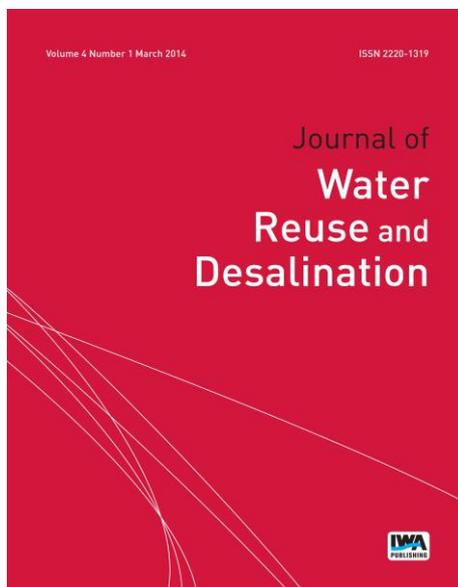


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Evaluation of water demand and supply in the south of Iraq

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ABSTRACT

This paper presents results from the first study that focuses on water resources availability and demand for different purposes in the four oil-rich provinces of southern Iraq. The region accounts for 23% of the surface area and 18% of the country's population, but holds 88% of its oil. A water shortage of 430 Mm³/year for 2010 is estimated for this region where irrigation accounts for 81% of the total water demand. Dhi Qar is the largest agricultural producer and water consumer while Al Basrah and Al Muthanna have the largest water shortages among the four provinces. The interrelationship of energy–water production and utilization is discussed and the annual water balance for irrigation, industrial, domestic and livestock usage in the different provinces determined. On this basis recommendations are made for treating and utilizing the steadily increasing amounts of water produced from the oilfields to supplement the other sustainable water resources in that region.

Key words | Iraq, produced water, sustainable water supply, water demand, water shortage

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INTRODUCTION

Water self-sufficiency is essential to ensure food security and so it is one of the most important pillars for a developed and sustainable economy anywhere in the world. This is especially true in arid and semi-arid regions that are strongly dependent on water resources controlled from beyond their international borders, which is the case in Iraq.

Since ancient times the main water supply in Iraq has been provided by the rivers Tigris and Euphrates. These two rivers gave Iraq the Greek name Mesopotamia (the land between two rivers). The headwaters of the River Tigris and River Euphrates are in the Turkish mountains meeting in the Shatt-el-Arab River at the southern tip of Iraq, before finally discharging into the Arabian (Persian) Gulf. About 98% of the water consumption in Iraq is dependent on these two rivers and their branches (Al Bomola 2011).

Recently, Iraq has passed through exceptionally long, dry and warm seasons with frequent dust storms and the

lowest river levels in centuries. Water inflow and quality, monitored through 2014, have significantly reduced and salinity in Shatt-el-Arab River has deteriorated to alarming levels (Abdullah *et al.* 2015). Several studies have discussed in detail the causes and the size of major upstream developments along the Tigris and Euphrates leading to the present situation (Olcay Ünver 1997; Yuksel 2006; Tilmant *et al.* 2007; Jones *et al.* 2008; Shamout & Lahn 2015). Other causes include poor water management and global warming. Intrusion from the Arabian (Persian) Gulf has increased the salt content of the rivers and groundwater and brought unprecedented water crises deep into the southern region of Iraq. In this paper we will quantify the shortages by analyzing the water supply and demand in the south of Iraq focusing on the existing water resources and outlook for potential water sources and use.

The southern region of Iraq comprises four provinces: Al Basrah, Al Muthanna, Dhi Qar, and Maysan (Figure 1). These four provinces cover 23% of the total area of the country, provide homes for 18% of Iraq's population (i.e. 5.7 million inhabitants) while holding over 80% of Iraq's petroleum wealth (Ministry of Oil 2013). Al Basrah, with its harbor on the Arabian Gulf and its oil fields, is on the verge of becoming an international hub of industrial, agricultural, transport, construction and commercial activities. With this comes the need for alternative fresh water supply in large quantities in an area that is confronted with significant and persistent decline in water quantity and quality. This situation will become worse following an anticipated threefold increase in oil production by the end of this decade, rapid industrialization, and growth in irrigation to secure economic development and food supply for a rapidly growing population demanding a better quality of life.

