Marginal and Virtual Water for Sustainable Water Resources Management in Syria

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LUND UNIVERSITY

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Abstract

Arid and semiarid Middle Eastern countries generally, and Syria in particular, face serious water shortage problems and challenges with water sustainability. Climate change, population growth, and economic development play a major role in decreasing available water resources per capita. This, in turn, has great impact on domestic, agricultural, and industrial water use. In this study, marginal and virtual water are analysed in light of increasing water demands in Syria, and ways to increase available water resources per capita are presented. In particular, greywater reuse, rainwater harvesting, crop pattern changes based on virtual water contents, and the use of WEAP for water evaluation and planning in Syria are presented and discussed. Greywater reuse is becoming an increasingly important resource for potable water conservation in many countries. Due to the absence of rainwater sewer systems in many rural areas in Syria, priority in future policies and plans must be given to the design and construction of collection systems. Virtual water is the water embedded in a product. If agricultural plans take crop water requirements and virtual water concepts into consideration, they can reduce water needs. Recognizing all of the above, the thesis shows that the potential for potable water conservation through the use of greywater for toilet flushing in Syria can be up to 35% of domestically used water. The economic analysis of the treatment of greywater through artificial wetlands and commercial bio filters showed that, with the current water tariff, the payback periods would be 7 and 52 years, respectively. However, these periods could be reduced to 3 and 21 years, respectively, if beneficiaries paid the full water costs. Furthermore, additional roof rainwater harvesting in Syria could increase water availability to as much as 35 million m^3 (MCM) in rural areas. Rainwater harvesting could add up to 3% to available national water resources. In the agricultural sector, Syria could save more than 500 MCM of water if lower water consumption crops were substituted on half of the land currently planted with cotton. Crop change scenarios may depend on a national agricultural trade based on imports of high water consumption crops and exports of low water consumption crops. The implementation of modern irrigation techniques and improvement of national development policy play a vital role in reducing the gap between water supply and demand. Overall, it was found that the Syrian water shortage can be reduced from around 2000 MCM in 2010 to about 500 MCM in 2050 despite a projected population increase. To balance national water needs efficiently, the projected water availability and demand in all water basins need to be considered. The study of water availability, water demand, and water balance at a basin level helps in promoting optimal solutions to tackle water shortage problems. Thus, WEAP (Water Evaluation And Planning system) was used to study six different scenarios for the seven main Syrian water basins while taking development, regional cooperation, regional confrontation, and climate change into account. The model showed that excess water availability for some basins can help to balance projected water scarcity for other basins.

Key words: Artificial wetland; Climate change**;** Commercial bio filter, Crop patterns, Greywater**;** Marginal water; Middle East; Rainwater harvesting; Virtual water; WEAP.

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Doctoral Thesis

Marginal and virtual water for sustainable water resources management in Syria.

By

Khaldoon A. Mourad

LUND UNIVERSITY

September, 2012

Marginal and Virtual Water for Sustainable Water Resources Management in Syria

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DEDICATION

This thesis is dedicated to

All Syrian blood that was lost …....

الأهـــــداء

لـــكل الدمـــــاء الســـوريـــــة

التي ضاعت على أرض الوطن ....

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Khaldoon Abdalah Mourad

خـــلدون عــبدالله مـــــراد

Lund, Sweden, September 2012

ABSTRACT

Arid and semiarid Middle Eastern countries generally, and Syria in particular, face serious water shortage problems and challenges with water sustainability. Climate change, population growth, and economic development play a major role in decreasing available water resources per capita. This, in turn, has great impact on domestic, agricultural, and industrial water use. In this study, marginal and virtual water are analysed in light of increasing water demands in Syria, and ways to increase available water resources per capita are presented. In particular, greywater reuse, rainwater harvesting, crop pattern changes based on virtual water contents, and the use of WEAP for water evaluation and planning in Syria are presented and discussed. Greywater reuse is becoming an increasingly important resource for potable water conservation in many countries. Due to the absence of rainwater sewer systems in many rural areas in Syria, priority in future policies and plans must be given to the design and construction of collection systems. Virtual water is the water embedded in a product. If agricultural plans take crop water requirements and virtual water concepts into consideration, they can reduce water needs. Recognizing all of the above, the thesis shows that the potential for potable water conservation through the use of greywater for toilet flushing in Syria can be up to 35% of domestically used water. The economic analysis of the treatment of greywater through artificial wetlands and commercial bio filters showed that, with the current water tariff, the payback periods would be 7 and 52 years, respectively. However, these periods could be reduced to 3 and 21 years, respectively, if beneficiaries paid the full water costs. Furthermore, additional roof rainwater harvesting in Syria could increase water availability to as much as 35 million m3 (MCM) in rural areas. Rainwater harvesting could add up to 3% to available national water resources. In the agricultural sector, Syria could save more than 500 MCM of water if lower water consumption crops were substituted on half of the land currently planted with cotton. Crop change scenarios may depend on a national agricultural trade based on imports of high water consumption crops and exports of low water consumption crops. The implementation of modern irrigation techniques and improvement of national development policy play a vital role in reducing the gap between water supply and demand. Overall, it was found that the Syrian water shortage can be reduced from around 2000 MCM in 2010 to about 500 MCM in 2050 despite a projected population increase. To balance national water needs efficiently, the projected water availability and demand in all water basins need to be considered. The study of water availability, water demand, and water balance at a basin level helps in promoting optimal solutions to tackle water shortage problems. Thus, WEAP (Water Evaluation And Planning system) was used to study six different scenarios for the seven main Syrian water basins while taking development, regional cooperation, regional confrontation, and climate change into account. The model showed that excess water availability for some basins can help to balance projected water scarcity for other basins.

ABSTRACT (Arabic)

(أَفَرَأَيْتُمُ الْمَاء الَّذِي تَشْرَبُونَ) (الواقعة :68)

(وَفَجَّرْنَا الْأَرْضَ عُيُوناً فَالْتَقَى الْمَاء عَلَى أَمْرٍ قَدْ قُدِرَ) (القمر : 12)

وأنزلنا من السماء ماءً بقدر فأمسكناه في الأرض وإنا على ذهاب به لقادرون (المؤمنون: ١٨)

الملخص:

البلدان في المناطق الجافة وشبه الجافة في الشرق الأوسط عموما وسوريا بصورة خاصة تواجه مشاكل وتحديات كبيرة في نقص و استدامة المياه. لعب كل من تغير المناخ والنمو السكاني والتنمية الاقتصادية دورا كبيرا في خفض كمية موارد المياه المتاحة للفرد والذي بدوره كان له أثر كبير في استخدام المياه للأغراض المنزلية والزراعية والصناعية. في هذه الدراسة، تم تحليل المياه الهامشية و الافتراضية لتحقيق التوازن المائي في سوريا وزيادة موارد المياه المتاحة للفرد الواحد. من أجل ذلك تمت دراسة إعادة استخدام المياه الرمادية، وحصاد مياه الأمطار وتغيير أنماط المحاصيل وفقا لمحتواها من المياه الافتراضية، كما تم استخدام برنامج WEAP لتقييم وتخطيط المياه في سوريا. أصبح إعادة استخدام المياه الرمادية موردا هاما لتوفيرمياه الشرب في العديد من البلدان. غياب شبكات صرف مياه الأمطار في العديد من المناطق الريفية في سوريا يشير إلى ضرورة إعطاء الأولوية لتصميم وبناء شبكات تجميع مياه الأمطار في السياسات والخطط المستقبلية. يمكن للمياه الافتراضية - والتي هي المياه التي يحويها أو يستهلكها أي منتج- خفض الاحتياج المائي إذا وضعت الخطط الزراعية على اساس الاحتياجات المائية للمحاصيل ومفهوم المياه الافتراضية. اعتماداً على ما سبق، استخدام المياه الرمادية لتنظيف دورة المياه في سوريا يمكن ان يقلل حتى 35 % من الاحتياج المنزلي. كما أظهر التحليل الاقتصادي لمعالجة المياه الرمادية بواسطة الأراضي الرطبة الاصطناعية و المرشح البيولوجي وفق التعرفة الحالية للمياه، فإن فترة الاسترداد ستكون 7 و 52 عاما، على التوالي. ولكن هذه الفترة تصبح 3 و 21 عاما، على التوالي، إذا قام المستفيدون بدفع كامل تكاليف المياه. وعلاوة على ذلك، يمكن لحصاد مياه الأمطار من الأسطحة في المناطق الريفية أن يوفر ما يقارب 350 مليون متر مكعب . ويمكن لجمع مياه الأمطارأن يضيف ما يصل الى 3٪ إلى الموارد المائية المتاحة في سوريا. في القطاع الزراعي، يمكن لسوريا توفير أكثر من 500 مليون متر مكعب إذا تم استبدال نصف المساحة المزروعة بالقطن بمحاصيل منخفظة الاستهلاك المائي. تعتمد سيناريوهات تغيير المحاصيل على التجارة و الزراعية الوطنية من خلال استيراد المحاصيل عالية استهلاك المائي وتصدير المحاصيل الزراعية منخفضة الاستهلاك المائي. تنفيذ تقنيات الري الحديث وتحسين سياسات وخطط التنمية الوطنية تلعب دورا حيويا في تقليص الفجوة القائمة بين العرض والطلب على المياه. وعموما، وجد أنه يمكن الحد من النقص في مياه في سوريا من حوالي 2000 مليون متر مكعب في عام 2010 إلى نحو 500 مليون متر مكعب في عام 2050 على الرغم من الزيادة المتوقعة في عدد السكان. من أجل كفاءة تحقيق التوازن للمياه في سوريا، يجب دراسة جميع الأحواض المائية واستشراف الوضع المائي فيها. دراسة توفر المياه والطلب عليها و التوازن المائي على مستوى الحوض المائي يساعدة في إيجاد أفضل الحلول لمعالجة مشاكل نقص المياه. في هذا الصدد،) تم استخدام WEAP (برنامج تقييم وتخطيط المياه) لدراسة ستة سيناريوهات مختلفة للأحواض المائية السورية الرئيسية السبعة مع أخذ كل من التنمية والتعاون الإقليمي والمواجهة الإقليمية، والمناخ بعين الاعتبار. وأظهر هذا النموذج أن فائض توافر المياه في بعض الأحواض يمكن أن يساعد على تحقيق التوازن المائي لأحواض أخرى.

PAPERS

Appended papers

This thesis is submitted with the support of the following appended papers that will be referred to by their Roman numerals in the body text.

I. **Mourad, A.K**. and Berndtsson, R., 2011. Syrian water resources between the present and the future. *Air, Soil, and Water Research*, 4, pp. 93–100.

II. **Mourad, A.K**. and Berndtsson, R., 2012. Water status in the Syrian water basins. *Open Journal of Modern Hydrology*, 2, pp. 15-20.

III. **Mourad, K.A.,** Gaese, H. and Jabarin, S.A., 2010. Economic value of tree fruit production in Jordan Valley from a virtual water perspective. *Water Resources Management*, 24(10), pp. 2021-2034.

IV. **Mourad, A.K**. and Berndtsson, R., 2012. Analysis of agricultural production in Syria from a virtual water flow perspective. *Journal of Agricultural Science and Applications* (submitted).

V. **Mourad, A.K**. and Berndtsson, R., 2012. *Grapes as an alternative crop for water saving*. In: Ralph P.M. and Christopher K.S. Eds. Grapes: Cultivation, Varieties and Nutritional Uses. Nova Science Publishers. ISBN: 978-1-62100-016-7

VI. **Mourad, A.K**., Berndtsson, J.C. and Berndtsson, R., 2011. Potential fresh water saving using greywater in toilet flushing in Syria. *Journal of Environmental Management*, 92(10), pp. 2447-2453.

VII. **Mourad, A.K**. and Berndtsson, R. 2011. Potential water saving from rainwater harvesting in Syria. *Journal of Water Management and Research*, 67, pp. 113-117.

VIII. **Mourad, A.K.,** Berndtsson, R. And Aggestam, K.., 2011. Can integrated water resources management contribute to sustainable peace in the Middle East? *Water Policy* (submitted).

IX. **Mourad, A.K.**, Alshehabi, O. and Berndtsson, R., 2012. Assessment of future Syrian water resources supply and demand by WEAP model. *Hydrological Sciences Journal* (submitted).

Related publications

Journals

Mourad, K., Berndtsson, R., Abu-El-Sha'r, W., and Qudah M.A., 2012. Modeling tool for air stripping and carbon adsorbers to remove trace organic contaminants. *International Journal of Thermal & Environmental Engineering*, 4(1), pp. 99-106.

Conference papers

Mourad, A.K. and Berndtsson, R., 2012. The economic value of agricultural water in Syria. World Congress on Water, Climate and Energy, 13-18 May, 2012 in Dublin, Ireland.

Mourad, A.K. and Berndtsson, R., 2012. Domestic and industrial water demand in Syria. Hydrogeology of Arid Environment. March 14 - 17, 2012. Hannover, Germany.

Mourad, A.K. and Berndtsson, R., 2011. Future water availability in Syria. Paper submitted to the Middle East Studies Association (MESA) 2011 Annual Meeting, [Session P2736 : The Struggle for Water in the Middle East: Potential and Pitfalls of Transboundary Cooperation], Washington, DC, USA, 1-4 December 2011.

Mourad, A.K., Berndtsson, R. Aggestam, K., 2011. Water and peace in the Middle East: the role of integrated water resources management. International Water Week/ Young Professional Workshop. Amsterdam, the Netherlands, 29 October - 4 November 2011.

Mourad, A.K. and Berndtsson, R., 2011. Water availability in Syria, will it be enough? Paper presented in Management of Water in Changing World: Lessons Learnt and Innovative Perspectives. Dresden, Germany, P. 152, 11-12 October 2011.

Mourad, A.K., Berndtsson, J.C. and Berndtsson, R., 2011. Potential greywater reuse: Case study in Sweida area. The sixth IWA specialist conference on efficient use and management of water. Dead Sea, Jordan, 29 March - 2 April 2011.

Mourad, A.K., Gaese, H. and Jabarin, S. A. 2010. Economic value of tree fruit production in Jordan Valley from a virtual water perspective. World Congress for Middle Eastern Studies WOCMES. Barcelona, Spain, 19-24 July 2010.

ABBREVIATIONS & SYMBOLS

ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
AEW	Actual Embedded Water
AW	Artificial Wetland
AWPC	Available Water Per Capita
BAB	Barada and Awaj Basin
BGR	German Federal Institute for Geosciences and Natural Resources
CB	Coastal Basin
CBF	Commercial Biofilters
CBS	Central Bureau of Statistics
CWR	Crop Water Requirement
DB	Desert Basin
DKB	Dajleh and Khabour Basin
DSS	Decision Support System
EAB	Euphrates and Aleppo Basin
FAO	Food and Agriculture Organization
FM	Total number of family members
GCSAR	General Commission for Scientific Agricultural Research
GW	Greywater
Lpcd	Liter per capita per day
MW	Marginal Water
MAAR	Ministry of Agriculture and Agricultural Reform
MOI	Ministry of Irrigation
MOHC	Ministry of Housing and Construction
MCM	Million Cubic Meter
OB	Orontes Basin
Q_d	Drinking water (L)
Q_{sh}	Showers water (L)
Q_{tf}	Toilet flushing water (L)
Q_{tb}	Tooth brushing water L)
Q_{hw}	Hand washing water (L)
Q_{fw}	Face washing water (L)
Q_{wm}	Washing machine water (L)
Q_{dw}	Dish washing water (L)
Q_c	Cleaning water (L)
Q_{co}	Cooking water (L)
Q_{il}	Garden irrigation and livestock water (L)
Q_p	Pets and indoor plants water (L)
TEW	Total Embedded Water
VW	Virtual Water
W_d	Total daily water consumption (Lpcd)
W_p	Personal water consumption (Lpcd)
W_f	Daily water consumption within the family (Lpcd)
WEAP	Water Evaluation And Planning system
YB	Al-Yarmouk Basin

CONTENTS

1 Introduction

1.1 Background

The Middle East is the world's most water challenged region with possible future conflicts over shared water resources (e.g., Falkenmark, 1989; Starr and Stoll, 1988). Most countries in the Middle East are confronted by severe water problems due to both climatic conditions and socioeconomic factors. As a consequence, most of the countries exploit more than 50% of the renewable water resources and some nearly 100%.

Available Water Per Capita (AWPC) has decreased dramatically in the region due to population increase and economic development. In the future, climate change is expected to further aggravate this situation (e.g., Arnell, 1999). Furthermore, according to FAO, the average AWPC is going to be halved by 2025. Therefore, for better sustainable water management, water scarce countries in the Middle East should optimize the use of all available water resources and decrease losses. Research during the last decades has emphasized the overall importance of nonconventional water resources to solve some of the water scarcity problems in the Middle East (Haddad and Mizyed, 2004). Nonconventional water resources include marginal and virtual water. They can be considered as important pillars in national water budgets in arid and semiarid areas. Marginal water includes reused wastewater and rainwater harvesting.

1.1.1 Greywater

Due to the lack of freshwater, some countries have developed greywater reuse practices. Greywater is the water collected from domestic uses excluding that originating from toilets (Lombardo, 1982; Eriksson et al., 2002). Sometimes kitchen water is excluded as well (Li et al., 2009; Al-Jayyousi, 2003). The average greywater generation per capita is different from country to country; it varies from about 90 to 120 L/d (Li et al., 2009) depending on age, gender, living standards, habits, lifestyle, and the degree of water abundance. Climate also affects greywater generation. In a hot country like Oman, the greywater generation rate is about 151 liter per capita per day (Lpcd) (Jamrah et al., 2008) which corresponds to about 82% of the total fresh water consumption, 56% of which originate from showers, 28-33% from kitchens, 6-9% from laundry, and 5-7% from washing sinks. Reusing greywater for irrigation in the city of Los Angeles saves about 12-65% of the freshwater used annually (Sheikh, 1993). During recent years much research has been done to evaluate potential water savings through greywater reuse. Ghisi and Ferreira (2007) found that using greywater for toilet flushing saves between 29 and 35% of consumed water. Greywater, however, contains chemical and microbiological contaminants, which may stimulate the micro-organism growth in the greywater system (Widiastuti et al., 2008). All types of greywater have a good biodegradability but different characteristics. For example, laundry greywater contains less nitrogen and phosphorous than other greywater types. Kitchen greywater has a balanced COD:N:P ratio (Li et al., 2009). Due to the use of chemical products, laundry greywater has higher pH than other kinds of greywater (generally in the range 8-10; Eriksson et al., 2002). The COD and BOD fractions in greywater vary according to its source. For laundry greywater COD and BOD concentrations range between about 700-1800 and 50-500 mg/l, respectively. However, for mixed greywater the values may range between about 10-8000 and 90-350 mg/l for COD and BOD, respectively (Eriksson et al., 2002). Greywater cannot be used without treatment depending on its end uses. Organic removal decreases the chlorine demand and reduces the potential for microbial growth in the distribution system and in the toilet cistern (Winward et al., 2008). Irrigation with untreated laundry greywater may cause vital environmental hazards to the soil because of the excess sodium accumulation (Misra and Sivongxay, 2009). Untreated greywater cannot be used for toilet flushing due to its smell, potential staining of the toilet bowl, and the transport of bacteria and virus. According to USEPA standards reclaimed water used for toilet flushing should undergo filtration and disinfection. No detectable coliforms should appear in 100 ml of the effluent, BOD should be less than 10 mg/l and the residual chlorine should be more than 1 mg/l, pH equal to 6-9, and turbidity <2 NTU (Li et al., 2009; Al-Jayyousi, 2003). Based on the International Plumbing Code IPC 2000, greywater can be reused for toilet flushing after disinfection (GWPP, 2005). Greywater can be treated with natural zeolites (Widiastuti et al., 2008). The mulch tower has been tested to remove particulate matter and organic compounds from greywater (Zuma et al., 2009). Artificial wetlands, on the other hand, are very common to treat greywater before its further use for irrigation and/or toilet flushing (e.g., Li et al., 2009; Ghisi and Ferreira, 2007; Dallas et al., 2004). Greywater for toilet flushing can be treated in a bio reactor after the settling tank. It should also undergo disinfection before it is stored in the service tank (Goddard, 2006; Eriksson et al., 2009). However, due to its nature, high and medium polluted greywater cannot be efficiently chemically treated with use of coagulants and ion exchange resin if very strict standards are required. It needs to be followed by another process such as adsorption (Pidou et al., 2008).

1.1.2 Water harvesting

Rainwater harvesting, which is a technique to collect, store, and use rainwater for domestic and agricultural purposes, is considered one of the most important nonconventional water resources. Rainwater harvesting is a widely accepted solution to alleviate problems of water shortage (e.g., Cheng and Liao, 2009). In Australia, due to water shortage, rainwater tanks are considered a vital water storage technique in most of the rural areas. Eroksuz and Rahman (2010) found that large rainwater tanks, up to 70 m^3, in multi-unit residential buildings in Australia can provide up to 50% of the needed water for toilet flushing, laundry, hot water, and outdoor irrigation. Basinger et al. (2011) found that a significant percentage of the non-potable water needs of multifamily residential buildings in New York City can be supplied with roof harvested runoff. In Jordan, Abdulla and Shareef (2009) reported that a maximum of 15.5 MCM water can be collected from roofs of residential buildings. Other studies in Sweden, Brazil, and UK showed that using rainwater harvesting can give high percentage of potable water saving (e.g., Villarreal and Dixon, 2005; Ghisi et al., 2007; Fewkes, 1999). Harvested rainwater is considered a clean renewable water resource. Its quality in rural areas where air pollution is negligible depends on the receiving roofs and the collecting tanks. Rainwater harvesting can also be performed in the field by directing surface runoff toward a rainwater reservoir or to agricultural areas. Some rainwater harvesting techniques can also help in reducing soil erosion. Alkouri (2011) found that using large semi-circular bunds reduced erosion of agricultural soil in the Badia rangeland, which is located in the eastern part of Syria with an annual rainfall of less than 100 mm, by 16 to 53 %. Rainwater harvesting ponds (reservoirs) can be designed using topographical maps and GIS (e.g., Al- Adamat et al., 2010).

In Syria, water harvesting systems, such as surface water collection into reservoirs and transport by waterwheels, have traditionally been used since 3000 BC. According to the Syrian topography, 60% of the Syrian land may be appropriate for water harvesting systems. The Ministry of Agriculture and Agricultural Reform (MAAR) and the General Commission for Scientific Agricultural Research (GCSAR) have conducted much research in this field (e.g., Abdul, 2011). They found that the choice of the best water harvesting technique depends on the soil, the slope, the rainfall and runoff amounts, the socioeconomic situation, and the cultivation patterns in the studied area.

1.1.3 Virtual water

Virtual water was defined by Allan (1997) as the embedded water in the global trading system. Another definition is the embedded water in a product in a virtual sense that can be imported into a country as indigenous water (Hoekstra, 2003). For example, 1 ton of wheat needs about 1,000 tons of water in the USA to be produced while it needs 2,500 tons in Syria and 3,000 tons in Jordan. Hence, it has been shown that from an ecological point of view, it is better for Jordan to import 1 ton of wheat rather than piping 3,000 tons of water. Virtual water can solve many water-related issues, and local water shortages can be overcome by considering the virtual water content of water-consuming products (Allan, 2003). Yet, many countries still do not include their virtual water trade in the water scarcity problem. Water-poor countries often keep exporting products which are high consumers of water, while water-rich countries import products which are high consumers of water (Kumar and Singh, 2005). The use of virtual water can be developed over time. The great advantage of the virtual water concept is that it makes water invisible. Consequently, it can be applied beyond political borders and conflicts.

According to the above, water poor countries can save water by importing products that require large amounts of water and export products requiring small amounts of water (See **paper II**). In Egypt, e.g., one hectare of rice and wheat needs about 21000, and 4000 m^3 of irrigation water, respectively (Wichelns, 2001). Kumar and Singh (2005) analyzed 146 countries and found no relation between virtual water trade and water scarcity because most water-scarce countries keep producing high water consuming crops. Ansink (2010) refuted two claims on virtual water trade, that virtual water trade: (i) levels uneven water distribution, and (ii) reduces the potential for water conflict. It is, however, important that specialists, stakeholders, and decision makers are made aware of the role of virtual water in the international economy.

1.1.4 Water sustainability and IWRM

In order to manage water in a sustainable way the Integrated Water Resources Management (IWRM) approach should be used. IWRM ensures the participation and consideration of all water related sectors in the management and development of water resources by integrating all water sub-sectors with the social dimension in the management process. Fundamentally, IWRM is based on bridging the gap between policies and implementation (Rahaman and Varis, 2005).The natural, socio-economic, and institutional systems are the bases of any management approach (Figure 1). IWRM ensures their integration by considering demands and impacts.

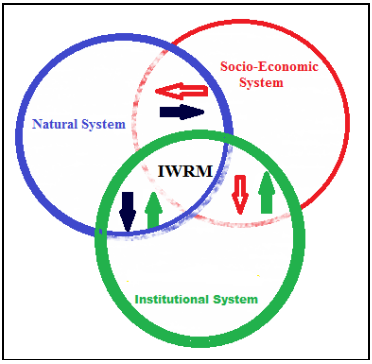

Figure 1. IWRM approach.

The Institutional system plays a vital role in IWRM. It controls water use through a set of laws, policies, and legislations. However, it may also have negative impacts on the environment due to construction projects. The Socio-Economic system, in turn, has its own impacts on and reactions to the Natural and the Institutional systems. In addition to the primary stakeholder/decision makers, local communities and consumers should be involved to guarantee water project sustainability. Many countries face a multitude of problems in implementing their water policies and laws because the participatory approach was not used while planning their projects. For Lake Tiberius and the Jordan River, any IWRM policy aimed at resolving the present hydrological, ecological, and political problems should take water quality and quantity into consideration (Berman, 1998) by enhancing public awareness and organizational development in the region. Moreover, the Institutional system is the body responsible for cooperation and agreement between countries at the river basin scale.

1.1.5 WEAP model

The recently developed WEAP model, which is an initiative of the Stockholm Environment Institute, provides a framework for water assessment and planning and can be used to represent current and future water conditions in a given area depending on key assumptions (Lévite et al., 2003). The model can also explore a wide range of demand and supply options for balancing environment and development (SEI, 2011). Along with this, WEAP can be used as an integrated decision support system (DSS) that helps policy makers and other stakeholders in their water plans in water resources, wastewater, and simulation between alternatives (e.g., Assaf and Saadeh, 2008; McKinney, 2004; Qin, 2011). WEAP can also be used to create water scenarios to be used by other models such as MONERIS and QUAL2K (Gaiser et al., 2008). Thus, the model may help in the assessment of water uses, reallocations among sectors, assessing upstream-downstream links, and testing options for matching water supply and water demand (e.g., George et al., 2011; Hoff et al., 2007). Hoff et al. (2011) developed a water resources tool for the Jordan River basin using WEAP, which indicated that climate and socio-economic change are both key drivers of future water scarcity in the basin. Droubi et al. (2008) studied the groundwater balance in the Zabadani Basin in Syria using the WEAP model together with MODFLOW. However, to the author´s knowledge WEAP has not been used before to assess the overall water status in the Syrian basins.

1.2 Objectives and Scope

For sustainable water management all affordable water should be taken into consideration. Reclaimed water and rainwater should be used optimally. Crop patterns should be changed according to countries' needs and water use ratio. Therefore, the main objective of this study was to elaborate on how to sustainably manage water resources in Syria. This objective was tackled carefully in the nine appended papers. The first part focuses on analysing water supply and needs in Syria and their projections to 2050 taking climate change, population, and development growth into consideration. The study utilized generally available data to analyse present and future domestic, industrial, and agricultural water demand. Available surface and groundwater that contribute to the national water budget were estimated. This part is presented in two papers, **Paper I** considering Syria as one unit and **Paper II** giving a more detailed analysis for the seven main watersheds in Syria.

Acknowledging agriculture as the main water consumer in Syria, suggestions to change crop patterns according to Crop Water Requirement CWR and Virtual Water VW are given as a first priority in order to save water for other uses. This is discussed in **Paper III, IV,** and **V**, acknowledging the economic value of water.

Water shortage at a national level shows the vital importance of reusing reclaimed water and rainwater harvesting in the national water budget. The main objective of Paper **VI** was to estimate the potential water saving from reusing greywater in toilet flushing and also to analyze it in economic terms for a typical Syrian city. For this purpose the Sweida city, in southern Syria, was chosen as case study. Two kinds of greywater reuse systems were investigated, namely artificial wetland and commercial bio filter. **Paper VII** aimed at estimating potential water saving from rainwater harvesting.

The historical records of water conflict in the Middle East (**Paper VIII**), gives water an important role in peace making. An integrated water resources management approach can introduce cooperation instead of confrontation between countries in the Middle East. **Paper IX** summarizes the thesis by using previous results to model water balances using the WEAP model. The model estimated unmet demand projections up to 2050 by different possible scenarios.

1.3 Thesis Structure

According to the above, the thesis is based on the nine appended papers. Accordingly, **Chapter 1** introduces the thesis subject. Water resources and demands in Syria are presented in **Chapter 2**. Marginal and virtual water are presented in **Chapter 3**. **Chapter 4** presents the main results, discussion, and suggestions for further research. Finally, **Chapter 5** presents the conclusions.

The methods, objectives, and results arrived at are included in the thesis summary; however, more details can be found in the nine appended papers.

2 Syrian Water

2.1 Water Resources

Syria, with a total area of about 185,180 km^2 and a total population of about 21.13 million (CBS-SYR, 2011), can be divided into seven main water basins: Barada and Awaj (BAB), Al-Yarmouk (YB), Orontes (OB), Dajleh and Khabour (DKB), Euphrates and Aleppo (EAB), Desert (DB), and the Coastal Basin (CB), each of which has its own geological, meteorological, hydrological, and demographical characteristics (Figure 2). Most of these basins are shared with other countries.

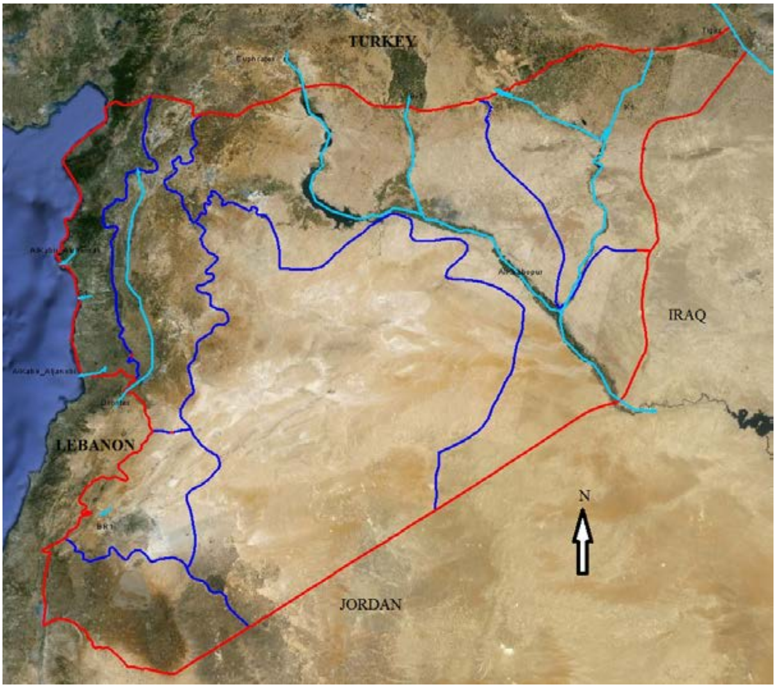

Figure 2. Main water basins charecteristics in Syria

2.1.1 Rainfall and evaporation

Annual rainfall can reach more than 1000 mm in the coast region. However the lowest values are around 60 mm per year. Depending on humidity and rainfall, Syria can be divided into five climatic zones: wet (>600 mm), semi-wet (300-600 mm), semi-arid (200-300 mm), arid (100-200 mm), and dry (<100 mm) (Figure 1; Abdul, 2011). Syria, on the other hand, has high evaporation rates. The potential evaporation rate is about 1300 mm/year in the western parts and reaches 3000 mm/year in the eastern and south-eastern parts of Syria (see **Paper I**).

2.1.2 Surface water

Surface waters include around 22 main rivers, some of which are shared with other countries in the region and some of which are just seasonal streams (Table 1), eight main lakes, and about 150 surface dams. Syria has made treaties with its neighbors Lebanon, Jordan, Iraq, and Turkey to ease the management of shared water resources.

Table 1. Major rivers in Syria.

River	Length (km)		River	Length (km)	
	Total	Inside Syria		Total	Inside Syria
Euphrates	2280	660	EL-kabir_J	76	56
Tigris	1850	44	Yarmouk	60	48
Khabour	477	402	El-Kabir_Sh	96	96
AL-Jarjab	78	26	Barada	81	81
AL-Zerkan	125	45	Awaj	70	70
AL-Jaghja	124	100	Al Abiad	20	20
AL-Beleikh	202	116	Al-Siberani	32	32
Al-Sajour	122	27	Banias_Coast	22	22
Orontes	485	366	Al-Sin	6	6
Efreen	136	74	Abu Kebais	6	6
QweiK	202	155	Al Bared	5.5	5.5

2.1.3 Groundwater

The Ministry of Irrigation (MoI) estimated average annual spring flow at about 1350 Million Cubic meters (MCM) and the total annual amount of renewable groundwater at about 4811 MCM, which includes almost all springs and legal wells. For groundwater flow, on the other hand, about 1200 and 130 MCM annually enter Syria from Turkey and Lebanon, respectively. However, about 90 and 250 MCM annually leave Syria to Jordan and the Occupied Lands, respectively (FAO, 2011). Syrian groundwater includes about 140 springs. At present, some of these springs are drying out. More than 40% of the springs have an average quantity of less than 15 L/s. Syria has more than 200,000 wells, about 50% of which are illegal wells. Therefore, any estimation of actually pumped groundwater will contain some errors and uncertainties (MoI-SYR, 2012).

2.1.4 Reclaimed water

According to the Ministry of Housing and Construction (MoHC), the reclaimed water in 2008 was about 2306, 671, and 407 MCM in the agricultural, domestic, and industrial sectors, respectively. This corresponds to about 15, 55, and 65% of the total water being consumed in the agricultural, domestic, and industrial sectors, respectively. In the national development plan, MoHC has announced the construction of more than 20 wastewater treatment plants within the next 20 years. According to this, domestic and industrial wastewater is assumed to be treated up to 85% by volume in 2040.

2.2 Water Demand

2.2.1 Domestic Demand

The domestic water consumption range is 100–200 (Lpcd) depending on lifestyle, water availability, and local circumstances. However, due to old networks and unqualified human resources, the losses in the drinking water system are more than 25% (MoHC, 2008). These losses were about 50% in the Rural Damascus governorate. According to MoHC, the actual domestic water production in 2008 was 1183 MCM and the population in Syria at the end of 2008 was about 19.9 million inhabitants (CBS-SYR, 2010). Consequently, the annual water consumed per capita equals 59.45 m^3. This gives a daily average per capita consumption including water losses of 163 L (totally produced water divided by population).

2.2.2 Industrial Demand

For the industrial sector, there are no comprehensive data about the quantity of water used in Syria. However, the Central Bureau of Statistics (CBS) estimated the demand to be about 623 MCM/year in 2008. The number of industrial projects is increasing every year.

2.2.3 Agricultural Demand

Agriculture is the main water consuming sector in Syria. Agricultural water consumption in 2008 was about 15400 MCM. Crops include cereals, vegetables, fruit trees, and industrial crops. Hence, irrigation practices and techniques play a vital role in water demand and crop production. Official statistics for 1978 to 2007 indicate that the average total cultivated land was about 24% (CBS-SYR, 2010). The changes in the irrigated land, non-irrigated land, and the total cultivated areas from 1970 to 2008 are presented in Figure 3, which shows that the increase in the cultivated land area is a result of irrigated land increase. The change in non-irrigated land area mainly depends on rainfall amount and distribution. Figure 3 indicates that the average annual increase in cultivated land area is about 1% (1978–2007). The average annual increase in the irrigated lands for the same period was about 3%. Consequently, the irrigated land area with modern irrigation techniques increased from about 215,000 ha in 2002 to about 282,000 ha in 2009, which are about 20% of the total irrigated lands. Figure 2 also indicates that the total cultivated land area appears to have reached a more or less constant level after around 1998.

