

Virtual industrial water usage and wastewater generation in the Middle East and North Africa 2011–2015

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Abstract This study presents useful methods for quantifying the volumes of water usage, wastewater generation, virtual water export, and wastewater generated by export for six relevant export industries in the Middle East and North Africa (MENA) region. These export industries are based in: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestinian Territories, Qatar, Saudi Arabia, Syria, Tunisia, and United Arab Emirates (UAE). Results show that approximately 4.26×10^9 m³ of water is used per annum and approximately 1.04×10^9 m³ of wastewater is generated during production by the studied industries in 2011. The difference (3.22×10^9 m³) between the used water and

generated wastewater volumes is related to water evaporation or injection underground (oil well pressure maintenance). The net virtual water export of the six studied commodities for the year 2015 from MENA to EU28 [i.e., 28 countries in the European Union] is approximately 3.0×10^8 m³, which is equivalent to approximately 7.05% of the water used by those industries. For example, Saudi Arabia represents the largest net virtual water exporter (approximately 1.25×10^8 m³). Crude oil represents approximately 2.59×10^8 m³ of the net virtual water export; fertilizers represent 6.5×10^7 m³, while pig iron and olive oil represent 3.9×10^5 , and 1.3×10^5 m³, respectively. The Saudi Arabian hydrological system is under the greatest pressure externally due to these exports to EU28, where the net virtual water export represents approximately 1.6% of the actual renewable water resources and desalination capacity of this country. In general, this study shows that, in terms of the grey water footprint (GWF), the pollution of water bodies caused by production (year 2011) is relevant for the crude oil, refined petroleum, and olive oil industries, whereas pollution caused by exports to EU28 countries (year 2015) is primarily related to the crude oil industry and olive oil mills. The GWFs for all the six industries caused by production and export are 111.8×10^9 (for the year 2011) and 18.7×10^9 m³/year (for the year 2015), respectively. One importance of the current work is that the specific water uses here could be compared to those of the same industries in developed countries. Based on these comparisons, decisions related to the need for water conservation can be made. The implementation of industrial water conservation in the MENA region could alleviate the pressure on water resources and help mitigate the water problems in the MENA. The time in which these

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results apply for production and export are the years 2011 and 2015, respectively.

Keywords Water usage · Wastewater generation · Virtual water export · Wastewater generated by export · MENA, EU28

Introduction

The region of the Middle East and North Africa (MENA) is the most water-scarce region in the world (World Bank 2012). In this region, including Malta and excluding Djibouti (MexcD), less than 1% of the world's renewable freshwater is available (Khedr 2006). The demand for water there began to exceed the supply in the early 1970s. For example, in Egypt, the demand is 25% higher than the available water resources, and the gap is satisfied by recycling agricultural drainage water and trapping water losses (Gad and Ali 2009). In the Kingdom of Saudi Arabia, the water deficit has been reported as unresolved in 1999 (Hong 2004), and the demand is largely satisfied through groundwater resources, through desalinating seawater and recycling of treated wastewater used for agriculture and industry (Abderrahman 2009).

Furthermore, certain countries of MENA (MexcD) have adequate quantities of renewable water resources, whereas others have low levels. The supply of urban water is intermittent in most of the cities of the latter region and particularly noticeable in the summer, when the municipal water is pumped to households only once or twice a week and turned off otherwise. There are 45 million people in this region that still lack adequate access to safe drinking water (Khedr 2006).

Water scarcity is linked to an important term to the present research namely “virtual water” (VW) that has been introduced by (Allan 1993). In that sense, it has been found that VW trade may curb the negative effects of water scarcity (Roson and Sartori 2010) and another study found that inverting VW flows could be a solution for alleviating this problem in central Asia (Porkka 2011). The countries that are water scarce should import commodities that are water intensive and export commodities that require much less water for its production. Doing that helps in alleviating this problem. This is why VW is a term that can be used to achieve an objective distribution of water resources around the world and it is vital to estimate virtual water flows into and out of the MENA region.