The main objective of this study is to assert the best estimates for water demand and supply in the south of Iraq for various purposes at present and in the future. We argue here that the current supply and demand can be partially balanced in that region by available strategic water resources that are not yet utilized and through rational use of water from recycling/treatment of these unexploited water resources, especially produced water (PW). We justify this by showing that the region has a large footprint from the demand side, with so far only a single source from the supply side, and that supplying sufficient quantity and quality of PW is a good and a manageable option. This is shown by calculating demand and supply for irrigation, industry, domestic and livestock purposes to determine the water balance and water shortages, based on information from the scientific literature, data from international and national organizations and institutes, and sometimes local information sources. This is the first study that quantifies the water demand and supply for the south of Iraq and proposes possible solutions to the increasing water scarcity in the region.

DATA AND METHODS

Water demand and supply were estimated for 2010 as the baseline for the calculations. To determine the water

needed for irrigation in south Iraq, we first need to specify the most important crops (we only considered the crops with production of more than 1,000 tons/year) that are cultivated there. For this, we rely on governmental data which are accessible from the Central Organization of Statistics and Information Technology (COSIT). The main crops in the south of Iraq in 2010 were (in descending order of production in ton/year): tomato, wheat, alfalfa, barley, date, okra, sugarcane, maize, lettuce, green beans, eggplant, onion, garlic, rice, turnip, carrot. These crops represent 99.9% of the total crops produced in the south of Iraq. Mekonnen & Hoekstra (2011) calculated the blue water footprint (BWF, which is defined by Hoekstra *et al.* (2011) as the use of blue water resources – surface and groundwater – along the supply chain of a product) for the various crops at national and subnational levels for the period from 1996 to 2005. We used the BWF data of the Iraqi provinces to estimate the irrigation water needed in the south of Iraq for the crops produced in 2010. To estimate the water demand for irrigation, we divided the BWF by the irrigation efficiency (the fraction of water diverted from the water source that is actually available for crop evapotranspiration) of Iraq which was obtained from Rohwer *et al.* (2007). Since there are no BWF data available for dates, sugarcane and alfalfa for Iraq, we used the standard estimates of Bhat *et al.* (2012) and Morton (1987) for dates and Brouwer & Heibloem (1986) for sugarcane and alfalfa to calculate irrigation water needs.

To determine the water demand for industrial purposes, we first identified the industrial plants for the four provinces in the south of Iraq. We used the official data (which are published on the websites of the Iraqi Ministry of Industry and Minerals and its directorates) for the production of the various industrial plants. Information about oil production from the southern oil fields was obtained from the South Oil Company (SOC) and Maysan Oil Company (MOC) official websites. Water consumption estimates have been made based on the standard estimates from various sources (Otts 1963; Walling & Otts 1967; Goldstein & Smith 2002; European Commission 2010; IEA 2012); for the petrochemical industries data was taken from MoEnv & MoInd (2008).

The amount of water supplied in the south of Iraq for domestic purposes was obtained from COSIT. The domestic water demands were calculated based on the Iraq standard



Figure 1 | Map of Iraq showing the four southern provinces comprising the study area of this paper (FAO 2009).

for daily consumption of domestic water, which is 392 L/day per capita (UN 2013).

Detailed data for the various species of livestock in Iraq are available from COSIT for 2008 for all 18 Iraqi provinces. Although we considered 2010 as a baseline for our estimations, we used the provincial proportion of livestock from the COSIT data for 2008 and the overall FAO (2010) data to estimate the livestock for the southern province in Iraq. Water consumption data – both drinking and servicing – per animal were obtained from Chapagain & Hoekstra (2003).

Information on water supply was obtained from the water resources authorities in the relevant provinces (Al Muthanna Governorate 2010; Shafaaq News 2010; Al Nasiriya 2012; IMN 2013). Part of the total run-off of a river (the so-called environmental flow) should be kept to sustain freshwater and estuarine ecosystems. Smakhtin et al. (2004) estimated the environmental flow requirements for the rivers Tigris and Euphrates at 26% of the total run-off. Thus, the utilizable water is calculated as the total run-off of the river in a province minus the environmental water requirements. We estimated water demands in Iraq for the period 2005–2020 based on FAO data for the period 1990–2000 using linear extrapolation. Water availability information for the period 1990–2020 was obtained from Tolba & Saab (2008).

Water demand

Irrigation

Agriculture is a primary reason for water stress across the entire Arab region in general and in Iraq in particular (WWAP 2012). Water needs for growing crops depend mainly on crop type and climate conditions. Such water can be supplied to the crops by rainfall, irrigation, or a combination of the two. Water supply for agriculture in the south of Iraq relies mainly on surface water. Figure 2 shows the distribution of water resources for agricultural water demand. It shows that surface water provides about 85% of the water consumption by agriculture. Moreover, rainfall is not reliable for irrigation, since the majority of the country is arid or semi-arid. Precipitation in the south of Iraq is in the order of just 100–200 mm per annum, and is also highly irregular (UNEP 2007).

