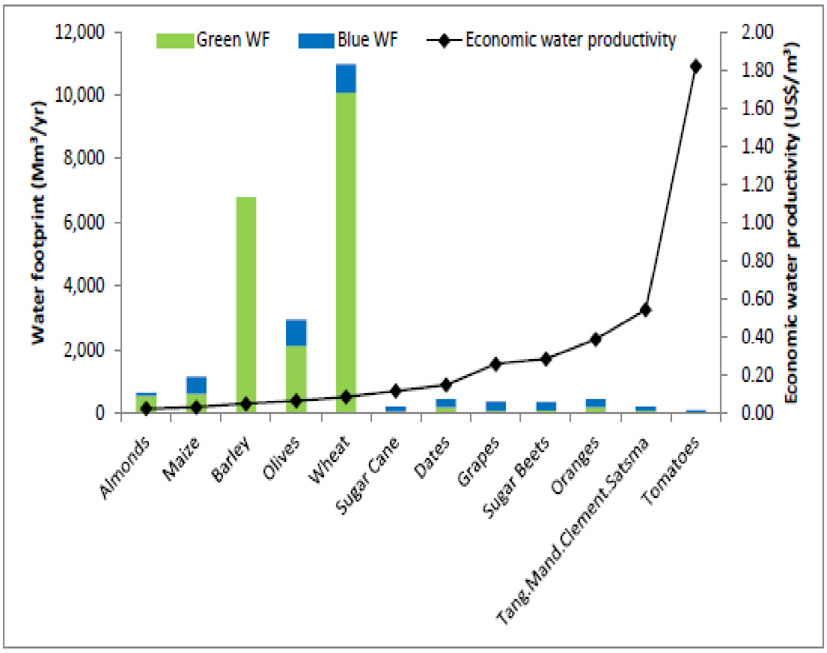


Figure 4-8 Economic water productivity (in US$/m³) and green and blue crop water use (in Mm³/year) of main crops in Morocco. Period: 1996-2005 (Schyns, 2014)

4.5.7 Experience from the Morocco case study: relevance to Libya

The main points that can be concluded about the water footprint assessment of Morocco are:

- Most of the Moroccan water footprint resulted from agricultural production in the period 1995-2005, representing 38.8 Gm^3/year, comprising 18% blue water, 5% grey water and 77% green water.
- Wheat and barley (i.e. cereals) production was considered as the largest contributor in the water footprint of production, followed by olives and maize.
- The main agricultural areas in the basins Oum Er Rbia and Sebou represented the largest WFs.

From an economic perspective, water resources in Morocco were mainly used to produce relatively low-value water-intensive crops in the period 1996-2005, such as cereals, olives and almonds. While having the lowest value per hectare cultivated, they have the largest share of the national harvest area. Although the production of grapes, sugar beet, citrus fruits and tomatoes generated more economic return per m^3 water and per hectare of land cultivated, they have a low share of national production compared with wheat and barley.

In the period 1996-2005, Morocco saved about 27.8% Gm^3/year (75% green, 21% blue and 4% grey) of local water resources as a result of virtual water trade, in which the total virtual water import was 12.6 Gm^3/year. Conversely, most of the virtual water export from Moroccan resources relates to export products of relatively low economic value. Although the virtual water export was 4.3 Gm^3/year, only 31% of this amount was produced in Morocco, the rest was re-exported. Most virtual water import and export was related to trade in crop products. Despite Morocco achieving quite significant savings by food imports, increasing food imports result in increasing food dependency, with negative effects on the domestic agricultural sector, which plays an important role in the economic and social stability of Morocco (Schyns, 2014).

Blue water scarcity and high levels of pollution were clearly significant on all river basins and most ground water in the basins of Bouregreg, Oum Er Rbia and Tensift in particular. It was also noticed that natural runoff was decreasing as a result of seasonal shortage. Therefore, it would be helpful in moving towards sustainable use of national water resources to discuss and agree on blue water footprint caps per river per month, and also for surface water and groundwater.

Low water footprints of the main crops on each river basin area can be achieved by improving the productivity of the main water-consuming crops. This could lead to potentially saving 2,462 Mm^3/year of green and blue water by 10% throughout Morocco (Schyns and Hoekstra (2014).

In this study, looking at the end-users and purposes of freshwater plays a crucial role in addressing the equitability and efficiency of water allocation in light of environmental and sustainable aspects at both river basin and national levels, which are appropriate for water-scarce countries such as Morocco. In addition, taking into account green and grey components of the water footprint adds a new angle to groundwater shortage, because the pressure on groundwater can be alleviated by improving use of rain water and reducing pollution.

The green water footprint, which is 77% of the total water footprint, shows the relevance of green water resources in arid and semi-arid countries that depend highly on blue water, particularly in the case of dominance of the green water on blue water flow, as is common in Africa. Therefore, the importance of green water footprint should be considered and not underestimated (Rockström et al., 2007).

From Schyns and Hoekstra (2014), it can be seen that because of the low economic value of some crops compared with others, types of crops grown in Morocco should be seen from the strict water economic point of view. Additionally, in practical terms, the national strategy of food security should consider land productivity with the water economic point of view based on the amount of water used for each tonne of crop (Schyns and Hoekstra's 'drop for crop') and dollar income per area. Estimating the economic value of water allocation is important for water-scarce countries such as Morocco. This can be achieved through identifying the extent to which foreign income gained from the exportation surpasses the direct and indirect costs of the water resources used. Although the concept of the water footprint is academically studied in Morocco and it looks useful for developing water management resources in Morocco, according to the study of Schyns and Hoekstra (2014) it is not practically applied yet as a tool in Moroccan water management.

4.6 Reflection on the application to Libya of the water footprint concept in the India, Netherlands, Morocco and Tunisia

The above four case studies, summarised in Table 3.16, show that the only one case (the Netherlands) has practically applied the water footprint concept as a tool in its water resources management (Wichelns, 2010, 2015). The others have not practically applied the water footprint; in the other words, the water footprints of India, Tunisia and Morocco were just academically studied. Although the water footprint was considered in the Netherlands' water resources management, which is considered as water rich country, and demonstrated an effective way to raise awareness among the general public, businesses and governments about the global scale of water appropriation, these water volumes hardly reflect environmental impact (Wichelns, 2010).

According to the study of Schyns & Hoekstra (2014) Water Footprint Assessment has an added value for national water policy in Morocco. Water Footprint Assessment requires consideration of end-users and uses of freshwater, which is key to determining efficient and fair water allocation within the boundaries of what is environmentally sustainable, both on the river basin and on the national level, which is in particular relevant for arid or semi-arid countries such as Morocco. In addition, it shows that considering the green and grey components of water footprint adds new perspective on blue water resources as the more efficient use of green and grey water might lead to reduced pressure on blue water resources.

Table 4-16 Key features of the four case studies

	India	Netherlands	Tunisia	Morocco
Climate	It is ranging from arid desert in the west, alpine tundra and glaciers in the north, and humid tropical regions supporting rainforests in the southwest and the island territories.	It is a temperate maritime climate influenced by the North Sea and Atlantic Ocean, with cool summers and moderate winters	It is divided into three provinces: the north has a Mediterranean climate; the south has a Sahara climate and the central region has a climate in between the previous two	It is influenced by the Atlantic Ocean and the Mediterranean, it is mostly semi-arid
Water resources	average precipitation 1170 mm/year distributed over 5-6 months. The total available fresh water in India is 4000 Gm^3/year	average precipitation is 800 mm/year	It is limited and estimated 4.87 b. m^3/year, of which 4.26 Gm^3/year are renewable	346 mm/year varying from 750mm/year in the northwest along the coast to less than 150mm/year.
Internal W. F	658 Gm^3/year	4 Gm^3/year	10.9 Gm^3/year	35.4 Gm^3/year
External W. F	119 Gm^3/year	24 Gm^3/year	8.1Gm^3/year	14.6 Gm^3/year
Total W. F	777 Gm^3/year	28 Gm^3/year	19 Gm^3/year	50.00 Gm^3/year

According to Chouchane, et al. (2013) Tunisia in general suffers noteworthy water scarcity, with a national blue WF of crop production. South Tunisia in particular experiences severe water scarcity where the blue WF depending on groundwater exceeds renewable groundwater resources, Central Tunisia significant scarcity and North Tunisia moderate scarcity. For groundwater, all three regions experience severe water scarcity, with the worst situation in South.

The study by Chouchance, et al. (2013) considers and analyses the water footprint of Tunisia at the national and sub-national level, assessing green, blue and grey water footprints for the period 1996-2005. It also added value of economic water and land productivities related to crop production for irrigated and rain-fed agriculture. It also assessed the economic returns of exports and the economic expenses of import per unit of virtual water.

The above case studies were chosen from different climate conditions, one of them, Tunisia, particularly in the south, is similar Libya in terms of climate condition and water resources. The chronological presentation of case studies shows the recent extension, which is not trivial, in discussion of water footprint and virtual water notion to include economic perspective of water footprint as there is substantial interest among policy makers.

Exploring the study of water footprint in Tunisia with considering economic value might be quite useful for assessing water footprint in Libya. Therefore, to critically examine the concept of the water footprint in the specific conditions and circumstances of Libya, the next chapter will discuss the background of agricultural development related to water consumption in Libya within the last fifty years and examine the current agricultural state in Libya in terms of food production and water use through irrigation and its effects on the natural water resources.

4.7 THE OVERVIEW OF WATER FOOTPRINT DEVELOPMENT, PUBLICATIONS AND EXISTING CASE STUDIES

Following the introduction of the virtual water concept, experts in the field have conducted several studies of virtual water flows for a number of water-shortage areas around the world. For instance, at the river basin level are studies on the Aral Sea and Mekong river (Thailand and Vietnam) basins (Nakayama, 2002), the Heihe river basin, (Chen et al., 2005), and the Nile river basin (Weyler, 2004 and Zeitoun et al., 2010 1); at the regional level, the SADC countries (Earle & Turton, 2003), the Middle East (Allan, 2003), and at the national level Egypt (El-Sadek, 2009), Lebanon (El-Fadel, 2003), Jordan (Haddadin, 2003), and Japan (Oki et al., 2003).

Regarding water footprints, the first study including water footprints and virtual water trade analysis was published by Chapagain & Hoekstra, 2004. This study represents the virtual water flows per country related to the international trade in crops, livestock and industrial products for the period 1997-2001, and the water footprint of national consumption for almost every country in the world.

According to these studies, addressing the sustainability and response formulation phases will be the major challenge in future studies. All these existing studies have been collected and presented in Table 3-17 below.

Table 4-17 Overview of water footprint publications (Hoekstra, et al. 2011)

Global and supranational water footprint and virtual water trade studies	• Global (Hoekstra and Hung, 2002, 2005; Hoekstra, 2003, 2006, 2008b; Chapagain and Hoekstra, 2004, 2008; Hoekstra and Chapagain, 2007a, 2008; Liu et al, 2009; Siebert and Döll, 2010) • Central Asia (Aldaya et al, 2010c)
National water footprint and virtual water trade studies	• China (Ma et al, 2006; Liu and Savenije, 2008; Hubacek et al, 2009; Zhao et al, 2009) • Germany (Sonnenberg et al, 2009) • India (Kumar and Jain, 2007; Kampman et al, 2008; Verma et al, 2009) • Indonesia (Bulsink et al, 2010) • Morocco (Hoekstra and Chapagain, 2007b) • Netherlands (Hoekstra and Chapagain, 2007b; Van Oel et al, 2008, 2009) • Romania (Ene and Teodosiu, 2009) • Spain (Novo et al, 2009; Aldaya et al, 2010b; Garrido et al, 2010) • Tunisia (Chahed et al, 2008) • UK (Chapagain and Orr, 2008; Yu et al, 2010)
Sub-national water footprint and virtual water trade studies	• Chinese provinces (Ma et al, 2006) • City of Beijing (Wang and Wang, 2009) • Indian states (Kampman et al, 2008) • Mancha Occidental Region, Spain (Aldaya et al, 2010d) • Andalusia, Spain (Dietzenbacher and Velazquez, 2007) • West Bank, Palestine (Nazer et al, 2008) • Guadiana basin, Spain (Aldaya and Llamas, 2008) • Lower Fraser Valley and the Okanagan basins, Canada (Brown et al, 2009) • Nile basin, Africa (Zeitoun et al, 2010)
Product water footprint studies	• bio-energy (Gerbens-Leenes et al, 2009a, 2009b; Gerbens-Leenes and Hoekstra, 2009, 2010; Dominguez-Faus et al, 2009; Yang et al, 2009; Galan-del-Castillo and Velazquez, 2010; Van Lienden et al, 2010) • coffee (Chapagain and Hoekstra, 2007; Humbert et al, 2009) • cotton (Chapagain et al, 2006b) • flowers (Mekonnen and Hoekstra, 2010b) • jatropha (Jongschaap et al, 2009; Maes et al, 2009; Gerbens-Leenes et al, 2009c; Hoekstra et al, 2009c) • mango (Ridoutt et al, 2010) • maize (Aldaya et al, 2010a) • meat (Chapagain and Hoekstra, 2003; Galloway et al, 2007; Hoekstra, 2010b) and onions (IFC et al, 2010) • paper (Van Oel and Hoekstra, 2010) • pasta (Aldaya and Hoekstra, 2010) pizza (Aldaya and Hoekstra, 2010) • rice (Chapagain and Hoekstra, 2010) • soft drinks (Ercin et al, 2009) • soybean (Aldaya et al, 2010a) • sugar (Gerbens-Leenes and Hoekstra, 2009) • tea (Chapagain and Hoekstra, 2007) • tomatoes (Chapagain and Orr, 2009) • wheat (Liu et al, 2007; Aldaya et al, 2010a; Zwart et al, 2010; Mekonnen and Hoekstra, 2010a) • food in general (Chapagain and Hoekstra, 2004; Hoekstra and Chapagain, 2008; Hoekstra, 2008c)
Business water footprint studies	• beer from SABMiller (SABMiller and WWF-UK, 2009; SABMiller et al, 2010) • cola and orange juice from the Coca-Cola Company (TCCC and TNC, 2010) • breakfast cereal from Nestlé (Chapagain and Orr, 2010) • candies and pasta sauce from Mars (Ridoutt et al, 2009)

In 2008, Hoekstra & Chapagain developed the analysis of virtual water and water footprints and this was presented in the book "Globalization of Water" with detailed discussion of specific case studies.

At the local levels, several water footprint studies have been conducted since 2004, whereas the interest from the governmental sector has only begun to arise. Most water footprint studies have been published after 2007 and these studies include international studies, national studies, regional and river basin studies, general product studies and company studies.

4.7.1 Critiques of Water Footprint Concept

Some supporters of the water footprint notion argue that the limitation of considering water footprints as a tool at the policy level is not because it is insufficient, but it may be because the governments are not quite aware of this new notion and have not fully explored it yet. Moreover, there are some countries that have already set frameworks for better water management. So, using water footprints as a new tool to revise water management approaches may be limited Chapagain and Tickner (2012).

Le Quesne (2010) also claims that the real challenge is often the implementation of existing water policy and any other measures, such as by involving water footprints as a new tool to some extent, may distract from the current implementation efforts.

However, although water footprints have a contribution to make in raising the awareness of decision-makers about water consumption, it considers only the volume of water consumed. There is no mention of the other inputs in crop production such as the water used in production of fertiliser and pesticides, and also it does not take in account the opportunity costs.

Wichelns (2011) points out that interactions that determine water allocation involve several factors such as physical, social and economic dimensions, which are not included in water footprint estimates, and information on the environmental impacts. Therefore, it is difficult to understand these complex interactions by depending on water volumes alone.

Rockström (2007) has mentioned another criticism of the concept of water footprints, which relates to the distinction between blue and green water. It is difficult to distinguish between blue and green because, as the green water is defined, the rainfall causes runoff, and most countries have built huge dams to store rainfall to create reservoirs. Yet when this water is delivered to farms, it is considered to be blue water not green water.

At the same time, when the runoff percolation becomes soil moisture, then it is considered to be green water. Thus, there is no clear-cut distinction between blue and green water. Therefore, Wichelns (2011) illustrates that in the hydrological system water can change condition from green to blue or vice-versa, and the value of these terms is unclear given the more intuitive and commonly used alternatives such as groundwater, surface runoff and rainfall etc.

Indeed, the terminology arising around the water footprint reflects the diverse interests concerned in water issues, which partly reflects commercial interests and not genuinely addressing water problems per se to alleviate food security challenges and reduce poverty.

Hastings & Pegram (2012) claim that water footprint concept does not add new useful information for water management because all the useful information given by a water footprint already exists with other tools of water resources management. The concept is also not sufficient to provide information for taking action and does not contribute to understanding and identifying the local impact of water use and opportunities for more efficient and effective water use.

Chapagain and Tickner (2012) also make this point: "Results from WF analyses can help to highlight interconnections and risks but do not provide solutions (other tools are more useful for this)".Water footprint has the potential to inform planning sectors and raise awareness and understanding between agriculture and other sectors such as trade and economic development. However, its potential is too unclear to create a clear link between water footprint and policy (Hastings and Pegram (2012)).

4.8 THE GAP IN KNOWLEDGE IN WATER FOOTPRINT LITERATURE

After the development of the concept of water footprint, it was refined as a method for quantifying water use, and several concerns and limitation have been addressed. According to Ridoutt et al., (2010) and Ridoutt and Pfister (2010) the main concern is about the fact that a water footprint represents only the quantity of water use regardless of the environmental impacts.

According to Hastings & Pegram (2012), reviewing previous case studies, particularly in developing countries, highlighted several points as follows:

- Water footprint contribution: guiding policymaking and increasing awareness, improving collaboration between stakeholders and coordinating a cohesive strategy for water security, economic development and environmental wellbeing.

- Water footprint challenges: existing efforts have not demonstrated a clear impact on policy.

Table 4-18 Gap in the literature of water footprint (Kuiper.et.al, 2010)

Gaps in knowledge	Suggestions
Accounting for virtual water trade in policy making	Accounting for water in the rules of international trade (WTO, EU) as a mechanism to improve global water efficiency based on water productivities and comparative advantage in water.
Land-use change implications in water resources quantity and quality	Further research on the water footprint of different land uses across time, including reforestation activities.
Developing country policy context	Further research on the water footprint and virtual water trade in developing countries and comparative analysis between developed and developing contexts.
Water footprint offsetting	Research on the concept and applications: better understanding and agreement.
Water neutrality	Research on the concept and applications: better understanding and agreement.

To gain full understanding of the concept of water footprints, they have to be analysed in the local context with consideration of the environmental, social and economic implications of water use and connected to the economic, social and environmental indicators (Kuiper.et.al, 2010).

The gap in knowledge in water footprint literature is summarised and presented in Table 3.18 above. From the review of water footprint literature, all the conducted studies were focused on estimation of water use quantity. There is no critical examination of water footprints in specific conditions and circumstances of arid countries like Libya, which can be considered as a gap in the literature. Therefore, this research will focus on this part to fill this gap in the literature.

CHAPTER 4 WATER RESOURCE IN LIBYA

5.1 INTRODUCTION

This chapter focuses on the availability of water resources and agriculture-related water use and food security in Libya. The objective of this chapter is to discuss the background of agricultural development related to water consumption in Libya within the last fifty years and its present performance. It also examines the current agricultural situation in Libya in terms of food production and water use through irrigation and its effects on natural water resources.

5.2 OVERVIEW

Libya is situated in the north of Africa, with a long coast (1,900 km) on the Mediterranean Sea and lies between 18° and 33° north and 9° and 25° east. The population of Libya in 2006 was 5,657,692 million people according to the general census of population (Libyan General Agency of Information and Documentation (GAI, 2008).

In the north of the country, the climate is determined by the Mediterranean, which it borders; however, away from the coastal strip the rest of the country has a desert climate (Abu Luqmah, 1995; El-Tantawi, 2005). Thus, the overall average rate of annual rainfall in Libya is characterized by the wide variations and irregularity with over 95% of the country not exceeding 100mm/year (Salem, 2007). The low level of precipitation has a significant influence on the water resources in the arid and semi-arid areas of Libya where water loss is increased by evaporation (Table 4-1). Under these conditions, the groundwater resources represent the main source of water for agricultural activities, which is responsible for up to 85% of water use (Wheida & Verhoeven, 2007) putting these resources under pressure.

Table 5-1 Annual Rainfall in the coastal and desert areas After General Water Authority (GWA) (2006)

Region	Average Rainfall (mm)
North-eastern	250-600
North-central	100-200
North-western	300-450
South (deep Sahara)	< 10

One effective way to maintain water resources in the arid and semi-arid areas is by growing water-rich- crops (high water dependent crops) in areas where water from renewable sources is abundant, such as in Europe and Asia and then import these products to be consumed inside the arid countries (Allan, 1976; World Bank, 2006).

However, In Libya, because of the large volumes of groundwater in the arid south of Libya, huge agricultural projects were set up there in the 1970s and 1980s, such as the Kofra and Sarir projects, in order to attempt to reach food self-sufficiency. Moreover, between 1987-2010 the Southern region of Libya witnessed a significant expansion in irrigated area as it can be seen in Figure 4.1 (UNEP, 2010).

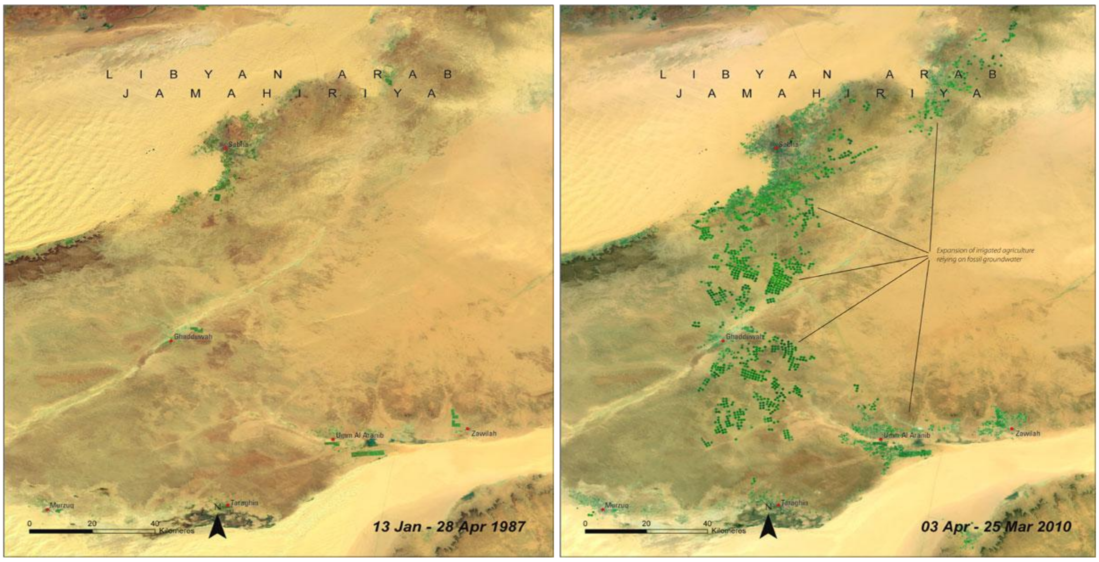


Figure 5-1 Satellite image irrigated area of crops across the South in1987-2010 (UNEP, 2010)

The combined effects of low annual rainfall and the use of non-renewable groundwater resources for intensive agriculture in the desert have encouraged researchers to develop a new and effective technical measure to bridge the gap between water use from non-renewable and renewable sources. The objective is creating a sustainable water management policy that can meet the growing demand for water in Libya.

The annual potential evaporation rate is as high as 6,000 mm in the Southern region and it is relatively low in the coastal strip, at 1,700 mm, where there is an abundance of arable land (Abdelrhem et al., 2009). In addition, the coastal strip area has a high rainfall rate (250-500 mm compared with 0-50 mm in the South).

The effective rainfall (that is, the portion of the precipitation which remains in the soil and is available for consumptive use) approaches 60% of total rainfall.

5.3 WATER RESOURCES

5.3.1 Groundwater

As Libya is an arid country, it depends heavily on groundwater, which accounts for up to 97% of the water used (Salem, 2007). In the past, extracting groundwater was easy through large-diameter traditional wells, since the water table was close to the surface. However, over the past 50 years, groundwater extraction rates have increased rapidly resulting in a lowering of the water table and it becomes necessary to use centrifugal and submersible pumps in order to extract groundwater (Abdelrhem, 2008).

Groundwater resources fall into two categories. The first is renewable aquifers which are located in Jabal Nafusah and Jifarah Plain in the north-western zone and Jabal al Akhdar in the north-eastern zone, which have relatively high precipitation rates.

The aquifers range in age from Quaternary to Cretaceous and they contribute about 2,400 million m^3/year to the water supply, against an annual recharge of less than 650 million m^3 (FAO, 2003; Salem, 2007).

They are extracted through wells ranging from a few metres in depth to more than 1000 m (Salem, 2007). This imbalance has resulted in the lowering of groundwater levels accompanied by deterioration in water quality due to seawater intrusion and invasion of saline water from adjacent aquifers (El-Baruni, 1995; El-Asswad, 1995; El-Hassadi, 2008).

The second category is non-renewable groundwater sources that are located in the central and southern parts of the country and contribute large quantities of fresh water, approaching 2800 Million m^3 (Salem, 2007). The Potentially Available Water from Renewable and Non-renewable Groundwater is shown in Figure 4.2.

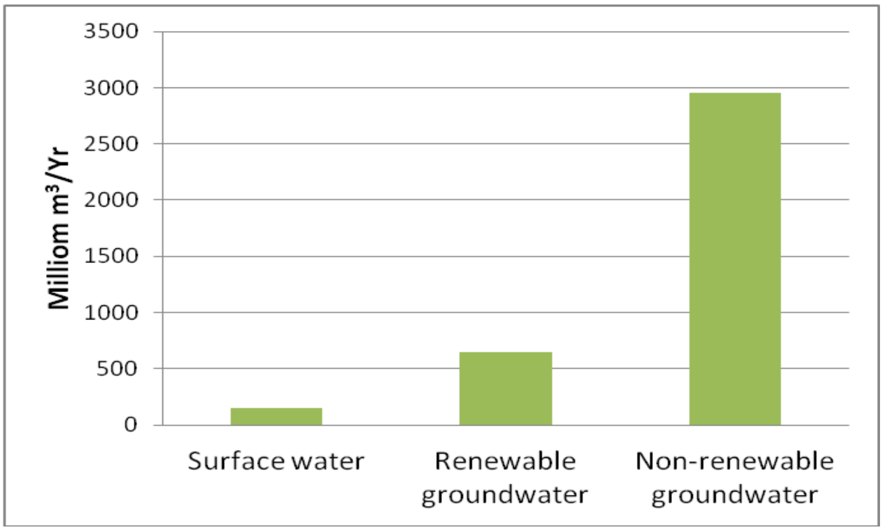


Figure 5-2Availability of Water Resources in Libya (GWA (2007)

Libya is heavily dependent on non-renewable groundwater of approximately 2800 Mm^3/year while surface water provides less than 240 Mm^3/year (Figure 4.3). Total groundwater extraction has grown from 1500 Mm^3/year in 1975 to more than 4200 Mm^3/year in 2000 and 4800 Mm^3/year in 2005 (National Investment Brief Libyan Arab Jamahiriya, 2008; Ramali & Holloway,2012) (See Figure 4.3 for more details). This rate of groundwater extraction, which is about 8 times the annual renewable groundwater over the same period of extraction, is used to fill the gap between the renewable rate and the escalating water demand.

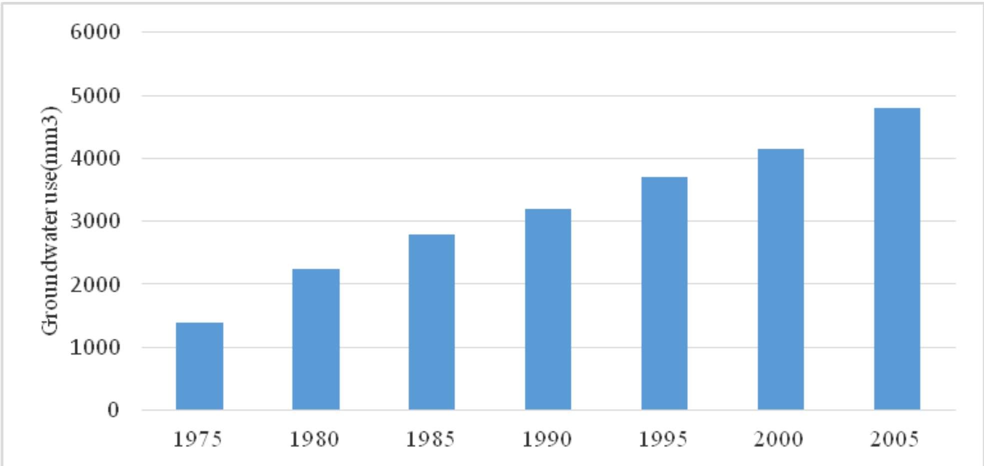


Figure 5-3 Groundwater Use 1975-2005 (Mm^3/year) (GWA, 2006)

This water deficit has caused a severe decline in the level of the groundwater resulting in seawater intrusion in the coastal area which has already invaded 10 km inland in the Tripoli region (Figure 4.4). This has affected the quality of groundwater in the coastal area and has made it unusable for drinking and agriculture (FAO, 2001; UN, 2008).

Ekhmaj et al. (2014) stated, in their The Situation of Seawater Intrusion in Tripoli, Libya, that "study area within the distance ranges between 9 and 12 km from the shoreline are injuriously and highly contaminated by seawater"

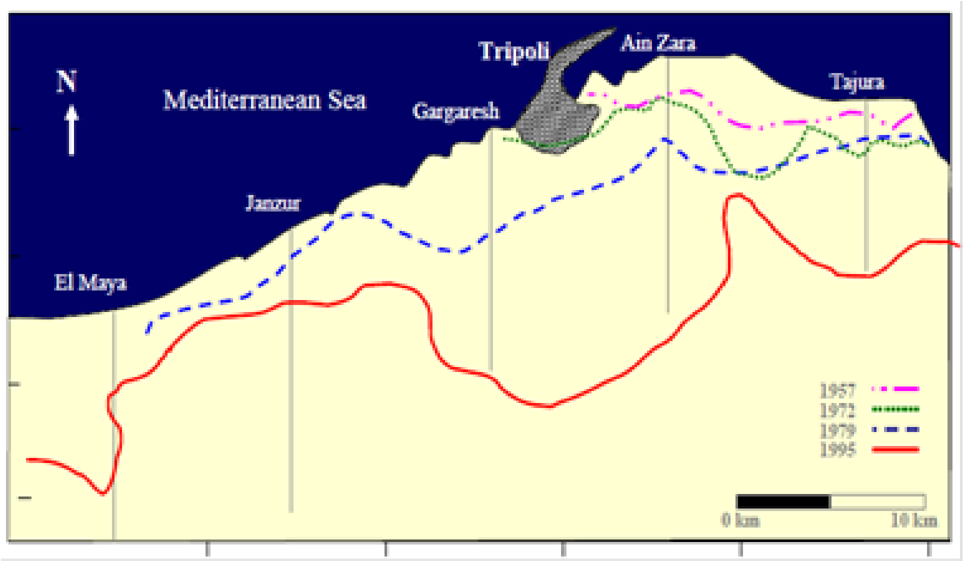


Figure.5-4 Sea Water Intrusion in the Coastal Area of Libya. (GWA, 2007)

MacDonald, et al (2012) illustrates that scientists were able for the first time to draw a map showing the distribution and size of the massive amounts of groundwater in the middle of the Sahara and other parts of the African continent (See Figure 4.5). "Large sedimentary aquifers in North Africa contain a considerable proportion of Africa's groundwater. Libya, Algeria, Sudan, Egypt and Chad have the largest groundwater reserves. Many of these Saharan aquifers are not, however, actively recharged, but were recharged more than 5000 year ago when the climate of the area was wetter".

The amount of storage in those basins is equivalent to 75m thickness of water across that area. The portion of groundwater in Libya is estimated at 99500 Km^3 (MacDonald, et al, 2012).

Scientists say that these sources of groundwater can provide sufficient water for human and agricultural consumption in the whole of Africa (MacDonald et al. 2012). However, they highlighted the difficulty of extracting the water because drilling could cause subsidence.

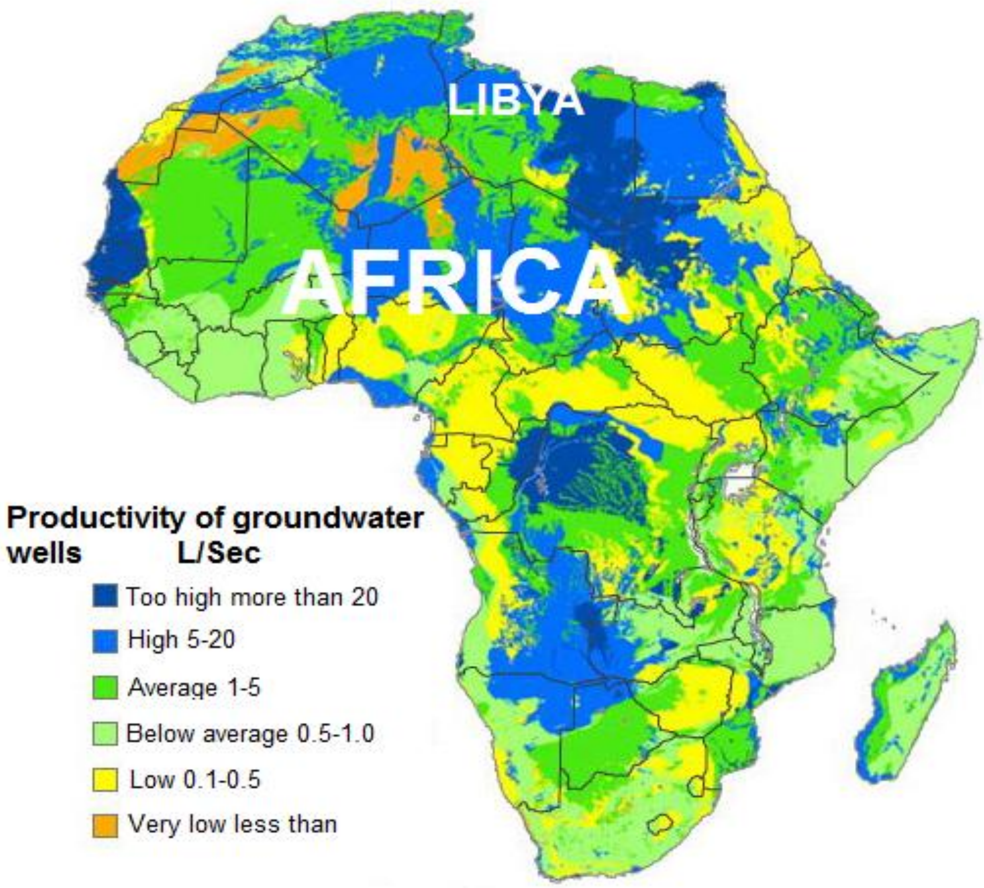


Figure.5-5 Groundwater Resources in Africa (MacDonald, et al. 2012)

5.3.2 Surface Water

Due to the scarcity of rain in Libya, surface water contributes little to the water budget. It is estimated to be around 3% of the total water used (Figure 4.2) (Ramali & Holloway, 2012). It consists of water that is stored in constructed dams, including 16 major ones across the country and from wades in rare flood periods. The total storage capacity of these dams is 385 Mm^3, but, with the decrease in rainfall in the past 30 years, the average annual storage is 60 Mm^3 (Table 4.2) (GEA, 2001; FAO , 2005). All these dams are built in the north of the country where runoff of surface water takes place in the winter. As a result of building the dams, a number of springs were found in the coastal mountains, improving seasonally the groundwater quality. Furthermore, agricultural projects started to use these dams for irrigation purposes instead of groundwater (El-Tantawi, 2005). Moreover, there are number of natural springs with good quality water that vary in discharge from 1 l/s up to 10 l/s. These springs are distributed across the country, for example, at Ayn Zayana, Ayn Kaam, Ayn Dabbousia and Ayn Tawargha (Wheida & Verhoeven, 2007).

