An-Najah National University
Faculty of Graduate Studies

Developing a Model for Assessing the Impact of Regional Virtual Water Trade and Water Footprints on the Water Conflicts in the Middle East: JRB as Case Study

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Dedication

To Fadia Daibes spirit

To my parents and my family

To my husband's family

To my husband, Hamza

To my son, Mohammad and to my daughter, Eleen

Acknowledgment

I would like to express my profound gratitude and appreciation to my advisor Dr. Numan Mizyed for his continuous support, guidance and effort contributed to the success of this study.

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Finally, my warmest thanks go to my husband who supported me through my study.

الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل عنوان:

Developing a Model for Assessing the Impact of Regional Virtual Water Trade and Water Footprints on the Water Conflicts in the Middle East: JRB as Case Study

نمذجة وتقييم أثر تجارة الماء الافتراضي وبصمة الماء على الصراعات على الماء في الشرق الأوسط، وادي نهر الأردن كحالة دراسية

اقر بان ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أي درجة علمية أو بحث علمي أو بحثي لدى أي مؤسسة علمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name:	....	اسم الطالب:
Signature:	....	التوقيع:
Date:	....	التاريخ:

Abbreviations

WF	: Water Footprint
JRB	: Jordan River Basin
WFg	: Green Water Footprint
WFb	: Blue Water Footprint
WFl	: Livestock Water Footprint
WFi	: Industrial Water Footprint
WFd	: Domestic Water Footprint
WFf	: Feed Ingredient Water Footprint
MCM	: Million Cubic Meter
VWC	: Virtual Water Content
BWB	: Blue Water Proportion
ER	: Effective Rainfall
I	: Irrigation Water
WA	: Water Availability
BWR	: Blue Water Resources
EFR	: Environmental Flow Requirements
Y	: Yield
BWS	: Blue Water Scarcity

Table of Contents

List of Tables

List of Figures

Developing a Model for Assessing the Impact of Regional Virtual Water Trade and Water Footprints on the Water Conflicts in the Middle East: JRB as Case Study

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Abstract

The continuous high demand of water in conjunction with water scarcity in the Jordan River Basin (JRB); makes determining the amount of water footprint (WF) at different levels an important issue. Despite the progress made in the WF research since the emergence of WF term by Hoekstra (2003), there are still very few WF studies focusing on specific river basins, especially for those in arid and semi-arid regions.

The aim of this study was to quantify the blue WF within the Jordan River Basin (JRB), linking the water footprint with the water conflicts, and try to develop a model and running some suggested scenarios on it to investigate optimal management of water resources which could help reducing water conflicts.

Because of data availability, this study focused only on three states of the Jordan River riparian States which are Jordan, Israel and Palestine.

The results show that the average annual blue WF was 2657 MC Min the JRB over the period 2009–2011. Agricultural activities were the largest water consumer, accounting for 48%of the blue WF (45%for crop production and 3% for livestock production). The remaining 52% was for

the domestic and industrial sectors with 45% for the domestic sector and 7% for industrial sector.

The study found that the JRB blue WF exceeded blue water availability (the ratio was more than 313%) making the region suffers from severe blue water scarcity. There are many indicators showing that water consumption for human activities in the JRB has exceeded the sustainable level of water availability during the period 2009-2011.

The severe water scarcity will reflect on water conflicts; it will increase the tensions and sensitivities in the region in addition to the already existing political tensions.

The developed model is important to examine the water footprint response (and also the water conflicts since we take WF as indicator of water conflicts) to the changing factors such as the production quantities and planting location.

The proposed scenarios did not give any real solution to the problem of fresh water scarcity and water conflictsin the region. Reducing water footprints (m^3/ton) in JRB by increasing water productivity (ton/ m^3) is key in reducing the pressure on the JRB water resources. This could be done by increasing green and blue water productivity that could be achieved by changing some agricultural practices and the locations for planting different crops. Developing a good water policy and good regional trade policy among the JRB riparian countries can on the long-term reach a more optimal use of water, minimize water footprint and maximize production per unit of water but will not be sufficient in eliminating or reducing water conflicts.

CHAPTER ONE

Introduction

Freshwater in sufficient quantities and adequate quality is a prerequisite for the development of human societies and the conservation of natural ecosystems (Costanza and Daly; 1992, Ercin et al; 2010). There are still more than 800 million people around the world lacking safe supplies of freshwater (Ban Ki-moo; 2012, Zeng et al 2012) and 2 billion people lacking basic water sanitation (Falconer et al; 2012, Zeng et al 2012).

The water scarcity and the water conflicts are the main challenges facing the Jordan River basin, particularly that these countries are located in arid and semi-arid regions. The Jordan River basin water problems as well as most river basins in arid and semi-arid regions are summarized in rivers drying up, pollution or groundwater table decline.

Recently and with the agreement of many water experts that water conflicts are not caused by the physical water scarcity but they are mainly due to poor water management. It is necessary to find new approaches and tools for better water management. By linking a large range of sectors and issues in the Jordan River basin, water footprint analyses provide an appropriate framework to find potential solutions and contribute to a better management of water resources which could reflect positively on reducing water conflicts.

The water footprint is a consumption based indicator of water use that looks at both direct and indirect water use of a consumer or producer (Hoekstra and Chapagain; 2007, 2008, Aldaya et al; 2010).

Another concept that should be addressed is virtual water content. The virtual water content of a product (a commodity, good or service) refers to the volume of water used in its production (Allan; 1997, 1999, Aldayaet al; 2010).

Although the number of studies that focus on water footprint has been increasing rapidly, there are still very few studies focusing on specific river basins (UNEP; 2011, Zeng et al; 2012), especially for those located in arid and semi-arid regions. Assessing Water Footprint at a river basin level is an important step to understand how human activities influence natural water cycles (Zeng et al; 2012), and it could form basis for integrated water resources management in order to achieve sustainable water uses which has a definite impact on water conflicts.

WF assessment studies for JRB are rare in the literature largely due to the lack of statistical data at river basin level. On the other hand, the emphasis is usually placed on the political reasons for the problem of water in this region.

In this study we tried to deal with data neutrally, avoid political conflicts, focus mainly on the water footprint and we tried to draw some scenarios in order to reach better water management which will reduce water conflicts from a scientific and impartial perspective in order to reach the desired results.

The objectives of this study were to assess WF at Jordan River basin and employ it in water management in order to reduce the water conflicts. And also to develop a model to run some scenarios to study the water foot print response.

The WF assessment conducted by considering the agricultural (i.e. cropproduction and livestock production), industrial and domestic sectors.

1.1 Study importance:

Previous research often pays attention to water recourses management at the river basin (Hoff et al; 2011, Comair et al; 2012) but a comprehensive WF assessment considering multiple sectors and multiple types of water (green and blue water) has never been done before.

This study is the first one that provides water footprint and water colors (blue and green) as an approach for water resources planning and management in the Jordan River basin. The blue WF assessment could be a key for better understanding of the entire scene of water consumption.

The model developed and proposed some scenarios were used to study how to employ the blue water footprint concept in water management to reduce water conflicts in the region.

1.2 Definition of terms:

This section includes definitions of the most important terms according to water footprint manual (Hoekstra et al; 2011):

Water footprint assessment (WF assessment): an analytical tool that can describe the relationship between human activities and water scarcity, and offer an innovative approach to integrated water resources management.

Water footprint (WF):an indicator of water (green and blue) use, that looks not only at direct water use of a consumer or producer, but also at the indirect water use.

Blue water: fresh surface or groundwater.

Green water: the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation.

Blue virtual water content (blue VWC): the volume of blue water used in the production of a commodity, good or service.

Green virtual water content (green VWC): the volume of green water used in the production of a commodity, good or service.

Virtual water content (VWC): the volume of water (green and blue) used in the production of a commodity, good or service.

Blue water proportion (BWP): the ratio of blue VWC to VWC (Liu etal; 2009, Zeng et al; 2012).

Blue water footprint (blue WF): an indicator of consumptive use of blue water.

Green water footprint (green WF): an indicator of the human use of the green water.

Water availability (blue WA): means the blue water resources under natural conditions without human intervention, or the natural runoff (total amount of surface and groundwater flows) minus environmental flow requirements.

Blue water scarcity (BWS): the ratio of the blue WF to the blue WA during a certain period.

1.3 The study area:

1.3.1Geography, climate and population:

The Jordan River Basin is a trans-boundary basin with a total area of about 18 500 km^2 of which 40 percent is located in Jordan, 37 percent in Israel, 10 percent in Syrian, 9 percent in Palestine, and 4 percent in Lebanon (Lehner et al; 2008, AQUASTAT; 2009) figure 1.1.

The headwater of the 250 km long Jordan River originates from three rivers, the Dan, the Banias and the Hasbani, which merge at a point 5 km south of the northern Israeli border then flow south through the Hula

Valley to join Lake Tiberias. With the outflow of the Jordan River from Lake Tiberias, the Lower Jordan River receives water from its main tributary, the Yarmouk River. The Yarmouk River originates in Jordan, then forms the border between Jordan and Syria and then between Jordan and Israel, before flowing into the Lower Jordan River. The river then continues flowing south, forming the border between Israel and the West Bank to the west and Jordan to the east and finally ends in the Dead Sea (Comair et al; 2012).

Ecosystems in the region are extremely diverse, ranging from sub-humid Mediterranean environments to arid climates across very small distances (FAO AQUASTAT; 2009).

The average annual precipitation in the basin is estimated at 380 mm, although it is highly variable over space and time. It ranges from more than 900 mm per year in the north of Israel to less than 100 mm south of the Dead Sea, with rainfall occurring only in winter months. Most of the runoff is generated in the upper catchment (north of Lake Tiberias), while the lower (southern) part of the basin has only few significant perennial tributaries. The southern and eastern parts of the basin depend more strongly on water transfers and groundwater (Hoff et al; 2011).

The largest part of the fertile land in the basin is located in Jordan and the West Bank, along the eastern and western banks of the Jordan River and the side wadis, in an area with annual rainfall of less than 350 mm. Other portions of the catchment area in Syria and Israel enjoy higher annual rainfall, more than 500 mm per year (Venot et al; 2006, FAO AQUASTAT; 2009). The average annual temperature of the entire Jordan River Basin is around 18 ºC.

The average temperature of the Jordan River Basin in January is 9 ºC, although it can drop to 5 ºC in the coldest places. In August, the average temperature in the Jordan River Basin reaches 26 ºC, rising to 30 ºC in the hotter places (New et al; 2002, FAO AQUASTAT; 2009).

Figure (1.1): Jordan River Basin (Comair et al; 2012).

1.3.2 Water resources:

The Upper Jordan River Basin, north of Lake Tiberias, is rich in water in contrast to the Lower Jordan River Basin, which represents 40 percent of the entire Jordan River Basin, which is suffering from water scarcity (Venot et al; 2006, FAO AQUASTAT; 2009). The Yarmouk River, which is the main water course in this latter part of the Valley, joins the Jordan River in an area partly occupied by Israel. During summer, most side streams dry up completely and capturing the winter floodwaters is one of the most critical aspects of water resources management in the Jordan River Basin. If these waters are not diverted or stored, they flow directly to the Dead Sea (Green Cross Italy; 2006, FAO AQUASTAT; 2009).

Surface water accounts for 35 percent of the existing water resources in the basin, groundwater aquifers account for 56 percent of the resources, while reused wastewater and other non-conventional sources of water represent around 9 percent (FAO AQUASTAT; 2009).

The surface water of the Jordan River Basin is the main surface water resource available for relatively stable use in the region. It is the major source of water for Israel and Jordan and also supports the many aquifers in both countries, extending the reliance on the river (Green Cross Italy; 2006, FAO AQUASTAT; 2009).

The three main aquifers in the system are west of the Jordan River and are central to the water supply of Israel, Jordan and Palestine: the western (or mountain) aquifer, the northeastern aquifer, and the eastern aquifer.

The region has one of the lowest per capita water resources worldwide, well below the typical absolute water scarcity threshold of 500 m^3/year per capita (FAO AQUASTAT; 2009). Moreover, water demand continues to increase rapidly due to high population growth rates and economic development.

1.3.3 The riparian countries

The Jordan River Basin location in one of the most unstable and conflict-driven regions in the world, and it is also located in one of the most heavily populated and water scarce regions of the world, placing the region's freshwater resources under severe stress (Meisen; 2011).

The Jordan River Basin is a trans-boundary watershed, so the water sources that supply the Jordan River cross international and political boundaries(Turner et al ; 2005,Meisen ; 2011).

The first riparian is Jordan or the Hashemite Kingdom of Jordan is a low to middle income country with limited natural resources and a semi-arid climate and an area of about 90 000 square kilometers (Nortcliff et al; 2008). The country borders Saudi Arabia to the east and south-east, Iraq to the north-east, Syria to the north and the West Bank and Israel to the west. Jordan's only port is at its south-western tip, at the Gulf of Aqaba, which is shared with Israel, Egypt, and Saudi Arabia.

Approximately 75% of Jordan is covered by the Arabian Desert. However, the western part of Jordan is arable land and forests. The capital city is Amman and the country is divided into 12 governorates. About 90% of the population live on only 10% of the country's surface area. As a result of continuous conflict in the Middle East, Jordan has hosted several waves of refugees and displaced peoples. This has had a significant impact on the population growth rate, leading to pressure on natural resources (fresh water mainly), growing income disparities and increase in poverty.

Jordan has a population of about 6.3 million people, of which almost 2 million are Palestinian refugees. Jordan's population is young, urban, and growing fairly rapidly at about 1% annually. The median age is just 22 years, and about35% of Jordan's population is under the age of 15. About 98% of Jordan's population are ethnically Arabs, and nearly 80% live in urban areas.

In Jordan, 13.3% of the population lived under the poverty line in 2008,this percentage varied from 8.3% in Amman to 31.9% in Mafraq (OCHA 2012).

The Jordan Topography is diverse and the major topographic and geomorphologic features in Jordan control the drainage pattern. The overall drainage system in Jordan consists of two main flow patterns. The first drains water towards the Jordan Rift Valley, through deeply incised wadis and rivers dissecting the Jordan Valley-Dead Sea escarpments, to discharge ultimately into the Dead

Sea. The second drains water through shallow streams and washes, which generally flow east wards from the western highlands towards the internal desert depressions and mudflats (Nortcliff et al; 2008).

The climate of Jordan ranges from Mediterranean to arid. The Rift Valley and the highlands belong to the semi-arid to arid climate zone, which is largely affected by moist westerly air masses in winter. In summer, dry easterly and north-easterly desert winds affect Jordan. Winds are generally westerly to south-westerly. A Mediterranean climate dominates most of the highlands on both sides of the Jordan River and in the mountain chains east of the Dead Sea and Wadi Araba extending as far south as Ras El Naqeb. Dry summers with an average maximum annual temperature of 39°C occur between April and October. In winter months, from November to March, the average minimum annual temperature is 0-1°C. In winter, the average mean daily temperatures recorded at Amman Airport and Deir Alla were 10°C and 17°C respectively, for the period 1981-1998 (Nortcliff et al; 2008).

The average temperature in the wet season is generally higher in the Jordan Valley than the western slopes and it falls down again over the highlands and within the eastern plateau. The average annual panevaporation rate ranges from 2,042 mm in Zarqa to 5,038 mm in Ma'anand from 2,594 mm in the Jordan Valley to 3,516 mm in the eastern hills (Mithen and Black ; 2011).

Rainfall affects the country between October and May. Eighty percent of the annual rainfall occurs between December and March. Average annual rainfall in Jordan, as shown in Figure 2, ranges from less than 50 mm in the eastern desert to approximately 600 mm over Ajloun heights. Approximately 80 per cent of the country receives less than 100mm per year and less than 5 per cent of the country receives more than 300mm which is considered to be the minimum threshold below which is not possible to grow wheat in the region (Mithen and Black ; 2011).

International perception considers Jordan as a water scarce country. Internationally a water scarce country is one with less than 1000 cubic meters of fresh water per person per year (FAO; 1997, Winpenny; 2000, Nortcliff et al; 2008).

The annual water consumption in Jordan was estimated to be 955 million cubic meters (MCM) whilst the renewable freshwater resources (surface and groundwater) were estimated to be only in the region of 780 to 850 MCM per year, with approximately 65 percent derived from surface waters and 35 percent from ground waters (JMOE; 2006, Nortcliff et al; 2008).

Surface water resources are spread across 15 major basins. The Yarmouk River forms 40 per cent of Jordan surface water. The River is the main source of water for the King Abdullah canal in the Jordan Valley (JMOE; 2006, Nortcliff et al; 2008).

There are 12 groundwater basins in Jordan, most comprising several interrelated aquifer systems, within the country, approximately 80 percent of the known reserves are concentrated in the Yarmouk, Amman-Zarqa and Dead Sea Basins. Current exploitation of these groundwater resources is at maximum capacity and in some cases exploitation is well above what is recognized as a safe yield (JMOE; 2006, Nortcliff et al; 2008).

The agricultural sector in Jordan is one of the most important pillars of the development in its economic, social and environmental terms. It helps in improving the trade balance, and other economic sectors rely on it. The agricultural sector is also very important from the social aspect, since it creates thousands of job opportunities for males and females in rural areas and also contribute significantly in the reduction of youth migration. On the environmental front, agriculture related to natural resources that will be a danger if they ignored to use in a balanced and sustainable ways.

It should be noted here that the agricultural sector in Jordan is poor at the level of productivity and competitiveness both in local markets or international markets. It is also characterized by the scarcity of investment by the private sector and the weakness of the use of modern technology in the process of agriculture as there are insufficient training programs, research and agricultural extension to keep up with developments.

The second riparian the study focused on is Palestine (the West Bank and the Gaza strip).Palestine has a total area of 6 020 km^2. The West Bank is a landlocked territory on the west bank of the Jordan River with a total area of 5 655 km^2, surrounded by Jordan to the east and Israel to the south, west and north.

The Gaza Strip is a narrow coastal strip of land along the Mediterranean Sea with a total area of 365 km^2, bordering with Egypt to the south and Israel to the north and east. It takes its name from Gaza, its main city.

Recently in 2012 Palestine was granted a non-member state status at the United Nations.

In accordance with Oslo accords, the Palestinians fully controll part, known as Area A, comprises the Gaza Strip and all of the eight largest West Bank municipalities, except 20 percent of Hebron which is under Israeli control. These municipalities include Ramallah, Jenin, Tulkarem, Nablus, Hebron, Bethlehem, Jericho and Quaqilye. Area B includes about 100 separate areas of rural land, delineated in the “Oslo Accords” maps, in which the Palestinian Authority has control over civil administration but the Israeli Authorities have control over all aspects of security.

The Israeli authorities remain in full control of Area C, which amounts to about 59 percent of the West Bank. The West Bank residents continue to face financial problems and hard living conditions. Israeli-imposed restrictions on movement have disrupted commerce and labor flow. Access to land and resources, along with import and export restrictions, remain a problem.

The climate in the Occupied Palestinian Territory is predominantly of the eastern Mediterranean type with cool and rainy winters, hot dry summers and an annual rainfall in the range of 100-700 mm (FAO AQUASTAT;2009).

The following are the five major zones (according to AQUASTAT version of 2009) based on several factors including climate, topography, soil types and farming systems:

- The Jordan Valley Region with an annual rainfall of only 100-200 mm. Soil salinization is a major problem. Irrigation is essential for farming operations and winter vegetables and grapes are the main irrigated crops.
- The Eastern Slopes Region is a transitional zone between the Mediterranean and Desert climate with rainfall of 150-300 mm/year. The main economic activity is livestock.
- The Central Highlands Region extends along the length of the West Bank with mountains ranging from 400-1000 m. Annual rainfall varies between 300 mm in the south to 600 mm in the north. Agriculture is primarily rain fed and includes olives, fruits, and field crops.
- The Semi-Coastal Region has an elevation of 100-300 m above sea level. Rainfall varies from 400-700 mm/year. It supports the same

rainfed crops as the Central Highlands Region but it also has a limited irrigated area under vegetables.

- The Coastal Plain is the Gaza Strip. It has a rainfall of 200-400 mm/year. The soils are fertile. Irrigated agriculture is substantially practiced using groundwater.

The water resources in Palestine are mainly groundwater and a little bit of surface water. Jordan River is the only permanent river which can be used as a source of surface water in the West Bank, Wadi flows and groundwater (utilized mainly through wells and springs) are the main water sources.