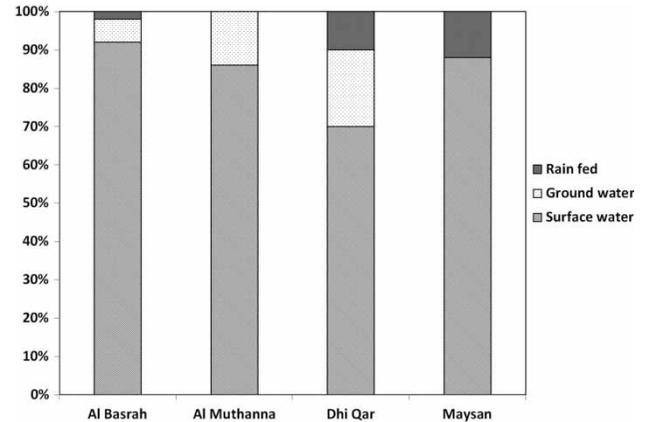


Figure 2 | Sources of irrigation water in the southern provinces in Iraq (IOM 2012).

We estimated the detailed water demands for irrigation of various crops that are grown in the four provinces in the south of Iraq. We can see from Table 1 that barley, wheat, and date consume most water in this region, about 89% of the total water required for irrigation. It was estimated that irrigation needed about 6,017 Mm³/year of surface and groundwater in the south of Iraq in 2010.

Industry

The geographical location directly on water ways and the Arabian Gulf and the availability of raw materials make the south of Iraq a good place for many industrial activities. The southern region of Iraq contains some of the key industrial plants in the country such as iron and steel, cement, fertilizer, paper, petrochemicals, and sugar factories. Furthermore, in 2010 more than 80% of Iraqi oil was produced in this region and four oil refineries are located there. Currently, some of these industrial plants are non-functioning due to power shortages, outdated equipment, and acts of sabotage after the invasion of Iraq in 2003. In Table 2 we specified the industrial plants in the south of Iraq, showing that Al Basrah accounts for the biggest portion of the industrial plants and consequently consumes most of the water which is required for industry.

An aggregate amount of 616 Mm³/year of water is required to supply the industrial activities in the southern region of Iraq (see Table 2). This amount is anticipated to increase in future years, especially when the non-functioning plants return to work and new factories are built as planned by the Iraqi government.

Table 1 | Agricultural production and water demands for irrigation in the south of Iraq

	Al Basrah		Al Muthanna		Dhi Qar		Maysan		Total	
	Production (ton/year) ^a	Water needs (Mm ³ /year)	Production (ton/year) ^a	Water needs (Mm ³ /year)	Production (ton/year) ^a	Water needs (Mm ³ /year)	Production (ton/year) ^a	Water needs (Mm ³ /year)	Production (ton/year)	Water needs (Mm ³ /year)
Alfalfa	4,144	7	29,358	26	148,747	43	16,728	14	198,977	89
Barley	3,927	41	30,987	368	89,694	1,065	66,864	674	191,472	2,148
Carrot	61	0.111	0	0	1,110	2	88	0.2	1,259	2
Date	54,513	608	19,513	318	32,674	505	7,580	83	114,280	1,514
Eggplant	298	0.23	842	0.64	9,660	7	1,532	1	12,332	9
Garlic	81	0.10	0	0.00	6,300	8	63	0.1	6,444	8
Green beans	133	0.16	505	0.59	3,800	4	8,400	9	12,838	14
Lettuce	252	0.32	0	0.00	8,568	10	4,636	5	13,456	16
Maize	0	–	11	0.05	2,666	13	16,016	74	18,693	87
Okra	22,085	0.16	3,613	0.59	15,843	4	9,368	9	50,909	14
Onion	0	–	38	0.05	10,328	12	1,358	2	11,724	14
Rice	0	–	4,150	60	776	12	170	3	5,096	74
Sugarcane	0	–	0	–	0	–	29,350	60	29,350	60
Tomato	360,888	274	11,589	8	12,502	9	6,681	4	391,660	295
Turnip	3	0.01	91	0.17	1,183	2	564	1	1,841	3
Wheat	16,900	138	26,500	215	92,000	730	81,400	587	216,800	1,670
Total	46,3285	1068	127,197	997	43,5851	2,426	250,798	1,526	1,526	6,017

^aAl-Fahad & Abbas (2011).