Table 5-2 Dams and Their Capacity After GWA (2006)

Dams	Construction date	Location	Precipitation Average mm/year	Reservoir Capacity (million m^3)	Average Annual Storage (million m^3/year)
Wadi Mejenin	1972	Jefara Plain	250	58.00	10.00
Wadi Ghan	1982	Jefara Plain	262	30.00	11.00
Wadi Zaret	1982	Jefara Plain	275	8.60	4.50
Wadi Kaam	1979	Kaam	260	111.00	13.00
Wadi Lebda	1982	Alkhoms	270	5.20	3.40
Wadi Zahawuiyah	1974	Sirt	150	2.80	0.70
Binjawad	1974	Binjawad	160	0.34	0.34
Wadi Tabrit	1978	Zlitin	250	1.60	0.50
Wadi Dakar	1978	Zliten	250	1.60	0.50
Wadi Jarif	1974	Sirt	200	2.40	0.30
Wadi Zaid	1973	Sirt	200	2.60	0.50
Wadi Qattara	2003	Benghazi	260	135.00	12.00
Murkus	1972	Ras-Helal	370	0.15	0.15
Zaza	1982	Al-Agoria	315	2.00	0.80
Derna	1977	Derna	275	1.15	1.00
Abu Mansur	1977	Derna	350	22.30	2.00
Total				384.74	60.69

5.3.3 The Water Balance in Libya: Overview

5.3.3.1 Water resources

In order to evaluate the water balance in Libya, it is necessary to analyse conventional and non-conventional water.

- Conventional water includes two categories, as follows (El Tantawi 2005):

  1- Renewable and non-renewable groundwater, which contributes 91% of the water resources in Libya and is found in five basins over the country (Figure 4.6).

  The first is called Jabal al-Akhdar with an area of 145000 km^2, renewable water of 200 Mm2/year and non- renewable water of 50 Mm^2/ year). The second is called Jefara Plain with an area of 18000 m2, renewable water 2000 Mm^3/year and non-renewable water of 50 Mm^3/ year. Third is called Nafusah/Hamada with an area of 215000km^2, renewable water of 250 Mm^2/ year and non-renewable water of 150 Mm^3/year. The fourth is called Murzek with an area of 350000 km^2 no renewable water and non-renewable water of 1800 Mm^3/year. The fifth is called Kufra and Sarir with an area of 700000 km^2, no renewable water and non-renewable water of 1800 Mm3/ year.

2- Surface water, which is limited by the annual rate of rainfall reflecting its deficiency in an absence of permanent streams. It contributes 3% of the total water resources in Libya 170 Mm^3 /year.

- Non-conventional water includes the following (General Environmental Authority (GEA) 2002):

1-Desalinated water, which comes from a number of desalination plants, represents 3% (120 Mm^3) of the total water use. It covers only a small portion of the domestic and industrial water demand.

2-Treated water, which comes from a number of sewage-treated water plants, representing 6% (200 Mm^3) of the total water use. It is still very limited and is mainly used for irrigation purposes.

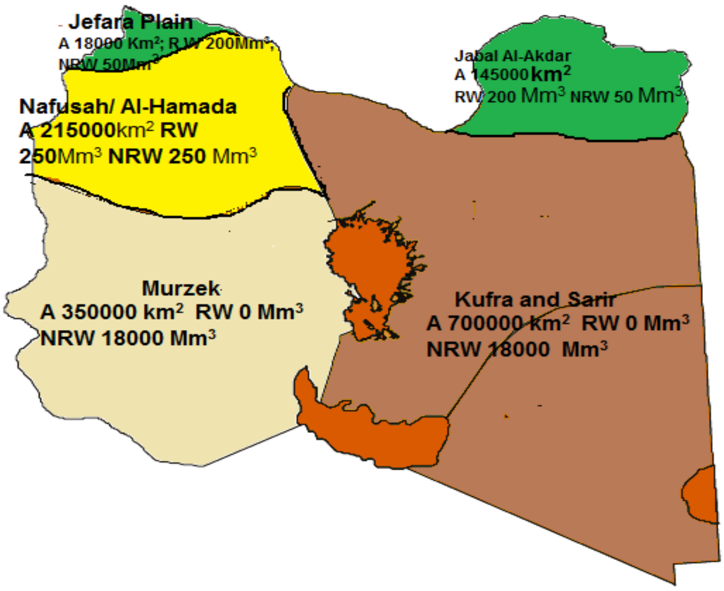


Figure 5-6 Groundwater Basins in Libya (After Abdelrahem et al, 2009)

The total balance of water in Libya is shown in Figure 4.7. The deficit of water is clearly shown to reach nearly 3 Gm^3 by 2020 but is expected to rapidly increase to almost 4 Gm^3 by 2025 (GWA, 2007)

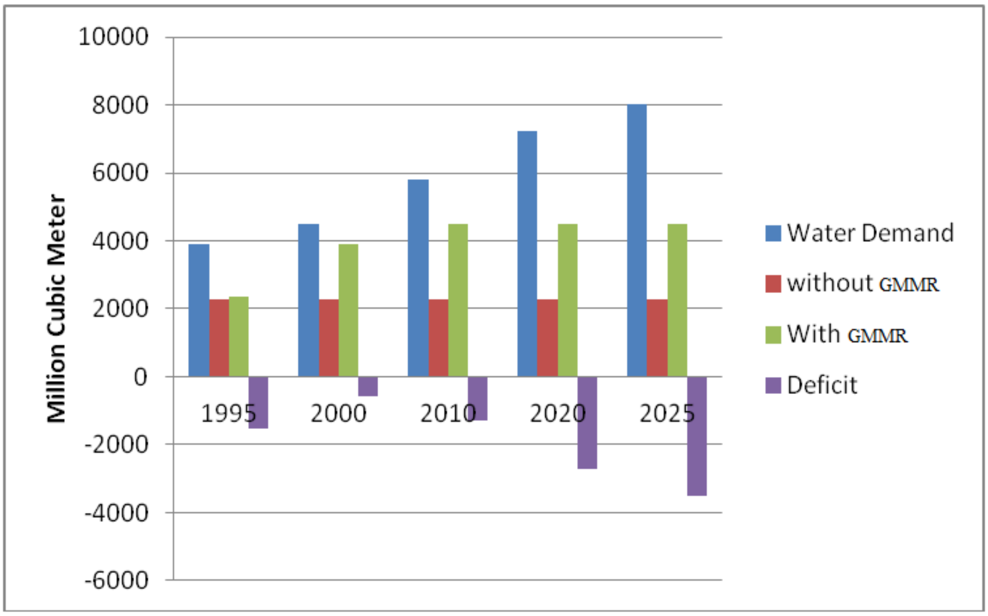


Figure 5-7 Past, present and expected future water balance including GMMR, Libya (After GWA, 2007)

The water deficit also raises technical and economic issues such as the expensive cost of well construction and maintenance, higher use of irrigation water in order to avoid salt accumulation in root zones, low crop productivity, the elimination of several fruits and crops that do not tolerate high salinity and the cost of conveying good quality water from distant sources.

Under these severe conditions, Alghariani (2007) points out that the national water balance requires a radical reformulation of water management policies and strategies. He emphasises that any technical solution will be effective only with policy showing awareness of peoples` socio-economic activities.

5.3.3.2 Water demand

Water demand is increasing rapidly due to high population growth rates; the population is anticipated to almost reach 12 million by 2025 (Figure 4.8) (NASID, 2006 cited in Alghariani, S. (2007)). More than 80% live in the urban environment and fully depend on municipal sources for water for domestic use. The demand for domestic water will increase with time as a function of income with the variation of location and incomes.

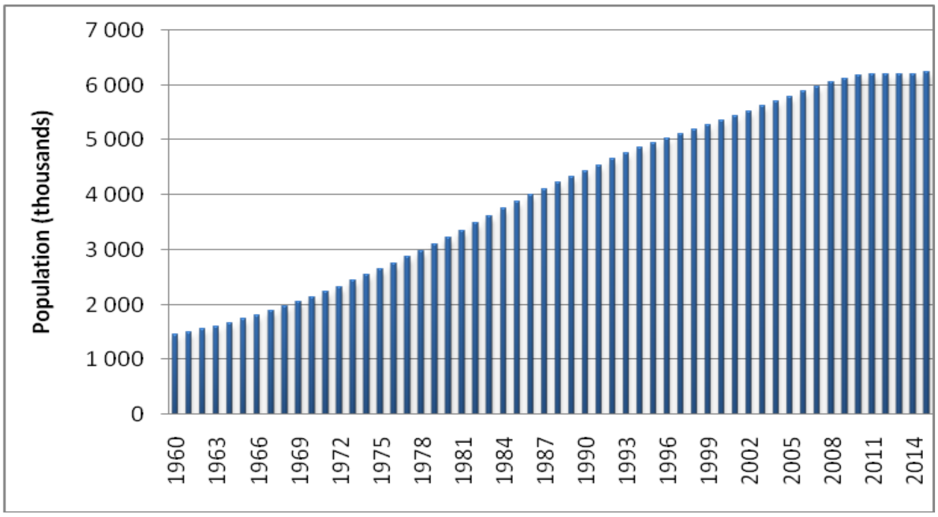


Figure 5-8Present and Projected Population (UN. Population Division, 2017)

The main demand for water is for agricultural use (Figure 4.9). This is expected to continue even with improving irrigation systems as a result of climatic conditions and an expansion in the irrigated area in order to meet population needs. Agricultural water demand was 3.885 million m^3 in 1995 and it is expected to reach nearly 8 Mm^3 by 2025 (Alghariani, 2007).

Industrial water demand, which approaches 4% of the total, is the lowest consumption of the three sectors. It includes different kinds of industrial water use such as petrochemicals, cement, textiles, steel, and food industries. The total current industrial water use is estimated at 145 Mm^3/year and it is expected to rise to 470 Mm^3/year by 2020 (Bindra, et al. 2003).

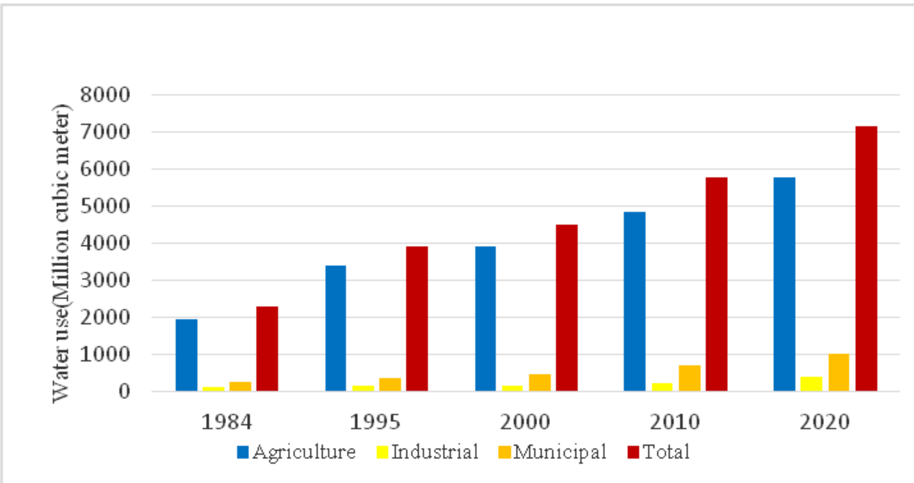


Figure 5-9 Historical and Future Water Use by Sector (’000 m^3/year) (After Algheriane, 2007)

In this situation of accelerated water demand with limited conventional water resources, Wheida and Verhoeven (2007) discuss the necessity of applying an integrated water management approach with a focus on developing sea water desalination and wastewater reuse.

5.4 WATER DEMAND IN DETAIL

5.4.1 Agriculture

Due to the low and highly fluctuating levels of precipitation, agricultural production is highly dependent on the irrigation system. Therefore, the agricultural production that is rain-fed is rather limited and contained in the coastal strip. According to the FAO (2005), only 38% of barley, 32% of wheat, 25% of dates, 34% of vegetables and 24% of olives are produced under rain-fed conditions. Abufayeda and El-Ghueleb (2001) point out that drought conditions, exacerbated by high levels of population growth have led to an increase in desertification, particularly with uncontrolled population growth. Table 4.3 highlights the high level of areas that suffer from aridity in Libya.

Table 5-3 Aridity Zones Al-Rabty, A. (1996).

Aridity Type	Average Annual Rainfall (mm)	Land Area (000' km2)	% of Total Area
Very dry	< 50	1589	90.8
Dry	50 – 200	130	7.4
Semi-arid	200 – 400	26	1.5
Sub-humid	>400	5	0.3
Total		1750	100

1.2% of the total area of Libya is cultivable which is equivalent to about 2.2 million ha, of which1.8 million ha is used for annual crops and 0.3 million ha for permanent crops. In addition, there is 13.3 million ha for permanent pastures (WAEA, 2008).

Although the agricultural sector uses the majority of the water, it only contributes around 9% of gross domestic product (GDP) and employs around 5% of the total economically active population (Libyan General Planning Council, 2003).

5.4.1.1 Irrigation and water control

More than 80% of Libya's agricultural products depend on irrigation from conventional groundwater. Nevertheless, in general, due to the prevailing shallow, coarse soils with limited natural fertility and high erosion risks, the productivity of crops such as wheat and barley is much lower than in other Mediterranean countries (Curtis, et al. 2002; Laytimi, 2005).

The actual irrigated area has been expanded since the 1970s, when it was less than 100,000 ha (Allan, 1974). By the end of the 1990s it had reached 435,000 ha. Although, the government spent almost 30% of total expenditure in that period in an effort to create food self-sufficiency, less than 25% of food demand is met. For example, production of cereals in 1998 (207,000 metric tons) met only 15% of the country's needs (Laytimi, 2005).

In 2000, about 300,000 ha of the actual irrigated area mentioned above completely depended on groundwater and the rest used surface water and treated wastewater. About 750,000 ha are estimated to be under irrigation dependent entirely on fossil water, of which 40,000 ha is in the coastal areas relying on renewable groundwater (EU-MED AGPOL Project, 2005).

The private irrigation sector accounts for over 80% of the total irrigated area. It is primarily associated with small-sized farms of 1-5 ha in the traditional agricultural areas located in Jifara Plain, Jabal al- Akhdar and Murzuq Basin (See Table 4.4) (FAOSTAT, 2005). Allan (1976) points out those large agricultural projects have been set up in the deep Sahara (Al Khufrah Oasis and Sirir) which depend on deep wells to provide water to pivot irrigation systems. However, 25 years of intensive irrigation has led to problems of drainage resulting in brackish water degrading the soil.

Table 5-4 Irrigated Areas in 2000 (ha) (FAOSTAT, 2005)

Area	Irrigated area in ha			
	State schemes	Private irrigation	Total	Private irrigation as % of total
Jabal al Akhdar	0	24,000	24,000	100.0
Al Kufrah- as Sarir	18,500	8,500	27,000	31.5
Jifarah	0	142,000	142,000	100.00
Hamada el Hamra	22,000	15000	37,000	40.5
Murzuq	18,500	67,500	86,000	78.5
Total	59,000	257,000	316,000	81.3

The climatic conditions and poor soils have meant that farm outputs in terms of domestic food production are limited and fail to meet domestic demand. For example, the peak for wheat production was 200,000 tonnes in 2010 and 300,000 tonnes of barley in 1999 (See Figures 4.10 and 4.11). According to the World Bank (2006) only about 25% of food demand is domestically produced. This issue has been aggravated by the growing population allied to growing incomes which have boosted food consumption. Therefore, the Libyan authorities have adopted the strategy of importing food to compensate for this gap in food demand.

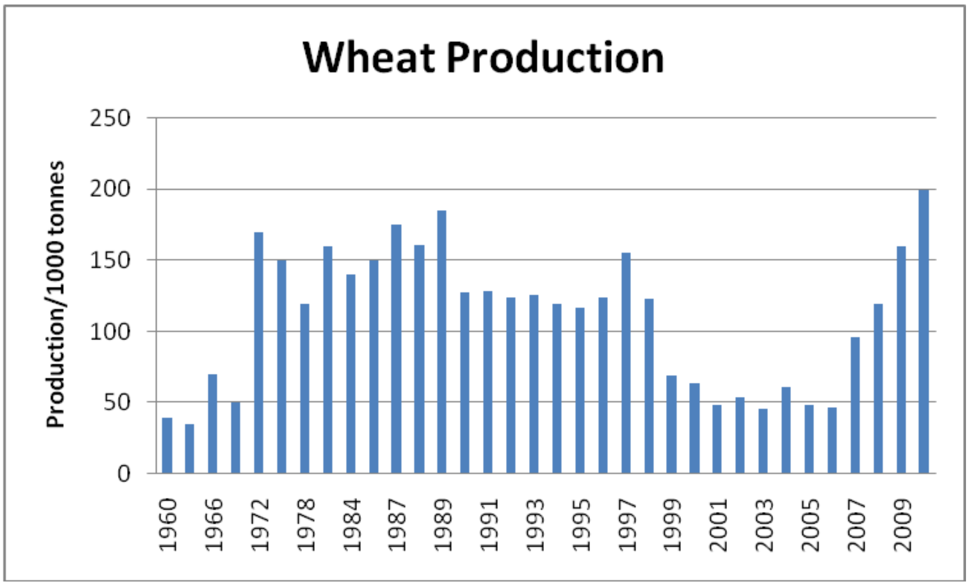


Figure 5-10. Wheat Production (Agricultural Ministry Annual Report, 2008 & 2010)

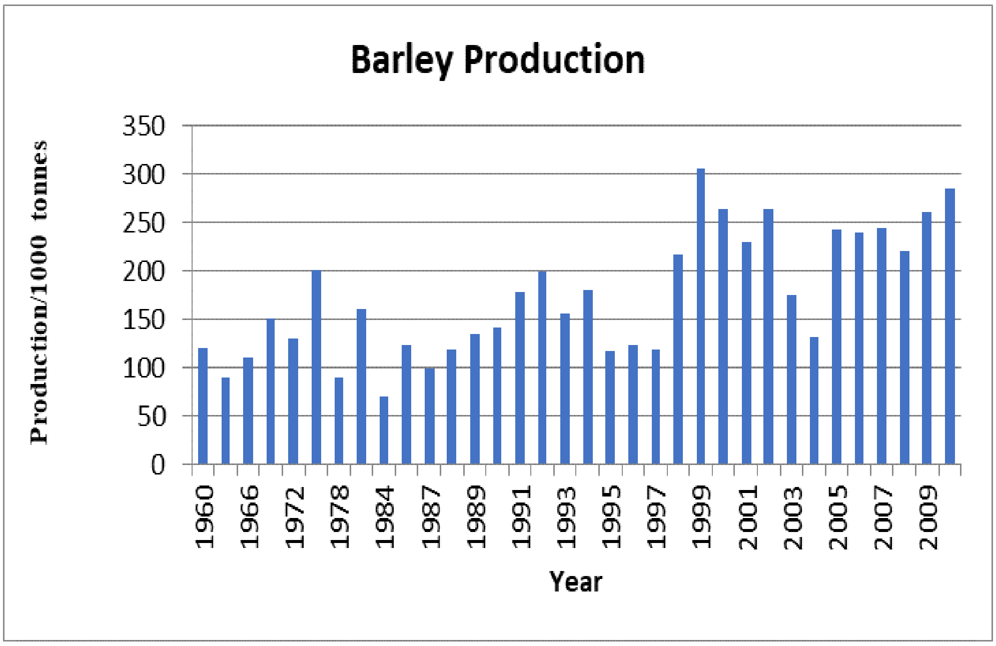


Figure.5-11. Barley Production (Agricultural Ministry Annual Report, 2008 and 2010)

5.4.2 Agricultural Trade in Food Products

While Libya has large exports of oil, it has large imports of food products in order to meet the growing gap between domestic production and demand. The trade balance for food products has been negative for many years. Not only are food imports growing but also agricultural product exports, even in good years, did not exceed 0.6% of total exports between the last years of the 1980s and the beginning of 2000s (Laytimi, 2005).

In the early 1970s, attaining food self-sufficiency was a prime focus for the leaders of the 1969 revolution; they used this as a moral commitment to the Libyan populace and as a sign that real independence could be achieved. Therefore, that period witnessed a huge expansion in irrigated agricultural projects across the country. However, by the 1980s, the leaders recognised that achieving food self-sufficiency was impossible and would become more difficult in the future, not least because of the lack of water resources (Wheida & Verhoeven, 2007). The authorities have had no option but to import food on the international market using revenues derived from the oil industry. In addition, the government has heavily subsidised many food imports. Goodland (2008) and FAO (2011) pointed out that about 75-80% of required food is imported, for example, the subsidies on flour alone exceed 2% of GDP, which is roughly equal to the combined administrative budgets of both the Ministries of Justice and Foreign Affairs.

The rise in the food import bill can be seen in Figure 4.12. It shows the rapid increase from US$100 million in 1970 to the nearly US$1,300 million by 2005, although the nominal value of the import bill fell at the beginning of the 1980s mainly due to the fall in food prices at that time (WAEA, 2008).

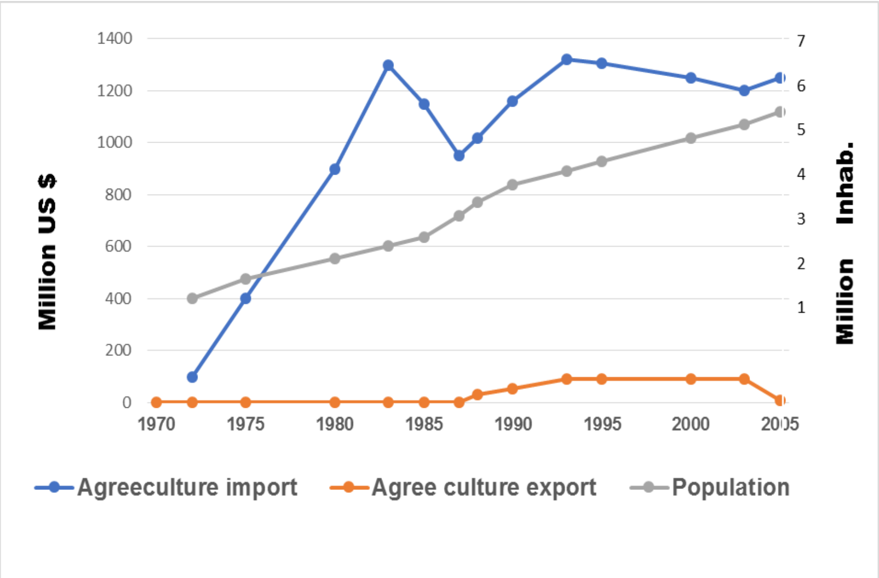


Figure 5-12 Imports and Exports of Food Products with the Population (WAEA, 2008)

Cereals represent the major imported goods to Libya where about 2,013 million tonnes of cereal were imported in the period 1995-2002. Up to 84% of annual domestic utilisation of cereal was imported of which the majority was wheat (67%) and then barley (11.7%) (Laytimi, 2005).

According to the FAO (2011) in 2008, the most-imported crop was wheat (1270513 tonne) followed by maize (530008 tonne). Table 4.5 shows the balance of food supply in Libya and the percentage of self-sufficiency in the main crops, with high dependency on external supply in cereals. However, it shows high reliance on local production in fruit production and oil products (Wheida & Verhogen (2007).

Table 5-5 Food Supply in the late of 1990s (Wheida & Verhogen, 2007)

Commodity	Production ('000 tonnes)	Supply ('000 tonnes)	Self-sufficiency (%)
Wheat	142	1360	10
Cereals other than wheat	69	857	8
Fruit (excluding wine)	366	388	95
Vegetables	864	1340	64
Oil crops	202	233	87

In the period 2000-2002, Libya exported about US$91,000 of wheat flour annually while it imported about US$220 million in the same period. Domestic fruit production met 91% of local demand in 1995-2002, with domestic production of 336,000 million tonnes. Local vegetable production accounts for 75% of Libyan needs, with the exception of tomatoes which are the major portion of vegetable imports. Conversely, about 10,000 tonnes of tomato and 4,000 tonnes of onions were exported in 1995-2002. Local production of olive oil is able to meet about 56% of domestic utilization (WAEA, 2008; Laytimi, 2005).

Despite increasing agricultural production with the expansion of irrigated farming projects and the use of fertilizer, production in the agriculture sector remains low compared with the level of domestic demand. Thus the country still needs to import large amounts of food to meet its food demand.

5.5 THE GREAT MAN-MADE RIVER PROJECT

There is a significant amount of groundwater located in the deep Sahara region in North Africa. The investigations conducted to explore oil have shown the reserves available and determined the capacity of huge aquifers at Sirt, Kufra, Murzuq and Ghadames at depths of less than 100 m below the ground's surface. This amount of water was recharged by tropical rain (Edmunds and Wrights 1979). These investigations have proven that each of these basins contains reserved water up to 3000×10^9 m^3 of economically accessible water (CEDARE, 2001). For instant, Salem (1994) and

CEDARE (2001) pointed out that the Nubian Basin (of which Al Kufra is part) was estimated to contain $373.3\times10^{12}m^3$. It was estimated by Allan (1974) that, with optimal use, the water level will decline up to 33m in 40 years.

The increase in population growth allied with low levels of renewable groundwater and the deterioration in the quality of groundwater in the coastal area because of salt water intrusion raises the question about how to best use this resource. Either the population could be transferred to the south or the water could be transported to the inhabitants in the north (Briginshaw, 2001).

In fact, the Libyan authorities used a combination of both solutions. In the 1970s, agricultural projects were developed in the heart of Sahara at Kufra and Sarir to grow cereals to meet domestic food demand (Allan, 1974). However, technical issues such as the lack of agricultural infrastructure, poor soil quality and the inability to produce crops at competitive prices constrained those projects, particularly with the development of drainage problems (Briginshaw, 2001).

Therefore, after taking into account the economic cost of water transfer compared to the cost of desalination of sea water and taking into account environmental considerations, the decision was taken in 1980 to go ahead with the second alternative. In 1983 the Libyan authority started building an artificial river under the supervision of Great Man-Made River Authority (GMRA) to transport 6.5 Mm^3 of water per day from those aquifers located beneath the deserts to the coastal cities. The mass transfer of water from the southern desert was to be achieved through the use of concrete pipes with 4m diameter (Brown & Root, 1992; Abosh, 2001; Alghariani, 2003; Elhassadi, 2008).

A comparison of the volume of water for each Libyan dinar for each alternative source of water is shown in Figure 4.13. Thus transferring water by pipeline from south Europe to Tripoli was estimated at $0.74m^3$/LD, desalination at 0.79 m^3/LD and transportation by ship was $1.05m^3$/LD. The best value was undoubtedly the Great Man-Made River (GMMR) project at 9.00 m^3/LD (GMMRWUA, 2002). However, Alghariani (2003) stated that the comparison did not take into account the dramatic drop in the price of desalination plant technology since the scheme was implemented, while the costs associated with the GMMR have escalated over the years.

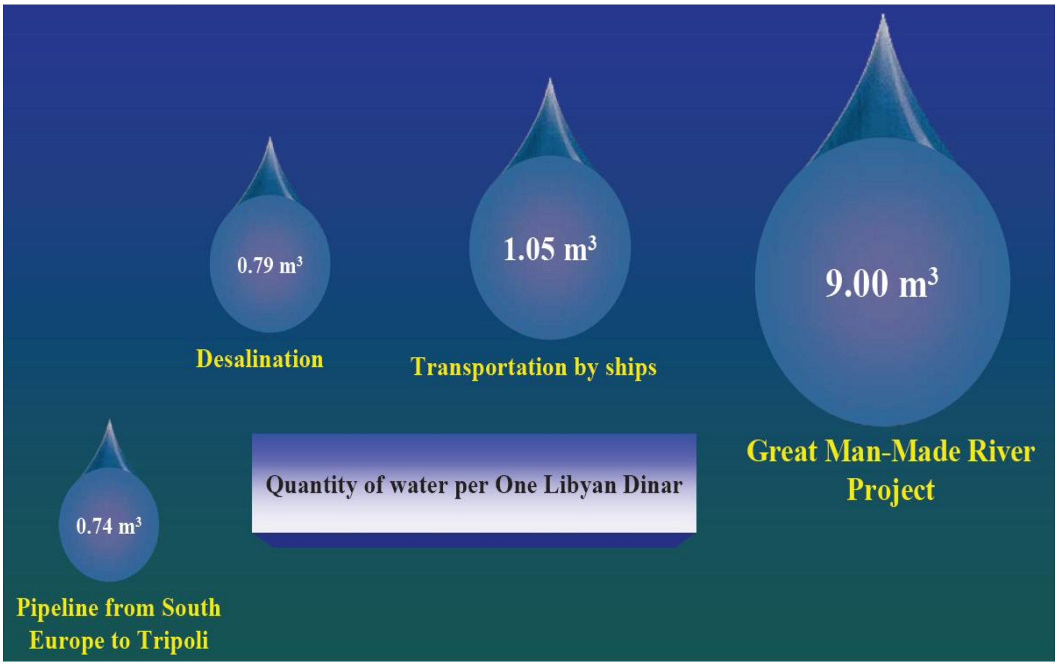


Figure.5-13 Comparative Cost between of Water Transportation Alternatives (GMMRWUA, 2002)

The cost of completion of this project was about US$14 billion which was achieved without any external loans. The idea for the project was first proposed with the discovery of oil in the 1960s and a feasibility study took place in 1974 with work commencing in 1984 (Abdul Aziz & Ekhmaj, 2007).

5.5.1 *Project Description*

The project was designed to bring a total of 6.5 million m^3 daily of underground fossil water from the south to the north through 4,000 km of 4 m pipes. It consists of five stages (Figure 4.14) which required the drilling of about 1300 wells (GMMRP Authority website).

5.5.1.1 ***Stage one***

This stage is called the Sarir/Sirt Tazerbo/Benghazi System and was completed by 1993. It involved the construction of 1,200 km of pipelines from the Sarir and Tazerbo basins in the south-east to bring 2 million m^3 of water daily to the coastal cities of Sirt, Benghazi and Briga via the Ajdabiya reservoir. The Tazerbo field consists of both production and piezometric observation wells and yields around 1 Mm^3/day. The wells at both Tazerbo and Sarir are about 450 m deep and are equipped with submersible pumps at a depth of 145 m.

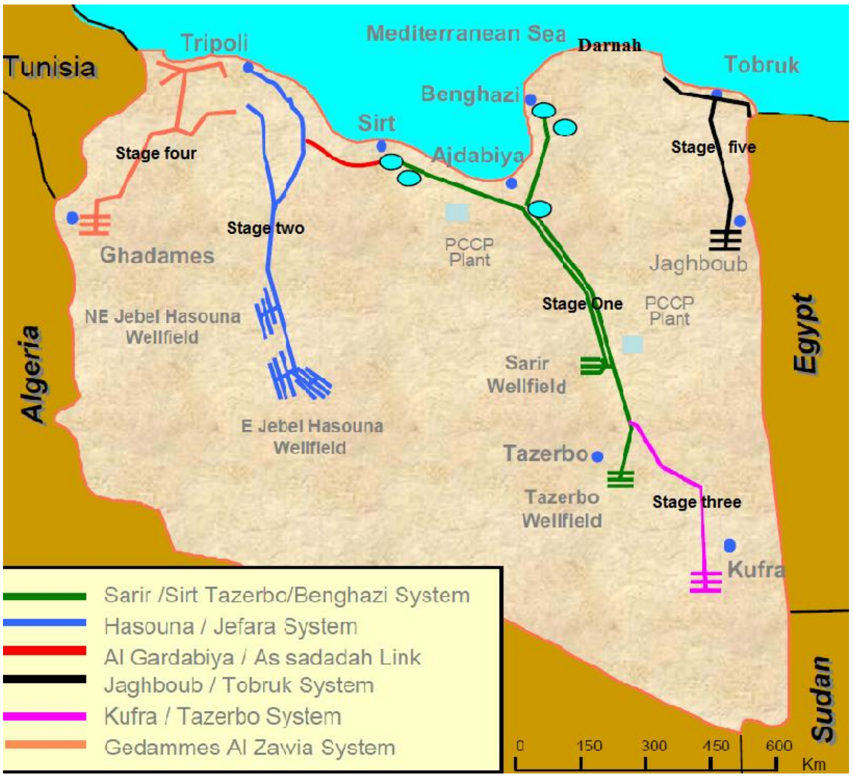


Figure 5-14 Great Man-Made River Stages (Salem, 2007)

5.5.1.2 <u>Stage two</u>

This stage is called the Hasouna-Jefar System and was completed in 1996. It created a pipeline transport system that could deliver 2 Mm^3 of water daily from aquifers located in Jabal al-Akhdar Hasouna to Tarhouna and the coastal cities located in the north-west around Tripoli and on the Jefara plain. This amount of water was pumped from 457 production well fields located in both the east and north east Jabal al-Akhdar Hasouna.

5.5.1.3 <u>Stage three</u>

This covered the construction of pumping stations at the Kufra well-field, a 380km pipeline linking the field with the Sarir/Tazerbo network, along with a 140,000 m^3 regulating tank.

5.5.1.4 <u>Future Developments: Stages Four and Five</u>

Stage four is called the Gedammes/Zwara System and aims to build a pipeline network from Gadammes to north-western cities such as Zwara and Zauia. Stage five is called the Jagboub/Tobruk System and aims to construct a pipeline from the Jagboub oasis to the city of Tubruk. Both the fourth and fifth stages have yet to be implemented. With the completion of the GMMR, about 8000 km2 of pipeline will be able to transport water to the north of the country and open the more fertile land to agricultural project investment, including foreign direct investment.

5.5.2 *Water use of Great Man-Made River*

According to the GMMRPWUA (2002) a number of large agricultural schemes were offered but priority was given to three projects situated around Benghazi, Sirte and Tripoli to produce forage crops and other higher value cash crops. Those projects are:

- The Tarhuna project which comprises 1200 ha with an annual water allocation of 12 Mm^3. This project took place outside Tarhuna city about 120 km south of Tripoli;
- The Sirt Al-Qardabia project which aims to irrigate about 5400 ha with an annual water allocation of about 57 Mm^3;
- The Al-Khadra project, located at south of Benghazi, aims to irrigate about 6000 ha with an annual water allocation of about 59 Mm^3.

According to Al-Rabty (1996) and GMMRPWUA (2002) these three projects, along with additional projects that the government intends to establish in the near future after finishing these three projects, will have a positive impact in terms of:

- Achieving a high percentage of self-sufficiency in grain and fodder crops.
- Increasing the capital investment in agricultural production and diversifying national income from oil by exporting high quality cash crops.
- Producing raw materials for the food processing industry.
- Achieving social development by encouraging and supporting agricultural settlement in the targeted places thereby increasing income and providing job opportunities in the agricultural sector.
- Protecting the environment and natural resources in the investment areas through soil conservation and vegetation cover programmes, growing windbreaks and establishing check dams to prevent soil erosion.