Israel controls all aquifers in Palestine; although the major part of fresh water supply in Palestine originates from the three aquifers of the West Bank.

The major ground water in the West Bank consist of three major basins which named according to their flow direction into: Western, Eastern and Northeastern Basins with a natural recharge of approximately 600-660 million cubic meter per year (Aliewi; 2007).

The western aquifer is the most important aquifer in the West Bank and also the largest one in historical Palestine. It is a shared aquifer between the West Bank, Israel and Egypt, with a surface area of 11,398 km^2 where the area located within the borders of the West Bank forms the main recharge area for this Basin estimated at about 1,596 km^2, and it is located within the heavy rainfall area (Aliewi; 2007).

The western basin has a safe yield of 443 MCM/yr; Israel exploits most of the water of this aquifer (about 95%) through more than 500 deep groundwater wells. Israel limits Palestinian use from this aquifer to 21 MCM/yr with total number of wells of134 (Aliewi; 2007).

The second basin is the Northeastern Aquifer Basin which has an area about 1,067.5 km^2. The annual groundwater recharge of this is approximated to be 145 MCM (Aliewi., 2007).

The third aquifer is the Eastern Aquifer Basin. Large parts of this aquifer basin are located within the eastern borders of the West Bank.The area of this basin is estimated at 3,079.5 km^2.The majority of the Eastern Aquifer Basin area is located within the areas featured by scarcity of rain, while the western part is located within an area featured by heavy rainfall. The eastern aquifer basin has a safe yield of 175 MCM/yr on average.

The number of Palestinian wells in the eastern aquifer is 95 wells with average abstraction of about 25 MCM/yr (Aliewi., 2007).

Agriculture was and still an important cultural tradition vital to the economy and society of the West Bank. Farming families have been part of Palestinian life for thousands of years. They do not only provide communities with food and jobs, they are a source of pride and a means of self sufficiency (ANERA; 2010).

The third riparian in the Jordan River Basin is Israel, Israel is a small modern emerging country which has been established on the territory of historical Palestine in 1948, with a total area of20,770 square kilometers.

Israel is divided into four regions (FAO AQUASTAT; 2008):

- The Mediterranean coastal plain stretches from the Lebanese border in the north to Gaza Strip in the south, interrupted only by Cape Carmel at Haifa Bay. It is about 40 km wide at Gaza Strip and narrows toward the north to about 5 km at the Lebanese border.
- The central highland region. The central highlands average 610 meters in height.
- The Jordan Rift Valley is a small part of the 6 500 km long Syrian - East African Rift. In Israel the Rift Valley is dominated by the River Jordan, Lake Tiberias, and the Dead Sea.
- The Negev Desert comprises approximately 12 000 square kilometers, more than half of Israel's total land area.

Israel's population is roughly 7.5 million people and is growing at an annual rate of roughly 1.6%. In addition, there are more than 500,000 Israeli settlers living in the occupied territories in the West Bank, Golan Heights, and East Jerusalem (Meisen., 2011).

"Israel is the most economically advanced of all the countries in the Jordan River Basin. Israel has intensively developed its agricultural and industrial sectors despite its limited natural resources, although it still depends heavily on foreign aid, particularly from the United States" (Meisen., 2011).

Israel has a Mediterranean climate characterized by long, hot, dry summers and short, cool, rainy winters, modified locally by altitude and latitude.

The climate is determined by Israel's location between the subtropical aridity characteristic of Egypt and the subtropical humidity of the Levant or eastern Mediterranean. January is the coldest month, with temperatures from 5 to 10°C, and August is the hottest month at 18 to 38°C.

About 70 percent of the average rainfall in the country falls between November and March, while the months June through August are often rainless. Rainfall is unevenly distributed, decreasing sharply as one moves southward. In the extreme south, rainfall averages less than 100 mm annually; in the north, average annual rainfall is more than 1100 mm (U.S. Library of Congress, 1988).

The only river in Israel is the Jordan River. The main sources of fresh water in Israel include (FAO AQUASTAT; 2009):

- Lake Tiberias, which divides the upper and lower portions of the Jordan River system, is the only natural freshwater lake in Israel. It has traditionally provided about a third of the country's domestic, agricultural and industrial water requirements.

- The Coastal Aquifer is a sandstone aquifer which extends along 120 kilometers of the Mediterranean coastline. It is naturally recharged by precipitation and artificially recharged by water from the National Water Carrier, effluents and excess irrigation water percolating from agricultural, industrial and domestic land uses as well as from streams and wadis.
- The Mountain Aquifer is a limestone aquifer which underlies the foothills in the center of the country.
- Relatively smaller aquifers are located in Western Galilee, Eastern Galilee, the Jordan Rift, and the Arava valley.

The fourth riparian state is Syria, with a total area of 185 180 km^2, is bordered in the north by Turkey, in the east and southeast by Iraq, in the south by Jordan, in the southwest by Israel and in the west by Lebanon and the Mediterranean Sea. Administratively the country is divided into 14 governorates, and its capital is Damascus.

The country can be divided into four physiographic regions:

- The coastal region between the mountains and the sea;
- The mountains and the highlands extending from north to south parallel to the Mediterranean coast;

- The plains or interior, located east of the highlands and including the plains of Damascus, Homs, Hama, Aleppo, Hassakeh and Dara;
- The Badiah and the desert plains in the southeastern part of the country, bordering Jordan and Iraq.

In 2005, total cultivable land was estimated at 5.91 million ha, or 32 percent of the total area of the country and the cultivated land was 5.74 million ha. Of the 5.53 million ha of cultivated land in 2004, temporarily fallow land represented 0.80 million ha and the effective cultivated land 4.73 million ha, of which over 30 percent was irrigated.

There are 16 main rivers and tributaries in the country, of which 6 are main international rivers:

- The Euphrates (Al Furat), which is the Syrian Arab Republic's the largest river. It comes from Turkey and flows to Iraq. Its total length is 2 330 km, 680 km of which are in the Syrian Arab Republic;
- The Afrin in the northwestern part of the country, which comes from Turkey, crosses the Syrian Arab Republic and flows back to Turkey;
- The Asi-Orontes in the western part of the country, coming from Lebanon and flowing into Turkey;
- The Yarmouk in the southwestern part of the country with sources in the Syrian Arab Republic and Jordan and which forms the border between these two countries before flowing into the Jordan river;

- The El-Kabir with sources in the Syrian Arab Republic and Lebanon and which forms the border between them before flowing to the sea;
- The Tigris, which forms the border between the Syrian Arab Republic and Turkey in the extreme northeastern part.

The main groundwater aquifers are those of Anti-Lebanon and the Alouite Mountains. Folding and faulting of the geological layers has resulted in the mingling of the sub-aquifer systems (FAO AQUASTAT; 2009).

The fifth riparian state is Lebanon, with a total area of 10 400 km^2, is situated east of the Mediterranean Sea and bordered by the Syrian Arab Republic to the north and east and by Israel to the south. It is a mountainous country.

The cultivable area is estimated at 360 000 ha, or 35 percent of the total area. In 2005, the cultivated area was 328 000 ha, of which 186 000 ha annual crops and 142 000 ha permanent crops.

While Lebanon is in a relatively favorable position as far as rainfall and water resources are concerned, constraints for development consist in the limited availability of water during the seven dry summer months due to the very low water storage capacity, the difficulty of capturing the water close to the sea, and the shortcomings of the existing water delivery systems and networks. The total length of streams in Lebanon is 730 km, mainly on the western side of the mountains, which have steep slopes.

There are about 40 major streams in Lebanon and, based on the hydrographic system, the country can be divided into five regions:

- The Asi-Orontes Basin in the north; the Asi-Orontes River flows into the Syrian Arab Republic in the northeast of the country;
- The Hasbani Basin in the southeast; the Hasbani River, which flows into Israel in the southeast of the country, is a tributary of the Jordan river;
- The Litani Basin in the east and south; the Litani River reaches the sea in the southwest of the country;
- All the remaining major coastal river basins; the northern El Kebir River Basin is shared with the Syrian Arab Republic, the river itself forming part of the border between the two countries before flowing into the sea;
- All the small, scattered and isolated sub-catchments remaining in-between, with no noticeable surface stream flow, such as the endcatchments and isolated coastal pockets.

There are eight major aquifers, with a total estimated volume of 1 360 million m^3. Exploitable groundwater ranges from 400 to 1 000 million m^3 (FAO AQUASTAT; 2009).

CHAPTER TWO

Background

2.1 Water footprint and related concepts:

Hoekstra (2003) introduced the concept of water footprint as a consumption-based indicator of water use that looks at both direct and indirect water uses of a consumer or producer. The water footprint offers a better and wider perspective on how a consumer or producer relates to the use of freshwater systems. It is a volumetric measure of water consumption and pollution (Hokestra et al; 2011)..Water footprint accounts give spatiotemporally clear information regarding how water is appropriated for various human purposes. Water footprint accounts also canfeed the discussion about sustainable and equitable water use and allocation and also form a good basis for a local assessment of environmental, social and economic impacts.

Closely linked to the concept of water footprint is that of virtual water. The virtual water content of a product (a commodity, good or service) refers to the volume of water used in its production (Allan 1997, 1999; Hoekstra 2003, Aldaya et al 2009). Building on this concept, virtual water 'trade' represents the amount of water embedded in traded products (Hoekstra and Hung 2005; Aldaya et al 2009).

Water footprint assessment is an analytical tool which describes the relationship between human activities and water scarcity, and offer a new approach to integrated water resources management. As a tool, a water footprint assessment provides insight, it does not tell people ‘what to do’. Rather it helps people to understand what can be done (Hoekstra et al 2011).

The final form of water footprint assessment largely depends on the focus of interest “one can be interested in the water footprint of one specific process step in a whole production chain, or in the water footprint of a final product. Alternatively, one can be interested in the water footprint of a consumer or group of consumers or in the water footprint of a producer or whole economic sector. Finally, one can take a geographic perspective, looking at the total water footprint within a delineated area such as a municipality, province, nation, catchment or river basin. Such a total water footprint is the aggregation of the water footprints of many separate processes taking place in the area”(Hoekstra et al., 2011). In this study water footprint assessment within the Jordan river basin was made considering crops, livestock, domestic and industrial water footprint.

2.2 Water footprint assessment phases:

A full water footprint assessment according to the water footprint assessment manual (Hoekstra et al., 2011) consists of four distinct phases:

2.2.1 Setting goals and scope:

The first phase is setting goals and scope; Water footprint studies may have various purposes and be applied in different contexts. Each purpose requires its own scope of analysis and will allow for different choices when making assumptions. One can assess the water footprint of different entities, so it is important to start specifying in which water footprint one is interested. In this study water footprint within a geographically delineated area (Jordan river basin) taken into account the agricultural consumption (crops and livestock) in the first place and also domestic and industrial consumptions. It is worth mentioning that at this phase one must be clear and explicit about what to include and what to exclude from the accounts and should be chosen as a function of the purpose of the account.

2.2.2 Water footprint accounting:

The second phase is water footprint accounting. The water footprint of one single 'process step' is the basic building block of all water footprint accounts. The water footprint of an intermediate or final 'product' (good or service) is the aggregate of the water footprints of the various process steps relevant in the production of the product. The water footprint of an individual consumer is a function of the water footprints of the various products consumed by the consumer. The water footprint of a community of consumers – for example, the inhabitants of a municipality, province, state or nation – is equal to the sum of the individual water footprints of the members of the community. The water footprint of a producer or whatever sort of business is equal to the sum of the water footprints of the products that the producer or business delivers. The water footprint within a geographically delineated area – be it a province, nation, catchment area or river basin – is equal to the sum of the water footprints of all processes taking place in that area. The total water footprint of humanity is equal to the sum of the water footprints of all consumers of the world, which is equal to the sum of the water footprints of all final consumer goods and services consumed annually and also equal to the sum of all water-consuming or polluting processes in the world (All of these above-mentioned definitions are based on the water footprint assessment manual which formed by Hoekstra et al (2011)).

2.2.3 Water footprint sustainability assessment:

The third phase is water footprint sustainability assessment, water footprint sustainability assessment is primarily about making this comparison of the human water footprint with what the Earth can sustainably support. The main aim of this phase is to get an idea of what the footprint size means, one will need to compare the water footprint to the available freshwater resources. Sustainability has different dimensions (environmental, social, economic), impacts can be formulated at different levels (primary, secondary impacts) and the water footprint has different colors (green, blue, grey).

The main question of the sustainability of water footprints at this study is if the blue water footprint within JRB is sustainable?

The sustainability of the water footprint within a catchment or river basin can be analyzed from three different perspectives: environmental, social and economic. From each of the perspectives there are some sustainability criteria (All of these above-mentioned definitions are based to the water footprint assessment manual which formed by Hoekstra et al (2011)).

2.2.4 Water footprint response formulation:

The fourth phase is water footprint response formulation. At this phase alternative response strategies should be formulated.

2.3 Water footprint levels:

Although Water Footprint is fairly new science but there are many previous studies that have focused on water footprint at many levels; at certain product or products level. Chapagain et al (2005) assessed the 'water footprint' of worldwide cotton consumption, identifying both the location and the character of the impacts. Their study distinguishes between three types of impact: evaporation of infiltrated rainwater for cotton growth (green water use), withdrawal of ground or surface water for irrigation or processing (blue water use) and water pollution during growth or processing (gray water use). The latter impact is quantified in terms of the dilution volume necessary to assimilate the pollution.

Aldaya et al (2010) analyzed the water footprint of Central Asian cotton, wheat and rice production, with a differentiation between the green and blue components, in order to know how the scarce water resources in the region are apparently allocated.

And there is another study that gives a global assessment of the green, blue and grey water footprint of rice, using a higher spatial resolution than earlier studies and applying local data on actual irrigation. CROPWAT model was used to calculate evapotranspiration from rice fields (Chapagain and Hoekstra; 2010). Another assessment of the green, blue and grey water footprint but this time for wheat and they have used a grid-based dynamic water balance model to calculate crop water use over time, with a time step of one day. The model takes into account the daily soil water balance and climatic conditions for each grid cell (Mekonnen and Hoekstra; 2010). Chapagainand Hoekstra (2007) assessed the global water footprint of the Dutch society in relation to its coffee and tea consumption. Their calculation was carried out based on the crop water requirements in the major coffee and tea exporting countries and the water requirements in the subsequent processing steps. Another study analyzes the water use related to pasta and pizza margheritain Italy. The study used the water footprint concept as a tool to quantify and localize the pasta and pizza water use (Aldaya and Hoekstra; 2010). Ercin et al (2012) quantified the water footprints of soy milk and soy burger and compare them with the water footprints of equivalent animal products (cow's milk and beef burger). Their study focuses on the assessment of the water footprint of soy milk produced in a specific factory in Belgium and soy burger produced in another factory in the Netherlands. Another study quantified the water footprint within the Lake Naivasha Basin (Kenya) and also assessed the potential for mitigating this footprint by involving cut-flower traders, retailers and consumers overseas (Mekonnen and Hoekstra; 2010).

Van Oel and Hoekstra (2012) estimated the water footprint for paper using different types of wood and in different parts of the world and at the end of the study they found that the use of recovered paper may be particularly effective in reducing water footprints. The water footprint of animal product considering different production systems and feed composition per animal type and country (Mekonnen and Hoekstra 2012). Gerbens-Leenesand Hoekstra (2009) assessed the green, blue and grey water footprint of sugar, high fructose maize syrup and ethanol in the main producing countries. In addition, an impact assessment is carried out for sugar cane and beet production in three large river basins: the Dnjepr, Indus and Ganges basins. In 2010 they calculated the water footprint of different transport modes using bio-ethanol, biodiesel or bio-electricity and of European transport if 10 percent of transport fuels is replaced by bio-ethanol. They compared results for Europe with similar goals for other regions (Africa, Asia, Latin America, the former USSR, Australia and

North America). In order to provide a context, they compared results with water footprint of food and cotton (Gerbens-Leenes and Hoekstra; 2010).

At the sector level, Aldaya et al (2010) calculated the WF of domestic, industrial and agricultural sectors in Spain and they found that there was inefficient allocation of water resources and mismanagement in the agricultural sector. They attributed the mismanagement to several factors such as the persistence of the former idea of food self-sufficiency, the still imperfect World Trade Organization regulations, the absence of appropriate economic instruments for water management, and the national policies that promote irrigated agriculture to contribute to regional stability and agricultural commodity prices.

And for Spain too Cazcarro et al (2013) calculated the water footprint of tourism sector, merging insights of the process analysis and input output analysis. They evaluated the virtual (both blue and green consumed) water trade of agricultural and industrial products, but also of services, especially through tourism, they found that 16% of the Spanish exports are due to foreign tourism, thus the water footprint of foreign tourism in Spain is 3.7 km^3. They also compared reductions in total tourism expenditure and the domestic and global water footprint of tourism using four scenarios.

At the nations level, some of the previous studies calculated the water footprint for a nation or group of nations, for example Hoekstraand

Chapagain (2007) presented a study that calculated the water footprint for many nations of the world for the period 1997–2001, Vanham et al (2013) calculated the EU28 water footprint for the consumption of different diets was analyzed (the current diet, a healthy diet, a vegetarian and combined diet).

Some studies calculated the water footprint for a particular nation; a study assessed the water footprint of China (Liu and Savenije; 2008), a study calculated the water footprint of India (Kampman et al; 2008), a study calculated the water footprint related to the consumption of crop products per Indonesian province (Bulsink et al; 2009), a study quantified the external water footprint of the Netherlands by partner country and import product and assessed the impact of this footprint by contrasting the geographically explicit water footprint with water scarcity in the different parts of the world (Van Oel et al; 2008).A report containing quantification and analysis of the water and carbon footprint of different types of household food and drink waste in the UK (Chapagain and James; 2011), a study for Switzerland the study focused on consumption perspective and then assessed water footprint (Ercin et al; 2012), a study assessed water footprint for France from both a production and consumption perspective (Ercin et al; 2012), and finally a study assessed the water footprints of Morocco as semi-arid / arid country, and the Netherlands, a humid country (Hoekstra and Chapagain; 2006).

At the global level, there is a study that quantified and mapped the water footprint of humanity at a high spatial resolution. It reported on consumptive use of green WF and blue WF and volumes of water polluted (gray WF). Water footprints are estimated per nation from both a production and consumption perspective. International virtual water flows are estimated based on trade in agricultural and industrial commodities (Hoekstra and Mekonnen; 2012).

Despite the number of literatures on water footprint has been increasing fast, there are still very few studies focusing on specific river basins (UNEP; 2011, Zeng et al; 2012). Water footprint assessment studies at river basin levels are rare in the literature largely due to the lack of statistical data at the river basin level (Zeng et al; 2012).

One of the very few studiesis Aldaya and Llamas (2008) study which assessed the water footprint for semi-arid Guadiana river basin.

Zeng et al (2012) presented a study that assessed the water foot print ofHeihe River Basin in northwest China as a case study, from the other hand this is the only study that assessed the water footprint at a river basin level with a bottom-up approach (Hoekstra et al; 2011) and our study will follow the same approach that stands in the water footprint manual.

However, Heihe River Basin study did not address the issue of water conflict and did not linked it with water footprint sustainability but only focused on the issue of sustainability of the water footprint. Therefore, our study will be the first study that try to link between water footprint at river basin level on the one hand and water conflicts on the other hand.

2.4 Trans-boundary water issues:

Some previous studies agreed that the JRB is subject to extreme water scarcity. Per-capita annual water availabilities in the three riparian countries included in the previous studies exceed all typical scarcity thresholds by far (Israel: 325 m^3, Jordan 150 m^3, Palestine 70 m^3, normally the threshold is set at 1,700 or sometimes at 1,000 m^3, Phillips et al; 2009, Hoff et al; 2011).

The previous studies used different criteria to calculate the water scarcity, these criteria did not use the water footprint concept as indicator of water consumption.

There are many studies on water conflict in the Middle East, some of these strategic studies which specializing in issues of conflict in the Middle East confirms that the future of the conflict will be about water resources, and although petroleum is vital, water will be more important. So policies for the control of water sources will increase, and conflicts will take place, and perhaps wars (Al-saed; 1993, Damo; 2012).

Nearly all the researchers in water conflict in the Middle East region agree that water conflicts associated the Arab-Israeli conflict, and therefore it will be watery dimension and another aspect of the conflict between the Arabs and Israel.