Domestic

Domestic water demand includes use for drinking, preparing food, bathing, washing clothes and dishes, air-conditioning, gardening and other household purposes. Domestic water in the south of Iraq is mainly supplied by the Tigris and its tributaries except in Al Muthanna where it is supplied by the Euphrates. It appears that, as shown in Table 3, most of the population does not have access to safe drinking water and use either untreated water or an insufficient amount of water (below the standard limit of 392 L/day per capita) (UN 2013).

Livestock

Water is essential for livestock farming and breeding. About 15% of the total livestock in Iraq is in the southern region of the country. To assess this issue quantitatively, we estimated the water required for livestock farming

and breeding. This water is made up of drinking water and service water (the water that is used to clean the farmyard, wash the animals and other necessary services). Detailed data for the various species of livestock in Iraq are available from COSIT for 2008 for all 18 Iraqi provinces. Table 4 shows that Dhi Qar has the largest water consumption for livestock, consuming about 38% of the total water required for livestock. Our calculations revealed that a quantity of about 12.8 Mm³/year is required to maintain the current livestock in the south of Iraq in an acceptably healthy condition. In general this amount is negligible compared to the demand for other purposes, especially irrigation. Nevertheless, the percentage of farmers that were forced to sell their livestock due to water scarcity in Al Basrah and Maysan was significantly above the figure for Iraq as a whole. In Al Muthanna and Dhi Qar most of the livestock faced water-related health problems such as sickness and even death (see Figure 3).

Table 2 | Key industrial plants in the south of Iraq and their water demands

Province	Industrial plant	Production	Water demands (Mm ³ /year)
Al Basrah	The state company of fertilizers-Basrah	1,000 ton/day	28
	The State Company for Petrochemical Industries (Ethylene)	79,200 ton/year	110
	The State Company for Petrochemical Industries (HDPDE)	16,650 ton/year	10
	The State Company for Petrochemical Industries (LDPE)	33,300 ton/year	26
	The State Company for Petrochemical Industries (Chlorine)	9,500 ton/year	3
	The State Company for Petrochemical Industries (Caustic soda)	19,000 ton/year	–
	The State Company for Petrochemical Industries (MVC & PVC)	0 ton/year	–
	Oil	2,150,000 bbl/day	187
	Refinery	140,000 bbl/day	90
	Paper	0 ton/year	–
	State company for iron and steel	440,000 ton/year	57
	State company for iron and steel (pipes)	200,000 ton/year	26
	Um Qasr cement plant (grilling of clinker)	360,000 ton/year	–
	Alhartha thermal power plant	130 MW	1
	Alnajibiyah thermal power plant	150 MW	1
	Khor Al-Zubair gas station	380 MW	–
	Alshiaibah gas station	73 MW	–
	Petrochemical gas station	80 MW	–
	Al Fao salt recovery plant	0 ton/year	–
	Total Al Basrah		
Al Muthanna	Al Muthanna cement plant (dry method)	241,860 ton/year	–
	Samawa (south) cement plant (wet method)	365,000 ton/year	–
	Salt recovery plant	137,000 ton/year	Rain and groundwater
	Oil	0 bbl/year	–
	Refineries	25,000 bbl/day	16
Samawa gas station	60 MW	–	
Total Al Muthanna			16
Dhi Qar	Nasiriyah thermal power station	500 MW	3
	Refinery	30,000 bbl/day	19
	Oil	35,000 bbl/day	3
Total Dhi Qar			25
Maysan	Sugar	0 ton/year	–
	Paper	0 ton/year	–
	Plastic	20 ton/year	–
	Vegetable oils	35 ton/week	–
	Refinery	30,000 bbl/day	19
	Oil	200,000 bbl/day	17
	Bazergan gas station	80 MW	–
Total Maysan			36
Total			616.13

bbl = barrel.

Water supply and shortage

The key source for water supply in the south of Iraq is surface water from the Tigris, the Euphrates and their tributaries. More than 90% of the marshes in the south of Iraq were drained in the 1990s (Canada-Iraq Marshlands

Initiative 2010). Groundwater has limited use in Iraq because it is pumped at rates faster than it is being replenished by rainfall. However, in the regions that are far from the rivers, groundwater resources are of more significance.

Agreed water quotas from the Tigris and the Euphrates are used to distribute water among the various provinces.