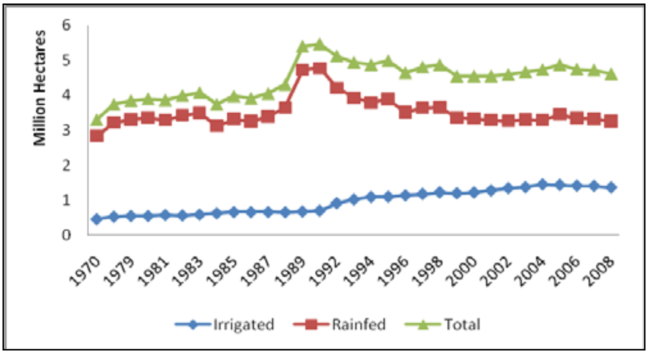

Figure 3. Cultivated land types in Syria

2.3 Water constraints

Many constraints are facing water use in Syria. These include physical, economic, technical, institutional, and climate change constraints:

1) Physical constraints: Large seasonal differences in rainfall requiring large storage capacity. About 60% of the country receives less than 250 mm/year.

2) Economic constraints: Most water resources projects depend on external funds which are coordinated by external consultants. This makes projects subject to vulnerability due to weak coordination and cooperation between different stakeholders. Corruption is another factor that tends to weaken the project implementation and local participation.

3) Environmental constraints: The limited number of wastewater treatment plants, operation problems, and lack of public awareness has created many environmental problems such as surface and groundwater pollution from using untreated wastewater for irrigation, and the damaging of treated effluent canals. Moreover, the absence of storm water drains in big cities, especially Damascus, has a negative effect on the operation and maintenance of treatment plants.

4) Technical constraints: High water losses, lack of wastewater treatment plants, groundwater contamination due to high nutrient concentration in the treated wastewater, and slow implementation of modern irrigation and water-saving technology. The losses in the drinking water system for example are around 25%.

5) Institutional constraints: Many ministries are involved in parts of the water sector in Syria. MoI is responsible for the monitoring, management, and development of surface and groundwater resources. The Ministry of Agriculture and Agrarian Reform (MAAR) is responsible for developing irrigation practices in agricultural areas and reusing treated wastewater. MoHC is responsible for the drinking water supply and treatment. The Ministry of State for Environmental Affairs is responsible for water protection. Each ministry has its own directorate in the governorates and many ministries include water

management in their annual plans. However, overlapping and lack of cooperation is negatively affecting efficient water resources planning and management.

6) Climate change: The Middle East is likely to face a decrease in precipitation by 20-25% up to 2050, which will reduce the runoff by about 23%, and the Euphrates River flow may be reduced by 30-70%. The Middle East average temperature may increase by about 2.5°C to 2050, which will affect evaporated water amounts (Trondalen, 2009; Breisinger et al., 2011). Evans (2010) found that climate change is likely to increase precipitation from southeastern Syria toward the mountains, and the Mediterranean Sea. Global Climate Models (GCMs), however, indicate that precipitation may decrease over the Eastern Mediterranean, Turkey, Syria, Northern Iraq, and Northeastern Iran. Moreover, according to Waimi (2010), who studied climate change in the Middle East and North Africa (MENA), Syria is located in the Asian Mashrek region, which may have an annual temperature increase of about 0.05°C, while the precipitation has a negative slope in the annual rainfall trend with an average value of -1.50 mm/year.

2.4 Regional Water Agreements

In addition to economic and social dimensions, water resources in Syria have a political dimension. Syria has realized this fact and made treaties with its neighbors, Lebanon, Jordan, Iraq, and Turkey to ease the management of shared water resources in the region (MoI-SY, 2007). In the case of the Euphrates River, shared among Turkey, Syria, and Iraq, Turkey agreed to release at least 500 m^3/s to Syria. Syria will use only 42%, while the rest will be released to Iraq, which means the annual Syrian share from the Euphrates is about 6623 MCM. Also agreed was that Syria can use an annual amount of water from the Tigris of about 1250 MCM. Two agreements were made with Lebanon. The first in 1994 concerned the Orontes River. The agreement states that Lebanon can use an annual amount of 80 MCM during years when the average river flow is more or equal to 400 MCM/year, and 20% otherwise. The second agreement in 2002 was for the Al-Kabir Al-Janubi River with an average annual flow of 150 MCM. The agreement divided the water into 60% for Syria and 40% for Lebanon regardless of hydrological circumstances (MoI-SYR, 2007).

2.5 Previous Research

Limited research has dealt with the overall water resources in Syria. Kaisi et al. (2004) reported that the total annual available regulated water resources in Syria are about 14,218 million cubic meters (MCM) and the total annual demand about 17,566 MCM, which gives about 3,348 MCM in water shortage. Most research has dealt with specific basins or specific sectors of Syrian water. Burdon and Safadi (1964) studied geological formation groundwater aquifers in Syria. Altinbilk (2004) studied development and management of the Euphrates and Tigris basin. Shaban et al. (2005) reviewed hydrological and watershed characteristics of the El-Kabir River between Syria and Lebanon. Kattan (2006) reviewed hydrological and environmental characteristics of surface and groundwater in Damascus, Barada & Awaj basin. Braemer et al. (2009) analyzed long-term management of water in Hawran, southern Syria. Abou Zakhem and Hafez (2007) have studied seawater intrusion on the Syrian coast. Barnes (2009) argued that the Syrian government has produced scarcity through its agricultural development policies, and the rapid population growth greatly affects water resource depletion. The problem may be clear if we compare the population trend of Syria which was about 9 million in 1981 and about 21 million in 2011 (CBS-SYR, 2010).

On the other hand, using WEAP, Droubi et al. (2008) have developed a Decision Support System (DSS) for Water Resources management in the Zabadani basin, which was carried out by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and the German Federal Institute for Geosciences and Natural Resources (BGR). Water balance was estimated taking Human activities (population growth, urbanization, domestic demands); Agricultural activities (land use, crop types, irrigation practices); Climate impacts (climate change models, regional climate cycles); Network characteristics (transmission link losses and limits, well field characteristics, well depths); and Additional resources (artificial recharge, waste water reuse) into account. Results show a preliminary shortage, calculated by WEAP, of about 66 MCM in the Zabadani basin.

3. Materials and Methods

To accomplish the objectives of this study, rainfall data, climatic areas, potable water supply, population, sanitation systems, and agricultural data were obtained from the Syrian ministries MoHC, MoI, and MAAR. Other types of data were taken from CBS and the General Commission for Scientific Agricultural Research (GCSAR). Some information was obtained through specific interviews.

3.1 Greywater

The water consumption was estimated through interviews in Sweida City. The billed water consumption was estimated based on water bills for six months. Two treatment methods were proposed: artificial wetlands (AW) and commercial bio filters (CBF). AW is a good method if land is available, otherwise, CBF can be the solution. For the economic analysis, all costs of the construction and implementation of such systems were taken into account and they are presented below.

In order to analyze the greywater status in Syria, a field survey was made to investigate the social attitude towards reusing greywater in the Sweida area and to find the following parameters through personal interviews: living place, land availability, number of family members, indoor and outdoor water activities, water bills, and their opinions about reusing greywater. The number of interviewees was determined using Eq. (1), which estimates a population-based representative sample (Ghisi and Ferreira, 2007).

$$n \geq (1/\epsilon^2)N / (1/\epsilon^2 + N) \qquad (1)$$

where n is the sample size, N is the population size, and ϵ is the sample error (from 1 to 20%).

Daily potable water consumption was estimated using Eqns. (2), (3), and (4):

$$W_d = W_p + W_f \qquad (2)$$

$$W_p = (Q_{sh} + Q_{tf} + Q_{tb} + Q_{hw} + Q_{fw} + Q_d) \qquad (3)$$

$$W_f = (Q_{wm} + Q_{dw} + Q_c + Q_{co} + Q_i + Q_l) / FM \qquad (4)$$

where W_d is the total daily water consumption (Lpcd), W_p is the personal water consumption (Lpcd), W_f is the water consumption within the family (Lpcd), Q_{sh}, Q_{tf}, Q_{tb}, Q_{hw}, Q_{fw}, Q_{wm}, Q_{dw}, Q_c, Q_d, $Q_{co,}$ and Q_{il} are the average water consumption, in liters, for showers, toilet flushing, tooth brushing, hand washing, face washing, washing machine, dish washing, cleaning, drinking, cooking, and garden irrigation & livestock, respectively, and FM is the total number of family members.

The average quantities for one event of face washing, hand washing, shower, and tooth brushing were taken from a group of ten volunteers, five males and five females. The group contained two teenagers, four singles, and four married persons. The average water consumption of water flushing and the frequencies of all uses were taken from the interviews by asking them about the frequencies of doing each activity and the toilet tank's size.

Economic analysis was performed considering the implementation of the greywater system for new flats and buildings. Material and equipment costs were estimated after visiting four local stores. The water tariff was taken according to the Syrian tariff system. Water cost in Syria is subsidized by the government, consumers pay just about 35% of the real cost.

3.2 Water Harvesting

For roof water harvesting, the total roof area in each governorate was calculated based on the average area and number of typical houses. The potential rainwater harvesting volume was estimated based on the total roof area, the average annual rainfall between 1978 and 2007, and the runoff coefficient. Then, the potential saving percentage was calculated by dividing the potential volume of harvested rainfall by the annual domestic demand. According to CBS, 60% of the Syrian lands receive less than 250 mm/year and 46% of the population lives in rural areas. Most dwellings in Syrian rural areas have one floor. However, after 2005 due to the economic crisis, the number of two and three floor dwellings increased especially near village centers. The total roof area in each governorate was estimated with the help of data from CBS.

The potentially harvested water (HW) for each governorate was estimated by the following equation:

$$HW = R*A*K \qquad (5)$$

where R is the average rainfall in the target governorate, A is the total roof area (assuming that all buildings have two floors), and K is the a run-off coefficient of 80%, which indicates a loss of 20% of the rainwater that is discarded for roof cleaning and evaporation (Abdulla and Al-Shareef, 2009).

Most dwellings in Syrian rural areas have one floor. However, after 2005 and due to the economic crisis, two and three floor dwellings increased especially near village centers. The total roof area in each governorate was estimated with the help of CBS. Table 2 presents the residential building roof area in each rural area of each governorate.

Table 2. Floor area in the Syrian rural areas.

Governorate	Floor Area 10^3 m^2	Governorate	Floor Area 10^3 m^2
Damascus Rural	20668	Al-hasakeh	11335
Aleppo	24844	Al-Rakka	7731
Homs	17046	Al Sweida	6574
Hama	15990	Dra'a	9873
Lattakia	13578	Tartous	26522
Deir Ezzor	7847	Quneitra	1374
Idleb	15280	Al-hasakeh	11335

After CBS-SY (2010).

3.3 Virtual Water

Virtual water can be easily defined as the embedded water (EW) to produce a good. Hence, we can estimate the EW for crops from the following equations:

EW= CWR/Y ....(6)
Y=CP/A .... (7)

where CWR: crop water requirement (m^3/ha) (Table 3), Y: yield (ton/ha), CP: crop production (ton), and A: cultivated area (ha).

Table 3. Crop Water Requirements for different crops (m^3/ha).

Cereals & dry legumes		Industrial crops		Fruit trees		Vegetables	
Crop	CWR	Crop	CWR	Crop	CWR	Crop	CWR
Wheat	4040	Cotton	13090	Grapes	4500	Tomatoes	6916
Barley	4040	Tobacco	7800	Citrus	9808	Potatoes	5641
Maize	7269	Sugar beet	12500	Apple	12192	Onion & Garlic	8777
Broad bean	3176	Cumin	12000	Almond	10989	Watermelon	3954
Lentil	3500	Anise	12000	Olive	4000	Summer veg.	6916
Chick peas	3500	Peanut	10000	Dates	13950	Winter veg.	4584
Dry bitter vetch	2000	Other ind-crops	10000	Pistachio	8519	Other veg.	6000
Other cereals	3000			Other fruits	6000		

Source: Own elaboration based on (MAAR, 2010), (Abdelgawad, 2006) & (Shatanawi et al., 1998)

In order to have a better picture of fruit tree production, the embedded water was estimated using two methods. The first one depends on fruit bearing area, which is named the actual embedded water AEW, while the second one depends on the total cultivated area and is named the total embedded water TEW. However, the TEW was used in the following estimations.

The net virtual water balance (NVW) in cubic meters was estimated after the estimation of the imported (IVW) and exported virtual water (EVW) for each kind of crop:

*IVW = Imports * EW*..(8)
*EVW= Exports *EW* .... (9)
NVW = IVW-EVW ....(10)

where imports and exports are in tons

The same methodology was used by Velázquez (2007) to estimate the water trade in Andalusia. However, Velázquez estimated the net virtual water by subtracting the virtual water exported from the virtual water imported.

For the economic analysis, we have estimated the Gross profit (GP), gross profit to water use ratio GP/ WU and the Gross Margin (GM):

GP = TS-TC..(11)
GP/WU= GP/CW..(12)

$$GM=GP/TS \qquad (13)$$

where TS: total sales (US$), TC: total costs (US$), CW: consumed water (m^3).

The total costs contain: 1) agricultural management, which includes tillage, fertilization flatting, irrigation, hoeing & weeding, planting, pesticide control, harvesting, sorting & packaging and crop transportation; 2) production requirements, which include: fertilizers, packages, seeds, water and pesticides; and 3) other costs such as: land rent, capital interest, and incidental expenses.

The economic efficiency of water use relates the value of output and the opportunity costs of water used in agricultural production to the value of water applied. Opportunity costs, on the other hand, reflect the values that could be generated with water in alternative uses. By relating net return to unit water, planners can describe which good generates greater economic return from the use of domestic resources (Wichelns, 1999).

3.4 WEAP Model

The following six scenarios were simulated using the WEAP model.

(1) Reference Scenario (RF). The water demand was assumed to continue increasing according to the population and industrial growth, and the water irrigation techniques to not change substantially up to 2050, which means there are no new developments or improvements regarding sanitation, drinking water, or irrigation systems.

(2) Climate change scenario (CC). The annual rainfall decrease will be about 0.5 %. Accordingly, the annual water resources are assumed to decrease by about 0.25%, while annual evaporation rates will increase by about 0.25%.

(3) Best available technology scenario (BAT). This scenario depends on using the best available technologies through the implementation of a modern irrigation system and using closed water cycles in industry. For the future domestic demand projections, we assumed, due to the expected improvement in the drinking water systems, that the domestic consumption will be 125 Lpcd (liter per capita per day) in 2050, which means that the annual daily per capita domestic water demand will be reduced by about 40% in 2050 as shown in Figure 4. Furthermore, we assumed that due to water shortage and urban development, the cultivated land will be constant and the implementation of modern irrigation practices will save about 10% of the consumed water in agriculture in each basin by 2050.

(4) High Tech Scenario (HT). This scenario is based on the BAT scenario, however, also includes high tech implementation, which depends on cloud seedings, rain water harvesting and greywater reuse in toilet flushing. We assumed that cloud seeding will increase the preciptation by about 10%, and rainwater harvesting may save another 1.5% of the annual rainfall by 2050. Greywater reuse, according to (**Paper IV**), can save up to 35% of drinking water by using greywater in toilet flushing.

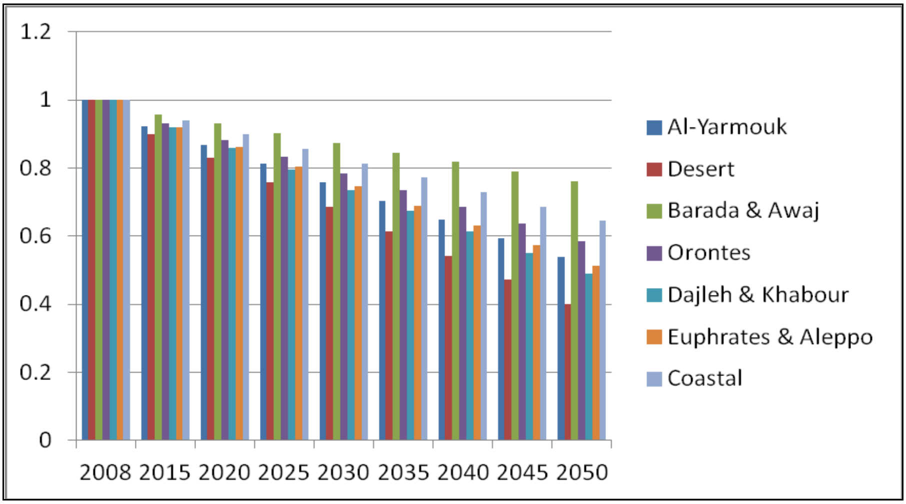

Figure. 4 The reduction in the daily domestic water demand in Syria.

(5) Regional Cooperation Scenario (RC). This scenario assumes that a peace agreement between Syria and Israel, which acknowledges Syrian water rights from Lake Tiberius and the Golan Heights, will be achieved. This agreement may increase surface and groundwater in YB and BAB by about 500 MCM/year. Another agreement with Turkey may increase the pumped water from the Tigris by about 500 MCM/year. Both agreements are expected to occur by 2015.

(6) Conflicts Scenario (CO). In contrast with the previous scenario, any conflict with Turkey may affect the water agreements between Syria and its neighbours. According to the current agreement between Syria, Turkey, and Iraq, Syria receives 500 m^3/s from the Euphrates River, 58% of which should be released to Iraq (MoI-SYR, 2012). In this scenario we assumed that, due to conflicts, Turkey will reduce this amount to be 250 m^3/s in 2015. The new key assumption here will be the reduction of surface water flow from the Euphrates by 50%.

4. Results and Discussion

4.1 Greywater Reuse

One hundred persons have been interviewed. Depending on age, gender and marital status, the sample was taken randomly. The first estimation of the survey is the family size; it has been found that the average family size is 5.3 members. Hence we take 5 members as an average in the coming analysis. According to the survey 83% of the respondents supported reusing treated greywater for toilet flushing or irrigation. The other 17% were not aware that wastewater treatment will make water safe to use. About 10% of the respondents are already using laundry water, without any kind of treatment, in irrigation or cleaning their houses. Figure 5 presents the average values for different water consumption activities.

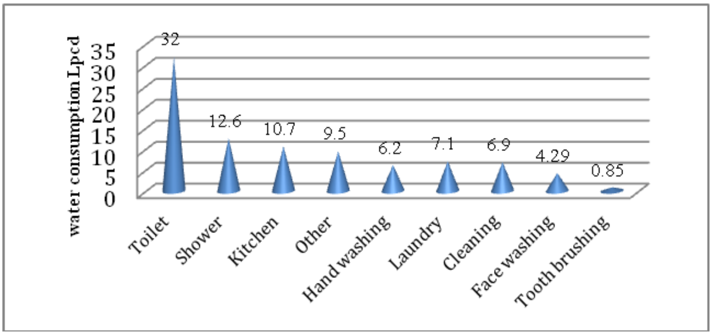

Figure 5. Water consumption for different activities in Sweida.

According to the water bills, water consumption was estimated by dividing the total recorded water consumption by the number of beneficiaries of each water meter. The average billed water consumption was 120 Lpcd. However, according to the survey the per capita of water consumption was 90 Lpcd (Figure 6). The reasons for the obtained difference between the estimated (through interviews) and the billed water consumption is the result of four factors: 1) interviewing just one person from each family which gives uncertain estimation of the water consumption, 2) water-meter problems in reading frequencies, leakage and low certainty of some old meters, and 3) water losses from tanks, which are located after the water meter, and 4) unmentioned uses such as car washing, street washing, and irrigation of some streets' trees.

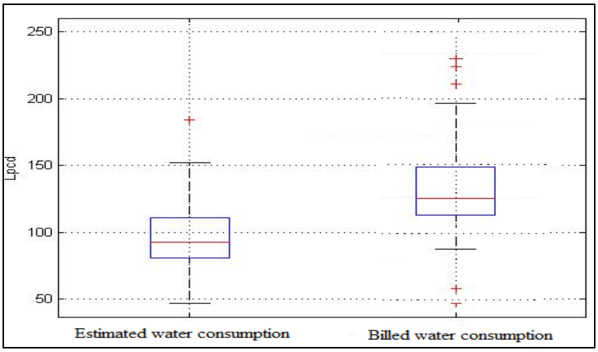

Figure 6. Boxplots of estimated and billed water consumption.

4.1.1 Greywater system

About 40% of the respondents live in single family houses; land prices in Sweida city are very high, which makes the use of constructed wetlands and biological treatment of grey water unfeasible in the city. It could, however, be feasible in the rural areas.

About 60% of the respondents live in flats in multi-storey buildings consisting of, on average, ten flats. In cases where land is available within the property a treatment wetland can be constructed. One wetland can be used for a block of four or more buildings. These buildings should be gathered in a way so that they can provide the land from their real estate area, yet commercial bio filters can be proposed when land is not available. Two systems were proposed according to the dwellings circumstances:

1) Individual system: This system is suitable for single family houses in the city and in the rural areas of Sweida city. In this case, each family, depending on its family members, can design its own small system.

2) Block system: This system can be implemented for a block of five multi-storey residential buildings. In this case, the system depends on the total number of served people in the building. Most of the multi-storey buildings in Sweida consist of five floors each with two apartments. For five member families, each building will serve 50 persons and the system will serve 200 persons in total, which means that the total produced greywater will be about 10 m^3/d.

For a minimum retention time of two days (Winward, 2008), the needed storage volume is 20 m^3. Taking 0.8 m^2/person (Li et al., 2009), the needed land is about 160 m^2 with a 50 cm depth. Using local gravel (nominal 20 mm) with 40% porosity an effective storage volume of about 32 m^3 would be obtained giving the retention time of 3.2 days.
The locally made elevated tank for each building should have a capacity of 2.5 m^3 corresponding to one day's greywater production. The four elevated tanks are connected to a collecting tank 20 m^3 that is located at the end of the AW system. Connections and pipes depend on the building itself and the distance between the buildings and the greywater system. Commercial bio filters can also be proposed for such system.

4.1.2 Economic analysis

The economic analysis focused on the fixed costs in order to estimate the payback period when installing constructed wetlands or commercial bio filters. The detailed costs for the AW for block and individual systems are presented in Table 4.

Table 4. Estimated cost of AW system for individual and block systems (SYP= 47.6 $US)

Material	Block system		Individual system	
	Quantity cost	Cost (SYP)	Quantity cost	Cost (SYP)
Excavations	Lump sum	4140	Lump sum	2070
Gravel	20 m^3	20650	2 m^3	2070
Collecting tank	3 m^3	8260	1 m^3	2580
Settling tank	3 m^3	8260	1 m^3	2070
Water pump	0.5HP	2070	1	1550
Elevated tank	2 m^3	6200	1 m^3	2580
Labor	Lump sum	5160	Lump sum	2070
Pipes & connections	15% of TC	8260	15% of TC	2270
Total cost (TC)		63000		17260

For the CBF, the cost of treatment plants depends on size and number of served persons. The system is more cost effective if shared. The CBF may also need an elevated tank and pipe connection. The cost for a single-family house (5 persons) and a multi-family building (50 persons) is 119000 and 465000 SYP, respectively.

The payback periods take individual and block systems into account. Two scenarios were proposed: In the first scenario we take a fixed water cost of 15 SYP/m^3, which presents about 35% of the real water cost (according to the Ministry of Housing and Construction in Syria). In the second scenario we assumed that the water cost is fully paid by the beneficiaries, which means that the water cost will be about 40 SYP/m^3. The payback period calculations are presented in Table 5.

Table 5. Payback period for the greywater systems.

Data	Individual system		Block system	
Treatment method	AW	CBF	AW	CBF
System cost (SYP)	17260	119000	63000	465000
served people	5		50	
Saved water (m^3/Year)	55		548	
First scenario				
Saving (SYP/Year)	860		8950	
Payback period (years)*	20	139	7	52
Second scenario				
Saving (SYP/Year)	2285		22680	
Payback period (years)*	8	52	3	21

*The payback period did not include operation costs (chlorine, maintenance and energy).

4.2 Rainwater Harvesting

The harvested rainwater for each rural area in each governorate was estimated by eq. (5). According to Table 2, it is seen that the total potential of harvested water from roofs in the Syrian rural areas could reach 35 MCM. Knowing that the Syrian population in the rural areas is about 9.4 million, the annual harvested water corresponds to 3.7 m^3 per capita. This amount can be stored and reused for garden irrigation, groundwater recharge, or for toilet flushing after mixing with greywater systems;

– Garden irrigation: this can be done in individual tanks or in block tanks. In both cases harvested water will be used for garden and/or street irrigation.

– Groundwater recharge: when it is applicable the harvested water can be directed into a recharge well, which helps in maintaining the groundwater balance. This option requires a governmental body in order to be implemented and financed. The Ministry of Irrigation, drinking water companies, and the municipality are the main stakeholders in such a project.

– Mixed with greywater: harvested rainwater can be mixed with a greywater system, when it is applicable, and the saved water can cover all garden and toilet flushing needs.

At the field level, depending on the crop water requirement (CWR; Table 3) areas with fruit trees can be divided into different zones. For example, in the Swaida area people cultivate apples, figs, and grapes. Thus, the land can be divided into three zones depending on CWR. Figure 7 shows how the land can be developed regarding different CWR and collection of rainwater. Crops with higher CWR should be located at lower levels to receive more water. This method can improve the yield without introducing irrigation in the field. However, a pilot project is needed for its verification.

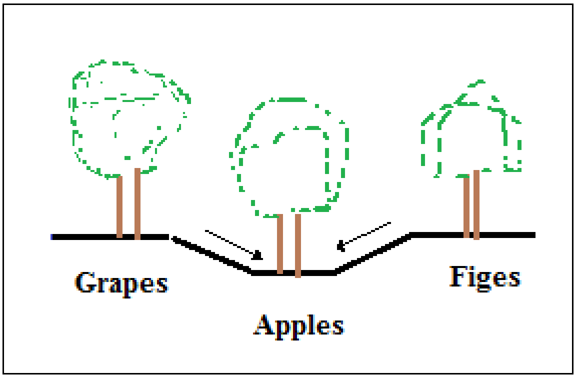

Figure 7. Rainwater harvesting at field level.

4.3 Virtual Water Estimation

The crop patterns in Syria in 2008 according to the MAAR in Syria were 71, 18, 7, and 4% for cereals & dry legumes, fruit trees, industrial crops, and vegetables, respectively (MAAR, 2010). The change in crop patterns, from 1979 to 2008, are shown in Figure 8.

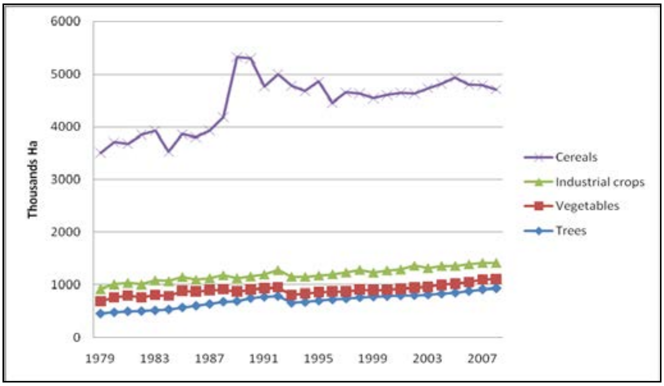

Figure 8. Crops patterns in Syria (own elaboration based on CBS & MAAR)

According to CWR, the annual consumed water for cereals and dry legumes, fruit trees, industrial crops, and vegetables are 13624, 4903, 4432, and 1122 MCM respectively (**Paper IV**). For cereal we found that embedded water in wheat is about 1800 m^3/t.

The industrial crop land cover is about 7% of the total cultivated land in Syria. Cotton, cumin, sugar beet, and tobacco represent 62, 18, 8, and 4%, respectively (Figure 9). Cotton consumes about 3000 million m^3 of water per year and the embedded water in cotton was 3331 m^3/ton. In this regard, Chapagain et al. (2005) found that the embedded water in cotton seeds in Turkey, Egypt, and Greece was 3100, 4231, and 2338 m^3/ton, respectively.

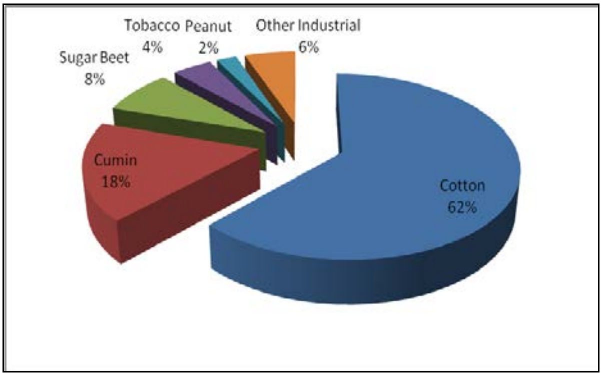

Figure 9. Industrial crops

About 80% of the vegetable land area is irrigated. Potatoes, tomatoes, and water melon represent about 60% of the total vegetable land area. In India, the embedded water in water melon was 362 m^3/ton (Kumar and Jain, 2007), which is close to the estimated value for Syria in this paper (See **Paper IV**).

4.4 Water Assessment Using WEAP

4.4.1 Water resources and demands

According to the above methodology, the model results indicate a big gap between supply and demand. The annual unmet demands are, e.g., groundwater representing about 2000 MCM.

Surface water and groundwater resources in all basins are fixed in the RF, BAT, and HT scenarios. However, they are assumed to change in the RC, CO, and CC scenarios. Marginal water resources, on the other hand, such as reclaimed water and rainwater harvesting depend on the respective scenario. Table 6 shows surface water and groundwater projections in 2050 in each basin according to the six scenarios. It shows that the RC scenario is important for the BAB, YB, and DKB basins. On the other hand, CO and CC scenarios have a vital impact on the EAB basin.

Table 6. Surface and groundwater projections in 2050 in MCM.

Basin	WEAP Scenarios			
	RF, BAT & HT	RC	CO	CC
BAB	507	652	507	454
YB	206	444	206	184
OB	1694	1694	1694	1517
DKB	5457	5958	5457	4891
EAB	8272	8272	4961	7392
DB	171	171	171	153
CB	1200	1200	1200	1074

Depending on each scenario, each water demand sector will be different. The total demand is the same in the BAT, RC, CC, and CO scenarios. However, the demand is greater for the RF scenario and less in the HT scenario. Table 7 presents water demand projections in 2050 for each basin according to the six scenarios, which presents HT scenario to be the best for reducing water demands for all basins.

Table 7. Water demand projections in 2050 (MCM).

Basin	WEAP Scenarios		
	RF	BAT, RC, CO & CC	HT
BAB	1342	1128	989
YB	479	359	324
OB	3158	2718	2625
DKB	4902	4326	4295
EAB	8258	7085	6935
DB	6205	5549	5540
CB	949	830	794

4.4.2 Unmet demands

Taking Syria as one unit and according to the reference scenario the unmet demands may exceed 3500 MCM in 2050 (Figure 10), which reflects the need to develop new technologies, new cooperation, or better water management plans to reduce this shortage. However, the implementation of the BAT scenario will reduce this shortage by about 50% in spite of the population and industrial growth, through the improvement of drinking water systems and the implementation of modern irrigation techniques.

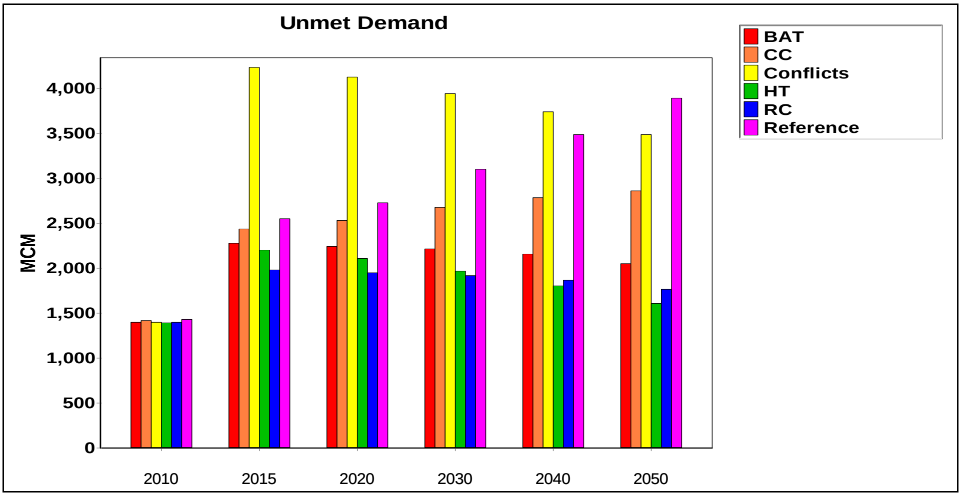

Figure 10. Unmet demand in Syria by 2050.

In order to study the water situation in a more detailed manner for Syria, each basin was studied and assessed separately using the WEAP and the results are shown below (Figure 11):

(1) BAB: the unmet demand starts from about 335 MCM and can be reduced up to 300 MCM by the HT or RC scenario. Moreover, the CC scenario may increase the unmet demand to 630 MCM in 2050.

(2) YB: the unmet demand will not be affected by the conflicts scenario, however, the RC may balance water needs. The CC may increase unmet demand by 20 MCM, as compared to the BAT scenario.

(3) OB: the implementation of all scenarios will not balance water shortage here. However, transferring water from a nearby basin can help. The unmet demand will start from about 800 MCM and can be reduced to about 700 and 600 MCM by the implementation of the BAT and the HT scenarios, respectively.

(4) DKB: the use of illegal wells could balance water needs by 2015. However, the unmet demand will increase and it may reach 450 MCM due to climate change. The BAT, HT, and RC scenarios may reduce this shortage to be about 300 MCM in 2050.

(5) EAB: there is no significant unmet demand in the first five scenarios. It is about 300 MCM in 2050. However, the conflict scenario will affect the agricultural sector, which may increase the unmet demand to be around 1800 MCM.

(6) DB: starting from 2015, this basin has a water shortage problem of about 400 MCM. However, the implementation of the BAT scenario will reduce this unmet demand to about 300 MCM in 2050.

(7) CB: according to all scenarios, the coastal basin will not face any kind of water shortage until 2050. Moreover, the coastal basin is the only basin that can keep storage of about 200 and 11 MCM of surface and groundwater, respectively. This will give an opportunity to transfer 200 MCM of water from the coast to the Orontes basin.

Another scenario can be studied, that of water transfer between basins. According to **Figure 11**, five of the seven water basins are in a water scarce condition by 2050. However, CB and EAB will continue in a decreasing positive track. In this scenario we can chose two neighboring basins, one with a water shortage problem and the other with more water availability. The following two examples were proposed.

a) The OB and CB. Pumping 600 MCM per year of water from the Coastal to the Orontes basin, will decrease water shortage in the Orontes basin.

b) EAB is rich in water. However, its neighbors DB and DKB have water shortage problems. If we keep the EAB and DB balanced we can pump 1960, 1614, 1308, and 974 MCM in 2020, 2030, 2040, and 2050, respectively to DKB. This is not enough for the basin, however, it can reduce the problem.