The history of water conflicts in the Middle East (Jordan, Palestine and Israel) started to appear with the establishment of Israel. As a result, water became a strategic and diplomatic issue that always threatened to bring the region into blows war.

Bernard Wasserstein notes that conflicts over the Jordan river waters played a significant part in the Six Day War of 1967 (Wasserstein; 2003). This war illustrated how essential the water management is in the region and how poorly this issue has been addressed (Mann; 2006).

In 1955, all Jordan River riparian (Jordan, Israel, Palestinian Authority, Syria and Lebanon) agreed to their rightful share of water in a plan drawn up with the assistance of an American diplomat (Johnston Plan 1955). Many experts agreed that Johnston plan cannot be considered to equate to the full present-day water rights of the riparian countries to that system. This is principally because no regard was given in the work by Johnston to the groundwater resources available to the riparian countries, and the only demand deemed to be of relevance was the use of water for agricultural irrigation (Phillips et al; 2007).

The weakness of the agreement was the fact that the technical resolution wasn't translated into a political accord because it would entail tacit Arab recognition of the state of Israe1(Mann; 2006).

After the Lack of success to formalize the Johnston Plan, Israel and Jordan proceeded with the development of the Jordan River system within their respective territory. In 1955, Israel started construction of its National Water Carrier, which involved the transfer of water from Lake Tiberias to the coastal region and the Negev. The National Water Carrier constituted the first out of basin transfer of water in the Jordan River system (Wolf; 1995, Zawahri; 2010). As for the state of Jordan, it undertook construction of the East Ghor Canal (later renamed the King Abdullah Canal), which transported water from the Yarmouk River to the Jordan Valley (Zawahri; 2010).

The 1967 Arab-Israeli war secured for Israel control of the Banias River and Lake Tiberias. Israel also gained greater access to the lower Jordan River and the Yarmouk River. Prior to the war, Israel's direct contact with the Yarmouk River was a six kilometer stretch. After gaining control of the Golan Heights, Israel's contact increased to almost 50 percent of the Yarmouk River (Lowi; 1993, Zawahri; 2010). Israel also came into control of highly fertile land located at the confluence of the Yarmouk and Jordan Rivers.

After the gain of the West Bank from Jordan, Israel secured access to the lower Jordan River. Due to this shift in the international border, the interdependence between Israel and Jordan increased because during the winter the Yarmouk River carries sediments that settle and clog the river during the summer season. To ensure the continued flow of water, it was essential to dredge the river. The failure of Jordan and Israel to communicate and coordinate a dredging operation resulted in years of sediment accumulation that eventually formed a sand bar, a small island with wild plants in the center of the river (Haddadin; 2002). The sand bar not only obstructed the river's flow, but it also began to choke the drop inlet of the King Abdullah Canal. In time, this situation culminated in the formation of an informal institution between Israel and Jordan, which was born out of necessity.

The Treaty of Peace between Israel (October 26, 1994) and Jordan is one of the exceptional examples of cooperation between Israelis and Arabs. It has a large attention by many scholars and politicians. Article 6 and Annex II of the Israeli–Jordanian Peace Treaty focus on managing all their shared water systems, which include the Yarmouk tributary, lower Jordan River, and Wadi Araba/ Arava (Peace Treaty, 1994).

Article 6 of the Peace Treaty sets the rights of Israel and Jordan to the Jordan River, Yarmouk River, and Wadi Araba waters, and secures their existing consumption from these shared hydrological systems.

Because existing water resources are insufficient to meet the growing demands of the riparian states, Article 6 calls upon the riparians to cooperate in the search for additional sources of water (Peace Treaty; 1994, Zawahri ; 2009).

The treaty didn't applied completely and so water management in the region has not fulfilled all the objectives stated in the treaty, but there was some changes in the water management in the regain (Manna; 2006).

In the first half of the 1990s water was a central issue throughout the peace negotiations. The working Group on Water Resources met on a regular basis between 1992 and 1996. These multilateral negotiations advanced a common understanding for future water management in the region.

The experts and academics with Arab and Israeli backgrounds convened in the framework of second track diplomacy and they discussed the Israeli-Palestinian conflict. The meetings on water reviewed technical solutions for the shared aquifers.

The first 'Israeli-Palestinian International Academic Conference on Water' was held in Zurich Switzerland in 1992.The main goal was to identify and structure joint management systems for the shared aquifers in the West Bank. This was a rather undeveloped field of research at that time. The meetings improved the exchange of information and assisted the negotiators in the peace process on both sides.

The Oslo II water agreement (1995) is the basis for the current water negotiations as well as focal point of the various discourses on the water conflict. The most contentious point is the initial paragraph on the Palestinian water rights: "Israel recognizes the Palestinian water rights in the West Bank. These will be negotiated in the permanent status negotiations and settled in the Permanent Status Agreement relating to the various water resources" (Burkart; 2012).

Since the Palestinian National Authority was established, it started to build an institutional framework for the governance of the water sector. The Palestinian Water Authority was established in 1994.

The Palestinian Water Authority assumed administrative responsibility for water resources, but Israel maintained overall control of all water, including the Palestinian water supply. While Palestinians had asked for 450 (MCM) of water annually, Oslo II provided only 28.6 MCM for immediate domestic use. Any increase was subject to the availability of new water resources. The future needs of the Palestinians on the West Bank were estimated at 70-80 (MCM/year) (Attili; 2004).

Unfortunately, history bears that all political attempts to resolve the water problem in the Middle East if not fail completely, a part of it has failed and did not live up to satisfy all adversaries.

The population growth in the Middle East is one of the highest in the world, which means a rapid increase in the water demands, and so in the water conflicts. Also the agriculture an integral part of the social and economic life of the population in the Jordan River basin, whether Jordanian or Palestinian or even Israeli, which means more water quantities for irrigation. These factors will worsen the water problem in the future, and so the need for scientific studies that do not rely only on policy is in a large increase.

Although there are many studies on water conflicts in the Middle East, but no one of the researchers suggested the water footprint assessment as an approach for water management and water conflicts resolve in Jordan River basin.

It is worth mentioning that a water footprint assessment in itself does not solve the water problems, but it certainly explains the water situation and thus open domains for solutions for water conflicts (Hoekstra et al; 2011).

At this study a bottom-up approach (Hoekstra et al; 2011) which promoted by the Water Footprint Network was used in assessing WF for JRB.

CHAPTER THREE

Water conflicts in the study area

3.1 Introduction

Water has historically played an important role in shaping the geopolitical boundaries of the Middle East.

The Middle East belongs to arid and semi arid areas. Such areas are characterized normally by low rainfall quantities and high temperature and high evapotranspiration. Scarcity of water is a common phenomena there.

The Jordan River basin is subject to extreme limited water recourses comparing with the high population growth and economic development.

Surface water accounts for 35 percent of the existing water resources in the basin, Jordan River is the main surface water resource available for relatively stable use in the region. It was the major source of water for Israel and Jordan and also supports the many aquifers in both countries.

In 1950s Jordan river had an average annual flow of 1300MCM, present records show that the annual flow from the Jordan River to the Dead Seais less than30 MCM (FoEME; 2010).

The increase in water demands and the limited availability of water resources are resulting in increasing the water shortages in the region. The increases in water shortages are yielding to over exploitation of existing water resources and thus limiting the sustainability of their use (Mizyed; 2009).

On the other hand these limited water recourses suffer from severely deteriorated quality in recent decades, for instance, the Lower Jordan River consists primarily of untreated sewage and agricultural return flows, groundwater seepage, as well as brackish water from springs diverted into the river away from the Lake Tiberias area.

The Lower Jordan River in particular is extremely polluted. Other environmental concerns include water level fluctuations in Lake Tiberias and the associated risk of saline water intrusion from below, and, more importantly, the decline of the Dead Sea, which all threaten the stability of the basin ecosystem.

Groundwater aquifers account for 56 percent (AQUASTAT) of the fresh water resources, these groundwater aquifers are facing severe challenges like depletion and pollution.

The population is increasing rapidly in the region which has one of the lowest per capita water resources worldwide, well below the typical absolute water scarcity threshold of 500 m^3/ year per capita.

Fresh water is a valuable natural resource for each state within the Jordan River basin, competing over fresh water in the Jordan River Basin produced a fertile environment for water conflicts along the political disputes between Israel and the Arab states.

The water conflicts in the Middle East attracted much attention for a long time. The following sections summarize the main plans and attempts to solve the water conflicts in Jordan River Basin during the previous one hundred years.

3.2 The water conflicts and solution attempts before 1948:

The water conflicts in the Jordan River Basin dates back to the late 1800s when the Zionist organizations chose Palestine to establish a homeland for the Jews. Zionist Organizations had plans prepared since 1899 and continued working on these plans until Israel was established in 1948.

In 1936, the government of Transjordan (after the British government commission's recommendation of Palestine partition) initiated a study for the utilization of the Jordan waters to determine their capacity to support three states: Jordan, Palestine, and a Jewish state. The study was conducted by a British engineer, Michael Ionedis.

Michael Ionedis estimated, for the first time, the available water resources of the Jordan river and the irrigable land in the Jordan Valley. His study focused on the irrigation of the East Jordan Valley but also contained ideas to irrigate the West Jordan Valley, he published his study for the first time in 1939.

In 1939 Lowdermilk visited Palestine as chief of the U.S Soil Conservation Service, during his visit he noted that the region needed a more efficient water and energy management plan.

Lowdermilk conceived such a plan, and in 1944 it was published as Palestine: Land of Promise.

The main two suggestions of this plan were:

- The irrigation of the Negev Desert with the waters of the Jordan and Litani rivers.

- The refilling of the Dead Sea through a canal from the Mediterranean Sea.

The plan was abandoned following the change of circumstances in the JR Basin after World War II with the creation of Israel and the influx of large numbers of refugees (Lowdermilk; 1944).

Lowdermilk plans were later elaborated by James B. Hays, an American engineer who worked as a consultant to the Jewish Agency.

3.3 The water conflicts and solution attempts between 1948 and 1967:

After the establishment of Israel, the water conflicts appeared in Jordan River Basin and commanded the attention of the United States.

In October 1953, the United States prepared the Johnston Plan attempt to solve the area's water crisis. The rising tension caused by the Israeli initiation of the National Water Carrier project, encouraged the United States to mediate between the two parties (Israel and the Arabs states).

The JP incorporated provisions and involved discussions of proposals germane to the following areas:

- Riparian water quotas, including quantities, basis of estimation, priorities of extraction, points of extraction, and spatial utilization (in and out of basin boundaries).
- Regulatory works, including diversion canals and dams and their location.
- A joint management body, including international representation.

JP Quotas:

The quotas that were assigned to the four riparians from the Jordan River system (the West Bank was then part of Jordan), together with recent uses, are exhibited in table (3.1)).

The overall volume that was to be distributed among the riparians was an average of 1,273 million cubic meters per year (MCM/y).

Table 3.1 Actual use versus quotas under the Johnston Plan in the Jordan River Basin (Elmusa; 2007).

Country	Quota (mcm/y)	Percent of total	Actual use(mcm/y)	Percent of total
Lebanon	35	3	20	<2
Syria	132	10	200	17
Israel	400	34	690	60
Jordan	720	56		
East bank	505	39	250	22
West bank	215	17	0	0
Total	1287	100	1160	100

According to JP Lebanon Both quotas and actual use from the Hasbani.

Syria quota 90 from the Yarmuk, 22 from the Jordan, and 20 from the Banyas, all actual use Syria was from the Yarmuk.

Israel quota 375 from the Jordan, 25 from the Yarmuk, Israel actual use was 550 from the Jordan and 70-100 from the Yarmuk.

Jordan quota 100 from the Jordan, 377 from the Yarmuk, and 243 from the western and eastern side wadis. The east bank quota 297 from the Jordan and the Yarmuk and 206 from the side wadis, actual use of the east bank was 130 from the Yarmuk and 120 from the side wadis. The West

Bank quota 180 from the Jordan and the Yarmuk and 35 from the side wadis.

In the Johnston plan, the Palestinian share in the Jordan River was considered as part of the Jordanian share as the West Bank was under the Jordanian rule. Since 1967 war and until present, Palestinians were prohibited by the Israeli army from using the Jordan river water and their lands and farms located along the western side of the river were confiscated and the area was declared as a restricted military security zone (Haddad; 1993, Haddad et al; 2008).

The quotas for Israel were largely a residual; that is, Israel would not divert them until the Arab riparians had tapped theirs. That meant they were not guaranteed quantities, owing to the fluctuation of rainfall. Yet Israel took much more under the Jonston Plan than had British-mandated Palestine under the Anglo French Convention.

The quotas rewarded Jordan handsomely as well. The reason for the generosity of the Jonston Plan allocations to Israel and Jordan undoubtedly lay in its broad goals, namely, putting Israel on its feet and re-settlement of Palestinian refugees in the Jordan Valley.

Lebanon and Syria, in contrast, did not get so well under the Jonston Plan, although the convention had accorded them first priority of use.

For both Israel and the Arab riparians as a whole, the quotas were less than each side had demanded in the course of the negotiations, but Israel was allocated about one-third of the total allocations and the three Arab riparians received two-thirds (Elmusa;2007).

The way of determining the shares in Jonstons plan:

The shares were calculated on the basis of the irrigable area within the Jordan basin. Agriculture at that time was considered the main vehicle of development and municipal and industrial use was still small. The quotas were to be tapped according to the geographical location of the ripariansin the system for example Lebanon was to get waterfrom al-Hasbani; Syria from Banyas.

It's mind-boggling the subject of quotas is if Jonston Plan permitted Israel to divert water outside the boundaries of the basin to the Negev and to the coastal plain, as it eventually did through its National Water Carrier (NWC).

There is a lot of evidence that the Arab negotiators did not have to agree to Israel’s demand for out of basin diversion. Proof of the previous the words of Mahmud Riyadh, who served on the Arab Technical Committee which negotiated with Johnston “Weobjected in principle to the use of the Jordan River water outside the basin” (Riyadh; 1984, Elmusa; 2007).

Engineering works and joint commission:

The JP had provisions for the engineering works that were to be used for harnessing water from the river system and regulating its flow. There were also inconclusive discussions regarding the institutional framework for unified management of the basin.

Syria's response to JP:

Syria appears never to have accepted the Johnston Plan. In the hydropolitical literature, emphasis has been placed on the political aspect of its rejection; it rejected the Jonston Plant because it meant recognition of Israel and provided the means for strengthening Israel's economy.There is a possibility that Syria was not satisfied with the size of its quota.

Lebanon's response to JP:

Although the literature that consider the Lebanon's response to Jonston Plant are rare; Lebanon, like the other Arab countries, did not accept the JP in 1955 on political grounds.

Israeli response to JP:

For Israel, the JP was without a doubt an achievement, giving it one-third of the water of the Jordan River system, even though mostly as a residual. Equally important, it secured the acknowledgment of the Arab countries that Israel was a co-riparian, which is tantamount to tacit recognition.

Although in 1964 Israel invoked the JP when it was about to inaugurate its National Water Carrier (NWC), and when the Arab countries, in response, decided to divert the headwaters of the Jordan through Syria and into Jordan.

Jordanian's response to JP:

Jordan favored the JP even when it opposed it onpolitical grounds. The Jordan River is its main water source and the JP granted it enough water to irrigate 50,000 ha in the Valley, the principal irrigable area in the country.

The United States itself had conditioned its aid to Israel and Jordan for projects in the Valley on their adherence to the Johnston Plan.

The Palestinian's response to JP:

At the time of the JP, the Palestinians opposed it, but not because of water shares: they wanted the water, but they wanted it in Palestine.

The quota that was allocated to Jordan and earmarked for the Valley's Palestinian and Jordanian farmers (the majority Palestinians), was generous 720 MCM/y of which 477 was from the Jordan and Yarmuk channels and 243 from the lateral wadis.

The Palestinian objection was to the idea of resettlement outside their original homes in Palestine. They did not accept the terms of the exchange, namely, Palestine for Jordan River water in the Valley.

3.4 The water conflicts between 1967 and 1993:

In 1967 war Israel had achieved the control of the main regional water resources in the Jordan River Basin, this was through its occupation of the Golan, which is crossed by the tributaries of the upper course of the Jordan river (the Dan and Banyas), and the West Bank, with the rich aquifers of the Mountain, and the coastal aquifer of Gaza. Through its control of the Golan, Israel gained total control of the Jordan river and was able to use water as a negotiating weapon.

After 1967 war the only source that remained outside of Israel's control was the Hasbani, which originates in southeast Lebanon.

Israel imposed many restrictions on Mountain aquifers use in the West Bank by the local Palestinian populations.

In this period and due to the explosive political situation, there were no serious attempts to resolve the water situation in the Jordan River Basin (Elmusa; 2007).

3.5 The water conflicts and solution attempts after 1993:

In 1993 Oslo I agreement confirmed the importance of the environment and water resources in the peace process, laying the foundation for future cooperation in this sector.

On October 26, 1994, Israel and Jordan signed the Treaty of Peace, water issues was of the main topics that addressed in this treaty, Israel and

Jordan have agreed on allocations of water from the Jordan and Yarmouk Rivers and from Arab aground waters. Israel has agreed to transfer to Jordan 50 million cubic meters of water annually from the northern part of Israel. In addition the two countries have agreed to cooperate to alleviate the water shortage by developing existing and new water resources, by preventing contamination of water resources, and by minimizing water wastage.

Oslo II is a temporary agreement signed between the Palestinians and Israelis in September 1995, named with reference to “Oslo I,” the initial Declaration of Principles which initiated the peace process in September 1993.

Article 40 of the Agreement of Oslo II, entitled “Water and Sewage”.

The main principles of Oslo II:

The Palestinians succeeded in including in the Agreement an explicit reference to water rights. The first substantive language of the water provisions of the Interim Agreement is as follows: “Israel recognizes the Palestinian water rights in the West Bank. These will be negotiated in the permanent status negotiations and settled in the Permanent Status Agreement relating to the various water resources” (Oslo II Article 40.1).

The Interim Agreements' principles focus on the necessity to augment existing reserves and to maintain existing uses (Article 40.2, 3a) and to prevent water quality deterioration (Article 40.3b, f).

The Agreement notably adds language on sustainability in terms of both quantity and quality and on the factoring of inter annual variability in hydrologic conditions (Article 40.3c,d).

Wastewater reuse is introduced as a principle (Article 40.3f), as is avoidance of harm (Article 40.3h).

The Agreement calls for coordinated operation, management, and development of water and sewage systems and insurance that the provisions of the Agreement are applied to all resources and systems, including those under private ownership or operation (Article40.3g,i).

The Agreement calls for transfer of authority; That "the Israeli side shall transfer to the Palestinian side, and the Palestinian side shall assume, powers and responsibilities in the sphere of water and sewage in the West Bank related solely to Palestinians, that are currently held by the military government and its Civil Administration, except for the issues that will be negotiated in the permanent status negotiations" (Article 40.4).

The agreement also indicates that the issue of ownership of water and sewage related infrastructure in the West Bank will be addressed in the permanent status negotiations (Article 40.5).

In Oslo II both sides have agreed that the future needs of the Palestinians in the West Bank are estimated to be between 70 - 80 MCM/year. In order to meet the immediate needs of the Palestinians in fresh water for domestic use, both sides recognize the necessity to make available to the Palestinians during the interim period a total quantity of 28.6 MCM/year (Article 40.6, 7).

In order to implement their undertakings under this Article, the two sides will establish, upon the signing of this Agreement, a permanent Joint Water Committee (JWC) for the interim period(Article 40.11), the function of the JWC shall be to deal with all water and sewage related issues in the West Bank see appendix A3 (Article 40.12, a , j).

The agreement also indicates that both sides recognize the necessity to establish a joint mechanism for supervision over and enforcement of their agreements in the field of water and sewage, in the West Bank, for this purpose, the agreement asked both sides to establish(upon the signing of this Agreement) Joint Supervision and Enforcement Teams (JSETS).

Schedule 10 of the Agreement places numerical estimates on the “utilization, extraction, and potentials” of the sub-basins of the Mountain Aquifer, which it refers to as the Eastern, Northeastern, and Western Aquifers.

The Eastern Aquifer is estimated to have an annual recharge of 172 MCM, of which 40 MCM (from wells) are utilized by Israelis, 54 MCM

(24 MCM from wells and 30 MCM from springs) are utilized by Palestinians and an additional 78 MCM are “to be developed.”