Goodland (2008) argues that once the all phases of the project are completed, about 75% of Libya's water use will be provided through the GMMR Project. Owing to the conflict that started in 2011, the GMMR Project has suffered many setbacks (see, for example, CEOBS, 2018) and Goodland`s projection is unlikely to have been fulfilled.

5.6 POLICIES AND LEGISLATION RELATED TO AGRICULTURAL WATER USE

In the 1970s, when serious water deficit problems started to surface, the Libyan government established the General Water Authority (GWA) with responsibility for water assessment and monitoring. This institution has six branches across the country (Saad, Shariff & Gairola, 2011). The Authority consists of six general directorates: planning; follow-up and statistics; water resources; dams, irrigation and drainage; soil; and finance and administration.

The GWA has conducted a number of studies and research in order to improve the irrigation system and drainage. Moreover, it has recently linked the centre for data storage to the Geographic Information System (GIS) and has established a central laboratory for basic and advanced analysis related to soil and water. Strategies of agricultural development in Libya has been engaged the Agricultural training as the once tools that empower farming sector to increase agricultural productivity and to conserve the natural resources (Abdelwhab, 2011).

This strategy has involved farmers and agricultural organisations, agricultural societies , universities and colleges across the country as the stakeholders to applied the policy of agricultural training .Therefore, this initiative implied through the supervision of the Ministry of agriculture through numerous organisations that involved in agricultural activities developments.

Abdelwhab (2011) pointed out that the programming of agricultural training aimed to enable peoples to develop their agricultural skills to meet the agricultural strategies needs and to achieve its targets. Furthermore, the collaboration with the international agricultural organisation is considered as the most important to implement the strategies of agricultural training programme (Lglesias et al, 2007).

In the following listing of the stakeholders that involved of the agricultural training programme in Libya;

- The Food and Agricultural organisation of the united nation (FAO).

- The international Centre for Agricultural Research in the Dry Area (ICARDA).
- The Arabic Centre for Agricultural Research in the Dry Area (ACSAD).
- European Union
- Farmers based association, Cooperative and Societies.
- Agricultural Research centres (six research centres across. The country)
- Department of agriculture extension Centre at the Ministry of agriculture
- Libyan universities
- Libyan Vocational Training centres
- Non-Public organisation (this involved the abroad delegation who came to Libya to give assistance to develop agriculture sector.

The responsibility for water and agricultural issues are shared with the Ministry of Agriculture which is responsible for the development of irrigated farming and for several agricultural projects implemented in the 1970s and 1980s. After completion of Phases 1 and 2 of the GMMR, the Great Man-Made River Water Utilisation Authority (GMMRWUA) was established, with the responsibility for the use of water delivered through the GMMR to the agricultural sector.

The lack of cohesion in terms of the responsibility for water and the limited coordination between the GWA and GMMRWUA has led to a weakness in many issues such as the regulation of well digging, and controlling cropping patterns. This issue was exacerbated by the decentralisation of regulation and support functions (GWA, 2000).

Overall, the lack of a Water Ministry that could be responsible for strategic planning and coordination of all aspects of water use and supply means water management is fragmented. Goodland (2008) highlights that the proposal was circulating to create a water coordination and integration ministry.

Some of the legislation related to the regulation of water use in agriculture in order to protect water resources that have been passed since 1972 are presented in Table 4.6.

Table 5-6 Important Laws, Decision and Decrees relating to the Environment and Water Resources (After Saad et al. 2011and Hamad, 2012)

Law	Main Objective of Law
Law 26 of 1972	The establishment of a Public Board of Water responsible for proposing public policies and legislation concerning water, following up their implementation, and overseeing the follow-up projects related to water abstraction, digging wells and the methods of using them.
Law 46 of 1972	Protection of shrub land.
Ministerial Decree 1976	Controlling the plantation of citrus trees.
Decision of Agricultural Ministry 1979	Banning the drilling of water wells in the Gefara Plain and surrounding mountain areas.
Law 827 of 1980	The establishment of the General Authority for Scientific Research and its bodies specialized in various fields.
Decision of the GPC 1981	Adopting certain measures concerning the re-planning and development of the coastal belt.
Law 3 of 1982	Ownership of water, responsibility for control and management, licensing for drilling, exploitation and use; pollution control and penalties.
Law 5 of 1982	Protection of pastures and forests.
Law 7 of 1982	Protection of the environment.
Law 790 of 1982	Organization of drilling operations and the preservation of water sources.
Law 1 of 1983	Agricultural inspection.
Decision of Agricultural Ministry 1983	Regulating irrigation.
Law 15 of 1984	Protection of animals and trees, prevention of hunting wild animals, and prevention of tree felling for urban expansion.
Law 72 of 1988	Establishment of the Arab Centre for Desert Research and Development of Desert Communities.
Law 15 of 1992	Protection of agricultural lands, pastures and forests and converting them to irrigated agricultural lands.
Decision 431 1994	Regulate the exploitation of water.
Decision 82 2002	Detached the drilling water wells permits and supervision from General Water Authority to local departments of agriculture.
Decision 625 2007	Cancellation of the Decision625 and prohibits water drilling in some regions in Libya.

According to Salem (2007) water law and legislation are satisfactory and cover all aspects of water conservation and protection. However, implementation of them is ineffective, even with the establishment of a special police force with full authorisation to monitor violations of the agricultural and water regulations and a special court to look into these cases of violations.

5.6.1 Water Policies

The water authorities have realised that the existing measures were of limited effectiveness in regulating water use either for agricultural use or in the municipalities.

Therefore, the authorities are working to reform and develop the existing policies and institutional framework in order to achieve a sustainable management of natural resources while improving productivity to meet changing patterns of food demand.

Salem (2007) observes that the new policy faces several challenges which are summarised by the questions: Do we know enough about water resource potential? Is it possible to achieve food security? How can urban water demand be achieved? How much GMMR project water should be used for irrigation? Can the deterioration in water quality be reversed?

The main objectives of the new policy are reducing the water deficit and avoiding water quality deterioration. Salem (2007) argued that these objectives can be achieved by applying the measures he proposed in GWA (2007), presented in Table 4.7.

Table 5-7 Proposed Policy Measures (After GWA, 2007)

Measures	Components
Capacity Building and Institutional Reforms	Integrated water resource planning. Balanced socio-economic development in the water regions. Restructuring water institutions. Defining priorities of water use.
Demand Management	Minimize losses in irrigation. Limit agricultural expansion in water stress areas. Redefine self-sufficiency and food security concepts. Apply safe yield principle for renewable aquifers. Use treated sewage water for irrigation. Ban export of agricultural products. Enforce laws and regulations governing water extraction. Lift subsidies on non-efficient irrigation systems. Educate farmers. Improve irrigation efficiency. Improve productivity. Encourage dry farming.
Re-allocation of GMMR Project Water	Give priority to domestic water supply. Substitute irrigation water in water stress areas. Re-allocation of GMMR project water
Water Pricing	
Public Awareness	
Development of Conventional and Non-Conventional Water Resources	Update information on groundwater basins. Construct additional dams and reservoirs. Build major desalination and sewage treatment plants. Develop conventional and non-conventional water resources. Protect water resources from pollution. Review and update water legislation. Environmental protection. Technical cooperation.

5.7 SUMMARY

This chapter focused on the development of agriculture in Libya in light of local water resources. It explored the limitations of water resources and the role of the national government in managing these limited resources to meet the food needs of the population. It identified the various attempts by the government to overcome the problems arising from the limitation of water resources and irrational use of water.

The purpose of this chapter was to give insight into the current agricultural activities and water management in Libya in terms of water institutions, regulation, and supply and demand management. The overview of agricultural activities and water management in Libya enables researchers to approach the problem of using and managing water resources sustainably, and to evaluate the current water management resources.

CHAPTER 5 METHODOLOGY

6.1 INTRODUCTION

This chapter deals with the methodology used for collecting and analysing data related to water resources management and strategy and major agricultural products (major crops) in order to calculate the water footprint of Libya. This chapter shows the research philosophy and the strategy of this research and also the methods that have been used to collect the required data and then the ways of analysing it.

6.2 RESEARCH PHILOSOPHY

Choosing the philosophical position and the methodological approach for a research project depends on and is framed by the nature of the research problem (Finn et al., 2000). The philosophical position of a researcher is the starting point in the discussion of research methodology which leads to the methodology and research strategy (Crotty, 1998). Saunders et al. (2009) have emphasized that the most important capability of a researcher is to consider deeply the philosophical choices he makes, which are categorized into realism, interpretivism, positivism, and pragmatism.

Academic research is often underpinned by philosophical paradigms of positivism and interpretivism and/or constructionism. The epistemology within positivism is objectivism while that of interpretivism is subjectivism. Subjectivism believes that the meaning of things comes from personal beliefs and values and not from the outside world. Closely related to interpretivism in terms of epistemology is constructionism that considers how social phenomena or objects of consciousness develop in social contexts (Grix, 2004).

According to Grix (2004: 63), ontology is the first step in any research. It defines 'what is it' we need to know about the nature of existence of an identified problem such as water scarcity in Libya. Ontology embodies an understanding of what is out there to know, and it is considered as the starting point of all research. After identifying the ontology of the research, epistemology is the next step. It is defined as what and how can the researcher know about the reality (knowledge) of the incident. It embraces what we need to know about the problem, and deals with "the nature of knowledge, its possibility, scope of the problem" (Gray, 2009). "Epistemology tries to understand it means to know and it provides a philosophical background for deciding what kind of knowledge is legitimate and adequate" (Gray, 2014:19).

Positivism is often about what can be seen, smelt and touched, etc. It usually deals with the natural sciences and involves gathering facts about the world for the purpose of generalising these facts over the world. Objectivism is concerned with objective reality and attempts to explore or discover this objective reality. Objectivism is linked to positivism (Gray, 2005; Grix, 2004).

The interpretivism paradigm believes that natural reality is different from social reality and they need to be studied differently. Subjectivism is the epistemology of interpretivism and it believes that the meaning of things comes from personal beliefs and values not from the outside world. Therefore, subjectivism is linked to interpritivism (Gray, 2005).

An interpretive approach (specifically, a hermeneutics approach) was applied to understand the text of data collected from the stakeholders in order to evaluate the current agricultural and water policies in Libya. Aristotle (1938 translation) cited in Arunachalam (2006) has defined hermeneutics as "…an operation of the mind [of the researcher] in articulating a true judgement about something". Hermeneutics endeavours to gain objectively the valid interpretation of the inner life of a person as it happened in a particular time and place. Later, Heidegger and Gadamer (1976 &1975) saw it as an ontological term for the phenomenology of being there.

Arunachalam (2006) used Heidegger and Gadamer's philosophical hermeneutics to understand community dialogue on degradation of water resources. Hermeneutics approaches have also been applied in other fields of research such as: accounting (Gray, 2002), organisational research, (Prasad, 2002) and in a variety of other fields (Mkhize, 2005).

Hermeneutics tries to investigate the interpretation circle between interpretations as lived experience and interpretation as a story of many things and continually affecting each other (Figure 5.1).

Bleicher (1982) pointed out that "adopting the hermeneutic perspective does not imply that the organizational researcher may not employ quantitative or statistical techniques of analysis”. The hermeneutic approach has the flexibility to allow management researchers to combine qualitative and quantitative methods (Prasad, 2002). Therefore, the hermeneutics approach was well suited to evaluating water and agriculture policies in Libya. This approach allowed the researcher to obtain a lot of information from the small number of people in charge. Employing hermeneutics’ interpretive approach enables the researcher to understand dialogue of people regarding the impact of agricultural activities on the water resources in quality and quantity.

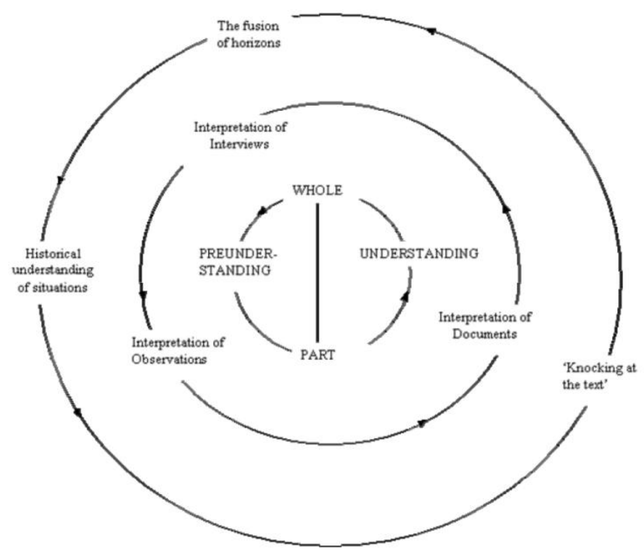


Figure 6-1 Application of Gadamer’s approach to Hermeneutics (Arunachalam, 2006)

Crotty (2003) clarifies that epistemology endeavours to provide a philosophical grounding for deciding what kinds of knowledge are possible and how we can ensure that they are both adequate and legitimate. Thus, by adopting appropriate ontological and epistemological approaches to research into the water shortage issue in Libya, a philosophical view can be provided on what knowledge is derived from the research and how to ensure that it is valid, satisfactory and justifiable. Gray (2009) supports this stance and is of the opinion that natural science and social science are two very different paradigms requiring different ontological and epistemological methods for understanding.

According to O’Leary (2010) ontology embodies understanding what type of things actually exist. It asks: what is out there to know? It is considered as the starting point of all research, after which one's epistemological and methodological positions logically follow. These can be defined as: what are the rules for discovering what exists (epistemology) and how we go about acquiring that knowledge (methodology).

6.2.1 Approach adopted

This research aims to examine critically the concept of the water footprint and to apply the concept to water management in Libya as a case study. To achieve the objectives of this research, two philosophical paradigms (positivism and interpretivism) are utilized to gather data related to water management systems in Libya. Thus data have been collected through interviews with key water institutions, questionnaires distributed to farmers, the examination of documents, and non-participant observation. The interpretivism side of this study is based on the interviews, while the positivism side based on the questionnaire.

6.3 RESEARCH STRATEGY

6.3.1 Developing the Strategy

In terms of research strategy, there is no perfect way to follow but a series of compromises. Patton (1990) points out that "research, like diplomacy, is the art of the possible".

The choice of research methodology and methods of data collection are often affected by the philosophical position of the researcher (Crotty, 1998).

The strategy of research is not the same for all research but each research project has its own specific approach for collecting and analysing data. Choice of strategy is determined by several factors as follows: "…the control over actual behavioural elements and the degree of focus on historical or contemporary events; are the conditions which should provide the ground for strategy choice" (Yin, 2003)

It was considered that the use of one methodology, either quantitative or qualitative, alone is inadequate for this study in view of the problem under consideration. Therefore, both qualitative and quantitative methods have been employed to achieve the aims and objectives of this research.

The methods used in this research have to reflect both the facts and the quality of people's meanings, understandings and interpretations. For this reason, a combination of the two research paradigms is more useful for gathering and analysing the data. Thus, mixed methods have been employed to avoid the weakness of each paradigm.

According to Creswell (2003) a mixed methods approach means using more than one method to collect and analyse quantitative and qualitative data in a single piece of research. This combination of methods allows researchers to gain more in-depth information and consequently improve the understanding of the phenomena being researched, generalise the findings from the research population and to reduce the bias resulting from one method or paradigm by introducing a balance between both methods (Hanson et al, 2005).

Combining quantitative and qualitative methods is an appropriate methodology here as multiple approaches can capitalise on the strengths of each approach and offset their different weaknesses. It could also provide more comprehensive answers to the research questions, thus going beyond the limitations of a single approach.

In this research, qualitative and quantitative methods were employed; therefore, both methods need to be explained. For all kinds of research, ontology is the starting point and it is then followed by the epistemological positions. From this point, qualitative methods look at the theory of knowledge in a subjective way; it tries to find the meaning of a situation where the researcher is part of the situation. Qualitative methods see and emphasise meanings (words) rather than frequencies and distributions (numbers) when collecting and analysing data. These methods often endeavour to create theory through the inductive approach. Quantitative methods look at the theory of knowledge in an objective way; it always strives for the facts and the researcher stands at a distance from the situation. Quantitative methods look to uncover the truth using mathematical logic. These methods endeavour to confirm theory through the deductive approach (Gray, 2009).

It is now necessary to explain how the two approaches have been combined and applied to achieve the aim of this research. In order to understand and assess properly the water shortage in Libya, data have been gathered qualitatively and quantitatively from four categories of people: farmers, specialists in water and agricultural institutions, water experts in Libyan universities and staff of the General Environmental Authority. Mixed methods have been applied at both stages of collecting and analysing data. The strategy of collecting the data started with quantitative methods followed by qualitative methods.

Quantitative methods helped the researcher to set out the main themes and concepts that were explored with the participants in the research.

6.3.2 Quantitative Methods

The first step required in this survey is to build a questionnaire. The concept or variable of the research questions needs to be identified before the questionnaire can be constructed in the proper way (May, 1997). Then, the questionnaire needs to be distributed to the selected samples. Finally, statistical analysis of all the data gathered is carried out before generalising the outcomes of this survey.

A cross sectional survey was employed as the method for undertaking the project, with the questionnaire as the measuring instrument. The survey was designed according to a number of assumptions that seek causes and effects of water scarcity in Libya. All incidents are caused as a result of circumstances that led to that incident. Thus, in order to assess any incident (phenomenon), these circumstances should be understood in order to control and prevent such incidents from occurring again in the future (Creswell, 2003).

Responsibility for water management in Libya lies with the official water authorities and policy makers, either in terms of regulating the water use through the applying a proper irrigation system and agricultural plans such as agricultural rotations, irrigation period, water pricing, etc. Aqeil, et. al (2012) argue, however, that although the GWA is responsible for water management, and has the right to prevent any violation and deterioration in quality and quantity of water, this authority has failed to take proper actions to regulate the amount of water used (by farmers and other users), which has led to water shortage.

he role of the GWA is to assess the problem of water scarcity in a systematic manner with the assistance of quantification which is necessary to enhance the accuracy in the description of the parameters and the relationship amongst them (Aqeil et al, 2012). It should be noted at this point that the writer is aware that he stands in a neutral position with respect to what he is researching.

The survey was designed to sample farmers with long experience in agricultural practices to get their opinion about the water use and how well it was managed and organised in terms of usage in the agricultural sector, including irrigation systems, type of crops grown, water regulation and the enforcement of water regulations. The questionnaire covered farmers of different regions over the country. The researcher was able to develop a number of themes from the questionnaire which were helpful in formulating questions to ask at the interview.

From an ontological point of view, the questions arising at this stage are: how can the concept of the water footprint be applied to water resource management in Libya? What are the experiences of the farmers and policy makers in the agricultural and water field in Libya? From a phenomenological stance that emphasises people's subjective experiences and interpretations of the world, the answer to these questions can be gained from the perceptions and thoughts of the people involved in the agricultural sector: farmers, experts and administrative staff in the water and agricultural institutions.

From an epistemological point of view, the questions are: what and how can we know and understand what happened to the water resources in Libya? Since the interest here is in understa

nding why this problem happened, interpretivism is more appropriate than positivism. Knowledge that can be gained subjectively is constructed by the experience of involved people through their memories and perceptions, and is also gained by objective enquiries with the involved people where the researcher has a neutral stance from the situation

Qualitative methods have been considered appropriate for this research to extract the perspectives of official and non-official water bodies about the water management systems. An earlier pilot study through direct observation by the author in the field and interviews with the official water institutions did not give deep insights into the water management system in Libya. This is because the official water institutions, for several reasons, reflect the official governmental views and not that of farmers. Thus, the researcher decided to include the views of farmers. However, it is impractical to conduct interviews with large numbers of farmers in terms of time and cost. Therefore, a quantitative approach using a questionnaire survey was adopted to gather data from a large population (of farmers 200 in total) on their perspective on strategies and implementation of water polices.

6.3.3 *Qualitative Methods*

The qualitative approach was employed through two methods. The first was by conducting semi-structured interviews with water experts and administrative staff in government institutions and independent water experts. The second was by reviewing the secondary data which includes water and agricultural plans and the water legislation that controls water use in the agricultural sector.

Strauss and Corbin (1990) defined the qualitative methods as "… any type of research that produces findings not arrived at by statistical procedures or other means of quantification".

The process of carrying out research is affected by several factors such as the nature and purpose of the study, time and other resource constraints. The interviews allowed interviewees to give valuable data from their point of view in their own words (Finn, et al. 2000).

The number of participants is determined according to the kind of research. Ethnography and ethno-science; Bernard (2000) and Creswell (1998) claim that sample between 30-60 is acceptable most studies, grounded theory methodology; between 20-30 sample is acceptable and in a phenomenological research is between 5 and 25. In this research project, the researcher targeted to conduct interviews with 4 farmers, 2 independent water experts at the Libyan universities and 4 members of the administrative staff at the official agricultural and water institutions, and 4 members of the non-official institutions.

According to Bell (2005), a semi-structured interview allows the interviewer to follow up the sequence of ideas or points and attempt to motivate the interviewee to explain in depth particular issues that the interviewer wishes to explore.

At the stage of data collection, the researcher needed to be fully conscious that there is a link between him and the participants being researched, and he should bear in mind that his understanding of the world is the starting point in understanding the others. To assess and understand the problem of water resources, the reality of the issue has to be negotiated and gained through dialogue between the researcher and interviewees. All the opinions of the interviewees emerged through that dialogue of conflicting interpretations.

6.4 ETHICAL CONSIDERATIONS

O'Leary (2010) points out that while conducting any research, ethical issues have to be considered and cannot be neglected. They have important implications for the negotiation of access to people and organisations while collecting data (Saunder, Lewis & Thornhill, 2003). In this research, ethical issues were taken into account in four main ways as described below.

The first area has to do with avoiding harm to participants. This has to be taken very seriously by positivist and interpretivist researchers. Managers and workers in official water and agricultural institutions will be expected to respond by expressing their views and opinions, which might include criticism of higher authorities. If individuals can be identified, then in extreme cases this could cause embarrassment for those people. Workers may be victimised for giving opinions which the management of the institution may consider as contrary. Therefore, confidentiality must be ensured, must be strictly adhered to and should not be breached under any circumstance as was affirmed in the ethical approval process for the project. Assurance of confidentiality was included in the letter of invitation to participate in the study (see Appendix 1 and 3). If it is known that confidentiality might be breached, the research must not go ahead. If there are any dangers that anonymity might be compromised, individuals and organizations (institutions of higher learning and employment organizations) must be informed of this so they can decide whether to participate or not.

The second area relates to ensuring informed consent. The participants (farmers, workers in the water and agricultural institutions, and independent water experts) should be provided with sufficient and accessible information about the research to enable them to make an informed decision as to whether to become involved, or not. Participants will be informed on the aim of the research, who will be undertaking it, the kind of information being sought, how much participant's time is required and who will have access to the data once it is collected. Respondents should also be informed that participation is voluntary, that responding to all questions is voluntary and that their anonymity will be preserved.

The third area has to do with respecting privacy of participants. Participants were ensured of their anonymity and confidentiality. The data collected were well stored with adequate control to prevent the data from being accessed and used by others. The study is expected to be submitted to policymakers and the government, and this was made known to the participants. The opinion and facts generated were presented just as supplied by the participants. The participants were also informed on their right to access the results of the research.

Finally, the research has avoided any form of deception. The researcher was candid to the participants. Particularly in the case of interview, the actual time required was made known to participants. The researcher avoided any act that might build a negative reputation or that might in the long term reduce levels of participant cooperation.

6.5 RESEARCH PROCESS

The first and fourth objectives of this research are to define and critically evaluate the concept of water footprint and to investigate how the concept of water footprint might be applied in Libya. These objectives were achieved by undertaking a critical review of literature on the concept of water footprint and how the concept applies in Libya. The scope of water footprint evaluation in Libya was limited to agricultural commodities due to the fact that agriculture is responsible for up to 85% of water use in Libya (Postel et al., 1996; Algeriane, 2003). The period of water footprint analyses was limited to a period from 2001 to 2009 since this is the most recent period for which all necessary data could be obtained.

The second and third objectives (investigate and explain the social and cultural context of Libya, and how this influences water use and to critically evaluate the current national policies and strategies of water resources management) were achieved by:

1. Reviewing documents in Libya on:
    - ❖ Water and agricultural policies and strategies.
    - ❖ Water and agricultural regulations and legislation.
    - ❖ Quantity and quality of water resources.
2. Conducting interviews with selected key players from water institutions and water experts in the Libya universities.

3. Conducting a questionnaire survey with farmers in the private sector in different regions in Libya.

4. Comparing the results of interview analysis with the results of questionnaire analysis.

The fifth objective was to examine the water footprint concept as a tool for the assessment of the consequences of current water management practices. It was achieved based on analysis of the interview and questionnaire data and water footprint estimates for Libya.

6.6 PILOT STUDY

Baker (1994) pointed out that a pilot study is applied for the pre-testing of a particular research instrument in order to draw the attention of the researcher to important issues that can lead to project failure, such as where research protocols may not be followed and whether proposed methods or instruments are inappropriate.

Pilot studies can be based on both quantitative and qualitative methods and more than one pilot study might be carried out in the case of large-scale studies before conducting the main survey. The first step of a pilot might be using in-depth interviews or focus groups to establish the issues to be addressed in the main project (Tashakkori & Teddlie, 1998).

This step was taken in order to explore the ease of accessibility to respondents and data, and the time required for conducting the interviews and distributing the questionnaires. The aim of the pilot study was also to establish advanced contacts with some institutions related to data resources. Hoggart et al. (2002) state that "in survey work, a first step in checking the credibility of an instrument is a pilot survey". Therefore, the pilot study is important, to test how the instrument works before conducting the whole research.

To determine how well an instrument works is a significant procedure and to ensure the validity of the research tools as Caunce (1994) stated, all data gathering for the survey questionnaire was tested by pilot study with a view to giving a chance to discover some content and structural issues that can be amended before commencing a full-scale survey.

A pilot study was conducted before the main data collection, which took place in September 2010, a two-month pilot study was conducted between June and August 2010 in the four selected regions, handing the questionnaires and conducting the interviews to test their validity and reliability. Ten copies of the questionnaire were handed to the farmers in each of the four agricultural regions of Libya, individual farmers being selected through convenience sampling. The participants in the pilot study were selected by snowball technique and asked to review the questionnaire and provide their opinions on the appropriateness of questions, the clarity of the concepts and to understand whether or not the questions posed were understood by the sample.

Some of the themes which were raised in the pilot study were discussed with one academic water expert who belongs to GWA and has had lengthy experience of water management in Libya. An informal meeting was also conducted with former Agricultural Minister of Libya during his presence in the UK to discuss some issues regarding water and agricultural policies and strategies. These preliminary discussions were not used in the thesis but were used to help the researcher to develop the questions.

Due to the large numbers of farmers and farms in the selected area, it was impossible to undertake a comprehensive survey. The pilot survey showed that many farmers were not literate enough to understanding the questionnaires in the questionnaire and formal interviews.

There was no considerable problems were encountered during the pilot study, only farmers in the regions did not understand some questions because they translated from English to pure Arabic language. For example, Alfalfa has different local name across the regions and in the question of irrigation type, flood irrigation has changed to conventional irrigation because some of respondents did not understand the meaning of flood irrigation.

6.7 DATA COLLECTION TECHNIQUES

Choosing methods for gathering the required information is the last step in the research planning and depends on the perspective of research philosophy. The philosophy, approach and methodology of this research illustrated in Figure 5.2 are discussed in the following sections.

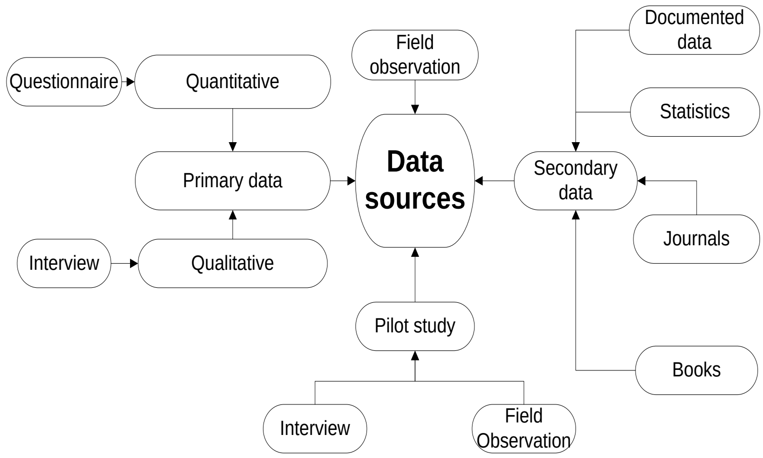


Figure 6-2 Data collection techniques

6.7.1 Secondary data

The secondary data included documented data from the literature survey which is the starting point for the researcher in order to confirm the research questions and to increase the researchers' understanding of the project (Denscombe, 1998).

Books and journals, websites, government publications and official statistics were the main source of documentary data. This method provides easy access to the information; it is inexpensive, permanent and available to be checked by other investigators. Secondary information can also help to set the questions of the questionnaire and interview.According to Denscombe (1998) reviewing documented data has some advantages such as easy access to the sources of information and low cost compared with other approaches, and such data are permanent and available to be checked by others. However, it has some disadvantages in that there is a need to evaluate the organisation of data sources to know the credibility of documents, and that the documents can reflect the view of the writer rather than objective reality.

The review of literature on the water footprint covered the following areas:

1. The main crops grown domestically and the main imported agricultural goods in Libya.

2. Crop water requirements of the main crops in Libya.

3. Total agricultural production.

4. Total imported agricultural goods.

5. Water balance of Libya (input and output of water).

6. Renewable and non-renewable water resources.

7. The present and projected water policy and strategy.

8. Libyan population size.

Because the agricultural sector is responsible for most water use and represents between 80 and 85% of the total, the data gathered will be used to estimate the agricultural water footprint of Libya according to the standard method established by Hoekstra & Chapagain (2008), which is as follows:

National water footprint (WFn) = Internal water footprint (WFi) + External water footprint (WFe)

The internal and external water footprints are calculated in equation (5.1):

$$(WFi) = WUa + WUi + WUd - Ve,d \tag{5.1}$$

Where WFi is internal water footprint, WUa is agricultural water use; WUi is industrial water use, (WUd) is domestic water use and (Ve,d) is the volume of virtual water that is exported to other countries.

Because Libya is not an exporting country and the export of agricultural products is very little, the virtual water that is exported to other countries was excluded from the calculation of the water footprint.

The volume of water used in the industrial sector was neglected as well because most water use in Libya is by the agricultural sector. Therefore,

$$WFi = WUa \tag{5.2}$$

Where WFi is internal water footprint and WUa is agricultural water use.

$$WFe = Vi - Ve,r \tag{5.3}$$

Where (WFe) is external water footprint, Vi is virtual water that is imported into a country and (Ve,r) imported virtual water for re-exported to other countries.

Because Libya is also a re-exporter for imported goods, the imported virtual water for exportation was neglected. Therefore,

$$WFe = Vi \qquad (5.4)$$

6.7.2 Primary data

To examine the concept of water footprint, it was necessary to investigate critically the current water management systems and policies in Libya. Interviews and questionnaires were used to collect the required data relying on the skills, abilities and agricultural experience of the researcher.

6.7.3 Questionnaires

Questionnaires yield information provided directly by people in response to questions asked. It is an adequate tool for data collection when the researcher knows exactly what is needed to achieve the research questions and objectives (Sekaran, 2000). There are two types of questionnaire: The first is called a pre-coded (closed) questionnaire, which asks a number of pre-set questions with limited choice to answer. The second is called an open-coded (open) questionnaire, which askes a number of pre-set questions but there is no pre-set choices of answer (Browne, 2011).The questionnaire is either left with the respondents to be collected later or is sent by post or via email for respondents to reply to (Saunders et al, 2007). There are some key advantages of questionnaires which can be summarised as follows: they are relatively low cost; postal questionnaires are easier to arrange than interviews; to some extent, the respondents are asked the same questions with no scope for variation that might occur with face to face interviews (Neuman, 2005). However, there are three main disadvantages: there is little opportunity in postal questionnaires to check the truthfulness of answers; pre-coded questions can bias the findings towards the researchers' opinions rather than respondents' perception; questions can be pre-coded in inappropriate ways which deter the respondents from answering these questions. Therefore, a box-ticking routine is more suitable to encourage people to answer (Denscombe, 1998).

Table 6-1 Reasons for the questionnaire questions

Question	Rationale / comment
1- Participant's name	Protected by assurance of confidentiality included in the letter of invitation to participate in the study (see Appendix 1).
2- Age	In the developing countries, Libya in particular, the educational developments programme has begun at 1960s and become extensively spread in 1970s and 1980s (Libya, statistic book 2006). So, farmers` age can be primary indication to the education level of those farmers.
3- Region	As Libya is a big and wide country and classified as arid and semi arid, this question is to determine the whether the farm locate in the South where the desert and the evaporation is high or in the north either West or East where is the evaporation is moderate and rain is significant compared with the south.
4- Function point	A distinctive point or landmark identifying the sample location in case it is necessary to return for any additional inquires related to the questions
5- Educational level of farmers 6-Are you a specialist in agriculture sector? 15-Do you receive any guidance programmes of agricultural practices and water usage	The level of education of farmers determines their ability to interpret information. Farmers with higher educational levels are more able to interpret information than those who have less education or no education all (Mather and Adelzadeh, 1998). Thus, education levels can affect the use of agricultural information and the implementation of agricultural practices, farmer education is very important in increasing farm efficiency in all regions. Farmers with basic education were 8.7% more productive than farmers with no education (Gasperini, 2000 cited in Eric et al, 2014).
7-Type of cultivated crops and which of these crops have been exported?	To determine whether the cultivated crops are high water requirements or low. Because the water footprint calculation excludes the exported goods from the calculation (Hoekstra, 2007)
8-Type of agriculture	To determine whether the farm depend on irrigation from ground or rain-fed
9-Source of irrigated water 10-Do you have a license to dig the well used in irrigated?	To determine whether the water resource used is controlled by the authority which means it is licensed under the monitoring and whether the well is in the restricted area that restricted by the GWA.
11-Do you pay for using water?	To explore to what extent the pricing water is practically applied as the part of water management strategy (Plaut, 2000)
12- Types of irrigation system that has been used?	To explore to what extent farmers chose the irrigation system that has high efficiency in terms of saving
13-Irrigation time	Time of irrigation is important as it has a significant impact on the increase of evaporation in peak time where the temperature is high up to 40°C (Hoekstra and Chapagain, 2008)
14- Do you receive subsidies from the government for developing the irrigation system	To explore to what extent the government encourage and help farmers to develop their irrigation system to be more efficient Abdelwhab (2011

The questionnaire employed in this research was designed to collect information on farmers' perspectives on water policies and agricultural practices in order to examine to what extent water management policies and strategies are implemented. The justification of the questionnaire summarised in Table 5.1.

From the pilot study carried out, the researcher realized that there are some contradictions between the statements of official interviewees and the viewpoint of some farmers and water experts who are no longer in charge of any official governmental responsibility.

The academic background of the researcher, the researcher's experience in the agricultural sector, which based on 15 years experience of working in agriculture, and the experiences from the pilot study, helped in developing and reformulating the questionnaire and in collecting data from the farmers. The questionnaire was designed based on all the themes that are covered in the interviews.

6.7.4 Interviews

Qualitative data gathered from the interviews provides averages of information on the experience and perceptions of the interviewee generated from his or her own written or spoken words or observable behaviour.