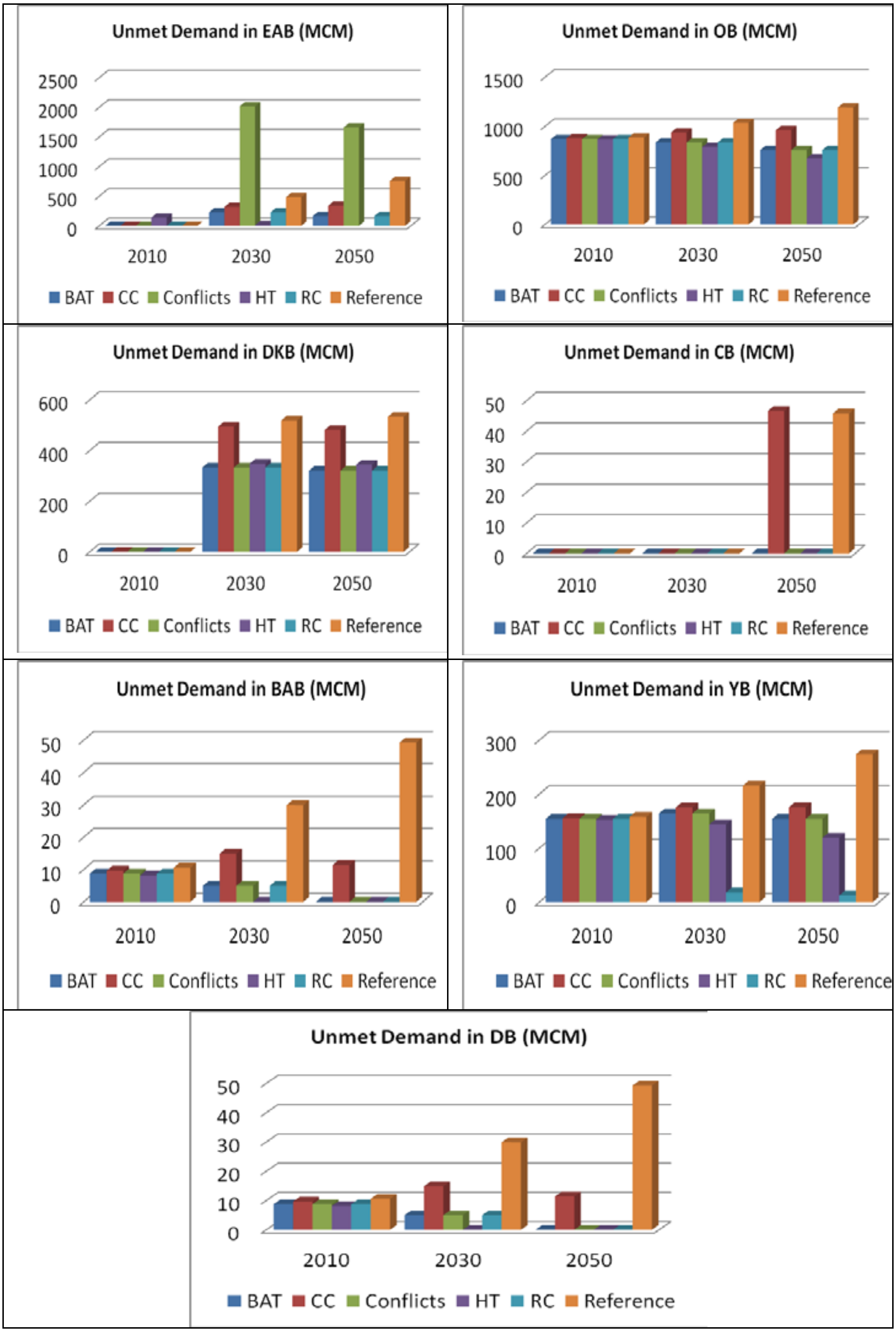

Figure 11. Unmet demand in the different Syrian water basins.

5 Conclusions

The main objective of this thesis was to elaborate on how to sustainably manage water resources in Syria. In order to achieve this goal the contribution of marginal and virtual water resources in the Syrian water balance was studied. The WEAP model was used to evaluate water demand and resources in Syria taking economical, social, and political issues into consideration. Regarding marginal water, the thesis showed that rainwater harvesting from roofs in the Syrian rural areas can add annually up to 35 MCM of water. Further, rainwater harvesting at field level is also a good technique by which fruit trees can be cultivated depending on topography for different CWR. The study showed that average total greywater production in a typical Syrian urban area was about 46% of the total water consumption. That is, almost half of the domestic water consumption is turned in to greywater. Thus, this amount represents a substantial resource if it can be reused safely. Toilet flushing on the other hand, consumed about 35% of the domestic water consumption. Therefore, using greywater for toilet flushing can save about 35% of the total domestic water consumption. Moreover, it was found that 83% of the interviewees were positive to reuse treated greywater. Already today, more than 10% of households are using untreated laundry water in irrigation and for house cleaning. Therefore, raising public awareness for greywater reuse is a vital issue that should be taken in consideration not only in Al-Sweida but all over Syria. Two kinds of treatment methods for individual and block systems were proposed; AW (artificial wetlands) and CBF (commercial bio filters). AW is a suitable treatment method for treating greywater when land area is available. For a block system consisting of one residential building (50 inhabitants) the saved drinking water may reach about 600 m^3/year. The AW can be designed especially for new buildings. The economic analysis showed that, within the current water tariff, the payback period for this system is about 7 years. CBF can also be installed in block systems; however, the payback period is estimated at about 52 years and thus unfeasible. However, if all water costs are paid by consumers the payback period will be 3 and 20 years for AW and CBF, respectively. On the other hand, installing greywater systems for individual buildings is not feasible. The payback period for a small household of five members reaches 20 and 139 years for AW and CBF, respectively

For virtual water estimation, agricultural crop patterns were analyzed. The results showed that more than 70% of the cultivated land is used for cereals and dry legumes. The annual water consumption in agriculture was about 28000 MCM, 55% of this for cereals and dry legumes, 20% for fruit trees, 19% for industrial crops, and 5% for vegetables. Virtual water estimation showed that the embedded water is large in industrial crops such as cumin and cotton, while it is low for tomatoes and potatoes. It also showed similarity for some crops with other countries such as cotton in Turkey, dates in Jordan, and water melon and maize in India. Green house plantation can be a good alternative for reducing water consumption because the CWR is less, while the yield is higher than in the open field. For example, for tomatoes the embedded water was less than 70 m^3/ton. Virtual water trade showed that the net virtual water balance from agricultural products is about 12790 MCM. The economic analysis of the crop patterns showed that citrus, tomatoes, potatoes, and onions have large gross profit to water use ratio GP/WU, while sugar beet and cotton have low values, which should be taken into consideration in future agricultural plans.

Comparison between irrigated and non-irrigated wheat and apples showed that irrigation is feasible from both a water saving and economic output perspective. Two scenarios for a changed crop patterns were proposed. In the first, it was found that changing half of the cotton land area will save about 564 MCM of water every year. In the second proposal, changing the cotton land area for garlic would save about 35 MCM of water per year.

For future water supply and demand assessment in Syria, the WEAP model was used. Six scenarios were analysed, namely, Reference, BAT, CC, Conflict, HT, and RC. None of these scenarios will solve the overall water shortage in the country as a whole. However, some scenarios could solve water problems in some major basins. The best solution was seen to be a combination of RC with BAT and HT scenarios, which could reduce the unmet demand to about 1000 MCM in 2050. According to this, being able to cooperate can reduce water stress significantly up to 2050. Acknowledging the Syrian rights to Golan Heights water can cover water needs in the Al-Yarmouk basin and can reduce water shortage in Barada & Awaj by about 40 MCM. Regarding climate, the results showed that climate change may reduce the inflow from the Euphrates, Tigris, and Orontes by 695, 132, and 34 MCM respectively in 2050. Other water resources will also be affected due to reduced rainfall and increasing evaporation. The predicted amount is about 700 MCM in 2050.

Finally, Syrian water needs special care in order to balance needs and demands. National development in irrigation, domestic and sanitation systems, and regional cooperation are the most important pillars that will contribute to water sustainability in Syria. In this regard, WEAP is a powerful tool that can assess and help to manage water resources in a basin. Therefore, knowing that agriculture consumes about 89% of the Syrian water, more detailed analysis about agricultural water and changing crop patterns for each catchment using WEAP will be the next approach to tackle water shortage in Syria.

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Paper I

Air, Soil and Water Research

ORIGINAL RESEARCH

Syrian Water Resources between the Present and the Future

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Abstract: Water scarcity is one of the main challenges facing Middle Eastern countries. A typical country in this respect is Syria. This paper estimates projections for the available water resources, water balance, and available water per capita (AWPC) in Syria until 2050 in relation to possible future climate changes, national development agendas, water constraints, and water management alternatives. Results show that the AWPC is likely to be reduced by about half up to 2050. Climate change and population growth will have a huge influence on water availability during the coming decades. However, effective water management can to a great extent counterbalance these negative effects. The implementation of modern irrigation practices and the reuse of domestic wastewater, for example, can save up to 400–800 million cubic meters in 2050. If rainwater harvesting systems are implemented water availability can be utilized much more efficiently. Consequently, it appears that there are reasons to be alarmed but also cautiously optimistic regarding Syria's water availability. This, however, depends on the implementation of good development practices, integrated management and public participation at all levels.

Keywords: Middle East, available water, water balance, climate change

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Introduction and Background

The Middle East is seen as the world's most water-challenged region with possible future conflicts over shared water resources.[1,2] Most countries in the Middle East are confronted by severe water problems due to both climatic conditions and socioeconomic factors. From an ecoclimatic point of view, most of the region extends across semiarid, arid, and hyper-arid zones. The semiarid belt has been particularly affected by cycles of drought and desertification over the past decades. Socioeconomically, the region is characterized by a quickly increasing population, which has resulted in a sharp decline of the per capita availability of water over the latest decades. Under these conditions water is the prime factor for sustainable environment and even more importantly for economic development.

Most Middle Eastern countries exploit more than 50% of the renewable water resources and some nearly 100% (eg, Egypt, Gaza, Libya, and Tunisia). Agriculture is the largest consumer of water resources with a strong trend towards developing irrigation. Urban development along the coasts increases demand and the amount of fresh water discharged into the sea. Tourists' needs amplify the demand for water in summer, as the countries around the Mediterranean are popular tourist destinations. Linked to these forecasts of water scarcity are growing estimates of food dependence in the same countries. Cereal imports, which represented 33% of needs in 1995, may increase to 50% up to 2025.[3]

Limited research has dealt with the overall water resources in Syria. However, Kaisi et al[4] reported that the total annual available regulated water resources in Syria are about 14218 Million Cubic Meters (MCM) and the total annual use was about 17566 MCM, which results in a 3348 MCM water shortage. Most research has dealt with specific basins or specific sectors of Syrian water. Burdon and Safadi[5] studied geological formation groundwater aquifers in Syria. Braemer et al[6] analyzed the long-term management of water in Hawran, southern Syria. Altinbilk[7] studied the development and management of the Euphrates and Tigris basin. Abou Zakhem and Hafez[8] have studied seawater intrusion on the Syrian coast. Shaban et al[9] reviewed the hydrological and watershed characteristics of the El-Kabir River between Syria and Lebanon. Kattan[7] reviewed the hydrological and environmental characteristics of surface and groundwater in Damascus within the Barada and Awaj basin.

In view of the above, the objectives of this paper are to give a comprehensive and critical review and update of water resources and needs in Syria at present and their projection up to 2050. This is meant to build scenarios for a better water future. We believe that Syria is an indicator country in the Middle East and its management of water resources will point toward the general water situation in the Middle East. Hence, the next section gives an account for assumptions, data and information sources, and methods being used. Following that, we provide results concerning the estimated water resources situation and demands at present, and an extrapolation to 2050. We also discuss management options and water availability and accessibility in view of possible climate change. We close with a discussion on the practical results of this study.

Methodology and Study Area

Syria, with an area of about 185,180 km^2 and a total population of 21.13 million,[10] has five agro-ecological zones depending on rainfall. Humid zones are located in the west, along the Mediterranean coast (Fig. 1). Arid and semiarid zones are located in the east, north, and south. There is a large seasonal variation in water resources availability due to main rainfall occurring in the winter from December to March. The annual rainfall in Syria decreases from about 900 mm at the coast to about 60 mm in the eastern parts. More than 60% of the country receives

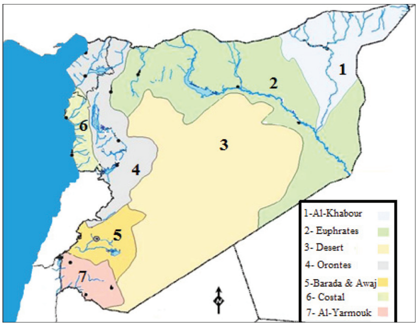

Figure 1. Hydrological basins in Syria.

less than 250 mm/year, which makes the country water scarce.[11] The potential evaporation rate is about 1300 mm/year in the western parts and reaches 3000 mm/year in the eastern and south-eastern parts of Syria.

Renewable and available water resources were estimated using all publically available data on surface and groundwater. Firstly, water balances were estimated by input minus output water. Input water consisted of annual renewable water resources (surface and groundwater entering the country). Output water included water consumption (domestic, industrial, and agricultural), and surface and groundwater that leaves the country. Most data needed for this were taken from Central Bureau of Statistics, Syria, (CBS), Ministry of Housing and Construction (MoHC), and Ministry of Irrigation (MoI).

The annual renewable water can be estimated by:

$$ARW = SW_{net} + GW_{net} + RW \qquad (1)$$

where SW_{net}: net surface water flow, GW_{net}: net groundwater flow, and RW: reclaimed water. According to the above, the following assumptions were used in the future projections:

- Due to water shortage, urban development and the cultivated land will be constant as shown in Figure 2 and the implementation of modern irrigation practices will annually save about 0.5% of the consumed water.
- Due to national development and according to Figure 3, the annual industrial demand is assumed to increase by 2%.
- According to Figure 4, the population growth will decrease annually by about 0.02%.

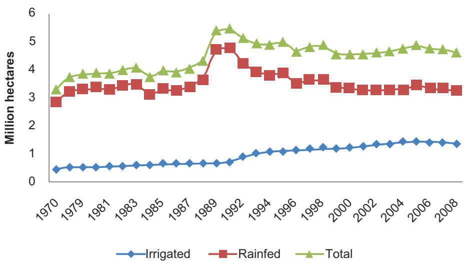

Figure 2. Cultivated lands in Syria (1970–2008; after[17]).

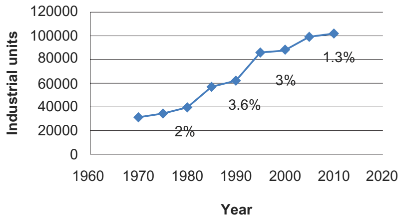

Figure 3. Industrial project increase in Syria (after[11]).

- Due to improvements in water infrastructure, the domestic consumption will be 125 Lpcd after 2030. This gives 1.9 Lpcd as an annual decrease in domestic water consumption till 2030.
- Due to national development, an average annual increase of treated domestic and industrial wastewater of about 1% and 0.5%, respectively was assumed.
- Due to climate change, an annual reduction in surface and groundwater resources by about 0.25% and an annual increase in the evaporation rate by about 0.25% were assumed.

Results and Discussion

Surface water

Syria can be divided into seven main water basins: Barada and Awaj, Al-Yarmouk, Orontes, Dajleh and Khabour, Euphrates and Aleppo, Desert, and the Coastal Basin, each of which has its own geological, meteorological, hydrological, and demographical characteristics (Fig. 1). For these basins, Syria has 21 main rivers, 12 of which are shared with other countries in the region and some of them are now seasonal streams. Syria has made treaties with its neighbors Lebanon, Jordan, Iraq, and Turkey to ease managing shared water resources

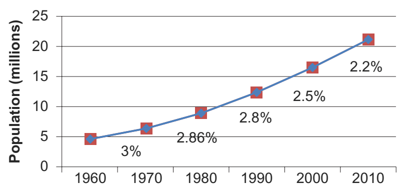

Figure 4. Population increase in Syria.

in the region.[12] For the Euphrates River, shared between Turkey, Syria, and Iraq, Turkey agreed to release at least 500 m^3/s to Syria. Syria will use only 42%, while the rest is released to Iraq, which means the annual Syrian share from the Euphrates is about 6623 MCM. Also agreed upon was that Syria can use an annual amount of water from the Tigris of about 1250 MCM. Two agreements were made with Lebanon. The first in 1994 concerned the Orontes River. The agreement states that Lebanon can use an annual amount of 80 MCM during years when the average river flow is more or equal to 400 MCM/year and otherwise 20%. The second agreement in 2002 was for the Al-Kabir Al-Janubi River with an average annual flow of 150 MCM. The agreement divided the water into 60% for Syria and 40% for Lebanon regardless of hydrological circumstances.[12] The total annual amount that enters Syria, according to these agreements, can thus be assumed to be 320 + 90 = 410 MCM.

Syria has eight main lakes: Al-Assad, Jabbul, Qattineh, Autayba, Khatunieh, Mzereeb, Al-Baath, and Masada. The Al-Assad lake is the largest (674 km^2), while Masada is the smallest (1 km^2). Syria has one big dam (Euphrates), seven medium dams (Al-Rastan, Katineh, Teshreen, Al-Baath, Al-Kabeer Al-Shemali, Basel Al-Assad, and Mouhardeh), and about 140 surface dams scattered over the basins, which harvest rainwater to be used for domestic and agricultural purposes.

Groundwater

The MoI estimated average annual spring flow at about 1350 MCM and the total annual amount of renewable groundwater at about 4811 MCM, which includes almost all springs and legal wells. For groundwater flow, on the other hand, about 1200 and 130 MCM annually enter Syria from Turkey and Lebanon, respectively. However, also about 90 and 250 MCM annually leave Syria to Jordan and the Occupied Lands, respectively.[3]

Reclaimed water

According to the MoHC, the reclaimed water in 2008 was about 2306, 671, and 407 MCM in the agricultural, domestic, and industrial sectors, respectively. This corresponds to about 15%, 55%, and 65% of the total water being consumed in the agricultural, domestic, and industrial sectors, respectively. In the national development plan, MoHC has announced the construction of more than 20 wastewater treatment plants within the next 20 years. According to this, domestic and industrial wastewater is assumed to be treated up to 85% by volume in 2040.

Surface and groundwater quality in Syria is affected by human practices. The lack of domestic and industrial wastewater treatment plants and unsustainable agricultural practices have led to severe problems in terms of water quantity and quality. Many cities have no wastewater treatment plants and some farmers are using wastewater to irrigate cultivated lands. Due to the deep groundwater table, cesspools are used in many rural areas in the southern part of Syria. Moreover, the use of treated wastewater in the Barada basin has affected the surface and groundwater quality by increasing nitrate concentrations.[13,14]

Climate change, on the other hand, will have severe impacts on regional water stress.[15] The Middle East is likely to face a decrease in the precipitation amount by 20%–25%, which will reduce the runoff by about 23%, and the Euphrates River flow may be reduced by 29%–73%. Moreover, the Middle East's average temperature may increase by about 2.5 °C by 2050, which will affect evaporated water amounts.[16]

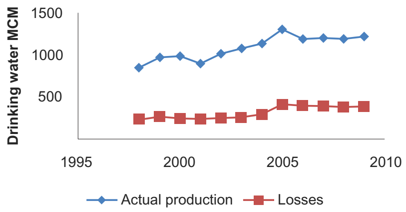

Figure 5. Drinking water actual production and losses.

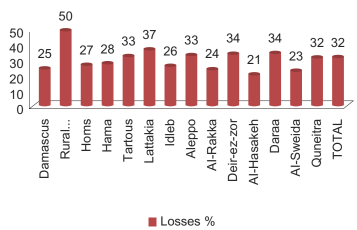

Figure 6. Water losses in 2009 in the Syrian governorates (after[19]).

Table 1. Population and water demand projections.

Year	2010	2020	2030	2040	2050
Population increase %	2.20	2.0	1.8	1.6	1.4
Population (million)	21.15	25.4	29.9	34.7	39.6
Consumption Lpcd	163	144	125	125	125
Domestic demand MCM	1258	1335	1364	1583	1807
Industrial demand MCM	648	778	933	1120	1344
Agricultural demand MCM	15400	14630	13899	13204	12543

Water demand

Water demand includes domestic, industrial, and agricultural uses. Agriculture is the main water consuming sector in Syria. Agricultural water consumption in 2008 was about 15400 MCM. Crops include cereals, vegetables, fruit trees, and industrial crops. Hence, irrigation practices and techniques play a vital role in water demand and crop production. Official statistics for 1978 to 2007 indicate that the average total cultivated land was about 24%.[17] The changes in the irrigated land, non-irrigated land, and the total cultivated areas from 1978 till 2007 are presented in Figure 2, which shows that the increase in the cultivated land area is a result of irrigated land increase. The change in non-irrigated land area mainly depends on rainfall amount and distribution.

Figure 2 indicates that the average annual increase in cultivated land area is about 1% (1978–2007). While the average annual increase in the irrigated lands for the same period was about 3%. Consequently, the irrigated land area, with modern irrigation techniques, increased from about 215,000 ha in 2002 to about 282,000 ha in 2009, which are about 20% of the total irrigated lands. Figure 2 also indicates that the total cultivated land area appears to have reached a more or less constant level after around 1998.

For the industrial sector, there are no comprehensive data about the quantity of water used in Syria. However, CBS estimated the demand to be about 623 MCM/year in 2008. The number of industrial projects is increasing every year. Figure 3 shows the average annual increase between 1970 and 2010.

According to the CBS, Figure 4 shows that the population increase decreased from 3% for 1960–1970 to 2.2% for 2000–2010.

The domestic water consumption range is 100–200 liter per capita per day (Lpcd) depending on lifestyle, water availability, and local circumstances. However, due to old networks and unqualified human resources,[18] the losses in the drinking water system are around 25% (Fig. 5).

These losses were about 50% in the Rural Damascus governorate (Fig. 6). According to MoHC, the actual domestic water production in 2008 was 1183 MCM and the population in Syria at the end of 2008 was about 19.9 million inhabitants.[17] Consequently, the annual water consumed per capita equals 59.45 m^3. This gives a daily average per capita consumption including water losses of 163 L (totally produced water divided by population).

According to the above, the population of Syria is expected to be 39.6 million with a daily water per capita consumption of about 125 liters (Table 1). Hence the annual domestic water demand will be about 1800 MCM in 2050. Due to the water saved through implementing modern irrigation systems, the annual agricultural

Table 2. Renewable water resources projections in Syria (MCM/year).

Year	Surface and groundwater	Reclaimed water			Total MCM
		Domestic	Industry	Agriculture	
2010	14084	692	421	2310	17507
2020	13732	868	545	2195	17339
2030	13389	1023	700	2085	17196
2040	13054	1346	896	1981	17276
2050	12728	1535	1142	1881	17286

Table 3. Water balance and AWPC in Syria till 2050 (MCM).

Year	Available water (MCM)	Demand (MCM)	Evaporation (MCM)	Water balance (MCM)	AWPC (m^3/ca)
2010	17507	17306	1854	–1653	828
2020	17339	16743	1900	–1305	683
2030	17196	16196	1948	–948	575
2040	17276	15907	1997	–628	498
2050	17286	15693	2046	–453	437

demand will be about 12500 MCM in 2050. However, annual water demand for industry will keep increasing to reach 1340 MCM in 2050 (Table 1).

As seen from Table 1, water demand in 2050 will be 80%, 11%, and 9% for agriculture, domestic, and industrial use, respectively. Consequently, this clearly reflects the need for more investment in modern irrigation practices to reduce losses due to low efficiency.

Renewable water resources

According to the above, the total annual renewable water in 2010, according to Eq. (1), was:

$$(6623 + 1250 + 410) + (1200 + 130 - 90 - 2504811) + 3400 = \mathbf{17484\ MCM}$$

Table 2 presents the estimated annually renewable water up to 2050 taking climate change into account. As seen from the table the total available amount is almost constant. Reclaimed water balances the effects of climate change to a great extent.

Water balance and available water per capita

From Tables 1 and 2, water balances and available water per capita (AWPC) for Syria until 2050 can be estimated (Table 3). As seen from Table 3 and Figure 7, AWPC is likely to be reduced by about half up to 2050 in spite of a decreasing total demand.

Scenarios for a better future

It must be remembered that the future is not fixed. Implementing wise water management policies will change and improve future water availability.

Rainwater harvesting scenario: We assumed that from 2020 till 2050 more rainwater can be harvested through the implementation of new rainwater harvesting techniques to be used for agriculture or groundwater recharge purposes. This amount may be assumed to be about 1% of the rainfall, ie, 46000 MCM.[20] This would give an increase in available water resources by about 460 MCM, which means an additional amount of water of about 15.3 MCM every year after 2020. If this scenario is realized Syria can overcome its water shortage by 2050.

Peace agreement scenario: In this scenario, we assumed that a peace agreement will be signed between Syria and Israel in 2020. In this case, Syria may use some water from the springs and water from the Tiberius Lake. The total amount of water may be assumed to be about 300 MCM, which would cover 25% of the Syrian water shortage. This amount will be reduced annually due to the climate change by 0.25%. In this case, Syria can overcome its water shortage by 2050.

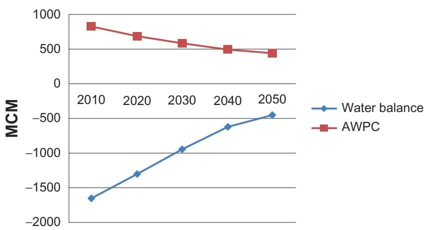

Figure 7. Water balance and AWPC.

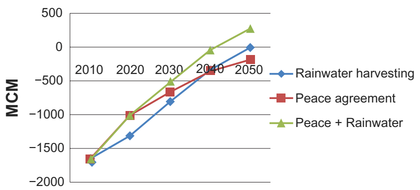

Figure 8. Scenarios for a better water future in Syria.

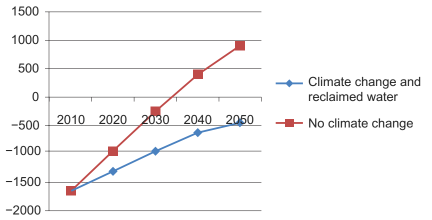

Figure 9. Water projections depending on climate change and reclaimed water impacts.

Mixed scenario: If both mentioned above scenarios are assumed the Syrian water will be balanced in 2040 (Fig. 8).

Sensitivity analysis

As seen from the above, major uncertainties regarding water availability will depend on climate change effects but also on water management policies such as on reclaimed water. These two factors will have a pronounced effect on future availabililty of water resources in Syria. If climate change is less severe water availability will increase greatly. On the other hand, reclaimed water will also play a vital role in increasing water availability in the next decades at the national level. Reclaimed water is assumed to produce more than 4000 MCM by 2050. Figure 9 shows available water amounts in this respect. Figure 9 also shows water availability assuming climate change, no climate change, and no reclaimed water. As seen from the figure these scenarios can completely change the picture regarding future water availability.

Conclusion and Discussion

Syria is considered a water-scarce country. However, good development practices and integrated water management at the national level will play a vital role in water resources sustainability. The population and industrial growth will increase water needs from 1900 MCM in 2010 to about 3150 MCM in 2050. This will lead to a reduction in AWPC from 830 m^3 in 2010 to about 440 m^3 in 2050. The available future water resources estimated in this paper were seen to be close to those estimated by the FAO (comparing the scenario for 2025). Even so, it must be remembered that the assumptions upon which the scenarios were built could greatly modify the outcomes. Water harvesting and peace in the Middle East, as seen from the proposed scenarios, can play a vital role in the Syrian water balance. Improving public awareness and participation in water projects at local, regional, and international levels may be a solution to better sustainability and effective water conservation measures.

On the other hand, climate change will have a severe effect on Syrian water resources. It will decrease the surface and groundwater by about 1300 MCM in 2050, and increase the evaporation from water bodies by about 190 MCM in 2050. This water shortage can only be balanced by proper water management practices and developments in sanitation and irrigation techniques. Implementing modern irrigation techniques and treated wastewater facilities can save about 7500 MCM of fresh water by 2050.

Syria is a key country in the Middle East that can serve as an indicator country for the area. As seen from the above, water resources shortage problems could be balanced through reclaimed water and rainwater harvesting. We believe that this is typical for all countries in the Middle East. Therefore, regional cooperation in successful case studies could help to achieve water sustainability in the Middle East.

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Paper II

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Water Status in the Syrian Water Basins

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ABSTRACT

Syrian water resources face economic and physical water scarcity. This together with a large population and development increase and the climate change may lead to increasing risks for international controversies and disputes in the coming decades. According to FAO, the available water resource per capita AWPC is going to be half by 2025. Depending on its seven water basins, this paper analyses water demand and supply in the Syria with their projections till 2050. The paper shows that two of the seven Syrian basins need a specific concern as they face water scarcity problem. However, two basins have extra water. Therefore, the paper focuses on the need for a sustainable water management, which takes all nonconventional water resources into account to contribute in the Syrian water balance such as rainwater harvesting and wastewater reuse.

Keywords: Renewable Water; Middle East; Sanitation; Water Harvesting

1. Introduction

Available water in a specific country is defined as the surface and groundwater resources volumes that are renewed each year. Annual available water per capita in Syria will decrease from 2684 m^3 in 1970 to 620 m^3 in 2025 [1].

Accessible water, on the other hand, is the renewable water that can be accessed and used to a reasonable cost. Good water resources management and by increasing the existing unconventional water resources (e.g., rainwater harvesting, re-use of treated sewage water, improving efficiency in agriculture) play a vital role in increasing the accessible water in a catchment. Decreasing the difference between the available and the accessible water, in a country, reflects the real development in water practices, management, and sanitation.

Water balance of a water basin refers to the balance between the input of water from precipitation, surface & groundwater flow and the output of water by evaporation, water uses, and stream flow (ground and surface water; [2,3]). However, errors and uncertainties can be included due to the difference between unaccounted inputs and outputs, variation in variables, and over-simplification using models [4].

2. Background and Study Area

2.1. Water Resources

Syria has about 21 million inhabitants distributed in fourteen governorates with a total area of about 185,180 km^2. Syria can also be divided into seven water basins: Barada & Awaj, Al-Yarmouk, Orontes, Dajleh & Khabour, Euphrates & Aleppo, Desert, and the Coastal Basin "**Figure 1**", each of which has its own geological, meteorological, hydrological, and demographical characteristics [5]. "**Table 1**" presents population; area and average precipitation of each water basin.

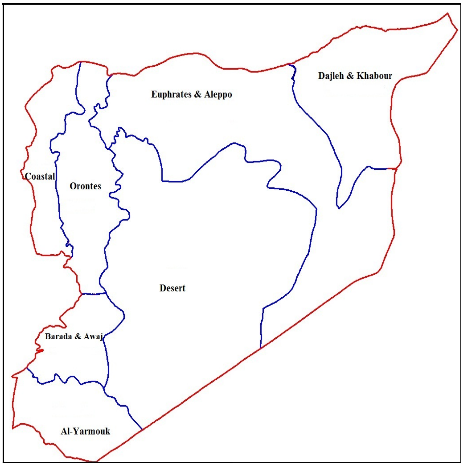

Figure 1. The Syrian water basins.

Table 1. Characteristics of the Syrian water basins.

Water basin	Population	Area[a] (Ha)	Precipitation (mm)
Barada & Awaj	5,700,000	8630	275
Al-Yarmouk	1,404,000	5764	318
Orontes	3,830,000	18,362	415
Dajleh & Khabour	1,340,000	21,129	279
Euphrates & Aleppo	5,930,000	51,238	217
Desert	369,000	70,786	141
Coastal	1,780,000	5049	1147

a. area inside Syrian (excluding the occupied lands).

The annual rainfall in Syria, which occurs from December to March, decreases from about 900 mm at the coast to about 60 mm in the eastern part of Syria with an average precipitation about 46000 MCM (Millions m^3) [6, 7]. Many cities and rural areas have no wastewater treatment plants and some farmers use wastewater in irrigation, which has affected the surface and groundwater quality by increasing nitrate concentrations [8].

The most important water resources in Syria are shared with other countries such as Euphrates, Tigris and Orontes rivers, which have many treaties with Lebanon, Jordan, Iraq, and Turkey to ease managing shared water resources in the region [9].

2.2. Water Demand

Depending on its demand sectors, agriculture consumes about 90% of the Syrian water, which indicates to a real need for further development in irrigation techniques. The total agricultural, domestic and industrial demands were in 2010 about 15,400, 1214, and 648 MCM. Cereal and dry legumes occupy more than 55% of the total cultivated lands.

2.3. Water Sector Constraints

Many constrains are facing water use in Syria. These include physical, economic, technical, and institutional. Below a summary of these are given.

1) Physical constrains: Large seasonal difference in rainfall requiring large storage capacity. About 60% of the country receives less than 250 mm/year.

2) Economic constraints: Most water resources projects depend on external funds, which are coordinated by external consultants. This makes projects subject to vulnerability due to weak coordination and cooperation between different stakeholders. Corruption is another factor that tends to weaken the project implementation and local participation.

3) Environmental constraints: The limited number of wastewater treatment plants, operation problems and lack of public awareness has created many environmental problems such as surface and groundwater pollution using untreated wastewater for irrigation, and damaging of treated effluent canals. Moreover, the absence of storm water drains in big cities, especially Damascus, has a negative effect on operation and maintenance of treatment plants.

4) Technical constraints: High water losses, lack of wastewater treatment plants, groundwater contamination due to high nutrient concentration in the treated wastewater and slow implementation of modern irrigation and water-saving technology. The losses in drinking water system for example, are around 25%.

5) Institutional constraints: Many ministries are involved parts of the water sector in Syria. The Ministry of Irrigation (MoI) is responsible for monitoring, management, and development of surface and groundwater resources. The Ministry of Agriculture and Agrarian Reform (MAAR) is responsible for developing irrigation practices in agricultural areas and reusing treated wastewater. The Ministry of Housing and Construction (MoHC) is responsible for drinking water supply and treatment. The Ministry of State for Environmental Affairs is responsible for water protection. Each ministry has its own directorate in the governorates and many ministries include water management in their annual plans. However, overlapping and lack of cooperation is negatively affecting efficient water resources planning and management.

In view of the above, the objective of this paper was to evaluate the water needs and supply in the different Syrian water basins in order to achieve future sustainability. Projections were made up to 2030 and 2050.

3. Material and Methods

Available water resources and water demands for each water basin in Syria were estimated using all publically available data from the Ministry of Irrigation (MoI), Central Bureau of Statistics in Syria (CBS), Ministry of Housing and construction (MOHC), and Ministry of Agriculture and Agrarian Reform (MAAR). The future estimated projections depend on the available data.

3.1. Water Demand Estimation

"**Table 2**" shows the actual domestic, industrial, and agricultural water needs in 2008 for the seven water basins according to MoHC and MoI.

Table 2. Water needs.

Water basin	Annual water demand (MCM)		
	Agriculture	Domestic	Industry
Barada & Awaj	675	340	33
Al-Yarmouk	205	118	32
Orontes	2195	298	235
Dajleh & Khabour	4669	126	11
Euphrates & Aleppo	7003	526	153
Desert	118	42	10
Coastal	530	126	45

3.1.1. Agricultural Demand:

For agricultural demand we assumed that due to water shortage, cultivated land will be constant and the implementation of modern irrigation practices will annually save about 0.5% of the consumed water.

3.1.2. Industrial Demand:

For the industrial sector, the number of industrial projects is increasing every year. According to CBS the annual increase between 1970-2010 was about 1.7%. Therefore we can assume that the annual industrial demand is to increase by 2%.

3.1.3. Domestic Demand:

According to **Tables 1** and **2**, we can estimate the daily per capita domestic needs in "**Figure 2**".

Moreover, According to CBS, the average population increase, all over Syria, decreased from 3% for 1960-1970 to 2.2% for 2000-2010. However the populations increase is different from basins to basin ("**Figure 3**"). For the future domestic demand projections, we assume, due to the expected improvement in the drinking water systems, that the domestic consumption will be reduced by 10% by 2030 and another 5% by 2050.

3.2. Annual Renewable Water Resources

The annual renewable water resources in a basin are the summation of the net surface water flow, the net groundwater flow, and the reclaimed water. The total surface water SW, groundwater GW and reclaimed water RW (agricultural, domestic, and industrial) for the Syrian water basins are presented in "**Table 3**".

According to MoI, the reclaimed water in 2008 was about 2306, 671, and 407 MCM in agriculture, domestic, and industrial sectors, respectively. This corresponds to about 15%, 55%, and 65% of the totally consumed water in agriculture, domestic, and industrial sector, respectively. In the national development plan, MoHC has announced the construction of more than 20 wastewater treatment plants within the next 20 years. According to this, domestic and industrial wastewaters will be treated up to 85% by volume in 2040. This gives an average annual increase of treated domestic and industrial wastewater of about 1% and 0.5%, respectively.