The Northeastern Aquifer is estimated to yield 145 MCM, of which 103 MCM) are utilized by Israelis and 42 MCM are utilized by Palestinians (25 MCM to users around Jenin and 17 MCM from the East Nablus springs).

The Western Aquifer is estimated to have an annual recharge of 362 MCM, of which 340 are utilized within Israel and only 20 MCM by the Palestinians. An additional 2 MCM from springs around Nablus is also to be utilized by Palestinians.

The Interim Agreement requires the parties to “take all necessary measures” for the prevention of water quality deterioration and pollution, the protection of water and sewage systems in their own and the counterpart’s jurisdictions (Article 40.21-24) as well as to reimburse the counterpart for “any unauthorized use or sabotage” to water systems under its responsibility (Article 40.24).

3.6 The current situation of water and water conflicts:

The evolution of the life of the Palestinian community led to increasing demand for water to achieve the goals of sustainable development and economic development, but the limited water resources available stand as an obstacle in front of it, in 2012 the amount of water available was 349.2 million m^3, of which 56.6 million m^3 are from the Israeli water company "Mekorot", which constitute 28% of the water supplied to the domestic sector in addition to the 130 million cubic meters of unfair pumping from the coastal basin in the Gaza Strip.

The growing number of the population and the stability of the amount of water available in the Oslo agreement have a significant impact in influencing the per capita share of the Palestinian water consumed (all numbers are according to the Palestinians water authority). This per capita was about 76.4 liters / person / day in 2012 in the West Bank while it was about 89.5 liters / capita / day in the Gaza Strip. However, more than 95% of the water consumed in the Gaza Strip does not comply with World Health Organization standards for drinking water. Also, in terms of quantity, this per capita is less than the minimum recommended by the organization itself, which (100 liters / capita / day) as a minimum. Based on the water information for the year 2012, the proportion of water that Palestinians get from the aquifers in the West Bank does not exceed 15% of the total water exploited.

Continuing the past and present approaches of dealing with the water problem will result in a serious harm to both people with different proportions and scales (Haddad 2007).

CHAPTER FUOR

Methodology

4.1 Scope of WF accounting:

In order to assess WF within the JRB, we need to know the WF of crops production, WF of livestock production, WF of the industrial sector and WF of the domestic sector in each riparian (Jordan, Palestine, Israel).

There are two types of water resources: blue water (surface water and groundwater), and green water (soil water) (Liu and Savenije; 2008, Zeng et al; 2012). Both types of blue and green components of WF were estimated for crops water footprint but only blue water footprint for livestock, industrial and domestic sectors were estimated. The blue water footprint of JRB were assessed.

The blue and green WF accounting and sustainability assessment are mainly based on the standard methods proposed in the Water Footprint Assessment Manual (Hoekstra et al; 2011).

The gray water footprint was not included in this study, because there were no available data about the amount of pollution in JRB water recourses.

In this study, we estimated WF within Palestine (West Bank and Gaza strip), Jordan and Israel, while neglecting Syria and Lebanon because of lack of data about them. We estimated WF in the JRB over 2009–2011 and used the annual results for the presentation of results.

4.2 Crop production and livestock production in the JRB:

There were many difficulties in finding the data at river basin level, so we collected data for administrative boundaries (Palestine, Jordan and Israel). The steps to calculate the WF of each country within the JRB are depicted in (Figure4.1).

The data like the percentage of winter and summer crops and protective crops percentage in each country were taken from the agricultural statistics in each country. We assumed that all the agricultural areas in the three countries as if they are located within the JRB and that the WF of JRB equals the summation of the WF of the three countries.

The crops and livestock products have the highest quantity of production.

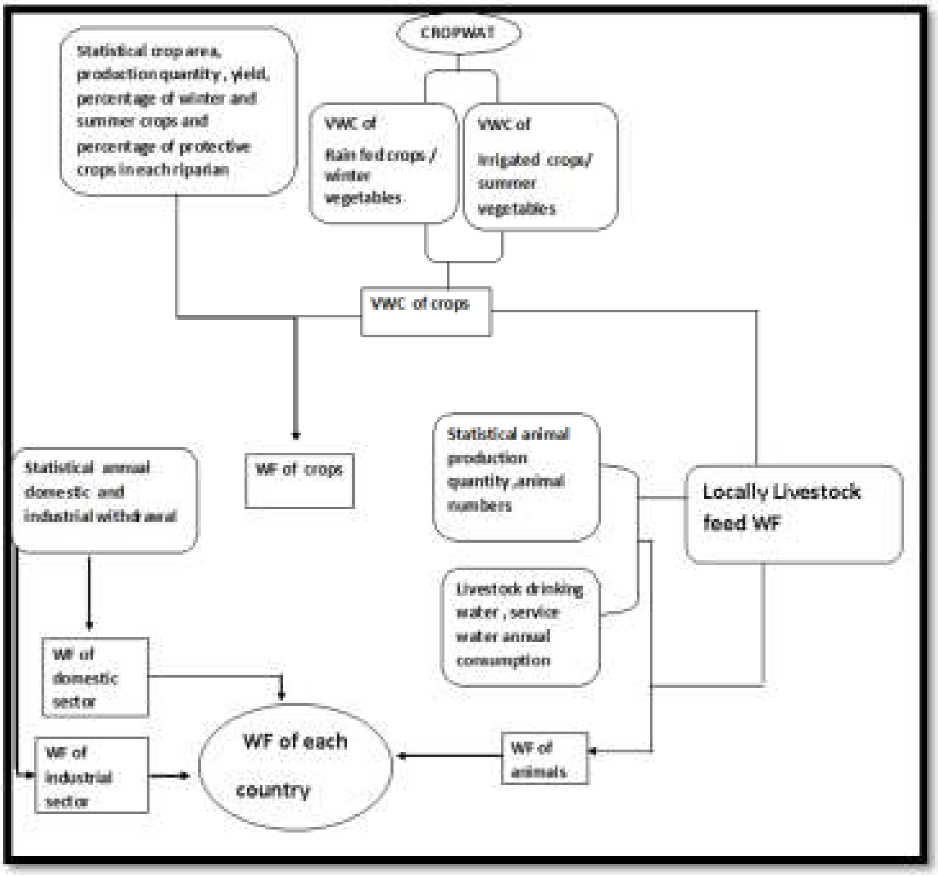

Figure (4.1): Steps to calculate water footprint (WF) in each country.

Usually the livestock production is calculated by multiplying the number of an animal type by its average production. In this study the production quantities in each riparian were obtained from FAOSTAT for the period under consideration (2009-2011).

4.3 WF of crop production:

WF of crops was calculated by multiplying virtual water content (VWC) of each crop with its production amount and then summing up all crops. VWC is defined as the amount of water (m^3) that is needed to produce a product per unit of crop (ton) during the crop growing period. The green and blue components of VWC are calculated as the ratio of effective rainfall (ER, m^3/ ha) or irrigation (I,m^3/ha) to the crop yield(Y, ton/ha).

The VWC of crops is the sum of green VWC (VWC_{green}) and blue VWC (VWC_{blue}) (Hokestra et al 2011).

$VWC_{green} = ER/Y$

$VWC_{blue} = I/Y$

$VWC = VWC_{green} + VWC_{blue}$

The CROPWAT model (FAO; 2010, Allen et al; 1998) was used to estimate ER and I for crops. Both the rain fed and irrigated conditions were taken into account. The green and blue water incorporated into the crops or water used in vegetative crop were not estimated because in general they account for very small (about 0.1% of the evaporated water, up to 1% at most) (Hoekstra et al; 2011, Zeng et al; 2012).

The CROPWAT model needs climate, crop and soil parameters to model evapotranspiration and crop irrigation requirements. Climate data include temperature, precipitation, humidity, sunshine, radiation and wind speed.

For each riparian the average climate data in each country were collected. Crop parameters such as crop coefficients, rooting depths, lengths of each crop development stages, were obtained from Jordan ministry of agricultural brochures and also from the FAOSTAT for

Mediterranean areas (appendicesA1 and A2) with some correction to the local conditions according to the values of the ministry of agriculture for each country. Because no information was available for maximum rooting depth FAO recommended values as shown as default parameters in CROPWAT were taken. For initial moisture conditions, it was assumed that the soil moisture content in the beginning and at the end of the season were at field capacity for irrigated agriculture. For rainfed agriculture, soil moisture was assumed at permanent wilting point at the start of winter as rainfall occurs only in winter months. At planting time, soil moisture was assumed to be at field capacity and could drop to the wilting point by the end of the cropping season. This is due to the common practice that farmers usually plant their rainfed crops after soil moisture reaches the field capacity. For rainfed trees, soil moisture was assumed at nearly permanent wilting point at the start of winter.

4.3.1 Vegetables Virtual Water Content and Water Footprint:

For each country of the riparian the data about the cultivated area with winter and summer vegetables were obtained from the agricultural branches of central statistical agencies. The winter vegetables planted in the period between October and December, in this study we took November, these vegetables depend on rainfall in addition to supplementary irrigation water.

The summer vegetables planted normally in the period between March and June, in this study we took April as planting date for summer vegetables. These vegetables depend mainly on blue irrigation water.

In this study, it was taking into account the ratio of the area that relied on protected agriculture, where it was assumed that the irrigation water consumption of protected vegetables water will decrease to nearly half at the same yield.

4.3.2 Field crops Virtual Water Content and Water Footprint:

The field crops were irrigated crops or rain fed crops or irrigated and rain fed crops. The harvested area and the amount of production for each crop were obtained from FAOSTAT and the irrigated areas percentage were obtained from the agricultural statistics in each country.

VWC and WF calculations for the main field crops in each riparian were considered. For Jordan, the rain fed field crops were mainly wheat and barley with average annual production in the period 2009-2011 of 18136 and 19002 tons respectively. The irrigated area percentage was 0.057% for wheat and 0.015% for barley. The irrigated crops of Jordan are maize and sorghum with production quantity of 21740 and 18193 tons respectively, and these two field crops are totally irrigated crops.

For Palestine wheat and barley are also the main rain fed field crops while sorghum is the main irrigated field crop. The average annual production was 21612 tons for wheat. Only 1.8% of them from irrigated wheat, barley average annual production was7190 tons only 1.3 % of them from irrigated barley. Sorghum annual production was 119tons 58% of them cultivated area was irrigated.

For Israel wheat and barley are totally rain fed field crops while cotton, sunflower and check peas are totally irrigated field crop. The average annual production of wheat (2009-2011) was 122437 tons and of barley about 4834 tons. Cotton average annual production (2009-2011) was 15900 tons and the sunflower average annual production at the same period was 15755 tones and the average annual production of check peas in the same period was15755 tons.

The green and blue VWC were calculated by dividing the effective rainfall (ER, m^3/ ha) and irrigation (I,m^3/ha) to the field crop yield (Y, ton/ha) which obtained from FAOSTAT. In order to calculate green WF, green VWC multiplied with the total production quantity. The blue WF calculated by multiplying the irrigated production with blue VWC.

4.3.3 Trees Virtual Water Content and Water Footprint:

The trees green and blue virtual water content were estimated as the ratio of effective rainfall (ER, m^3/ ha) and irrigation (I,m^3/ha) to the crop yield (Y, ton/ha). The needed data for CROPWAT model were obtained from Jordan ministry of agriculture (assumed the same numbers for the three countries) the missed data were FAO values for Mediterranean areas see Appendices A1 and A2).

The green water footprint of each type of trees was calculated by multiplying green VWC with the average annual production (2009-2011). The blue water foot print was estimated by multiplying blue VWC with the average annual irrigated production (2009-2011).The average annual irrigated production was estimated by multiplying the average irrigated harvest area with the average yield for the same period.

4.4 WF of livestock production:

The water footprint of a live animal consists of different components: the indirect water footprint of the feed and the direct water footprint related to the drinking water and service water consumed (Chapagain and Hoekstra; 2003, Mekonnen and Hoekstra; 2012).

The water footprint of an animal is expressed as:

$$WFl = WF_{feed} + WF_{drink} + WF_{serv}$$

Where WF_{feed} related to feed water consumption, WF_{drink} related to drinking water consumption and WF_{serv} related to service water consumption water which refers to the water used to clean the farmyard, wash the animal and carry out all other services. Livestock WF was expressed in terms of MCM/year.

The WF of animal products was calculated by multiplying VWC of a type of livestock product with its production and then summing up all types of livestock types.

VWC of meat is defined as the amount of water (m^3) that is needed to produce a unit of meat (ton). For the indigenous chicken meat and indigenous turkey meat the WF calculations were performed at the end of animal lifetime (40 days for chicken and 150 days for turkey). In the calculations of milk and eggs WF, we looked at the water footprint of the animal per year (averaged over its lifetime), because one can easily relate this annual animal water footprint to its average annual production (milk, eggs).

The water footprint of an animal related to the feed consumed consists of two parts: the water footprint of the various feed ingredients and the water that is used to mix the feed (Mekonnen and Hoekstra; 2012). In this study we excluded WF of mixing since it’s a part of water footprint of industrial sector and it’s a mistake to introduce it twice.

$$WFfeed = \sum_{c=1}^{c=n} \left(\mathrm{F(ton/y)} \times \mathrm{WFf(m3/ton)} \right)$$

Where F represents the annual amount of feed ingredient consumed (ton/y), WFf the water footprint of feed ingredient f(m^3/ton),all the previous definitions for animal category a and production system s in a nation c.

The blue water footprints of feed crops was estimated only for irrigated feed crops and for crops that not included in crops water footprint calculations. Blue VWC of feed crops was calculated using the CROPWAT model.

The blue WF of feed crops was estimated by multiplying of each type production by its blue VWC. The main irrigated livestock feed crops that locally cultivated in Israel and not included in crops WF calculations were sorghum and green fodder, for Jordan clover trefoil was the main irrigated livestock field crop, for Palestine there were no irrigated feed crops.

All poultry feed raw components in the JRB imported from foreign countries (such as Ukraine), the green and blue water used in the cultivation of these crops drawn from water resources outside JRB and so it will be ignored in this study.

Drinking and processing water is dominantly blue. The data about the amount of drinking water and service water were taken from ministries of agricultural and asking the farmers and specialists in each sector.

4.5 WF of industrial and domestic sectors (WFi and WFd):

The WF of industrial and domestic sectors is estimated by multiplying water withdrawal with a water consumption ratio (WCR) for each sector in each riparian. According to the FAO's global water information system AQUASTAT, Jordan water withdrawal for domestic purposes in 2005 was 291.3MCM and for industrial purposes it was 38.4MCM.

The (WCR) for domestic and industrial sectors in Jordan was 31% and 4.1% respectively and with 166 m^3 water withdrawal per capita.

For Israel and according to the AQUASTAT the available data was for the year 2004 the domestic withdrawal was 712 MCM and the withdrawal for industrial sector was 113MCMwith(WCR) for domestic and industrial sectors 36.4% and 5.8% respectively and with 282.4 m^3 water withdrawal per capita.

For Palestine, and according to the AQUASTAT the water withdrawal for domestic purposes in 2005 was 200 MCM and the withdrawal for industrial sector was 29 MCM with (WCR) for domestic and industrial sectors 47.8% and 6.9% respectively and with 112.1 m^3water withdrawal per capita.

The WF of industrial and domestic sectors in the JRB was estimated by summation the WF of each sector in each one of the three riparian countries. At JRB level (the three riparian countries) WF of domestic sector was 1203.3 MCM, and WF for industrial sector was 180.4 MCM.

4.6 WF sustainability assessment:

The WF sustainability was assessed by comparing blue WF with blue water availability (blue WA) at Jordan River basin.

Hoekstra et al (2011) in the water footprint manual said that the blue water footprint in a specific period in a specific catchment forms a hotspot when the blue water footprint exceeds blue water availability. In other words when blue WF exceeds blue WA, there is a reason for sustainability concern.

Because the estimation of green water availability is difficult process the analyzing of green water footprint sustainability was ignored.

According to Hoekstra et al(2011), blue WA was estimated as below:

$$\text{Blue WA} = \text{BWR} - \text{EFR}$$

Where BWR means the blue water resources under natural conditions without human intervention, or the natural runoff. It was estimated as the total amount of surface and groundwater flows in JRB (the summation of three riparians blue water resources). The annual BWR was taken from AQUASTAT countries water resources sheets.

EFR stands for environmental flow requirements and it was taken as 80% of natural runoff as it was suggested in Hoekstra et al (2011).

In order to assess the WF social sustainability at this study we examine two conditions the first was if human needs are met by all people in the study area and the second if the basic rules of fairness are met in JRB.

4.7 Linking WF sustainability with water conflicts in the JRB:

It is clear that there is a strong relation between WF sustainability and water conflicts; that the places and times with unsustainable WF forms fertile social conflicts over water will often arise at the same time as when environmental conflicts occur. Therefore, the identification of environmental hotspots will also generate a list of potential social hotspots (Hoekstra et al; 2011). In this study WF sustainability was considered as strong and reverse indicator for water conflicts.

CHAPTERFIVE

Results and Discussions

5.1 Jordan results:

Jordan has two main agricultural production zones: the first zone is the Jordan Valley, which specializes in the production of winter crops, the second zone is the highlands zone which specializes in the production of summer crops.

The harvest of vegetables in the Jordan Valley starts from the beginning of the December and continues until the end of May of the following year. The highland areas such as Amman and the Zarqa basin area harvest vegetables starting from the beginning May and lasts until October.

Jordanian farmers rely on various systems of agricultural practices in the cultivation of vegetables, it was clear in the Jordanian overall results of the agricultural census (2007) which indicate that the percentage of irrigated cultivation of vegetables was 79 percent of the total cultivation of vegetables in Jordan.

5.1.1 Virtual Water Content and Water Footprint of Jordanian crops:

Vegetables:

VWC of vegetables is the amount of water (m^3) that is needed to produce a unit of a specific type of vegetables (ton)during the vegetables growing period. The green and blue components of VWC were calculated as the ratio of effective rainfall (ER, m^3/ ha) and irrigation (I,m^3/ha) to the crop yield (Y, ton/ha) respectively.

The CROPWAT model was used to estimate ER and I of vegetables. Both the rainfed and irrigated conditions taking into account the percentage of cultivated land with protected vegetables and we assume that the consumption of irrigation water will be about the half of open cultivated area at the same productivity.

As we mentioned in the previous chapter, every type of vegetables divided to winter planted and summer plating, taking into account the percentage of the protected vegetables of each type.

The following table shows the calculated green and blue VWC for winter and summer vegetables of Jordan.

Table (5.1): Green and blue Virtual Water Content of winter and summer vegetables in Jordan (2009-2011).

Vegetable type	Winter vegetables		Summer vegetables	
	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)
Tomatoes	17.81	41.57	0.02	176.59
Cucumbers	7.77	6.96	0.01	52.89
Potatoes	27.45	53.92	0.03	258.48
Eggplants (aubergines)	22.35	42.35	0.02	199.63
Watermelons	17.45	29.39	0.02	152.83
Cauliflowers &broccoli	29.40	61.51	0.03	271.29
Pumpkins, squash & gourds	32.31	48.65	0.04	264.89
Chillies & peppers, green	25.07	46.37	0.03	223.23
Lettuce & chicory	17.04	39.92	0.04	166.30
Other melons	23.22	38.47	0.03	198.47

The overall blue VWC of each type of vegetables was calculated as the following :

$$VWC_{blue} = (VWC_{blue\text{-}s}\,(m^3/ton) \times P_s(\%)) + (VWC_{blue\text{-}w}\,(m^3/ton) \times P_w(\%))$$

Where $\mathbf{VWC_{blue}}$ the blue VWC of any type of vegetables, $\mathbf{VWC_{blue\text{-}s}}$ is the blue VWC of the summer planted of the same type, P_s the percentage of summer production of the same type, $\mathbf{VWC_{blue\text{-}w}}$ is the blue VWC of the winter planted of the same type, P_w the percentage of winter production of the same type.

Table 5.2 shows the blue VWC and the total VWC of the main vegetables types in Jordan. The blue VWC ranged between 59.84m^3/ton and 332.81m^3/ton.

Among all vegetables studied for Jordan, melons (cantaloupe) have the largest VWCof193.05m^3/ton, 192.10m^3/ton of that are blue water (figure 5.1). Cauliflowers and broccoli also have high VWC of171.55m^3/ton. Vegetables of Jordan in general have blue VWC values ranging from 20.23 to 192.1 m^3/ton table (5.2).