The main instruments for gathering data qualitatively are interviews, which provide more of an in-depth insight into the topic. Qualitative data are obtained from fewer informants which means it requires methods or experience that allow the researcher to be able to capture language and behaviour (Maykut and Morehouse, 1994).

According to Bell (2005) there are four types of interview, as follows:

1. Unstructured interviews, which focus on introducing a theme or topic and letting the interviewee develop his ideas about the topic.

2. Structured interviews, which control the questions and answers and are administrated face to face with the interviewees. This kind of interview is often used with large volumes of data from a wide range of people such as in a social survey. In this kind of interview, the respondent has limited options as far as

responses to the questions are concerned. It is used in order to collect qualitative and quantitative data.

3. Semi-structured interviews, which are flexible and allow the interviewee to develop his ideas and speak more widely about the topics. It also allows the interviewee to reveal things about complex issues and address their personal experiences and feelings. At the same time the interviewer can control the interviewee if there any deviation from the subject.

4. Telephone interviews, which can be used in places where there is wide coverage of telephones because it has less cost than face to face interviews. Maxim (1999) pointed out that telephone interviews can be used to follow up responses of people in depth and may allow the interviewee to give his opinion about the key topic with more clarification.

For this study, the semi-structured interview has been selected as suitable for the exploratory part of the research in order to keep the interview under control in terms of time and the scope of discourse.

The choice of semi-structured interview was to enable the interviewee to elaborate and explain his point of view by generating additional questions to provide more details about specific points that the researcher might want to explore.

The interview questions were designed to cover the vital themes related to the research objectives. The researcher carefully developed the questions in order to address the aim and objectives of the study and also to ensure they obtain the maximum information from each respondent.

The interviews were conducted with representative interviewees both from official water bodies (such as the General Water Authority (GWA), the General Environment Authority (GEA), the Agricultural Research Centre and the Ministry of Agriculture) and from non-official water bodies (such as water experts at the universities, the Farmers' Union and the Agricultural Engineers Association). A first phase of interview was conducted in August 2010. The justification of the interview summarised in Table 5.2.

Table 6-2 Reasons for the interview questions

Question	Rationale / comment
Name/ position	For the confidentiality issue the name and his position are taken
Q1- What and how do you see the challenges that face the water management in Libya?	To explore that to what extent water resource management team are aware about the challenges and how they deal with them.
Q2. What are the main ground water aquifers?	General information about the ground water supply
Q3. Dose the pollution happens in the surface aquifers or in all others?	To explore to what extent the ground water is usable for both agricultural and municipal use.
Q4. Do you have strategies to deal with these challenges? Yes certainly. What are they?	To explore to what the water resource management team do to deal with those challenges
Q5. According to your personal point view, are all of these steps taken place on the ground?	To explore to what extent that those strategies are applied on the ground to be compared with questionnaire respondents and researcher field observation
Q6. How do you see the effectiveness of water regulation in terms of its ability to reduce water depletion?	To explore to what extent that those strategies are applied on the ground to be compared with questionnaire respondents and researcher field observation
Q7. What are measures taken to reduce water depletion in general and in the affected zones in particular?	To explore to what extent that the water resource management team has already taken some measures to reduce the depletion in ground water resource.
Q8. How do you estimate water demand for the future?	To explore the measures that use to estimate water demand in the future and how they deal with it.
Q9-As you have pointed out above that water resources are limited, is there any alternative sources to compensate for these limitations?	To explore to what extent that water resource teat has already taken some measures to compensate the limitation of water resources.
Q10- What about using power plants in agricultural sector?	To explore to what extent that water resource teat has already taken some measures to compensate the limitation of water resources
Q11- Have you already had plans and strategies to utilize the water of GMMR in the right ways and to avoid the previous problems that led to depletion of groundwater in the North?	To explore to what extent that the water resource management team has already taken necessary measures to protect the new water supply to avoid any depletion that may happen.
Q12- What about using water pricing mechanism?	To explore to what extent that the water resource management team has already applied some polices or ways to reduce water use and increase water supply such as charges policy , as the water payment charges is one of the effective way to reduce water consumption,
Q13- What about the method inject reservoir by rain water?	To explore to what extent that the water resource management team has already applied some polices or ways to reduce water use and increase water supply such as inject reservoir my rain water
Q14- As a General Water Authority is responsible for water resources management, are you familiar with the concept of water footprint?	To know to what extent that water resource management team is updated with the new knowledge and concepts related water resource management
Q15- Do you want to add any comments?	To let the interviewee take his time if he want to add any information that may forget to say during the interview

6.7.5 Direct field observation

Direct field observation of the agricultural practices based on the experience of the researcher was used to augment the data collected by other methods and to gain an in-depth understanding the effectiveness of current water policies and the extent to which the policies on water and agricultural regulation are implemented.

Taylor and Steele (1996) pointed out that observation is a suitable way to collect information by paying random visits to sites such as farms and it is a more reliable indicator of whether the people use practices recommended than asking them.

The field observations were carried out in the summer of 2010, while distributing the questionnaires to farmers, conducting the interviews and travelling throughout the farms. During this period, the researcher was observing and recording notes and taking photographs.

According to Yin (2003), the observation evidences are important and helpful in getting more information about the researched topic. In light of this, a number of visits was made to the different agricultural regions in Libya in order to observe the agricultural activities and to assess their impacts on the water resources.

The agricultural activities that are practiced such as type of grown crops, irrigation tools used, and time of irrigation were observed.

Because the interviewees will only represent their perceptions, it is critical to verify the collected data by observed action (Patton, 1990; Burns, 2000). Therefore, the observation visits were useful in validating the gained information either from the office or by the questionnaire and interviews and helped crosscheck answers of respondents.

6.7.6 Reflection on the method employed

The questions in the questionnaire and the main questions of the interviews were selected after one year reviewing the literature to arrive at the criteria for selecting those questions and were revised and amended after carrying out the pilot study.

A network of researcher contacts (friends and relatives) was employed for this purpose. It took a month travelling across the country between four regions using aeroplane and car with the support of my relatives and friends. Some difficulties were faced by the researcher in terms of farmers' concerns about some of the questions, many didn’t allow the researcher to take photographs while some of them were openly welcoming, allowing a systematic record of the visit to be made.

The interview journey was more difficult than the questionnaire as it was so difficult to arrange an appointment with the water and agricultural experts in the government institutions. It needed the researcher to stay and wait a long time to achieve one interview, which cost the researcher time and money.

6.8 SAMPLING TECHNIQUES

The population of the study for both the interviews and questionnaires is shown in Table 5.3. The interviewees represented both official and non-official water institutions in Libya, the sample being chosen based on the role of the institutions in relation to water and agricultural policies and strategies.

Table 6-3 Questionnaire samples

Region	Zone	Number of farmers in each region*	Number Of questionnaire distributed	Actual respondents	Response (%)
Northern-western	Tripoli	32025	76	40	52.6
North Eastern	Al-Jabal Al-Akhtar	9753	26	18	69.2
Southern	Fezan	14839	34	25	73.5
North Central	Mosrata	25831	64	42	65.6
Total		82448	200	115	57.5

*Libyan Annual Census report (2009)

The interviewees were chosen based on the results of the pilot study. Samples were selected as purposeful sampling, which means the participants are selected intentionally to have lengthy experience in this field.

According to Creswell et al. (2007) qualitative research seeks to probe data from a limited number of subjects in great depth; the more subjects are involved, the less potential there is for deeper probing within the conventional time limitations of a research project. Typically, when cases are reported, a small number is used, such as 4 to 10.”Therefore, the targeted sample size of interviews with purposeful sampling was 14 participants from different institutions related to the water and agricultural field. The actual response was 8 participants from different organisations.

For the purpose of the survey, Libya was divided into four regions based on, variation of crop production (Figure 5.3). Within each region, one administrative district

(Shabia) was chosen for study, based on the number of farmers in the region (Table 5.1). The number of farmers shown in Figure 5.3.

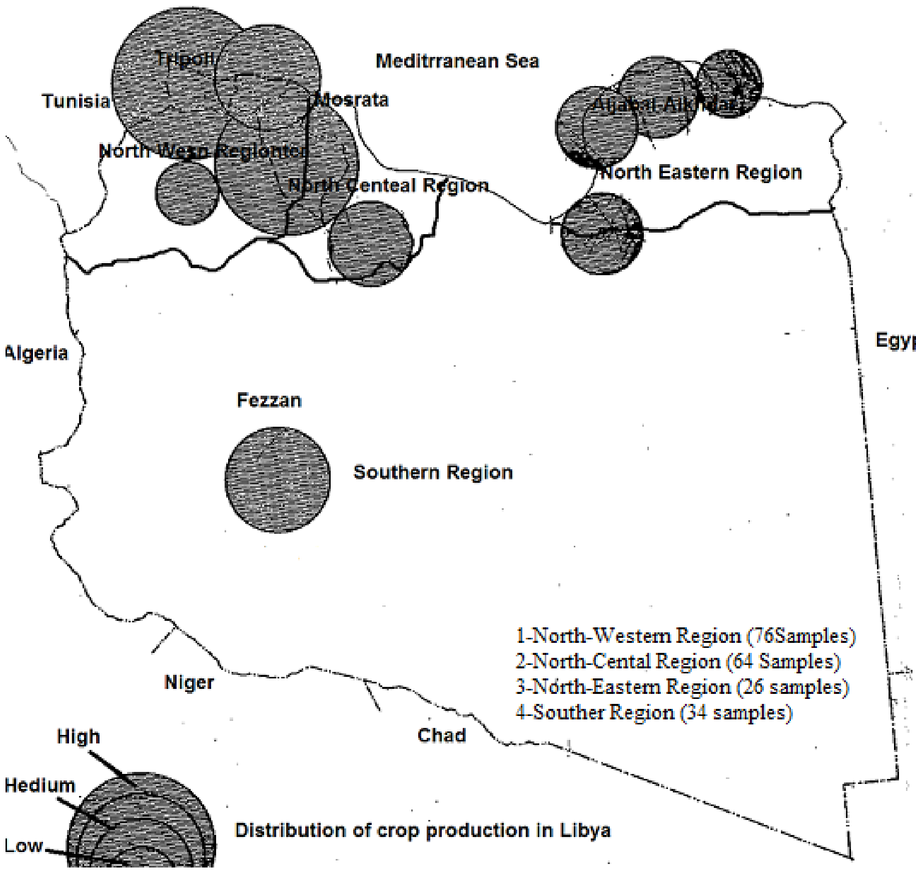


Figure.6-3 Sampling locations (adapted from Almehdawi, 1998

Purposeful sampling techniques were employed in choosing the interviewees. This technique helped the interviewer to access a particular group of people and it allowed the researcher to reject people who did not fit a particular profile (Saunders et al. 2003). The sample size for the interview was 8; 5 from official water institutions and 3 from non-official water institution (Table 5.4).

Table 6.4 Characteristics of the interview and questionnaire samples

Method	Institutions	Number of Participants
Interview	water experts in government and public water institution	8
Questionnaire	Farmers: 200 farmers divided to 4 parts of Libya based on the agricultural area	
	North-western region	76
	North Eastern region	26
	Southern region	34
	Middle of the North centre	64
Direct observation	Direct field observation was conducted based on the research background and experience of the researcher in the agriculture and water management fields. Records were kept using note book, video recorder and camera.	

The sampling frame of the quantitative survey is the total number of farmers in Libya, which is 82,448 according to formal statistics (General Authority for Information (GAI), 2007). The sample size was determined according to the total number of farmers, size of study area, costs, time and other practical constraints in accessing participants over such a large area. 200 questionnaires were distributed to farmers proportionally in each of the four selected districts (See Table 3.1 above). This sample size was chosen according to Israel (1992) who illustrated precision and confidence levels of selected sizes, according to which the confidence level of the research sample size here is 93%. The researcher handed the questionnaires personally to the farmers but the completed questionnaires were returned by post. A total of 115 questionnaires were returned (table 5.3).

6.9 DATA ANALYSIS

The information obtained from the secondary sources in relation to imported and exported agricultural production, the water requirements of major crops, and area cultivated were used to estimate the agricultural water footprint according to the standard methods established by Hoekstra & Chapagain (2008). The water footprint was calculated according to the major crops that are grown in Libya and the main imported crops within the period time as shown in Table 5.5.

Table 6-4 Major crops grown and imported to Libya

Major crops crown in Libya	Wheat, barley, tomato, water melon, potato, onion, olive oil and dates
Imported crops to Libya	Wheat, barley, tomato, rice, maize, corn oil, onion, olive oil and dates
Scope of study	2000 to 2009

Qualitative data procedures fall into main types as following: Organising data where the data collected should be listed according to date: when, where and with whom; immersion in the data where reading through the data is a key factor achieving familiarity; paying attention to how data are collated is very important through the research; generating categories and themes which should be internally consistent but distinct from each other; coding the data so that each theme and category is given a coding scheme.

According to Saunders et al (2009) the technique most frequently used in the coding of qualitative data is identification of a short phrase or a word that indicates the essence of the subject. Creswell (2007) explained that in the stage of coding qualitative data, the researcher looks for patterns such as similarities and then creates or forms categories that eventually constitute the themes.

Coding facilitates searching through the data and makes data comparison and the identification of patterns easier. It can be based on: themes, topics, ideas, concepts, terms, phrases and keywords (Creswell, 2007). Coding can be carried out using software or manual analysis. Using software to analysis qualitative data will assist the researcher to manage data. Bazely (2013) mentioned that it is particularly important in qualitative research to manage data, which can be of various types and complex content. Managing data indexes theoretical and conceptual knowledge emergent from the data analysed, assisted by querying the data and using graphical models in some cases to provide a preliminary database. According to Gibbs, and Taylor (2005) codes can start with themes identified from the literature or they can develop from codes and categories that arise from the data.

Due to the small interview sample size in this study, following translation from Arabic to English all the interviews were analysed and interpreted manually. The interview was analysed based on the research themes which aimed to answer the research questions and to achieve the research aims and objectives. All codes started with pre-existing themes identified in the literature and then all the data related to each theme were interpreted in the context of that theme.

The questionnaires were translated from Arabic language to the English language, coded and then loaded into Excel program. The results of qualitative and quantitative studies are reported and discussed in Chapter 6, the discussion chapter.

6.10 SUMMARY

To summarise, this research tried to gain a better understanding of water management in Libya in order to critically examine the concept of water footprint as a tool in developing water management in the specific conditions and circumstances of an arid developing country in North Africa. To achieve the objectives of this research, two philosophical paradigms (positivism and interpretivism) were utilized to gather data related to the water management system in Libya. Data were collected through semi-structured interviews conducted with selected participants, questionnaires distributed to farmers, critical analysis of pertinent official documents and academic studies, and the researcher`s own non-participant observation.

The methods used in this research reflect both the facts and the quality of people's meanings, understandings and interpretations concerning the research subject. For this reason, a combination of the two research paradigms was more useful for gathering and analysing the data. Thus, mixed methods were employed to counteract the weaknesses inherent in each individual paradigm.

Ethical issues were considered in terms of confidentiality in order to avoid any possibility of harm to participants, and informed consent was sought and obtained. Steps were taken to ensure the privacy of participants and any form of deception was avoided. Finally, the researcher sought to maintain friendly rapport with participants in order to encourage their active and meaningful cooperation.

Direct field observation of the agricultural practices was conducted based on the experience of the researcher and was used to augment the data collected by other methods and to gain an in-depth understanding of the effectiveness of current water policies and the extent to which the policies on water and agricultural regulation are implemented.

A pilot study was conducted before distributing the questionnaires and conducting the interviews to test the validity and reliability of the research instruments. Ten copies of the questionnaire were randomly handed to the farmers over the four agricultural regions of Libya for this purpose.

The gathered data were used to estimate the agricultural water footprint of Libya according to the standard methods established by Hoekstra & Chapagain (2008) relating to agricultural water use, which accounts for 80-85% of water use in Libya.

CHAPTER 6 RESULTS AND ANALYSIS

7.1 INTRODUCTION

This chapter focuses on the analysis of collected data pertaining to the current state of water and agricultural management. It also calculates the national water footprint based on the primary data gathered via questionnaires and interviews. The chapter is divided into three sections.

The first is quantitative analysis of the data gained from the questionnaire survey over the country. The second is qualitative analysis of the interviews conducted with official and non-official water and agricultural organisations over the country. The third represents a calculation of the water footprint and analysis of its application with reference to: national water scarcity, national water dependency and national water self-sufficiency.

7.2 QUANTITATIVE ANALYSES

The results of the questionnaire survey that was carried out in four regions, North-Western (Tripoli), Southern (Fazzan), North-Eastern (Al-Jabal al-Akhdar) and North-Central (Misrata) (table 6.1), locations of agricultural activity. The quantitative data were collected from 115 out of 200 farmers with at least 10 years' experience in the agricultural field. The response rate of the questionnaire was 57.5%

Table 7-1 Survey distributions of four regions

Region	Number of questionnaire distributed	Actual respondents	%
Northern-western	76	40	52.6
North Eastern	26	18	69.2
Southern	34	25	73.5
North Central	64	42	65.6
Total	200	115	57.5

The age and the level of education of farmers are among the most important factors in agricultural activities in terms of showing the ability of farmers to keep pace with developments. The age of sampled farmers was categorized into four groups as it is shown in Figure 6.1.

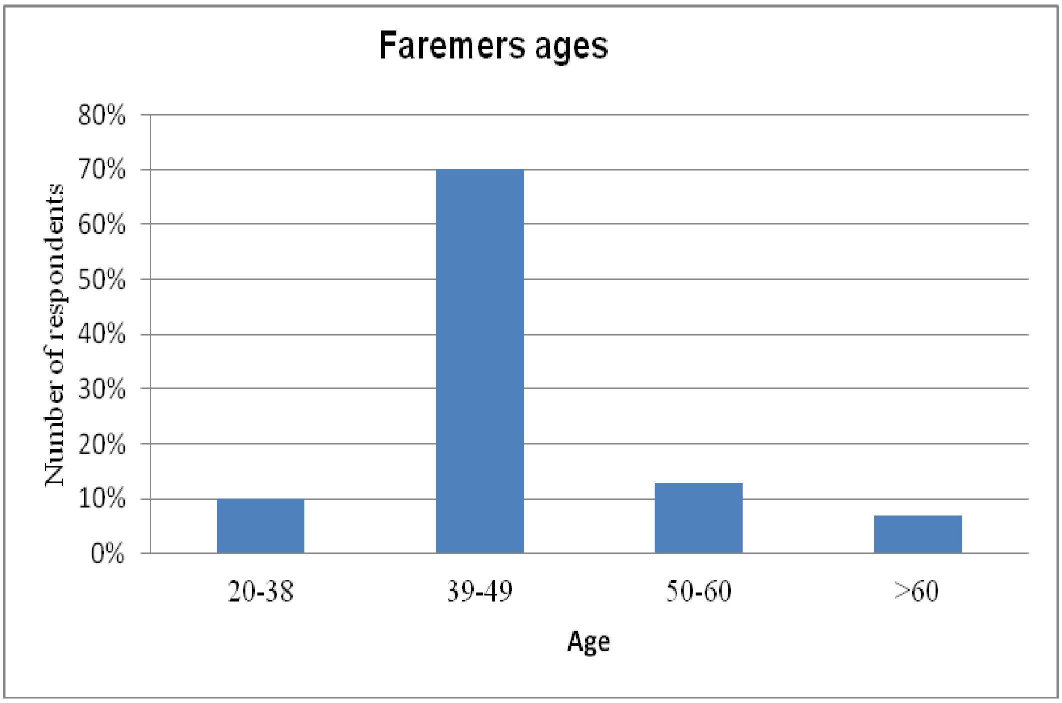


Figure.7-1 Farmer`s age

Figure 6.1 shows that farmers aged between 28-38 years formed 10% of the questionnaire respondents, farmers aged between 39-65 formed 83% and the rest (older than 65) formed 7%. It can be seen that the category of farmers between 20-38 is small. It suggests that the young generation trends away from practising farming. However, the old farmers might be less willing to adopt new methods.

The farmers' education level may be helpful to the farmers in terms of interpreting and understanding the information that is received from the Ministry of Agriculture or any other institution regarding agricultural practices and water use. Thus, the farmers with higher education level or with long experience might be expected to have more ability to interpret the information than others and, therefore, the education level might be expected to affect directly agriculture practices and water use. The education level of farmers is shown in Figure 6.2 below.

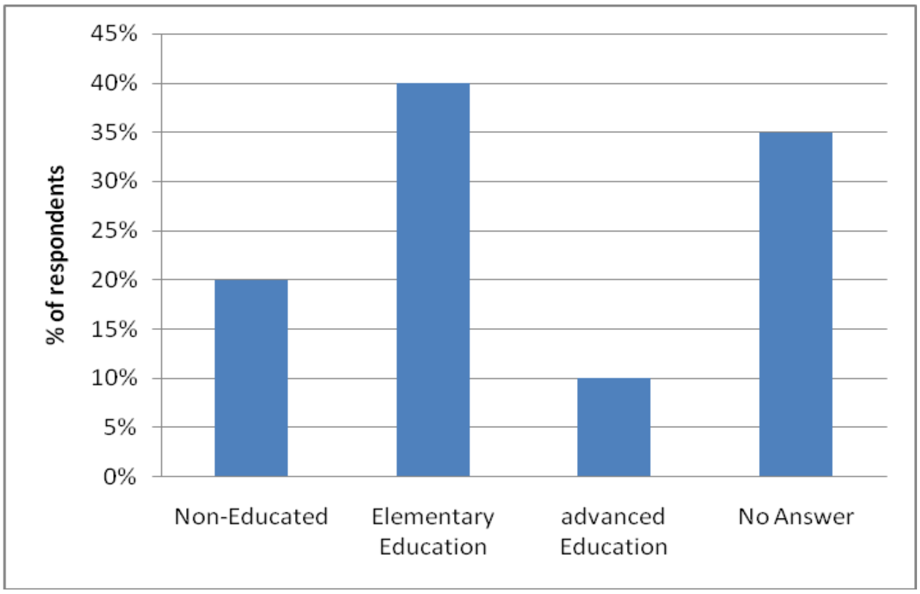


Figure 7-2 Education levels of farmers

Figure 6.2 illustrates that the most of farmers (50%) have some education, of which 40% had elementary education (from primary to high levels) and 10% with advanced education (after high levels to postgraduate). Only 20% of farmers are non-educated. It can be seen that farmers with advanced education represent a low percent.

The farmers' agricultural training is important for managing the farm (Abdelwahab, 2011). Even for farmers who do not have advanced education, the training courses can be useful and helpful for the farmers in making the right decisions and taking the right action at the right time to develop their agricultural practices at farms. Figure 6.3 shows, however, that the majority of farmers (70%) do not receive any agricultural training.

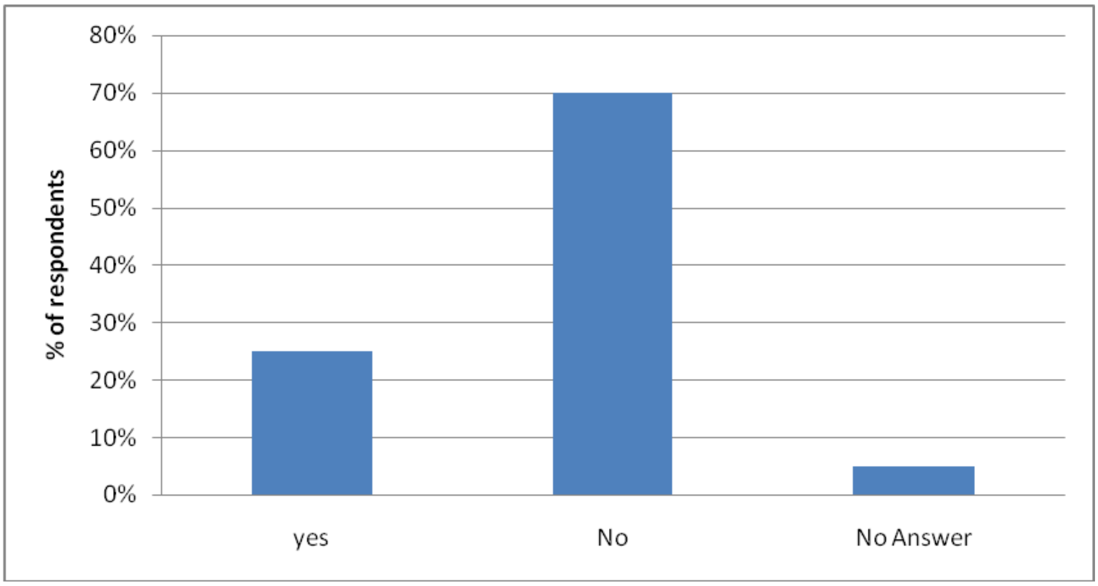


Figure 7-3 Farmers' agricultural training

The type of farm is important to give clear background about the nature of the agriculture in Libya and gives a general background about water use in the agricultural sector (see section 4.6). The types of farms were categorised into two groups in terms of water use to produce the agricultural production. It is shown in Figure 6.4 below.

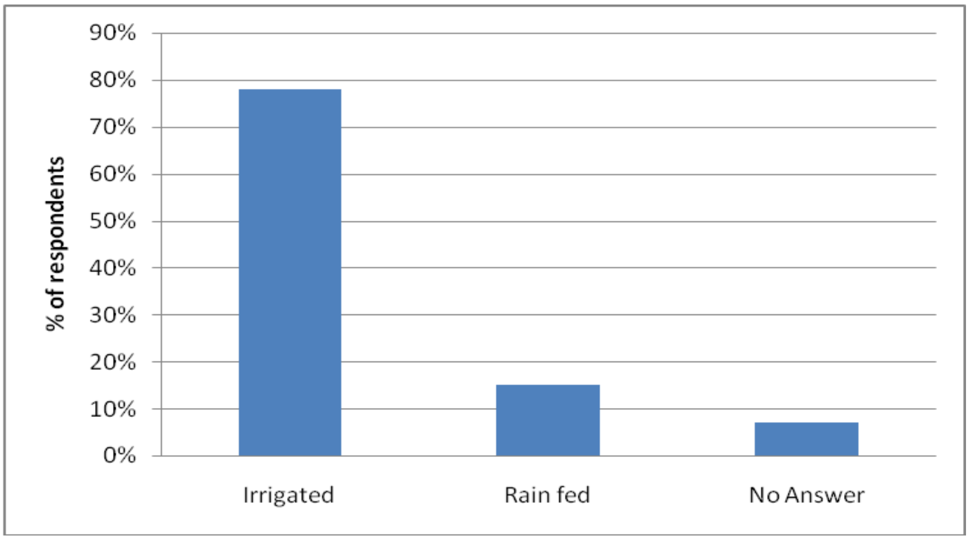


Figure 7-4 types of farms

Figure 6.4 shows that most of the famers are irrigated (78%) whereas only 15% are rain fed. The rest of respondents (7%) did not answer this question.The water supply of farms influences water management in terms of GWA controlled well-sharing or using a private well for each farm which means increasing number of private wells, which leads to increased exploitation of groundwater. The water supply was categorised into two groups: private wells and sharing wells as shown in Figure 6.5 below.

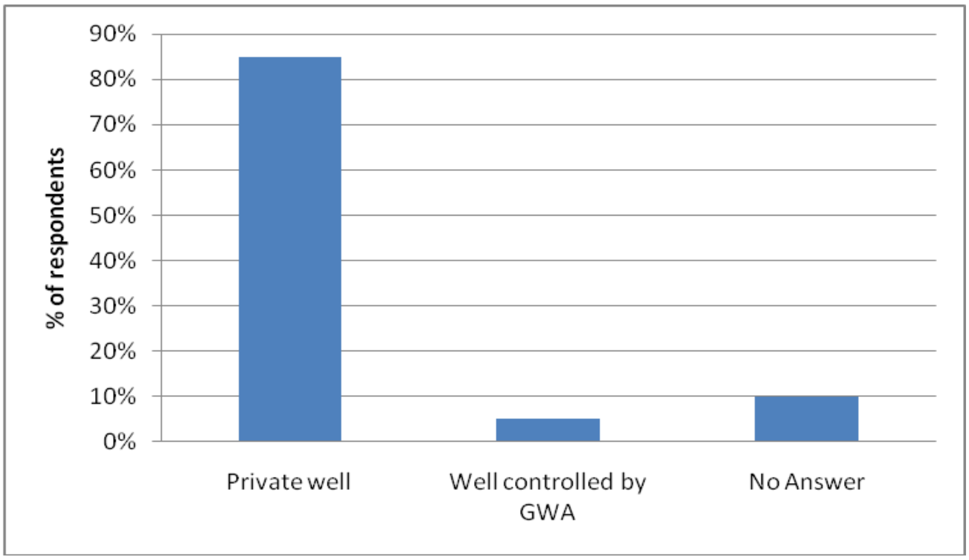


Figure 7-5 Water supply

Figure 6.5 shows that most of the farmers (85%) use a private (own) well to irrigate their farms whereas the minority share the well. Getting licences for wells in the farms means those wells conform to the specifications of the General Water Authority (GWA). Getting licences from the GWA is categorised into three groups as shown in Figure 6.6 which shows that the fifth of respondents did not answer this question while the less than a quarter do not get the licence for their wells.

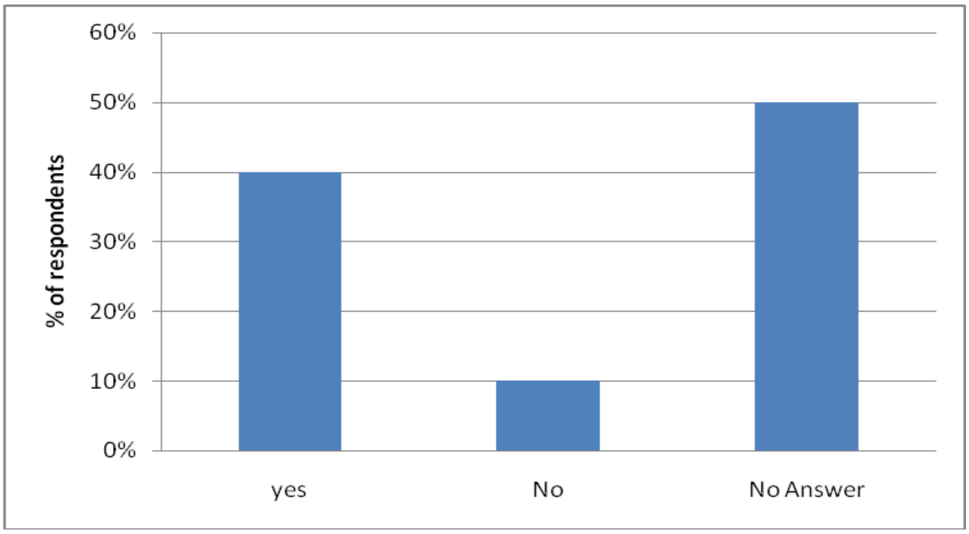


Figure 7-6 Licence of wells obtained

Water pricing is one effective way to reduce water use in all sectors, particularly in the agricultural sector (Wheida, 2007). This means that farmers who have a mechanism to pay for water consumption are more careful to protect and save water and reduce the excessive use of water.

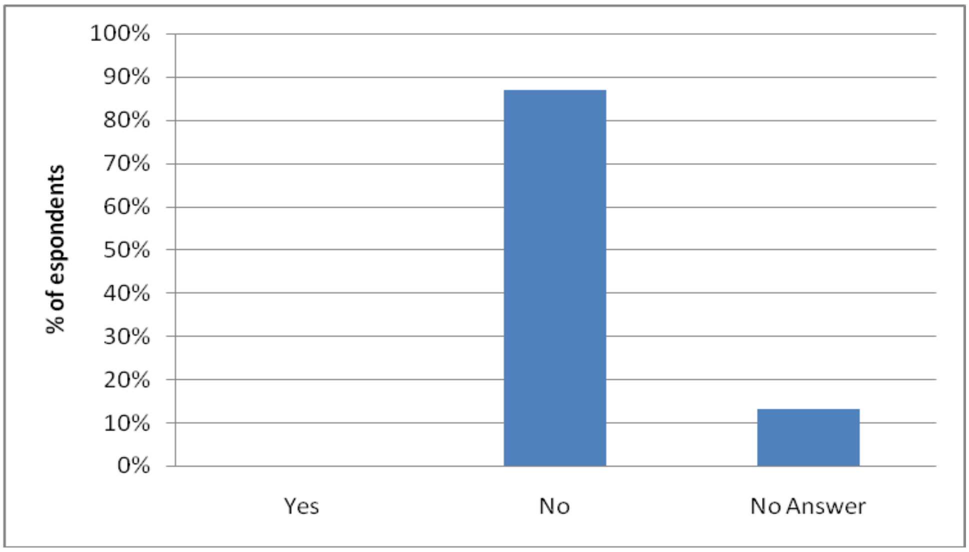


Figure 7-7 Water charge paid

Figure 6.7 illustrates that the majority of respondents (87%) did not fix water metering on their wells at the farms and they did not pay for water consumption.

The type of irrigation system is a crucial factor in water management. The irrigation system is selected according the availability of water resources, the climate conditions and other factors such as soil topography and kind of crops. Choosing an irrigation system is very effective way to alleviate the pressure on the ground water and reduce the water loss. Types of irrigation system were categorised into four categories as illustrated in Figure 6.8 below.

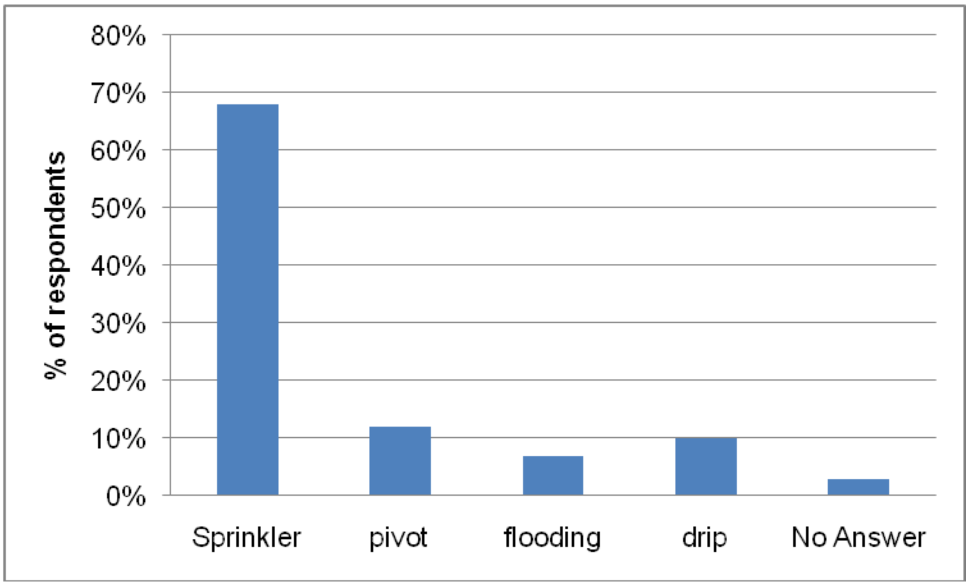


Figure 7-8 Type of irrigation system

Figure 6.8 shows that more than fifth of the respondents use the sprinkler irrigation systems, while less than a quarter of respondents use drip irrigation systems.