3.3. Climate Change Effect

Climate change will have severe impacts on regional water stress [10]. The Middle East is likely to face a decrease in precipitation amount by 20% - 25%, which will reduce the runoff with about 23%, and Euphrates River flow may be reduced by 29% - 73% [11]. Moreover, Middle East average temperature may increase by about 2.5˚C to 2050, which will affect evaporated water amounts [11]. Hence,

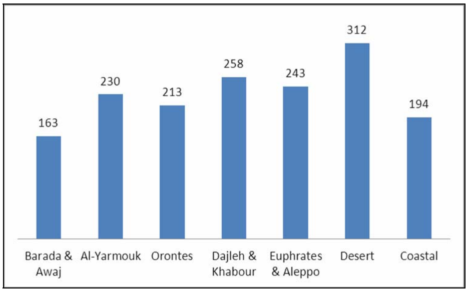

Figure 2. The daily water consumption per capita (L).

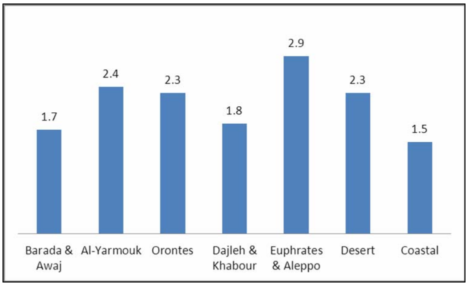

Figure 3. Annual population increases (%).

Table 3. Annual renewable water resources.

Water basin	Annual water resources (MCM)				
	SW	GW	RW Ag.	RW Do.	RW In.
Barada & Awaj	37	470	99	204	26
Al-Yarmouk	24	170	9	47	26
Orontes	662	891	53	32	188
Dajleh & Khabour	152	2000	467	101	9
Euphrates & Aleppo	7134	645	1410	210	122
Desert	21	150	0	3	0
Coastal	715	485	53	32	36

we assumed an annual reduction in surface and groundwater resources by about 0.25% and an annual increase in evaporation rate by about 0.25% up to 2050.

4. Results and Discussion

4.1. Water Demand and Resources Projections

According to the above, without building any scenario, population, agricultural demand, industrial demand, and domestic demand of the Syrian water basins for 2030 and 2050 are presented in **Table 4**. While **Table 5** presents water demands and resources projections in 2030 and 2050.

Table 4. Water demands projections.

Water basin	2030				2050			
	Population	Water demand (MCM)			Population	Water demand (MCM)		
		Domestic	Agriculture	Industry		Domestic	Agriculture	Industry
Barada & Awaj	8029476	430	631	49	10991550	559	625	71
Al-Yarmouk	2242356	169	192	48	3447847	247	190	69
Orontes	6011108	421	2053	350	9094206	605	2033	504
Dajleh & Khabour	1922739	163	4367	16	2677222	216	4323	24
Euphrates & Aleppo	10140774	809	6550	228	16614645	1260	6485	328
Desert	569028	58	110	15	846941	82	109	21
Coastal	2325178	148	496	67	2969020	180	491	96

Table 5. Water resources projections.

Water basin	2030					Water basin	2050				
	Surface water	Ground water	Reclaimed water				Surface water	Ground water	Reclaimed water		
			Do.	Ag.	In.				Do.	Ag.	In.
Barada & Awaj	35	447	259	93	39	Barada & Awaj	33	425	336	92	56
Al-Yarmouk	23	162	68	8	39	Al-Yarmouk	22	154	99	8	56
Orontes	629	847	45	50	280	Orontes	598	805	65	49	403
Dajleh & Khabour	144	1901	130	437	13	Dajleh & Khabour	137	1807	173	432	19
Euphrates & Aleppo	6782	613	323	1319	182	Euphrates & Aleppo	6447	583	503	1306	261
Desert	20	143	4	0	0	Desert	19	136	6	0	0
Coastal	680	461	38	50	54	Coastal	646	438	46	49	77

4.2. Water Balance

According to **Tables 4** and **5** water balance calculations showed that five of the seven water basins are in a water scarce condition till 2050. However, Coastal and Euphrates & Aleppo Basins will keep in the decreasing positive track (F**igure 4**). Therefore, a vital action is needed to solve these water shortages.

4.3. Scenarios for a Better future

4.3.1. Water Transfer between Basins.

In this scenario we chose two neighboring basins, one with a water shortage problem and the other with more water availability. The following two examples were proposed.

a) The Orontes and Coastal basins.

Pumping 600 MCM per year of water from the Coastal basin to the Orontes basin, will decrease water shortage in the Orontes basin. However, this also means that the Coastal basin needs extra water according to "**Figure 5**".

b) The Desert, Dajleh & Khabour and Euphrates & Aleppo basins.

Euphrates & Aleppo basin is rich with water. However, its neighbors Desert and Dajleh & Khabour basins have water shortage problems. If we keep the Euphrates & Aleppo and Desert basins balanced we can pump 1960, 1614, 1308, and 974 MCM in 2020, 2030, 2040, and 2050, respectively to Dajleh & Khabour basin. Yet this is not enough for this basin "**Figure 6**".

4.3.2. Regional Cooperation.

Regional cooperation is needed to solve Dajleh & Khabour, Barada & Awaj, and Al-Yarmouk basins. For Dajleh & Khabour basin, an annual amount of 500 MCM of water from Tigris river with some water saving and modern irrigation can keep the basin balanced. Al-Yarmouk and Barada & Awaj basins can be balanced by the Syrian water in the occupied Golan heights.

4.3.3. Technical Scenario.

We assumed an optimistic scenario that the water consumption per capita will be 125 liters in 2030, due to the improvements in the water supply networks and the implementation of water saving devices, which gives 1.9, 5.25, 4.4, 6.65, 5.9, 9.35, and 3.45 Lpcd as an annual decrease in the domestic water consumption till 2030 in the Barada & Awaj, Al-Yarmouk, Orontes, Dajleh & Khabour, Euphrates & Aleppo, Desert, and the Coastal basin, respectively. Moreover, we assumed that all domestic and industrial wastewater will be reused (90% of the demand) and that rainwater-harvesting techniques will save another 1.5 % of the total rainfall in each basin by 2030. The results from this scenario are presented in "**Figure 7**".

Figure 7 shows that this scenario can balance more basins. However, Dajleh & Khabour and Orontes basins still have water shortage status.

5. Conclusions

Syria is considered a water-scarce country as five of its seven water basins face a real water shortage problem. However, good development practices and water cooperation at national and regional level can help in balancing water needs and water supplies. The improvement of drinking water systems can help in reducing domestic water losses as it reached more than 50% in some cities. The results showed that reusing all domestic and Industrial wastewater might increase reclaimed water by 1000 MCM in 2050. On the other hand, climate change will have a severe effect on the Syrian water resources. It will decrease the surface and groundwater by about 1300 MCM in 2050. However, rainwater harvesting can contribute as a climate change adaptation technique that can save annually about 2000 MCM.

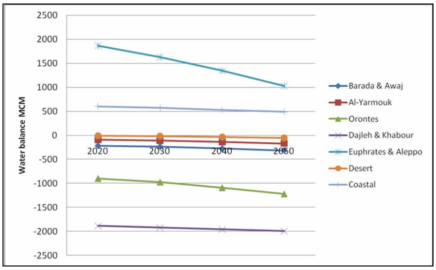

Figure 4. Water balance in the Syrian basins.

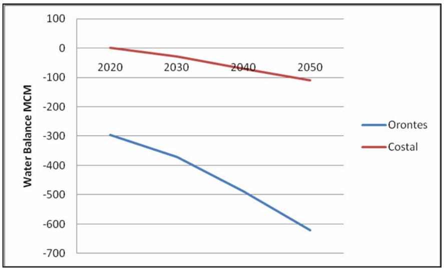

Figure 5. Orontes and costal basins scenario.

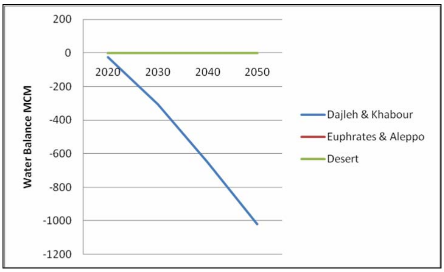

Figure 6. Desert, Dajleh & Khabour and Euphrates & Aleppo basins scenario.

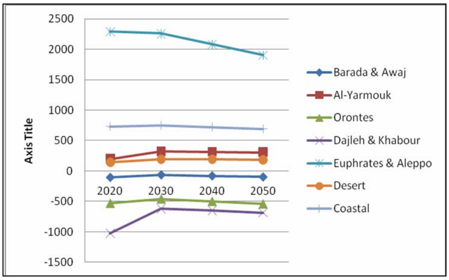

Figure 7. The technical scenario.

Syria is a key country in the Middle East and can possibly serve as an indicator for the area. As seen from the above need its water resources shortage problems could be balanced by reclaimed water and rainwater harvesting. We believe that this is typical for all countries in the Middle East.

6. Acknowledgements

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Paper III

Economic value of tree fruit production in Jordan Valley from a virtual water perspective

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ABSTRACT

The continuous high demand of water resources for agricultural uses in Jordan is leading to a water crisis. A possible partial solution may be to import food which requires large amounts of water to grow instead of cultivating high water consuming crops. Crops such as banana and citrus cause a huge virtual water loss, which can be reduced by cultivating other less water-demanding crops. This paper focuses on analyzing the economic value of cultivating tree fruit from a virtual water perspective. The virtual water calculations in this study depend on the average rainfall, water quota, and the crops' water requirements (CWR). The gross profit to the water use ratio showed that banana has the lowest value 0.085 JD/m^3, while lemon has the highest value 1.65 JD/m^3. The calculations show that the average embedded water in fruit varies from about 470 m^3/ton for grapes to about 2500 m^3/ton for dates. Banana and citrus plantations consume about 24 and 85 million cubic meters (MCM) annually, respectively, which represent about 85% of the total water consumption in fruit tree plantation. The virtual water flow estimation embedded in the tree fruit shows that Jordan imports about 105 MCM per year. However it exports about 31 MCM per year. The results were analyzed from an integrated water resources management (IWRM) perspective. The analysis shows that a way to recover some of the water costs involved in, e.g., banana production, would be to increase the fertilizer cost by about 10%. This would double the water cost and increase the banana production cost by about 6.8%. Using this alternative could be a way to better manage the huge losses in virtual water involved in banana production in the Jordan Valley.

Key words: Crop Water Requirement, Integrated Water Resources Management (IWRM), Virtual Water.

1 INTRODUCTION

Water efficiency is a key concept all over the world to solve water shortage problems in water-poor countries. In line with this, policymakers and stakeholders need to focus on crops' water productivity when forming effective water management plans and strategies.

Virtual water can solve many water-related issues. Virtual water, by definition, is the embedded water in a product in a virtual sense that can be imported into a country as indigenous water (Hoekstra, 2003). For example, one ton of wheat needs about 1000 tons of water in USA to be produced while it needs 2500 tons in Syria and 3000 tons in Jordan. Hence, it has been shown that from an ecological point of view, it is better for Jordan to import one ton of wheat than piping 3000 tons of water. Many countries do still not include their virtual water trade in the water scarcity problem. Water-poor countries often keep exporting products which are high consumers of water, while water-rich countries import products which are high consumers of water (Kumar and Singh, 2005). The use of virtual water can be developed over time. The great advantage of the virtual water concept is that it makes water invisible. Consequently, it can be applied beyond political borders and conflicts.

Water-poor countries may thus balance water scarcity by importing high water content products and exporting low water content products. Jordan, for example, imports about 5 to 7 billion cubic meters of virtual water per year (El-Naser and Abbadi, 2005). About 1.5 million cubic meters (MCM) of this are embedded in agricultural products such as wheat and rice (Haddadin et al., 2006). However, Jordan exports virtual water that is embedded in tomatoes and eggplants mostly to the Gulf States, and it produces banana which is considered one of the most high water consuming crops for its local market. The total annual water cost for banana, citrus, and vegetable plantations in the Jordan Valley, depending on the water tariff, is 350, 138, and 67 $/ha/year, respectively. However, in order to recover the total costs (O&M + capital costs) the total costs will be 1454, 573, and 278 $/ha/year for banana, citrus, and vegetables respectively (Molle et al., 2008). Moreover, Haddadin et al., (2006) reported that the estimated water quantities in Jordan in 2002 for field crops, vegetables, and fruit trees are 391, 110, and 753 MCM, respectively. This equals 1254 MCM/year.

The Hashemite Kingdom of Jordan is located between latitude 29.0^o and 33.5^o north and longitude 35.0^o and 39.5^o east. The country has a total area of about 98000 km^2 and a population of about 6 million and is considered one of the most water scarce countries in the world (DOS, 2008). Due to the rapid population increase especially after the two Gulf Wars, the annual per capita availability of renewable water resources is now only about 160 m^3/year (Wardam, 2006). Jordan can be divided into three main regions: the Jordan Rift Valley, the highlands, and the desert (Mallon and Kingswood, 2001). Jordan is also divided into fifteen surface water and twelve groundwater basins, each of which has its own hydrological characteristics, and some of which are shared with other countries such as Syria, Israel, Palestine, and Saudi Arabia (FAO, 2008).

Surface water resources in Jordan include: I) Three rivers: (Al Yarmouk, which is located at the border between Syria and Jordan; the Zarqa River, which flows from the north of Jordan to the King Talal Dam (KTD), and the Jordan River, II) the King Abdullah Canal, III) eleven seasonal wadis, and IV) nine surface water reservoirs: (Unity Dam, Arab Dam, Shurabil Dam, KTD, Karameh Dam, Shueib Dam, Al Mujeb Dam, Al Tanour Dam, and Kafrein Dam). Groundwater resources in Jordan are distributed between 12 basins. Most of them are concentrated in the Yarmouk, Amman-Zarqa, and Dead Sea basins. The renewable groundwater resources have been estimated to be 500 MCM/year (FAO, 2008). Water salinity, the increase of dissolved salts, is a big problem for groundwater because of the high pumping rate. Groundwater is rapidly becomes brackish (salinity >3000 ppm), which makes it unsuitable for planting some crops such as bananas.

Jordan is characterized by a long, hot and dry summer; the rain falls mainly in winter, its annual average varies between 40 and 500 mm (FAO, 2008), which is not enough for agriculture and makes irrigation vital for all kinds of crops. The cultivated land area was estimated at 252,236 ha in 2006 (DOS, 2008), 34% of which are planted with fruit trees.

The objectives of this study are to estimate the amount of virtual water embedded in tree fruit production in the Jordan Valley and the virtual water flows in relation to tree fruit trade. The analysis will give a more realistic view of possibilities to increase water efficiency in the water scarce Jordan. For this purpose current water use of agriculture and tree fruit production in the Jordan Valley are analyzed and discussed from an economic viewpoint. The results are discussed using an integrated water management perspective. We close with a discussion of practical results of the study.

2 METHODOLOGY

To accomplish the objective of this research, it was necessary to obtain data on meteorological conditions, cultivated areas, production of tree fruit, crop water requirements, water consumption by agriculture, and other production costs. Then, the virtual water embedded in the fruit was estimated based on the average rainfall, cultivated areas, crop water requirements, and the average yields. The average rainfall was taken from the Meteorological Department of Jordan. The embedded water was calculated by dividing the total water consumption by the annual fruit production. The gross profit to the water use ratio was estimated by dividing the gross profit for some tree fruits by the total water consumption. The virtual water flow from fruit trees was estimated according to the fruit tree product imports and exports. For the above the following assumptions were made. The soil water content was assumed not to contribute to fruit tree production. This may be valid due to the more or less constant soil water storage over longer periods. We also assumed the net runoff at farm level to be negligible. Finally, water embedded in fertilizers and herbicides was assumed to be equal to zero. Moreover, within this research, two field surveys were made in Jordan Valley with the help of Jordan University staff, to find out the relation between variable costs and water cost.

Jordan Valley

The Jordan Valley is a low strip between Lake Tiberia in the north, about 220 m below sea surface level, and the Dead Sea about 400 m below sea surface level. The Jordan Valley is about 104 km long; its width varies from 4 to 16 km between the Jordan River and the East Mountains chain (Al-Weshah, 2001). The Jordan Valley Authority (JVA) has divided the Jordan Valley into four agricultural zones (Table 1).

Table 1: Main features of agricultural zones in the Jordan Valley.

Characteristics	Zone 1	Zone 2	Zone 3	Zone 4
Elevation below sea level (m)	205–235	235–315	315–395	395–430
Administrative centre	North Shouna	Deir Ala’a	South Shouna	Safi
Degree of aridity	Semiarid	Semiarid-arid	Arid-extremely arid	Extremely arid

Source: (Al-Zabet, 2002).

Rainfall in the Jordan Valley occurs from November to April. The areal annual distribution is about 100 mm in the south to about 500 mm in the north (Al-Weshah, 2001). The effective rainfall, excluding runoff and evaporation, is less than 40% of the total rainfall. The average rainfall in Dair 'Alla, which is located at the centre of the Jordan Valley, was 290 mm/year between 1976 and 2005, while the average rainfall in Ghour Al Safi for the same period was about 75 mm/year, which is not sufficient for the agricultural sector (MD, 2008).

The average temperature in Dair 'Alla ranges from about 18ºC in January to about 38ºC in July and August (MD, 2008). The warm winter has given the valley a special economic importance in producing some crops, which are ripe several weeks earlier than anywhere else in the region.

The irrigation projects in the Jordan Valley were developed after the establishment of the Jordan Valley Authority (JVA) and the construction of the 69 km King Abdullah Canal (KAC) between 1958 and 1966 (Molle et al., 2008). The Jordan Valley Authority (JVA) supplies irrigation water in the Jordan Rift Valley (JRV) using surface water from the Yarmouk River and the contributing wadis, in addition to treated wastewater. Groundwater is used to a lesser extent in the valley mostly by farmers in the southern parts.

The total irrigated area in the Jordan Valley is about 23000 ha (Molle et al., 2008). The irrigation system was converted from open channels to pressurized systems in the middle of the nineties (Venot et al., 2007). Irrigation's share of the total water use shows a significant decrease in the period 1985-2002 (from 78% in 1985 to 64% in 2002). The restrictions on drilling wells, the establishment of water meters and the drought that occurred in Jordan throughout 1998–2002 are the most important reasons behind the decreasing irrigation in the Jordan Valley. The percentage of cultivated areas in the Jordan Valley in 2006 was 59%, 10%, and 31% for vegetables, field crops, and fruit trees, respectively.

Due to the vast replacement of fresh water with treated wastewater originating mainly from the highlands of the Amman-Zarqa urban area, the use of treated wastewater for irrigation in the Jordan Valley has steadily increased from a nationwide 59 MCM (10%) in 1996 to 70 MCM in 2007 (15%) (MWI, 2008).

In the early fifties the crop patterns in the Jordan Valley were as follows: 75% field crops, 19% vegetables, and 6% fruit trees. Since that time, due to noncooperation between farmers and the government, the farmers have increased their production by growing the crops with highest commercial value, which has led to a huge increase (35%) in fruit trees in North Shouna. This has created water shortage problems, over supply in the market, and soil depletion (Al-Zabet, 2002). Figure 1 presents the variation of crops' types between 2000 and 2006 (DOS, 2008), which shows a decrease in fruit trees after 2002 and increase in vegetable area because of the drought and governmental legislation.

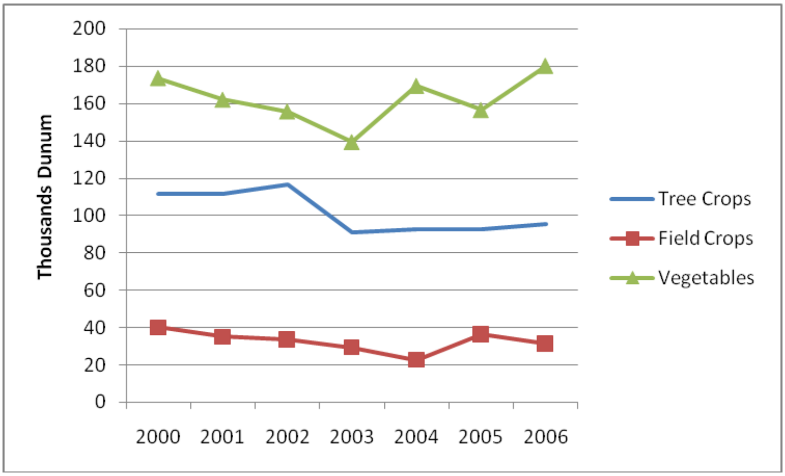

Figure 1: Cultivated areas in the Jordan Valley between 2000-2006 (after DOS, 2008).

Fruit Trees

Banana and citrus are the most water consuming crops in the Jordan Valley. In terms of cultivated area, banana plantations hold the second place after citrus orchards. The total area planted with bananas in 2006 was 1427 ha (DOS, 2008) and the average production was estimated at about 20 t/ha between 1998 and 2006. The plantation of bananas is sometimes restricted to certain areas in the Jordan Valley. The Al Kafrrin and Al-Rama villages are some of these areas. The most common banana types in the Jordan Valley are Balady, Paz, Cavendish, Grand Naine, and Williams (De Langhe et al., 2002).

The total citrus area in 2006, on the other hand, was about 6530 ha (DOS, 2008). Lemon trees represent the highest percentage of the citrus crops in the Jordan Valley, about 27% in 2006. Olives hold the third place in the Jordan Valley and then dates with average areas about 6 and 5 ha, respectively. Other kinds of fruit trees include grapes, guava, apples, figs, peaches, pears, and pomegranates.

Due to the variety in climate and prices in the region, fruit dealers at the Syrian borders import many kinds of fruit from Syria that are cheaper than the Jordanian fruits, while other dealers export fruits to the Gulf countries. Exports and imports depend on the availability and the prices. Syrian and Jordanian apples can be found at the same market.

3 RESULTS

Rainfall estimation

The Jordan Valley was assumed to have an average annual rainfall of 300 mm. while the effective rainfall (ERF) was assumed to be about 1/3. Hence, the total amount of effective rainfall per hectare can be estimated by the following equation:

$$Q=A*ERF \quad (1)$$

where: Q is the water amount in m^3/ha, A is the area (m^2), and ERF is the effective rainfall (m) and hence Q= 10000*0.100=1000 m^3/ ha.

Crops' water requirements (CWR)

The crops' water requirements were taken from Shatanawi et al. (1998; Table 2).

Table 2: Crop's Water Requirements CWR.

Crops	Citrus	Bananas	Olives	Grapes	Figs	Pomegranates, Apricots, Guava, and Peaches	Apples	Dates	Others
CWR (m^3/ha)	10860	16090	4000	4500	3500	7500	13000	13950	6000

Source: Shatanawi et al. (1998).

Depending on the crops' water requirements, the Jordan Valley Authority has published a water quota that divides the year into specific periods with specific irrigation amounts (Molle et al., 2008; Table 3).

Table 3: The current quota system in the Jordan Valley (implemented after 2004).

Period of the year	Quotas (m^3 /ha/day)		
	Vegetables	Citrus	Bananas
16/3–31/3	15	On-demand but ≤ 20	
1/4–15/4	15	20	30
16/4–30/4	20	20	30
1/5–15/6	20	30	50
16/6–15/8	On-demand but ≤ 10	40	70
16/8–15/9	10	40	70
16/9–15/10	15	30	50
16/10–31/10	20	30	50
01/11–15/12	20	On-demand but ≤ 20	
16/12–15/03	10	On-demand but ≤ 20	

Source: Molle et al. (2008).

The estimation of embedded water was done in accordance with two scenarios regarding the effective rainfall and the annual yield. The first one was based on the crops' water requirements and the second on the water quota and the effective rainfall.

CWR scenario

In CWR scenario, the consumed water has been estimated depending on the crops' water requirements. Then the embedded water was estimated by dividing the consumed water by the total yield. Table 4 presents the detailed calculations for different kinds of fruit trees. It is obvious that grapes and figs have low embedded water values while dates have the highest embedded water value equal, to 2447 m^3/ton due to the fact that less than two thirds of date trees produce fruit.

Table 4: The average embedded water in tree fruits between 2004 and 2006 based on CWR.

Crops	Area (ha)	Production (ton)	CWR (m^3/ha)	Consumed water (MCM)	Embedded water (m^3/ton)
Citrus	6494	131972.8	10860	70.52	534
Olives	617	4213.4	4000	2.47	586
Grapes	135	2157.5	4500	0.61	282
Figs	2.4	30.3	3500	0.01	277
Peaches	0.1	0.9	7500	0.00	833
Apricots	2.3	13.4	7500	0.02	1287
Apples	10	120.2	13000	0.13	1082
Pomegranates	87	1522.8	7500	0.65	428

Guava	71	694.4	7500	0.53	767
Dates	509	2901.4	13950	7.10	2447
Bananas	1318	36764.3	16090	21.21	577
Others	133	1112.8	6000	0.80	717
Total	9379			104	

Water quota scenario

In this scenario, the irrigation volumes were estimated using the current water quota system (Table 3). Table 5 presents the annual water consumption for different crops per hectare in the Jordan Valley according to the water quota. It is seen that the annual irrigation volume for one hectare of bananas, other fruit trees, and vegetables are 14960, 10060, and 4965 m^3/ha, respectively (assuming that all farmers who cultivate the same crop, use the same amount of water).

Table 5: The annual water consumption for fruit trees and vegetables in the Jordan Valley.

Period of the year	Number of days	Banana m^3/ha	Other fruit trees m^3/ha	Vegetables m^3/ha
16/3–31/3	16	320	320	240
1/4–15/4	15	450	300	225
16/4–30/4	15	450	300	300
1/5–15/6	46	2300	1380	920
16/6–15/8	61	4270	2440	610
16/8–15/9	31	2170	1240	310
16/9–15/10	30	1500	900	240
16/10–31/10	16	800	480	320
01/11–15/12	45	900	900	900
16/12–15/03	90	1800	1800	900
Total	**365**	**14960**	**10060**	**4965**

Using the results from Table 5, we can estimate the total amount of irrigation water for fruits between 2004 and 2006. Table 6 presents the total cultivated areas, total production, water consumption, and the embedded water for different kinds of fruit trees.

Table 6: Cultivated products and average embedded water in fruits between 2004 and 2006 based on water quotas.

Crops	Area (he)	Production (ton)	Effective Rainfall m^3/ha	Water quota	Consumed water (MCM)	Embedded water (m^3/ton)
Citrus	6494	131972.8	1000	10060	71.82	544
Olives	617	4213.4	1000	10060	6.82	1620
Grapes	135	2157.5	1000	10060	1.49	692
Figs	2.4	30.3	1000	10060	0.03	876
Peaches	0.1	0.9	1000	10060	0.00	1229

Apricots	2.3	13.4	1000	10060	0.03	1898
Apples	10	120.2	1000	10060	0.11	920
Pomegranates	87	1522.8	1000	10060	0.96	632
Guava	71	694.4	1000	10060	0.79	1131
Dates	509	2901.4	1000	10060	5.63	1940
Bananas	1318	36764.3	1000	14960	21.04	572
Others	133	1112.8	1000	10060	1.47	1322
Total					110	

Both scenarios give us, for a certain period, the same final results for citrus and bananas. They show that fruit trees consume about 110 MCM/year, bananas and citrus consume about 84% of the fruit trees' water. However, there is a big difference when it comes to specific fruit trees such as figs, apples, dates, and grapes. The fixed water quota for these crops results in a large difference. Hence, the current water quota needs some modification and new specifications for different kinds of fruit trees. It should be lower for figs and grapes, while it should be higher for dates and apples. On the other hand, some farmers in the Jordan Valley do not have their full share of water quotas, while other farmers may have more by illegal groundwater utilization.

Virtual water flow

Knowing that some farmers in the Jordan Valley do not take their full water quota, the virtual water flow for fruit trees in Jordan was estimated based on the first scenario by multiplying the embedded water with the total amount of exports and imports. According to this, Table 7 shows that Jordan exports about 29 MCM/year. However it imports about 77 MCM of water embedded in fruits each year.

Table 7: The virtual water flow embedded in fruits.

Crops	Embedded Water (m^3/ton)	Exports (ton)	Exported virtual water (MCM)	Imports (ton)	Imported virtual water (MCM)
Citrus	544	11531	6.3	28793	15.7
Olives	1620	2870	4.6	50	0.1
Grapes	692	1666	1.2	5774	4.0
Figs	876	42	0.04		
Peaches	1229	9583	11.8	237	0.3
Apricots	1898	547	1.0	266.2	0.5
Apples	920	1074	1.0	20053.4	18.5
Pear	632	250	0.2	2926.3	1.8
Pomegranates	1131	218	0.2	145.2	0.2
Guava	1940	210	0.4	541.8	1.1
Dates	572	1063	0.6	10245	5.9
Bananas	1322	143	0.2	13650.4	18
Others	544	1092	1.2	10255	11
Total			28.7		77

4 ANALYZING RESULTS FROM IWRM PERSPECTIVE

Integrated Water Resources Management (IWRM) is a comprehensive approach which involves all water partners and stakeholders in managing and solving water-related issues. This involvement is based on cooperation and coordination between all sectors, notably the public, agriculture, water, environment, economy, and policy in order to maximize economic and social welfare in a sustainable way.

Economic Dimension:

To compute the economic value of water we can estimate the gross profit/water use ratio according to:

Gross profit = total sales - total costs (2)

Water use = the higher of [(effective rainfall + irrigation) or (water quota)]

Table 8 and 9 present these ratios for some fruit trees and some vegetables in Deir Alla, respectively, which give a clear idea that water embedded in lemons has the highest value. However bananas' water has the lowest value, equal to 0.09 JD/m^3. For vegetables the water use ratios range between 0.24 for eggplants and 0.52 for cauliflower.

Table 8: GP/WU ratio for some fruit trees in Deir Alla.

Crop	Banana	Orange	Grape	Lemon	Date
Gross profit (JD/ha)	1500	1200	18240	21720	7000
Water use (m^3/ha)	16090	11060	11060	11060	13950
GP/WU (JD/m^3)	0.09	0.11	1.65	1.96	0,5

Table 9: GP/WU ratio for some vegetables in Deir Alla.

Crop*	Hot pepper	Cauliflower	Onions	Eggplant
Gross profit (JD/ha)	1300	1550	1000	730
Water use (m^3/ha)	3000	3000	3000	3000
GP/WU (JD/m^3)	0.44	0.52	0.35	0.24

* Data for one season.

According to the water tariff, the farmers pay only 0.015 JD for one cubic meter of water, which is about 72% of the operation and maintenance costs and bearing in mind that the total cost is about treble the O&M costs (Molle et al., 2008). Accordingly, the real water price can be estimated from the following equation:

Real water price = 3* (O&M) = 3* (0.015 + 0.005) = 0.06 JD/m^3 (3)

Looking at values in Table 9 and 10, Eq. (2) indicates that the return to water is higher than its cost for all fruit production. However, it indicates that planting bananas and oranges can almost cover the real water costs, which has no great benefit at the country level. In this regard it is worth saying that some farmers gave high cost figures, which have reflected on their real profits. On the other hand, according to the survey that has been done in Deir Alla, fertilizers present the highest percentage of variable costs. This it is about 68% for banana plantations, while the water cost is only 5% (Figure 2).

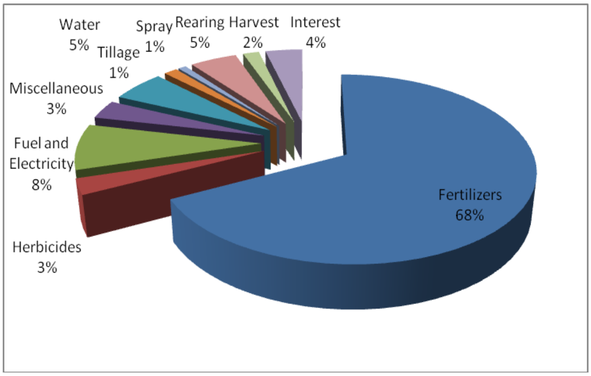

Figure 2: The percentages of the variable costs of banana plantation in Deir Alla.

In other words, the variable costs can be estimated by the following equation:

Variable costs = [Water costs + Fertilizer cost + Fuel and electricity cost+ Herbicides + Other cost] (4)

Hence we can increase water costs without any increase in water price if this would produce public objections, by introducing taxation on fertilizers, fuel and electricity, or herbicides costs. Accordingly, this new tax may return to the water costs. Moreover, a statistical analysis made on potatoes, tomatoes, eggplant, and okra farms in the Jordan Valley have showed that doubling the water price will not affect the net profit. On the other hand, some researchers have related water subsidies and soft laws in the Jordan Valley to enhancing settlement and job opportunities in the valley. However, according to the department of statistics of Jordan, only 22% of the permanent labors in the Jordan Valley are Jordanian. Figure 3 shows the number of permanent employees in Jordan between 1998 and 2006 (DOS 2008).

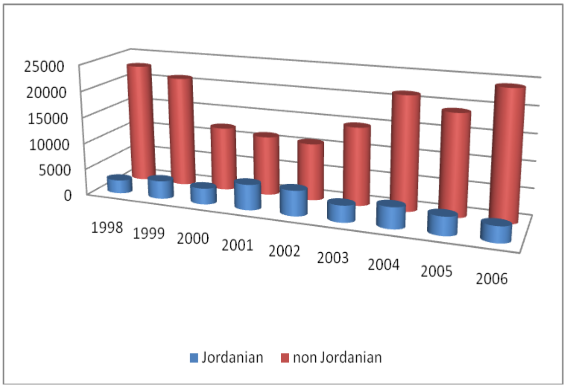

Figure 3: The total number of permanent laborers in Jordan between 1998 and 2006.

Hence, it would be better for Jordan to modify its employment policy and set new employment priorities in order to employ its own citizens inside and outside the agricultural sector.

Agricultural Dimension

Some countries have changed their crop pattern as a result of shortages of water. Farmers in some water poor areas, e.g., Spain, have started to plant grapes and olives instead of corn (WWC, 2004). In 1991 the government of Jordan stopped issuing new banana licenses. However no alternatives were proposed. Alternatives should be based on return to water and crops' water requirements. Theoretically, according to differences between vegetables and fruit trees quota, Jordan can save about 47 MCM/year if farmers in the Jordan Valley exchange fruit trees for vegetables.

Switching between fruit trees involves a 5 to 8 year waste of water to produce the first good sized and viable crop. Therefore, care should be taken when a decision is made to change crop patterns. Choosing crop patterns should also depend on the country's needs. Jordan in 2006 imported 224 tons of pistachios from Syria; however, it exported 0.1 and 1 tons to the United Arab Emirates and Qatar, respectively (MOA, 2008). Pistachio needs 400 mm/year of rainfall and it can be cultivated in semiarid areas with subtropical dry summers. Pistachio can tolerate a wide range of temperatures from 0 to 40^{o} C. (FAO, 2008). Until now there is no full study about planting pistachios in the Jordan Valley as an alternative to bananas. However, it is suitable for the middle and the upper Jordan Valley with small amounts of irrigation. Other alternatives should be based in the genuine needs of the country and the availability of the foreign markets. Exports of eggplant, hot pepper, and cucumber in 2007 to the European countries were 88, 320, and 1453 tons, respectively. However, 228, 5, and 3629 tons, respectively, were exported to the Gulf States and Middle Eastern countries. Therefore, trade relations can be improved to enhance such vegetables as alternatives to banana production.

Water Dimension

It was reported that there is a 231 MCM groundwater deficiency in the Jordan water budget of 2006/2007 (MWI, 2008), which should be compensated for by new regulations and legislation. The government of Jordan has played a significant role by decreasing water quotas. According to the old water quota system, the Jordan Valley Authority grants water depending on crop patterns and the planted area. Hence, water volume is the water depth multiplied by the planted area. The total daily water depths, from the beginning of May to the end of October, are 2, 4, and 8 mm for vegetables, fruit trees, and bananas, respectively. It is on demand during the rest of the year, when demand is low (Venot et al., 2007; Nachbaur, 2004). Table 10 presents the water saved annually as a result of the application of the new quota system, from the beginning of May until the end of October. The water saved annually for one hectare is 3680 m^3, and 920 m^3 for banana and other fruit tree farms, respectively. Hence, the saved water in 2006 from applying the new water quota, for example, equals 5 and 6 MCM from banana and citrus, respectively.