The blue water proportion(BWP) is defined as the ratio of blue VWC to VWC (Liu etal., 2009, Zeng et al 2012).Nearly all of Jordan vegetables have BWP more than 80% because of the large reliance on irrigation with blue water.

Cucumbers and gherkins have the lowest BWP because these vegetables are mainly protected agriculture (90% of the production comes from protected agricultural cultivation) and it has low blue water consumption per ton of production compared with other vegetables.

Table (5.2): Virtual water content, water footprints and blue water proportion of main vegetables of Jordan (2009-20011).

Crop type	VWC_{blue} (m^3/ton)	VWC(m^3/ton)	WFg (MCM)	WFb (MCM)	WF(MCM)	BWP (%)
Tomatoes	87.18	98.98	8.54	61.89	70.43	88.08
Cucumbers and gherkins	20.23	25.76	1.00	1.98	2.98	78.54
Potatoes	102.65	123.56	3.55	17.39	20.94	83.07
Eggplants (aubergines)	82.54	99.18	1.82	8.79	10.61	83.22
Watermelons	141.67	143.27	0.20	13.53	13.73	98.88
Cauliflowers and broccoli	155.28	171.55	1.07	10.22	11.29	90.51
Pumpkins, squash & gourds	115.47	137.82	1.66	7.97	9.63	83.79
Chillies and peppers, green	127.17	140.80	0.74	6.24	6.98	90.32
Lettuce and chicory	74.65	87.01	0.53	3.20	3.73	85.79
Other melons	192.10	193.05	0.03	5.07	5.10	99.51
Other vegetables	-------	--------	1.66	11.85	13.51	-----
Total			**20.80**	**148.13**	**168.93**	

WF of vegetables was calculated by multiplying virtual water content(VWC) of each vegetable type with its production amount and then summing up all vegetables water footprints. The blue WF was calculated by multiplying blue VWC of each vegetables type with each type production amount and then summing up all vegetables water footprints.

The average annual WF of vegetables was169 million m^3in Jordan during 2009–20011. About 87.7 % (148MCM) of them was due to the use of blue water, while the remaining 12.3% (21MCM) was from the use of green water (Figure 4.2). Tomatoes and potatoes accounted for more than the half of the vegetables WF (58% of the total vegetables WF).

Cucumbers and gherkins have the lowest WF(3MCM) despite they have high production of about 180470 tones. This high production with small WF related to the use of protective cultivation and the use of modern methods of irrigation management.

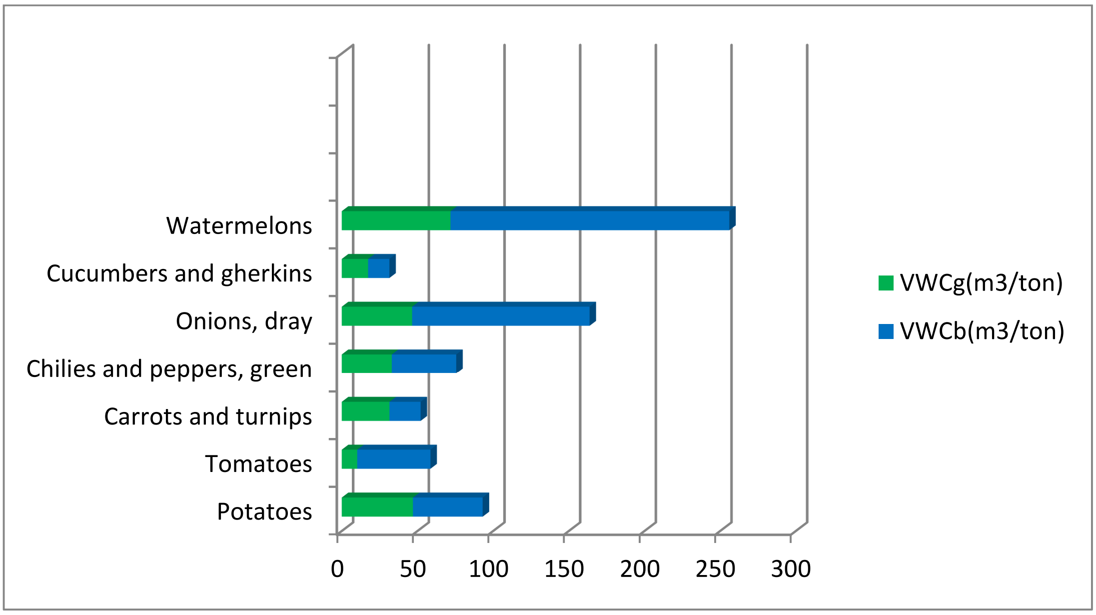

Figure (5.1): Blue and green virtual water content (VWC) of vegetables in Jordan (2009-2011).

Field crops:

The field crops in Jordan and in JRB generally are rain fed, the main rain fed field crops in Jordan are wheat and barley.

More than 94% of Jordanian wheat depends only on rainfall water and just 6% takes supplemental blue water irrigation.

The estimated green WF of wheat (2009-2011) was 10.68 MCM. These values will change according to the precipitation ratios. The blue WF of the 6% irrigated wheat was 6.84 MCM which is a huge number compared with the small percentage (6%).

More than 98.5% of barley in Jordan are rain fed with green WF of 24.94 MCM and blue WF of 1.04 MCM for the remaining 1.5%. The other cereals like lentils, vetch and check- peas are mainly rainfed.

The main irrigated field crops in Jordan are maize and sorghum, the estimated blue WF of maize was 3.16 MCM and for sorghum 2.95 MCM

The other field crops blue WF was about 12.13 MCM. The total blue WF of Jordanians field crops was estimated at 26.12 MCM. The blue WF of clover trefoil was estimated in livestock blue WF.

Trees:

According to department of Statistics/ Agricultural Census 2007 harvested area of fruit Trees in Jordan is 813054 hectares 433265 hectares of them are Irrigated and 379789 are Non-Irrigated.

Table 5.3 shows the main fruit trees types considered in this study with the percentage of irrigated area of each type. It also shows the estimated green and blue WF for each type.

Table (5.3): Green and blue WF of Fruit Trees in Jordan (2009-2011).

Tree Type	% Irrigated	WFg(MCM)	WFb(MCM)
Olives	41	14.31	154.21
Bananas	100	2.16	20.38
Citrus Fruit	100	6.84	37.20
Grapes	68	3.42	10.85
Apples	78	0.38	11.64
Peaches	91	0.39	12.71
Dates	100	2.00	42.87
Other trees	41	1.24	12.17
Total	**----**	**30.74**	**302.02**

Olive trees have the largest green and blue WF of 14.31 MCM and 154.21 MCM respectively. Olives have a large blue WF although the percentage of irrigated area is less than half percent (about 0.41%) and this is due to the large area cultivated with olives compared with other tree types. Dates and citrus fruit also have a large blue water 42.87MCM and 37.2MCM respectively that they are totally irrigated trees. Grapes have small blue water of 10.85MCM.

The total green WF of trees considered in the study in Jordan for the period 2009-2011 was 29.5MCM and the blue WF was 289.85MCM which are huge numbers compared with vegetables WF.

5.1.2 Blue WF of animal products of Jordan:

The blue WF of animal products was calculated by multiplying VWC of a type of livestock product with its production and then summing up all types of livestock types.

VWC of indigenous chicken meat is the amount of water (m^3) that is needed to produce a unit of meat (ton). The calculation performed at the end of animal lifetime (40 day).

In the calculations of milk and eggs WF, we looked at the water footprint of the animal per year (averaged over its lifetime), because one can easily relate this annual animal water footprint to its average annual production (milk, eggs).The average annual blue WF of livestock was

5.93MCM during 2009–2011.Sheep's milk and cow's milk accounted for over 61% of livestock blue WF. This is due to the large amount of drinking and serves water consumption compared with poultry table 5.4.

Table (5.4): Blue Water footprint of Animal products in Jordan (2009-2011).

Animal product	WFl(MCM/year)
Cow milk, whole, fresh	1.18
Indigenous Chicken Meat	2.11
Sheep milk, whole, fresh	2.43
Hen eggs, in shell	0.20
Total	**5.93**
Livestock blue WF (for irrigated feed ingredients)	2.21
Total	**8.14**

5.1.3 WF of Jordan industrial and domestic sectors:

The WF of industrial and domestic sectors of Jordan was estimated by multiplying water withdrawal with a water consumption ratio (WCR) for each sector. The available data for Jordan water withdrawal was for the year of 2005. Table 3.4 shows the Water Foot print of domestic and industrial sectors for Jordan.

Table (5.5): Water footprint of domestic and industrial sectors in Jordan.

Sector	WF(MCM/y)
Domestic	291.3
Industrial	38.4
Total	**329.7**

According to AQUASTAT the FAO's global water information system

5.2 Palestine results:

The cultivated area in Palestine was estimated at 185400 hectares, or 31% of the total area of the West Bank and the Gaza Strip out of which 91% in the West Bank and 9% in the Gaza Strip. The rain-fed area constitutes 86% while the irrigated area constitutes 14% of the total cultivated area.

The Palestinian territory is rich of agricultural biodiversity and enjoys a diversity of climate and multiple agricultural environments, that qualify it to produce several crops over different periods of the year. The global climate change Impacts negatively affects Palestinian agriculture, particularly in terms of increasing and recurrent years of drought, frost and floods.

Since the Palestinian agriculture depends mainly on rain fall, the production fluctuates from one year to another depending on the amount of rain, which in turn affects the production mainly of olives and field crops. The production might reach in a year of good rain nearly five times more than in a years of low rainfall. The same applies on numbers and production of livestock especially sheep and goats which depend mainly on the fodder prices, and rainfall (Palestinian ministry of agriculture "agricultural sector strategy 2011-2013").

5.2.1 Virtual Water Content and Water Footprint of Palestinian crops:

Vegetables:

The steps of virtual water content and water footprint calculations were the same as mentioned in Jordan results (section 5.1.1).

The following table shows the calculated green and blue VWC for winter and summer vegetables of Palestine.

Table (5.6): Green and blue Virtual Water Content of winter and summer vegetables in Palestine (2009-2011).

Crop type	Winter vegetables		Summer vegetables	
	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)
Cucumbers and gherkins	15.45	3.35	0.25	51.44
Tomatoes	15.62	8.11	0.20	62.58
Potatoes	62.81	53.17	0.78	261.89
Eggplants (aubergine)	32.14	13.71	0.41	118.54
Pumpkins, squash & gourds	74.31	12.41	1.20	238.84
Onions, dry	66.82	40.70	0.83	276.34
Cauliflowers and broccoli	38.64	14.82	0.55	145.66
Cabbages & other brassicas	37.01	14.20	0.52	139.52
Maize , green	88.90	45.51	1.10	355.17

The method of calculation over all blue VWC of any type of vegetables is the same as that mentioned in section 5.1.1.

Among all vegetables studied for Palestine, green maize has the largest VWC of 204m^3/ton,143m^3/ton of them blue water (figure 5.2). Potatoes also have high VWC of176m^3/ton.

Vegetables of Palestine in general have blue VWC values ranging from 24to 143m^3/ton table (5.7).

The blue water proportion (BWP) of Palestinian vegetables ranges from 36.17% for cabbages to 78.75%for potatoes.

Cabbages have the lowest BWP because these vegetables are mainly winter vegetables that rely mainly on rainfall.

Compared with vegetables grown in Jordan vegetables cultivated in Palestine have a less ratios of BWP due to the differences in climate and annual rainfall between the two countries.

Table (5.7): Virtual water content, water footprints and blue water proportion of main vegetables of Palestine(2009-20011).

Crop type	VWC$_{blue}$ (m^3/ton)	VWC (m^3/ton)	WFg(MCM)	WFb(MCM)	WF (MCM)	BWP (%)
Cucumbers and gherkins	24.16	33.03	1.99	4.23	6.22	73.15
Tomatoes	27.82	37.86	1.99	4.42	6.41	73.48
Potatoes	138.65	176.06	2.00	7.36	9.37	78.75
Eggplants (aubergine)	44.46	67.29	1.17	2.20	3.37	66.06
Pumpkins, squash and gourds	60.18	119.06	2.29	2.33	4.62	50.55
Onions, dry	40.70	107.52	1.89	1.15	3.04	37.86
Cauliflowers and broccoli	29.90	64.15	0.96	0.83	1.79	46.61
Cabbages and other brassicas	20.02	55.33	0.76	0.43	1.19	36.17
Maize, green	143.25	204.44	0.86	1.64	2.50	70.07
Other vegetables	--------	--------	6.71	13.83	20.54	---
Total			**18.63**	**38.42**	**57.05**	

The average annual WF of vegetables was 57 million m^3 in Palestine during 2009–20011. About 67.34% (38.42million m^3) of them was due to the use of blue water, while the remaining 32.66% (18.63MCM) was from the use of green water. Potatoes have the largest WF (9.37MCM, 7.36 MCM of them blue water). Tomatoes also have a large WF of 6.41 MCM. The low WF of the rest of vegetables related to the low production quantities with the exception of cucumbers and gherkins, which depend on protective cultivation.

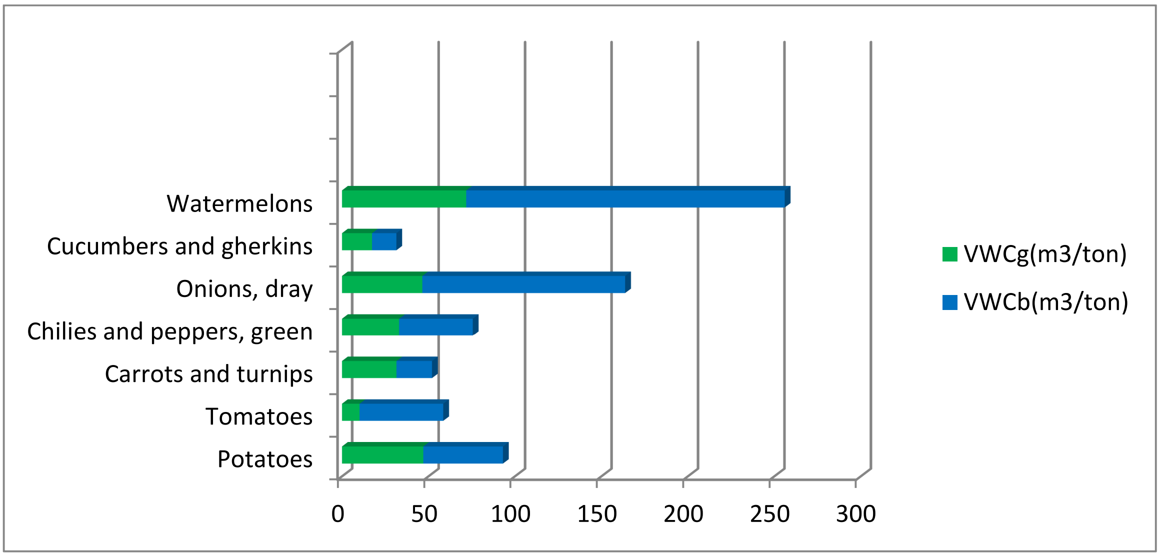

Figure (5.2): Blue and green virtual water content (VWC) of vegetables in Palestine (2009-2011).

Field crops:

Field crops in the Palestinian territories form 26.9% of the cultivated area, and represent an important food item for humans and animals. In Palestine field crops usually rain fed, and rarely cultivated irrigated.

The total area cultivated with field crops in Palestine in the years 2010/2011 about24541 hectares, 22088 hectares of them in the West Bank and 2453 hectares in the Gaza Strip.

At the governorate level Hebron occupies the first place, including 25.4 % of area cultivated with field crops in Palestine and Jerusalem came in last place by 0.4%.

The cultivated area of rainfed field crops in 2010/2011 was 23081.5 hectares with a percentage of 94.1% of field crops cultivated area in Palestine. The area of irrigated field crops was 1459.9 hectares.

Wheat is the most important field crops that rely on rainfall. The estimated green WF of wheat (2009-2011) in Palestine was 28.8 MCM and this values will change according to the precipitation ratios. The blue WF of the 24.8 irrigated hectares of wheat was 1.41 MCM which is a huge number comparing with the small percentage (less than 1%). More than 99.9% of barley in Palestine are rain fed with green WF of 10.65 MCM and blue WF of 0.03 MCM for the remaining 0.1% the other cereals like lentils, vetch and check- peas are mainly rainfed. The animal feed like “chrisna”, “biqia” and” gelbana” are totally rain fed crops.

The main irrigated filed crops in Palestine according to the results of the agricultural census year 2009/2010, by the Ministry of Agriculture and the Palestinian Central Bureau of Statistics (2012) are sorghum and thyme, the estimated green WF of sorghum was 0.01 MCM and the blue WF was 0.96 MCM. The estimation of green and blue WF of thyme could not be hold separately her because there were no information about this plant. The blue WF of all other field crops was about 1.60 MCM and the total blue WF of Palestinian field crops was about 4.01 MCM.

Trees:

The total area planted with fruit trees, including olive trees in 2010 was 54200 hectares according to agricultural census81% of them in the West Bank and 19 % in Gaza (about 4054.5 hectares). The main trees types in Palestine are olives, citrus, grapes, dates and guava.

Other crops types with taking into account the percentage of irrigated area of each type of trees.

The green and blue WF of each type of trees were estimated by multiplying green or blue VWC with the average annual production during 2009-2011Table 5.8 shows the main fruit trees and the estimated green and blue WF for each type the blue .

Table (5.8):Green and blue WF of Fruit Trees in Palestine (2009-2011).

Tree Type	% irrigated	WFg(MCM)	WFb(MCM)
Olives	2.5	29.43	13.07
Citrus	100	4.42	18.66
Guava	100	1.88	6.77
Grapes	70	6.59	19.17
Almonds	3	1.01	0.74
Other trees	2.5	0.62	0.46
Total	**---------**	**44.1**	**59.48**

Grapes and citrus have the largest blue WF of 19.17 MCM and 18.66MCM.

5.2.2 Blue WF of animal products of Palestine:

The average annual blue WFl was 2.77 MCM during 2009–2011.Sheep's milk and goat milk have the largest blue WFl of 0.79 and 0.71 MCM respectively. This is due to the large amount of drinking and service water consumption compared with poultry table 5.9

Table (5.9): Blue Water footprint of Animal products in Palestine (2009-2011).

Animal product	WFl(million m3/y)
Cow milk, whole, fresh	0.60
Indigenous Chicken Meat	0.48
Sheep milk, whole, fresh	0.79
Hen eggs, in shell	0.20
Goat milk, whole, fresh	0.71
Total	**2.77**

It was noticed that there were no irrigated feed crops in Palestine and nearly all the locally feed crops are rain fed.

5.2.3 WF of Palestine industrial and domestic sectors:

The WF of industrial and domestic sectors of Palestine was estimated by multiplying water withdrawal with a water consumption ratio (WCR) for each sector table 4.8. The available data for Palestine water withdrawal was for the year of 2005.

Table (5.10): Blue Water footprint of domestic and industrial sectors in Palestine.

Sector	**WF(MCM/y)**
Domestic	200
Industrial	29
Total	229

According to AQUASTAT the FAO's global water information system

5.3 Israel results:

5.3.1 VWC and WF of Israeli crops:

The total cultivated area in Israel in 2010 according to Israeli CBS, statistical abstract (2013) was 280960 hectares.

The steps of VWC and WF calculations are the same as mentioned in the previous sections.

Vegetables:

The following table shows the calculated green and blue VWC for winter and summer vegetables of Israel.

Table (5.11): Green and blue Virtual Water Content of winter and summer vegetables in Israel (2009-2011).

Crop type	Winter Vegetables		Summer vegetables	
	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)	VWC_{green} (m^3/ton)	VWC_{blue} (m^3/ton)
Potatoes	67.56	1.01	0.00	149.28
Tomatoes	30.12	1.48	0.00	72.33
Carrots and turnips	38.69	3.97	0.00	93.31
Chilies & peppers, green	52.30	1.21	0.00	113.63
Onions, dray	93.05	7.03	0.00	227.25
Cucumbers & gherkins	23.83	0.53	0.00	50.49
Watermelons	159.40	2.67	0.00	333.10

Table (5.12) shows the virtual water content, water footprints and blue water proportion of main vegetables of Israel (2009-20011).