The VW term is also related to the water footprint (WF) that has been introduced by Hoekstra in 2003. For example, VW is used in the calculation of the water footprint of nations where the VW exported and imported by the nation

is used in this calculation. There have been substantial efforts to quantify the VW flows between nations in recent years (Hoekstra and Hung 2002; Chapagain and Hoekstra 2003, 2004; Zimmer and Renault 2003; Oki et al. 2003). The first attempt on an international level was performed by Hoekstra and Hung (2002), and several studies were subsequently conducted on global VW flows related to international trade (food and non-food commodities), global WFs, and VW flows related to the trade of five crops and three livestock products (Chapagain and Hoekstra 2004; Zhan-Ming and Chen 2013; Hanasaki et al. 2010). The industrial VW flows and WFs of all nations have also been estimated (Hoekstra and Mekonnen 2012). For example, the VW flows related to the Spanish international grain trade ranged between 3420 and 8415 million m³ in the years 1997–2005 (Novo et al. 2009). Andalusian crop net VW import within Spain has been estimated as 1377 million m³ for the year 2002 (Velázquez 2007). Moreover, agricultural product trade between the Nile basin states and the rest of the world showed an annual net virtual water import of 27,000 million m³ in the period from 1998 to 2004 (Zeitoun et al. 2010). VW flows within India and China have also been estimated. Regarding India, the mean annual inter-state VW trade in crops is 106,000 million m³ for the years 1997–2001 (Verma et al. 2009), while China's northern and southern parts have been found to be a net virtual water exporter [having a value of 4225.4 million m³ (year 1997)] and net virtual water importer [having a value of 148.1 million m³ (year 1997)], respectively (Guan and Hubacek 2007). There have also been efforts to estimate the WFs of products, cities, countries, regions, and processes (Van Oel and Hoekstra 2012; Mekonnen and Hoekstra 2012a, b; Erzin et al. 2012; Gerbens-Leenes and Hoekstra 2012; Jefferies et al. 2012; Ruini et al. 2013; Zhang et al. 2011; Chapagain and Hoekstra 2011; Dong et al. 2013; Vanham and Bidoglio 2013; Van Oel et al. 2009; Niccolucci et al. 2011). For example, Chapagain and Hoekstra (2011) estimated the global water footprint of rice production as 784,000 million m³/year in the period from 2000 to 2004. Zhang et al. (2011) estimated the water footprint of Beijing in 2002 as 4498.4 million m³/year, while Van Oel et al. (2009) estimated the water footprint of the Netherlands as 2300 m³/cap/year for the period 1996–2005. Finally, Dong et al. (2013) estimated the water footprint of Liaoning in 2007 as 7300 million m³. However, published reports are not available on the net VW export through the trade of potash, fertilizers, crude oil, refined petroleum, olive oil, and pig iron to the 28 countries of the European Union (EU28) (2016), especially from the MENA region.

The goal of this paper is to quantitatively assess the volumes of water usage, generated wastewater, VW

exported to EU28, and wastewater generated by export (WWGE) for six export-relevant industries of MENA. These export industries are based in: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestinian Territories, Qatar, Saudi Arabia, Syria, Tunisia, and United Arab Emirates (UAE). Production data in this study are for the year 2011 and those for export are 2015. The production data are all for the year 2011 due to the unavailability of complete fertilizer production data for the relevant countries after that year. The estimated industrial water use volumes can be divided by the weights of the products of each specific industry, thus resulting in specific water uses that can be compared to those of the same industries in developed countries. Based on these comparisons, decisions related to the need for water conservation can be made. The implementation of industrial water conservation in the MENA region could alleviate the pressure on water resources and help mitigate the corresponding problems in the region. Reducing the specific amount of water used for production will also affect the virtual industrial water use volume of the EU28. This will lead to a reduction of this use, and it will also help mitigate the related problems in the MENA region. Moreover, we aim to estimate the volume of industrial grey water flows, which provide important contributions to the design and construction of treatment plants for MENA industries. These are also important because of their potential for pollution and the cost of environmental repair. For example, certain MENA industries, such as the olive oil industry, do not have treatment plants; consequently, determining wastewater volumes will assist in the future design of these plants.