Table 3 | Domestic water supply and demands

Province	Population	Amount of water provided for domestic use (Mm ³ /year) ^a	Amount of water required for domestic use (Mm ³ /year)
Al Basrah	2,409,391	280	345
Al Muthanna	684,367	77	98
Dhi Qar	1,745,800	160	250
Maysan	924,300	150	132
Total	5,763,858	667	825

The southern provinces take the smallest amount of water due to their downstream location as well as due to the presence of several dams which are situated upstream and controlled by the upstream provinces.

Al Basrah

Al Basrah is the economic center of Iraq with the largest oil fields, Iraq's main harbors, and major industrial plants such as oil, petrochemical, iron, steel, fertilizers, and paper. It produces more than three-quarters of the oil produced in the country. In terms of population, it is the third largest province in Iraq with 2.4 million inhabitants in 2009. However, Al Basrah has the worst water situation in Iraq in terms of quantity and quality. It is the last province in the downstream area of the Tigris and the Euphrates which means it receives all the irrigation return flows from the upstream provinces and most of the water is used by the upstream cities. The water quota of Al Basrah is 50 m³/s which is provided mainly by the River Tigris. It has been reported that the quality of larger parts of Shatt-el-Arab River is not

suitable for domestic and irrigation uses (Al-Hamad 2010). Freshwater supply to Al Basrah is below actual needs: we found an estimated water shortage of 790 Mm³/year in 2010 in Al Basrah (Table 5). Currently, the people of Al Basrah either do not get enough water or they use poor quality water such as that from Shatt-el-Arab River for domestic and irrigation purposes. Agricultural lands, especially in the south of Al Basrah, have decreased due to water shortage in terms of quality and quantity (Al-Hamad 2010).

Al Muthanna

Al Muthanna lies on the Euphrates River and uses its water as the main source for various purposes. The province has the lowest population, the smallest agricultural and industrial sector and the lowest water demand for livestock of the four provinces. The water quota of the province (which is 16.8 m³/s) is also the lowest among the southern provinces. Poor quality of the Euphrates is recorded starting from Al Muthanna to its confluence with the Tigris at Al Qurna (Rahi & Halihan 2010). It was found that water supply to Al Muthanna province is less than half of its water demands. This water shortage has affected agriculture to a great extent. According to the water resources department in Al Muthanna, about 30% of the agricultural land is at stake if the province water quota does not increase to 28 m³/s.

Dhi Qar

The province of Dhi Qar has the highest water quota among the other provinces because it has the largest agricultural

Table 4 | Number of animals and corresponding water needs in the south of Iraq

	Al Basrah		Al Muthanna		Dhi Qar		Maysan		Total	
	Number of animals	Water needs (Mm ³ /year)	Number of animals	Water needs (Mm ³ /year)	Number of animals	Water needs (Mm ³ /year)	Number of animals	Water needs (Mm ³ /year)	Number of animals	Water needs (Mm ³ /year)
Buffalo	59,590	1.5	7,080	0.2	51,035	1.3	25,075	0.63	142,780	3.6
Cows	33,127	0.5	26,817	0.4	105,692	1.5	82,030	1.14	247,666	3.4
Goats	9,114	0.03	44,051	0.14	74,431	0.23	25,823	0.08	153,419	0.5
Poultry	138,000	0.01	2,403,000	0.24	407,000	0.04	252,000	0.02	3,200,000	0.3
Sheep	56,000	0.24	280,000	1.21	400,000	1.72	400,000	1.72	1,136,000	5
Total	295,831	2.23	2,760,948	2.13	1,038,158	4.74	784,928	3.59	4,879,865	12.8

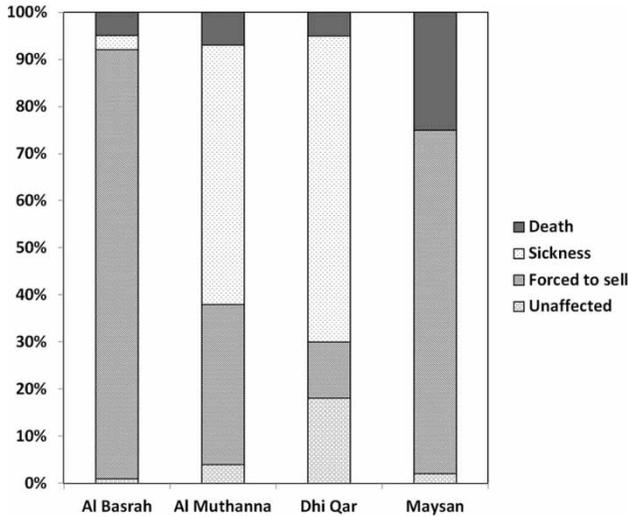


Figure 3 | Effect of water scarcity on livestock in Iraq (WWAP 2012).

