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

Air, Soil and Water Research 2011:4 93–100

doi: 10.4137/ASWR.S8076

This article is available from http://www.la-press.com.

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

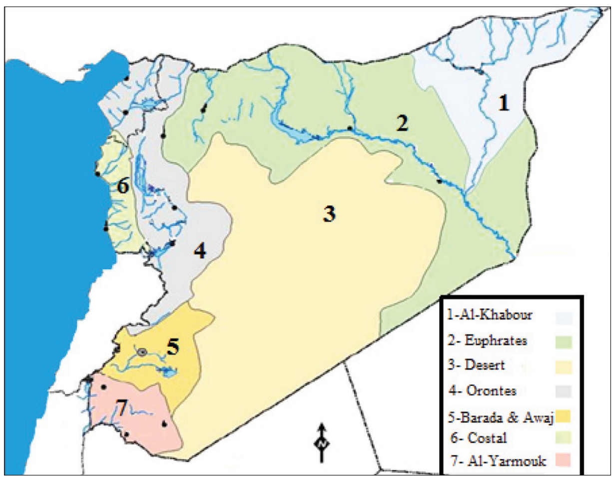

Figure 1. Hydrological basins in Syria.

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:

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

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%.

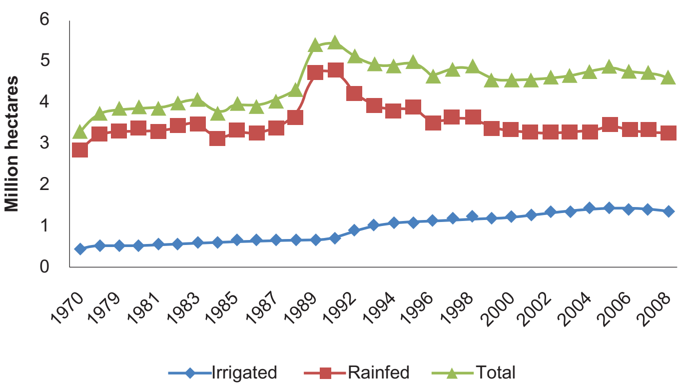

Figure 2. Cultivated lands in Syria (1970–2008; after[17]).

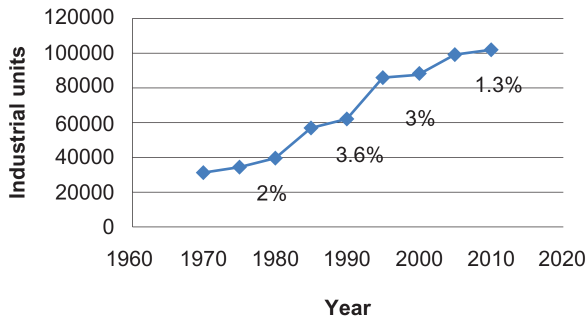

Figure 3. Industrial project increase in Syria (after[11]).

- 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

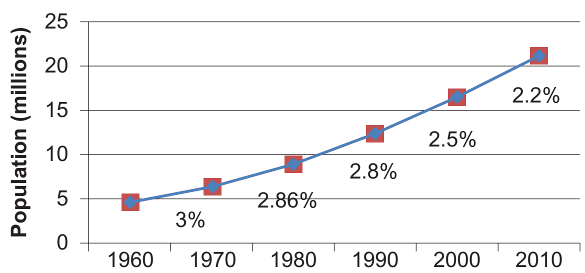

Figure 4. Population increase in Syria.

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]

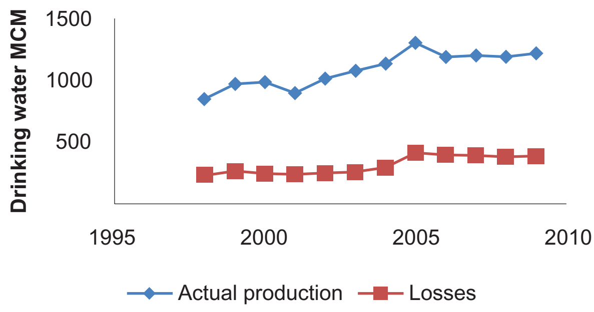

Figure 5. Drinking water actual production and losses.