Irrigation time is an important point in evaluating water management policies and to what extent farmers implement the instructions of irrigation policy. Choosing the right time for irrigation, in the morning or evening, for example, is a very effective way to save water by reducing the amount of water that is lost to by evaporation. Here, the irrigation time was categorised into five categories as shown in Figure 6.9 below

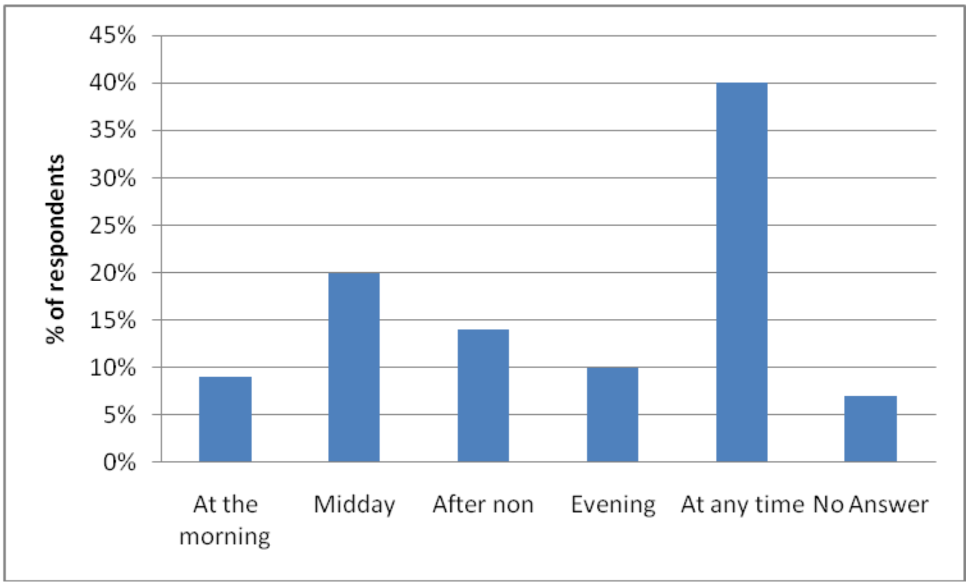


Figure 7-9 Irrigation time

Figure 6.9 shows the time of irrigation farmers chose to irrigate their crops. It can be seen that more than the fifth of respondents irrigate crops at midday and any time while less than a quarter irrigate crops in the morning and in the evening. Receiving subsidies from the local authority for developing irrigation systems is one of the policies established by the government to encourage farmers to set up the proper irrigation systems in their farms. Considering the climate conditions, local authorities should help the farmers to use the proper irrigation system, such as a drip system, to reduce water use as far as it is possible

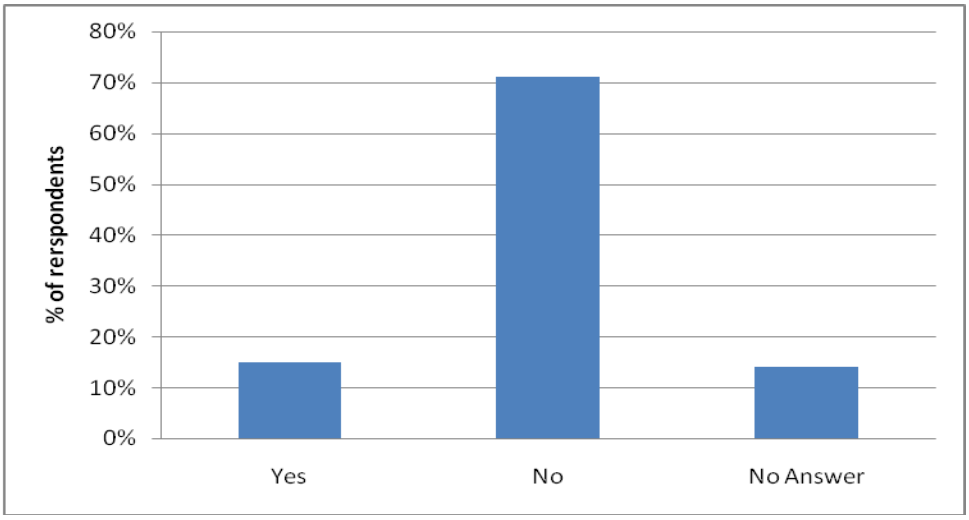


Figure 7-10 Receiving subsidies

Figure 6.10 shows the majority of respondents claim that they not receive subsidies to help them to develop their irrigation system while less than a quarter of respondents do.

Of the respondents who received the subsidies, three quarter of respondents claim that they received subsidies of less than 25% of the total cost of the irrigation system.

The guidance programmes about agricultural practices and using irrigation water are very helpful for farmers to develop their ability and for the rational use of water in the agricultural sector.

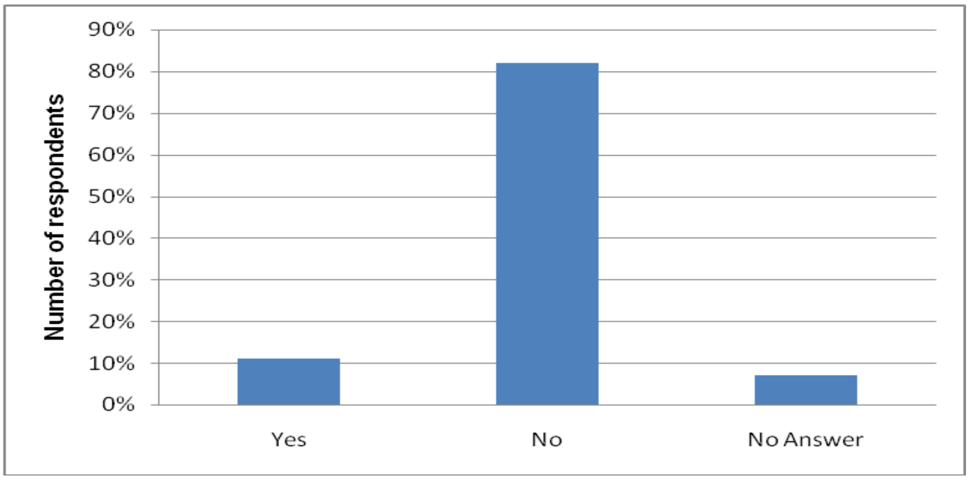


Figure.7-11 Guidance programmes of agricultural practices and water usage

Figure 6.11 shows the majority of respondents (82.5%) did not receive any guide program regarding agricultural practices in general or for proper water use for irrigation while the minority of them (8.6%) did so. Water quality of irrigation is a good indicator of the state of water resources that are used for irrigation. The water quality of irrigation in this survey was categorised into three categories as it is illustrated in Figure 6.12.

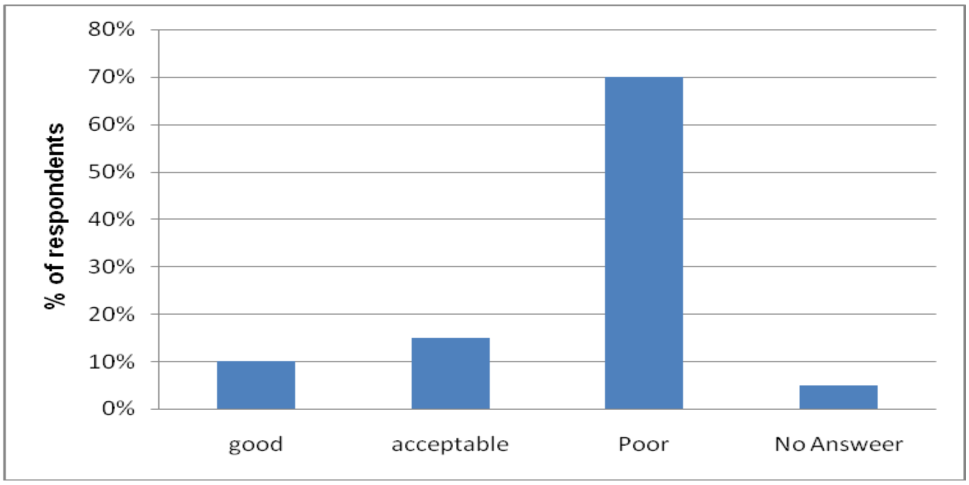


Figure 7-12 Perceived water quality of irrigation

Figure 6.12 shows that the majority of the respondents perceive that the quality of water is poor while the minority considers it to be good. Determining type of cultivated crops in the farm according to the water resources availability is an important factor towards developing water management policies to reduce water consumption in the agricultural sector.

In this survey, 15 type of crops, which are the major crops in Libya, were selected and the cultivated are was categorised into four categories as shown in Figure 6.13 below

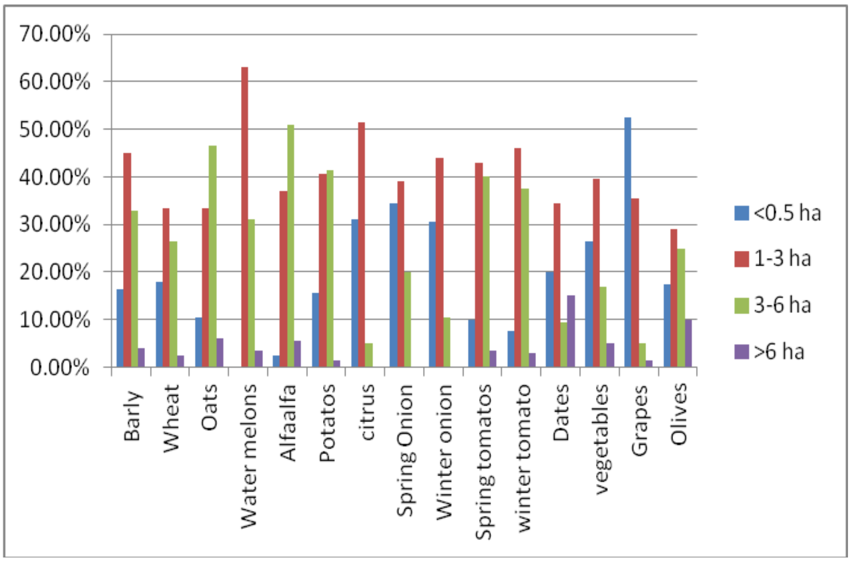


Figure 7-13 Land use for different types of cultivated crops

Figure 6.13 shows that the cultivated area for the majority of crops ranges between 1 and 6 ha. Most of the cultivated area of grape, which has low water requirement, crop is less than 0.5 ha, whereas the range of the cultivated area of high water requirement crops such as water melon, alfalfa and tomato is between1-6 ha. All the cultivated area of cereal crops is between1-6 ha and the cultivated area over 6ha is negligible. The cultivated area of fruits crops such as citrus and vegetables is between 0.5-3 ha.

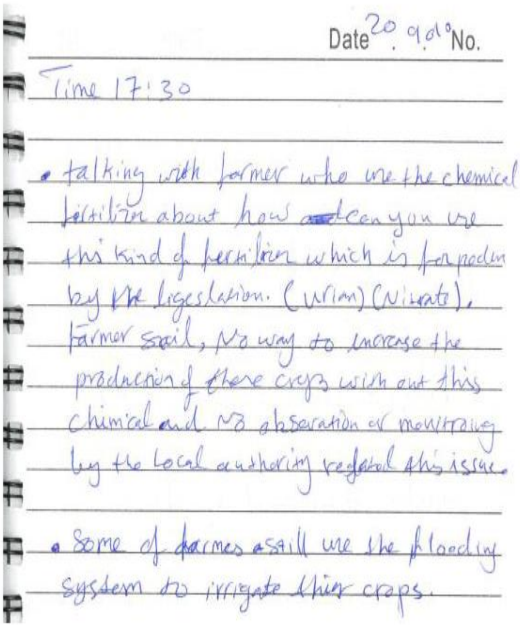
7.3 FIELD OBSERVATION ANALYSES

Field observations were undertaken to see whether what the respondents said is a real representation of what they were in fact doing. In this study, the field observation showed that some farmers had suspicion about the researcher's questions particularly those related to issues surrounding the regulations. So, to avoid personal risk, the respondents appear to have given answers that they think the researcher wants to hear or they avoid answering those questions. This can be clearly seen in the answers related to irrigation system, crops grown, irrigation time and getting well licences, because those issues are controlled by the law and any violation to these regulations will be fined.

Figure 7-14a/b Alfalfa crop and irrigation method

From the Figures 6.14 that were taken during the field observation, it can be seen that although the formal strategies prevent the growing of crops with high water requirements and prevent irrigation at the peak time where the temperature is usually high (between 30-40°C) in the summer season, alfalfa is still grown and produced and it is irrigated at the peak time of the day using flood irrigation method.

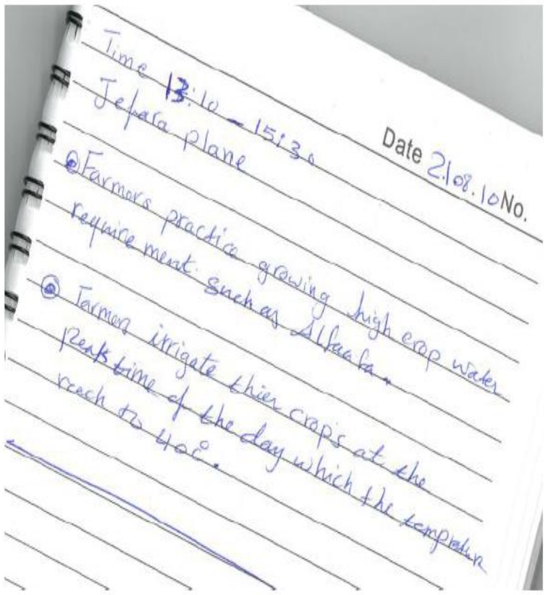
In some of the questionnaire responses, farmers did not acknowledge the use of the flood irrigation shown in Figure 6.15.


Date 20.9.010 No.

Time 17:30

• talking with farmer who use the chemical fertilizer about how can you use this kind of fertilizer which is forbidden by the legislation. (urian) (Nitrate), farmer said, No way to increase the production of these crops without this chimical and no abservation or monitoring by the local authority regarding this issue.

• Some of farmers still use the flooding system to irrigate thier crops.


Time 13:10 – 15:30

Date 21.08.10 No.

Jefara plane

• Farmers practice growing high crop water requirement such as Alfaalfa.

• Farmers irrigate thier crops at the peak time of the day which the tempratur reach to 40c°.

Figure 7-15 Researcher's field trip notices

7.4 QUALITATIVE ANALYSES

This section presents the analysis of qualitative data that was gained by semi- structured interview. The interviews were conducted with eight official governmental and public institutions. A summary of the key interviews findings is provided in Table 6.2.

Table 7-2 summary of the key interview findings

Themes	Findings
Quantity and quality of water resources	Interviewee 1 and 2: Water situation in Libya today is getting worse than many years ago. Interviewee 3 and 4: most of the groundwater in the north-western region has become unusable for drinking and agricultural purposes Interviewee 5, 7 and 8: water resources need careful management for sustainable use Both the official authorities and farmers have contributed significantly to this current situation. Groundwater aquifers have become affected by seawater intrusion, particularly in the coastal area where the groundwater aquifers are shallow
Water policies and strategies	Interviewee 1, 2 and 3: There are a significant number of water regulations. Interviewee 2 and 5: Although the formal policies on water resources include some crucial points and steps that will contribute to relieving water shortages, there are no practical and serious steps to achieve these policies. Current water legislation and regulations seem to be largely helpful for protecting these resources, but there is lack of proper implementation of these regulations The current policies and strategies are not fully implemented on the ground there have been no actual steps towards implementation of water pricing these regulations have not been implemented on the ground for several socio-cultural reasons, including corruption of the official executive authority which is responsible for enforcing these regulations lack of seriousness of the state institutions themselves in implementing this legislation as a social factor that hinders to a large extent the right implementation of these regulations both official and non-official institutions involved with water and agricultural issues water are responsible for ineffective implementations of water and agricultural policies and they do not use effective language in water discourse
Water management challenges	the instability of the administrative institutions for water, which affects the effective application of laws and policy change financial problems which greatly obstruct the implementation of any water plans weaknesses in farmers' awareness about environmental issues and the seriousness of these issues right now demand and supply water resources management
Co-ordination between state institutions	weakness in co-ordination between water institutions and the other institutions of the country, which has led to conflicting decisions
Supply and demand water management	Libyan water management has largely focused on water supply management more than demand management. the large expansion in irrigated farming relying on the Great Man-Made River Without effective and wise water management the exploitation of new water supply, this water will not be sustainable The only step taken is importing a large part of Libya's food needs from other countries

These interviews were conducted to discover to what extent water and agricultural policies recognise and take into account the limitations of water resources and also to explore the extent of actual implementation of these policies on the ground and to identify obstacles and challenges that these organisations face from the perspective of official and non-official experts.

Eight of 14 interviews conducted with people targeted as key players in the official and non-official water institutions in Libya and water experts at public institutions

The analysis was carried out thematically and is presented in five themes: (1) quantity and quality of water resources, (2) water policy and strategy, (3) water management challenges, (4) co-ordination between state institutions, and (5) supply and demand water management.

7.4.1 Quantity and quality of water resources

Libya is classified as an arid area with very limited renewable water resources of either surface water or groundwater. Both formal water institutions and water experts at Libyan universities have agreed that water resources in Libya are limited. Interviewees A and D from GWA mentioned that the "water situation in Libya today is getting worse than many years ago". They also pointed out that most of the groundwater in the north-western region has become unusable for drinking and agricultural purposes. "…it can be said, that only the groundwater from the southern region is still usable for drinking and agricultural activities. This water has already come into use in the north since finishing the first stage of the Great Man-Made River".

Interviewees stated that these resources need careful management for sustainable use. Interviewee A claimed that this situation of water resources is because of two main reasons.

The first is a physical or natural reason and the second is mismanagement of water resources. For example, the lack of good practices in the agricultural sector, and uncontrolled irrigation in farming led to increase the water consumption. However, there are different points of view on the reasons behind this situation; water institutions attribute the cause to a lack of public awareness and cooperation, and water experts attribute the cause to a lack of willingness on the part of local authorities and government to properly implement policies and strategies (interviewee B). Furthermore, interviewee E mentioned that the instability in the administrative system is affecting policies' continuity and the people who are in charge of water and agricultural institutions lack updated knowledge about water resources.

Both the official authorities and farmers have contributed significantly to this current situation. On one hand there is a lack of seriousness by local authorities in implementing the existing legislation and negligence in tackling control violations committed by citizens. Furthermore, citizens' lack of commitment to preserving water resources is also important. However, on the other hand, this lack of commitment to preservation of water resources is due to an inadequate awareness of the governmental preservation program.

Interviewee B mentioned that "I can say that there is no effective program to raise the farmers' awareness about water issues and how to maintain water resources, which consequently led to this situation"

7.4.2 Water policies and strategies

There are a number of policies which have been adopted in the water management field in Libya to regulate and protect water resources. However, these polices have not been fully implemented or are ineffective for several reasons.

Although the formal policies on water resources include some crucial points and steps that will contribute to relieving water shortages, there are no practical and serious steps to achieve these policies (Salem, 2007).

A policy of water utilization in Libya is not appropriate for the scale of the challenge. Interviewee E pointed out that water policy needs to be reviewed it can be said that all water polices need to be reviewed, revised and reformulated to meet the limitations on water resources in order to achieve sustainable use of water resources.

One of these policies restricts well-digging in affected zones. According to water regulations, digging wells must be licensed by the General Water Authority.

Interviewee A points out that a ban on digging wells without a licence and without consideration of specifications and instructions approved by GWA would be helpful. Decentralisation of supervision of groundwater aquifers and the issuing of licences for digging wells have to be approved from GWA. Intensifying the control and monitoring of the affected and restricted zones to observe the groundwater level in these areas would also help conserve water. However, interviewee A and researcher observation have shown that a significant number of wells are not authorised and do not meet the specifications approved by the GWA.

Interviewee A emphasises that these policies are not fully implemented on the ground "In fact, I can say only 40-50% of them are implemented". As a result of uncontrolled well-digging, ground water aquifers have become affected by seawater intrusion, particularly in the coastal area where the groundwater aquifers are shallow.

Interviewee B mentioned this point, saying " the seawater intrusion has been addressed in the coastal areas that represent a high density of population and intensively agricultural activities". Interviewee F also pointed to another issue, that there is a problem with pollution either from seawater intrusion or from septic tanks (black wells) which represents the main source of pollution to groundwater aquifers.

In spite of the advantages and effectiveness of water pricing policy and its adoption in the Master Plan of Water Management (2000), there have been no actual steps towards implementation of water pricing. Interviewee A mentions water pricing as an effective policy: "…from my viewpoint, it is an effective way to protect water resources but in Libya it is still not applied yet".

Only one attempt was made to fix water meters on the water supply for the purpose of controlling and monitoring water abstraction. This attempt failed as well "…the plan failed due to unresponsiveness of farmers and they disabled these meters" (interviewee A).

This attempt is doomed to failure because of social attitudes. Interviewee C claims that the authorities are not serious in terms of attempting to implement this, and the farmers also do not want it as they believe that water is a natural right from God, so they do not think they should be charged or that the water will be irreparably diminished.

So, this mechanism could not be applied unless there was an intensive programme to raise the public's awareness about the importance of saving water resources.

To successfully achieve any of the objectives of a water management programme, it is necessary to issue effective regulations along with a strong enforcement system to ensure implementation of these regulations.

Across the world, there are different regulations to save natural resources in general and water resources in **particular**. In the Libyan context, all the interviewees agreed that there are a significant number of water regulations. Interviewee A has said that "…Actually, I can say in theory the laws and regulations regarding water are valid and sufficient to reduce water degradation if they are correctly implemented, but the problem is they are not completely implemented on the ground … I can say only 40-50% of them are implemented".

These regulations cover all the aspects of water problem as interviewee B claims that "… I see they are enough but the biggest problem is that they are not properly implemented…"

Current water legislation and regulations seem to be largely helpful for protecting these resources, but there is lack of proper implementation of these regulations (interviewee C). Meanwhile, interviewee E says that "…I think we need to rebuild the legislation which can preserve our water resources for future life. The other thing is to establish a special authority or organization to be responsible for implementation of all laws and regulations governing water use and to investigate any breaches".

However, these regulations have not been implemented on the ground for several socio-cultural reasons, including corruption of the official executive authority which is responsible for enforcing these regulations, as interviewee A points out: "I think the first reason is the complicity of executive authorities due to the power of social cohesion and some private business between some employees of executive authorities and offenders". That was confirmed by interviewee H as well

Interviewees' points of view, and the researcher`s observation show that there is ineffective implementation of water regulation on the ground for different reasons. Interviewees A and C referred to the lack of public awareness and the water experts thought the reason was the poor performance of water management systems, and the weakness of the public awareness program itself. Interviewee C, for example, pointed out that "…The reasons behind this, as I see it, can be summarised as: instability of water institutions, overlapping their power with other institutions, lack of trained and licensed water works managers".

Interviewee D noted the lack of seriousness of the state institutions themselves in implementing this legislation as a social factor that hinders to a large extent the right implementation of these regulations, and also noted the obvious deficiencies in the public awareness and rationalization programme for farmers.

The researcher's observations show that both official and non-official institutions involved with water and agricultural issues water are responsible for ineffective implementations of water and agricultural policies and they do not use effective language in water discourse. It is also the observation of the researcher, as informal discussion with farmers and some ordinary workers at those institutions illustrate, that it is the view of many farmers that these policies and regulations were introduced as a political issue which greatly increases the unpopularity of this discourse.

Despite an education programme for farmers being one of the objectives of Master Plan 2000, limited steps have been taken towards this objective such as issuing some booklets about water importance and the necessity of saving these resources. From the simple field observation, farmers' practice does not seem to reflect any influence of these guides. For example, most farmers still grow high water requirement crops such as alfalfa and watermelon. Moreover, the researcher observed that most of these crops are irrigated in the peak summer season when the temperature is high which increases the evaporation of water.

Water and agricultural expert interviewee C makes the same point when stating that if you go fact-finding in the countryside you see flagrant violations exhibited before inspectors, who don't take any action – for example, many farmers apply irrigation at midday in the summer and nobody cares. This was confirmed by interviewee E as well.

7.4.3 Water management challenges

The agricultural use of water has significant effects on the both quantity and quality of water, including sea water intrusion in the coastal area and declining groundwater levels as a result of over-exploitation. Interviewee B, of the GWA, and water expert C mention sharp declines in levels in lower aquifers in Jefara Plain, which exceeded 8m. This issue is one of main challenges of water management, particularly in this region, which is significant for agricultural activities and in a coastal area with the highest population (interviewees A and B).

The quality of ground water has also been affected by septic tanks, which are widespread outside city centres because of the lack of sewage networks. Moreover, these tanks are built without the control of local authorities and do not conform to technical specifications. These tanks are a significant threat to the quality of ground water in the aquifers in general and at the coastal area in particular because they do not meet specifications and because of the shallowness of the ground water aquifer in this area. “Septic tanks (black wells) represent the main source of pollution to aquifer biggest…” (Interviewee F, from the GAE). Although technical specifications for these tanks in terms of depth and leakage have been issued since the 1970s, there are, according to interviewee B, no inspections of these tanks by local authorities.

The other obstacle is the financial problems which greatly obstruct the implementation of any water plans. In this context, Interviewee A illustrated that although many dams have been constructed to preserve rain water to be fed to groundwater by injection to the aquifers; this method has unfortunately been cut due to the lack of money for maintenance of the injection wells.

The same interviewee gave the Lake of Kaam dam, as an example. That lake worked well for two years thanks to the use of injection wells to reduce the salinity of seawater intrusion and improve the quality of groundwater. However, these wells became blocked by silt and sand and became ineffective in feeding the aquifers. Therefore a huge amount of water, around 60-90 Mm^3 a year is evaporated. These wells have never been maintained for financial reasons. Interviewee B says that executive institutions do face legal and economic barriers; this institution needs more budget allocation for strategy and training technical staff.

The interviewee also illustrated that due to the fluctuation in rainfall, these lakes have become dry.

Another obstacle that faces water management is the instability of the administrative institutions for water, which affects the effective application of laws and policy change. Interviewee C pointed out that “... as I see it, it can be summarized as unstable administration of water institutions, overlapping their power with other institutions...”

For example, the quick change from centralisation to decentralization of the water administration system has led to duplication and overlapping of powers between the administrative divisions and branches in the areas of water institutions. Moreover, this also has led to chaos in dealing with some irregularities, especially in the case of the lack of awareness amongst community leaders about water issues and their significance. Interviewee D mentions the same issue that "... the institutions themselves are OK but they still need some development in terms of two main things: The first is stability in these institutions and their branches over all Libya".

Interviewees B, F and G have illustrated that the most important obstacles that face the water management institution are the weaknesses in farmers' awareness about environmental issues and the seriousness of these issues right now.

7.4.4 Co-ordination between state institutions

There is also weakness in co-ordination between water institutions and the other institutions of the country, which has led to conflicting decisions. Interviewee E mentions that "… in our institution, we have conducted several studies related agricultural practices and water use and of course there are some recommendations. However, only a small part of these recommendations was considered by the government".

Interviewee G confirmed that as well. For example, in spite of Libya being a water-scarce country, it has witnessed a huge expansion in irrigated crops, particularly in Southern regions. This expansion has led to water consumption as a result of increasing the amount of evaporation. In addition, the state has the financial ability to import these crops from water-rich states or at least grow these crops locally in the Northern regions where the evaporation rate is low. Moreover, the amount of precipitation is relatively high, making the water requirement for these crops close to half the water requirements in the Southern region.

According to water experts in public institution, there is no positive co-ordination between research centres and universities and decision makers in terms of considering the studies that are conducted by these institutions.

These studies to large extent offer more scientific and practical recommendations. Interviewee G has illustrated that most of these recommendations are rarely considered by local authorities and decision-makers. For example, they should be determining planted crops in relation to water consumption and not just for economic returns, particularly in water-restricted areas already affected by the deterioration of groundwater". Interviewees E and F confirmed this as well. The experts mentioned that several studies have recommended that some high-water requirements crops should be banned immediately, particularly in the high evaporation areas such as the Southern region. However, there has been expansion in growing these crops, such as alfalfa, watermelon, wheat and barley in this area (interviewees E and C).

7.4.5 Supply and demand water management

Libyan water management has largely focused on water supply management more than demand management. This has led to continuing water depletion and deterioration. Interviewees A and B give the GMMR project as an example of that policy. They point out that this project is considered one of water supply management because it is a project of transferring water from non-renewable groundwater in the south through the desert to the north.

It can be considered only as a part of the solution to the water resources problem because it will only last 50 years. The benefit of this project is conditional on the optimal utilization of this water and this is uncertain in light of the current water management and its problems. Moreover, there is a huge expansion in irrigated projects to increase wheat production, dependent on water from the GMMR project. This is considered as contradiction between formal water strategies and what really implemented (interviewees E and G) is.

Although the achieving food self-sufficiency would not be possible in light of water resource conditions, water management policy still adopts the water supply management approach. Interviewee C says that focusing on supply management is as a result of dictating the thinking of decision-makers to achieve food self-sufficiency.

Regarding water demand management, there are several steps towards water demand management that could be taken. For example, increasing water productivity and efficiency of water use and using modern irrigation systems. Interviewee C points out that "The only step taken is importing a large part of Libya's food needs from other countries". However, this policy seems to be temporary, given the large expansion in irrigated farming relying on the Great Man-Made River. This may be a risk in light of indications that GMMR will only last 50 years and the increasing cost per m^3 of the water after including maintenance costs. Without effective and wise water management the exploitation of this water will not be sustainable (interviewees G and E).

7.5 REFLECTION ON INTERVIEW EVIDENCE IN RELATION TO QUESTIONNAIRE FINDINGS AND FIELD OBSERVATION

In this research, field observation and questionnaire responses did, to some extent, agree with the interviewees' views while there is, to a lesser extent, limited agreement between field observation and questionnaire respondents. For example, in spite of Libya being a water-scarce country, it has witnessed a huge expansion in irrigated crops, particularly in Southern regions.

The researcher`s observation show that there is ineffective implementation of water regulation on the ground. Current water legislation and regulations seem to be largely helpful in principle for protecting these resources, but there is lack of proper implementation of these regulations in practice (interviewee C)

According to water regulations, digging wells must be licensed by the General Water Authority. Interviewee A points out, however, that a ban on digging wells without a licence in affected zones digging wells is banned, the researcher confirmed that there are a significant number of boreholes situated at the restricted zones established by the GWA.

Although the formal strategies prevent the growing of crops with high water requirements and prevent irrigation at the peak time where the temperature is usually high (between 30-40°C) (Figures 6.14 and 6.15), the questionnaire responses show that more than the fifth of respondents irrigate crops at midday and at any time while less than a quarter irrigate crops in the morning and in the evening which is to large extent agrees with the researcher's field observation (Figures 6.9, 6.14).

In certain areas of the questionnaire (irrigation time, borehole licences), the questionnaire responses disagree to a large extent with the field observations when the question is related to violation of the regulations. From the knowledge of the researcher and field observation, it could be suggested that, there is not a significant level of non compliance with regulations between regions related to restrict growing high water requirement crops, irrigation timer and boreholes licence.

The level of farmers` training, whether or not a well licence is obtained, water charge paid, irrigation time guidance programmes for agricultural practices followed, regulations implemented, co-ordination between institutions and land use of different types of cultivated crops, determination of which is difficult through the use of questionnaires and interviews, all have profound implications for water management and calculation of the water footprint.

7.6 WATER FOOTPRINT CALCULATION

7.6.1 Internal Water footprint

Libya's internal water footprint was calculated using the formula mentioned in the literature review in chapter 2.

It is the sum of the water used for each crop, as follows:

$$WFtotal = WFC1 + WFC2 + WFC3 + \dots \qquad 6\text{-}1$$

The virtual water content of the crop (Vc) is equal to the water required to produce the crop (Uc) divided by the total crop production (Yc) where:

$$Vc\, m3/tonne = Uc\, m3\ /\ Yc\, tonne - 1 \qquad 6\text{-}2$$

Uc is calculated using the standard reference of crops' water requirements published by GWA (2006).

The major crops and their productivity (tonnes/ha) were selected based on the Agriculture Ministry reports 2000-2009. The water requirements (m^3) used in the calculations presented in Table 6.1 were based on figures provided by the GWA (2006) and the area cultivated was calculated by the researcher using GWA productivity figures (GWA 2006). The imported amounts of goods used were based on the General Customs Authority (GCA) data. Therefore, the internal and external water footprint of major crops is respectively illustrated in the (Table 6.3 and 6.6).

Table 7-3 The total crop production of Libya (x 10^3 tonnes). Period 2001-2009 (after GWA, 2010)

	Wheat	Barley	Tomato	Water melon	Potato	Onion	Olive Oil	Dates	Total
2001	49	230	160	216	168	133	26	103	1085
2002	54	263	190	300	173	236	27.6	104	1347.6
2003	46	175	181	300	185	226	26.5	110	1249.5
2004	61	132	207	240	170	210	23	112	1155
2005	48	234	197	214	300	250	25	118	1386
2006	104	240	160	218	295	227	24	122	1390
2007	96	244	212	250	265	182	22	130	1401
2008	156	220	212	240	235	182	24.5	135	1404.5
2009	160	260	220	225	250	186	22.3	142	1465.3
Total	774	1998	1739	2203	2041	1832	220.9	1076	11883.9

Table 6.3 shows that during the period (2001-2009), Libya produced barley in the amount of 1998 x 10^3 tonnes while it produced wheat in the amount of 774 x 10^3 tonnes. The highest production was for water melon, 2203 x 10^3 tonnes, while the lowest production was for olive oil at 220.9 x 10^3 tonnes. The crop production of farmers who responded to the questionnaire in this study broadly reflects the range of crops presented in Table 6.4.

It also can be seen that although the wheat production slightly increased from 2001 to 2009, the annual production of barley, tomato and water melon were more than wheat, and in some years were double, as in 2004 and 2005, and in some years almost triple, as in 2001, 2002 and 2003.

Table 7-4 Area cultivated/ha (after GWA, 2010)

	Wheat	Barley	Tomato	Water melon	Potato	Onion	Olives	Dates	Total
2001	14000	65714	8889	21600	11200	7000	17333	20600	166,336
2002	15429	75143	10556	30000	11533	12421	18400	20800	194,282
2003	13143	50000	10055	30000	12333	11895	17666	22000	167,092
2004	17429	37714	11500	24000	11333	11053	15333	22400	150,762
2005	13714	66857	10944	21400	20000	13158	16667	23600	186,340
2006	29714	68571	8889	21800	19666	11947	16000	24400	200987
2007	27429	69714	11777	25000	17666	9579	14666	26000	201,831
2008	44571	62857	11777	24000	15667	9579	16333	27000	211,784
2009	45714	74285	12222	22500	16667	9789	14867	28400	224,444
Total	221143	570855	96609	220300	136065	96421	147265	215200	1,703,858

Table 6.4 shows the cultivated area for crop production during the scope of this study (2001-2009). It can be seen that area cultivated for barley was the highest (570,855 ha) while area cultivated for onion was the smallest (96,421 ha). From the respondents' samples, it can be noticed that the most grown crops are wheat, barley over the four regions while the high water requirement crops, such as Alfalfa and water melon, are grown in the south, north-western and north- central.