Table 5 | Total water supply and demand for different purposes

	Water supply Mm ³ /year	Utilizable water Mm ³ /year	Total demand Mm ³ /year	The difference Mm ³ /year
Al Basrah	1,577	1,167	1,954	-787
Al Muthanna	530	392	1,114	-722
Dhi Qar	4,415	3,267	2,707	560
Maysan	2,996	2,217	1,698	519
Total	9,518	7,043	7,473	-430

area. Dhi Qar relied on the Euphrates water as the main source for water supply until the mid-1970s, and now depends on the Al Gharraf River, a side branch of the Tigris (Al-Sabah *et al.* 2011). This is due to the low flow rate and the increasing salinity of the Euphrates which reached 5,500 mg/L in 2002 in Dhi Qar (Rahi & Halihan 2010). The reasons for the increased salinity are irrigation return flows, the decrease in discharge of the river, and passage of the river through the salty area in Al Muthanna. The water quota of Dhi Qar from Al Gharraf River is 140 m³/s, which is regulated by Al Kut barrage.

Maysan

After the disastrous drainage of marshes in the 1990s, Maysan has lost most of its agricultural lands and water supply is now mainly dependent on the Tigris River. Since

it is the last province in the course of the Tigris before meeting the Euphrates in Al Qurna (100 km southward), Maysan receives poor quality water with low discharge (Al-Sabah *et al.* 2011). The water quota for the province of Maysan as specified by the water resources authorities is 95 m³/s. Our calculation shows that this amount is sufficient for current water demands (Table 5). However, water demands will increase when the non-functioning industrial plants in Maysan such as sugar, paper, and plastic are back to work as planned in the next few years. Moreover, part of the Maysan water supply goes to the marshes restoration project, but we have no information about the water quantities used for this purpose.

Water demand and supply results in the south of Iraq are summarized in Table 5. Overall water deficit is estimated at about 430 Mm³/year; this amount can be balanced by using proper water management and alternative water resources.

Water management solutions

In this section we introduce sustainable solutions which might help to improve the water situation in the south of Iraq. Based on our findings, we can discern that water problems in the south of Iraq are not just a matter of quantity but also of the management of water resources in this region. We make the recommendations outlined below:

1. Treat oilfield PW and use it for one or more of many useful purposes such as industrial applications, irrigation, rangeland restoration, cattle and other animal consumption, and even domestic water use for washing, air-conditioning, gardening, and even for drinking. Waisi *et al.* (2015) estimated an amount of PW of 54 Mm³/year in the south of Iraq; most of this amount is currently either reinjected into the ground or put in evaporation ponds. This amount is anticipated to increase by the end of this decade as oil production is planned to reach three times its current production and because PW quantities increase with the age of a given oilfield.
2. Desalination of Arabian Gulf water can be a significant and stable water source for Al Basrah which can be used for various purposes. A seawater desalination plant is to be constructed in the south of Iraq to provide

the required water for injection in the oil industry (IEA 2012). This option is not practical for the other provinces because of the long distances involved.

3. Reclaim municipal wastewater using modern efficient technologies such as membrane bioreactors (MBR) and moving bed bioreactors (MBBR) followed by a disinfection step (UV or chemical disinfection by peracetic acid or chlorine dioxide).
4. Consider groundwater as an additional water resource, because 7 billion m³ of groundwater was available for extraction in 2010 in Iraq (Al-Hadawi *et al.* 2011).
5. Rainwater harvesting is one of the methods that can ensure availability of water for winter crops. By this technique, the excess rainwater (run-off) is stored in small reservoirs or dams of different sizes to be supplied later when required to satisfy crop requirements (Zakaria 2012).
6. Increase efforts towards the marshes restoration to enhance agricultural activities and livestock farming in the marshlands.
7. Consider more efficient irrigation techniques such as drip irrigation and sprinkle irrigation instead of surface irrigation (flood irrigation) which is the main method that is currently used in the south of Iraq. Surface irrigation consumes huge amounts of water and produces high salinity water – as a result of high evaporation rates – which drains back to the surface water as return flow.
8. Consider a water allocation rule between the Euphrates-Tigris river basin countries. Sakamoto *et al.* (2013) investigated the application of a game theoretical approach to water resources allocation for agricultural purposes in the Euphrates-Tigris river basin.