Among all vegetables studied for Israel, water melons have the largest VWC of 256m^3/ton with blue VWC of 184m^3/ton (figure 5.3). Dry onions also have high VWC of164m^3/ton. Vegetables of Israel in general have blue VWC values ranging from 14 to 184m^3/ton as shown in table (5.12).

The blue water proportion (BWP) of Israeli vegetables ranges from 39.48 for Carrots and turnips to 82.62 for tomatoes.

Table (5.12): Virtual water content, water footprints and blue water proportion of main vegetables of Israel (2009-20011).

Crop type	VWC_{blue} (m^3/ton)	VWC (m^3/ton)	WFg (MCM)	WFb (MCM)	WF (MCM)	BWP (%)
Potatoes	46.07	93.10	27.86	27.30	55.16	49.49
Tomatoes	48.39	58.57	4.45	14.31	18.77	82.62
Carrots and turnips	20.55	52.06	7.95	4.62	12.57	39.48
Chilies and peppers, green	42.59	75.64	6.96	5.26	12.22	56.31
Onions, dray	117.28	163.74	3.87	9.68	13.56	71.62
Cucumbers and gherkins	14.07	31.44	1.96	0.89	2.85	44.76
Watermelons	184.20	256.03	7.64	17.32	24.96	71.95
Other vegetables	------	--------	15.96	20.89	36.85	---
Total			**76.14**	**99.66**	**175.80**	

The average annual WF of vegetables was175.8MCM in Israel during 2009–20011. About 56.7% (99.66MCM) of them was due to the use of blue water, while the remaining 43.3% (76.14MCM) was from the use of green water. Potatoes have the largest WF (55.16 MCM 27.3MCMof them blue water). Watermelons also have a large blue WF of 17.32 MCM. The low WF of cucumbers and gherkins related to the totally use of protective cultivation.

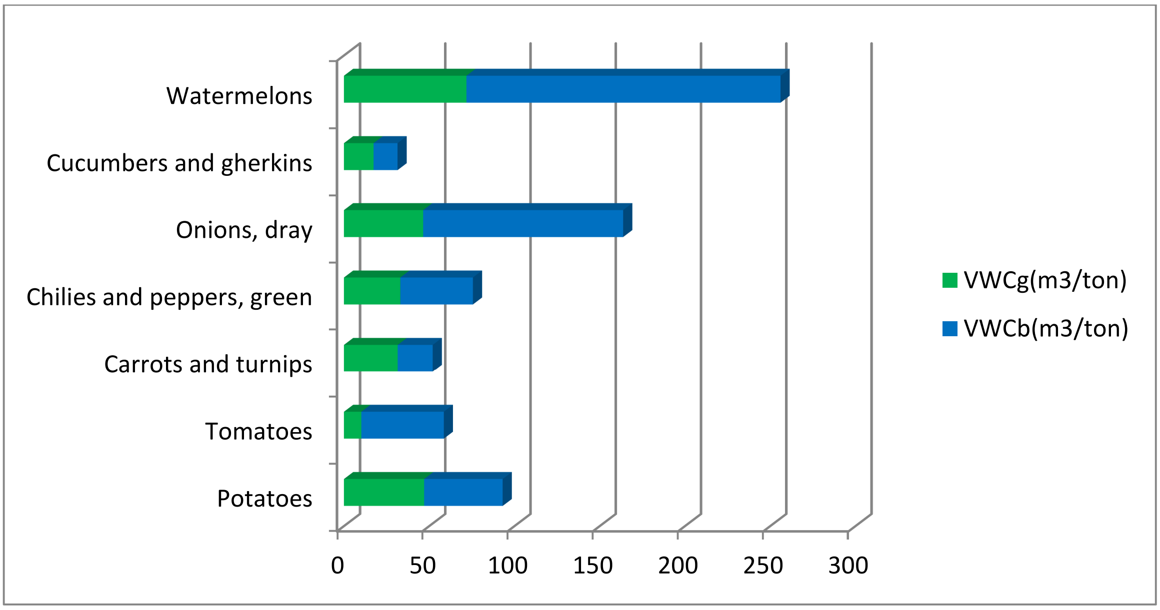

Figure (5.3): Blue and green virtual water content (VWC) of vegetables in Israel (2009-2011).

Field crops:

In 2010/2011 the field crops in Israel formed about 47.3% of the total cultivated area, and it divided to winter rainfed crops (such as wheat and barley) and summer crops (such as cotton, sunflowers, chickpeas).

The total area cultivated with field crops in Israel in 2010/2011 was about132835hectares, 31150 hectares of them cultivated with irrigated crops and 101685 cultivated with rainfed crops (Israeli CBS, statistical abstract of Israel (2013)).

Wheat occupies the first place in terms of area cultivated with field crops of about 63060 hectares rely totally on rainfall. The estimated green WF of wheat (2009-2011) in Israel was 136 MCM and this values will change according to the precipitation ratios. The second totally rainfed crop was barley with green WF of 11.66 MCM.

The main irrigated filed crops in Israel (2009-2011) are cotton, sunflower and check peas. The estimated green WF of these crops was small (0.02, 0.01and 0.01 MCM respectively) the blue WF of cotton was 44.9 MCM which is a huge number. The blue WF of check pea was 20.62 MCM and the blue WF of sunflower was 14.11 MCM. The blue WF of the other irrigated field crops in Israel (2009-2011) was more than 105.62 MCM. The total field crops blue WF was about 185.60 MCM. It is worth mentioning that not all the irrigation water quantity are fresh water, but there is a percentage of treated wastewater (about 38% of irrigation water in 2010 was from effluent (Planning Department of the Israeli Water Authority; 2011)).

Trees:

Table 5.13 shows the estimated green and blue WF for the main fruit trees in Israel (2009-2011).

Table (5.13):Water footprint of Fruit Trees in Israel (2009-2011).

Tree Type	WFg(MCM)	WFb(MCM)	WF(MCM)
Citrus	42.14	84.43	126.57
Apples	3.08	20.81	23.89
Bananas	6.76	21.50	28.26
Grapes	0.03	31.07	31.09
Avocados	16.62	33.30	49.92
Olives	15.48	27.53	43.01
Other trees	9.45	24.56	34.01
Total	**93.56**	**233.20**	**326.76**

Citrus has the largest blue WF of 84.43 MCM, avocados and grapes also have large blue WF of 33.3 MCM and 31.07MCM respectively.

5.3.2 Blue WF of animal products:

The average annual blue WF of livestock was 15.27 MCM in Israel. Indigenous Chicken Meat and Cow milk have the largest blue WF of 6.44 and 5.46 MCM respectively. This is due to the large production of these products table 5.14.

The locally planted feed ingredient (only irrigated and not included in crop WF estimation) blue WF about 56.17 MCM, this number should be added to WF of livestock.

Table (5.14): Blue Water footprint of main Animal products in Israel (2009-2011).

Animal product	**WFl(MCM/y)**
indigenous Chicken Meat	6.44
Hen eggs, in shell	0.98
Cow milk, whole, fresh	5.46
Indigenous Turkey Meat	2.39
Total	**15.27**
Livestock blue WF (for irrigated feed ingredients)	56.17
Total	**71.44**

It is clear from table 5.14 that Israel growing part of its animals feed using irrigated cultivation, which significantly affected the blue water footprint of livestock in Israel, comparing with Jordan and Palestine, Israel has a large livestock blue WF, the main types of feed crops in Israel are barley, wheat, cotton, sorghum, and green fodder. In livestock WF calculation we considered only the crops that were not considered in crops water footprint calculations.

5.3.3 WF of industrial and domestic sectors:

The WF of industrial and domestic sectors of Israel was estimated by multiplying water withdrawal with a water consumption ratio (WCR) for each sector. The available data for Israel water withdrawal was for the year of 2004(AQUASTAT Israel fact sheet). Table 5.15 shows the Water Foot print of domestic and industrial sectors for Israel.

Table (5.15): Blue Water footprint of domestic and industrial sectors in Israel (2009-2011).

Sector	WF(million m3/y)
Domestic	712
Industrial	113

According to AQUASTAT the FAO's global water information system

5.4 Water Footprint in Jordan River Basin:

The average annual blue WF of JRB during 2009-2011 was 2657 MCM. 48% of the total annual blue WF was from agricultural activities (vegetables, field crops, fruit trees and livestock production).

The livestock production accounted for 3% of the annual blue WF.

The annual WF of domestic and industrial sectors in the JRB was 1203and 180 MCM respectively. The domestic sector alone forms 45 % of the average annual blue WF figure 5.4.

For crops blue WF, Fruit trees were the largest water user of blue WF 595 MCM. For blue WF of livestock the blue water from which consumed in irrigated feed ingredients (in Israel and Jordan) was very large comparing with WF of drinking and WF of services. Cows, sheep and goats were the biggest water user since some of their feed ingredients are locally produced (within JRB) and they need irrigation.

In JRB about 79% of vegetables WF was blue. For fruit trees 80% of WF was blue.

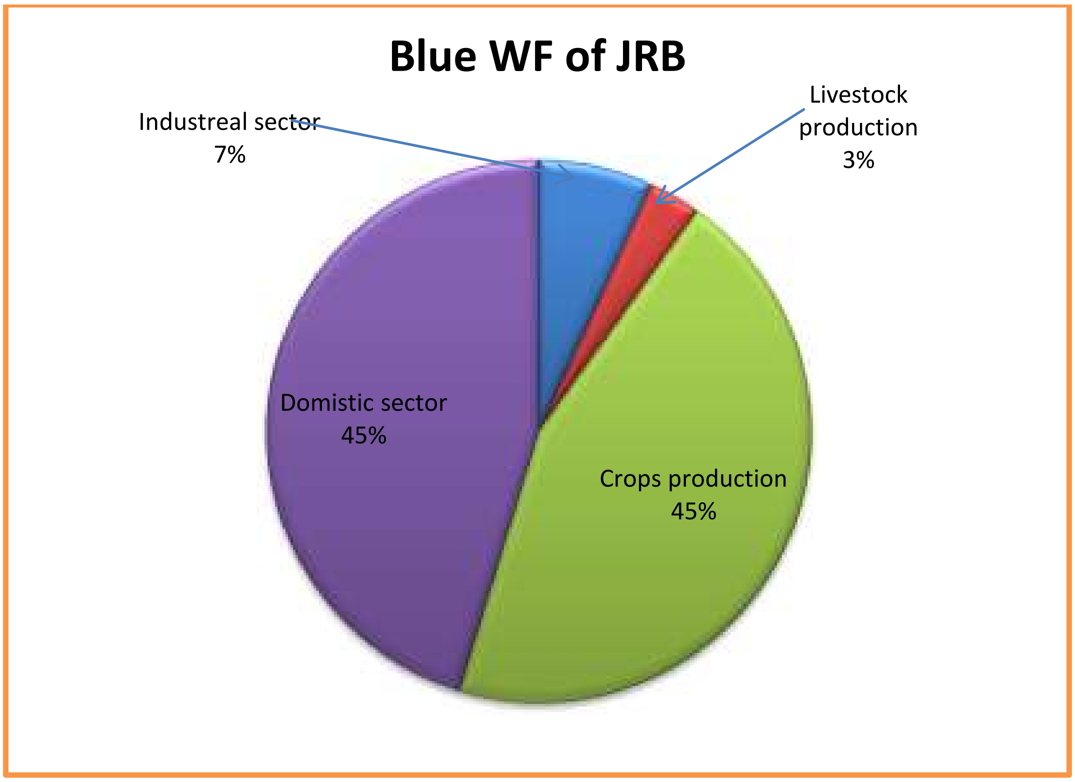

Figure (5.4): Blue WF of JRB.

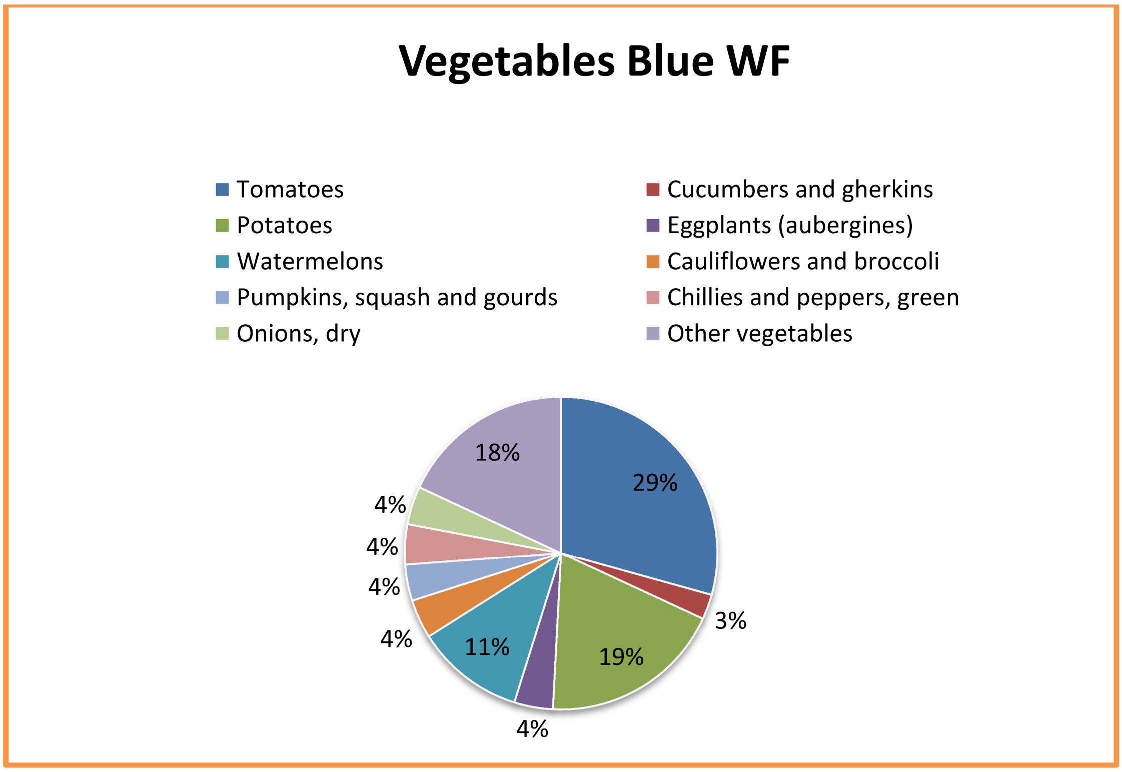

Figure (5.5): Blue WF of JRB vegetables.

5.5 Comparison with other studies:

The per capita blue WF of the JRB is estimated to be 144 m^3 per capita per year. According to the AQUASTAT data the annual water withdrawal per capita in Israel in 2004 was 282.4 m^3 which is a large number compared with 144 m^3, for Jordan the annual water withdrawal per capita in 2005 was 166 m^3, for Palestine in 2005 the annual water withdrawal per capita was 112 m^3 which is smaller than the per capita JRB blue WF.

There were no previous studies that estimated WF of JRB or for any one of the three riparians, on the other hand there were some studies that included WF estimation for some crops types. Mourad et al (2009) estimated the WF of Jordan valley fruit trees which is a part of Jordan trees.

For different fruit trees of Jordan, the blue VWC of crops estimated in this study is slightly lower than Jordan valley values from Mourad et al (2009).The two exceptions were olives and grapes since there yields in Jordan valley study (for the period 2004-2006) were much bigger than that in this study. The climatic condition is one important reason for the higher blue VWC values in the Jordan valley.

In general, the BWP of crop production in the JRB is more than 50%which is much higher than the global average of 19%reported by Liu et al (2009).

5.6 Sustainability analysis:

In this study, we compared blue WF with blue water availability (blue WA) to indicate blue water scarcity (BWS) on a yearly basis.

Hoekstra et al (2012) provide an approach to quantify BWS. At a river basin level, the BWS is defined as the ratio of the blue WF to the blue WA during a certain period. It is classified into four levels: low BWS (< 100%), moderate BWS (100–150%), significant BWS (150–200%) and severe BWS (> 200%).

Blue WA was estimated According to Hoekstra et al (2011), blue water available equals blue water resources in the three riparian countries minus the environmental flow requirements (it was assumed as 80% of the blue water resources).

The BWR estimated as the summation of natural water resources of the three countries (AQUASTAT water resources sheets), the estimated BWR was 4239 MCM (1622MCM for Jordan, 1780 MCM for Israel and 837 MCM for Palestine) (AQUASTAT countries water resources sheets).

The EFR assumed to be 80% of the BWR and equal 3391.2 MCM. The blue WA was 847.8 MCM

In the JRB, the annual blue WF was 2657 MCM during 2009–2011, and it was much greater than the blue WA of 847.8 MCM. The average annual BWS value was 313.5 %; hence, according to the above definitions, severe BWS occurred on an annual basis in the JRB.

The blue WF was 63% of the total natural runoff (BWR); hence, runoff in the JRB was severe modified by human activities. This indicates that water consumption for human activities has exceeded the sustainable level of water availability.

5.7 WF and water withdrawal:

Water withdrawal usually used in statistical water use reports in JRB riparians. The main question here is which is better to use water withdrawal or water footprint.

A large part of water withdrawal will return to local water bodies and may be used again. For example, on a global scale, about 40% of agricultural water withdrawals are not consumed, but go back to downstream water bodies as return flows (Shiklomanov, 2000; Perry, 2007; Zeng et al, 2012). According to our estimation, the average annual blue WF was 2657 MCM during 2009–2011. At the river basin level, there is very little statistical information on water use, but at nations level AQUASTAT reports the water use withdrawal for each one of the three riparians. The summation of the three riparian withdrawals in 2005 was about 3313 MCM, and this number increased in the period of study due to the population increase. The summation of water withdrawals includes a large amount of return flow that could be used again within the JRB. The WF shows the real water consumption.

It is clear that the use water footprint instead of water withdrawal is better to expresses the actual human consumption of water. Statistics on blue and green WF are suggested to be reported in statistics.

5.8 WF and water resources utilization:

As mentioned in section 5.6 above (sustainability assessment), the JRB region is in a severe blue water scarcity and the human activities has exceeded the sustainable level of water availability which is reflected on water conflicts and increases the tensions and sensitivities in the region in addition to the already existing political tensions. This requires optimizing the utilization of water resources in the region.

In this study we considered the blue WF as strong indicator for the intensity of water conflicts, in order to minimize the water conflicts intensity we must minimize the blue WF. For this objective we developed an optimization model using linear programming to examine the response of blue WF value to different vegetable cultivation and water utilization scenarios.

5.9 JRB blue WF model and proposed Scenarios:

In order to examine the JRB blue WF response to the changing in the vegetables cultivation places (places with different blue WF/ton), and also to production quantities, we developed an optimization model that links blue WF with these factors used as constraints in the model development.

In the development of the model we rely on the following formula for the objective function:

$$\text{JRB blue WF}_{\text{v}} = wf_1 \times X_1 + wf_2 \times X_2 + \cdots wf_n \times X_n$$

Where JRB blue WF_{v} is the total annual water footprint of the vegetables in the JRB (Palestine, Israel and Jordan) $(m^3/year)$, wf_n the blue water footprint of vegetables type n, X_n the production quantity of vegetables type n.

Here we took the vegetables since they are the main consumers of fresh water in the agricultural sector that could be controlled easily (the places of cultivation, the quantity of production and the agricultural practices), and because the choice of using treated waste water in the irrigation of vegetables is still unacceptable for many peoples and societies.

Other agriculture uses of water such as irrigation of trees and fodders could be utilized from treated wastewater.

Microsoft Excel solver tool was used to develop and run this model. The different scenarios proposed were implemented in some sort of constrains incorporated to the Model (using the Excel solver tool) such as that the areas of vegetables cultivation in each country shouldn’t exceed potential areas suitable for cultivation, the amounts of production should also be used as constraints. The model will give the locations of production for the producing the amounts of vegetables under consideration utilizing the minimum water (minimum water foot print) assuming open markets and possibility of moving crops among the region freely (political boundaries are not considered as obstacles to moving crops).

In using the excel solver for our model (for each scenario) we obtain the minimum blue WF of vegetables which is the minimum amount of water required to produce the amount of vegetables specified in the constraints considering the scenario under consideration.

Four scenarios were proposed in order to guide us in understanding which lines of alternative response strategies can be formulated.

5.9.1 First Scenario (Minimizing water foot production for the vegetables produced in the region):

Blue water footprints (m^3/ton) in agriculture can generally be reduced substantially by increasing green and blue water productivity (ton/m^3).