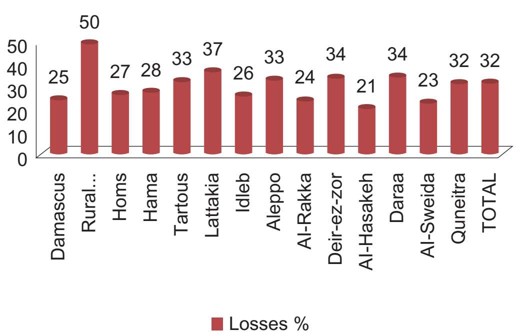

Figure 6. Water losses in 2009 in the Syrian governorates (after[19]).

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.

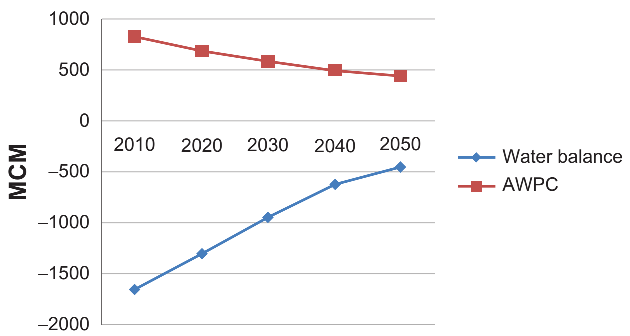

Figure 7. Water balance and AWPC.

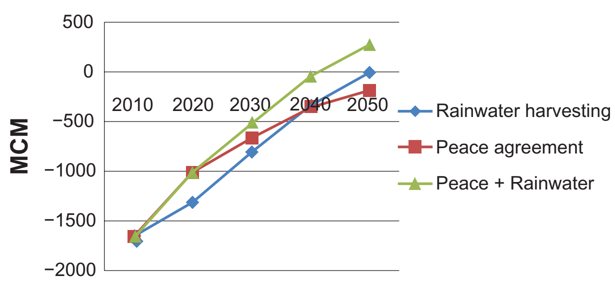

Figure 8. Scenarios for a better water future in Syria.

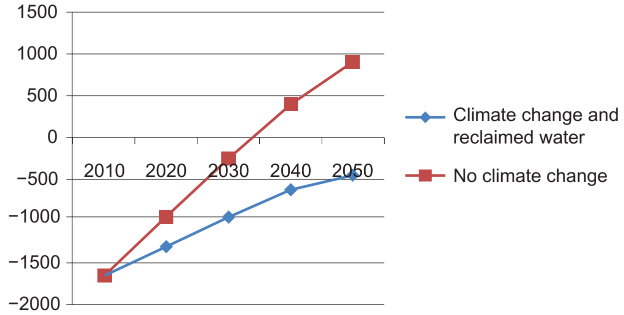

Figure 9. Water projections depending on climate change and reclaimed water impacts.

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.

Acknowledgments

Funding from the European Union Erasmus exchange program and the MECW project at the Center for Middle Eastern Studies, Lund University, is gratefully acknowledged.

Disclosures

Author(s) have provided signed confirmations to the publisher of their compliance with all applicable legal and ethical obligations in respect to declaration of conflicts of interest, funding, authorship and contributorship, and compliance with ethical requirements in respect to treatment of human and animal test subjects. If this article contains identifiable human subject(s) author(s) were required to supply signed patient consent prior to publication. Author(s) have confirmed that the published article is unique and not under consideration nor published by any other publication and that they have consent to reproduce any copyrighted material. The peer reviewers declared no conflicts of interest.

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