The possible solutions to solve water scarcity will be different for the various provinces as shown in Table 6. These solutions depend on the location of the province,

the available resources in this province such as oilfield PW and sea water, and the need due to water shortage. Here, we describe how we constructed Table 6. For instance, PW is a promising solution for Al Basrah and Maysan where the oil is extracted, while for Al Muthanna and Dhi Qar it is not the best choice because of the large distances from the giant oilfield in Al Basrah of 300 km and 200 km, respectively. Desalination of seawater is a possible solution for Al Basrah because it is the closest city in Iraq to the sea. A giant Common Seawater Supply Facility (CSSF) to treat seawater from the Arabian Gulf is planned to be built in 2017 to provide the required water for the oilfields in Al Basrah (Waisi *et al.* 2015). The anticipated capacity of the CSSF is 10–12 Mbbbl/day. This solution has the benefits of providing a secure water supply, independent of future water availability; it also reduces stress on freshwater resources, freeing them for other uses (IEA 2012). Groundwater could be an important resource in the desert of Al Muthanna; Mohammed (2008) reported that the renewable reserve of the groundwater in the desert of Al Muthanna is 250 Mm³/year with total dissolved solids (TDS) of 2000 mg/L in the south and west of the desert, which is suitable for irrigation and livestock. Although rainfall is of low value in the southern region, rainwater harvesting in the desert of Al Muthanna could contribute to the water resources in the region. Reuse of municipal wastewater has most potential in Al Muthanna where currently no central wastewater treatment plant is available. The daily amount of 10,000 m³ of municipal wastewater in Al Muthanna (COSIT 2010) can be used for irrigation purposes instead of discharging it to the river or directing it to evaporation ponds. This will also better serve the environment. Since in the other provinces, where central wastewater treatment plants do exist, the effluent is also discharged to the river, we consider it as a potential solution for all provinces.

Table 6 | Possible options for alternative water resources for the four provinces in the south of Iraq

	Groundwater	Arabian Gulf	Marshes	Water harvesting	Produced water	Wastewater
Al Basrah	✓	✓			✓	✓
Al Muthanna	✓			✓		✓
Dhi Qar	✓		✓	✓		✓
Maysan			✓		✓	✓

Produced water as a potential solution for water scarcity in Iraq

Production of oil and gas is always accompanied by large amounts of effluent water, called 'produced water'. These huge quantities of water can be used (if treated efficiently and economically) for many useful purposes such as industrial applications, irrigation, cattle and animal consumption, and domestic water use for washing, air-cooling, gardening, and even for drinking. PW is most often considered as wastewater, but industrial companies and policy makers have started to see it as a sustainable source of water. However, the handling of this water requires special attention. The treatment of PW has the potential to produce a valuable product rather than waste. Selection of PW treatment options is a challenging problem that is steered by the overall treatment objective, the quantity and quality of the PW. Besides the oil constituents, one of the most important concerns for PW is its high salinity (Ahmaduna *et al.* 2009). Salt content of the PW in the south of Iraq reaches elevated levels of more than 240 g/L (Al-Rubaie *et al.* 2015). Advanced technologies are necessary to treat the PW to the desired water quality levels. Recent studies have shown that some technologies can handle such hyper-saline PW: for example, forward osmosis and membrane distillation (Shaffer *et al.* 2013).

Water–energy nexus

The water need for energy production will be increasingly important. About 15% of global water use in 2010 was related to energy production (IEA 2012). Water availability can be the limiting factor for electric power in Iraq.

In the south of Iraq, energy is produced either by thermal power plants or gas power plants. The thermal power plant consumes water explicitly to generate steam which is used to drive a turbine generating the electricity, while in the gas power plant fuel is used to heat up gases which drive the turbines. In the gas power plant, water is implicitly included in the fuel which consumes water in the different stages of extraction and refining. At the same time, energy is required to produce freshwater from the various sources such as surface water, groundwater and wastewater.

During the production life of an oil well, this interrelation manifests strongly in the lifecycle of PW in production, re-injection or dumping as wastewater, recycling, purification and subsequent injection for enhancing oil and gas recovery. Energy in return is required to deal with this water reuse whether in the energy industry or the other sectors.

Planners have to take into account this nexus when planning for energy production or water treatment. To produce 1 kWh, 0.757 m³ of fresh water is needed (Goldstein & Smith 2002), while to provide 1 m³ of fresh water from surface water resources such as rivers, 0.5 kWh is needed (Olsson 2012). Accordingly, it is very important to think about alternative water resources which can be used for various purposes using less energy-intensive techniques or renewable energy resources.

DISCUSSION

Water consumption by the agricultural sector in the south of Iraq accounts for about 81% of the total water consumption, which is larger than the average figure for the country of about 72% (calculated from Table 7).