Agriculture experts in JRB are often focused on maximizing land productivity (ton/ha), which could be useful when land is scarce and freshwater is abundant, but when water is scarcer than land, maximizing water productivity is more important (Hoekstra et al; 2011).

Scenario description:

This scenario assumes that boundaries in the JRB are not obstacles for moving crops to minimize water foot print. The scenario minimizes water foot print required for producing the amounts of main vegetables which are currently produce through changing locations of planting each vegetable type. The model finds the best place for planting each vegetable which is usually the area with lowest foot print per unit production of that vegetable.

In this scenario; the main objective was minimizing vegetables blue water footprint by changing planting places without changing the production quantities.

If we take the main vegetables and compare the blue VWC of each type in each country; for example the blue VWC of tomatoes in Palestine is about 28 m^3/ton which is smaller than that of Jordan and Israel, on the other hand the blue VWC of cucumbers in Israel is smaller than that in other riparian countries. This variation of blue VWC value is due to climate conditions and the variations in agricultural practices of each country.

Scenario analysis:

For example the average total production quantity of tomatoes in JRB (2009-2011) was 1357750 tons annually with blue water consumption of about 80.63 MCM. If the total quantity of tomatoes produced in the areas with the lowest foot print per ton, the tomatoes water consumption will reduce. We used the excel solver to find the optimum distribution of vegetables production in order to minimize vegetables blue water footprint.

Results of analysis:

The existing vegetables blue water footprint was estimated at 231.6 MCM annually, however, using this scenario will save only about 5.1 MCM annually. This result was somehow disappointing, especially that the distribution looked unfair to some of the parties considering the variability in prices of the different crops. This scenario indicates that if we want to minimize the water foot prints in the region and allow moving crops freely in the region, the amount of water that will be saved is only 2%. This amount is too small and does not look to be worth the socio-economic implications of this scenario. This result is due to the fact that the variability in water foot prints for the different crops in the region is small as the region is relatively small with similar climatic conditions. The variability in the agricultural practices is also small as farmers learn from each other and from the experiences in other countries methods and practices to minimize water use. The effect of the variability in climate is small because farmers adjust to that in changing planting times at the different locations. For example, the Jordan valley (the Ghore) is very hot compared to the coastal region and it is expected that vegetables planted in the Jordan valley will require water a lot more than the coastal regions. However, this is not necessary true because farmers plant vegetables during winter in the Ghore when the temperature is low, while planting in the coastal and mountainous regions will be in spring and summer. In the end, the differences in the amounts of water used in the different areas become small resulting in minor variations in water foot prints. The following table shows the optimum distribution for vegetables in the three countries for the first scenario.

Table (5.16): First scenario output.

Type	Israel Production (ton/year)	Palestine production (ton/year)	Jordan production (ton/year)
Tomatoes	387578	970200	0
Potatoes	826366	0	0
Cucumbers and Gherkins	0	0	3550876
Chillies and peppers, green	276754	0	0
Eggplants	206581	0	0
Onion , dry	0	0	14229.7
Watermelon	30255.5	0	213150

As seen in the table above, the optimization model for each crop selects the country with minimum water foot print for producing the amounts of that crop. Although this result will utilize less water and minimize water foot print but it does not consider the variability in the prices of the different crops which makes this scenario not attractive to people.

Scenario obstacles:

The following are the main two obstacles of this scenario:

- This scenario causes losing the region important feature which is different harvesting time for vegetables. Considering climate variability in the basin of the Jordan River, the planting and harvesting dates vary from one area to another, thus ensuring availability of fresh vegetables year-round.
- This scenario also has socio-economic obstacles, Socially, it is difficult for farmers to replace the types of vegetables which accustomed to and replace them with other types, and that each region is famous for a particular type of agriculture, farmers will find great difficulty in accepting the idea of change. Economically, it could cause economic loss when changing the type of vegetable, despite it will be in the areas of low blue VWC, but it may be not economically feasible.

Conclusion

The scenario of reallocation of vegetable production and according to our model result seems not worth the trying for two main reasons:

- The quantity of saved water was small and not worth the scio-economic obstacles and it will not has an effect on water conflict. This small quantity (5.1 MCM or 2% of water utilized) can be saved in easier and less complicated ways, see section 5.10.

- The distribution was unfair to some of the parties, and it is impossible for them to accept this scenario, because agriculture is a source of livelihood and work and it is a part of their life system,in addition, the unfair distribution will increase disputes between the parties

5.9.2 Second Scenario (Using the Virtual Water import option):

Scenario description:

The second scenario assumes that the JRB riparians will dispense the cultivation of crops which have high water foot print per ton and replace these products with imported products from countries outside JRB.

At this scenario excel solver will except the high water consumption vegetables and replace it with a less-consuming.

The objective function of this scenario is exception produce of the high water consumption vegetables and replace it with less consumption vegetables. The only constrain was that the total available areas should be exploited in cultivation of small water consumption vegetables, and it doesn't matter that all types of vegetables covered.

The significant issue in this scenario that it ensures importing of virtual water in order to protect JRB limited water and leave the cultivation of some vegetables result in significant social consequences.

Scenario analysis:

In this scenario running, the only constrain was that the total available areas should be exploited in cultivation of small water consumption vegetables, and it doesn't matter that all types of vegetables covered.

After running this scenario on our model the only two types that achieve minimization of the vegetables blue water footprint were cucumber and onion. The solver distribute these two types on the study area.

Results of analysis:

Table 5.17 shows the results of this scenario running, the amount of cucumber and onion produce were very huge.

Table (5.17): Second scenario output.

Type	Israel Production (ton/year)	Palestine production (ton/year)	Jordan production (ton/year)
Tomatoes	0	0	0
Potatoes	0	0	0
Cucumbers and Gherkins	4137117	0	4609845
Chillies and peppers, green	0	0	0
Eggplants	0	0	0
Onion , dry	0	230787	0
Watermelon	0	0	0

As seen in the table above, the total blue water footprint of vegetables was 160.9 MCM, this means that the left of cultivation vegetables except cucumber and onion, will save about 76MCM of fresh water annually.

Scenario obstacles:

This scenario seems illogical and faced many obstacles, the following are some of these obstacles:

- The JRB is agricultural area which characterized by the diversity of vegetables, farmers have used to produce many kinds of vegetables from many years, it is impossible to agree on the sufficiency planting one type.
- If we assume that the process of importing the rest of the vegetables types with a good quality and price has become possible, the question is whether farmers will be able to discharge the surplus of cucumbers and onions? Though this would be economically feasible?

Conclusion:

The scenario of using the Virtual Water import option and according to our model result seems useful in terms blue water footprint and water conflict reduction, but it has significant consequences related to farmers Who are accustomed to certain varieties of vegetables. This scenario will increase the unemployment in some areas and would turn the region to a consuming region.

5.9.3 Third scenario (reduction the vegetables quantities to the half):

Scenario description:

This scenario assumes that no boundaries in the JRB, producing half the amount of main vegetables which is currently produce through planting each vegetable type at areas with lowest foot print per unit production of the same type.

At this scenario; the main objective was minimizing vegetables blue water footprint by changing planting places and changing the production quantities to the half.

Scenario analysis:

For example the average total production quantity of tomatoes in JRB (2009-2011) was 1357750 ton annually, at this scenario we assume that the production is the half of that and so on for the rest of vegetables (we put that as constrain in the solver), the other constrain that all the areas in the three countries should be cultivated.

Results of analysis:

The total vegetables blue water footprint for this scenario was 187.5 MCM, this means that reduction the production quantities to the half (with optimization method for distribution according to the areas fresh water consumption per ton of production), will reduce the vegetables blue water footprint about 21% which could be used in other sectors like domestic.

Table 5.18 shows the results of this scenario running,

Table (5.18): Third scenario output.

Type	Israel Production (ton/year)	Palestine production (ton/year)	Jordan production (ton/year)
Tomatoes	0	678887	0
Potatoes	413181	0	0
Cucumbers and Gherkins	1427066	0	4606304
Chillies and peppers, green	138375	0	0
Eggplants	103288	0	0
Onion , dry	0	69294	820
Watermelon	121699	0	0

Scenario obstacles:

Although this scenario seems more logical than the previous scenario, it has some obstacles, the following are some of these obstacles:

- Distribution of vegetables types on the areas would not be fair for some farmers, the farmers refuse to change the types that are accustomed.
- Farmers will not accept reduce the amount of production for economic reasons.
- Reduce production means less manpower and increase unemployment.

Conclusion:

This scenario could be good choice but not for this region. Although this scenario may reduce the water conflict in certain areas, but at the same time it will be rejected since most of the farmers and their families seek to increase production, so we can't consider the production reduction as water conflicts reduction approach.

5.9.4 Fourth Scenario (Double production, future scenario):

With the growing of population and the increasing of food demand, it was necessary to propose such a scenario.

Scenario description:

This scenario proposed increasing in the production to the double, in order to know the required vegetable blue footprint to that, and also to test whether the available fresh water will be sufficient or not.

The same constrains of the previous scenario except the production is the double of the current production (in the previous scenario was the half).

Scenario analysis and results:

Table (5.19) shows the future scenario output, the average annual vegetables blue water footprint will be 374.5 MCM, this means that there will be a shortage of about 137.8 MCM per year for vegetables only. This result puts many questions about the potential sources of these additional amounts of water. It must be noted that this scenario run in our model and in optimization for the distribution of the vegetables types (in terms of the lowest water footprint per unit of production), the question is how much will be the shortage on the ground and without the minimization of the vegetables blue water footprint.

Table (5.19): Fourth scenario output.

Type	Israel Production (ton/year)	Palestine production (ton/year)	Jordan production (ton/year)
Tomatoes	1745372	970183	0
Potatoes	0	0	698904
Cucumbers and Gherkins	0	0	1007708
Chillies and peppers, green	2566355	0	296872
Eggplants	413160	0	0
Onion , dry	280457	0	0
Watermelon	0	0	486805

Conclusion:

The result of future scenario raises our concerns about the JRB future, with the increase in population and limited fresh water, it also became doubtful that the use of water footprint and redistribution is the solution to the water issue in the region. The future scenario runs on the optimization method to minimize the water footprint. However, the futurefresh water shortage is definite making it impossible to increase the amounts of fresh water needed for agriculture. Thus, utilizing the concept of water foot prints in water allocation could help in reducing water use and water demands but will not be able to solve the water shortages and water conflicts in the region. The amount of water available is not sufficient for the growing needs and demands for water in the region. There is a need to utilize non-conventional water sources to solve the shortages in water and the water conflicts in the region.

At the end of this section it should be noted that other scenarios running like (All livestock feed importing scenario) will save about 58.37 MCM annually.

5.10 Response Options:

Maximizing blue water productivity means applying less irrigation water in a smarter way, in order to give a higher yield per cubic meter of water evaporated.

some practices, for agricultural sector that could be achieved by replacing water-intensive vegetables (like Tomatoes and Potatoes in Jordan) with that of less water consume (like Cucumbers and Gherkinsin Jordan).

In irrigated agriculture, changing irrigation technique can reduce the blue water footprint. Using drip irrigation instead of sprinkler or furrow irrigation can reduce evaporation substantially and also the use of protective cultivation (that was clear from the results of protective crops).

Changing crop patterns from fruit trees to vegetables in Jordan river basin could reduce the blue water footprint due the large consumption of blue water for trees irrigation.

Instead of applying full irrigation, it may be wiser to choose deficit irrigation, an irrigation philosophy that aims at obtaining maximum crop water productivity (ton/m^3) rather than maximum yields (ton/ha).

In deficit irrigation, water is applied during the drought-sensitive growth stages of a crop; outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water.

Farmers could use supplementary irrigation, which saves even more water. In this irrigation, small amounts of water are added to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields.

The following are some options for farmers to reduce their green water footprint:

- Increase land yield (ton/ha) in rainfed agriculture by improving agricultural practice since the amount of green water remains the same, water productivity (m^3/ton) will increase and green WF will reduce.
- Mulching of the soil, thus reducing evaporation from the soil surface.

In regions that suffer from blue water scarcity like JRB it is important to reduce blue water footprint, the following are some options for farmers to reduce their blue water footprint:

- Shift to protected agriculture (lower evaporation loss and lower blue water consumptions).
- Shift to an irrigation technique with lower evaporation loss, using drip irrigation instead of sprinkler or furrow irrigation can reduce evaporation substantially, deficit irrigation and supplementary irrigation could be used.
- Choose crops of less irrigation water consumption, for Jordan cucumbers and gherkins could be cultivated instead of tomatoes and potatoes, for Palestine green maize cultivation could be replaced with tomatoes and cucumbers, for Israel potatoes and water melons could be replaced with cucumbers and gherkins.

- Changing crop patterns from fruit trees to vegetables.
- Increase blue water productivity (ton/m^3) instead of maximizing land productivity (yield, ton/ha).
- Reduce evaporation losses from water storage in reservoirs and from the water distribution system.

For livestock farmers, a major concern should be the water footprint of the feed they buy or produce themselves, increasing the quantities of rainfed feed ingredients, and decrease the quantities of irrigated feed ingredients helps in the blue water footprint reduction. On the other hand the import of water-intensive feed is a good alternative.

Developing a good water policy is an important part in order to achieve sustainable water footprint.

The water policies of the three riparian countries governments should aim to use freshwater resources in a way that is environmentally sustainable, socially equitable and economically efficient.

National trade policy in each country should reduce export of water-intensive products from JRB since it’s a severe water scarce areas, and increase import.

5.11 Shortcomings:

There are several shortcomings in this study. First, there are no crop or livestock production data at the river basin level. We have to calculate them based on the data of each riparian, but this method will remain necessary when statistical data are not available at the river basin level. This study is the first one for the assessment of WF at the JRB, and it is very difficult to validate the results obtained from the models used, such as the VWC of crop from the CROPWAT model.

Second, for the EFR value, we choose 80% as a threshold based on Hoekstra et al (2011,2012). It is still questionable whether such a threshold can be used for JRB.

Third, there were several factors that we did not take into account. First, grey WF is not included due to the lack of data on pollutant discharge. Second, we do not calculate WF for Syria and Lebanon which are located within the JRB boundaries. Third, this study did not include green water sustainability assessment because there was no standard method.

CHAPTER SIX

Conclusions and Recommendations

6.1 Conclusions:

We conclude from this study that agricultural activities have the biggest share of blue WF in JRB (48% of blue WF), followed by domestic sector (45% of WF).

The high value of domestic water footprint with the huge increase in population, will lead to a serious water crisis in the coming years.

Israel has the largest blue WF per capita of the three riparians with about 184 m^3followed by Jordan of about 126 m^3 per capita. Palestinians have the lowest blue WF per capita of less than 80 m^3 per year. We conclude from this study that human needs are not met by all people in the study area and also that the basic rules of fairness are not met in JRB.

We also conclude that it is better to use WF instead of water withdrawal since the water withdrawal cannot completely demonstrate human appropriation of water resources.

We also conclude that JRB suffers from severe blue water scarcity and there are many indicators that water consumption for human activities in JRB has exceeded the sustainable level of water availability, so the region is moving towards a dangerous curves in the conditions of the sustainability of the water, which will reflect negatively on water disputes in the region.

From the results of the developed model and from the running of the developed scenarios, we conclude that minimizing water footprints for the vegetables produced in the region by reallocation of vegetable production seems not worth the trying. This is because the amount of water saved from such option is very small and thus will not have significant impacts on reducing water conflicts in the region.

Also we conclude using the Virtual Water import option seems useful in terms blue water footprint, but has significant consequences related to farmers who are accustomed to certain varieties of vegetables.

Also we conclude that the reduction of vegetables quantities to the half and using virtual water trade option to cover the short fall could be a good choice to reduce water consumption but will have negative socio-economic impacts in the region since most of the farmers and their families seek to increase production and improve their income from agriculture.

Also we conclude from the running of the future scenario in our model that the problem of the shortage of fresh water is increasing with time and the use of water footprint and redistribution of agriculture production will not be sufficient to solve water conflicts in the region. The severity in water availability requires focusing on increasing water availability through enhancing existing water resources and utilizing non conventional water resources such treated wastewater and brackish water.

Reducing water footprints (m^3/ton) in JRB by increasing water productivity (ton/ m^3) is key in reducing the pressure on the JRB water resources. Increasing green and blue water productivity could be achieved by changing some agricultural practices, also by replacing water-intensive crops with that of low VWC.

The high value of domestic water footprint with the huge increasing in the population growth, that will lead to a serious water crisis in the coming years.

Developing a good water policy and good regional trade policy in JRB riparian countries can on the long-term reduce scarcity problems and reach a more optimal use of water.

Generally, there is no accurate WF assessment because of the complex processes of water cycles and human activities, and the lack of many important input data at a river basin level. However, it is worth extra efforts to collect more detailed information to increase the accuracy of WF assessment at river basin scale.

6.2 Recommendations:

In this study all the WF estimation was done on annual basis, the average annually blue WF was compared with the average annually available blue water in order to determine the level of annually water scarcity but when comparing the monthly blue WF with the monthly available water, one can identify which months will have water scarcity and these monthly estimations will be very useful in the development of annual plans for water management.

Through the work of this study, it was observed that all the water statistics was documented using water withdrawals, which we explained previously that it is not accurate to use such statistics on WF and its components (green and blue) are suggested to be reported in statistics.

Green water plays an important role in food production in JRB especially in field crops production such as cereals production. Improving green use efficiency will leads JRB to better water management and it will reduce the pressure on blue water. Therefore, this study recommends giving more attention to the issue of the exploitation of green water and employed as part of the solutions to water problems in the region.

This study also recommends to make further analyze for the economic and social impacts (like trade, income, employment, etc.) of WF in order enable the WF to become a more comprehensive indicator for decision makers in JRB.

The analysis of this research has shown that there is a vital need to deal with the severe water scarcity in JRB, all sides must overlook the political differences and give serious thought to finding appropriate solutions to the sustainability of the scarce water sources in the region.

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Appendices

Appendix A1

Lengths of crop development stages for various planting periods and climatic regions (days) according to FAO.