Table 7-5 Internal Water footprint (x 10^6 m^3)

	Wheat	Barley	Tomato	Water melon	Potato	Onion	Olive Oil	Dates	Total
Blue W.F m^3	1455.6	2413	1135.6	2874	1357.5	691	1390	6619	17,936.9
Green W.F m^3	190	468	9660.9	37.4	61	21	119	135.5	1042.6
Total W.F m^3	1645.8	2881.3	1145	2911.7	1418.7	712.4	1509.4	6754.6	18,979.6

Table 6.5 illustrates the amount of water used to produce individual and total crops consumed in Libya. The highest internal water footprint of the major crops is for dates, water melon and barley, which represented 6754.6x10^6 m^3 and about 6278 m^3/tonne, 2911.7x10^6 m^3 and about 1322 m^3/tonne, and 2881.3x10^6 m^3 and about 1442 m^3/tonnes respectively. However, the onion and tomato crops represented the lowest water footprint at 712.4x10^6 m^3 and about 389 m^3/tonnes and 1145x10^6 m^3 and about 659 m^3/tonnes respectively.

The total internal water footprint was about 19 Gm^3 (5% green and 95% blue). The blue water footprint was almost 17 times higher than the green water footprint.

7.6.2 External Water footprint

As mentioned in chapter 2, external water footprint is defined as the volume of water used to produce products and services to be consumed outside the country of production. It equals the virtual water (Vi) that is imported into a country minus the volume of imported virtual water (Vi) that is re-exported to other countries (Ve,r)

$$WFe = Vi - Ve,r \qquad 6\text{-}3$$

Since Libya exports only a small amount agricultural crops abroad, this amount was neglected. Therefore, external water footprint was calculated as

$$WFe = Vi \qquad 6\text{-}4$$

The virtual water content of products is described in terms of consumption site, where it represents the volume of water that would be needed to produce this product.

Table 7-6 Total imported commodities (x10^3 tonnes)

	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive Oil	Date	Total
2001	1259	282	36.6	92	150	23	120	17	0.824	1982.6
2002	1542	251	65.8	100	302	10	86	21.8	0.995	2381
2003	998.7	90	10.6	112.8	141.6	9	99	0.458	0.201	1463.7
2004	1653	210	45.5	94.8	295	5	65.8	0.054	0.092	2370.7
2005	1556	135	12.8	45.7	460	6	91.7	0.020	0.037	2308.7
2006	1329.8	165	29.8	100.9	386	12	15	0.110	0.050	2040
2007	1297	55	17.7	130	301.5	7	79	0.035	0.651	1889
2008	1706	100.7	46.7	33	359.7	10	41	0.030	1.207	2299
2009	1513	198	42.7	74	295.6	13.9	58	0.062	0.782	2196.8
Total	12856	1489.5	308.6	784	2693	99.5	656.9	39.7	4.839	18,932.7

Table 6.6 shows that wheat represented the highest imported crop quantity followed by maize, 12,856x10^3 tonnes and 2,693x10^3 tonnes respectively, while dates represented the lowest quantity followed by olive oil, 4.839x10^3 tonnes and 39.7x10^3 tonnes respectively. It also shows that average annual imports were 2103635 tonnes during the scope of study with the highest imports for a year in 2002; 2381x10^3 tonnes, and the lowest in 2007; 1889 x10^3 tonnes.

Table 7-7 Area required producing the imported amount of crops(ha)

	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
2001	359852	80713	2038	13204	62533	1226	699698	54773	165	1274202
2002	440577	71811	3659	14290	126005	563	500279	70196	199	1227579
2003	285361	25871	591	16117	59035	487	577872	1457	40	966831
2004	472426	60022	2530	13550	123065	289	382733	173	18	1054806
2005	444644	38576	713	6539	191787	358	533384	64	7	1216072
2006	379945	47208	1658	14417	161009	661	88389	353	10	693650
2007	370602	1591	988	18587	125662	374	460389	112	130	978435
2008	487447	28780	2599	4738	149878	549	238634	96	241	912962
2009	432329	56674	2374	10580	123184	735	337808	199	156	964039
Total	367,3183	411,246	17,150	112,022	1,122,158	5,242	3,819,186	127,423	966	9,288,576

From table 6.7, it can be seen that the average area required to produce the imported amount of crops was 1,032,064 ha. Maize and wheat represent the highest required area, of 3819186 ha and 3673183 ha respectively, while dates and onion represented the lowest required area at 966 ha and 5242 ha respectively.

Table 7-8 External Blue and green water footprint

	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
Blue WF Gm^3	24.1	1.7	0.20	1.13	13.46	0.37	45.83	0.79	0.029	87.40
Green WF Gm^3	3.15	0.33	0.0017	0	0.0044	0.0011	0	0.068	0.00060	3.57
Total WF Gm^3	27.33	0.21	0.20	1.13	13.46	0.04	45.83	0.86	0.03	90.98

From Table 6.8, it can be seen that wheat had the highest green water footprint while rice and corn oil had the lowest, 3.1Gm^3 and 0 m^3 respectively. However, corn oil represents the highest blue water footprint followed by wheat at 45.8 Gm^3 and 24.1Gm^3. The total external water footprint was 9.9 Gm^3. It also can be seen that the external blue water footprint 24 times the external green water footprint.

Table 7-9 W.F applications; total internal W.F, external W.F, national water dependency and national water self-sufficiency.

Year	Internal WFG/m^3	External WF/Gm^3	total WF/Gm^3	Renewable water(Mm^3)*	national water self-sufficiency%	national water Dependency%	national water Scarcity%	Traditional National water Scarcity%
2001	1.81	12.52	14.33	650	13	87	2206	280
2002	2.06	12.07	14.14	650	15	85	2176	318
2003	1.95	10.08	12.04	650	16	84	1852	300
2004	1.83	10.06	11.89	650	15	83	1830	282
2005	2.07	12.28	14.35	650	14	86	2208	318
2006	2.18	6.23	8.42	650	26	74	1295	336
2007	2.24	10.01	12.25	650	18	82	1885	346
2008	2.35	8.52	10.88	650	27	78	1674	362
2009	1.44	9.18	10.66	650	21	79	1789	376
Total	18.97	90.97	109.95	650	17	82	1877	324

* Agricultural Ministry Report (2009)

Table 6.9 illustrates year by year and the total water footprint for the study period. The internal water footprint was 18.9 Gm^3, the external water footprint was 90.9 Gm^3 and the total water footprint of Libya during the period of study scope was 109.9 Gm^3. With the average renewable water at 650 Mm^3, it also shows the national water dependency as 83%, national water scarcity as 1878%, and traditional national water scarcity as 324% and national self-sufficiency as 17%. From this table it can be seen that Libya depends highly on the international market to ensure required food with the small percentage of self-sufficiency. It also shows that the actual water scarcity (1878.9%), which is based on the water withdrawn and water consumed, is higher than the previous measure of water scarcity (324%), based on the water withdrawn from domestic resources.

7.7 SUMMARY

In this chapter the data collected through the questionnaire were analysed using the Microsoft Excel software program to identify frequencies, and interviews were analysed manually to identify thematic information by understanding the individual sentences within the context of whole-text interview transcriptions to gain a comprehensive understanding of the interviewees' perspectives. The field observations were analysed as well, according to the notes collected by the researcher.

The water footprint was calculated for the agricultural sector according to the major cultivated crops in Libya and the technique of the Hoekstra framework (2006). The imported crops were estimated in virtual water form at the national level and required water and land if the imported crops were being grown domestically.

The applications of water footprint were estimated, such as water national scarcity, water dependency and national water self-sufficiency.

CHAPTER 7 DISCUSSION

8.1 INTRODUCTION

The discussion focuses on the most important findings from the analysis in terms of the current water and agricultural management situation in Libya, to what extent the formal water policies are implemented on the ground, and the measures and tools of water management in particular water footprint that could be applied. This chapter discusses the key findings of the primary research within the context of the literature reviewed in chapters 2 and 3. The structure of this chapter is based on the objectives of the research, namely:

- To critically evaluate the current national water resources management policy.
- To examine the water footprint concept as a tool for the assessment of the consequences of current water management practices.
- To assess to what extent applying the concept of the water footprint will successfully tackle water scarcity and protect water resources in Libya.

The chapter is in two main sections. The first section provides an overview of the characteristics of Libyan water and agricultural management. The second section addresses and analyses the water footprint of Libya including virtual water and to what extent the water footprint as a tool is helpful in developing water management in Libya.

8.2 CURRENT WATER MANAGMENT

8.2.1 Water Resources Index

Water resources in Libya are limited and need careful management in order to achieve their sustainable use. This fact has been addressed by several studies in the literature such as Wheida and Verhoeven (2007), Goodland (2008) and recently Ramali and Holloway (2012). The issue was also raised by Interviewees A and D who both said that “the water situation in Libya today is getting worse than many years ago”. However, there are different points of view on the reasons behind this situation (the inefficient management of water resources); water institutions attribute the cause to a lack of farmers’ awareness and co-operation between the other water-related institutions, while water experts attribute the cause to a lack of willingness on the part of local authorities and government to implement policies and strategies properly. Furthermore, instability in the administrative system is affecting policy continuity, and those in charge of administration usually lack knowledge about water resources (Interviewee C). In fact, this can be seen in the questionnaire survey and field observation which show that the water management measures that previously existed, such as the regulation of well development, support to improve the efficiency of irrigation and the control of cropping patterns, have been weakened by the decentralization of regulation and support functions. This also has been pointed out by the report of General Authority for Investment. The GMMR Water Central Region (GAIGWCR) (2012) shows that despite the water regulation banning cultivation of water-rich crops, several hundreds of hectares have been cultivated for alfalfa.

The over-exploitation of water resources is mainly the result of limited rainfall, which is on average100mm/year, and a significant population increase during the 20 years to 2011 when it reached 5.6 million (UNDP, 2012). The population is projected to reach 12 million by 2025, which will lead to further over-exploitation of the local aquifers to meet the escalating water demand (Salem, 2007). However, from the writer's evaluation of the evidence gathered in this study, both the official authorities and farmers have contributed significantly to the current deterioration and violation of water regulations. On the one hand, despite the previous efforts designed to mitigate the water-resource problem including the construction of dams, seawater desalination and treatment plants and, significantly, the implementation of the ‘Great Man-made River Project’ (GMMR), there is a lack of seriousness by local authorities in implementing the existing legislation and a failure to tackle control violations committed by citizens. On the other hand, supplying water freely to the farmers is a major concern in the allocation of this vital resource while the lack of citizens’ commitment to the preservation of water resources is also important. However, this lack of commitment is due to an inadequate awareness of the governmental preservation programme which has resulted in a lack of knowledge about the relative values of groundwater resources used in specific agricultural activities. This point was clearly seen in the results of the questionnaire survey which illustrated that the majority (70%) of farmers did not receive any agricultural training. In addition, interviewee B asserted that: “I can say that there is no effective programme in order to raise the public awareness about water issues and how to maintain them, which consequently has led to this situation”. This was confirmed by the questionnaire survey in which the majority of respondents (82.5%) did not receive any guidance regarding agricultural practices in general and the proper use of irrigation in particular. Although ElAzzabi (1999) pointed out that the agricultural research institutes have undertaken research and training in accordance with the country's agricultural potential and its development plan, the success of the strategy has been restricted by limited collaboration with universities and insufficient financial resources.

8.2.2 Current Water Management Practices

As agricultural use accounts for around 85% of water resources, it has significant impacts on both the quantity and quality of water; for example, the intrusion of salty sea water into the groundwater environment in the coastal region and declining water table levels as a result of over-exploitation. Albaroni (1994) and Ali (2003) have reported sharply declining levels of over 8 metres in the lower aquifers in the Jefara Plain. This issue is one of the main challenges facing water management and is particularly significant for agriculture in the coastal area where the highest density of agricultural activities is situated.

To achieve any objectives of a management programme successfully, it is necessary to issue effective regulations establishing a strong enforcement system that will ensure the implementation of regulations. There are various regulations across the world that focus on saving natural resources in general and water resources in particular. In the Libyan context a number of policies have been established in the water management field in an attempt to regulate and protect water resources but these polices have not been fully applied or they are ineffective in practice. Salem (2007) claims that although there are formal policies which could contribute to relieve water shortages, there are no serious practical steps to implement these policies. Interviewee C agreed with the point: "I can say that in theory the laws regulating water are invalid and sufficient to reduce water degradation … but the problem is they are not completely enforced … to be honest, I can say only 40-50% of them are implemented". Although Wheida (2007) argues that all water polices need to be reviewed, revised and reformulated, it can be argued that current water legislation and regulation in relation to resources appear to be well drafted. Hamad (2012) also adds that the legislation has not considered the specific environmental circumstances of some regions, such as al-Jabal al-Akhdar. However, the regulations have not been correctly implemented. Furthermore, a special authority responsible for implementing laws and regulations governing water use and investigating any breaches needs to be established with powers to punish abuse of the laws. This can be seen clearly in the questionnaire survey which highlighted that more than 50% of respondents have wells without a licence.

The administrative instability of water institutions and the lack of trained workers in these institutions have significantly undermined the effectiveness of water regulations and legislation. Interviewee C supports this view quoting the example of the quick change from a centralised to a decentralised administration system of water institutions which resulted in duplication and overlapping powers between the administrative divisions and branches. This has led to chaos in dealing with some irregularities such as Law 3 of 1982 which determines ownership of water, responsibility for control and management, licensing for drilling, exploitation and use of water and pollution control and penalties. The effectiveness of Law 3 is undermined by the lack of awareness of social community leaders about water issues and their significance. However, the current water management in the al-Jabal al-Akhdar region, where there is an office of the GWA which is responsible for water management resources in that area, is weak and not updated and it needs to be reformed for several reasons. Hamad (2012) pointed out that there is a traditional management system for water resources in al-Jabal al-Akhdar, which is manifest from the barriers reviewed (related to lack of stakeholder involvement and regulatory incoherence). A fundamental overhaul of the water sector with a regulatory review is essential for sustainability in al- Jabal al-Akhdar, using the management principles of integrated water resources planning.

From the analysis, it can be seen that, despite the adoption by the Master Plan of Water Management (2000) with its apparent advantages and effectiveness in relation to water pricing policy, no actual steps towards water pricing have been taken. Interviewee A pointed out that although it is an effective way to protect water resources, in Libya it has not been applied yet. Only one attempt has been made to use water meters to control and monitor water abstraction in AL-Ezizia which is part of Jefara Plain in the end of 1970s where the GWA selected that area to test the pricing water concept where the meters were fitted on the water supply of each farm in order to know the water consumption of each farm. However, According to Hamdy (2000) this attempt unfortunately failed due to social attitudes of farmers. According to Interviewee A, “farmers believe that water cannot be charged as it is a gift from God, can never be drained out and nobody has a right to charge them for using it”. This point is confirmed by Hamdy (2000) who argues that there are several reasons which constrain the implementation of water pricing in general, including social, political, religious and cultural considerations.

Although most of the failure in the enforcement of regulation and polices are the result of such social and cultural reasons, the issue of financial and administrative corruption in the executive of the official institutions also has a share of the responsibility. Interviewee C pointed out that executive authorities are complicit in many cases due to the close family and economic links between private businesses and government employees [the system of nepotism knows as wasta].

From the analysis it can be seen that there is a lack of commitment by the authorities towards considering the limiting the use of water resources in irrigation, growing water-intensive crops and so on. The actual area under irrigation has expanded more than fourfold since the 1970s when it was less than 100,000 ha (Allan, 1974) to the end of the 1990s when it reached 435,000 ha (Laytimi, 2005).

Interviewees B and C pointed out that several studies have recommended that certain high-water requirement crops should be banned immediately, particularly in the high evaporation areas such as the southern region. However, there has been expansion in the growing of these types of crops including alfalfa, watermelon, wheat and barley. The GWA (2007) confirms that Libya has witnessed a huge expansion in irrigated crops (see Figure 4.1, particularly in southern regions where temperatures are high, which increases the amount of evaporation. Moreover, according to the questionnaire survey, it can be seen that there is no schedule for irrigation time; 70.5% of respondents irrigate crops at any time including times of maximum evaporation while only about 25% irrigate crops in the early morning and late evening.

Taking into account the interviewees' views, the questionnaire survey and the researcher`s observations, it can be concluded that there is a consensus on the ineffective implementation of water regulation in practice. However, this failure is attributed to various causes such as tribal social system, as a result of land heredity system; the arable land is divided to small parts which lead to illegal well drilling (Aqeil, et. al 2012).

8.2.3 Water Management Obstacles and Challenges

As discussed above, the agricultural over-use of water has had significant effects on the both quantity and quality of water. The issue of the quality of the water was confirmed in the questionnaire survey which highlighted that more than half of the respondents (54%) claim that the quality of water is bad while only 18% of respondents claim that the quality of water is good. Abdelrahem, et. al (2009:523) also highlights the problem: “As a result there has been an intrusion of seawater in the coastal aquifer with a marked increase in salinity, which has reached 7,000 ppm in the Tripoli region”. Thus, the FAO (2001) and the UN (2008) have both raised concerns that over-exploitation has caused a severe decline in the level of the groundwater resulting in seawater intrusion in the coastal area up to 10km inland in the Tripoli region.

This has affected the quality of groundwater and has made it unusable for drinking and agriculture. In addition, the quality of ground water has also been affected by septic tanks, which are widespread outside city centres because of the lack of sewage networks. Moreover, these tanks are built without the control of local authorities and do not conform to technical specifications. Interviewee B confirms the challenge caused by septic tanks when he says that groundwater aquifers in coastal areas are particularly affected by tanks due to the shallowness of the groundwater and because they do not meet required specifications.

However, despite the importance of monitoring groundwater pollution from waste water, no regular monitoring is in place. Furthermore, FAO (2009) highlights that there are no available official data on agricultural pollution.

The second obstacle is the financial problems which significantly obstruct the implementation of any water plans. Interviewee A mentioned that the Lake of Kaam dam gave good and visible results and for two years it worked well via injection wells to reduce the salinity of seawater intrusion and improve the quality of groundwater. However, these wells became blocked by silt and sand and became ineffective in feeding aquifers; therefore, a huge amount of water, around 60-90 Mm^3 a year, is lost through evaporation. These wells have not been maintained for financial reasons. This fact was confirmed by Ali (2003) when he pointed out that preserving rain water to feed groundwater by injection to the aquifers has unfortunately been interrupted due to the lack of money for maintenance of the injection wells.

8.2.4 Co-Ordination between State Institutions

To achieve effective water management, co-ordination between water-related institutions has to be considered. Water institutions cannot achieve successful management practices without being integrated with other institutions in order to understand the complete picture of the country's water index. From the analysis, it can be seen that there is weakness in co-ordination between water institutions and the other institutions of the country, which has led to conflicting decisions. Interviewee C highlight this lack of coordination where he mentioned that "there is no positive co-ordination between research centres and universities and decision makers in terms of considering the studies that are conducted by these institutions, which to a large extent offer scientific and practical recommendations".

A clear example of the lack of co-ordination was provided when Interviewee D mentioned that the benefit of this project is conditional on the optimal utilization of this water and this is uncertain in light of the current water management practices, particularly with the intention of expansion in irrigated projects to increase wheat production using water from the GMMR. This is a contradiction between formal water strategies, which stress decreasing use of water in irrigation projects, and what is implemented in reality.

Furthermore, several studies such as Algheriani (2003; 2007), Wehida (2007; 2012), GWA (2007), Goodland (2008), and recently Ramali and Holloway (2012) and Abdelrahem, et. al. (2013), all highlight the issue. These studies raise concerns about the critical water resources and give recommendations to alleviate the pressure placed on groundwater aquifers by agricultural practices. Those studies pointed out that "current irrigation water pumping to meet demand at agriculture projects and human use poses a serious threat for the long-term sustainability of the Murzuk basin". Algheriani (2007) has made some recommendations to improve water productivity and water use efficiency by replacing sprinkler irrigation with localized systems and by moving crop production from the southern zone that is affected by high evaporation rates to the coastal zone of much lower evaporation which would maximizes crop yield. However, the satellite images (see Figures 4.1 in Chapter 4) show the large increase in centre-pivot irrigation on the Murzuq Basin in south eastern Libya between 1987 and 2010. From the questionnaire survey, despite the importance of using the most appropriate irrigation system in saving water, about 71% of respondents have not received subsidies from the government to improve the efficiency of the irrigation systems they use.

This can be seen in the questionnaire analysis that shows only 9.5% of respondents use a drip irrigation system where it is possible such as irrigation trees. This highlights the lack of co-ordination between institutions. Therefore, from the analysis of the data it can be concluded that there is a clear gap in coordination between water authorities themselves and other government institutions.

8.2.5 Supply and Demand Water Management

The traditional approach to meeting rising water demand was by developing and expanding water resources. This has created serious problems of unbalanced water resources in terms of water availability and withdrawal, water shortages, and the degradation of water quality. Water management in Libya has focused more on water supply management than on demand management which has led to continuing water depletion and deterioration (GWA, 2000). Interviewee E stated that the target of water resource management during the 1970s and 1980s was to achieve food self-sufficiency which has resulted in the over-exploitation of water resources in order to meet the increased agricultural water requirements. Wheida (2007) argues that the desire to achieve food self-sufficiency has led to undesirable environmental issues such as soil degradation and deteriorating water quality. Therefore, achieving food self-sufficiency appears to be unrealistic in the case of Libya with its limited domestic water resources.

Interviewees A and B highlight the GMMR project as an example of the emphasis on supply rather than demand, pointing out that it is just a transfer of a huge volume of fossil water from the south through the desert to the north. This point has been reiterated by Salem (2007) when he claimed that the GMMR, which was launched to expand the water supply, can only be considered as a partial solution because it will only last 50 years. The WFP and FAO (2011) mention that “Libyan officials have concluded that the project does not provide a total solution to the country’s water needs and that more water sources will be required”. Moreover, the benefit of this project is conditional on the optimal utilization of this water and this is uncertain in light of the current water management practices, particularly with the intention of expansion in irrigated projects to increase wheat production using water from the GMMR (Interviewee D).

Fraiture and Wichelns (2010) point out that expanding the irrigated area can generate more reliable increases in agricultural output, but expansion opportunities are limited in many parts of Asia and North Africa due to water constraints. In light of the dry climate condition in Libya, focusing only on additional water supply is an inadequate and unwise strategy. Therefore, water demand management in the case of Libya is a more effective way towards implementing a sustainable use of limited water resources. There are a number of different steps towards water demand management that could be taken. Herbertson (2001) highlighted that increasing efficient water use can be achieved through several ways as following:

1. Technical tools such as drip and sprinkler irrigation, economic and regulatory measures.

2. Using motivational policy to encourage farmers to save water (for instance, farmers who save water will have access to a greater proportion of that resource later).

3. Developing the appropriate institutional capacity through awareness-raising and training.

4. As Wheida (2007) mentioned, importing food instead of growing it domestically can help reduce demand.

From the data analysis, it can be concluded that there is a lack of focus on water demand management in the current water management. Interviewee C pointed out that the “only step that has been taken is importing a large part of Libya’s food needs from other countries”. However, this policy appears to be temporary, given the large expansion in irrigated farming relying on GMMR. This may be a risk in light of indications that GMMR will only last 50 years and taking into account potential increases in the maintenance costs of delivering the water. Thus, interviewee F expressed concerns that without effective water management, the exploitation of this project would not even last for 50 years.

8.3 WATER FOOTPRINT

The calculations done in this research show that import of agricultural commodities mean that Libya imports more virtual water than it exports, which makes it dependent on water resources elsewhere in the world. According to Fraiture and Wichelns (2009) Libya imports about 70% of its agricultural requirements. Therefore, in the period 2001–2009 Libya imported between 6-12 Gm^3/year of water in virtual form while internal water use in the agricultural sector was between 1.9-2.5 Gm^3/year. Although this trend seems to be effective in reducing the pressure on the limited local water resources and can physically save the domestic water resources, it has negative impacts in terms of political issues such as political blackmail in case of any political conflicts between Libya and one of the exporting countries (Salem, 2007). Decision-makers in Libya have established an integrated water management approach to achieve a balance between supply and demand water management (Salem, 2007) but the evidence of the field studies suggests that the established plans have not implemented on the ground for several reasons (section 7.2.5) whereas it can be seen the expansion in irrigated farming.

8.3.1 Water Footprint Value to Water Management in Libya

Chapagain (2006) criticises the traditional way of estimating national water use because it is based on the volume of water extracted in the country. He argues that while this is useful, it does not reflect the actual water needs of the population because some of the needs are fulfilled through imported virtual water and some of the water produced is exported to other countries. In response to this type of criticism, a measure of water withdrawal was developed by Hoekstra (2003) to include the imported goods that are consumed within a country in virtual water form. Consequently, this measure shows both direct and indirect water use in a country. In this light, adopting a water footprint as a tool in water management in general is helpful to raise awareness of a country about how much actually they consume. In the case of Libya, as it is illustrated in the data analysis (chapter 5), the calculation of the internal water footprint shows that Libya used 19 Gm^3 of water to produce about 12 million tonnes of the selected crops during the scope of study period. FAOSTAT (2011) point out that Libya exports very little agricultural produce. Thus the researcher argues that the amount of exports can be neglected. Therefore, it can be said that the internal water footprint, which refers to the domestic freshwater used to produce the goods and services consumed within the country and excluding exported products, is equal to the volume of water extraction in the country. As a result, the internal water footprint is not any different from the traditional way to estimate national water use. From the data analysis, the average water extracted to produce the 8 selected agricultural crops is 2 Gm^3/year. With the addition of municipal and industrial use, this figure will be in line with the estimates of the GWA and FAO (2009) of 3.744 Gm^3/year.

From the evidence presented in this thesis, it can be argued that since Libya is a water-scarce country, the water management system needs to adopt particular approaches that help in protecting and alleviating the pressure on the groundwater as well as identifying how much water is consumed; for instance, management of water through the application of water demand management tools to improve the efficiency of water use. In addition, Hoekstra's (2009) definition of the internal water footprint only considers the amount of water that is consumed internally because it excludes the amount of water that is used to produce exported goods. This thesis concludes that it does not reflect the actual water withdrawal and would not, therefore, be helpful in water resource management in Libya. As a result, the traditional way of estimating water based on the volume of water extraction in the country are more helpful than water footprint measures in a country such as Libya.

In the case of the external water footprint, the analysis shows that Libya is a highly dependent country, importing up to 2.4 M tonnes a year of food (a total of 19 M tonnes during the period 2001- 2009)Table 6.4 which would need 9 M ha of land to grow this amount internally, along with 91 Gm^3 of water. In this context, the use of a water footprint as a tool appears to be helpful in showing how much water is consumed within a country and could be used to raise a public awareness about water consumption. The water footprint shows globally how much water is being consumed by Libya. However, it can be noted that the GWA already knows the amount of water consumed and required to be withdrawn from domestic water resources (Figure 4.4 and 4.7). Thus this knowledge is already available to the decision-makers but the policy of imports and production of crops has been adopted for other purposes such as political and economic reasons rather than on the basis of the water footprint.

8.4 WATER FOOTPRINT SUSTAINABILITY AND ENVIRONMENTAL ASPECTS

The water footprint indicator does not reflect real environmental impacts because some crops are grown in the water-rich areas with small environmental impacts. However, some crops have a low water footprint but exert significant environmental impacts since they are grown in scarce blue water [volume of surface and ground water required for the production of a good or service] areas. Therefore, compared with the traditional measures of water withdrawal, a focus on blue water withdrawal renders a more accurate picture of the environmental impacts in that area. In this case, the water footprint measures do not add any real value for the water management for water scarce countries such as Libya in terms of environmental protection.

Miller and WWF (2009) has pointed out that considering green water [rainwater used to produce a product which does not run off or recharge groundwater] in the water footprint and concern about evapo-transpiration is against the natural hydrological cycle as the author says that "evaporation of rainwater and transpiration from plants are natural processes of the hydrological cycle". Moreover, the evapo-transpiration from natural vegetation may exceed the evapo-transpiration from crops (Miller, 2009). Hoekstra and Mekonnen (2012, cited in Witmer and Cleij, 2012) mentioned that international trade and resource use can benefit from green water analysis; in this context, green water is primarily an economic consideration related to resource scarcity rather than an environmental issue.

Witmer and Cleij (2012) also mentioned that the water footprint indicator does not offer correct information for consumers to make a sustainable choice. Furthermore, the large amounts of 'virtual' water imported into the Netherlands do not necessarily reflect a large environmental impact. Although the global impact of water appropriation is increasingly acknowledged thanks to the concept of the water footprint, but more awareness is needed among the general public, the private sector and government. However, water volume does not really shed much light on environmental impacts, and setting realistic and achievable goals is impossible using water footprint alone, particularly in relation to sustainability (Witmer and Cleij, 2012).

The present study concurs with Witmer and Cleij (2012) in concluding that, in the case of Libya and arid countries, it would not be useful to use water footprint as a tool to determine appropriate policies or strategies regarding water management because of the lack of information regarding the scarcity value of water use which is more important to those countries than the amount of water used to produce imported commodities.

The researcher agrees that the idea of water footprint and virtual water may be helpful to inform people and decision-makers about water consumption. It also can help and serve as a tool in foreign policies of dependent countries to diversify their portfolio of food and to avoid any political coercion. However, water scarce countries which import food have no care about the amount of water used to produce imported food; however, they have deep concern about the price and reliability of exporters who provide them with suitable quality and price of food.

From the sustainability point of view, the water footprint does not seem to provide a proper indicator to be adopted for setting sustainability strategies for water use. For example, a large water footprint in water-rich areas may be more sustainable than a small water footprint in water-scarce areas under overexploited water resources. Witmer and Cleij (2012) pointed out that knowing the amount of water amount used or required to produce crops and other goods does not provide substantive information about the sustainability of water use.

8.5 SUMMARY

This chapter discussed the findings of the triangulated research to evaluate the current water resource management and consider how water and agricultural management in Libya can be developed and improved. Several key issues were identified, such as limited farmers' awareness about the limitations of domestic water resources, lack of implementation of water regulation and lack of co-ordination between water institutions and other related institutions.

After establishing this baseline understanding of water management in Libya, the water footprint was examined as a tool of water management in the specific conditions and circumstances of Libya, the case study. The results were discussed to establish conclusions about the value of the water footprint for water management in the specific conditions of Libya. A number of criticisms of the concept of water footprint were addressed and discussed.

In the final chapter, these issues are brought to a conclusion and recommendations are drawn from the research findings on how the water management in Libya might be developed and why water footprint as a tool does not contribute to the further development of water management in Libya.

CHAPTER 8 CONCLUSION, CONTRIBUTION TO KNOWLEDGE AND RESEARCH LIMITATION

9.1 INTRODUCTION

The purpose of this chapter is to summarise the insights developed in the previous chapters regarding water management in Libya. It also brings together the overall conclusion of in-depth study focusing on the extent to which the concept of water footprint as a tool can contribute in developing water management. It also explains the contribution to knowledge of this thesis. Finally, the limitations and further research are proposed.

The current literature, such as Hoekstra & Chapagain (2008) and Wichlns (2011) is largely focused on the calculation of water consumed to produce products and services; it does not include why and how this amount of water can be properly managed. Although plenty of research, such as Chapagain and Tickner (2012), Rockstro¨m (2009), has demonstrated the amount of water consumed by people on a national basis, there is a lack of clear explanation to show to what extent that water footprint calculation can help in developing water management. No previous research based on national water and agricultural management data has been conducted to estimate the national water footprint on the Libyan national scale. The only relevant study was that by Hoekstra (2007), which does not in fact reflect the precise information about water and agricultural information.

This thesis focuses on critically examining the concept of the water footprint in the specific conditions and circumstances of Libya, an arid and water-scarce country. It also explores how existing water resource management needs to be developed to meet the increasing water demand to attain food security, and attempts a critical evaluation of the water footprint concept as a tool for water management policy makers in Libya.

The research addressed the main research question concerning to what extent the concept of the water footprint can contribute to the development of a water management strategy for Libya. The researcher applied qualitative and quantitative approaches to collect data through questionnaires with farmers in three agricultural regions in Libya. Interviews were conducted with agricultural experts from both governmental and non-governmental organisations and individuals with a rich experience in agriculture. The water footprint was calculated according to national statistical information.

9.2 THE KEY FINDINGS

The study has identified a number of key issues in relation to current water and agriculture management practices and the potential use of the water footprint as a tool to develop water management. Those key issues were identified through answering the following research questions.

9.2.1 Is the current water resources management approach in Libya effective for balancing the water needs of the present and the future (sustainable water use)?

Overall, this research found that water resources in Libya are limited and agricultural use accounts for around 85% of water demand. This has significant impacts on both the quantity and quality of water; for example, the intrusion of salty sea water into shallow aquifers in the coastal regions and declining ground water levels as a result of over-exploitation are serious environmental and food security considerations.

Although the current water management seems to be well drafted (in theory), it is not implemented and water polices need to be reviewed, revised and reformulated in order to achieve sustainability. For example, the GWA (2007) confirms that Libya has witnessed a huge expansion in irrigated crops (see Figure 4.1 chapter 4), particularly in southern regions where temperatures are high, which increases the amount of evaporation. Moreover, according to the researcher's survey, it can be seen that there is no schedule for irrigation time; 70.5% of respondents irrigate crops at any time including peak times whereas the temperature reaches to 45c° while only about 25% irrigate crops in the early morning and late evening. The problem of the over-exploitation of water resources was identified and aggravated as a result of the ineffective implementation of water regulation in practice Interviewee C state that "I can say that in theory the laws regulating water are valid and sufficient to reduce water degradation … but the problem is they are not completely enforced … to be honest, I can say only 40-50% of them are implemented. However, this failure is attributed to various causes, the first and foremost of which is a lack of commitment among the local authorities to implement the existing legislation, and a failure to tackle control violations committed by citizens. Salen, 2007) stated that there are no practical and serious steps to achieve these policies. Hamad (2012) mentioned that, the regulations have not been correctly implemented. Secondly, both the official authorities and farmers have contributed significantly to the current deterioration and violation of water regulation. Thirdly, the administrative instability of water institutions, interviewee E mentioned that the instability in the administrative system is affecting policies' continuity and the people who are in charge of water and agricultural institutions lack updated knowledge about water resources, and the lack of trained workers in these institutions have significantly undermined the effectiveness of water regulations and legislation. Interviewee B mentioned that "I can say that there is no effective program to raise the farmers' awareness about water issues and how to maintain water resources, which consequently led to this situation". Fourthly, there is reluctance by the authorities to consider limiting the use of water resources in irrigation. interviewee C demonstrated this point when stating that if you go fact-finding in the countryside you see flagrant violations exhibited before inspectors, who don't take any action – for example; many farmers apply irrigation at midday in the summer and nobody cares. It also, continuing growing of water-intensive crops such as Alfalfa and tomato, particularly in southern regions where temperatures are high, increasing the amount of water loss to evaporation. From the questionnaire survey and researcher field observation, it can be seen that whereas the range of the cultivated area of high water requirement crops such as water melon (64% of respondents), alfalfa (50% of respondents) and tomato is between1-6 ha. From the knowledge of the researcher and field observation, it could be suggested that, there is no a great level of non-compliance with regulation between regions related restricted growing high water requirement crops, irrigation timer and boreholes licence.

Furthermore, supplying water freely to the farmers is a major concern in the allocation of this vital resource. An inadequate awareness of the governmental water conservation programme has resulted in a lack of knowledge about the relative values of groundwater resources used in specific agricultural activities which has led to a lack of public commitment to the conservation of water resources. Interviewee B mentioned that "I can say that there is no effective program to raise the farmers' awareness about water issues and how to maintain water resources, which consequently led to this situation". In addition to the social and cultural reasons, the issue of financial and administrative corruption in the executive of the official institutions also contributes to the crisis.

Interviewee C stated that “the system of nepotism knows as wasta) has limited the implementation of regulation.