Table 7 | Past, current, and future water demands and availability in Iraq

	1990	1995	2000	2005	2010	2015	2020
Total water demand billion m ³ /year ^a	42.8	54.4	66	77.6	89.2	100.8	112.4
Domestic demand billion m ³ /year ^a	1.28	2.79	4.3	5.81	7.32	8.83	10.34
Industrial demand billion m ³ /year ^a	2.14	5.92	9.7	13.48	17.26	21.04	24.82
Irrigation billion m ³ /year ^a	39.38	45.69	52	58.31	64.62	70.93	77.24
Water availability m ³ /year/capita ^b	6029		3100		2400		1900

^a1990–2000 estimations from FAO (2013), 2005–2020 our estimations using linear extrapolation.

^bTolba & Saab (2008).

This result is compatible with the fact that the southern region contains the majority of the agricultural land in Iraq. While industry consumes about 20% of the total water demand in Iraq, it accounts for only 8% in the southern provinces. This is most likely because the majority of the industrial plants are situated in Baghdad.

Water demands in Dhi Qar constitute about 40% of the total water demand in the south of Iraq, as shown in Figure 4. This is because Dhi Qar has the highest agricultural production among the four provinces. Also, our estimations showed that more than 80% of the industrial activities in the south are currently based in Al Basrah. These findings can be used in the management of available freshwater resources, as discussed previously.

The water situation in Iraq is anticipated to worsen in future years because water demands in the country are going to increase as shown in Table 7, whereas water supply is going to decrease due to upstream damming of the Tigris and the Euphrates, and climate change.

The increase in water demand is mainly driven by population and industrial growth driven by increased wealth. The water needed for irrigation may also increase due to climate change besides the effect of population growth; however, in Iraq the effect of population growth on water demand will be much larger than that of climate change (Chenoweth et al. 2011).

Despite the current and future water shortage in Iraq, the annual water availability per capita in Iraq is the highest among the other Arabian countries (Tolba &

Saab 2008). However, international organizations have reported that if the current water management situation continues, the Tigris and the Euphrates will dry up by 2040 (UNCT 2013). So it is critical to begin immediately with the utilization of alternative water resources and new technologies as suggested in previous sections, to guarantee a secure water demand–supply balance through a rational use of all the available water resources.

CONCLUSIONS

Water shortage in the south of Iraq is a serious issue that is only expected to worsen in the future because of population growth, increased abstractions upstream, poor management of the available water resources and climate change. The utilizable water for consumption in the south of Iraq was estimated at 7043 Mm³/year compared to 7473 Mm³/year for water demand. A total water deficit of 430 Mm³/year was calculated for the four southern provinces in 2010. Irrigation claims about 81% of the consumed water in the south of Iraq where the province Dhi Qar is the main consumer. The worst water situation was reported in Al Muthanna and Al Basrah, while the other two provinces of the southern region (Maysan and Dhi Qar) suffer from poor quality water rather than insufficient water quantity. This can be dealt with by application of modern water treatment techniques.

There are some potential solutions that can be applied to overcome water scarcity in the south of Iraq such as treatment of oilfield PW and municipal wastewater, desalination of Arabian Gulf water, groundwater abstraction, rainwater harvesting, and use of modern irrigation techniques. There is no unique solution for this problem but considering a combination of various potential solutions will lead to sustainable use of water. PW can be an important water resource in the region; modern technologies that are more efficient and consume less energy need to be applied to provide clean water that can be used for irrigation and industrial consumption and even other purposes. The water–energy nexus should be taken into account when dealing with water and energy management issues.

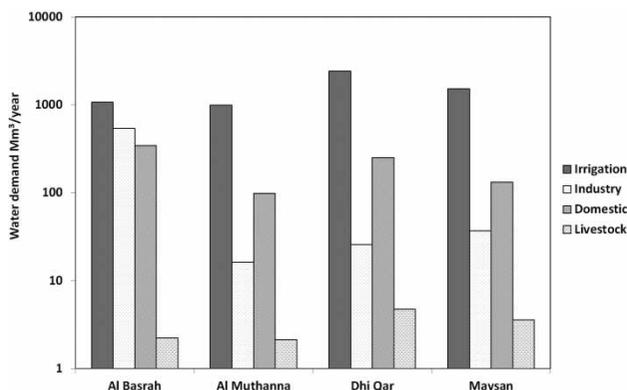


Figure 4 | Water consumption by the various purposes and different provinces in the south of Iraq (note the log scale).

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