Table 10: The annual saved water from applying the new quota system.

Period	Days	Current quota (m^3/ha)		Old quota (m^3/ha)		Saved water (m^3/ha)	
		Other fruit trees	Banana	Other fruit trees	Banana	Other fruit trees	Banana
1/5–15/6	46	1380	2300	1840	3680	460	1380
16/6–15/8	61	2440	4270	2440	4880	0	610

16/8–15/9	31	1240	2170	1240	2480	0	310
16/9–15/10	30	900	1500	1200	2400	300	900
16/10–31/10	16	480	800	640	1280	160	480
Total						920	3680

Integrated solution

The invisibility of the virtual water trade makes it extremely successful because it can be applied without any political conflict. But, this invisibility may also lead to postponement of needed political reforms such as water allocation (WWC, 2004). Therefore, and due to the lack of knowledge about virtual water, raising awareness is vitally needed at all levels. Awareness campaigns should include local communities as well as other stakeholders and it should focus on water consumption and comparisons between different crops from a virtual water perspective.

It has been found that it is not easy to reallocate water in connection with banana crops. Some lobby groups are extremely powerful; therefore it is better to find alternative ways of encouraging farmers to change their crop patterns without creating new conflicts. As discussed above, there is little support for increase in water price, so the problem can be dealt with using the IWRM approach.

The integrated solution is shared between all stakeholders and can be achieved by IWRM committees that include all stakeholders and partners, from the farm level to the decision maker level, in order to reach a comprehensive solution. Moreover, these committees may have some representatives from the ministry of industry and the ministry of tourism in order to propose other alternatives from outside the agricultural sector.

5 CONCLUSIONS

We conclude that water poor countries such as Jordan may reconsider their water policies and study them from a virtual water perspective. One of the most important measures in choosing crop pattern is the gross profit to water use ratio or, in other words, embedded virtual water. We found that the water embedded in fruit from trees, due to the low production rates, have high values, more than 2000 m^3/ton for dates. While the embedded water in bananas and citrus are 575 and 540 m^3/ton, respectively.

It is not advisable to switch between fruit trees. Changing crop patterns from fruit trees to vegetables is better and give quicker profits. Moreover, the values of gross profit to water use ratio showed that bananas is perhaps the least desirable crop to be grown in the Jordan Valley. However, existing lemon trees are a good value. Hence, new crop patterns should be based on their gross profit to water use ratio and the needs of the country. Pistachio is a good alternative to banana in some areas in the Jordan Valley because it is imported from Syria. Jordanian eggplants, hot pepper and cucumber have a good market in Europe, the Gulf, and the Middle East. So they could be made more attractive as alternatives to bananas.

The results of this research showed that fruit trees in the Jordan Valley consumed about 110 MCM of water per year, 72 and 21 MCM of which are consumed by citrus and banana, respectively. Jordan exports 29 MCM of water embedded in fruit production, however it also imports 77 MCM of water embedded in fruit production. The Jordan government can thus save water through new regulations and proper legislation. For example, in 2006 the Jordan Valley Authority saved about 12 MCM by applying new water quotas, 5 MCM and 6 MCM of which were saved from banana and citrus production, respectively, and it can propose new activities outside the agricultural sector, which is one of the most important alternatives for water poor countries.

The analysis of this research has shown that there is a vital need to deal with the agricultural sector while taking all view points into account. First of all there is no need to fight against farmers who cultivate banana or citrus; the government can involve them in the decision making process (make them motivated and responsible). Hence, an approach which raises awareness and participation is the most important policy that should be implemented in the Jordan Valley. There is a need to formulate a responsible body to manage relations between farmers in Jordan and external trade agencies in the world in order to enhance exporting vegetables and low water crops to the European countries.

On the other hand, the Jordanian government can increase the variable costs of any kind of fruit tree by increasing some variable costs such as fertilizers, and this increase can be used to recover water costs.

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Paper IV

Analysis of Agricultural Production in Syria from a Virtual Water Flow Perspective

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Abstract- **In this paper, the agricultural status in Syria regarding virtual water flow is presented. Crop patterns, area, yield, and water consumption in agriculture are discussed. The historical change in crop pattern and the cultivated land are analyzed. The embedded water in different crops and the virtual water flow due to agriculture products were estimated. It was found that the annual imported and exported virtual water from agricultural products are about 14580 and 1790 million cubic meters (MCM), respectively. The economic analysis shows that citrus, tomatoes, and potatoes have high values of gross profit to water use ratio GP/WU, while sugar beet, and cotton has low values.**

Keywords-* *Crop patterns, Gross profit, Embedded water, Cultivated land.

I. INTRODUCTION

Several countries in the Middle East are facing serious water scarcity that negatively affects the economic development. Syria with an agriculture-based economy is one of these countries. With population growth the agricultural sector consumes larger and larger amounts of the country´s water resources. Important agricultural products include cereals, vegetables, fruits, and industrial crops.

Virtual water is defined as the embedded water in the global trading system [1]. Thus, virtual water content can also be defined for different crops´ water need. Local water shortage could be overcome by considering the virtual water content of water-consuming products [2]. In other words, water poor countries can save water by importing products that otherwise would have required large amounts of water [3]. In Egypt, e.g., one hectare of rice and wheat needs about 21000, and 4000 m^3 of irrigation water, respectively [4]. Taking an average annual yield of about 7 ton/ha for rice [5] and 6 ton/ha for wheat [6] the embedded water in rice will be about five times more as compared to that for wheat. To save water it would be preferable for Egypt to produce wheat instead of rice. Also, Egypt consumes annually about 14 and 4 million ton of wheat and rice, respectively. It imports more than 50% of its wheat and exports about 700,000 tons of rice. Jordan is considered to be one of the most water scarce countries in the region. Fruit trees consume 104 million m^3 of water per year, 71 and 21 million m^3 of which are consumed by citrus and banana, respectively [3]. Thus, to save water Jordan would have to change the crop production pattern.

After analyzing 146 countries [7], it was found that no relation exists between virtual water trade and water scarcity because most water-scarce countries keep producing high water consuming crops. Ansink [8] refuted two claims on virtual water trade; that virtual water trade: (i) levels uneven water distribution, and (ii) reduces the potential for water conflict. It is, however, important that specialists, stakeholders, and decision makers are made aware of the role of virtual water in the international economy. The economic efficiency of water use relates the value of output and the opportunity costs of water used in agricultural production to the value of water applied [9]. Opportunity costs, on the other hand, reflect the values that could be generated with water in alternative uses. By relating net return to unit water, planners can describe which good generates greater economic return from the use of domestic resources [10].

According to the above, the main objectives of this paper were to analyze the Syrian agricultural production from a virtual water content perspective. Thus, by comparing the economic value and embedded water in different crops, a more water efficient crop production could be proposed. For this purpose the agricultural status in Syria from 1999 till 2008 from a crop, land, and water consumption point of view was investigated including the virtual water trade due to agricultural export and import. The paper proposes a more water efficient agricultural crop production pattern for Syria

II. DATA AND METHODOLOGY

Syria is located in between 35°00' North latitude and 38°00' East longitude. The country has a total area of about 185 million km^2 and a population of about 20.4 million [11]. According to [12], land use in Syria is divided into 45% desert and semiarid land, 32% cultivated land, 20% uncultivated, and 3% forests (Fig. 1). However, according to the Ministry of Agriculture and Agrarian Reform (MAAR) the average value of the totally cultivated land in 2008 was 30% [13].

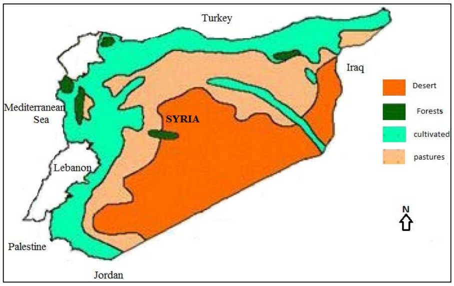

Fig. 1 Land use in Syria (after [12]).

TABLE 1.
CROP WATER REQUIREMENT (CWR) (m^3/ha).

Cereals & dry legumes		Industrial crops	
Crop	CWR	Crop	CWR
Wheat	4040	Cotton	13090
Barley	4040	Tobacco	7800
Maize	7269	Sugar beet	12500
Broad bean	3176	Cumin	12000
Lentil	3500	Anise	12000
Chick peas	3500	Peanut	10000
Dry bitter vetch	2000	Other ind. crops	10000
Other cereals	3000		
Fruit trees		Vegetables	
Grapes	4500	Tomato	6916
Citrus	9808	Potato	5641
Apple	12192	Onion & Garlic	8777
Almond	10989	Water melon	3954
Olive	4000	Summer veg.	6916
Dates	13950	Winter veg.	4584
Pistachio	8519	Other Veg.	6000
Other fruits	6000		

Source: Own elaboration based on [13, 14, 15].

Virtual water can be easily defined as the embedded water (EW) that is needed to produce a good. Hence, we can estimate the EW for crops from the following equation:

$$EW = CWR/Y \quad (1)$$

where: CWR: crop's water requirement (m^3/ha), Y: yield (ton/ha), CP: crop's production (ton), and A: cultivated area (ha).

In order to have a better picture on fruit trees production, the embedded water was estimated by two methods. The first one depends on fruit bearing area and is called actual embedded water AEW, while the second one depends on the total cultivated areas hereafter called total embedded water TEW. The TEW was used in the following estimations.

The net virtual water balance (NVW) in cubic meters was estimated after the determination of the imported (IVW) and exported virtual water (EVW) for each kind of crop:

$$IVW = Imports * EW \quad (2)$$
$$EVW = Exports * EW \quad (3)$$
$$NVW = IVW - EVW \quad (4)$$

where: Imports and Exports are in tons.

The same methodology was used by [16] to estimate the water trade in Andalusia. However, Velázquez estimated the net virtual water by subtracting the virtual water exported from the virtual water imported. For the economic analysis, we have estimated the Gross profit (GP), gross profit to water use ratio GP/ WU, and the Gross Margin (GM):

$$GP = TS - TC \quad (5)$$
$$GP/WU = GP/CW \quad (6)$$
$$GM = GP/TS \quad (7)$$

where: TS: total sales (US$), TC: total costs (US$), and CW: consumed water (m^3).

The total costs contain: 1) the agricultural operations, including tillage, fertilization flatting, irrigation, hoeing & weeding, planting, pesticide control, harvesting, sorting & packaging, and crop transportation; 2) production requirements, which includes: fertilizers, packages, seeds, water and pesticides; and 3) other costs such as: land rent, capital interest, and incidental expenses.

III. Results

The total cultivated area in Syria in 2008 was more than five million hectares. The crop pattern in Syria in 2008 according to the Ministry of Agriculture and Agriculture Reform in Syria was 71, 18, 7, and 4% for cereals & dry legumes, fruit trees, industrial crops, and vegetables, respectively [13]. The change in crops pattern from 1979 till 2008 is shown in Fig. 2.

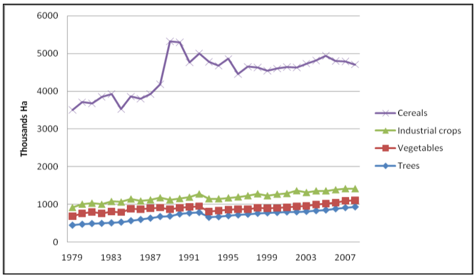

Fig. 2 Crop pattern in Syria.

The change in irrigated land, rainfed land, and the total cultivated area from 1970 till 2008, according to CBS, are presented in Fig. 3. It shows that the increase in the cultivated land is the result of the irrigated land increase. However, the change in the non-irrigated land depends on the hydrological year. Analyzing Fig. 3 shows that the average annual increase in the cultivated land is about 1%. While the average annual increase in the irrigated land is about 3%.

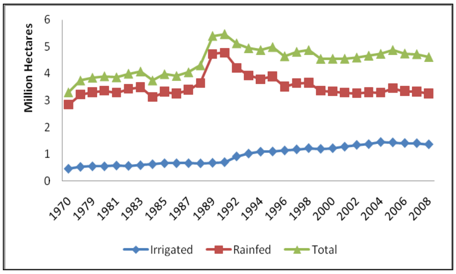

Fig. 3 Cultivated land in Syria.

The measurable use of the modern irrigation started in 2002 with about 200,000 ha and in 2008 the total irrigated area with drop and sprinkler irrigation was 91 and 162 thousand ha, respectively [11].

A. Cereals and dry legumes

Cereals and dry legumes cover more than 70% of the cultivated land area in Syria, 75% of these are irrigated of which 51 and 39% are for wheat and barley, respectively. The annually consumed water for cereals and dry legumes is presented it Table 2. We found that the embedded water in wheat is about 1800 m^3/t. In this regard, [17] found that the embedded water in wheat and barley in India, was 1654 and 1937 m^3/ton, respectively.

TABLE 2.
AVERAGE CEREAL AND DRY LEGUMES LAND COVER AND PRODUCTION (1999-2008).

Crops	Area (10^3 ha)	Yield (t/ha)	Consumed water (MCM)	EW (m^3/ton)
Wheat	1712	2.3	6916	1760
Barley	1324	0.7	5349	5770
Lentil	138	1	483	3500
Chick Pea	83	1.15	291	3045
Maize	56	3.7	408	1965
Dry Broad Bean	15	1.9	48	1672
Others	43	0.8	129	3750
Total	3371		13624	

B. Fruit trees

The land area cultivated with fruit trees has doubled during the last two decades. In 2008 fruit trees occupied about 18% of the totally cultivated land. More than 60% of these were olive trees (Fig. 4). Analyzing different fruit tree production between 1999 and 2008 shows that the largest increase was for olive trees from 28.6 to 63.9 thousand ha and for almond trees from 27.3 to 64.2 thousand ha. However, there was a decrease for some fruit trees such as quince from 689 to 500 ha. About 70% of the fruit tree land are irrigated. Table 3 shows that the annual water consumption for fruit trees is about 5000 MCM. To compare with Jordan, fruit trees consume annually about 105 MCM and the embedded water in citrus, apples, and dates, based on CWRs, are 534, 1082, 2447 m^3/t, respectively. This is based on the totally cultivated area [3].

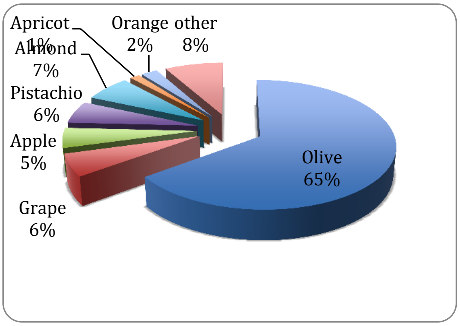

Fig. 4 Fruit trees in Syria.

TABLE 3.
AVERAGE FRUIT TREE LAND COVER AND PRODUCTION (1999-2008).

Crops	**Area (10^3 ha)**	**Fruit bearing %**	**Actual yield (ton/ha)**	**Consumed water (MCM)**	**TEW (m^3/ton)**	**AEW (m^3/ton)**
Olive	572	70	2.0	2286	2667	2000
Grape	58	73	7.8	263	804	577

Almond	54	58	3.3	594	5495	3330
Pistachio	52	60	1.3	445	8519	6553
Apple	47	70	9.0	571	1583	1355
Citrus	31	84	32.0	304	380	307
Date	0.6	35	24.8	8	2180	563
Other	72	67	12.5	432	1154	480
TOTAL	887			4903		

The industrial cropland cover is about 7% of the total cultivated land in Syria. Cotton, cumin, sugar beet, and tobacco represent 62, 18, 8, and 4%, respectively (Fig. 5). About 80% of the industrial croplands are irrigated. Cotton consumes about 3000 million m^3 of water per year and the embedded water in cotton is 3331 m^3/ton (Table 4). In this regard, [18] found that the embedded water in cotton in Turkey, Egypt, and Greece was 3100, 4231, and 2338 m^3/ton, respectively.

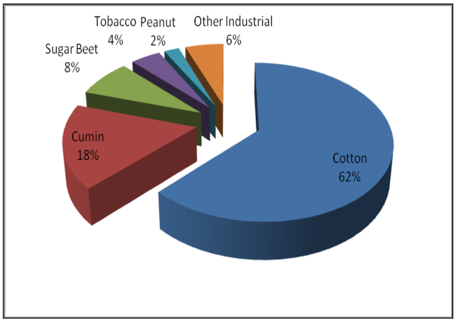

Fig. 5 Industrial crops.

TABLE 4.
AVERAGE INDUSTRIAL CROPS LAND COVER AND PRODUCTION
(1999-2008)

Crops	Area 10^3 ha	Yield ton/ha	Consumed water (MCM)	EW m^3/ton
Cotton	223	3.93	2923	3331
Cumin	62	0.55	749	21818
Sugar Beet	29	44.36	357	282
Tobacco	16	1.63	122	4785
Peanut	8	2.9	80	3448
Soya beans	2	1.6	20	6250
Other	18	1.25	181	8000
Total	358		4432	

D. Vegetables

About 80% of the vegetable land area are irrigated. Potatoes, tomatoes, and watermelon represent about 60% of the total vegetable land area. The total annually consumed water for vegetables is about 1000 million m^3 (Table 5). In India, the embedded water in watermelon was 362 m^3/ton [19], which is close to the estimated value for Syria in this paper. For green house vegetables water requirement is smaller. Tomatoes, eggplants, and sweet pepper, e.g., represented the highest yield of 6.3, 6.5, and 4.4 kg/plant with a seasonal water application of 260, 380, and 300 mm [20]. For cucumber, [21] found that the yield after applying 507, 383, 366, 342, and 292 mm of irrigation during 3.5 months was 4.5, 4.4, 5.1, 3.7, and 4.3 kg/plant, respectively. In our estimations, tomatoes water requirement in green houses during three seasons of production, was about 9000 m^3/ha.

TABLE 5.
AVERAGE VEGETABLE LAND COVER AND PRODUCTION
(1999-2008).

Crops	Area 10^3 ha	Yield ton/ha	Consumed water (MCM)	EW m^3/ton
Potatoes [a]	55	20	309	282
Tomatoes [a]	15	36	103	192
Green house tomatoes	3	134	27	67
Dry garlic	4	9	35	975
Dry onion	6	18.3	48	480
Water and musk melon	30	18.8	208	368
Summer vegetables	45	12.3	311	562
Winter vegetables	10	18.8	46	244
Other vegetables	6	13.3	35	451
TOTAL	173		1122	

[a] Data for three seasons.

E. Virtual water

Virtual water estimations in Table 2-5 show that the embedded water in industrial crops are high compared to other crops. The average EW in industrial crops, fruit trees, cereals, and vegetables were 6845, 2848, 3066, and 402 m^3/ton, respectively. According to the agricultural trade statistics for Syria, we estimated the EVW, IVW, and NVW (Table 6). This showed that the net annual virtual water trade is about 12800 million m^3, which means that Syria can be considered a virtual water importer from an agricultural point of view.

TABLE 6.
VIRTUAL WATER FLOW EMBEDDED IN AGRICULTURAL PRODUCTS

Crops	EW m^3/ton	Exports 10^3 ton	EVW [b] MCM/Y	Imports [b] 10^3 ton	IVW MCM/Y	NVW MCM/Y
Potatoes	282	123	35	10	3	-32
Tomatoes	192	368	71	109	21	-50
Water melon	368	104	38			-38
Other vegetables	451	272	123			-123
Onion	480			25	12	12
Garlic	975			107	104	104
Citrus	380	109	41	28	11	-30
Apple	1583	89	141			-141
Banana	575[a]			220	127	127
Date	2180			40	87	87
Pistachio	8519			2.6	22	22
Other fruit	1154	94	108	170	196	88
Legume	3750	44	165	18	68	-97
Wheat	1760	163	287	302	532	245
Barley	5770			1201	6930	6930
Maize	1965			1009	1983	1983
Soya bean	6250			501	3131	3131
Seed	21818	31	676	62	1353	677
Cotton	3331	32	107			-107
TOTAL			1792		14580	12788

Sources: [a] [3], [b] [22],

F. Economic analysis

An economic analysis was performed regarding some of the above crops. Total cost (TC) and total sale (TS) were estimated according to local market conditions. The total cost included all types of cost such as agricultural operations, production requirements, interest and incidental expenses, which were estimated with the help of MAAR. Then, gross profit (GP), gross profit margin (GPM), and gross profit to water use ratio (GP/WU) were estimated (Table 7). Table 7 shows that there was a high return on water use for vegetable, apple, and olive production. However, cotton, sugar beet, and maize had low return to water use ratio.

TABLE 7.
ECONOMIC ANALYSIS FOR SOME CROPS IN 2008.

Crops	**TC [a] US$/ha**	**TS [a] US$/ha**	**GP US$/ha**	**GPM %**	**GP/WU US$/$m^3$**
Olive	1160	2260	1100	49	0.28
Grape	1700	3390	1690	50	0.38
Irr. Apples	6370	10000	3630	36	0.30
Citrus	4350	12000	7650	64	0.78
Potato	4350	6500	2150	33	0.38
Tomato	4700	7830	3130	40	0.45
Onion	2425	4775	2350	49	0.27
Garlic	3500	7600	4100	54	0.47
Maize	1126	2010	884	44	0.12
Irr. Wheat	1030	1750	720	41	0.18
Irr. Barley	450	760	310	40	0.08
Peanut	3013	4000	987	25	0.10
Sugar beet	3780	4700	920	20	0.07
Cotton	2800	3600	800	22	0.06

[a] elaboration based on the Syrian markets and [13].

On the other hand, although wheat does not give a high GP, it is still feasible to produce for national and food security reasons as it gives a good GP/WU ratio. To compare irrigated and rainfed crops, we made a specific comparison between wheat and apples. For wheat, it was found that irrigation triples the yield but also the costs. While for apples, irrigation doubles the cost and also the yield (Table 8). Using the CWR, water cubic meter prices were 0.06 and 0.1 US$/$m^3$, for wheat and apples, respectively. Hence, and taking the GP/WU into account, it is feasible to irrigate these crops. Another comparison was made for potatoes depending on the planting season, which shows a lower GP in the summer season because of the water costs (Table 9).

TABLE 8.
COMPARISON BETWEEN IRRIGATED AND RAINFED CROPS.

Crop	Yield (t)	Water cost US$/ha	GP US$/ha	GPM %
Irrigated wheat	3.8	225	720	41
Rainfed wheat	1.2	-	310	51
Irrigated barely	1.8	225	320	40
Rainfed barely	0.7	-	152	50
Irrigated apple	13.8	1180	2630	29
Rainfed apple	7.1	-	1800	39

TABLE 9.
ANALYSIS OF POTATOES PRODUCTION IN 2008.

Season	Yield ton/ha	Water costs US$/ha	GP US$/ha	GPM %
Autumn	16	460	2000	38
Spring	25	560	2710	33
Summer	26	860	3400	40

G. Changing crop pattern scenario

Changing the crop pattern depends on the national trade and the GP/WU ratio. According to the Syrian trade statistics, Syria imports annually 109, 107, 25, and 10 thousand tons of tomatoes, garlic, onion, and potatoes, respectively. It also imports 500 and 120 thousand tons of soya beans and barley. On the other hand, Syria exports 32000 tons of cotton, which has a low GP/WU ratio. In the first scenario, we proposed to change half of the cotton land by other crops that Syria would need and we estimated the annual amount of saved water from this scenario to be about 560 MCM, Table 10. In the second scenario, and in order not to affect the industrial sector, we proposed to change the cotton land area by other crops that Syria would need. Consequently, according to Table 4, 32000 ton of cotton would need 8100 ha, which is almost the same area needed for cultivating garlic. Accordingly, depending on the CWR, the saved water from this scenario can be easily estimated by multiplying the difference between cotton's water requirement and garlic's water requirement by the cultivated area. The saved water would be 35 MCM. This scenario could be a start for a new agricultural plan in Syria, for saving water, and for creating new water allocation strategies. Other scenarios would be possible, for example changing maize and sugar beet areas, which have low GP/WU ratios, by some vegetables that are needed for the national market.

TABLE 10.
SAVING WATER BY CHANGING CROP PATTERN.

Crop	Tomatoes	Garlic	Onions	Potatoes	Soya beans	Barley	Cotton
GP	2300	2800	2800	1400	1000	720	
Yield (t/ha)	44.7	7	19.7	20	1.6	2	
Imports (10^3 ton)	109	107	25	10	500	120	
Area (10^3 ha)	2.4	8.1	2	0.5	65.5	33	111.5
Consumed water (MCM/y)	17	71	18	3	655	133	1460
Saved water MCM/y							564

IV. Conclusions

Agricultural crop patterns were analyzed. The results showed that more than 70% of the cultivated land are used for cereals and dry legumes. The annual water consumption in agriculture was about 28000 MCM, 55% of which are for cereals and dry legumes, 20% for fruit trees, 19% for industrial crops, and 5% for vegetables. Virtual water estimation showed that the embedded water is large in industrial crops such as cumin and cotton, while it is low for tomatoes and potatoes. It also showed similarity for some crops with other countries such as cotton in Turkey, dates in Jordan, and watermelon and maize in India. Green house production can be a good alternative for reducing water consumption because the CWR is less, while the yield is higher than in the open field. For example, for tomatoes the embedded water was less than 70 m^3/ton. Virtual water trade showed that the net virtual water balance from agricultural products is about 12790 MCM. The economic analysis of the crop pattern showed that citrus, tomatoes, potatoes, and onions have large gross profit to water use ratio GP/WU, while sugar beet and cotton have low values, which should be taken into consideration in future agricultural plans. Comparison between irrigated and non-irrigated wheat and apples showed that irrigation is feasible from both a water saving and economic output perspective. Two scenarios for a changed crop pattern were proposed. In the first, it was found that changing half of the cotton land area would save about 564 MCM of water every year. In the second proposal, changing the cotton land area for garlic would save about 35 MCM of water per year.

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Paper V

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Grapes as an alternative crop for water saving

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Abstract:

Fruit trees have a vast range of water needs. When it comes to Crop Water Requirement (CWR), grapes may be considered as a low water consumption crop. Thus, grapes can be a good alternative in arid and semiarid areas as compared to dates, citrus, and bananas that have higher CWR. Much water can be saved if agricultural management focuses on high-yield crops with low CWR. Therefore, changing existing water-wasting practices from high to lower CWR crops can save water and improve the virtual water (embedded water) balance for water-scarce countries. This chapter estimates and discusses the potentially saved water amount from changing crop pattern into grapes in Syria and Jordan by computing the embedded water in different typical crops. The results can be used to better manage scarce water resources and lead forward to sustainable water management. This is especially important in the Middle East that faces rapidly depleted renewable water resources.

Keywords. crop pattern, integrated water resources management, virtual water, Jordan, Syria.

1. Introduction

Water poor countries in Middle East and North Africa (MENA) region have to reallocate agricultural water for more sustainable use of scarce water resources. For a sustainable agriculture, governments should base their agricultural plans on water productivity, virtual water, and crop water requirement (CWR), acknowledging that these three dimensions can play a vital role in a warmer climate and with a larger population.

1.1 Water productivity

1.2 Virtual water

The embedded water in a product is called virtual water. Virtual water trade is a way that water can cross borders without being affected by political intentions or conflicts. This can be considered as an international water trade. Therefore, water-poor countries can balance water scarcity at their national level by importing high water content products and exporting low water content products.

Estimating the virtual water in a product means including all embedded water that were used in its producing process. This means, for an agricultural product, including water from rainfall, fertilizers, pesticides, and other types of indirect water usage. However, some of the indirect water usage may be difficult to quantify. Virtual water content can be estimated from CWR as suggested by Mourad et al. (2010) .

1.3 Crop Water Requirement (CWR)

CWR is the water needed for the crop during its life cycle. CWR depends mainly on climate conditions, namely temperature, evaporation, humidity, and rainfall. For the same crop, CWR is higher in arid and semiarid areas as compared to humid areas. Estimating CWR must be based on experiments, field work, and research. According to Shatanawi et al. (1998) grape water requirement in Jordan is about 4500 m^3/ha (Fig. 1), which is similar as for Syria (MAAR, 2010). As shown in Fig. 1, planting figs, olives, and grapes can save water as compared to apples, bananas, and dates (Santesteban et al., 2011).

MORE then (García García et al., 2011)

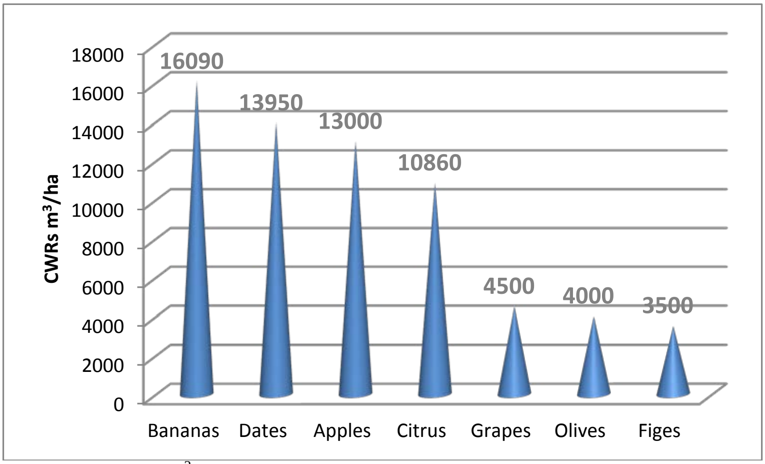

Figure 1. CWRs (m^3/ha) for fruit trees in Jordan.

1.4 Grape cultivation

Grape/vine needs specific climatic conditions;

1) Temperature: Grapes need cold winters with low temperature (2–10°C) during at least two months. Temperature below zero can cause serious damage to grape cultivation especially in a long term. On the other hand, grapes need a long warm growing season (25–30°C) to complete maturity. However, high temperature (more than 38°C) can damage its vegetation growth.
2) Humidity: High air humidity at flowering season can cause flower drop-off, which is noted in areas with fog and clouds. Furthermore, high humidity during the summer growing season can spread fungal diseases.
3) Rainfall and irrigation: For rainfed agriculture, grapes need about 500 mm annually to grow without irrigation. However, if rainfall is not enough, irrigation is needed especially

during dry months (June, July, and August). Irrigation, on the other hand, increases yield, vine water status, vegetative growth, and vine evapotranspiration (e.g., Intrigliolo and Castel, 2007). Irrigation also increases sugar content in the grapes and rises pH in wine later on, which affect the wine quality (Intrigliolo and Castel, 2009). Deficit irrigation, reducing canopy vigor, increasing fruit exposure to light and reducing fruit growth to avoid dilution effects can be considered as a good strategy to improve fruit composition for premium quality wines (e.g., McCarthy et al., 2000).

2. Background

2.1 Syria

Syria, 35°00' North latitude and 38°00' East longitude, with a total area of about 185,180 km^2 and a total population of about 20.4 million has a long dry season and a short winter (CBS-SYR, 2010). Depending on humidity and rainfall, Syria can be divided into five zones: wet (annual rainfall about 1000 mm), semi-wet, semiarid, arid, and dry (annual rainfall about 600 mm). The total cultivated area in Syria is about 5,664 thousand ha. Crops include cereals and dry legumes, fruit trees, industrial crops, and vegetables. About 23% of agricultural land are constituted by fruit farming. This figure doubled during the last two decades. Olives occupy more than 60% of the fruit tree land, while grapes occupy only 6% (55.9 thousand ha; Figure 2). Analyzing different fruit tree production between 1998 and 2009 shows that the largest increase was for olive trees from 459.7 to 635.7 thousand ha and for almond trees from 38.2 to 64.2 thousand ha. However, there was a decrease for some fruit trees such as figs from 10.7 to 9.7 thousand ha and quince from 1000 to 500 ha (CBS-SYS, 2010).

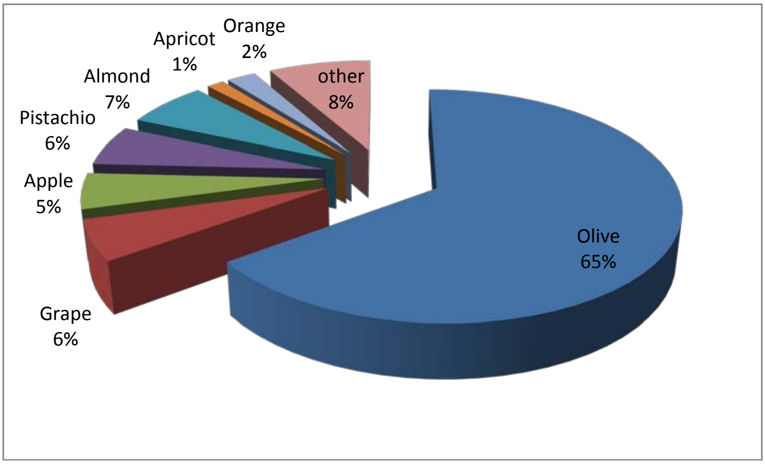

Figure 2. Fruit trees in Syria, 2009.

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2.2 Jordan

Jordan with 5.98 million inhabitants on 89,318 km^2 of land, is located between latitude 29.0◦ and 33.5◦ North and longitude 35.0◦ and 39.5◦ East. The country is considered one of the most water scarce countries in the world. The country is characterized by a long, hot, and dry summers and a short winter with an average rainfall range between 40 and 500 mm. The total cultivated land are about 224,190 ha. Fruit trees represent about 37% of which …. … (DOS-JO, 2010).

2.1 Fruit trees in Syria and Jordan

Fruit tree lands in Jordan, on the other hand, occupy about 30% of the cultivated land (). Grapes occupy about 31.4 thousand ha, 60% of which are irrigated trees, that produce about 34475 tons of grapes every year (DoS-JO, 2009). MORE

3. Changing crop patterns

There are many factors affecting changing crop pattern, each of which solves the problem from its own horizon. In order to reach water sustainability, however, integrated water resources management (IWRM) is needed. In the following, main factors that should be taken into consideration while planning changing crop pattern are discussed.

1- Virtual water/embedded water

Based on the CWR of grapes, 4500 m^3/ha, and knowing that the total grape cultivated area in Jordan and Syria are 3138 and 55861 ha (DoS-JO, 2009; DoS-SYS, 2009), grape plantation will totally consume about 14 and 252 million cubic meters (MCM) each year, respectively. The embedded water (EW) can be estimated using the following equations:

$$EW= CWR/Y \quad (1)$$
$$Y= CP/A \quad (2)$$

where Y is the yield (ton/ha); CP is crop production (ton), and A is crop area (ha). Using the crop area in Eq. (2) will give us the actual embedded water. However, when it comes to the international virtual water flow the total area may be included instead. Hereunder, in Tables 1 and 2, the embedded water in grapes and other fruit trees according to CWRs in Syria and Jordan were estimated. A quick look at these tables shows high EW values for apples and dates in comparison with grapes and pomegranates.

Table 1. Embedded water in some fruit trees in Syria

Fruit tree	Crop area (ha)	Production	CWR (m^{3}ha)	EW

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		(ton)		(m^3/ton)
Olives	444983	885942	4000	2009
Grapes	40779	358000	4500	513
Apples	34943	360978	12192	1180
Dates	129	4037	13950	446
Pomegranates	3482	60055	6000	347

Table 2. Embedded water in some fruit trees in Jordan

Fruit tree	Bearing area (ha)	Production (ton)	CWR (m^3ha)	EW (m^3/ton)
Grapes	2456	34475	4500	409
Apples	2261	31111	13000	944
Dates	1235	9681	13950	1780
Pomegranates	218	3490	6000	375

2- Economic value of water

An economic analysis was performed regarding some of the above crops. Total cost (TC) and total sale (TS) were estimated according to the local market conditions. The total costs contain: 1) the agricultural operations, which includes tillage, fertilization flatting, irrigation, hoeing and weeding, planting, pesticide control, harvesting, sorting and packaging, and crop transportation; 2) production requirements, which include fertilizers, packages, seeds, water and pesticides; and 3) other costs such as: land rent, capital interest and incidental expenses. The TC was estimated with the help of Ministry of Agriculture and Agricultural Reforms (MAAR) in Syria and Jordan University in Jordan. Figure 3 shows grape cost percentage in Syria in 2009.