Another goal is to shed light on the industries that are the most relevant in terms of pollution caused by production and export through calculating their grey water footprint (GWF) and determining their indirect water consumption by EU28 through the import of goods from the MENA region.

In summary, this study aims to quantify and evaluate the indirect pressure that EU28 poses on the hydrological systems of the MENA region. In “[Important terms and rationales for selecting the industries studied in this work](#)”, we define important terms and identify our reasons for selecting the industries studied in this work. “[Methodology and assumptions](#)” presents a summary of the methodology and assumptions used for the calculations. “[Results and interpretations](#)” displays the results and interpretations. In “[Discussion](#)”, we discuss the results, and in “[Conclusions](#)”, we end with conclusions.

Important terms and rationales for selecting the industries studied in this work

Definition of important terms

VW: Water that is required to produce agricultural or industrial goods

WF: Indicator of freshwater use considers direct and indirect water use; the WF is a volumetric measure of water consumption and pollution (Hoekstra et al. 2011)

Water use

1. For the fertilizer and refining industries, water use represents water that is consumed through evaporation and released as wastewater.
2. For the crude oil industry, water use represents water that is injected underground and used to wash crude oil.
3. For potash and olive oil industries, water use represents water that is released as wastewater.
4. For all industries, water use represents water that is withdrawn either from the surface, ground, or sea.

GWF

The volume of freshwater required to assimilate the load of pollutants which is based on natural background concentrations and ambient water quality standards (Hoekstra et al. 2011).

MENA (World Bank2 2017)

The region that includes the following countries: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestinian Territories, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates (UAE), and Yemen.

Actual renewable water resources

The sum of internal renewable water resources (average fresh water resources renewably available over a year from precipitation falling within a country's borders) and external renewable water resources which is the country's renewable water resources that enter from upstream countries through rivers (external surface water) or aquifers (external groundwater resources) (Food and Agriculture Organization of the United Nations FAO 2003).

EU28 (European Union)

the union that includes the following countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom (U.K).

Rationales for selecting the industries studied in this work

The six export-relevant industries that are considered include crude oil (based in: Algeria, Egypt, Iran, Iraq, Kuwait, Libya, Oman, Qatar, Saudi Arabia, Tunisia, and UAE), refined petroleum (based in: Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Kuwait, Libya, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, and UAE), fertilizer (based in: Algeria, Egypt, Iran, Israel, Kuwait, Lebanon, Libya, Morocco, Saudi Arabia, Syria, Tunisia, and UAE), pig iron (based in Algeria), potash (based in: Israel and Jordan), and olive oil (based in: Algeria, Egypt, Israel, Lebanon, Morocco, Palestinian Territories, Syria, and Tunisia). The first five of these industries were selected, because they are considered to be major industries (Shaikh Al-Deen and El-Kholy 2001; CIA The World Factbook 2015; The Report: Emerging Algeria 2008; Yager 2005; Mobbs 2005a). An

industry is classified as ‘major’ based on several factors, such as its contribution to gross domestic product (GDP), the percentage of the population it employs, and its gross business receipts (Economy Watch 2010). These three economic indicators show the importance of the first five industries listed above. The major industry of a country is classified after ranking all the country’s industries according to their contributions to the GDP and the percentage of the population they employ. The industries at the top of the list are the major industries [According to D. Clark (personal communication, 15 Jan 2011) and J. Biddle (personal communication, 13 January 2011)].