Crop	Init.L L_{ini}	DevL L_{dev}	Mid L_{mid}	Lat L_{lae}	Total	Plant Date	Region
a. Small Vegetables							
Broccoli	35	45	40	15	135	Sept	Calif. Desert, USA
Cabbage	40	60	50	15	165	Sept	Calif. Desert, USA
Carrots	20	30	50/30	20	100	Oct/ Jan	Arid climate
	30	40	60	20	150	Feb/ Mar	Mediterra-nean
	30	50	90	30	200	Oct	Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25	40	95	20	180	Oct	(Semi) Arid
	25	40	45	15	125	April	Mediterranean
	30	55	105	20	210	Jan	(Semi) Arid
Crucifers[1]	20	30	20	10	80	April	Mediterranean
	25	35	25	10	95	Feb.	Mediterra-nean
	30	35	90	40	195	Oct/ Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/ Jan	Mediterranean
	25	35	30	10	100	Oct/ Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean

Onion (dry)	15	25	70	40	150	April	Mediterranean
	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
Onion (green)	25	30	10	5	70	April /May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	Nov.	Arid Region
Radish	5	10	15	5	35	Mar/ Apr	Medit.; Europe
	10	10	15	5	40	Winter	Arid Region
b. Vegetables - Solanum Family *(Solanaceae)*							
Egg plant	30	40	40	20	130\1	October	Arid Region
	30	45	40	25	40	May/ June	Mediterranean
Sweet peppers (bell)	25/30	35	40	20	125	April/ June	Europe and Medit.
	30	40	110	30	210	October	Arid Region
Tomato	30	40	40	25	135	January	Arid Region
	35	40	50	30	155	Apr/ May	Calif., USA
	25	40	60	30	155	Jan	Calif. Desert, USA
	35	45	70	30	180	Oct/ Nov	Arid Region
	30	40	45	30	145	April/ May	Mediterranean
c. Vegetables - Cucumber Family *(Cucurbitaceae)*							
Cantaloupe	30	45	35	10	120	Jan	Calif., USA
	10	60	25	25	120	Aug	Calif., USA
Cucumber	20	30	40	15	105	June/ Aug	Arid Region
	25	35	50	20	130	Nov; Feb	Arid Region

Pumpkin, Winter squash	3	30	30	20	100	Mar, Aug	Mediterranean
	25	35	35	25	120	June	Europe
Squash, Zucchini	25	35	25	15	100	Apr; Dec.	Medit.; Arid Reg.
	20	30	25	15	90	May/ June	Medit.; Europe
Sweet melons	25	35	40	20	120	May	Mediterranean
	30	30	50	30	140	March	Calif., USA
	15	40	65	15	135	Aug	Calif. Desert, USA
	30	45	65	20	160	Dec/ Jan	Arid Region
Water melons	20	30	30	30	110	April	Italy
	10	20	20	30	80	Mat/ Aug	Near East (desert)
d. Roots and Tubers							
Beets, table	15	25	20	10	70	Apr/ May	Mediterranean
	25	30	25	10	90	Feb/ Mar	Mediterranean & Arid
Cassava: year 1	20	40	90	60	210	Rainy	Tropical regions
year 2	150	40	110	60	360	season	
Potato	25	30	30/45	30	115/130	Jan/ Nov	(Semi) Arid Climate
	25	30	45	30	130	May	Continental Climate
	30	35	50	30	145	April	Europe
	45	30	70	20	165	Apr/ May	Idaho, USA
	30	35	50	25	140	Dec	Calif. Desert, USA
Sweet potato	20	30	60	40	150	April	Mediterranean
	15	30	50	30	125	Rainy seas.	Tropical regions
Sugarbeet	30	45	90	15	180	March	Calif., USA
	25	30	90	10	155	June	Calif., USA

	25	65	100	65	255	Sept	Calif. Desert, USA
	50	40	50	40	180	April	Idaho, USA
	25	35	50	50	160	May	Mediterranean
	45	75	80	30	230	Nov.	Mediterranean
	35	60	70	40	205	Nov.	Arid Regions
e. Legumes *(Leguminosae)*							
Beans (green)	20	30	30	10	90	Feb/ Mar	Calif., Mediterranean
	15	25	25	10	75	Aug/ Sep	Calif., Egypt, Lebanon
Beans (dry)	20	30	40	20	110	May/ June	Continental Climates
	15	25	35	20	95	June	Pakistan, Calif.
	25	25	30	20	100	June	Idaho, USA
Faba bean, broad bean	15	25	35	15	90	May	Europe
	20	30	35	15	100	Mar/ Apr	Mediterranean
- dry	90	45	40	60	235	Nov	Europe
- green	90	45	40	0	175	Nov	Europe
Green gram, cowpeas	20	30	30	20	110	March	Mediterranean
Groundnut	25	35	45	25	130	Dry	West Africa
	35	35	35	35	140	season	High Latitudes
	35	45	35	25	140	May May/ June	Mediterranean
Lentil	20	30	60	40	150	April	Europe
	25	35	70	40	170	Oct/ Nov	Arid Region
Peas	15	25	35	15	90	May	Europe
	20	30	35	15	100	Mar/ Apr	Mediterranean
	35	25	30	20	110	April	Idaho, USA
Soybeans	15	15	40	15	85	Dec	Tropics
	20	30/35	60	25	140	May	Central USA
	20	25	75	30	150	June	Japan

f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)							
Artichoke	40	40	250	30	360	Apr (1st yr)	California
	20	25	250	30	325	May (2nd yr)	(cut in May)
Asparagus	50	30	100	50	230	Feb	Warm Winter
	90	30	200	45	365	Feb	Mediterranean
g. Fibre Crops							
Cotton	30	50	60	55	195	Mar-May	Egypt; Pakistan; Calif.
	45	90	45	45	225	Mar	Calif. Desert, USA
	30	50	60	55	195	Sept	Yemen
	30	50	55	45	180	April	Texas
Flax	25	35	50	40	150	April	Europe
	30	40	100	50	220	October	Arizona
h. Oil Crops							
Castor beans	25	40	65	50	180	March	(Semi) Arid Climates
	20	40	50	25	135	Nov.	Indonesia
Safflower	20	35	45	25	125	April	California, USA
	25	35	55	30	145	Mar	High Latitudes
	35	55	60	40	190	Oct/ Nov	Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/ May	Medit.; California
i. Cereals							
Barley/Oats/ Wheat	15	25	50	30	120	November	Central India
	20	25	60	30	135	March/ Apr	35-45 °L
	15	30	65	40	150	July	East Africa
	40	30	40	20	130	Apr	
	40	60	60	40	200	Nov	

	20	50	60	30	160	Dec	Calif. Desert, USA
Winter Wheat	202	602	70	30	180	Dec.	Calif., USA
	30	140	40	30	240	Nov.	Mediterranean
	160	75	75	25	335	October	Idaho, USA
Grains (small)	20	30	60	40	150	April	Mediterranean
	25	35	65	40	165	Oct/ Nov	Pakistan; Arid Reg.
Maize (grain)	30	50	60	40	180	April	East Africa (alt.)
	25	40	45	30	140	Dec/Jan	Arid Climate
	20	35	40	30	125	June	Nigeria (humid)
	20	35	40	30	125	October	India (dry, cool)
	30	40	50	30	150	April	Spain (spr, sum.); Calif.
	30	40	50	50	170	April	Idaho, USA
Maize (sweet)	20	20	30	10	80	March	Philippines
	20	25	25	10	80	May /June	Mediterranean
	20	30	50/30	10	90	Oct/ Dec	Arid Climate
	30	30	30	103	110	April	Idaho, USA
	20	40	70	10	140	Jan	Calif. Desert, USA
Millet	15	25	40	25	105	June	Pakistan
	20	30	55	35	140	April	Central USA
Sorghum	20	35	40	30	130	May/June	USA, Pakis., Med.
	20	35	45	30	140	Mar/ April	Arid Region

Rice	30	30	60	30	150	Dec; May	Tropics; Mediterranean
	30	30	80	40	180	May	Tropics
j. Forages							
Alfalfa, total season [4]	10	30	var.	var.	var.		last -4°C in spring until first -4°C in fall
Alfalfa [4] 1st cutting cycle	10	20	20	10	60	Jan Apr (last -4°C)	Calif., USA.
	10	30	25	10	75		Idaho, USA.
Alfalfa [4], other cutting cycles	5	10	10	5	30	Mar	Calif., USA.
	5	20	10	10	45	Jun	Idaho, USA.
Bermuda for seed	10	25	35	35	105	March	Calif. Desert, USA
Bermuda for hay (several cuttings)	10	15	75	35	135	---	Calif. Desert, USA
Grass Pasture [4]	10	20	--	--	--		7 days before last -4°C in spring until 7 days after first -4°C in fall
Sudan, 1st cutting cycle	25	25	15	10	75	Apr	Calif. Desert, USA
Sudan, other cutting cycles	3	15	12	7	37	June	Calif. Desert, USA
k. Sugar Cane							
Sugarcane, virgin	35	60	190	120	405		Low Latitudes
	50	70	220	140	480		Tropics
	75	105	330	210	720		Hawaii, USA
Sugarcane, ratoon	25	70	135	50	280		Low Latitudes
	30	50	180	60	320		Tropics
	35	105	210	70	420		Hawaii, USA

l. Tropical Fruits and Trees							
Banana, 1st yr	120	90	120	60	390	Mar	Mediterranean
Banana, 2nd yr	120	60	180	5	365	Feb	Mediterranean
Pineapple	60	120	600	10	790		Hawaii, USA
m. Grapes and Berries							
Grapes	20	40	120	60	240	April	Low Latitudes
	20	50	75	60	205	Mar	Calif., USA
	20	50	90	20	180	May	High Latitudes
	30	60	40	80	210	April	Mid Latitudes (wine)
Hops	25	40	80	10	155	April	Idaho, USA
n. Fruit Trees							
Citrus	60	90	120	95	365	Jan	Mediterranean
Deciduous Orchard	20	70	90	30	210	March	High Latitudes
	20	70	120	60	270	March	Low Latitudes
	30	50	130	30	240	March	Calif., USA
Olives	30	90	*60*	90	2705	March	Mediterranean
Pistachios	20	60	30	40	150	Feb	Mediterranean
Walnuts	20	10	130	30	190	April	Utah, USA
o. Wetlands - Temperate Climate							
Wetlands (Cattails, Bulrush)	10	30	80	20	140	May	Utah, USA; killing frost
	180	60	90	35	365	Nov.	Florida, USA
Wetlands (short veg.)	180	60	90	35	365	Nov.	frost-free climate

Appendix A2

Single (time-averaged) crop coefficients, K_c, and mean maximum plant heights for non stressed, well-managed crops in sub-humid climates (RH_{min} » 45%, u_2 » 2 m/s) for use with the FAO Penman-MonteithET_o.

crop		Kcini	Kc mid	Kc end	Maximum Crop Height (h) (m)
a. Small Vegetables		**0.7**	**1.05**	**0.95**	
Broccoli			1.05	0.95	0.3
Brussel Sprouts			1.05	0.95	0.4
Cabbage			1.05	0.95	0.4
Carrots			1.05	0.95	0.3
Cauliflower			1.05	0.95	0.4
Celery			1.05	1	0.6
Garlic			1	0.7	0.3
Lettuce			1	0.95	0.3
Onions					
	- dry		1.05	0.75	0.4
	- green		1	1	0.3
	- seed		1.05	0.8	0.5
Spinach			1	0.95	0.3
Radish			0.9	0.85	0.3
b. Vegetables - Solanum Family *(Solanaceae)*		**0.6**	**1.15**	**0.8**	
Egg Plant			1.05	0.9	0.8
Sweet Peppers (bell)			1.052	0.9	0.7
Tomato			1.152	0.70-0.90	0.6
c. Vegetables - Cucumber Family *(Cucurbitaceae)*		**0.5**	**1**	**0.8**	
Cantaloupe		0.5	0.85	0.6	0.3
Cucumber					
	- Fresh Market	0.6	1.002	0.75	0.3
	- Machine harvest	0.5	1	0.9	0.3
Pumpkin, Winter Squash			1	0.8	0.4
Squash, Zucchini			0.95	0.75	0.3
Sweet Melons			1.05	0.75	0.4
Watermelon		0.4	1	0.75	0.4
d. Roots and Tubers		**0.5**	**1.1**	**0.95**	
Beets, table			1.05	0.95	0.4
Cassava					

- year 1	0.3	0.803	0.3	1
- year 2	0.3	1.1	0.5	1.5
Parsnip	0.5	1.05	0.95	0.4
Potato		1.15	0.754	0.6
Sweet Potato		1.15	0.65	0.4
Turnip (and Rutabaga)		1.1	0.95	0.6
Sugar Beet	0.35	1.2	0.705	0.5
e. Legumes *(Leguminosae)*	**0.4**	**1.15**	**0.55**	
Beans, green	0.5	1.052	0.9	0.4
Beans, dry and Pulses	0.4	1.152	0.35	0.4
Chick pea		1	0.35	0.4
Fababean (broad bean)				
- Fresh	0.5	1.152	1.1	0.8
- Dry/Seed	0.5	1.152	0.3	0.8
Grabanzo	0.4	1.15	0.35	0.8
Green Gram and Cowpeas		1.05	0.60-0.35[6]	0.4
Groundnut (Peanut)		1.15	0.6	0.4
Lentil		1.1	0.3	0.5
Peas				
- Fresh	0.5	1.152	1.1	0.5
- Dry/Seed		1.15	0.3	0.5
Soybeans		1.15	0.5	0.5-1.0
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	**0.5**	**1**	**0.8**	
Artichokes	0.5	1	0.95	0.7
Asparagus	0.5	0.957	0.3	0.2-0.8
Mint	0.6	1.15	1.1	0.6-0.8
Strawberries	0.4	0.85	0.75	0.2
g. Fibre Crops	**0.35**			
Cotton		1.15-1.20	0.70-0.50	1.2-1.5
Flax		1.1	0.25	1.2
Sisal [8]		0.4-0.7	0.4-0.7	1.5
h. Oil Crops	**0.35**	**1.15**	**0.35**	
Castorbean (*Ricinus*)		1.15	0.55	0.3
Rapeseed, Canola		1.0-1.15[9]	0.35	0.6
Safflower		1.0-1.15[9]	0.25	0.8
Sesame		1.1	0.25	1
Sunflower		1.0-1.15[9]	0.35	2

i. Cereals	**0.3**	**1.15**	**0.4**	
Barley		1.15	0.25	1
Oats		1.15	0.25	1
Spring Wheat		1.15	0.25-0.4[10]	1
Winter Wheat				
- with frozen soils	0.4	1.15	0.25-0.4[10]	1
- with non-frozen soils	0.7	1.15	0.25-0.4[10]	
Maize, Field (grain) *(field corn)*		1.2	0.60-0.35[11]	2
Maize, Sweet *(sweet corn)*		1.15	1.0512	1.5
Millet		1	0.3	1.5
Sorghum				
- grain		1.00-1.10	0.55	2-Jan
- sweet		1.2	1.05	4-Feb
Rice	1.05	1.2	0.90-0.60	1
j. Forages				
Alfalfa Hay				
- averaged cutting effects	0.4	0.9513	0.9	0.7
- individual cutting periods	0.4014	1.2014	1.1514	0.7
- for seed	0.4	0.5	0.5	0.7
Bermuda hay				
- averaged cutting effects	0.55	1.0013	0.85	0.35
- Spring crop for seed	0.35	0.9	0.65	0.4
Clover hay, Berseem				
- averaged cutting effects	0.4	0.9013	0.85	0.6
- individual cutting periods	0.4014	1.1514	1.1014	0.6
Rye Grass hay				
- averaged cutting effects	0.95	1.05	1	0.3
Sudan Grass hay (annual)				
- averaged cutting effects	0.5	0.9014	0.85	1.2

	- individual cutting periods	0.5014	1.1514	1.1014	1.2
Grazing Pasture					
	- Rotated Grazing	0.4	0.85-1.05	0.85	0.15-0.30
	- Extensive Grazing	0.3	0.75	0.75	0.1
Turf grass					
	- cool season [15]	0.90	0.95	0.95	0.1
	- warm season[15]	0.80	0.85	0.85	0.1
k. Sugar Cane		**0.4**	**1.25**	**0.75**	**3**
l. Tropical Fruits and Trees					
Banana					
	- 1st year	0.5	1.1	1	3
	- 2nd year	1	1.2	1.1	4
Cacao		1	1.05	1.05	3
Coffee					
	- bare ground cover	0.9	0.95	0.95	3-Feb
	- with weeds	1.05	1.1	1.1	3-Feb
Date Palms		0.9	0.95	0.95	8
Palm Trees		0.95	1	1	8
Pineapple [16]					
	- bare soil	0.5	0.3	0.3	0.6-1.2
	- with grass cover	0.5	0.5	0.5	0.6-1.2
Rubber Trees		0.95	1	1	10
Tea					
	- non-shaded	0.95	1	1	1.5
	- shaded [17]	1.10	1.15	1.15	2
m. Grapes and Berries					
Berries (bushes)		0.3	1.05	0.5	1.5
Grapes					
	- Table or Raisin	0.3	0.85	0.45	2
	- Wine	0.3	0.7	0.45	1.5-2
Hops		0.3	1.05	0.85	5
n. Fruit Trees					
Almonds, no ground cover		0.4	0.9	0.6518	5
Apples, Cherries, Pears[19]					
	- no ground cover, killing frost	0.45	0.95	0.7018	4
	- no ground cover, no frosts	0.6	0.95	0.7518	4

	- active ground cover, killing frost	0.5	1.2	0.9518	4
	- active ground cover, no frosts	0.8	1.2	0.8518	4
Apricots, Peaches, Stone Fruit[19, 20]					
	- no ground cover, killing frost	0.45	0.9	0.6518	3
	- no ground cover, no frosts	0.55	0.9	0.6518	3
	- active ground cover, killing frost	0.5	1.15	0.9018	3
	- active ground cover, no frosts	0.8	1.15	0.8518	3
Avocado, no ground cover		0.6	0.85	0.75	3
Citrus, no ground cover[21]					
	- 70% canopy	0.70	0.65	0.7	4
	- 50% canopy	0.65	0.6	0.65	3
	- 20% canopy	0.50	0.45	0.55	2
Citrus, with active ground cover or weeds[22]					
	- 70% canopy	0.75	0.7	0.75	4
	- 50% canopy	0.80	0.8	0.8	3
	- 20% canopy	0.85	0.85	0.85	2
Conifer Trees [23]		1	1	1	10
Kiwi		0.4	1.05	1.05	3
Olives (40 to 60% ground coverage by canopy) [24]		0.65	0.7	0.7	5-Mar
Pistachios, no ground cover		0.4	1.1	0.45	5-Mar
Walnut Orchard [19]		0.5	1.1	0.6518	5-Apr
o. Wetlands - temperate climate					
Cattails, Bulrushes, killingfrost		0.3	1.2	0.3	2
Cattails, Bulrushes, no frost		0.6	1.2	0.6	2
Short Veg., no frost		1.05	1.1	1.1	0.3
Reed Swamp, standing water		1	1.2	1	3-Jan
Reed Swamp, moist soil		0.9	1.2	0.7	3-Jan
p. Special					
Open Water, < 2 m depth or in subhumid climates or tropics			1.05	1.05	
Open Water, > 5 m depth, clear of turbidity, temperate climate			0.6525	1.2525	

جامعة النجاح الوطنية
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د. نعمان مزيد

الملخص

ارتفاع الطلب المستمر على المياه بالتعاون مع ندرة المياه في حوض نهر الأردن يجعل تحديد بصمة المياه على مستويات مختلفة قضية هامة على الرغم من التقدم المحرز في البحوث بصمة الماء منذ ظهور المصطلح من قبل هويكسترا (2003)، لا يزال هناك نقص كبير في الدراسات التي على أحواض انهار محددة، خصوصا بالنسبة لتلك الواقعة في المناطق الصحراوية وشبه الصحراوية.

كان الهدف من هذه الدراسة هو حساب بصمة الماء الزرقاء لحوض نهر الأردن، وربطها مع الصراعات المائية، وتطوير نموذج وتشغيل بعض السيناريوهات المقترحة. أظهرت النتائج أن المتوسط السنوي لبصمة الماء الزرقاء كانت 2657 مليون متر مكعب خلال الفترة المذكورة، وكانت الأنشطة الزراعية أكبر مستهلك للمياه، وهو ما يمثل 48٪ من بصمة الماء الزرقاء (45٪ لإنتاج المحاصيل و3٪ للإنتاج الحيواني كان المتبقي 52٪ للقطاعات المنزلية والصناعية مع 45 ٪ للقطاع المنزلي و 7٪ للقطاع الصناعي).

وجدت الدراسة أن بصمة الماء الزرقاء تجاوزت الكمية المتاحة من المياه الزرقاء (كانت النسبة أكثر من 313 ٪) مما يجعل المنطقة تعاني من شح شديد في المياه الزرقاء.

هناك العديد من المؤشرات التي تبين أن استهلاك المياه للأنشطة البشرية في حوض نهر الأردن قد تجاوز مستوى الاستدامة من توافر المياه خلال فترة 2009–2011.

سوف تنعكس ندرة المياه الشديدة على الصراعات المائية؛ وسوف تزيد من التوترات والحساسيات في المنطقة بالإضافة إلى التوترات السياسية القائمة بالفعل.

النموذج المطور يعتبر مهم جدا، من أجل دراسة استجابة البصمة المائية (وكذلك الصراعات المائية حيث إن بصمة المياه في هذه الدراسة تم اعتبارها مؤشر للصراعات المائية) إلى عدة متغيرات؛ مثل كميات الإنتاج و موقع الزراعة. إن السيناريوهات المقترحة لا تعطي أي حلول حقيقية لمشكلة المياه في المنطقة.

الحد من استهلاك الماء (m^3/ton) فيحوض نهر الأردن عن طريق زيادة إنتاجية المياه (ton/m^3) هو الحل للحد من الضغط على الموارد المائية. ويمكن تحقيق زيادة إنتاجية المياه عن طريق تغيير بعض الممارسات الزراعية.

وضع السياسة المائية الجيدة والسياسة التجارية الوطنية الجيدة في البلدان المتشاطئة في حوض نهر الأردن على المدى الطويل يمكن أن يقلل مشاكل ندرة المياه والتوصل إلى استخدام أمثل للمياه.

نظراً للاستهلاك الكبير للمياه على الزراعة فان اختيار المزروعات المناسبة واستغلال المياه الخضراء قد يكون جزء مهم من حل مشكلة استدامة المياه في حوض نهر الأردن.