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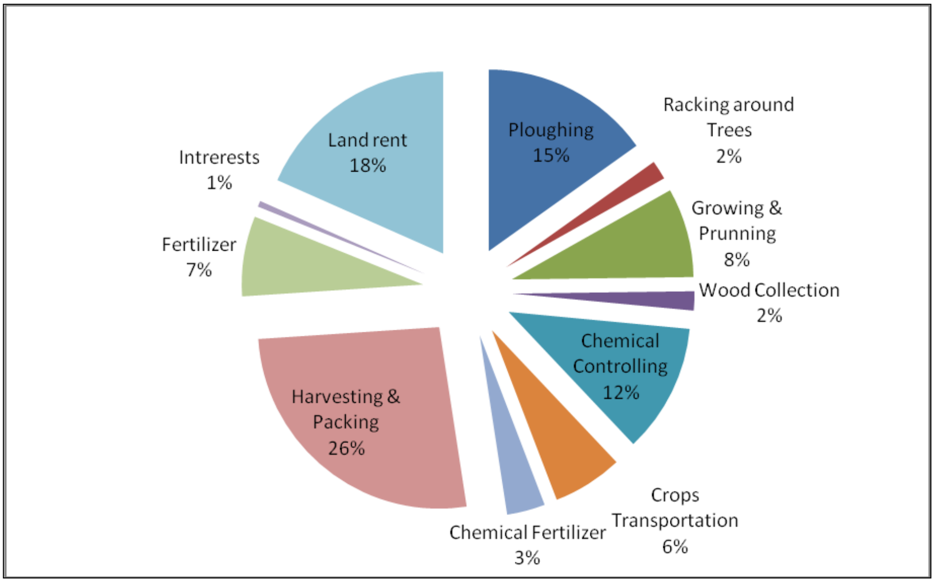

Figure 3. Grape total costs percentage in Syria.

Then, gross profit (GP), and gross profit to water use ratio (GP/WU) were estimated by the following equations:

$$GP = TS - TC \quad (3)$$

$$GP/WU = GP/CWR \quad (4)$$

$$GM = GP/TS \quad (5)$$

where TS is total sales (US$) and TC is total costs (US$). The results of these economic analysis are shown in Tables 3 and 4 for Syria and Jordan, respectively.

Table 3. Economic analysis for some crops in Syria

Crop	GP (US$/ha)	CWR (m^3/ha)	GP/WU (US$/$m^3$)
Grapes	1690	4500	0.38
Olives	1100	4000	0.28
Citrus	7650	9808	0.78
Apples	3630	12192	0.3
Tomatoes	3130	6916	0.45
Garlic	3500	8777	0.47
Cotton	800	13090	0.06

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Table 4. Economic analysis for some crops in Jordan

Crop	GP (US$/ha)	CWR (m^3/ha)	GP/WU (US$/$m^3$)
Grapes	13218	4500	2.9
Citrus	10000	10860	0. 9
Bananas	1087	16090	0.07
Dates	5073	13950	0.36
Hot pepper	1795	3000	0.6
Onion	1380	3000	0.46

3- Country trade

Changing crop pattern should take the national trade into consideration. Therefore, viewing the national exports and imports is the first step towards changing crop pattern. This will solve the most vital questions, does the country need such a crop? and 1) are there markets for the extra production?

From the national trade data of Syria and Jordan we found that Syria imports annually 109, 107, 25, 10, 500, and 120 thousand tons of tomatoes, garlic, onion, potatoes, soya beans, and barley, respectively. However, Syria exports 31595 and 61243 tons of grapes and combed cotton, which has a low GP/WU ratio. Jordan, on the other hand, imports 5774 and 20000 tons of grapes and apples, respectively, and exports 134 and 20 tons of bananas and apples, respectively. Taking the three factors that are presented above, we can suggest the following scenarios:

For Syria:

As Syria does not import grapes, we have three different scenarios:

- The first scenario depends mainly on changing the exported crops. As it is seen in Table 3 grapes has higher value of GP/WU than cotton. Therefore, Syria may plan to expand grape exports or enhance grape production in Syria. The 61243 tons of cotton, which are exported, need 15580 ha. However this area can become vine farms. In this case, and according to CWRs of grapes and cotton, the saved water from this scenario can be easily estimated by multiplying the difference between cotton's water requirement and grape's water requirement by the cultivated area, which would be 8590 m^3 per ha (13090-4500), which means an annual saving of about 134 MCM.

- In the second scenario, and in order not to affect the industrial sector, we propose to change the cotton land area by other crops that Syria would need. The 15580 ha of exported cotton can be changed into garlic. Accordingly, depending on the CWRs, the saved water from this scenario can be easily estimated as in the first scenario, (13090-8777). The saved water would be 67 MCM.

- In the third scenario, we propose to change the exported cotton land by other crops that Syria would need or export. We estimated the annual amount of saved water from this scenario to be about 106 MCM, Table 5.

Table 5. Saving water by changing crop pattern in Syria.

Crop	Grape	Garlic	Onion	Potato	Cotton
Yield (ton/ha)	7.8	7	19.7	20	

Amount (ton)	50000	50000	10000	5000	
Area (ha)	6410	7143	508	250	15580
CWR (m^3/ha)	4500	8777	8777	5641	13090
Consumed water (MCM/year)	28.8	63	4.5	1.4	203.9
Saved water MCM/year					106

Other scenarios would be possible, for example, changing maize and sugar beet areas, which have low GP/WU ratios, by some vegetables that are needed for the national market.

For Jordan:

Because of climatic reasons in Jordan, land used for bananas is not suitable for grape plantation. However, as it has a higher GP/WU, grapes can be planted instead of apples. The total apple land area are about 2307 ha, which needs about 30 MCM of water. However, if this land is planted with grapes, the total consumed water will be about 10 MCM, which means a total saving about 20 MCM per year.

4. Conclusions

This chapter tried to assess water value in agriculture for some specific fruit production. The focus in water scarce countries shows a vital need to save water by all means. One of the most effective way in estimating and achieving water saving is the virtual water/embedded water concept. Virtual water together with gross profit to water use ratio should be the basis for any agricultural plan in water-scarce countries such as Jordan and Syria. These countries may reconsider their water and agricultural policies and study them from a virtual water perspective. This chapter shows that grapes have lower embedded water value comparing with some other crops in Syria and Jordan due to its low CWR (4500 m^3/ha). The water embedded in grapes is about 513 and 409 m^3/ton in Syria and Jordan, respectively. Changing crop pattern can help in saving water. For Syria, changing areas that were planted with cotton for exportation in Syria may save about 134 MCM per year. Other scenarios can be proposed for the same target. For Jordan, on the other hand, changing apple land into grapes can save about 20 MCM per year.

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Paper VI

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Potential fresh water saving using greywater in toilet flushing in Syria

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ABSTRACT

Greywater reuse is becoming an increasingly important factor for potable water saving in many countries. Syria is one of the most water scarce countries in the Middle East. However, greywater reuse is still not common in the country. Regulations and standards for greywater reuse are not available. Recently, however, several stakeholders have started to plan for greywater reuse. The main objective of this paper is to evaluate the potential for potable water saving by using greywater for toilet flushing in a typical Syrian city. The Sweida city in the southern part of Syria was chosen for this purpose. Interviews were made in order to reflect the social acceptance, water consumption, and the percentage of different indoor water uses. An artificial wetland (AW) and a commercial bio filter (CBF) were proposed to treat the greywater, and an economic analysis was performed for the treatment system. Results show that using treated greywater for toilet flushing would save about 35% of the drinking water. The economic analyses of the two proposed systems showed that, in the current water tariff, the payback period for AW and CBF in block systems is 7 and 52 years, respectively. However, this period will reduce to 3 and 21 years, respectively, if full water costs are paid by beneficiaries. Hence, introducing artificial wetlands in order to make greywater use efficient appears to be a viable alternative to save potable water.

1. Introduction

Greywater reuse can help water-poor countries facing water shortage problems by saving potable water. Greywater is the collected water from domestic uses excluding that originating from toilets (Lombardo, 1982; Eriksson et al., 2002). Sometimes kitchen water is excluded as well (Li et al., 2009; Al-Jayyousi, 2003). The average greywater generation per capita is different from country to country; it varies from about 90 to 120 Ld (Li et al., 2009; Morel and Diener, 2007) depending on the age, gender, living standards, habits, lifestyle and the degree of water abundance. Climate also affects greywater generation. In a hot country like Oman, the greywater generation rate is about 151 Lpcd (Jamrah et al., 2008) which corresponds to about 82% of the total fresh water consumption, 56% of which originates from showers, 28–33% from kitchen, 6–9% from laundry, and 5–7% from sinks.

Due to the lack of freshwater, some countries have developed greywater reuse practices. For example reusing greywater in Los Angeles city for irrigation saves about 12–65% of annual used freshwater (Sheikh, 1993). During recent years much research has been made to evaluate the potential water saving by reusing greywater. Ghisi and Ferreira (2007), for example, found that using greywater for toilet flushing saves between 29 and 35% of consumed water.

Greywater, however, contains chemical and microbiological contaminants, which may stimulate the micro-organism growth in the greywater system (Widiastuti et al., 2008). All types of greywater have a good biodegradability but different characteristics. For example, laundry greywater contains less nitrogen and phosphorous than other greywater types. Kitchen greywater has a balanced COD:N:P ratio (Li et al., 2009). Due to the use of chemical products, laundry greywater has higher pH than other kinds of greywater (generally in the range 8–10; Eriksson et al., 2002). The COD and BOD fractions in greywater vary according to its source. For laundry greywater COD and BOD concentrations range between about 700–1800 and 50–500 mg/l, respectively. However, for mixed greywater the values may range between about 10–8000 and 90–350 mg/l for COD and BOD, respectively (Eriksson et al., 2002). According to Pidou et al. (2008), BOD and COD concentrations in shower water are about 130–200 and 470–670 mg/l respectively, while these are 22–55 and 80–200 mg/l in mixed greywater, respectively. Halalsheh et al. (2008) studied greywater characteristics in Mafraq-Jordan. They found that the average COD, BOD and TSS values were 2568 mg/l, 1056 mg/l and 845 mg/l respectively.

Greywater cannot be used without treatment depending on its end uses. Organic removal decreases the chlorine demand and reduces the potential for microbial growth in the distribution

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system and, in the toilet cistern (Winward et al., 2008). Irrigation with untreated laundry greywater may cause vital environmental hazards to the soil because of the excess sodium accumulation (Misra and Sivongxay, 2009). Untreated greywater cannot be used for toilet flushing due to its smell, potential staining of toilet bowl, and transport of bacteria and virus. According to USEPA standards reclaimed water used for toilet flushing should undergo filtration and disinfection. No detectable coliforms should appear in 100 ml of the effluent, BOD should be less than 10 mg/l and the residual chlorine should be more than 1 mg/l, pH equal to 6–9, and turbidity ≤2 NTU (Li et al., 2009; Al-Jayyousi, 2003). Based on the International Plumbing Code IPC 2000 appendix c, greywater can be reused for toilet flushing after disinfection (GWPP, 2005).

Greywater can be treated by natural zeolites (Widiastuti et al., 2008). Mulch tower has been tested to remove particulate matter and organic compounds from greywater (Zuma et al., 2009). Artificial wetlands, on the other hand is very common to treat greywater before its further use for irrigation and/or toilet flushing (e.g., Li et al., 2009; Ghisi and Ferreira, 2007; Dallas et al., 2004). Greywater for toilet flushing can be treated in a bio reactor after settling tank. It should also undergo disinfection before it is stored in the service tank (Goddard, 2006; Eriksson et al., 2009). However, due to its nature, high and medium polluted greywater cannot be efficiently chemically treated with use of coagulants and ion exchange resin if very strict standards are required. It needs to be followed by another process such as adsorption (Pidou et al., 2008).

March et al. (2004) reported on greywater reuse for toilet flushing in Spain. In their study, the greywater came from bathtubs and hand-washing basins. The treatment plant consisted of filtration, sedimentation, and disinfection using hypochlorite. The treated water was stored in an underground tank before it was pumped to a terrace tank. The system allowed addition of water supply when necessary. They found that the storage time should be less than 48 h in order to assure disinfection along the system. The residual chlorine concentration in the greywater system, including the toilet tank, should be greater than 1 mg/l. With this concentration level observed samples were negative for total coliform bacteria. Gual et al. (2008) in their pilot plant tested treatment of wastewater which was a mixture of a rejection flow from an osmosis unit and treated greywater from bathrooms. The treated wastewater was reused to flush toilets in a hotel. They found that filtration and chlorination are necessary treatment allowing use of greywater effluents for toilet flushing. The hypochlorite was injected in two stages; the first one before mixing with the osmosis rejection flow; the second after the mixing with the osmosis rejection flow. Campisano and Modica (2010) have studied six households to evaluate water saving by the reuse of greywater for toilet flushing, they found that water saving increases as the toilet cistern volume decreases. In their cost-benefit analysis on reusing greywater for toilet flushing and irrigating the food crops in residential schools in Madhya Pradesh, India, Godfrey et al. (2009) found that the benefits of greywater reuse were substantially higher than costs. Moreover, March et al. (2004) found that a payback period of 14 years was needed for installing a greywater recycling system in a hotel in Mallorca Island, Spain.

Syria is an arid country with large population increase and serious water scarcity. Even so, greywater treatment and reuse in Syria has not yet received much attention. Consequently, there are still no standardized water quality indices for greywater use in Syria. However, in view of present and future increasing water scarcity in Syria water saving techniques are urgent. Hence, the objective of this study was to evaluate the potential of saving potable water by reusing greywater for toilet flushing and also to analyze it in economical terms for a typical Syrian city. For this purpose the Sweida city, in southern Syria, was chosen as case study. Two kinds of greywater reuse systems were investigated, namely artificial wetland and commercial bio filter. The results are discussed in terms of potential water supply savings and payback period for investment costs. We close the paper by discussing potential upscaling benefits.

2. Materials and methods

2.1. Study site

Syria is surrounded by Turkey, Iraq, Jordan, Palestine, Lebanon, and the Mediterranean Sea with a total area of about 185 170 km^2 and a total population of about 20.4 million (CBS-SYR, 2010). The country has a large variation in rainfall and water resources distribution. Water shortage problems are concentrated to the eastern and southern parts of Syria, including the capital city Damascus. In general, cities in Syria have a high population growth due to urbanization and population increase.

Sweida city (Long. 36°34′0″ East and Lat.32°42′0″ North; Fig. 1) with a total area of about 650 ha and a total population of about 352 000 (CBS-SYR, 2010) is representative in terms of population growth and water scarcity. The elevation in Sweida ranges between 650 and 1200 m a.m.s.l. Sweida is located in three main water basins: Barada and Al Awaj basin in northern direction, Al Badeiah basin in the east, and Al-Yarmouk basin in the south west.

Sweida water and sewerage authority (SWSA) is responsible for water and wastewater in the city, under the supervision by the Ministry of housing and construction (MOHC). Drinking water reaches all people in the city and in the rural areas. Due to the water shortage, SWSA has divided the city into sectors and pumps water once a week. The totally produced water resources are about 50 000 m^3/day. Hence, the water consumption per capita equals about 140 l/d. The two springs Era and Bader are the only natural water sources available for Sweida city. The main water resources are dams and wells beside the springs. Sweida has 18 dams. About 8 of them are used for drinking water purposes, while the others, with lower quality, are used for livestock and irrigation. Moreover, Sweida has more than 225 wells for supplying its peri-urban areas with drinking water and 900 wells for irrigation (SWSA-MOHC, 2009; MOI-SY, 2009). There is a sewage system in the central parts of the city without a treatment plant, however, and due to the fact that groundwater level is deep, all houses in the country sides and some in the city have cesspools.

Bathrooms, toilets, and kitchen are usually located at the exterior wall in apartments. Furthermore, the greywater pipes usually join the toilet pipe close to the exterior wall before these enter the sewage system, which makes it easy to install any kind of greywater separation system.

2.2. Interviews

A field survey was made to investigate the social attitude toward reusing greywater in Sweida city and to find out the following parameters through personal interviews: living place, land availability, family members, indoor and outdoor water use, water bills, and their opinion about reusing greywater. The number of interviewees was estimated by using Eq. (1), which estimates a population-based representative sample (Ghisi and Ferreira, 2007).

$$n \geq \left(1/\varepsilon^2\right)N/\left(1/\varepsilon^2 + N\right) \quad (1)$$

where n is the sample size, N is the population size, and ε is the sample error (from 1% to 20%). Taking the total population of the city, excluding peri-urban areas and assuming a 10% sample error, one hundred interviews were needed according to (1). The

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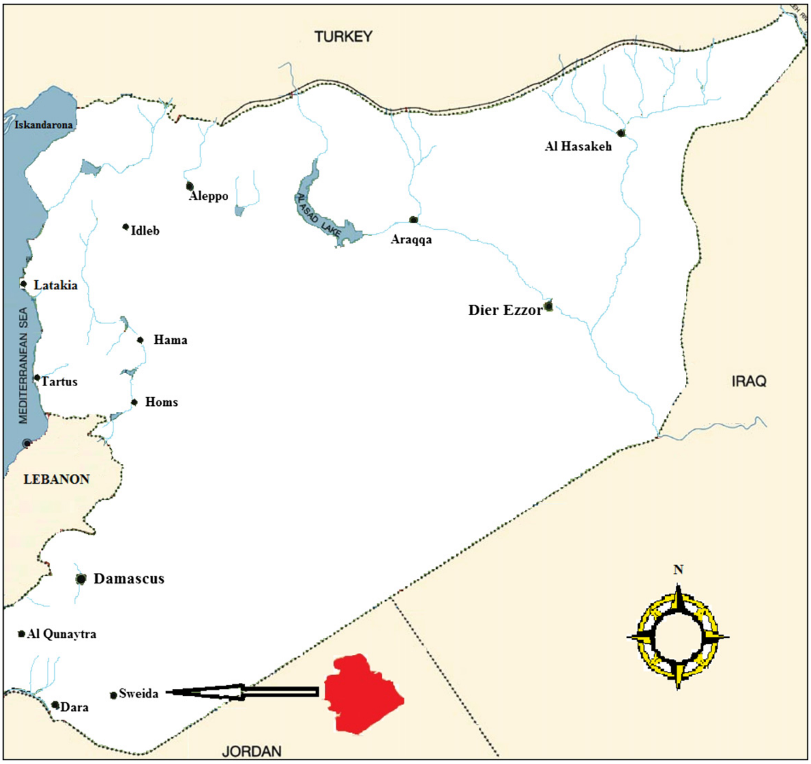

Fig. 1. Map of Syria showing Sweida city.

respondents were chosen randomly; 50% men and 50% women. The interviews were made at homes, offices, schools, and bus stations. The questions in the interviews included water meter availability, house and garden area, family members, social acceptance of reusing greywater for toilet flushing, billed water during the last six months, and frequency of shower, face and hand washing, tooth brushing, clothes and dish washing, house cleaning, and toilet use. The results of the interview investigation are described below.

2.3. Estimation of daily potable water consumption

Equations (2)–(4) were used to estimate the daily water consumption

$$W_d = W_p + W_f \quad (2)$$

$$W_p = \left(F_s \times Q_s + F_{tf} \times Q_{tf} + F_{tb} \times Q_{tb} + F_{hw} + Q_{hw} + F_{fw} \times Q_{fw}\right) \quad (3)$$

$$W_f = (F_{wm} \times Q_{wm} + F_{dw} \times Q_{dw} + F_c \times Q_c + F_p + Q_p + F_i \times Q_i + F_1 \times Q_1)/FM \quad (4)$$

where W_d is the water consumption (Lpcd), W_p is the personal water consumption (Lpcd); W_f is the water consumption within the family (Lpcd); F_s, F_{tf}, F_{tb}, F_{hw}, F_{fw}, F_{wm}, F_{dw}, F_c, F_p, F_i, and F_l are the daily frequency of using showers, toilet flushing, tooth brushing, hand and face washing, clothes and dish washing, cleaning, irrigation, and livestock, respectively; Q_s, Q_{tf}, Q_{tb}, Q_{hw}, Q_{fw}, Q_{wm}, Q_{dw}, Q_c, Q_i, and Q_l are the average water consumption, in liters, for one use of showers, toilet flushing, tooth brushing, hand and face washing, washing machine, clothes and dish washing, cleaning, irrigation, and livestock, respectively; and FM is a number representing the family members.

The average quantities for one event of face washing, hand washing, shower, and tooth brushing were taken from a group of ten volunteers, five males and five females. The group contained two teenagers, four singles, and four married persons. While the average water consumption of water flushing and the frequencies of all uses were taken from the interviews by asking them about the frequencies of doing each activity and the toilet tank's size.

2.4. Billed potable water consumption

The billed water consumption was estimated from the water bills for the period between September 2008 and February 2009 by using the following equation:

$$W_{da} = Q_b \times 1000/(FM \times 180) \quad (5)$$

where W_{da} is the per capita actual water consumption (l/d), and Q_b is the water consumption during six months (m^3). Depending on the water bills, the monthly per capita water cost was estimated using the following equation:

$$Wc_m = Wc_b/(6 \times FM) \quad (6)$$

where Wc_m is the monthly per capita water cost and Wc_b is the water cost according to the water bills during the six months. The average greywater consumption as identified through interviews was used in the analysis.

2.5. Options for greywater treatment

Two treatment methods were analyzed; artificial wetlands (AW) and a commercial bio filter (CBF), each of which has its own characteristics and conditions to be applied. The AW system is a biological filter composed of gravel and wetland plants. This system is suitable for buildings and separate houses that have available land, the needed area is about 0,8 m^2 per person (Ghisi and Ferreira, 2007). The CBF, on the other hand, is a commercial product that is sold as a unit. Many international companies produce such systems, which treat greywater in three steps: sedimentation, filtration, adsorption, and disinfection via ultraviolet light. These systems do not need any involvement from the owner. The treated water is suitable for irrigation and toilet flushing. Typically each unit can treat up to about 1.2 m^3/d (Nubian, 2011).

2.6. Economic analysis

Economic analysis was performed considering implementation of the greywater system for new flats and buildings. Material and equipment costs were estimated after visiting four local stores. The water tariff was taken according to the Syrian tariff system. Water cost in Syria is subsidized by the government; people pay just about 35% of the real cost. The water tariff depends on the consumption during a two-month period (Table 1). If the consumed water amount reaches class 4 or 5, subscribers will not have any benefit from the previous classes and they must pay 0.48 or 0.65 US$ for the all consumed water. From the survey, most bills do not exceed the third class level. Consequently, we will locate the saved water price within the third class equal to 0.33 US$/$m^3$. In order to estimate the payback period, the per capita annual saved water cost for the greywater system was estimated as:

$$W_{s-\text{cost}} = W_s \times \text{water tariff} \times 365 \times \text{number of served people} \quad (7)$$

$$T = G_c/W_s \quad (8)$$

where W_s is the daily saved water (m^3/d.p), $W_{s\text{-cost}}$ is the saved water cost (US$/year), G_c is the total costs for implementing the greywater system, and T is the investment payback period (years).

Table 1
Water tariff in Syria.

Class	Consumption (m^3)	Water tariff US$/$m^3$
1	1–30	0.05
2	31–50	0.15
3	51–80	0.33
4	81–120	0.48
5	121–9999	0.65

Table 2
Frequency and water consumption per capita ($n = 100$).

Activity	Frequency (per day)	Quantity per one use (l/capita)
Face washing	4	1.1
Hand washing	8.6	0.7
Tooth brushing	1.7	0.5
Shower	0.6	22.6
Toilet flushing	4.1	8.9

3. Results

3.1. Interviews

Sweida inhabitants have since decades adapted to water shortage conditions. Due to the fact that tap water is available once a week only, each household has usually at least one 2 cubic meter water tank to cover water needs during the week. From the interviews it was found that the average family size is 5 persons. The survey also showed that 83% of the respondents supported reusing treated greywater for toilet flushing or irrigation. The other 17% were not aware that treatment means a safe reuse of the water. About 10% of the respondents were already using laundry water, without any kind of treatment, in irrigation or in cleaning of their houses. In this regard, a survey in Oman showed that 84% of the respondents were in favor of treating and reusing greywater and 47% felt that it would be harmful to human health (Prathapara et al., 2005). Consequently, it is clear that public awareness of benefits and safe reuse of treated greywater needs to be increased.

3.2. Water consumption

Table 2 presents the average frequency and quantity of different personal water use per capita and day.

Typical household activities leading to water consumption such as laundry, dish washing, cleaning, and cooking were estimated by taking the average of all interviewed individuals multiplied with average household size (5 persons), Table 3.

From the interviews, water end-use per capita was estimated. Fig. 2 shows the different water consumption types in Sweida city. The total greywater that can be reused for toilet flushing is about 43 and 161 Lpcd for Sweida and Muscat, respectively. However, the needed water for toilet flushing is only 35 and 11 Lpcd for Sweida and Muscat, respectively. Hence, greywater can cover all needed water for toilet flushing. Thus, reusing greywater in toilet flushing will save 35% of Sweida's consumed potable water. The difference between the two countries depends on general lifestyle and local conditions. The shower amount is much larger in Oman which may be a function of temperature. The difference in toilet water consumption is a result of using water saving toilets in Oman.

The estimated water consumption from interviews was compared to the billed water consumption. The average billed water consumption was 130 Lpcd. According to Table 3 the interviews gave a water consumption of just 94 Lpcd. Possible reasons for the obtained difference between the estimated (through

Table 3
Frequency and water consumption per household.

Activity	Frequency (per day)	Quantity (l/household)
Laundry	0.6	60
Dish washing	3.4	15.5
Cooking	1	15
Cleaning	0.8	45.7

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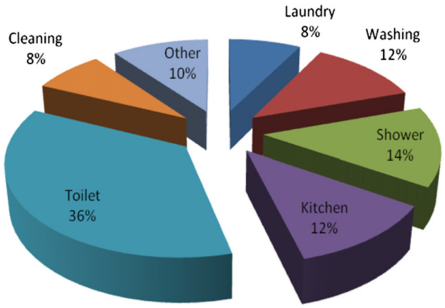

Fig. 2. Water consumption for different activities.

interviews) and billed water consumption may be the result of four factors: 1) interviewing just one person from each family could give uncertain estimation of the water consumption, 2) water-metering may not be exact due to reading frequency, leakage and low certainty of old meters, and 3) water losses from tanks, which are located after the water meter, and 4) unmentioned water use such as car washing, street cleaning, and irrigation of plants along street. However, assuming a proportional error in all water consumption types in Table 3 would mean that the percentage of greywater generation would still cover the total toilet flushing. Consequently, the absolute figures in Table 3 could be wrong but the relation between the different uses could be approximately correct.

3.3. Greywater system

The designed greywater system could be introduced for single-family houses (individual system) or multi-family buildings (block system):

1) The individual system would be suitable for single-family houses in the city or in rural areas. In this case, each family or groups of families could construct/purchase its own small system. According to the survey, 22% of the respondents live in single-family houses. These families could probably use some of their real state to install a constructed wetland system. Commercial bio filter, on the other hand, does not need a large space. It can be installed near the front of the house. However, this system is more expensive.
2) The block system can be implemented for several multi-family residential buildings. According to the survey, 78% of the respondents live in flats in multi-storey buildings consisting of, on average, ten flats. In cases where land is available within the property a treatment wetland can be constructed. Yet commercial bio filters can be proposed when land is not available. The size of the system depends on the total number of people living in the building. In this study we choose a building with ten flats. Hence, for a five member families, the system will serve 50 persons, producing 2 m^3 greywater per day.

The typical flat design in Syria has a toilet near the outside wall of the building or it has an open shared area with other flats (Fig. 3). Therefore, connecting the treated greywater to the flushing pipe is considered an easy task. However, a more difficult task is the collection system. The wastewater system is typically combined so that greywater needs to be separated from the black water. The cost for such work is 100–300 US$ depending on flat size and location. On the other hand, such costs would not arise for new buildings.

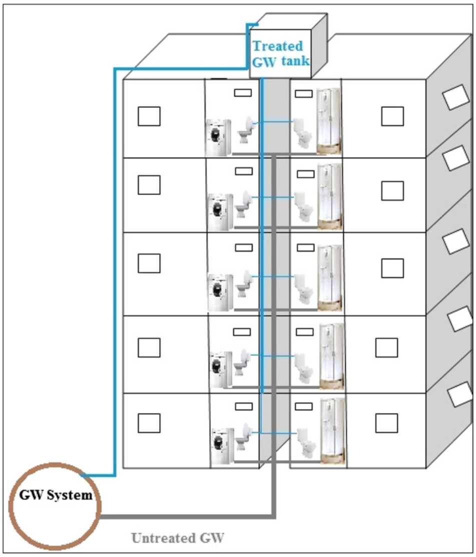

Fig. 3. Schematic illustration for GW collection and supply system.

3.4. Economic analysis

In order to estimate the payback period an economic analysis was made focusing on the fixed costs for installing AW or CBF. Costs were estimated from local market conditions. For AW costs include excavation, gravel, and civil work. For a block system, serving 50 inhabitants the AW system cost is about 1330 US$. Table 4 presents material costs involved in the AW for block and individual systems.

For the CBF, the cost of treatment plants depends on size and number of served persons. The system is more cost effective if shared. The CBF also needs an elevated tank and pipe connection. The cost for a single-family house (5 persons) and a multi-family building (50 persons) is 2500 and 9783 US$, respectively.

Table 4
Estimated cost of AW system for block and individual systems (base year 2009).

Material	Quantity cost Block system	Total cost (US$)	Quantity cost Individual system	Total cost (US$)
Excavations	Lump sum	87.0	Lump sum	43.5
Gravel	20 m^3	434.8	2 m^3	43.5
Collecting tank	3 m^3	173.9	0.5 m^3	54.3
Settling tank	3 m^3	173.9	0.5 m^3	43.5
Water pump	0.5 HP	43.5	0.5 HP	32.6
Elevated tank	2 m^3	130.4	0.25 m^3	54.3
Labor	Lump sum	108.7	Lump sum	43.5
Pipes and connections	15% of the total cost	173.9	15% of the total cost	47.8
Total cost		1326		363.0
Per capita cost		**26.5**		**72.6**

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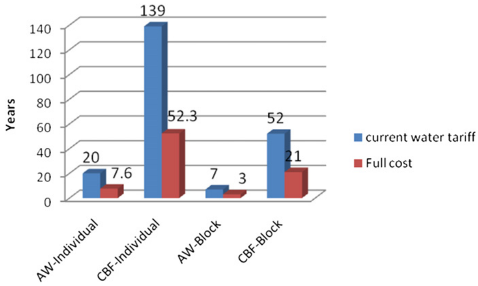

Fig. 4. Payback periods estimation.

To estimate payback period, two scenarios were used: the first scenario assumed a fixed water cost of 0.33 US$/m^3 (15 SYP/m^3), which represents about 35% of real water cost (according to the Ministry of Housing and Construction in Syria) and a 30 Lpcd saved water from reusing greywater in toilet flushing. In the second scenario we assumed that the water cost is fully paid by the beneficiaries, which means that the water cost will be about 0.87 US$/m^3 (40 SYP/m^3). The payback periods for the different systems and different water cost are presented in Fig. 4.

According to Fig. 4, it is seen that the payback period varies between about 3–20 years for the AW system to more unrealistic values for the CBF system (21–139 years). An individual system is not economically viable unless for perhaps the AW (payback period of about 8 years). For a block system, however, the second scenario gives a payback period of about 3 years only using the AW. Consequently, an AW where consumers may cover all costs appears economically feasible. As mentioned above, however, the public awareness using reusing greywater must be improved. In this context and according to the interviews, most people appeared willing to pay for the separation cost of the greywater reuse systems. However, the authors think Ministry of Housing and Construction, Ministry of State for Environmental Affairs, and Ministry of Local Administration should share this responsibility.

Reuse of greywater may be a small step toward sustainable water management in Syria as well as in the Middle East. This study showed, however, that all toilet flushing can be saved using a simple and economically feasible greywater treatment system. Potentially, this could have a large effect the country's potable was need. An initial survey assuming similar living conditions as for inhabitants in Sweída city shows that Syria could save up to about 101 MCM potable water per year. This figure includes inhabitants that are living in rural and peri-urban areas (CBS-SYR, 2010).

4. Conclusions

The study showed that average total greywater production in a typical Syrian urban area was about 46% of the total water consumption. That is, almost half of the domestic water consumption is turned in to greywater. Thus, this amount represents a substantial resource if it can be re-used safely. Toilet flushing on the other hand, consumed about 35% of the domestic water consumption. Therefore, using greywater for toilet flushing can save about 35% of the total domestic water consumption. Moreover, it was found that 83% of the interviewees were positive to use treated greywater. Already today, more than 10% of households are using untreated laundry water in irrigation and for house cleaning. Therefore, raising public awareness for greywater reuse is a vital issue that should be taken in to consideration not only in Sweida city but also in Syria in general and also other water scarce Middle Eastern countries.

Two kinds of treatment methods for individual and block systems were proposed; AW (artificial wetland) and CBF (commercial bio filter). AW is a suitable treatment method for greywater when land area is available. For a block system consisting of one residential building (50 inhabitants) the saved drinking water may reach about 600 m^3/year. The AW can be designed especially for new buildings. The economic analysis showed that, within the current water tariff, the payback period for this system is about 7 years. CBF can also be installed in block systems; however, the payback period was estimated to about 52 years and thus unfeasible. However, if all water costs are paid by consumers the payback period will be 3 and 20 years for AW and CBF, respectively. On the other hand, installing greywater systems for individual buildings is not feasible. The payback period for a small household of five members reach 20 and 139 years for AW and CBF, respectively.

Finally, not only Sweida city but more or less all Syrian areas suffer from water shortage. Therefore, new water policy should urgently be proposed to overcome this problem. Greywater reuse is one of the best alternatives which should be recommended by stakeholders for national and international organizations to fund pilot projects in order to show how to guarantee water sustainability. In this regards, there is a need to study greywater characteristics in urban areas to give input to design of treatment. Other studies may focus on reusing greywater excluding the kitchen wastewater. AW can also be proposed for treating wastewater in small communities using permeable septic tanks, taking into consideration the limited risk of polluting the deep groundwater in this region.

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Paper VII

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POTENTIAL WATER SAVING FROM RAINWATER HARVESTING IN SYRIA

Potentiell vattenbesparing genom insamling av regnvatten i Syrien

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Abstract
Syria, as well as many other countries in the Middle East, faces serious water shortage problems. Available water per capita (AWPC) will dramatically decrease due to climate change, population increase, and water needed for economic growth. Rainwater harvesting can play an important role in increasing available water in Syria. However, the absence of rainwater sewer systems in many rural areas in Syria necessitates giving a priority to construct collecting systems for future policies and plans. The objective of this paper is to estimate the potential increase in available water from collecting roof rainwater in small reservoirs and using other rainwater harvesting techniques. The potential increase in water availability due to rainwater harvesting could be as much as 35 million m^3 of water by roof rainwater harvesting in rural areas. This could be combined with other rainwater harvesting techniques in both urban and rural areas. Rainwater harvesting can be used to irrigate fruit trees that are less sensitive to changes in water quality and that can be especially adapted for passive irrigation techniques.

Key words – Middle East, Syria, rainwater harvesting, climate change, reservoirs, water shortage

Sammanfattning
Liksom många andra länder i mellanöstern står Syrien inför allvarliga problem med vattenbrist. Tillgängligt vatten per person kommer att minska dramatiskt i framtiden på grund av klimatförändringar, populationsökning och ekonomisk tillväxt. Insamling av regnvatten kan komma att spela en viktig roll för att klara av det ökande vattenbehovet i Syrien. Detta är något som planerare måste ta hänsyn till och prioritera i framtiden. Syftet med denna artikel är att uppskatta de potentiella vattenvolymerna man kan erhålla från takavrinning och från andra källor. Vi fann att upp till 35 millioner m^3 kan erhållas från takavrinning i rurala områden. Man kan kombinera detta med andra system för att samla in regnvatten, både i rurala och urbana miljöer. Det erhållna vattnet kan exempelvis användas till bevattning av frukträd, som inte är lika känsliga för vattenföroreningar som andra grödor.