Table 1 shows the percentage contribution of the five major industries to the total GDP of a country and the total export income, whereas Table 2 shows the percentage contribution to GDP and percentage share of the total export income, the relative water use to other industries, and the relative pollution in terms of biological oxygen demand (BOD) to the pollution of the textile industry. These industries provide a considerable contribution to GDP and the export income. The water use is 0.3- to 45.9-fold higher than that of other industries, and the pollution potential is 0.1- to 1.3-fold higher than that of the textile industry; thus, the water use and pollution potential are considerable.

The selection of the olive oil industry can be justified economically and environmentally. The olive sector in

Table 1 Range of percentage contribution to the total GDP and export income for the five major industries in MENA

Industry	% contribution to the total GDP of country	% contribution to the total export income of country ^f
Crude oil	6–70 ^a	10–100
Refineries	0.2–4.2 ^b	0.1–70
Fertilizers	0.1–3 ^c	0–12
Potash	0–3 ^d	0–9
Pig iron	0.2 ^e	0.05

^a Sources: Central Bank of the Islamic Republic of Iran-National Accounts (2012/2013) [total GDP of Iran for the year 2013 was obtained from World Bank Database (2005–2013)], Saudi Industrial Development Fund. Marketing Consultancy Division. Export Consultancy Unit (ECU) (2012), The Logistics Sector on the Southern Shores of the Western Mediterranean (2010), Central Statistical Organization-Iraq (2007), Eid et al. (2014), Rao (2010) [total GDP of Kuwait for the year 2005 was obtained from World Bank Database (2005–2013)], Istaitieh et al. (2007), According to M, Taib (personal communication, 4 February, 2015), Oman. Energy, Laws and Regulations Handbook (2015), Taib (2012)

^b Sources: General Authority for Statistics, Kingdom of Saudi Arabia (2011), Eid et al. (2014), Bureau of Statistics and Census Libya (2010) [total GDP of Libya for the year 2009 was obtained from World Bank Database (2005–2013)], Central Bank of the Islamic Republic of Iran-National Accounts (2012/2013), Encyclopedia Britannica Almanac (2010) (GDP per capita for Iraq (year 1995) was taken from UN data A World of Information (1995), population of Iraq in 1995 was taken from World bank data on total population), GCC Gulf Petrochemicals & Chemicals Association (2012); GDP of refined products for Morocco was taken from UN data A world of information (2010) 2010 [total GDP of Morocco for the year 2010 was obtained from World Bank Database (2005–2013)]

^c Sources: UN data A World of Information (2007–2010) [total GDP of Lebanon, Morocco, Iran for the years (2007–2010) was obtained from World Bank Database (2005–2013)], Mobbs (2005b)

^d Sources: The Report: Emerging Jordan (2007)

^e Sources: UN data A World of Information (2008), 2008 [total GDP of Algeria for the year 2008 was obtained from the World Bank Database (2005–2013)]

^f Sources: value of commodity exports taken from UN Comtrade database (2009–2015), while total export income obtained from OPEC Annual Statistical Bulletin (2013) and World Bank Database (2009–2015)

Table 2 Percentage shares of the GDP, total export income, relative water use to other industries, and relative pollution to textile industry for five major industries in relevant countries in the MENA region

Country	Industry	% share of the total country's GDP	Year	% share of the total export income ^f	Year	Water use relative to other industries	Pollution relative to the textile industry ^k
Egypt	Crude oil	7.3 ^a	2011/ 2012	10.3	2012	0.3 ^g	0.2
Iran	Refining	4.0 ^b	2012/ 2013	0.8	2011	0.6 ^h	1.3
Morocco	Fertilizers	1.1 ^c	2007	11.3	2012	45.9 ⁱ	0.8
Jordan	Potash	2.4 ^d	2007	8.5	2012	4.1 ^j	0.1
Algeria	Pig iron	0.2 ^e	2008	0.05	2012	1.6 ^j	–

^a Eid et al. (2014)

^b Central Bank of the Islamic Republic of Iran-National Accounts (2012/2013) [total GDP of Iran for the year 2013 was obtained from World Bank Database (2005–2013)]