According to interviewee C and Hamad (2012), there were attempts by the water resources management system in Libya to successfully implement a water plan but unfortunately those attempts faced major barriers. The financial issue was considered as a significant obstruction at the governmental level, Interviewee A, and on a practical level the deteriorating groundwater quality and monitoring of groundwater pollution from waste water severely undermine the utility of natural reserves. The lack of urban planning (i.e. the inadequacy and limited reach of the sewage network beyond the urban core) has precipitated the construction of ad hoc dwellings with septic tanks beyond the auspices of the local authorities that do not conform to necessary technical specifications, which is compounded by the incursion of sea water into shallow aquifers.

The urban planning and infrastructure problems reflect the lack of co-ordination between institutions. There is a clear gap in coordination between water authorities themselves and other government institutions, which has led to conflicting decisions and aggravates the pollution problem of groundwater. Water experts in Libyan public institution stated that there is no positive co-ordination between research centres and universities and decision makers in terms of considering the studies that are conducted by these institutions. (interviewees E, G and C).

Water management during the period from the 1970s to the 1990s in Libya was focused more on water supply management than on demand management, which has led to continuing water depletion and deterioration (GWA, 2000). In light of the dry climate conditions in Libya, focusing only on additional water supply is an inadequate and unwise strategy. Therefore, water demand management in the case of Libya is a more effective way towards implementing the sustainable use of limited water resources. One market development that has already taken place towards demand water management is importing required food from abroad. Water demand management could increase the efficiency of water use in terms of applying technical tools such as drip and sprinkler irrigation, economic and regulatory measures and using motivation policy. For instance, farmers who save water will have access to a greater proportion of that resource later, and developing the appropriate institutional capacity through awareness-raising and training to encourage farmers to save water.

The benefits of the water resources made available by the Great Man Made River Project (GMMRP) are conditional upon the optimal utilisation of this water, which is uncertain in light of the current water management practices, particularly with the intention of expansion in irrigated projects to increase crop production using water from the GMMRP. Therefore, there is a concern from the researcher and interviewee F that without effective water management, the exploitation of this project would not be sustainable.

The researcher concluded that in the case of Libya and other arid countries the water footprint is not a useful tool to determine appropriate policies or strategies regarding wider water management considerations because of the lack of information regarding the scarcity value of water use and environmental aspects which are more important to those countries than the amount of water used to produce imported commodities.

9.2.2 How far will applying the concept of the water footprint successfully tackle the water limitation and protect water resources in Libya?

In light of the above research question, the researcher undertook to estimate and analyse the national water footprint of Libya for the period 2001–2009. The internal water footprint (internal water use) in the agricultural sector was between 1.9-2.5 Gm^3/year, while the external water footprint (imported products) was between 6-12 Gm^3/year of water in virtual form. The calculation of internal water footprint showed that Libya used 19 Gm^3 of water to produce about 12 million tonnes of the selected crops during the study period Table 6.1.

The amount of agricultural produce exported by Libya is negligible (Figure 4.12) whereas the agricultural product exports, even in good years; do not exceed 0.6% of the total exports (Goodland, 2008: Laytimi, 2005: and FAOSTAT, 2011). Thus exports were excluded from analysis. It can be concluded that the internal water footprint, which refers to the domestic freshwater used to produce the goods and services consumed within the country, and excluding exported products, is equal to the volume of water extraction in the country. As a result, the internal water footprint does not differ from the traditional way of estimating national water use.

However, this study concluded that since Libya is a water-scarce country, the water management system needs to adopt particular approaches that help in protecting and alleviating the pressure on the groundwater rather than simply highlighting how much water is consumed; for instance, the management of water through the application of water demand management tools to improve the efficiency of water use. The study concluded that internal water footprint as a measure of water use does not reflect the actual water withdrawal as it represents only water withdrawn that is used to produce products consumed by inhabitants excluding water withdrawn for exported products. However, in some countries, which have negligible exportation such as Libya, it would not add value for water resource management because, in that case, internal water footprint would be as same as actual water withdrawal. As a result, the traditional way of estimating water use is more helpful than water footprint measures in a country that exports agricultural products, such as Tunisia and Morocco.

In the case of the external water footprint, the analysis shows that Libya is a highly dependent country, importing up to 2.4 M tonnes of food a year (a total of 19 M tonnes during the study period), which would require 9 million ha of land for conventional internal yield, along with 91 Gm^3 of water. In this context, the use of a water footprint as a tool appears to be helpful in showing how much water is consumed within a country and could be used to raise a public awareness about water consumption in total. It showed globally how much water was consumed by Libya. However, the authorities of a region or a country already know the amount of water consumed and required to be withdrawn from domestic water resources. Thus, this knowledge is already available to the decision-makers and the concept of virtual water contributes little to the improvement of water management in Libya.

To understand the behaviour of decision-makers in Libya one must understand the erratic course of the country’s international position in recent decades. Intermittent periods of international sanctions on Libya prompted a search for numerous sources of food imports, to avoid dependence on a limited number of countries. Furthermore, the growing population and other factors necessitated the adoption of an integrated water management approach to achieve a balance between supply and demand water management (Salem, 2007).

The water footprint might be useful in that it provides insight into the use of virtual water within a country and might, therefore, be helpful in informing people and decision makers about overall water consumption. It can also help and serve as a tool in the foreign policies of dependent countries to diversify their food portfolios and to avoid any external political coercion (blackmailing). Some authors such as Roth and Warner (2008) and Neubert (2008) have raised concerns that virtual water trading may expose the importing countries to the political blackmailing of water-rich exporting countries. Therefore, those authors have recommendations to exclude developing countries from virtual water trading strategy.

Importing water-scarce countries have no care about the amount of water used to produce imported food in the exporting countries; however, they have deep concern about the price and reliability of exporters who provide them with suitable quality and price of food.

From the sustainability point of view, the water footprint does not seem to provide a proper indicator to be adopted for setting sustainability strategies for water use. For example, a large water footprint in water-rich areas may be more sustainable than a small water footprint in water-scarce areas with overexploited water resources. For example, producing crops in countries with high rainfall (green water) such as UK will have less negative environmental impacts than crops produced in water-shortage countries such as Morocco, dependent on groundwater resources (blue water). Knowing water amounts that are used or required to produce crops and goods is interesting, but it does not provide substantive information about the sustainability of water use (Witmer and Cleij, 2012).

9.2.3 What components should be included and excluded in calculating national water footprint?

Water footprint has a contribution to make in raising the awareness of decision-makers about water consumption. However, it considers only the volume of water consumed and there is no mention of other inputs of crop production, such as the water used in the production of fertiliser and pesticides, nor does it take into account opportunity costs. Interactions that determine water allocation involve several factors such as physical, social and economic dimensions whereas the freshwater should be allocated based on the human needs, therefore, using freshwater for commercial production should be reconsidered. Necessary Water flow in terms of quantity and quality should be continued for ecological needs. In terms of the economic perspective, the water footprint should include the full water cost in light of opportunity cost (Hastings & Pegram, 2012). Unfortunately, these factors are not included in water footprint estimation or consideration of environmental impacts (Wichlns, 2011). Therefore, it is difficult to understand the complex interactions when focusing on water volumes alone. It is also insufficient to provide information for taking action and to understand and identify the local impact of water use and opportunities for more efficient and effective water use.

It has also suggested by Rockström (2009) that it is difficult to distinguish between blue and green in the water footprint concept because, as the green water is defined, the rainfall causes runoff and most countries have built huge dams to reserve rainfall to create reservoirs. So, when this water is delivered to the farms, it is considered to be blue water not green water. At the same time, when the runoff percolation becomes soil moisture, it is considered to be green water. Thus, there is no clear distinction between blue and green water.

It has been suggested by Garrido et al. (2010) (Section 2.6.6) that virtual water analysis falls short of developing our understanding of important water resource issues and also does not provide a legitimate conceptual framework to support its technique. For example, no theory suggests that a country or region should always import water-intensive products from water-rich countries (Garrido et al. 2010). Thus, there is no obligation for the importing country to import their needs from either water-rich or water-scarce places. In addition, importing countries do not much care about the negative environmental impacts in exporting countries that may happen as a result of overuse of water and using chemical pesticides and fertiliser. Some exporting countries suffer from a depletion of their local resources that impact negatively on the local eco-system. For instance, the over-exploitation of the Ogallala aquifer in the USA for agriculture and cattle-breeding means the level of the water table is declining by up to 1.5m a year (Partzsch and Schepelmann, 2005).

Several researchers such as Kitaka et al. (2002) and Gitachi (2005) (See section 2.6.5.3) mention that there is a large nutrient deficiency in the upper catchment of Lake

Naivasha Basin in Kenya as a result of intensive commercial farming of flowers for export, as a result of which vegetation on the riverbank could be lost.

This example illustrates that any virtual water trade should be introduced as a part of a comprehensive water resource management strategy in order to ensure that it is ecologically sound and avoids simply shifting the groundwater problem from one country to another.

From the literature of this study, the virtual water concept has vague drawbacks, which cannot be comprehended by quantitative study.

9.3 CONTRIBUTION TO KNOWLEDGE AND UNDERSTANDING

The purpose of this study was not just an application of existing theory or a technical framework for improving polices but it attempted to critically examine the concept of water footprint in the specific conditions and circumstances of Libya as a case study, the first study to do so. Thus, the estimation of the water footprint of Libya is not the main purpose of this study but it is nevertheless a key issue in this research. Therefore, the contribution to knowledge of this study might be validating or modifying this concept depending on the outcome of this research. Also, the outcomes might be of significance to some other countries in developing their water resource management system depending on the circumstances and conditions of the country under study.

This study contributes to the empirical research to enhance the literature on the concept of the water footprint by opening a discussion about the value of applying it as a tool in developing water management for specific conditions and circumstances, using Libya as a case study. It contributes to the debate about the value of adopting water footprint in developing water management systems in water-scarce countries, particularly in arid desert regions.

This study has critically analysed the water footprint literature and has concluded that the concept of the water footprint adds no value to the water management at the national level, because the local water authorities already know the amount of water consumed and required to be withdrawn from domestic water resources; thus this knowledge is already available to the decision-makers. It also lacks information regarding the scarcity value of water used and the environmental aspects, which are more important to those countries than the amount (i.e. volume) of water used to produce imported commodities.

From the sustainability point of view, the water footprint does not provide substantive information about the sustainability of water use.

This study tried to modify the water footprint calculation framework by including the amount of water used to produce exported goods to reflect the real picture of water extracted from local water resources. However, to avoid double calculation, this framework works only at the national level.

At the national level, this study tried to evaluate the current water management of Libya to uncover the real reasons behind the deterioration of local water resources by employing a hermeneutic interpretive approach. This enabled the researcher to understand dialogue with stakeholders regarding the impact of agricultural activities on water resources in terms of sides, quality and quantity. This approach allowed the researcher to obtain a lot of information from a small number of people in charge.

This study develops a novel approach to collecting information from an extensive sample of ordinary farmers in this emerging economy and samples their views alongside those of expert senior stakeholders. The outputs that result from the study will be of interest to a growing body of water researchers globally.

The main contribution of this study is that it provides (for the first time) a detailed assessment of stakeholder views of agricultural and water management in Libya. As such, the study provides a unique criticism for the concept of water footprint for future work in countries that have the same circumstances of Libya and also an insight into stakeholder issues related to the development of water management.

9.4 RESEARCH LIMITATIONS

This research was not achieved without some limiting factors. The factors that contributed to the study's limitation are as follows. The first is the difficulty encountered during the gathering of data in relation to virtual water and water footprint concerns. Getting data on water footprint in Libya was not easy and this contributed to delays in completion of the research. The data required for this research was for the whole of Libya and the challenge encountered was the lack of data that was already classified according to the regions of the country. In view of this problem, the researcher had to first of all calculate the water foot print for the whole of Libya in order to generate the data required for the analysis conducted.

Thirdly, at the time of conducting the field study at Libya, the data available on exports and imports of agricultural crops was not comprehensive in the sense that the data in which transactions occurred were not recorded. In addition, the data was not classified according to regions of Libya. As a result of these, the level of crops consumption for each region of Libya was not presented in this research. More so, the lack of information for each region made it difficulties for the researcher to calculate the rate of regional water consumption.

Fourthly, as this was the first study to be carried out on water foot print in Libya, the researcher was made to obtain permission before government could release a huge data that it considered as national security data. Obtaining this necessary permission took very long time and this further contributed to delays in the completion of the research.

Lastly, the chaos and political instability in the country, as a result of the civil war that started in Libya in 2011 considerably limited access to updated research data for the study.

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Appendix 1 Invitation for Interview-Farmers

Sheffield Hallam University

Dear Farmer

Peace and God's Blessing be upon you.

The researcher is undertaking a study to explore how existing water resource management needs to be developed to meet the increasing water demand to attain food security as a part of the study to examine critically the concept of the water footprint in relation to sustainable water management in Libya and illustrate whether this concept can be a helpful tool in developing water management policy in Libya. This study is for a PhD research degree at Sheffield Hallam University in the UK. As a part of the research, the enclosed questionnaire is intended to collect some necessary information about agricultural infrastructure at the farm and the regional level and what its impact is on operating farming practices and activities.

I hope you will participate by completing the attached questionnaire. Kindly answer the questionnaire as you deem appropriate. All information and details you give will be treated as confidential and used for research purpose only. The researcher believes that your wide experience is significant to the successful outcome of this research.

Thank you in advance for your interest, contribution and cooperation.

Best Regards

Allafi Ali

Researcher

Appendix 2: Farmer Questionnaire

1-Name (optional)
……………………………………………………………………………………………
……………………………………………………………………………………………

2-Age:

28-38 { }   39-49 { }   50-60 { }   61+ { }

3- region

Northern { }   eastern { }   southern { }   western { }

4-The function point
……………………………………………………………………………………………
…………………………………………………………………………………………

5- Educational level of farmers

No education { }   Primary education { }   High education { }   N/A { }

6-Areyou a specialist in agriculture sector?

Yes { }   No{ }

7-Type of cultivated crops

Type of crops	Cultivated area /hector				Crop yield
	Less than 0.5	From 1-3	4-6	6+	
oats					
Alfalfa					
Barley					
Wheat					
watermelon					
Citrus					
grapes					
potatoes					
Spring onion					
Winter onions					
Winter tomatoes					
Spring tomatoes					
olives					
Date palms					
Vegetables					

which of these crops have been exported? Please mention below

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

8-Type of agriculture

Irrigated { } Rain fed { } N/A { }

If the type of agriculture is irrigated, please answer the following question

9-Source of irrigated water

Private well { } well controlled by GAW { } N/A { }

10-Do you have a license to dig the well used in irrigated?

Yes { } No { } N/A { }

11-Do you pay for using water?

Yes { } No { } N/A { }

If yes , what do you think of the fees?

Suitable { } Not suitable { }

12-types of irrigation system that have been used?

Sprinkle { } Pivot { } Flooding { } Drip { } N/A

13-Irrigation time:

Morning { } Mid-day { } Afternoon { } Evening { } N/A { }

14- do you receive subsidies from the government for developing the irrigation system?

Yes { } No { } N/A { }

If yes, please tick the percentage of subsidies

Less than 25% { }   26-51% { }   51% + { }

15-Do you receive any guidance programmes of agricultural practices and water usage?

Yes { }   No { }   N/A { }

16-The quality of the irrigation water

Good { }   Acceptable { }   Poor { }   N/A {

Appendix 3: How respondents answered questions

Respondent	Questions															Comments
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	B	D		C	B			A	A	A	B	B	AD	B	B	B	(Q10, 11&13) 1, 4, 7 &8.
2	C	D		B	A			A	A	B	0	B	CD	B	B	B	
3	B	D		B	B			A	A	0	0	B	AD	B	B	C	(Q11,13&14) 1,3,4&6
4	D	C		A	B			A	A	B	B	AD	A	0	B	C	
5	B	C		C	A			B	A	A	B	D	AD	B	B	C	(Q13 &14) 1,2,3&7
6	B	A		C	A			B	A	0	B	D	A	B	A	C	
7	B	A		C	A			B	A	A	B	D	AD	A	A	B	
8	B	A		C	A			B	A	0	B	D	A	B	B	C	(Q11&14) 1,2&3
9	B	C		B	B			A	B	0	B	D	D	A	B	C	(Q11,13&14) 1,2,3&6
10	B	D		B	B			A	B	B	B	D	AD	B	B	B	
11	A	C		C	A			A	B	B	B	A	AD	B	B	C	
12	D	C		A	B			A	B	0	B	AC	A	A	B	C	(Q11) 1&2
13	D	C		B	B			A	B	0	B	ACD	B	B	B	C	
14	B	C		C	A			A	0	B	B	AD	AD	B	B	C	
15	B	C		B	B			A	0	0	B	AD	AD	B	B	C	(Q11&13) 1,2&4
16	C	C		C	B			A	0	0	B	D	D	B	B	C	(Q11,13&14) 1,2,3&4
17	B	C		B	B			A	0	0	B	A	AD	B	B	C	(Q11) 1&2
18	B	D		C	B			B	0	0	0	0	0	0	0	0	(Q11,13&14) 1,2,3,4&6

19	B	B		B	B			A	A	0	B	A	ACD	B	B	C	(Q11) 1&2
20	B	B		B	A			A	A	0	B	A	ACD	B	B	C	(Q11&14) 1,2&3
21	D	B		A	B			A	A	0	B	AC	BC	B	B	C	(Q11) 1&2
22	B	B		B	B			A	A	A	B	AD	ABC	B	B	C	
23	B	B		B	B			B	A	0	B	AC	ACD	B	B	C	(Q11) 1&2
24	B	B		B	B			A	A	0	B	AC	ABD	B	B	C	(Q11) 1&2
25	D	B		A	B			A	A	A	B	A	ACD	B	B	C	
26	B	B		B	A			B	0	0	0	0	0	B	B	C	(Q11,13&14) 1,2,3&4&6
27	C	B		B	B			A	A	A	B	A	ACD	B	B	C	(Q11) 1&2
28	B	B		C	B			B	A	A	B	AD	AD	B	B	C	(Q11) 1&2
29	B	B		C	B			A	A	A	B	A	AD	B	B	C	(Q11) 1,2,6&7
30	B	B		C	B			B	0	0	0	0	0	B	B	C	(Q11,13&14) 1,2,3&4&6
31	B	B		C	B			B	0	0	0	0	0	B	B	C	(Q11,13&14) 1,2,3&4&6
32	B	B		C	B			A	A	A	B	A	ACD	B	B	C	(Q11) 1,2,6&7
33	B	C		B	B			B	0	0	0	0	0	0	0	0	(Q11,13&14) 1,2,3&4&6
34	B	C		B	B			B	0	0	0	0	0	0	0	0	(Q11,13&14) 1,2,3&4&6
35	B	B		B	B			A	A	0	B	A	AC	B	B	C	(Q11) 1&2
36	B	B		B	B			A	A	A	B	A	AC	B	B	C	
37	D	B		B	B			A	A	0	B	A	ACD	B	B	C	
38	D	B		B	B			A	A	A	B	A	AD	B	B	C	
39	B	B		C	B			A	A	0	B	AD	AD	B	B	C	
40	C	D		B	A			A	A	B	B	AD	ACD	B	B	B	

41	C	C		C	B			B	0	0	0	0	0	0	0	0	(Q11,13&14) 1,2,3&4&6
42	B	D		C	B			A	A	A	B	AD	D	B	B	B	(Q11&13) 1,4&6
43	B	D		C	B			A	A	A	B	AD	ACD	B	B	B	(Q11&13) 4&8
44	B	D		A	B			A	A	A	B	CD	ABCD	B	B	C	(Q11) 1
45	B	D		C	B			A	A	A	B	AD	AD	B	B	B	(Q11) 1
46	B	D		A	B			A	A	A	B	AD	AD	B	B	B	(Q11) 1&2
47	C	D		B	B			A	A	0	B	B	AD	B	B	C	(Q11) 1&5
48	B	D		B	B			A	A	A	B	CD	AD	B	B	A	(Q11) 1,6&8
49	C	D		B	B			A	A	A	B	AB	AD	B	B	B	
50	B	D		C	B			B	0	0	0	0	0	0	0	0	(Q11) 1&5
51	A	D		C	B			A	A	A	B	AB	AD	B	B	B	(Q11) 1&2
52	B	D		C	B			A	A	A	B	BD	AD	B	B	A	
53	B	D		C	B			A	A	A	B	A	CD	A	B	B	(Q11) 1
54	A	D		B	B			A	A	0	B	AD	D	A	B	A	(Q11) 1&5
55	B	D		C	B			A	A	A	B	BD	AD	B	B	C	
56	B	D		C	B			AB	A	A	B	ABD	AC	B	B	B	(Q11) 1
57	C	D		C	B			A	A	A	B	B	AD	B	B	C	(Q11) 1
58	B	D		B	B			A	A	0	0	B	D	B	B	B	(Q11,13&14) 1,2,3,4&6
59	C	D		B	B			AB	A	A	B	CD	AD	A	B	B	(Q11&13) 1,2&4
60	A	A	7	C	B			A	A	B	B	AD	AD	B	B	A	(Q13) 4
61	C	C		B	B			A	A	A	B	AC	CD	B	B	C	
62	A	C		C	A			A	A	B	B	AD	ACD	B	B	C	

63	B	C		A	B			A	A	A	B	AC	ABCD	A	B	C	
64	A	B		B	B			A	A	0	B	C	CD	B	B	C	(Q11) 1&2
65	B	B		A	B			A	A	0	B	AC	ABC	B	A	C	
66	C	A		B	B			A	A	0	B	AD	AD	A	B	A	(Q11) 1&2
67	B	C		A	B			A	A	A	B	AC	ABCD	B	B	C	
68	A	A		B	A			A	A	0	B	AD	AD	0	0	0	(Q11) 1&2
69	B	A		B	B			A	A	A	B	AD	AC	B	A	A	
70	A	B		B	B			A	A	0	B	AD	AD	0	A	C	(Q11,13&14) 1,2,3&4&6
71	B	D		B	A			AB	A	A	B	B	D	0	A	C	
72	A	C		B	B			A	A	0	B	AC	AC	0	0	C	(Q11) 1&2
73	B	A		B	A			A	A	A	B	AD	AD	B	B	A	
74	B	B		A	B			A	A	B	B	AC	ABC	B	B	C	
75	C	B		C	B			A	A	B	B	AD	AD	A	B	C	(Q13&14) 1,3&4&6
76	A	A		C	B			A	A	0	B	D	ACD	B	B	A	(Q11) 1&2
77	A	C		B	B			A	A	0	B	A	D	A	A	C	(Q11,13&14) 1,2,3&4&6
78	B	B		A	B			A	A	0	B	AC	C	0	A	C	(Q11) 1&2
79	B	B		B	B			A	A	0	B	A	CD	0	A	C	(Q11,13&14) 1,2,3&4&6
80	B	A		C	B			A	A	0	B	A	AD	B	B	A	(Q11&13) 1,2&4
81	0	A		B	A			A	A	0	B	D	CD	0	B	A	(Q11) 1,2&6
82	C	C		B	B			A	A	A	B	AC	ABC	0	B	C	
83	B	B		C	A			A	A	A	B	A	D	A	B	C	(Q11) 1&2
84	0	A		B	B			A	A	A	B	AD	AD	A	B	B	

85	B	B		B	B			A	A	0	B	AC	ABC	B	B	C	(Q11) 1&2
86	C	C		B	B			A	A	0	B	AC	BC	0	A	C	
87	B	A		B	B			A	A	0	B	AD	CD	A	B	B	
88	B	C		B	B			A	A	A	B	A	BC	B	B	C	(Q11) 1
89	B	A		C	A			A	A	A	B	AD	AD	0	B	C	(Q11) 1
90	B	B		B	B			A	A	A	B	AD	D	A	B	C	
91	B	A		B	A			A	A	A	B	AD	DC	B	B	C	
92	B	B		C	B			A	A	0	B	A	CD	B	B	C	(Q11) 1&2
93	B	B		B	B			0	A	0	B	A	AC	A	B	C	(Q11) 1
94	B	C		C	A			A	A	0	B	AD	CD	B	B	C	(Q11) 1&2
95	B	C		B	A			A	A	0	B	A	AC	A	B	C	(Q11) 1&2
96	B	B		B	B			A	A	0	B	AD	D	A	B	C	(Q11) 1
97	B	A		B	B			A	A	0	B	AD	AC	B	B	C	(Q11) 1
98	B	B		C	B			0	A	A	B	A	AD	B	B	C	(Q13&14) 3,4&6
99	B	C		B	B			A	A	A	B	C	BC	A	B	C	
100	B	A		C	B			A	A	A	B	AD	CD	B	B	C	
101	B	B		B	B			0	A	A	B	AD	C	B	B	C	
102	B	B		C	B			A	A	A	B	AC	ABC	B	B	C	
103	B	B		C	B			A	A	0	0	A	C	B	B	C	(Q11) 1
104	B	A		B	B			A	A	0	B	D	CD	A	B	A	(Q11&13) 1,3,4&6
105	B	B		B	B			0	A	A	B	AC	C	A	B	C	
106	B	C		C	B			A	A	0	0	AC	CD	B	B	C	(Q11) 1

107	D	C		0	B			0	A	A	B	AC	ABC	A	A	C	
108	B	B		C	B			0	A	0	B	A	C	B	B	C	(Q11) 1&7
109	B	C		0	B			A	A	0	0	A	CD	B	B	C	(Q11) 1
110	B	C		0	B			A	A	0	0	AC	BC	B	A	C	(Q11,13&14) 1,2,3&4&6
111	0	B		B	B			A	A	0	B	A	C	A	B	C	(Q11,13&14) 1,2,3&4&6
112	B	C		0	B			A	A	0	B	A	ACD	B	B	C	(Q11) 1
113	B	C		0	C			A	A	A	B	A	CD	A	B	C	
114	B	B		0	B			0	A	0	B	A	D	B	A	C	
115	B	C		B	B			0	A	B	B	AC	AB	B	B	C	

Comments

(1) The field observation were not consistent with the responses

(2) had a borehole in a protected area (by the law it is not allowed to dig well in this area)

(3) By the law it is taboo to irrigate in this time or growing crops high water requirement

(4) clearly used flood irrigation while stating in Question 13 to other methods of irrigation was used

(5) Clearly had a borehole because it is noticed that many crops are grown there.

(6) Clearly had a borehole while the respondent did not answer this question (irrigation system tool is visible)

(7) Clearly had a well, he use the electrical generated to have water instead of using public electrical net work despite the electrical net work is there.

(8) No approve for well license

The comments above relate to Question 11, 13 and 14which asked about well license, irrigation system and irrigation time which are most observed by the researcher4

Appendix 4 Invitation for interview (Agricultural and water experts)

Dear Sir/ Madam

Peace and God's Blessing be upon you.

The researcher is undertaking a study to examine critically the concept of the water footprint in relation to sustainable water management in Libya. It will also explore how existing water resource management needs to be developed to meet the increasing water demand to attain food security and illustrate whether this concept can be a helpful tool in developing water management policy in Libya. This study is for a PhD research degree at Sheffield Hallam University in the UK. As a part of the research, I would like to conduct an interview with you as an expert in the agricultural and water sector to collect some necessary information about the agricultural practicing and water management at regional and national level.

You are assured that all information and details you give will be treated as confidential and used for research purpose only. The researcher believes that your wide experience is significant to the successful outcome of this research.

Thank you in advance for your interest, contribution and cooperation.

Best Regards

Allafi Ali

Researcher

Appendix 5 Internal water footprint

o			Internal	W.F					
				2001					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	49000	230000	160000	216000	168000	133000	26000	103000	1085000
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	14000	65714	8889	21600	11200	7000	17333	20600	166336
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Eff.R m/ha	860	820	100	170	450	220	810	630	
Blue W.F m3	92155000	277805935	104490195	281815200	111742400	50183000	163623520	633614800	1715430050
Green W.F m3	12040000	53885480	888900	3672000	5040000	1540000	14039730	12978000	104084110
Total W.F m3	104195000	331691415	105379095	285487200	116782400	51723000	177663250	646592800	1819514160
				2002					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	54000	263000	190000	300000	173000	236000	27600	104000	1347600
Average WR m3/ha *	7442.5	7442.5	5047.5	11855	13217	10427	7389	10250	
Productivity tonne/ha **	3.5	3.5	3.5	18	10	15	19	1.5	
Area/ha***	15429	75143	10556	30000	11533	12421	18400	20800	194282
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	101561392.5	317667032.5	124085780	391410000	115064741	89046149	173696000	639766400	1952297495
Green W.F m3	13268940	61617260	1055600	5100000	5189850	2732620	14904000	13104000	116972270
Total W.F m3	114830332.5	379284292.5	125141380	396510000	120254591	91778769	188600000	652870400	2069269765
				2003					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	46000	175000	181000	300000	185000	226000	26500	110000	1249500
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	13143	50000	10055	30000	12333	11895	17666	22000	167092
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	86513797.5	211375000	118196525	391410000	123046341	85275255	166767040	676676000	1859259959
Green W.F m3	11302980	41000000	1005500	5100000	5549850	2616900	14309460	13860000	94744690
Total W.F m3	97816777.5	252375000	119202025	396510000	128596191	87892155	181076500	690536000	1954004649
				2004					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	61000	132000	207000	240000	170000	210000	23000	112000	1155000
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	17429	37714	11500	24000	11333	11053	15333	22400	150762
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	114726392.5	159435935	135182500	313128000	113069341	79238957	144743520	688979200	1748503846
Green W.F m3	14988940	30925480	1150000	4080000	5099850	2431660	12419730	14112000	85207660
Total W.F m3	129715332.5	190361415	136332500	317208000	118169191	81670617	157163250	703091200	1833711506
				2005					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	48000	234000	197000	214000	300000	250000	25000	118000	1386000
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	13714	66857	10944	21400	20000	13158	16667	23600	186340
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	90272405	282637967.5	128646720	279205800	199540000	94329702	157336480	725888800	1957857875
Green W.F m3	11794040	54822740	1094400	3638000	9000000	2894760	13500270	14868000	111612210
Total W.F m3	102066445	337460707.5	129741120	282843800	208540000	97224462	170836750	740756800	2069470085
				2006					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	104000	240000	160000	218000	295000	227000	24000	122000	1390000
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	29714	68571	8889	21800	19666	11947	16000	24400	200987
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	195592405	289883902.5	104490195	284424600	196207682	85648043	151040000	750495200	2057782028
Green W.F m3	25554040	56228220	888900	3706000	8849700	2628340	12960000	15372000	126187200
Total W.F m3	221146445	346112122.5	105379095	288130600	205057382	88276383	164000000	765867200	2183969228
				2007					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	96000	244000	212000	250000	265000	182000	22000	130000	1401000
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	27429	69714	11777	25000	17666	9579	14666	26000	201831
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	180551392.5	294715935	138438635	326175000	176253682	68671851	138447040	799708000	2122961536
Green W.F m3	23588940	57165480	1177700	4250000	7949700	2107380	11879460	16380000	124498660
Total W.F m3	204140332.5	351881415	139616335	330425000	184203382	70779231	150326500	816088000	2247460196
				2008					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	156000	220000	212000	240000	235000	182000	24500	135000	1404500
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	44571	62857	11777	24000	15667	9579	16333	27000	211784
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	293388607.5	265727967.5	138438635	313128000	156309659	68671851	154183520	830466000	2220314240
Green W.F m3	38331060	51542740	1177700	4080000	7050150	2107380	13229730	17010000	134528760
Total W.F m3	331719667.5	317270707.5	139616335	317208000	163359809	70779231	167413250	847476000	2354843000
				2009					
	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
quantitycrop production	160000	260000	220000	225000	250000	186000	22300	142000	1465300
Average WR m3/ha *	7442.5	5047.5	11855	13217	10427	7389	10250	31388	
Productivity tonne/ha **	3.5	3.5	18	10	15	19	1.5	5	
Area/ha***	45714	74285	12222	22500	16667	9789	14867	28400	224444
WU m3/tonne	2126	1442	659	1322	695	389	6833	6277	
Eff.Rain m3/ha	860	820	100	170	450	220	810	630	
Eff.R m3/t	246	234	6	17	30	12	540	126	
Blue water Use m3/tonne	1880	1208	653	1305	665	377	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	13047	9977	7169	9440	30758	
Blue W.F m3	300912405	314039837.5	143669610	293557500	166286659	70177341	140344480	873527200	2302515033
Green W.F m3	39314040	60913700	1222200	3825000	7500150	2153580	12042270	17892000	144862940
Total W.F m3	340226445	374953537.5	144891810	297382500	173786809	72330921	152386750	891419200	2447377973

				Blue	W.F					
		Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
2001	Blue W.F m3	92155000	277805935	104490195	281815200	111742400	50183000	163623520	633614800	1715430050
2002	Blue W.F m3	101561392.5	317667032.5	124085780	391410000	115064741	89046149	173696000	639766400	1952297495
2003	Blue W.F m3	86513797.5	211375000	118196525	391410000	123046341	85275255	166767040	676676000	1859259959
2004	Blue W.F m3	114726392.5	159435935	135182500	313128000	113069341	79238957	144743520	688979200	1748503846
2005	Blue W.F m3	90272405	282637967.5	128646720	279205800	199540000	94329702	157336480	725888800	1957857875
2006	Blue W.F m3	195592405	289883902.5	104490195	284424600	196207682	85648043	151040000	750495200	2057782028
2007	Blue W.F m3	180551392.5	294715935	138438635	326175000	176253682	68671851	138447040	799708000	2122961536
2008	Blue W.F m3	293388607.5	265727967.5	138438635	313128000	156309659	68671851	154183520	830466000	2220314240
2009	Blue W.F m3	300912405	314039837.5	143669610	293557500	166286659	70177341	140344480	873527200	2302515033
Total		1455673798	2413289513	1135638795	2874254100	1357520505	691242149	1390181600	6619121600	17936922059
				Green	**W.F**					
2001	Green W.F m3	12040000	53885480	888900	3672000	5040000	1540000	14039730	12978000	104084110
2002	Green W.F m3	13268940	61617260	1055600	5100000	5189850	2732620	14904000	13104000	116972270
2003	Green W.F m3	11302980	41000000	1005500	5100000	5549850	2616900	14309460	13860000	94744690
2004	Green W.F m3	14988940	30925480	1150000	4080000	5099850	2431660	12419730	14112000	85207660
2005	Green W.F m3	11794040	54822740	1094400	3638000	9000000	2894760	13500270	14868000	111612210
2006	Green W.F m3	25554040	56228220	888900	3706000	8849700	2628340	12960000	15372000	126187200
2007	Green W.F m3	23588940	57165480	1177700	4250000	7949700	2107380	11879460	16380000	124498660
2008	Green W.F m3	38331060	51542740	1177700	4080000	7050150	2107380	13229730	17010000	134528760
2009	Green W.F m3	39314040	60913700	1222200	3825000	7500150	2153580	12042270	17892000	144862940
Total		190182980	468101100	9660900	37451000	61229250	21212620	119284650	135576000	1042698500
					Total W.F m3					
2001	Total W.F m3	104195000	331691415	105379095	285487200	116782400	51723000	177663250	646592800	1819514160
2002	Total W.F m3	114830332.5	379284292.5	125141380	396510000	120254591	91778769	188600000	652870400	2069269765
2003	Total W.F m3	97816777.5	252375000	119202025	396510000	128596191	87892155	181076500	690536000	1954004649
2004	Total W.F m3	129715332.5	190361415	136332500	317208000	118169191	81670617	157163250	703091200	1833711506
2005	Total W.F m3	102066445	337460707.5	129741120	282843800	208540000	97224462	170836750	740756800	2069470085
2006	Total W.F m3	221146445	346112122.5	105379095	288130600	205057382	88276383	164000000	765867200	2183969228
2007	Total W.F m3	204140332.5	351881415	139616335	330425000	184203382	70779231	150326500	816088000	2247460196
2008	Total W.F m3	331719667.5	317270707.5	139616335	317208000	163359809	70779231	167413250	847476000	2354843000
2009	Total W.F m3	340226445	374953537.5	144891810	297382500	173786809	72330921	152386750	891419200	2447377973
Total		1645856778	2881390613	1145299695	2911705100	1418749755	712454769	1509466250	6754697600	18979620559