1 Introduction

For a better sustainable water management in the Middle East, water scarce countries should optimize use of all available water resources and decrease losses. Available Water Per Capita (AWPC) has witnessed a dramatic decrease in the region due to population increase and economic development. Another future change is expected due to climate change (e.g., Arnell, 1999). Climate change will reduce water resources in Syria by some 1300 MCM (million m^3) by 2050 (Mourad and Berndtsson, 2011). Research during the last decades has emphasized the importance of nonconventional water resources in the country's future water budget. For example, greywater reuse in toilet flushing can save up to 35 % of drinking water (Mourad et al., 2011).

Rainwater harvesting, which is a technique to collect, store, and use rainwater for domestic or agriculture purposes, is considered one of the most important non-conventional water resources in the world. Rainwater harvesting is a widely accepted solution to alleviate problems of water shortage (e.g., Cheng and Liao, 2009). In Australia, due to the water shortage, rainwater tanks are considered a vital water resource in most of the rural areas. Eroksuz and Rahman (2010) found that large rainwater tanks, up to 70 m^3, in multi-unit residential buildings in Australia can provide up to 50 % of the needed water for toilet flushing, laundry, hot water, and outdoor irrigation. Basinger et al. (2011) found that a significant percentage of the non-potable water needs of multifamily residential buildings in New York City can be supplied with roof harvested runoff. In Jordan, Abdulla and Shareef (2009) reported that a maximum of 15.5 MCM water can be collected from roofs of residential buildings. Other studies in Sweden, Brazil, and UK showed that using rainwater harvesting can give high percentage of potable water saving (e.g., Villarreal and Dixon, 2005; Ghisi et al., 2007; Fewkes, 1999).

Harvested rainwater is considered a clean renewable water resource, its quality in rural areas where air pollution is negligible, depends on the receiving roofs and the collecting tanks. Rainwater harvesting can also be performed in the field by directing surface runoff toward a rainwater reservoir or to agricultural areas. Some rainwater harvesting techniques can also help in reducing soil erosion. Alkouri (2011) found that using large semi-circular bunds reduced erosion of agricultural soil in the Badia rangeland, which is located in the eastern part of Syria with an annual rainfall less than 100 mm, by 16 to 53 %. Rainwater harvesting ponds (reservoirs) can be designed using topographical maps and GIS (e.g., Al-Adamat et al., 2010).

Syria has a vast variability in rainfall depending on season and location. Rainfall can reach more than 1000 mm/year in coastal regions. The lowest rainfall, about 60 mm/year, is found in the east and southeast. Depending on humidity and rainfall, Syria can be divided into five climatic zones: wet (>600 mm), semi-wet (300–600 mm), semiarid (200–300 mm), arid (100–200 mm), and dry (< 100 mm), (Abdul, 2011), see Figure 1.

According to the Ministry of Irrigation in Syria (MoI), the annual renewable available water is about 17000 MCM. The total population is 20.4 million, which means that the available water per capita and year (AWPC) is about 833 m^3. Due to the long dry season, from May to November, evaporation has a great impact in reducing available water. The annual evaporated amount from water bodies may reach 1854 MCM (Mourad and Berndtsson, 2011). Urban development, climate change, and a high population growth rate will

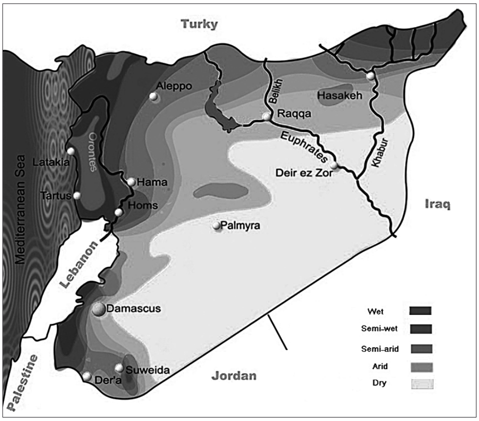

Figure 1. *Climatic zones in Syria (after Abdul, 2011).*

have a vital impact on reducing AWPC. It has been reported that AWPC will decrease to about 620 m^3 in 2025 (FAO, 2008).

Water harvesting systems in Syria, such as surface water collection in to reservoirs and transport by waterwheels, have traditionally been used since 3000 BC. According to the Syrian topography, 60 % of the Syrian land may be appropriate for water harvesting systems. The Ministry of Agriculture and Agricultural Reform (MAAR) and the General Commission for Scientific Agricultural Research (GCSAR) have conducted a lot of research in this field, see e.g., Abdul (2011). They found the choice of the best water harvesting technique depends on soil, slope, rainfall and runoff amount, socio-economic situation, and cultivation patterns in the studied area.

Terraces, which are mechanical structures comprising a channel and a bank made of soil or stones, can be considered a good water harvesting technique. They are systematically constructed perpendicular to the slope. Thus terraces intercept runoff, and encourage it to infiltrate,

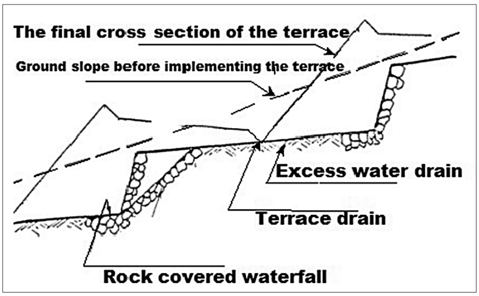

Figure 2. *Terraces (Bakir and Liang, 2004).*

Table 1. *Average precipitation and population in the Syrian Governorates.*

Governorate	Area (km^2)	Rainfall (mm/year)	Total population (million)	Rural population
Damascus	18140	255	1.702	0
Damascus Rural		328	2.613	0.915
Aleppo	18500	378	4.566	1.715
Homs	42220	749	1.705	0.78
Hama	8880	842	1.541	0.973
Lattakia	2300	141	0.967	0.47
Tartous	1890	516	0.768	0.549
Idleb	6100	382	1.41	1.007
Deir Ezzor	33060	218	1.146	0.635
Dra'a	3730	332	0.957	0.528
Al Sweida	5550	308	0.355	0.244
Al-Hasakeh	23330	897	1.425	0.913
Al-Rakka	19620	619	0.887	0.544
Quneitra	1860	255	0.083	0.083
Total	*185180*		*20.125*	*9.356*

After CBS-SY (2010).

evaporate or to be diverted towards a predetermined and protected safe outlet at a controlled velocity to avoid channel erosion (Bakir and Liang, 2004).

Contour farming can also be used for rainwater harvesting and it controls the erosion. In this method, crops are planted along topography perpendicularly to the slope gradient. Contour farming is, e.g., practiced in Al-Badia in Syria (Bakir and Liang, 2004), see Figure 2.

The objective of the present study was to estimate the potential of rainwater harvesting in Syria from mainly urban areas. By rainwater harvesting other types of high-quality water can be saved for purposes such as drinking water. The needs for this are urgent in Syria.

2 Methods and study area

To accomplish the objective of the study, rainfall data, climatic areas, potable water supply, population, and housing type in each governorate were obtained from CSB, MoI, MAAR, and GCSAR. For roof water harvesting, the total roof area in each governorate was calculated based on the average area and number of typical houses. The potential rainwater harvesting volume was estimated based on the total roof area, the average annual rainfall between 1978 and 2007, and the runoff coefficient. Then, the potential saving percentage was calculated by dividing the potential volume of harvested rainfall by the annual domestic demand.

According to CBS, 60 % of the Syrian lands receive less than 250 mm/year and 46 % of the population lives in rural areas (Table 1). Most dwellings in the Syrian rural areas have one floor. However, after 2005 due to the economic crisis, the number of two and three floor dwellings increased especially near village centers. The total roof area in each governorate was estimated with the help of CBS. Table 2 presents the residential building roof area in each rural area of each governorate.

The potentially harvested water (HW) for each governorate was estimated by the following equation:

$$HW= R*A*K \qquad (1)$$

where R is the average rainfall in the target governorate, A is the total roof area (assuming that all buildings have two floors), and K is the a run-off coefficient of 80 %, which indicates a loss of 20 % of the rainwater that is discarded for roof cleaning and evaporation (Abdulla and Al-Shareef, 2009).

At the field level, rainwater can be directed to trees by teracess or contour farming (Bakir and Liang, 2004). The result can be improved if trees can be planted in lines depending on slopes and crop water requirement CWR. Further details are described in the results.

Table 2. *Floor area in the Syrian rural areas.*

Governorate	Floor Area 10^3 m^2	Governorate	Floor Area 10^3 m^2
Damascus Rural	20668	Al-hasakeh	11335
Aleppo	24844	Al-Rakka	7731
Homs	17046	Al Sweida	6574
Hama	15990	Dra'a	9873
Lattakia	13578	Tartous	26522
Deir Ezzor	7847	Quneitra	1374
Idleb	15280	Al-hasakeh	11335

After CBS-SY (2010).

Table 3. *Roof runoff in the Syrian rural area.*

Governorate	Roof area 10^{3*} m^2	Rainfall (mm/year)	Harvested water MCM
Damascus Rural	20668	255	2.11
Aleppo	24844	328	3.26
Homs	17046	378	2.58
Hama	15990	749	4.79
Lattakia	13578	842	4.57
Deir Ezzor	7847	141	0.44
Idleb	15280	516	3.15
Al-Hasakeh	11335	382	1.73
Al-Rakka	7731	218	0.67
Al Sweida	6574	332	0.87
Dra'a	9873	308	1.22
Tartous	26522	897	9.52
Quneitra	1374	619	0.34
Total	*169011*		*35.26*

3 Results and discussion

3.1 Roof rainwater harvesting

The harvested rainwater for each rural area in each governorate was estimated by eq. (1). According to Table 3, it is seen that the total potential of harvested water from roofs in the Syrian rural areas could reach 35 MCM. Knowing that the Syrian population in the rural areas is about 9.4 millions (Table 1), the harvested water corresponds to 3.7 m^3 per capita and year. This amount can be stored and reused for garden irrigation, groundwater recharge, or for toilet flushing after mixing with greywater systems;

- Garden irrigation: this can be done in individual tanks or in block tanks. In both cases harvested water will be used for garden and/or street irrigation.
- Groundwater recharge: when it is applicable the harvested water can be directed into a recharge well, which help in maintaining the groundwater balance. This option needs a governmental body to be implemented and financed. The Ministry of irrigation, drinking water companies, and the municipality are the main stakeholders in such a project.
- Mixed with greywater: harvested rainwater can be mixed with a greywater system, when it is applicable, the saved water can cover all garden and toilet flushing needs.

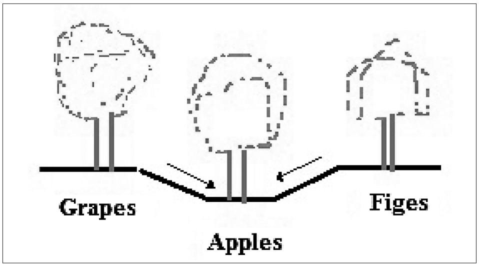

Figure. 3. *Rainwater harvesting at field level.*

3.2 Rainwater harvesting at field level

Depending on crop water requirement (CWR; Table 4), areas with fruit trees can be divided into different zones. For example, in the Al-Swaida area people cultivate apples, figs, and grapes. Thus, the land can be divided into three zones depending on CWR. Figure 3 shows how the land can be developed regarding different CWR and collection of rainwater. Crops with higher CWR should be located at lower levels to receive more water. This method can improve the yield without introducing irrigation in the field. However, a pilot project is needed for its verification.

4 Conclusions

Rainwater harvesting plays a vital role for water saving in arid and semiarid regions. It is important that these techniques are further developed to alleviate water stress from climate change and population increase. Syria can save up to 35 MCM of water by roof rainwater harvesting in urban areas. Further, rainwater harvesting at field level is also a good technique by which fruit trees can be cultivated depending on topography for different CWR. Contour farming controls erosion and increase pasture areas. Small, medium and large surface water reservoirs, which are constructed in most of the Syrian rural areas, help in providing a good resource for irrigation.

Acknowledgments

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Table 4. Crop water requirement (CWR).

Crops	Grapes	Citrus	Apple	Almond	Olive	Dates	Figs
CWRs (m^3/ha)	4500	9808	12192	10989	4000	13950	3500

Source: Own elaboration based on MAAR-SY (2010) and Shatanawi et al. (1998).

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Paper VIII

Can Integrated Water Resources Management contribute to sustainable peace in the Middle East?

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Abstract: Water resource scarcity in the Middle East is an important issue connected to the 4th June 1967 Line in the Middle East peace process. This paper focuses on the Integrated Water Resources Management (IWRM) approach to contribute to the peace process between Israel and Arab countries emphasizing fruitful cooperation to resolve the 4th June 1967 Line issue. The paper shows that start of a possible cooperation could be founded on interest-based negotiations and built on IWRM principles by a simple geographical allocation plan for the Lake Tiberias water between Israel and Syria together with a joint environmental protection plan to build cooperation instead of confrontation and integration instead of fragmentation. In a better cooperative climate, withdrawing from the 4th June 1967 Line could be a possibility because negotiation results would incur safer access to sustainable water resources and a comprehensive peace.

Key words: Lake Tiberias, negotiations, comprehensive peace.

1. INTRODUCTION

History has shown that lack of freshwater supply may lead to instability that in turn creates political conflicts within shared water resources. In January 2005, 18 people died in a clash between two ethnic groups in southern Sudan over the use of common river water (Juizo, Liden, and Vaz, 2006). After his visit to Darfur in 2007, the UN Secretary General Ban Ki-Moon stated that ‘Darfur is an environmental crisis - a conflict that grew at least in part from desertification, ecological degradation and a scarcity of resources, foremost among the water’ (Zeitoun and Mirumachi 2008). Access to and control of Shatt-al-Arab waterway was one factor that led to the eight-year war between Iraq and Iran (1980-1988) (Workman 1991). Moreover, water has been the roots, means, and causes of war in the Jordan River basin (Mimi and Sawalhi, 2003).

In 1951 and after the Jordan announcement of a plan to irrigate the Eastern Ghor, Israel closed the water gates of Lake Tiberias, which led to a series of border skirmishes between Syria and Israel (Wolf 1996). In 1953, Israel made concrete plans to divert the Jordan River and to pump water from Lake Tiberias through the construction of the National Water Carrier (NWC) in northern parts of Lake Tiberias. This resulted in Syria protesting to the United Nations (UN). The UN, in turn, made Israel change the intake place of the carrier in 1954 (Smith, 1966). The U.S. president, Eisenhower, sent Eric Johnston to solve the water issue in the region. After his first proposal for water allocation and under the objections of the Arab states, Johnston proposed a unified plan as follows: 400 MCM (million cubic meters) for Israel, 720 MCM for Jordan, 35 MCM for Lebanon, and 132 MCM for Syria. Although the plan was accepted it was not ratified and countries in the region have continued to develop their water resources while ignoring other countries’ needs (Brooks, 1994; Wolf, 1996; Murakami, 1995).

In 1964 Israel had completed its NWC which pumps an annual water amount of 440 MCM for domestic use, and another 100 MCM are pumped every year for agriculture purposes (Courcier et al. 2005). This action disturbed the Arab states which began to prevent water from reaching Israel by directing the Hasbani into the Litani in Lebanon and the Banias into the Yarmouk for Syria. In March, May, and August 1965 the Israeli army attacked the diversion works in Syria which was one of the vital causes for the 1967 War (Cooley, 1984).
After the 1967 War Israel controlled half of the length of the Yarmouk River (80 km), compared to 10 km before the war (Murakami, 1995). Moreover, in the 1967 War the Israeli army destroyed more than 140

Palestinian wells (Humphries, 2006), which again indicates that water was the most important factor leading to the war (Brooks, 1994; Bhat, 2007). Furthermore, the Israeli occupation of the Golan Heights and the 1982 Israeli invasion of Lebanon have given Israel full control of the Jordan River flow and increased their fresh water supplies by almost 50%, especially when they included Hasbani and Wazzani rivers in their security zone (Hewedy, 1989). Israel also aimed, during the 1982 invasion, at capturing the Litani water and directing it into Israel (Cooley, 1984).

Due to water scarcity, and lack of water management and regional cooperation, the Middle East is considered a hot spot in terms of water shortage and security. Water shortage has affected regional relationships between countries and their policies, especially in arid and semiarid regions where regional river development, trans-boundary watershed management, and stakeholders have not been considered by the water resources planners. Hence, many water-related problems could become more serious in the near future, especially in light of the absence of the UN in solving such problems or implementing its resolutions (Resolutions 242 and 338 are good examples).

Integrated water resources management (IWRM) ensures that social, economic, environmental, and technical dimensions are taken into account in the management and development of water resources. IWRM is based on bridging the gap between agreed policies and implementation (Rahaman and Varis, 2005). Gaps between the participatory principle and its implementation in practice was exemplified by Petit and Baron (2009) for Burkina Faso. They found that social environments are characterized by strong hierarchical relationships that may hinder a rational IWRM approach. In studying the Mhlatuze catchment in South Africa, Funke et al. (2007) found that due to insufficient alignment and cooperation between the policies of different government departments and the practices of different water use sectors, many institutional challenges persist. Therefore, it is vital to integrate water sub-sectors such as hydropower, water supply and sanitation, agriculture, and the environment with the social dimension in the management process. Water policy, for example, plays a vital role in IWRM. It controls the water use in each country through a set of laws, policies, and legislations. Many countries face a multitude of problems in implementing their water policies and laws because they have not implemented the participatory approach while setting up their projects.

For Lake Tiberias and the northern Jordan River, any IWRM policy that aims at resolving the present hydrological, ecological and political problems should take water quality and water quantity into consideration (Berman, 1998). Due to the importance of local participation in all water projects, this should be enhanced by public awareness and organizational development in the region. Riparian countries, water user groups and individuals should realize that they all depend on each other now and in the future. This should lead to the building of institutional linkages that reciprocate and mirror the water flows in the upstream–downstream context, which is the base of any IWRM approach (Savenije and Van der Zaag, 2008).

Acknowledging the finite water resources in the Middle East region, countries should develop new water allocation approaches and strategies in order to meet the growing water demand in a sustainable way. In view of the above, the objectives of this study were to analyze the 4th June 1967 Line issue in the Middle East and to suggest an IWRM approach that can be a starting point for fruitful cooperation to resolve the present conflict between Syria and Israel. An IWRM approach would ensure the integration of all sectors and stakeholders at regional and international levels to realize justice and comprehensive peace and to achieve stability and security in the region. This is a formidable task that cannot be resolved in a single paper. However, we suggest a solution to the issue of Lake Tiberias through a simple approach. This, together with a comprehensive environmental protection plan for the Lake and its surroundings and a water saving demonstration project involving several villages in an international context, could be a starting point for further international collaboration. Consequently, the paper starts off by giving a resume of water agreements and the peace process in the Middle East. After this, we outline important aspects of the IWRM for the area. Finally, we suggest an approach based on IWRM and a starting point by settling the Lake Tiberias issue. We close the paper with a discussion of practical aspects of the results.

2. WATER CONFLICTS IN THE MIDDLE EAST

The most important water conflicts in the Middle East are concentrated to three different regions:

a. The first one is between Syria, Lebanon, Jordan, and Palestine on one hand and Israel on the other hand. This conflict axis is considered the most dangerous in the world because of its political conditions. "When it comes to the common water resources shared with Palestinians and other Arabs, Israel ... acts like a great sponge" (Elmusa 1993).
The Jordan River has three water courses: the Hasbani in Lebanon, the Banias in Syria, and the Dan in Israel (Zeitoun et al., 2009; Fig. 1). They join together and flow into Lake Tiberias. The Yarmouk River, with a total length of about 360 km, starts in Syria and then joins the Jordan River, and discharges into the Dead Sea (Daoudy, 2008). After the 1967 War Israel prohibited Arabs on the West Bank from drilling new wells without Israeli permission, which was almost impossible. In a report to the Center for Strategic and International Studies in Washington D.C., Starr and Stoll (1987) noted that water resources are exploited up to 4.5 and 95.5% in the West Bank and Israel, respectively. Israel also began to use between 50–75% of the Jordan River flow. On the other hand, Lake Tiberias (Sea of Galilee) is considered the most sensitive lake in the region. Consequently, it appears clear that the occupation of the Syrian Golan Heights by Israel was not for security reasons. Instead it had a water resources dimension. Israel could, by occupying the Golan Heights, control all water resources that supply the Jordan River and Lake Tiberias, in addition to its control of some parts of the Yarmouk River.

Figure 1: Water resources supplying Lake Tiberias (after Zeitoun et al., 2009).

In spite of the signing of a peace treaty between Jordan and Israel in 1994, which pointed out the water issue in article no. 6, Israel has up to now ignored the water problem. On the other hand, the peace negotiations between Israel and Syria ended without any kind of progress because Israel claimed ten meters into the eastern bank of Lake Tiberias, which could be regarded as Syrian land.

b. The second region involves Syria and Iraq on the one hand, and Syria and Turkey on the other. The Euphrates and the Tigris are the main water conflict sources in this area. The Euphrates River is 2700 km long and it originates in Turkey by two major tributaries and enters Syria at Karakamis. After entering Syria, two tributaries join the main stream, Al-Khabur and Al-Balikh. Then it enters Iraq after 1213 km where it joins the Tigris near the city of Qurna, and the combined river is called Shatt Al-Arab. The Karun River from Iran joins Shatt Al-Arab at Al-Basra city, and discharges into the Arab Gulf.

c. The third region is located between Egypt, Sudan, and Ethiopia. The Nile basin is shared among ten countries: Egypt, Sudan, Ethiopia, Eritrea, Kenya, Tanzania, Rwanda, Burundi, Uganda, and Zaire. Water dependency in these countries is not the same. Egypt and Sudan, for example, are totally dependent on the Nile water, while the other eight countries are only partially dependent.

3. BILATERAL WATER AGREEMENTS

3.1 Syria and Jordan

On the 3rd of September 1987, Syria and Jordan signed the Yarmouk River agreement, according to which the two countries have rights to water and electricity from the river through the construction of the Unity Dam and to use its lake. Jordan will construct the 100 m high Unity Dam and Syria has the right to use all the springs that originate from its land in the Yarmouk basin except those upstream from the dam with water level less than 250 m. Jordan has the right to use water that flows from the dam and from the producing electricity centre (MOI-SY, 2008). Later on, after extended negotiations, on the 24th of November 1998, Syria and Jordan signed the Yarmouk River Water Agreement with full focus on the construction of the Unity Dam. The Syrian-Jordanian committee discussed the cost of the Unity Dam project in light of a new study presented by the Jordanian side.

3.2 Jordan and Israel

In 1994 Israel signed a peace agreement with Jordan. Water was a major issue in this agreement. Both countries agreed that Israel would take 25 MCM/year (12 MCM in summer and 13 MCM in winter) from the Yarmouk River. Israel, moreover, would transfer 20 MCM/year from the Jordan River in the summer period. Jordan, on the other hand, could take an annual quantity of 10 MCM of desalinated water from about 20 MCM of saline springs that are diverted to the Jordan River, while the operation and maintenance costs would be financed by Israel. The two countries agreed on the establishment of a Joint Water Committee of three members from each country that may have a number of specialized sub-committees for solving technical tasks and water management (Jägerskog, 2003).

3.3 Israel and Palestinian Authority

In Article 40 of the Oslo II Interim Agreement in September 1995, Israel acknowledged Palestinian water rights for the first time. The agreement formed a Joint Water Committee to discuss water shares and needs. The article also acknowledged Palestinian future water needs on the West Bank to be between 70-80 MCM/year (Jägerskog 2003).

4. NEGOTIATIONS IN THE MIDDLE EAST PEACE PROCESS

4.1 General about the peace process

The Middle East peace process was launched at the Madrid conference on the 31st of October 1991. Within this process five multilateral working groups were set up to complement the bilateral negotiations covering water resources, the environment, arms control and regional security, refugees, and regional economic development (Haddadin, 2002). Since about 55% of Israel's total water supply comes from non-Israeli sources, 280 MCM from the Golan Heights, 415 MCM from the West Bank, and 215 MCM from Lebanon, Syria, and Jordan (Zarour 1992), from the beginning of the Middle East talks Israel had insisted on full cooperation in water projects in a regional framework.

The complexity of the water issue in the Middle East creates conflicts that require experts and mediators to be involved in the negotiation approach. Conflicts are resolved by negotiation. In general, negotiations can be rights-based, power-based, or interest-based. The rights-based approach has not worked for more than sixty years and it will not be, by itself, the way to resolve the conflicts in the Middle East because Israel has refused to admit or to apply the United Nation resolutions (242 and 338). The power-based approach, on the other hand, means resolving the conflicts in accordance with the more powerful side's interests. It is not the way to resolve conflicts in the Middle East where Arabs and Israel have had many wars since 1948 (i.e., 1967, 1973, 1979, and 1982). Moreover, the last two wars against Lebanon in 2006 and Palestine in 2008 have shown that power will not bring a sustainable peace. Instead it has brought destruction and hate to human beings inside and outside the region. Power also allows the conflicts to recur. Therefore, interest-based negotiations, which look for equal needs and concerns of the parties (depending on why and not only what) is the best approach to solve water conflicts in the Middle East. In this mixed approach, problems will be solved at a regional level and many options can be developed to reach the best agreement.

Even so, a co-author of this study made a study on water and peace in the Middle East involving educated Syrian employees. She found that 75% thought that water is the major issue that affected the last peace negotiations, while only 5% thought that security was the main issue. About 80% thought that peace between Syria and Israel had no chance in the current negotiation in Turkey because Israel has no plans to lose water resources by withdrawing to the 4th June 1967 Line. Moreover, 60% of them thought that the basic reason for the Israeli occupation is water resources in the Golan Heights. On the other hand, 10% did not want not give a statement on the subject because they thought it is a too controversial issue and did not want to talk about politics.

Negotiators need to build their decisions on trust. There are no clear intentions toward approaching a complete and comprehensive peace in the Middle East. Israel, for example, wants to solve future questions, security, trade and political relations, before the vital basics are agreed upon, which are the United Nations Resolutions. Thus, the application of UN Resolutions 242 and 338 would be an indication that Israel intends to actively support the peace process. Water issues affect the application of these resolutions and they create many questions about the Syrian-Israeli border. Lake Tiberias is the most essential issue in the 4th June 1967 question. Lake Tiberias is supplied by many springs and wadis from the Golan Heights including the Banias River, the Hasbani River, and the Dan River. Water resources in the Golan Heights include the Yarmouk River and other streams such as Jilabun, Daliyot, Yehudia, Zavitan, Meitzar, Samakh, Orvim, Hamdal, El Al, and Nov. The Golan Heights are the source of about one-third of Israel's total fresh water (Zaslavsky, 2000). In addition to controlling Lake Tiberias, Israel benefits from the occupation of the Golan Heights as an early-warning capability and defense line (Hajjar, 1999).

4.2 Lake Tiberias (Sea of Galilee)

Lake Tiberias is located between Syria and Palestine at and Lat. 32°50' N., Long. 35°35' E., with a total surface area of about 170 km^2 It is about 22 km long, 14 km wide, and has an average depth of about 24m (Berman, 1998; ME-WDBP, 1998;Fig.2). Historically, the management of the lake has changed from one convention to another. In the Sykes-Picot Agreement in 1916, between the governments of Britain and France, Syria had full control over the lake. However, under the Convention of Obadr Clemenso, 1919, the lake was in Palestinian hands. While under the Treaty of San Remo in 1920 Syria had part of the lake, this part was redefined in the Paris Treaty, 1920, to be one third of the lake. Yet, the 1923 Treaty gave the whole lake to Palestine (Stas, 2008). The 1923 treaty had two contradictory articles. The first located the international border between Syria and Palestine 10 m east of the lake shore. However, the second one gave Syria the right to use Lake Tiberias for navigation and fishing (Stas, 2008).

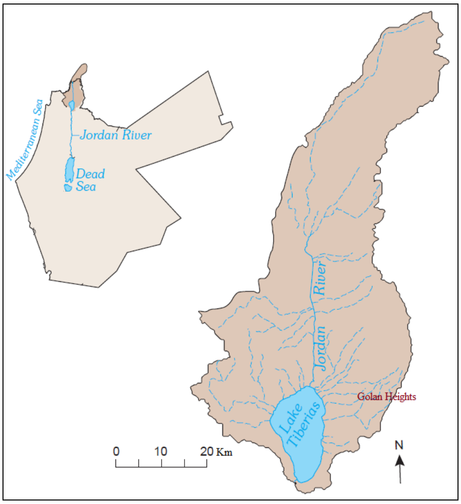

Figure 2. Lake Tiberias (after ME-WDBP, 1998).

Due to the truce treaty (20th September 1949) between Syria and Israel after the 1948 War, the international border was the shore of the lake. Syria had enjoyed the use of the eastern coast of the lake, which is called the 4th June 1967 Line, until the 1967 War. Syria now wants to return to this border again. However, Israel has not agreed on this because if Israel withdraws to the 4th June 1967 Line it will grant 40 MCM/year to Syria (Schiff, 1993). The Clinton summit in Geneva on March 26, 2000, did not achieve any progress. It showed that the main obstacles were access to Lake Tiberias, the security arrangements, and the early-warning station (Migdalovitz, 2005). Yet, Israel cannot return the Golan Heights in order not to lose its control of springs, rivers, and Lake Tiberias (Humphries, 2006).

Lake Tiberias, through the National Water Carrier System, provides about one-third of Israeli freshwater needs (Tal, 2006). The lake receives 70 % of its surface water from the northern Jordan River (Borisover et al., 2009). There are three main rivers that contribute 80 % of the annual lake recharge through the Jordan River: the Dan River supplies 250 MCM; the Banias River, which is located on the Syrian occupied land, supplies about 130 MCM; and the Hasbani River, which is located on Lebanese land, supplies about 130 MCM per year (Berman 1998).

According to Courcies et al (2005), before the 1950s Lake Tiberias together with the Yarmouk River contributed to the Jordan River flow by 605 and 465 MCM per year, respectively. However, in 1970s, after the Israeli occupation of Palestinian land and the Golan Heights and after the construction of the NWC, the picture changed completely (Table 1). Table 1 shows how the change affected the water sustainability of Lake Tiberias as well as the Jordan River flow and the Dead Sea, which at present only receives reclaimed water.

Table 1. Water balance in Lake Tiberias

	Lake Tiberias						Into the Dead Sea
Year	Inflow (MCM)		Outflow (MCM)				
	Upper Jordan	Yarmouk River	Evaporation	NWC	North Irrigation	Jordan River	
1950s	890	0	285	0	0	605	1285
1970s	505	45	285	440	100	65	505
2000s	475	65	285	440	100	35	0

5. RESULTS AND DISCUSSION FROM IWRM PERSPECTIVE

Recognizing IWRM principles while resolving water conflicts means the integration of all sectors in the negotiation process. This integration may balance interests between all parties, ensuring stakeholder participation and the use of conflict management tools in the management process. Stakeholder participation should be at all levels which may affect water management decisions. Participation means being part of the process and accepting the need for change to ensure water sustainability, peace, and other water users' rights. Managing water through an integrated approach will solve water shortage by studying the situation while taking into consideration the water supply, water demand, water allocation, water socioeconomics, and water policy. In such an integrated climate new strategies can be built and new horizons can be opened. Below follow some specific aspects of IWRM that we believe would be especially important to consider for a successful application in the studied area. IWRM has four dimensions: water resources, water users, spatial scale, and temporal scales & patterns (Savenije and Van der Zaag, 2008). The discussion below follows these four dimensions.

5.1 Water resources

The first challenge that IWRM faces is quantifying the available water resources. According to FAO the annual renewable water availability per capita in the Middle East is decreasing due to population and development growth, and the figures in 2025 will be about 60% of those in 1970 (FAO, 2010). In addition to surface and groundwater, water resources include non-conventional resources such as reclaimed, desalinated, and harvested waters. Treated wastewater is used all over the region for irrigation. Jordan plans to use reclaimed water discharged from about 36 wastewater treatment plants by 2013, 19 of them are currently working that produce about 72 MCM per year (Ammary, 2007). Syria has four plants and is planning to construct more than twenty new wastewater treatment plants. Extending the irrigation with treated wastewater could lead to significant water savings. Israel, on the other hand, produces an annual amount of about 500 MCM of wastewater, 85% of which was treated in 2008 (IWA, 2010). Greywater, which is water from showers, kitchens, and laundry, can be safely reused in agriculture. Jamrah et al. (2008) found that reusing greywater in Oman can save between 12 and 65% of the total fresh water use. Greywater can also be used for toilet flushing and save between 29 and 35% of potable water (Ghisi and Ferreira, 2007). In a study made in Sweida City, Syria, Mourad et al (2011) found that the city can save about 35% of its drinking water if treated greywater is used for toilet flushing.

Collecting and storing rainwater is generally named water harvesting. Water harvesting is a traditional method used throughout the Middle East to manage finite water supply. Indications of early water harvesting facilities constructed over 9000 years ago have been found in the Edom Mountains in southern Jordan (Nasr, 1999). Water from roofs can be stored and used in irrigation or for other uses. In Jordan, for example, a maximum of 15.5 MCM/year of rainwater can be collected from roofs of residential buildings on the assumption that all rain falling on the surfaces is collected (Abdulla and Al-Shareef, 2009). This represents about 7% (231 MCM/year) of the total groundwater shortage in Jordan (MWI-JO, 2009). Water harvesting can also be done by collecting flood and stream water within a water basin in surface dams. These dams will enhance groundwater recharge and the harvested water can be used for irrigation or drinking water. Many areas in rural Syria and Jordan already depend on these small dams for local water needs.

5.2 Water users

Water uses include: domestic, industry, agriculture, fisheries, ecosystems, hydropower, navigation, recreation, etc. For the domestic sector, the WHO minimum standard per capita water consumption is 100 Lpcd (liter per capita per day). The per capita of water consumption in the Middle East differs from country to country; it is 120 Lpcd for Syria, according to the Ministry of Housing and construction in Syria, 55 Lpcd for the Palestinian population (Abu Zahra, 2001), 190 Lpcd for Lebanon (El-Fadel, Zeinati, and Jamali, 2000), and 225 Lpcd in Israel (Portnov and Meir, 2008). Therefore, full consideration should be taken regarding water consumption for all riparian people to sustain their vital needs and to find new instruments for water demand management and water saving in order to reduce water losses within the water system and for domestic uses. Moreover, a field survey is very necessary to reflect the actual water consumption in these countries, which may indicate a vital need for increased public awareness and/or rehabilitation of water systems.

In this regard, countries can decrease domestic water consumption by introducing new water saving practices and techniques. Some water saving devices, which can be installed in water taps, can save more than 20% of the water consumed for washing and showers. Furthermore, the average toilet tank in the region is 9 LPF (liter per flush). A daily average of five flushes per person means daily consumed water in toilet flushing is equal to 45 liters per person. However, installing a dual flush toilet, for example, will reduce the flushed water to 21 liters, which means about 50% of the toilet water can be saved (VCI, 2002).

The agricultural sector is the largest consumer of water in the Middle East (Table 2). Therefore great care should be taken towards increasing irrigation efficiency and selecting crops with small consumptive use.

Table 2. Water use in some countries in the Middle East

Water use (%)	Syria	Jordan*	Lebanon**	Israel***
Agriculture	89	66	53	48
Domestic)	8	29	24	35
Industry	3	5	23	11
Other	-	-	-	6

* Ammary (2007), ** El-Fadel et al. (2000), *** Dreizin et al. (2008)

In this regard, using the virtual water concept, which is the water embedded in producing any kind of good, can help countries in saving water. Banana production in Israel, for example, consumes 1.4 kg of water per kg of banana (Pohoryles, 2000). Hence, taking into consideration that banana is not a vital crop for countries, it would be better for Israel to import banana instead of fighting its neighbors for water. Thus, countries in the region should use water to produce benefits that cannot be imported (Heinzen, 2001) and set their crop pattern according to gross profit per water use ratio. For example Jordan can save about 47 MCM/year if farmers in the Jordan Valley change from fruit trees to vegetables (Mourad, Gaese, and Jabarin. 2010). Thus, new agricultural strategies may be recommended, within regional cooperation, in order to reach higher water productivity and to suggest new allocation plans. Furthermore, the invisibility of the virtual water trade makes it extremely successful because it can be applied without political conflicts (Mourad, Gaese, and Jabarin. 2010).