^c UN data A World of Information (2007–2010) [total GDP of Morocco was obtained from the World Bank Database (2005–2013)]

^d The Report: Emerging Jordan (2007)

^e UN data A World of Information (2008) [total GDP of Algeria was obtained from the World Bank Database (2005–2013)]

^f UN Comtrade database [total export income obtained from OPEC Annual Statistical Bulletin 2013 and World Bank Database (2009–2015)]

^g This study, industrial water use is divided by that of the spinning and weaving obtained from Doss and Milne (2001), because the textile industry in Egypt is considered to be one of the most important industries, since it has a share of 3% of GDP (27% of total industrial production) (Ahmed 2009)

^h This study, industrial water use is divided by that of sugar industry obtained from Ahmadi et al. (2004), since the latter industry is one of the largest water users in Iran (Ahmadi et al. 2004)

ⁱ This study, industrial water use is divided by that of textile industry obtained from Pollution Prevention in the Textile Industry within the Mediterranean region (PPTIMR) (2002), since it contributes 17% of the total industrial GDP and 10% of GDP, which employs 42% of the total working force in Morocco (PPTIMR 2002, COFACE for safer trade 2015), and is a main industry in Algeria (SMEToolkit 2013)

^j This study, industrial water use is divided by that in the manufacture of soft drinks and the production of mineral water (obtained from Karablieh 2012), since the latter industry is a major water user in Jordan (Karablieh 2012)

^k This study, industrial pollution in terms of BOD is divided by the BOD emissions from the textile industry obtained from EconStats (1997–2006), since the textile industry contributes 7–45% of the total industrial BOD emission in these countries (EconStats 1997–2006)

Morocco and Tunisia provides employment for more than 3 million people, which is approximately 19.5% of the total labor force, and it generates earnings of approximately half a billion US \$ from the export of Tunisian olive oil (1.26% of GDP) and 124 million US \$ from the export of Moroccan table olives and olive oil (0.14% of GDP) (International Olive Council (IOC) (2006a, b). The olive oil industries in Algeria, Egypt, Israel, Lebanon, Palestinian Territories, and Syria were selected because of environmental reasons, that is because olive oil mill effluent is among the strongest industrial wastewaters (e.g., chemical oxygen demand (COD): 6.4–162 g/l; BOD: 1.5–100 g/l; and phenols: 4.5 g/l), and it is harmful to the environment.

Data used in this study were collected from numerous sources which can be found in the supplementary material.

Methodology and assumptions

In the following section, we summarize the methods of calculating the yearly volumes of water use, wastewater generation, VW export, WWGE, BOD load for

production/export, and GWF. More details can be found in the supplementary material. Note that for the specific volumes of water usage and wastewater generated by the production of the relevant items, the numbers (or rates) of the MENA industries were used.

Calculation of water usage and wastewater generation related to production

Crude oil

1. Water usage because of crude oil production = water for repressurizing oil fields (WRO) + water for washing the crude oil (CW).
2. Wastewater generated because of crude oil production = annual wastewater from desalter = CW + entrained formation water (EFW) wastewater.

Refineries

Data were obtained for the water requirements and wastewater generated in certain MENA refineries.

Estimations were performed when the latter values were missing.

Fertilizers

1. The annual water requirement (AWR) for MENA fertilizer plants (except in Egypt, Algeria, Iran, and Syria) that produce ammonia was estimated as follows:

$AWR = \text{annual cooling tower make-up water (ACTMW)} + \text{part of the estimated boiler make-up water (PEBMW)}$;

$PEBMW < \text{specific boiler make-up water (SBMW)} \times \text{yearly production of ammonia and urea}$;

SBMW is in m^3/ton (ammonia and urea).

2. For MENA countries (except Egypt) that produce ammonia, the annual wastewater generated (AWG) is calculated as follows:

$AWG = \text{ammonia cooling tower blowdown (ACTB)}$.