	Wheat	**Barley**	**Tomato**	**Water melon**	**Potato**	**Onion**	**Olive Oil**	**Dates**	**Total**
Blue W.F m3	1455673798	2413289513	1135638795	2874254100	1357520505	691242149	1390181600	6619121600	17936922059
Green W.F m3	190182980	468101100	9660900	37451000	61229250	21212620	119284650	135576000	1042698500
Total W.F m3	1645856778	2881390613	1145299695	2911705100	1418749755	712454769	1509466250	6754697600	**18979620559**

Appendix 6 External water footprint

			External	water	footprint					
				2001						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1259482	282497	36679	92425	150080	23292	120348	17065	824	1982692
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	359852	80713	2038	13204	62533	1226	699698	54773	165	1274202
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2367826160	341256376	23951387	133646550	750174880	8781084	8396318916	107390045	5068424	12134413822
Green W.F m3	309832572	66104298	220074	0	240128	279504	0	9215100	103824	385995500
Total W.F m3	2677658732	407360674	24171461	133646550	750415008	9060588	8396318916	116605145	5172248	12520409322
				2002						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1542020	251340	65870	100031	302411	10694	86048	21870	995	2381279
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	440577	71811	3659	14290	126005	563	500279	70196	199	1227579
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2900098103	303581002.5	43011545	144643380	1511555980	4036147	6003348000	662650240	6120842	11579045239
Green W.F m3	378896220	58885020	365900	0	504020	123860	0	56858760	125370	495759150
Total W.F m3	3278994323	362466022.5	43377445	144643380	1512060000	4160007	6003348000	719509000	6246212	12074804389
				2003						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	998765	90550	10635	112820	141684	9245	99394	458	201	1463752
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	285361	25871	591	16117	59035	487	577872	1457	40	966831
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	1878388783	109369652.5	6947205	163136274	708183860	3491303	6934464000	13754080	1230320	9818965477
Green W.F m3	245410460	21214220	59100	0	236140	107140	0	1180170	25200	268232430
Total W.F m3	2123799243	130583872.5	7006305	163136274	708420000	3598443	6934464000	14934250	1255520	10087197907
				2004						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1653491	210078	45531	94849	295356	5487	65830	54	92	2370768
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	472426	60022	2530	13550	123065	289	382733	173	18	1054806
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	3109744145	253743005	29740150	137153100	1476287740	2071841	4592796000	1633120	553644	9603722745
Green W.F m3	406286360	49218040	253000	0	492260	63580	0	140130	11340	456464710
Total W.F m3	3516030505	302961045	29993150	137153100	1476780000	2135421	4592796000	1773250	564984	10060187455
				2005						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1556254	135016	12825	45771	460288	6794	91742	20	37	2308747
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	444644	38576	713	6539	191787	358	533384	64	7	1216072
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2926869130	163080040	8381315	66187758	2300676852	2566502	6400608000	604160	215306	11869189063
Green W.F m3	382393840	31632320	71300	0	767148	78760	0	51840	4410	414999618
Total W.F m3	3309262970	194712360	8452615	66187758	2301444000	2645262	6400608000	656000	219716	12284188681
				2006						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1329809	165224	29842	100917	386421	12568	15203	110	50	2040144
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	379945	47208	1658	14417	161009	661	88389	353	10	693650
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2500987963	199571820	19489790	145928874	1931463964	4738709	1060668000	3332320	307580	5866489020
Green W.F m3	326752700	38710560	165800	0	644036	145420	0	285930	6300	366710746
Total W.F m3	2827740663	238282380	19655590	145928874	1932108000	4884129	1060668000	3618250	313880	6233199766
				2007						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1297109	55740	17790	130112	301589	7103	79187	35	651	1889316
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	370602	1591	988	18587	125662	374	460389	112	130	978435
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2439487665	6725952.5	11613940	188137614	1507441352	2681206	5524668000	1057280	3998540	9685811550
Green W.F m3	318717720	1304620	98800	0	502648	82280	0	90720	81900	320878688
Total W.F m3	2758205385	8030572.5	11712740	188137614	1507944000	2763486	5524668000	1148000	4080440	10006690238
				2008						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1706063	100731	46780	33167	359706	10430	41045	30	1207	2299159
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	487447	28780	2599	4738	149878	549	238634	96	241	912962
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	3208619878	121667450	30551245	47958036	1797936488	3935781	2863608000	906240	7412678	8082595796
Green W.F m3	419204420	23599600	259900	0	599512	120780	0	77760	151830	444013802
Total W.F m3	3627824298	145267050	30811145	47958036	1798536000	4056561	2863608000	984000	7564508	8526609598
				2009						
	Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
quantity imported	1513152	198362	42730	74060	295642	13970	58103	62	782	2196863
Average WR m3/ha *	7442.5	5047.5	11855	10122	12000	7391	12000	10250	31385	
Productivity tonne/ha **	3.5	3.5	18	7	2.4	19	0.172	1.5	5	
Area required/ha	432329	56674	2374	10580	123184	735	337808	199	156	964039
WU m3/tonne	2126	1442	659	1446	5000	389	69767	6833	6277	
Eff.R m3/t	246	234	6	0	1.6	12	0	540	126	
Blue water Use m3/tonne	1880	1208	653	1446	4998.5	377	69767	6293	6151	
Blue WU m3/ha	6582.5	4227.5	11755	10122	11996	7169	12000	9440	30758	
Eff.R m/ha	860	820	100	0	4	220	0	810	630	
Blue W.F m3	2845805643	239589335	27906370	107090760	1477715264	5269215	4053696000	1878560	4798248	8763749395
Green W.F m3	371802940	46472680	237400	0	492736	161700	0	161190	98280	419426926
Total W.F m3	3217608583	286062015	28143770	107090760	1478208000	5430915	4053696000	2039750	4896528	9183176321

				Blue	W.F						
		Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
2001	Blue W.F m3	2367826160	341256376	23951387	133646550	750174880	8781084	8396318916	107390045	5068424	12134413822
2002	Blue W.F m3	2900098103	303581002.5	43011545	144643380	1511555980	4036147	6003348000	662650240	6120842	11579045239
2003	Blue W.F m3	1878388783	109369652.5	6947205	163136274	708183860	3491303	6934464000	13754080	1230320	9818965477
2004	Blue W.F m3	3109744145	253743005	29740150	137153100	1476287740	2071841	4592796000	1633120	553644	9603722745
2005	Blue W.F m3	2926869130	163080040	8381315	66187758	2300676852	2566502	6400608000	604160	215306	11869189063
2006	Blue W.F m3	2500987963	199571820	19489790	145928874	1931463964	4738709	1060668000	3332320	307580	5866489020
2007	Blue W.F m3	2439487665	6725952.5	11613940	188137614	1507441352	2681206	5524668000	1057280	3998540	9685811550
2008	Blue W.F m3	3208619878	121667450	30551245	47958036	1797936488	3935781	2863608000	906240	7412678	8082595796
2009	Blue W.F m3	2845805643	239589335	27906370	107090760	1477715264	5269215	4053696000	1878560	4798248	8763749395
Total		24177827468	1738584634	201592947	1133882346	13461436380	37571788	45830174916	793206045	29705582	87403982105

				Green	W.F						
		Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
2001	Green W.F m3	309832572	66104298	220074	0	240128	279504	0	9215100	103824	385995500
2002	Green W.F m3	378896220	58885020	365900	0	504020	123860	0	56858760	125370	495759150
2003	Green W.F m3	245410460	21214220	59100	0	236140	107140	0	1180170	25200	268232430
2004	Green W.F m3	406286360	49218040	253000	0	492260	63580	0	140130	11340	456464710
2005	Green W.F m3	382393840	31632320	71300	0	767148	78760	0	51840	4410	414999618
2006	Green W.F m3	326752700	38710560	165800	0	644036	145420	0	285930	6300	366710746
2007	Green W.F m3	318717720	1304620	98800	0	502648	82280	0	90720	81900	320878688
2008	Green W.F m3	419204420	23599600	259900	0	599512	120780	0	77760	151830	444013802
2009	Green W.F m3	371802940	46472680	237400	0	492736	161700	0	161190	98280	419426926
Total		3159297232	337141358	1731274	0	4478628	1163024	0	68061600	608454	3572481570

				Total	W.F						
2001	Total W.F m3	2677658732	407360674	24171461	133646550	750415008	9060588	8396318916	116605145	5172248	12520409322
2002	Total W.F m3	3278994323	362466022.5	43377445	144643380	1512060000	4160007	6003348000	719509000	6246212	12074804389
2003	Total W.F m3	2123799243	130583872.5	7006305	163136274	708420000	3598443	6934464000	14934250	1255520	10087197907
2004	Total W.F m3	3516030505	302961045	29993150	137153100	1476780000	2135421	4592796000	1773250	564984	10060187455
2005	Total W.F m3	3309262970	194712360	8452615	66187758	2301444000	2645262	6400608000	656000	219716	12284188681
2006	Total W.F m3	2827740663	238282380	19655590	145928874	1932108000	4884129	1060668000	3618250	313880	6233199766
2007	Total W.F m3	2758205385	8030572.5	11712740	188137614	1507944000	2763486	5524668000	1148000	4080440	10006690238
2008	Total W.F m3	3627824298	145267050	30811145	47958036	1798536000	4056561	2863608000	984000	7564508	8526609598
2009	Total W.F m3	3217608583	286062015	28143770	107090760	1478208000	5430915	4053696000	2039750	4896528	9183176321
Total		27337124700	2075725992	203324221	1133882346	13465915008	38734812	45830174916	861267645	30314036	90976463675

				Total	W.F						
		Wheat	Barley	Tomato	Rice	Maize	Onion	Corn oil	Olive oil	Date	total
Total	**Blue W.F m3**	**24177827468**	**1738584634**	**201592947**	**1133882346**	**13461436380**	**37571788**	**45830174916**	**793206045**	**29705582**	**87403982105**
Total	**Green W.F m3**	**3159297232**	**337141358**	**1731274**	**0**	**4478628**	**1163024**	**0**	**68061600**	**608454**	**3572481570**
Total	**Total W.F m3**	**27337124700**	**2075725992**	**203324221**	**1133882346**	**13465915008**	**38734812**	**45830174916**	**861267645**	**30314036**	**90976463675**

Appendix 7 Sample of Interview Questions

Q1- What and how do you see the challenges that face the water management in Libya?

Q2. What are the main ground water aquifers?

Q3. Dose the pollution happens in the surface aquifers or in all others?

Q4. Do you have strategies to deal with these challenges? Yes certainly. What are they?

Q5. According to your personal point view, are all of these steps taken place on the ground?

Q5. How do you see the effectiveness of water regulation in terms of its ability to reduce water depletion?

Q6. What are measures taken to reduce water depletion in general and in the affected zones in particular?

Q7. How do you estimate water demand for the future?

Q8-As you have pointed out above that water resources are limited, is there any alternative sources to compensate for these limitations?

Q9- What about using power plants in agricultural sector?

Q10- Have you already had plans and strategies to utilize the water of GMMR in the right ways and to avoid the previous problems that led to depletion of groundwater in the North?

Q11- What about using water pricing mechanism?

Q12- What about the method inject reservoir by rain water?

Q13- As a General Water Authority is responsible for water resources management, are you familiar with the concept of water footprint?

Q14- Do you want to add any comments?

Appendix 8 sample of interviews

The first interview

Mr. XXXXXXXX

30 years experience, General Water Authority

Q1- In fact there is several challenges are facing the water management in Libya that can be summarized in the following:

Limitation of local water resources, digging wells without licence and non-compliance with specifications approved by the GWA, and digging wells in the water restricted area. These points are coincided with the fluctuation in precipitation and growing crops with high water requirements such as Alfalfa, Water melon… which led to increase the pressure on the ground water aquifers. As a result of those, a serious problem which is known as "the sea water intrusion" has been addressed in the costal areas that represent a high density of population and intensively agricultural activities.

Q2. What are the main ground water aquifers?

Well, there are four main aquifers as; Sandstone, Nubian, surface aquifer in the costal area, and the second aquifers that is called Kikla aquifer.

Q. Dose the pollution happens in the surface aquifers or in all others?

Actually, most of pollution has been addressed in the surface aquifers. Why? As I said, it is as a result of overexploitation from this aquifers and fluctuation of rainfall rate which means lack of compensation in the last thirty years and the deepness of surface aquifers which about15- 60m in depth. That has led to sea water intrusion as a source of pollution and also the Septic Tanks (black wells) as another source of pollution to the ground water.

Q. Do you have strategies to deal wit these challenges? Yes certainly. What are they?

There are practical steps have been taken to deal with these challenges such as:

- ban digging wells without license with consideration of specification and instructions approved by GWA,
- Recentralisation of supervision on groundwater aquifers and issuing licenses for digging wells have to be approved from GWA,
- intensify the control and monitoring on the affected and restricted zones to observe the groundwater level in these areas.

Q. According to your personal point view, are all of these steps taken place on the ground?

In fact, to be honest, I can say that it is in place by only 40-50%. What is the reason behind that? I think the first reason is the complicity of executive authorities due to power of social cohesion and some private business between some employees of executive authorities and offenders. In overall, I can say that although there is some reduction in digging wells the last few years, the social cohesions is the main reason behind the lack of implementation of regulation related water management more control and monitor are still needed.

Q. How do you see the effectiveness of water regulation in terms of its ability to reduce water depletion?

Actually, I can say in theory the laws and regulations of water are valid and sufficient to reduce water degradation if they are correctly implemented but the problem is they are not completely implemented on the ground.

Q. What are measures taken to reduce water depletion in general and in the affected zones in particular?

In the past, we had a plan - I think it was very effective- to fix water meters on the water wells to record accurate meter readings of water actually withdrawn. However, although these meters had fixed in some areas, the plan failed due to unresponsiveness of farmers and they disable these meters. The farmers believed that they would pay fees for water use. Did you prosecute them? Unfortunately, not and turn blind eye about them. The another point I would to mention to is those meters were fixed only on the licensed wells which- although the effectiveness of this plan- will not reflect actual water withdrawn due to there are many unlicensed wells.

Q. How do you estimate water demand for the future?

As it is well known, water demand is estimated by calculating the water withdrawn for last several years (could be 3-5yr) with consideration of population size and population rate by using fixed and known equations in the field of water science. Do you mean water demand is estimated related to production perspective? Yeas exactly

Q-As you have pointed out above that water resources are limited, is there any alternative sources to compensate for these limitations?

In fact, the last attempt was transfer a huge amount of ground water from Nubian aquifer in the south to survive life in the North through the pipeline through the desert. This project -as indicated studies- will be enough for 50 years from the start of exploitation. However, this step can actually not be considered as alternative resource but reallocate to the groundwater in the area.

Q- What about using power plants in agricultural sector?

To some extent right now, it is very limited and confined for drinking water only but using seawater in agricultural purpose to the extent is considered very costly and expensive. In the future, it could be used when the nuclear energy is available and not costly.

Q- Have you already had plans and strategies to utilize the water of GMMR in the right ways and to avoid the previous problems that led to depletion of groundwater in the North?

It can be said that there a good plans and programmes for how to exploit and manage this water according to the scientific standard. However, I am still saying if these plans are implemented correctly. Right now, the farms are planned well and there is a control to plant types of crop hat less water requirements and using a suitable irrigation system.

Q- What about using water pricing mechanism?

This mechanism is already applied in different countries and it, from my viewpoint, it is effective way to protect water resources but in Libya it is still not applied yet. Why?

As I see, the authority is not quit serious to apply this mechanism and the farmers do not accept this now due to several reason such as they still believe that water is endowments from God so, it is not acceptable to be charged and would not drained. Therefore, this mechanism would not be applied unless intensive programme to raise the public awareness about the importance of saving water resources.

Q- What about the method inject reservoir by rain water?

Actually, this method was used in last years by inject rainwater from lake of dams such as Kaam dam and gave a good results and visible but the problem was the silt and sand were deposited and close the filters which hampers water flow to the reservoir. These injection wells need to be maintained yearly and get rid of silt but this never happen due to financial reasons which led to block this wells and became ineffective to feed aquifers and the a huge amount of water are evaporated. For example, Lake of Kaam annually receives 60-100 million m^3 of rain water which if it is fed to the reservoir, it will work to reduce the salty of seawater intrusion and improve the quality of groundwater.

Q- As a General Water Authority is responsible for water resources management, are you familiar with the concept of water footprint?

I personally, did not hear anything of it, so I can not tell you anything about this matter.

Q- Do you want to add any comments?

NO, thanks and best wishes

Second interview

Mr. XXXXXXXXX

Administration of planning following up in the General Environmental Authority- 20 years experience

Q- What is the role of this institution related to protect water resources?

If I talk about water resources in Libya, I can generally say they are limited but this institution is not responsible for these resources in terms of quantity. This institution is responsible for water resources in terms of water quality and to develop plans to deal with pollution problems of both surface and ground water and rationalize people to save water and push up the government to re-use wastewater for agricultural purposes and irrigation of parks and green spaces.

Q- Do you have periodic surveys for monitoring and controlling resources of pollution?

To be honest, for the groundwater we did not do these surveys in particular, but whenever there is contamination problem either by leak oil from pipelines or seawater intrusion or from septic tanks (black wells) which represents the main source of pollution to ground water aquifer biggest problem, the institution immediately send technical team to study this issue and determine the kind and source of pollution. In general, our periodic studies are usually undertaken at the mouths of drainage to identify contamination areas.

Q- Are you conducting survey studies about the quality of water resources?

As I have just mentioned before that this issue is responsibility of GWA. I mean in terms of water of pollution? Oh, unfortunately no, in this issue, our action is just taken when the pollution problem is reported then our technical team starts off to study this problem to determine the sources and kind of pollution and recommend the solutions to this issue. In this point, I would like to mention that the role of this institution is not executive authority but it is a technical advisory. So, our role is report the problem, assess and suggest the solution to deal with this problem.

Q- According to your experience, what are the main sources of pollution that threat quality of water resources?

It is known, in general, pollution is caused by human activities, for example, contamination of sea water at the beaches area, leakage of oil pipelines at the coastal area and seawater intrusion which is resulted from over-extraction quarries of white brick in great depths (up to 30m in depth). These quarries work as a filter or barrier prevents flowing seawater forward groundwater aquifers. As well as, the fluctuation of runoff as a result of lack of rainfall in the last 3 decades coinciding with expanding in irrigated agricultural which increase the pressure on the groundwater aquifers.

Q-Is there an environmental map including the quality of water resources?

Right now, there is no map in this format exactly. Have you started of the work on it? Actually, we have started of the work on the project wider than this of which is to map pollutants over the county that identify all pollutants sources of natural resources including water resources.

Q-How do see the coordination between you and the other institutions related to the subject of water?

Of course, there is positive the co-operation and co-operation between us and other related institutions such as GWA and Agricultural Ministry. For example, in 2006 we established a conference in co-operation with GWA; I saw a success and valuable papers were presented in. This event showed to the extent the cooperation and coordination is and a close relation between these institutions. So, we as an institution, have not any difficulties in the mutual technical cooperation.

Q- What are your current and future plans to manage the degradation of water resources quality?

We, as the institution, deal with the pollution issues according to the source of pollution either comes from the seawater or agriculture and so on…etc. what I want to say is, any plan will not be active and implemented unless directly involvement and under supervision the executive authority. For example, the problem of septic Tanks (black wells) in costal area would not be resolved without sound infrastructure and sewer system to accommodate all these septic Tanks. Did you addressed the General People`s

Committee of Facilities and report them all these issues? Yes, of course, we did but you know the development of infrastructure program is going on so we hope most of these issues will be sorted out. The other point I would like to mention to is most of the sewage treatment plants on the costal area which are about 12 plants) are out of work.

Q-What obstacles do you face in achieving your plan and policies to protect the quality of water resources?

Here, I would say that this institution is a technical advisory but the most important obstacles that we face are weakness of public awareness about environmental issues and the extent of seriousness of these issues right now and in the future and also lack of public co-operation with the executive bodies to deal with these issues. In my point view, any environmental problem can not be resolved with out positive cooperation from public. It is true that the executive bodies may face some financial and legal obstacles, this institution it self need financial support for developing its strategies training its technical staff which necessary to achieve its role. By the way, how the technical capacities of technical staff are? In all sincerity, they need more training and need to be updated.

Q-Are the current laws and regulation concerned with protection of water resources effective?

I see they are enough but the most problem is they are not proper implemented. Why? It is because of several reasons such as social and cultural reasons and weakness of enforcement system.

Q-Do you have specific department in this authority responsible for observing and monitoring water resources? Do you have the required manpower resources to monitor water resources?

Actually, we have a unit for groundwater belong the department of monitoring of water pollutants. Here I would like to mention to the most important environmental issues are affecting groundwater is Septic Tanks in the costal area in particular. Why in the costal area in particular? Because the ground water aquifer in the costal area is shallow it is about 20-50m in depth whereas in it is about 120m in depth in inside regions. This does not mean that no problem in inside region but it takes time to be addressed. Have you addressed certain standards for Septic Tanks? Yes, they are existed since the seventies in terms of leakage and depth. Do you think they are in the place on the ground and there is following up to? Of course not, because if these standards were implemented, these problems may not be addressed.

Q-What is the role played by the General Environment Authority to raise the public awareness about the importance of water resources and how to protect these resources?

Yes we established environmental leaflets and booklets in general and about gory water and rationalize water consumption in particular. In fact these establishments have targeted the Youth. We conducted a survey to illustrate the extent of wasteful of water between using water by children directly from tap or using a cup of water for brush their teeth. This survey found out that the percentage was amazing it was 1:15 liter which has significant impact on the ground water.

Water expert at the Libyan universities

Dr. XXXXXX

Independent Water expert XXXXXXX

Q1 Through your attention to the issue of water in Libya, how do you see the situation of water resources in Libya?

Well, as it is known, Libya is classified as arid area and limited renew able water resources either surface water or groundwater. This situation of water resources in Libya has aggravated since late of sixteenths of last concur through a huge expansion in irrigated farming for purpose of achieving food self-sufficing as a step of full independent. This trend has led to several problem affecting ground water resources in both quality and quantity.

Therefore, it can be said, that water resources in Libya are exhausted in many parts of country. Only resource that still usable is situated in the Southern of Libya which is now started to exploit it by transferring this water to the North.

Q2Are the current policies effective for best utilization of water resources? Are these policies adequate for best utilization of water resources for the future?

As I have mentioned above, this situation is as a result of deficit in water resource management system that lacks major basic inputs to be included in planning, management and pollution control. The main issue is that water management could not sustain itself in a free market of cost benefit analysis.

This, clear, means ineffective the current water policy and is not adequate for ensuring best utilization of water. They lacked the monitoring system for seasonal evaluation and consequently attacked by salts and pollutants. The high demand on water for agriculture, industry and domestic use calls for Libya to look for other options of water resources from sea using solar energy or oil.

Q3 what is your assessment of the performance of institutions in charge of supervising water resources?

You sure mean the staff of these institutions, if it is, it can be simply said that the performance of water institutions is poor because the situation of water resources is as a result of inefficiency of this institutions. This due to inefficient water workers managers and they are improperly trained and licensed

Q4 Do you have any comments on the agricultural policy in relation to water utilization?

What can be said here is similar as what has already said above regarding water policies. Agricultural policies and water policies are is much related and affects each other in general and particularly when the agricultural sector is responsible for consuming the large share of water. Therefore, it can be said that the current situation of water resources is resulted from the improper agricultural policies which have largely contributed to deteriorating water resources.

Q5 How do you see the public awareness programs carried out by water and agriculture institutions for the best water use and conservation?

In this context, I can say that there is no effective program to in order to raise the public awareness about water issues and how to maintain them and that to this situation, it turned out water resources in Libya, as if there is enough public awareness of what came of water resources to these situation it now. Unguided agricultural practices such as growing intensive water crops are the good example for absence of public awareness. To be honest, even the book leaflets that have been established and small portion of media that have been used, they were formulated a mostly in political language which made them undesirable.

Q6 How do you see the present legislation and regulation related to preservation of water resources and their effectiveness?

Of course, they are not effective enough. It is approved by the water resources situation. Although the current water legislation and regulation seem largely helpful for protecting these resources, but lack of proper implementation of these regulations. This is the main point where it is lacking water resource management. The reasons behind this, as I see, can be summarized in; instability administrative of water institutions, overlapping their power with other institutions, lack of trained and licensed water works managers

Q7 As research institutions you have made several recommendations to the government on the best use of water resources? To what extent has the government accepted and implemented these recommendations?

To be honest, although several researches are conducted in different research institutions such as universities, these researches are rarely considered by local authorities and decision makers. For example, several researches have recommended for banding planting intensive water requirement particularly in restricted area which is already affected by deterioration of ground water.

Water expert at the Libyan universities

Dr. XXXX

Independent Water experts

Q1 Through your attention to the issue of water in Libya. How do you see the situation of water resources in Libya?

From my long experience in the field of water and agricultural overall, I can say that as it is known Libya is classified as arid area with very limited renew able water resources either surface water or groundwater which is as a result of the shortage in precipitation. The water resources in Libya have been put under heavy pressure to compensate shortage of rainfall and to meet the increasing water demand in the last four decades. In this period, there was a huge expansion in irrigated farming for attempting to achieve food self-sufficiency to satisfy the ambition of political and revolutionary that prevailed at the beginning of the seventies and eighties to achieve full independence. This trend has led to several negative impacts on the water resources in terms of quality and quantity.

Therefore, it can be said, that only the groundwater in the southern region is still usable for drinking and agricultural activities which has already started in use since fishing the first stage of the Great Man Made River which transfers a huge amount of water from the Southern region to the North through the desert.

Q2 Are the current policies effective for best utilization of water resources? Are these policies adequate for best utilization of water resources for the future?

Let me say that this situation of water resources is because of two main reasons, first is physical or natural reason and the second is miss- management of water resources. For example, the lack of good practices in agricultural sector, and uncontrolled in irrigated agricultural farming led to increase the water consumption. All of these issues have led to increase water demand particularly with the lack of adaptation effective ways to alleviate the pressure on the water resources such as virtual water trade.

From this point I can say that the current polices of water management needs to be developed in terms of adopting a modern system in water management with reviewing the water practices that are still practicing. As well as the most important thing is ensuring the good implementation for this polices with the strong enforcement of water law. I can say that the current water management is basically not bad but needs to be developed and find out a mechanism for implementation of this policy. Therefore, I call for all the institutions of water to consider this points and looking for other available alternative water resources from the sea using solar energy.

Q3 What is your assessment of the performance of institutions in charge of supervising water resources?

Om, the institutions them self are Ok but they are still need some development in terms of two main things, first is stability in this institutions and their branches over all Libya . What do you mean by stability? I mean administrative stability, where as the administrative stability in terms of the subordination of these institutions sometimes to the Ministry of Agriculture, sometimes to an independent body of water and at other times to an administrative division. The second is the staff of these institutions is not updated and they are inefficient people who are in charge as managers or specialists are not trained properly. So, for these reasons, the performance of these institutions was weak.

Q4 Do you have any comments on the agricultural policy in relation to water utilization?

In fact, the agricultural policies (In theory) are going towards saving and protecting water in terms of, for example, determining planted crops and irrigation time, using high efficiency of irrigation system and …etc. However, the implementation of these policies on the ground is very weak as we can see that most of the planted crops are rich-water crops such as Alfalfa and water melon and there is no control of the time of irrigation. Many of farmers irrigate their crops ate any time regardless the peak of day particularly in the summer season whereas the temperature up to 40 degrees. Therefore, it can be said that there is no harmony between the agricultural policies and the available water resources in practice which has led to sever shortage in water resources in terms of quality and quantity.

Q5 How do you see the public awareness programs carried out by water and agriculture institutions for the best water use and conservation?

In this respect , I believe that people assume they're familiar enough with respect to water because our religion strongly urges against the excessive and wasteful use of water, but nonetheless this should not, in my view, leave people, especially farmers, without awareness programs and the rationalization of how the exploitation of limited water resources. This is what we did not touch and see on the ground. Water institutions that responsible for the management of water and the Ministry of Agriculture, which is supervisor of agricultural operations should be responsible for achieving effective awareness programs to raise the public awareness. There are a limited attempts from these institutions to establish some Newsletters (Periodicals) to show farmers the kinds of crops suitable for semi-arid environment (our environment), the best methods for irrigation for these crops and irrigation time to reduce losing water by evaporation.

Q6 How do you see the present legislation and regulation related to preservation of water resources and their effectiveness to protect these resources?

I can say that the current legislation of water is acceptable whit some need for developing to be more practical. What do you exactly mean by practical? Do you mean in terms of a real implementation? Yah, exactly, I mean this legislation is not implemented seriously on the ground. So, if you have an exploratory tour in the countryside you will see many violations of the law practiced by farmers in front of eyes and ears of regulators without taking any action about it. For instance, you can see you will see many of farmers are irrigating their crops at the mid day in the summer although the legislation prevents this but no body care about. What the reason behind this as you think? Well, I think there are several reasons behind this whereas the main points are; lacking of seriousness of the state institutions themselves in implementing of these legislation, the social factor that hinders to a large extent the right implementation of these regulations and also do not forget the obvious deficiencies in the public awareness and rationalization program of farmers. Moreover, the administrative instability of water institution and other institutions related and overlapping the power with other institutions.

Q7 As research institutions you have made several recommendations to the government on the best use of water resources? To what extent has the government accepted and implemented these recommendations?

Yah, there many studies have been conducted in this field and made several recommendations for reducing water utilization and best practices in agricultural activities. However, Most of these recommendations are rarely considered by local authorities and decision makers. For example, determining planted crops related to the water consumption not just for economic returns particularly in restricted area which is already affected by deterioration of ground water.

Water expert at the Libyan universities

Dr. xxx

Independent Water experts

Q1Through your attention to the issue of water in Libya. How do you see the situation of water resources in Libya?

I believe that water situation in Libya today is getting worse than many years ago. That because the lack of cultural awareness about the current reality of the situation of water resources and also because of the careless of people and local institutions to implement the legislation to regulate water use in the country.

Q2 Are the current policies effective for best utilization of water resources? Are these policies adequate for best utilization of water resources for the future?

I do not see any obligation with the policies of utilization of water resources. I also do not think policy of water utilization is going forward with the limitation of water resources in this country. For example, planting high water-crops such as water melon, Alfalfa, and Tomato which need a high amount of water in the production stage where as they require respectively about 23330m^{3,} 47320m^3 and 21650m^3 during the production stages. Another mistake that made by agricultural Ministry is trying to produce bananas internally whereas it is known that bananas are one of the tropical fruit with rich- water requirement. In this case, I believe that the water resources are getting exhausted. Therefore, it can be said that al water polices need to be reviewed, revised and reformulated to meet the water limitation of resources which mean exactly look forward for sustainable use of water resources.

Q3What is your assessment of the performance of institutions in charge of supervising water resources?

Supervising water resources in the country is so weak. In terms of what? Om, I mean in terms of implementation of water legislation for the same reasons that I mentioned early. So, I think the institutions related need to be committed with the water legislation of utilization.

Q4 Do you have any comments on the agricultural policy in relation to water utilization?

Yeas, I have I have some, I think they should consider that Libya is very limited water resources with the arid and semi-arid conditions. Therefore, the water institutions and all others related to this issue have to take serious steps to protect the current water resources and establish practical polices for sustainable water use particularly in the agricultural sector since it is responsible for up to 85% of water consumption in the country. For instance, selecting carefully what we should plant and what kind of irrigation system should be used for this purpose.

Q5How do you see the public awareness programs carried out by water and agriculture institutions for the best water use and conservation?

I think public awareness is still insufficient and I think the institution should keep contact with the public to develop and increase the awareness. This needs many institutions should be involved in this program. These institutions, for example, local social institutions and institutions of education relation institutions such as Mosques have important role to raise a public awareness for sustainable water use.

Q6 How do you see the present legislation and regulation related to preservation of water resources and their effectiveness to protect these resources?

The current legislation and regulation need to be developed with consideration of the current situation of water in Libya. This, I think needs to rebuilt the legislation which can preserve our water resources for future life. The other thing is to establish special authority or organization to be responsible for implementation all laws and regulations governing water use and to investigate any breaches.

Q7 As research institutions you have made several recommendations to the government on the best use of water resources? To what extent has the government accepted and implemented these recommendations?

Yeas, in our institution we have conducted several studies related agriculture practices and water use and of course there are some recommendation. However, just small part of these recommendations was considered by the government.

Appendix 9: Sample of Transcribed Interview (Independent Water expert at the **Libyan)**

Q1. Through your attention to the issue of water in Libya, how do you see the situation of water resources in Libya?

Interviewee A

Well, as it is known, Libya is classified as arid area and limited renewable water resources either surface water or groundwater. This situation of water resources in Libya is poor and has aggravated since late of sixteenths of last concur through a huge expansion in irrigated farming for purpose of achieving food self-sufficing as a step of full independent. This trend has led to several problem affecting ground water resources in both quality and quantity.

Therefore, it can be said, that water resources in Libya are exhausted in many parts of country. Only resource that still usable is situated in the Southern of Libya which is now started to exploit it by transferring this water to the North.

Interviewee B

From my long experience in the field of water and agricultural overall, I can say that as it is known Libya is classified as arid area with very limited renewable water resources either surface water or groundwater which is as a result of the shortage in precipitation. The water resources in Libya have been put under heavy pressure to compensate shortage of rainfall and to meet the increasing water demand in the last four decades. In this period, there was a huge expansion in irrigated farming for attempting to achieve food self-sufficiency to satisfy the ambition of political and revolutionary that prevailed at the beginning of the seventies and eighties to achieve full independence. This trend has led to several negative impacts on the water resources in terms of quality and quantity.

Therefore, it can be said, that only the groundwater in the southern region is still usable for drinking and agricultural activities which has already started in use since fishing the first stage of the Great Man-Made River which transfers a huge amount of water from the Southern region to the North through the desert.

Interviewee C

I believe that water situation in Libya today is getting worse than many years ago. That because the lack of cultural awareness about the current reality of the situation of water resources and also because of the careless of people and local institutions to implement the legislation to regulate water use in the country.

Q2. Are the current policies effective for the best utilization of water resources? Are these policies adequate for best utilization of water resources for the future?

Interviewee A

As I have mentioned above, this situation is as a result of deficit in water resource management system that lacks major basic inputs to be included in planning, management and pollution control. The main issue is that water management could not sustain itself in a free market of cost benefit analysis.

This, clear, means ineffective the current water policy and is not adequate for ensuring best utilization of water. They lacked the monitoring system for seasonal evaluation and consequently attacked by salts and pollutants. The high demand on water for agriculture, industry and domestic use calls for Libya to look for other options of water resources from sea using solar energy or oil.

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Interviewee C

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Interviewee CYes, in our institution we have conducted several studies related agriculture practices and water use and of course there are some recommendations. However, just small part of these recommendations was considered by the government.