5.3 Spatial scale

Although IWRM can be applied at local and national levels, it can also be applied at regional and international levels. However, the operational management inside the institutions should have interactions between all levels, which means that the lower level interests should be taken into consideration at higher levels (Savenije and Van der Zaag, 2008). Spatial scale includes the allocation of water rights as well. Zarour and Isaac (1992) proposed the following formula for the allocation of water rights in Lake Tiberias:

$$S_{(i)} = 50 * \left[\frac{B_{(i)}}{B_{(T)}} + \frac{I_{(i)} - L_{(i)}}{I_{(T)} - L_{(T)}} \right] \qquad (1)$$

where $S_{(i)}$ is the size of the right/obligation of state *i* (percent); $B_{(i)}$ is the area of the basin/storage volume within or under the territory of state *i;* $B_{(T)}$ is the total area/storage volume of the basin; $I_{(i)}$ is the natural input to the basin originating within the territories of state *i;* $I_{(T)}$ is the total input to basin *T;* $L_{(i)}$ is the natural loss from the basin's water occurring within the territories of state *i;* and $L_{(T)}$ is the total natural loss of water occurring throughout the basin.

The application of Eq. (1) needs data from and cooperation among all parties to estimate correct parameter values, otherwise this may create new disputes between the counteracting parties. $B_{(i)}$ is the most important variable that should be agreed on. Israel wanted to retain a 400 m strip on the northern shore of the lake which means Israel will continue using the lake alone. Syria, on the other hand, wants to have access to the lake. A recent suggestion is that the northeastern shoreline could be a joint tourist area for Syrians, Israelis, and other international persons, under UN security supervision (Ma'oz, 2005).

5.4 Temporal scales and patterns

Acknowledging the temporal patterns of the water resources and the users means acknowledging floods, droughts, base flow, peak demands and other vital demands. This should constitute a basis for water demand management aiming at a better allocation of water resources. Moreover, water models should be used to predict best and worst water scenarios in order to set new strategies and plans that face future water scarcity problems, which will be a base for a better management of water balance between different hydrological years and different water basins.

5.5 Application to Lake Tiberias

The IWRM approach should be based on the previous dimensions. According to international water law, riparian countries of a watercourse should include sustainability, optimal use, protection, and control of the water resources in their joint management plan (Elmusa 1996). However, reviewing Eq. (1) shows an absence of the water sustainability term in the lake. In 2000, due to the Israeli water use, Lake Tiberias water level experienced an all-time low exceeding the red danger line. Besides the lake water level, Zaslavsky (2000), for example, indicated that the Israeli water use in the region was non-sustainable. Therefore, any suggested approach should take sustainability into consideration by taking the length of the water shores, the renewable amount of water that can be used, and the catchment areas and water amounts in each country that contributes in feeding the lake into account.

Therefore, the IWRM approach will include many tasks, starting from the implementation of the United Nations resolutions, saving water to ensure its sustainability, concentrating on water productivity to get the optimal use regimes, and protecting water resources from environmental impact. The application of such approach needs full cooperation instead of confrontation between riparian countries at scientific and political levels. In such cooperative plan, basis for sustainable peace will be built. The following points can be a basis for an IWRM approach:

1- Implementation of the United Nations resolutions: As illustrated before, Syria would have the right to reach the Lake Tiberias shore through the implementation of the Resolutions 242 and 338, which is the first step towards any peace agreement.

2- Allocation of Lake Tiberias water: Knowing that the total surface area of the lake is about A = 167 km^2 and the total circumference of the lake is about C = 53 km, the surface area of the lake that can be used by Syria A_S and Israel A_I, for fishing and swimming, depending on the regional circumference of the lake C_S and C_I , can be computed by:

$$A_{S,I} = A \times (Cs,i/C) \qquad (2)$$

For the discharged water, the Syrian and the Israeli share depends on the total catchment area, which is about 2730 km^2 (ME-WDBP, 1998), and the feeding water amounts in each country, which means the higher the feeding amounts the higher the discharge rate, taking water sustainability into account. The average lake level is 210.4 m below sea level with an average range of about 1.3 m (ME-WDBP, 1998). Therefore, for lake sustainability, it is advised to maintain this range. From Berman (1998), we can roughly estimate the Syrian share to be at least 20% of the total water discharge from the lake. The location of the intake and the exact amount need more study and can be agreed on within a positive atmosphere.

3- Joint management plan: Creation of a joint management plan based on the participation of all sectors that deal with water at all levels. The negotiation within the plan should be interest-based and the main target of the plan could be water for peace. The following constitute a suggested line of action:

a. Protecting Lake Tiberias from negative environmental impact by formulating a joint environmental protection plan in order to suggest parameters for the determination of water quality in the lake and to set water quality monitoring systems at the main inflow points. A regional water policy for Lake Tiberias catchment can help in the protection of water quantity and quality in the lake for better water management that can be enhanced by all stakeholders from Syria, Lebanon, Jordan, and Israel.

b. Proposing a greywater, water harvesting, and/or water saving devices project for four villages from Syria, Jordan, Lebanon, and Israel. The main objectives of the project would be to save domestic water by reusing greywater and harvested water in toilet flushing and in garden irrigation, and to estimate the potential savings from the implementation of water saving devices. Such projects could be funded by international organizations as it focuses on water for peace.

c. Analyzing the agricultural status in both countries trying to isolate wasteful crops by introducing the virtual water and water productivity concepts in future agricultural plans without ignoring food security issues.

d. Merging water, energy, and economic issues. A feasibility study is needed to compare pumping water from Lake Tiberias, taking the distance and the elevation 210 m below sea level into account, with a seawater desalination plant. Construction of a desalination plant would decrease water needs in the area.

e. Taking local needs, priorities, and sustainability issues into account while planning any policy or project by enhancing the participatory approach.

4- Regional environmental plan that contains all stakeholders in the region aiming at maintaining the Jordan River, of which the flow at present is almost non-existent.

With such an approach Middle Eastern countries will have a new target to focus on instead of gunfire. New projects can be implemented and new targets can be achieved, which can create a new future for the region at national, regional, and international levels.

6. CONCLUSION

Based on the foregoing, gunfire cannot provide drinking water to thirsty people, nor can it solve the present water crisis in the Middle East. Money that is used for arming the region can be used for improving the regional situation. Therefore, policy makers may think of reforming their policies depending on the real situation. What is needed is a new emphasis on cooperation for the establishment of a regional water policy, to advocate cooperation instead of confrontation, and integration instead of fragmentation, which cannot be achieved before reaching a complete and comprehensive peace based on the United Nations resolutions.

The historical records about the international borders between Syria and Israel show that Syria has the right to use Lake Tiberias. However, the size of this right and the purposes of its exercise should be agreed on within a framework under United Nations supervision and a positive negotiation atmosphere. Construction of a sew water desalination plant may decrease the area’s water stress and may also improve the environmental characteristics of the Jordan basin. A fruitful interest-based negotiation process aimed at solving the actual water problems in the region can be the base for water sustainability and peace in the region.

Integrated water resources management is an approach to solve the water shortage in the Middle East by engaging in the participatory approach, acknowledging the environmental characteristics of the region, and recognizing water best practices in irrigation and in potable water conservation. The integration of sectors and stakeholders at a regional level should be based on cooperation and transparency. The cooperation should be built on a scientific basis in order to save water by carrying out water and agricultural research that focuses on virtual water, reclaimed water, water saving techniques, and new water allocation strategies aimed at saving water resources at the regional level to form the basis for a joint management plan. In such a cooperative plan, withdrawing to the 4th June 1967 border line will create new future for the region. It will direct all efforts towards a sustainable peace.

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Paper IX

Assessment of future Syrian water resources supply and demand by WEAP model

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Abstract Water availability is one of the most important factors for economic development in the Middle East. The Water Evaluation and Planning (WEAP) model was used to assess present and future water demand and supply in Syria until 2050. Nonconventional water resources, climate change, development, industrial growth, regional cooperation, and the implementation of new water saving techniques were considered important factors to include in the analysis using the WEAP model. Six scenarios were evaluated depending on the actual situation, climate change, the best available technology, advanced technology, regional cooperation, and regional conflict. The results showed a vital need for new water resources to balance the unmet water demands. Climate change will have a major effect on the Syrian water resources; possible regional conflict will also affect water balance to a major extent. However, regional cooperation and use of the best available technology can help in minimizing the gap between supply and demand.

Key words demand; supply; nonconventional water; climate change; Syria

1 INTRODUCTION

Balancing water supply and needs in arid and semiarid areas will be a great challenge over the coming decades. The Middle East is one of the world´s most water-challenged areas with possible future conflicts over shared water resources (e.g., Falkenmark 1989; Starr and Stoll 1988). Like most countries in the Middle East, Syria is confronted with severe water problems due to both climatic conditions and socioeconomic factors. The region is characterized by a fast growing population, which has resulted in a sharp decline of the per capita water availability. Under these conditions water is the prime factor in maintaining a sustainable environment and even more importantly economic development.

Agriculture is the largest consumer of water resources with a strong trend towards developing irrigation. Linked to these forecasts of water scarcity are growing estimates of food dependence. Cereal imports, which represented 33% of needs in 1995, may increase by 50% by 2025 (FAO 2008). Another future change is expected due to climate change (e.g., Arnell 1999). Climate change will reduce Syrian water resources by some 1300 MCM (million cubic meters) by 2050 (Mourad & Berndtsson 2011). Several studies have been made at a country level regarding available future water supply and demand in Syria. Far fewer studies have been made at a sub-country level. Even if a country displays a balance between supply and demand at the country level great imbalances may appear at sub-country levels that need to be addressed.

The recently developed WEAP model, which is is an initiative of the Stockholm Environment Institute, provides a framework for water assessment and planning and can be used to represent current and future water conditions in a given area depending on key assumptions (Lévite et al. 2003). The model can also be used to explore a wide range of demand and supply options for balancing the environment and development (SEI 2011). In addition, WEAP can be used as an integrated decision support system (DSS) that helps policy makers and other stakeholders in their water plans in water resources, wastewater, and simulation between alternatives (e.g., Assaf and Saadeh 2008; McKinney 2004; Qin 2011). WEAP can also be used to create water scenarios to be used by other models such as MONERIS and QUAL2K (Gaiser et al. 2008). Thus, the model may help in the assessment of water uses, reallocations among sectors, assessing upstream-downstream links, and testing options for matching water supply and water demand (e.g., George et al. 2011; Hoff et al. 2007). Hoff et al. (2011) developed a water resources tool for the Jordan River basin using WEAP, which indicated that climate and socio-economic change are both key drivers of future water scarcity in the basin. Droubi et al. (2008) studied the groundwater balance in Zabadani Basin in Syria using the WEAP model together with MODFLOW. However, to the authors´ knowledge WEAP has not been used before to assess the overall water status in the Syrian basins.

The main objective of this study was to assess the impacts of future climate change and water demand on future water supply within the

Syrian water basins. There is a large climatic difference between the coastal and inland basins in Syria. Even if there were a balance between demand and supply at the Syrian country level, WEAP would be able to indicate if some basins would need re-allocation of water between the basins of contrasting climate.

2 METHODS AND DATA

Syria has a population of 21 million on an area of 185,180 km^2 (including the occupied lands). The country has a complex water situation. The country includes seven water catchments: Barada & Awaj (BAB), Al-Yarmouk (YB), Orontes (OB), Dajleh & Khabour (DKB), Euphrates & Aleppo (EAB), Desert (DB), and the Coast basin (CB), each of which has its own characteristics (Fig. 1). Most of these basins are shared with other countries. Each basin has surface and groundwater resources. Surface waters include 21 main rivers, 12 of which are shared with other countries in the region and some of which are just seasonal streams, eight main lakes, and 150 surface dams. Syrian groundwater includes about 140 springs. At present, some of these springs are not giving any water due to prolonged drought. More than 40% of the springs have an average quantity of less than 15 L/s. Syria has more than 200,000 wells, about 50% of which are illegal wells. Therefore, any estimation of actually pumped groundwater will contain some errors and uncertainties (MoI-SYR 2012).

The WEAP model was used to consolidate all needed data in order to simulate current and future water status in the Syrian water basins. Water resources and demands data were obtained from a variety of sources. For water supply, we used all available data on surface water and groundwater from the Ministry of Irrigation (MoI-SYR 2012) and the Central Bureau of Statistics in Syria (CBS-SYR 2012). For water demand, most data were taken from the Ministry General Commission for Scientific Agricultural Research (GCSAR 2011) and the Ministry of Agriculture and Agrarian Reform (MAAR-SYR 2012). Due to the large number of reservoirs, rivers, springs, and wells within the Syrian water basins, surface water, groundwater, and net evaporation were taken as an average number for each basin. Moreover, due to the difficulty in accessing data during this period, 2008 was used as a basis for comparison with future estimates.

The WEAP model for Syria was run at an annual time step, so that all input data, including surface and groundwater inflows and water demands, were aggregated to annual values. In addition to these data, WEAP depends on key assumptions to build future scenarios. The first key assumption was the population growth. The highest population growth of 2.9% occurs in EAB, where important economic development and agriculture projects are taking place. CB, on the other hand, has the lowest population growth of 1.5% (Mourad and Berndtsson 2012). Furthermore, according to CBS, there was a decrease in the average population growth from 3.05% in 1965 to about 2.3 in 2010 (CBS-SY 2011). Accordingly, population increase will not be the same at spatial and temporal scales.

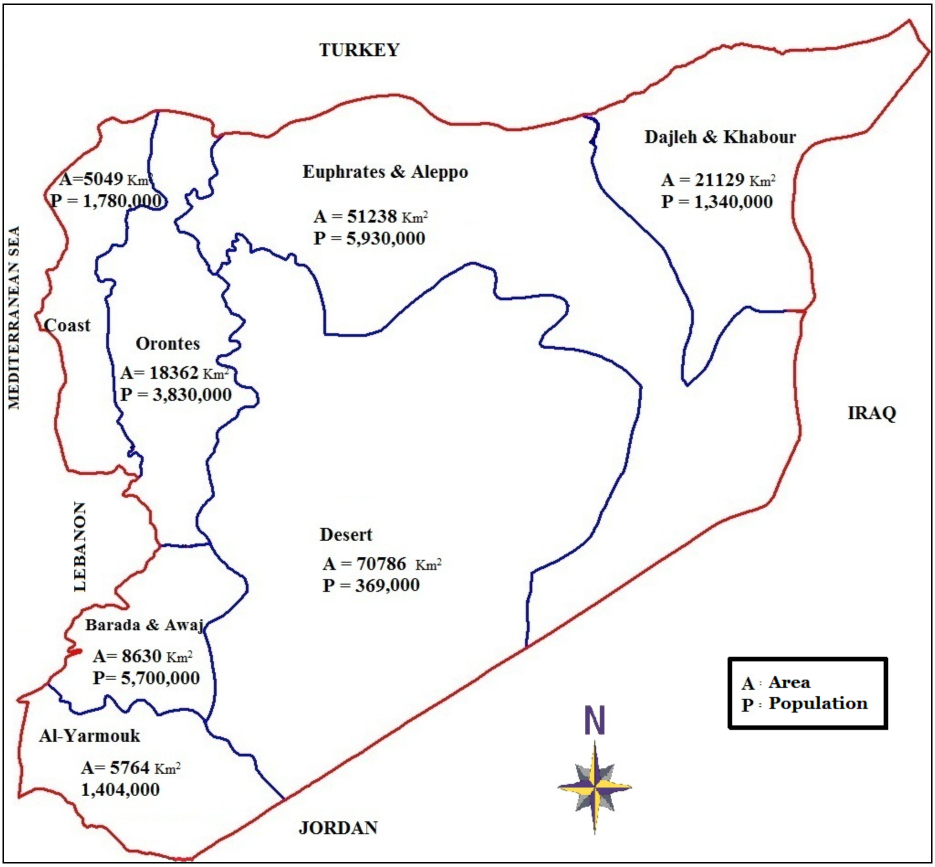

Fig. 1 Syrian water basins,

The second key assumption was the industrial growth. According to CBS the industrial development increased from about 30000 in 1970 to about 100000 in 2010, which gives an average annual industrial increase of about 2%. This was assumed to increase industrial water consumption by the same percentage (Mourad and Berndtsson 2011).

The following six scenarios were simulated in the WEAP model.

(1) Reference Scenario (RF). The water demand was assumed to continue increasing according to the population and industrial growth and the water irrigation techniques were assumed not to change substantially up to 2050, which means there are no new developments or improvements regarding sanitation, drinking water, or irrigation systems.

(2) Climate change scenario (CC). The Middle East is likely to face a decrease in precipitation amount by 20-25%, which will reduce the runoff by about 23%, and the Euphrates River flow may be reduced by 30-70%. The Middle East average temperature may increase by about 2.5°C to 2050, which will affect evaporated water amounts (Trondalen 2009; Breisinger et al. 2011). Evans (2010) found that climate change is likely to increase precipitation from southeastern Syria, toward the mountains and the Mediterranean Sea. Global Climate Models (GCMs), however, indicate that precipitation may decrease over the Eastern Mediterranean, Turkey, Syria, Northern Iraq, and Northeastern Iran. Moreover, according to Waimi (2010), who studied climate change in the Middle East and North Africa (MENA), Syria is located in the Asian Mashrek region, which may have an annual temperature increase of about 0.05°C, while the precipitation has a negative slope in the annual rainfall trend with an average value of -1.50 mm/year. Accordingly and as the average rainfall in Syria is about 46000 MCM (Mourad and Berndtsson 2012), the annual rainfall decrease will be about 0.5 %. Due to this and the fact that more than 50% of the Syrian water resources are transboundary resources, the annual water resources are assumed to decrease by about 0.25%, while annual evaporation rates will increase by about 0.25%.

(3) Best available technology scenario (BAT). This scenario depends on using the best available technologies by the implementation of modern irrigation systems and using closed water cycles in industry. For the future domestic demand projections, we assumed, due to the expected improvement in the drinking water systems, that the domestic consumption will be 125 Lpcd (liter per capita per day) in 2050, which means that the annual daily per capita domestic water demand will be reduced by about 40% in 2050 as shown in Fig. 2. Furthermore, we assumed that due to water shortage and urban development, the cultivated land will be constant and the implementation of modern irrigation practices will save about 10% of the consumed water in agriculture in each basin by 2050.

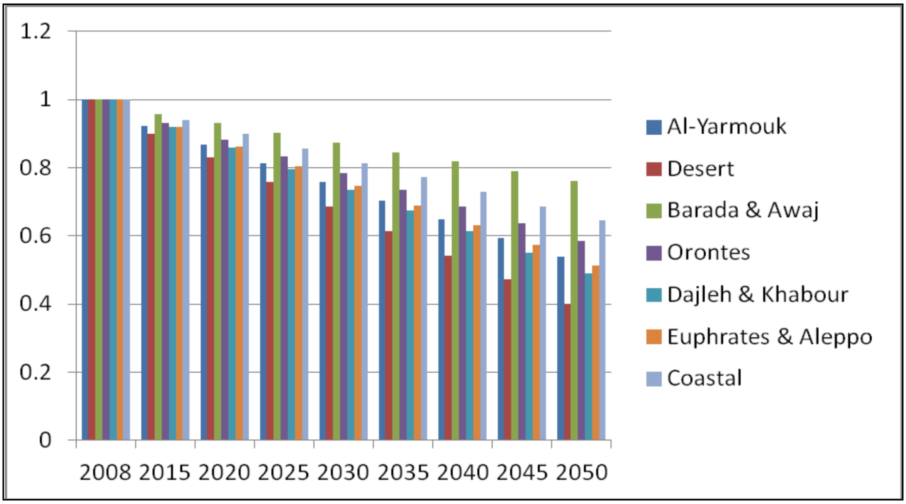

Fig. 2 The reduction in the daily domestic water demand in Syria.

(4) High Tech Scenario (HT). This scenario is based on the BAT scenario, however, it also includes high tech implementation, which depends on cloud seedings, rain water harvesting and greywater reuse in toilet flushing. We assumed that cloud seeding will increase the preciptation by about 10%, rainwater harvesting may save another 1.5% of the annual rainfall by 2050. For greywater reuse and according to Mourad et al. (2011), Syria can save up to 35% of its drinking water by using greywater in toilet flushing.

(5) Regional Cooperation Scenario (RC). This scenario assumes that a peace agreement between Syria and Israel, which acknowledges the Syrian water rights from Lake Tiberius & Golan Heights, will be achieved. This agreement may increase surface and groundwater in YB and BAB by about 500 MCM/year. Another agreement with Turkey may increase the pumped water from the Tigris by about 500 MCM/year. Both agreements are expected to occur by 2015.

(6) Conflicts Scenario (CO). In contrast with the previous scenario, any conflict with Turkey may affect the water agreements between Syria and its neighbours. According to the current agreement between Syria, Turkey, and Iraq, Syria receives 500 m^3/s from Euphrates River, 58% of which should be released to Iraq (MoI 2012). In this scenario we assumed that, due to conflicts, Turkey will reduce this amount to 250 m^3/s in 2015. The new key assumption here will be the reduction of surface water flow from the Euphrates by 50%.

3 RESULTS AND DISCUSSION

3.1 Population growth

The expected population increase after 2008 is shown in Fig. 3. The figure indicates that the population in EAB will be 90% larger in 2050. The population in CB in 2050 will be 50% larger as compared to 2008.

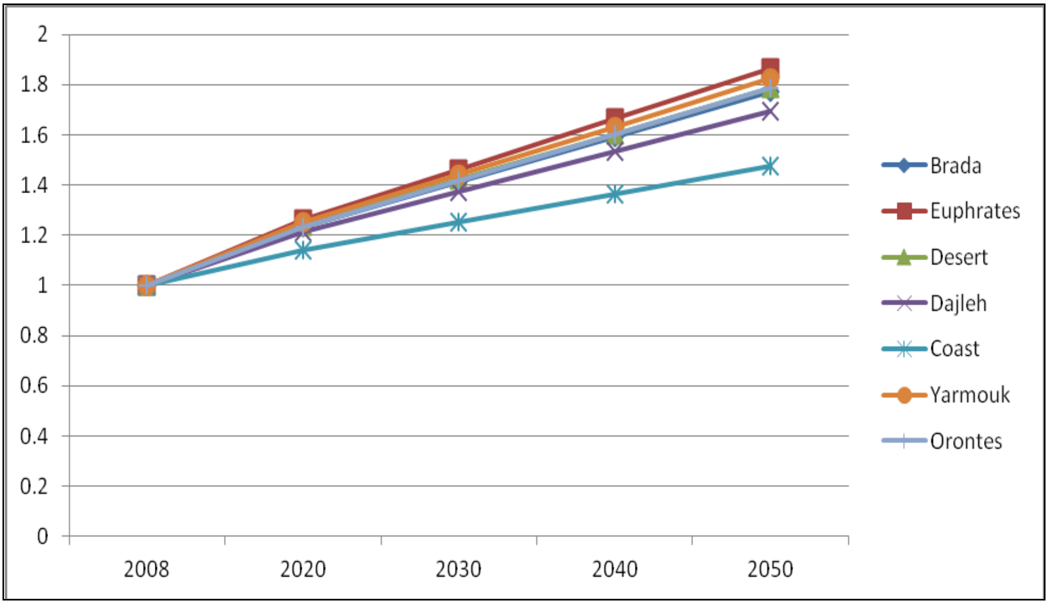

Fig. 3 Population increase in the Syrian water basin.

3.2 Water resources

According to the above methodology, the model results indicate a big gap between supply and demand. The annual unmet demands are, e.g., groundwater representing about 2000 MCM.

Surface water and groundwater resources in all basins are fixed in the RF, BAT, and HT scenarios. However, they are assumed to change in the RC, CO, and CC scenarios. Nonconventional water resources, on the other hand, such as reclaimed water and rainwater harvesting depend on the respective scenario. Table 1 shows surface water and groundwater projections in 2050 in each basin according to the six scenarios. It shows that the RC scenario is very needed in the BAB, YB, and DKB basins. On the other hand, the CO and CC scenarios have a vital impact on EAB basin

Table 1 Surface and groundwater projections in 2050 in MCM.

Basin	WEAP Scenarios			
	RF, BAT & HT	RC	CO	CC

BAB	507	652	507	454
YB	206	444	206	184
OB	1694	1694	1694	1517
DKB	5457	5958	5457	4891
EAB	8272	8272	4961	7392
DB	171	171	171	153
CB	1200	1200	1200	1074

3.3 Water demand

Depending on each scenario, each water demand sector will be different. The total demand is the same in the BAT, RC, CC, and CO scenarios. However, it is more in the RF scenario and less in the HT scenario. Table 2 presents water demand projections in 2050 for each basin according to the six scenarios, which presents the HT scenario as the best for reducing water demands in all basins.

Table 2 water demands projections in 2050 in MCM.

Basin	WEAP Scenarios		
	RF	BAT, RC, CO & CC	HT
BAB	1342	1128	989
YB	479	359	324
OB	3158	2718	2625
DKB	4902	4326	4295
EAB	8258	7085	6935
DB	6205	5549	5540
CB	949	830	794

3.4 Unmet demands in Syria

Taking Syria as a one unit and according to the reference scenario, the unmet demands may exceed 3500 MCM in 2050 (Fig. 4), which reflects the need to develop new technologies, new cooperation, or better water management plans to reduce this shortage. However, the implementation of the BAT scenario will reduce this shortage by about 50%, in spite of the population and industrial growth, through the improvement of drinking water systems and the implementation of modern irrigation systems (Table 3).

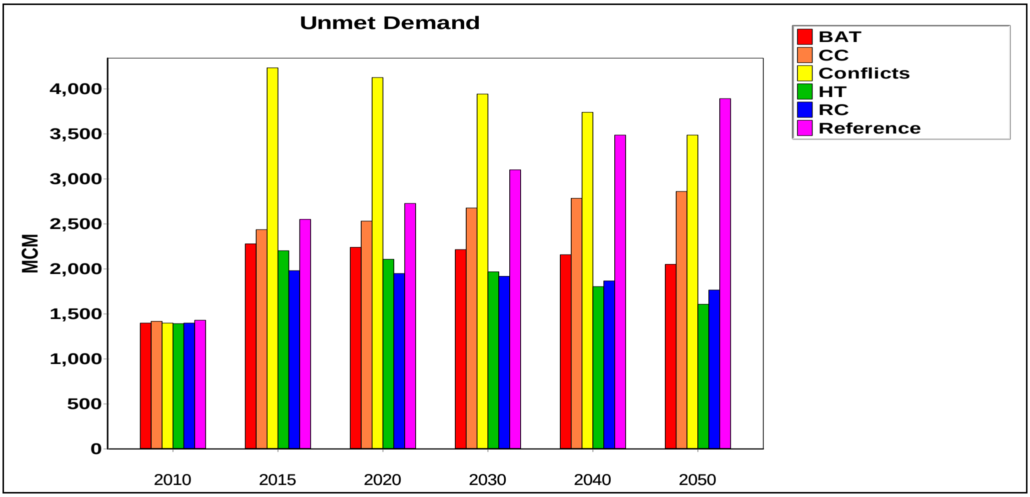

Fig. 4 Unmet demand in Syria.

Table 3 Total domestic and agricultural water saving by the BAT scenario.

Basin	Water demands 2008 (MCM)		Water demands 2050 (MCM)		Saved water (MCM)	
	Domestic	Agriculture	Domestic	Agriculture	Domestic	Agriculture
BAB	340	675	460	608	-120	67
YB	118	205	117	185	1	20
OB	298	2195	311	1976	-23	219
BKB	126	4667	105	4202	21	465
EAB	526	7003	504	6303	22	700
DB	42	118	30	106	12	12
CB	126	530	122	477	4	53

For the HT scenario, model results showed that Syria can save more than 600 MCM/year by rainwater harvesting (Table 4).

Table 4 Total rainwater saving in each catchment.

Basin	BAB	YB	OB	DKB	EAB	DB	CB
Rainfall MCM	2373	1833	7620	5895	11119	9981	5791
Harvested rainfall MCM	36	27	114	88	167	150	87

Therefore, the BAT scenario was assumed to be the base for the other four scenarios. Accordingly, the HT and RC scenarios can minimize the problem. However the conflicts scenario will certainly enlarge it. As we categorize drinking water to be a first priority, the unmet demand will mainly affect the agricultural sector. However, illegal wells may cover this unmet demand. On the other hand, this consumes non-renewable water. The effect of climate change is less than the conflicts and reference scenarios, which means that water resources can be adapted to climate change by proper water saving techniques. This indicates that cooperating through transboundary water cooperation may well be a climate change adaptation strategy.

3.5 Unmet demands in each water basin

In order to have a better view for water situation in Syria, each basin was studied and assessed separately by WEAP and the results of these assessments are shown below:

(1) Barada & Awaj basin: the unmet demand starts from about 335 MCM and can be reduced up to 300 MCM by the HT or RC scenario. Moreover, the CC scenario may increase the unmet demand up to 630 MCM in 2050 (Table 5).

Table 5 Unmet demand in Barada & Awaj Basin.

Scenario	Unmet demand (MCM)		
	2008	2020	2050
BAT	335	379	439

CC	335	423	632
Conflicts	335	379	439
HT	335	358	306
RC	335	234	294
Reference	335	422	628

(2) Al-Yarmouk basin: the unmet demand will not be affected by the conflicts scenario, however, the RC may balance water needs. The CC may increase unmet demand by 20 MCM, as compared to the BAT scenario.

(3) Orontes basin: the implementation of all scenarios will not balance water shortage here. However, transferring water from a nearby basin can help. The unmet demand will start from about 800 MCM and can be reduced to about 700 and 600 MCM by the implementation of the BAT and the HT scenarios, respectively.

(4) Dajleh & Khabour basin: the use of illegal wells could balance water needs until 2015. However, the unmet demand will increase and it may reach 450 MCM due to climate change. The BAT, HT, and RC scenarios may reduce this shortage to around 300 MCM in 2050 (Fig. 5).

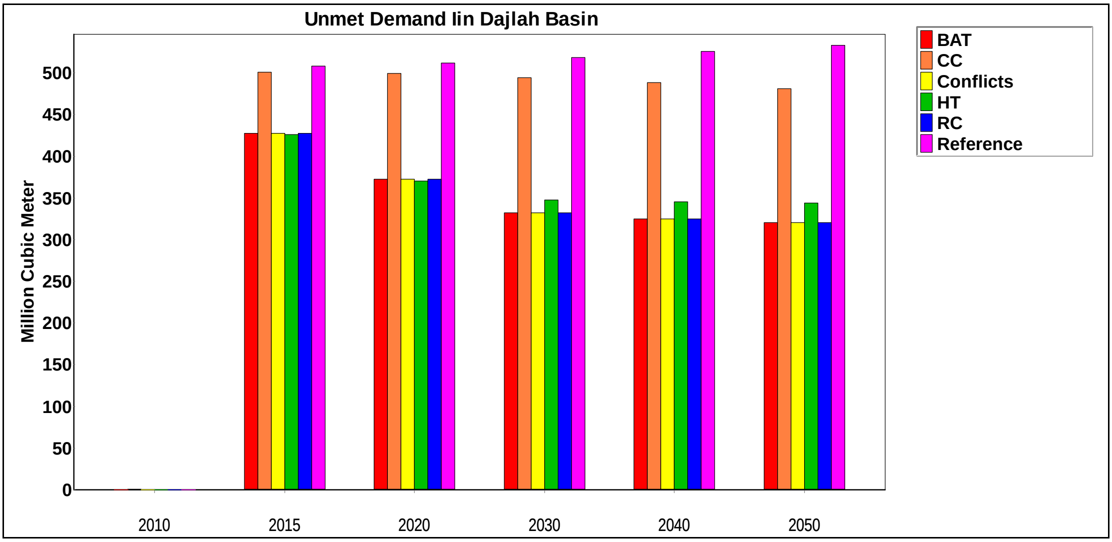

Fig. 5 Unmet demand in Dajleh & Khabour basin.

(5) Euphrates & Aleppo basin: there is no significant unmet demand in the first five scenarios. It is about 300 MCM in 2050. However, the conflict scenario will affect the agricultural sector, which may increase the unmet demand to around 1800 MCM (Fig. 6).

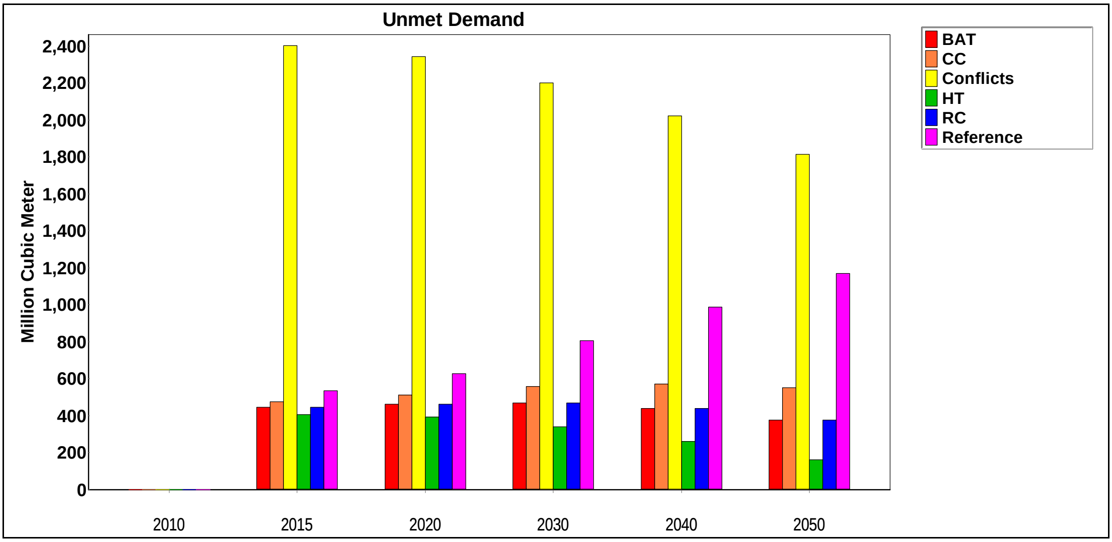

Fig. 6 Unmet demand in Euphrates & Aleppo basin.

(6) Desert basin: starting from 2015, this basin has a water shortage problem by about 400 MCM. However, the implementation of the BAT scenario will reduce this unmet demand to about 300 MCM in 2050.

(7) Coastal basin: according to all scenarios, the coastal basin will not face any kind of water shortage until 2050. Moreover, the coastal basin is the only basin that can keep storage of about 200 and 11 MCM of surface and groundwater, respectively. This will provide an opportunity to transfer 200 MCM of water from the coast to the Orontes basin.

4 CONCLUSIONS

The WEAP model was used to assess future water supply and demand in Syria. Six scenarios were represented, namely, the Reference, BAT, CC, Conflict, HT, and RC scenarios. None of these scenarios will solve the overall water shortage in the country as a whole. However, some scenarios could solve water problems in some catchments. The best solution was seen to be a combination of the RC with the BAT and HT scenarios, which could reduce the unmet demand to about 1000 MCM in 2050. Accordingly, being able to cooperate can reduce water stress significantly up to 2050. Acknowledging Syrian rights to Golan Heights water can cover water needs in the Al-Yarmouk basin and can reduce water shortage in Barada & Awaj by about 40 MCM. Regarding climate, the results showed that climate change may reduce the inflow from the Euphrates, Tigris, and Orontes by 695, 132, and 34 MCM respectively in 2050. Other water resources will be also affected due to reduced rainfall and increasing evaporation. The predicted amount is about 700 MCM in 2050.

Finally, WEAP is a powerful tool that can assess, and manage water status in a water basin. Therefore, knowing that agriculture consumes about 89% of the Syrian water, more detailed analysis about agriculture water and changing crop patterns for each catchment using WEAP will be the next approach to tackle water shortage in Syria.

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