Pig iron

1. The AWR related to the production of pig iron in Algeria = specific water use because of the production of pig iron (SWUPI) \times yearly production of pig iron.

SWUPI is an Algerian number in m^3/ton pig iron.

2. The AWG because of the production of pig iron in Algeria is stored, processed, and recycled (Organisation Mondiale de la Santé 1983).

Olive oil

Israel:

1. $AWR = \text{specific water use for three-phase extraction systems (SWUTPES)} \times (\text{annual olives produced} - \text{annual table olives produced})$.

SWUTPES is applied for a typical olive oil mill (OOM) in m^3/ton olives fed.

2. The AWG for the OOMs in Israel is obtained from Laor et al. (2007).

Potash

For Israel and Jordan:

1. $AWR = \text{specific average Jordanian water use (SAJWU)} \times \text{yearly production of potash}$.

SAJWU is in m^3/ton potash.

2. The AWG is assumed to be equal to the AWR in the relevant countries.

Calculation of net VW export

The calculation of net VW exported from MENA to EU28 (VWE1-VWE2) (VWE is an abbreviation for the Virtual Water Exported) for two commodities is mentioned. VWE1 is estimated using a method that is analogous to the method used by Hoekstra and Hung (2002) and is presented as follows. The VWE2 is also estimated in the following section.

Crude oil case

The specific water demand (SWD) in m^3/ton crude was calculated as the sum of the CW and WRO in m^3/year divided by the annual production of crude oil (APCO) in tons:

$$SWD = (CW + WRO)/APCO$$

The VWE1 in m^3/year was estimated as follows:

$VWE1 = SWD \times \text{annual crude oil exported (ACOE)}$ in EU28 (ACOE is an abbreviation for the Annual Crude Oil Exported).

The ACOE was obtained from the UN Comtrade database, which has the commodity code 2709 (HS1996).

VWE2 is the VW export in the form of crude oil from the EU28 to MENA and is estimated as follows:

$$VWE2 = SWD \times \text{annual crude oil exported to MENA}$$

$$\text{Net VW export} = VWE1 - VWE2.$$

Phosphatic fertilizer (triple superphosphate) case

Triple superphosphate The SWD is presented in m^3/ton triple superphosphate (TSP) and was calculated as the sum of the water required for TSP production (WTSP), sulfuric acid production (WSA), phosphoric acid production (WPA), and rock phosphate production (WRP) in m^3/year divided by the annual production of TSP (APTSP) in tons:

$$SWD = (WTSP + WSA + WPA + WRP)/APTSP$$

VW export from MENA to EU28 (VWE1) was estimated as follows:

$$VWE1 = SWD \times \text{annual TSP exported to EU28 (ATSPE)}$$

VW export from EU28 to MENA in form of TSP (VWE2) is as follows:

$$VWE2 = SWD_{PA} \times \text{PARM} + SWD_{SA} \times \text{SARM} + SWD_{TSP} \times \text{TSP exported}$$

where

SWD_{PA} is the specific water demand for the production of phosphoric acid in m^3/ton PA.

PARM is the phosphoric acid amount required for the production of TSP in tons.

SWD_{SA} is the specific water demand for the production of sulfuric acid in m³/ton SA.

SARM is the sulfuric acid amount required for the production of TSP in tons.

SWD_{TSP} is the specific water demand for the production of TSP in m³/ton TSP.

TSP_{exported} is the annual TSP exported to MENA in tons.

Calculation of WWGE

The calculation of wastewater generated because of exports from MENA to EU28 for one commodity is provided.

Crude oil case

The specific wastewater generation (SWG) was estimated in m³/ton of crude oil as the sum of the CW and EFW in m³/year, which was divided by APCO in tons:

$$SWG = (CW + EFW)/APCO$$

$$WWGE = SWG \times ACOE$$

Calculation of GWF

The GWF was calculated here by dividing the pollutant load by the difference between the ambient water quality standard for the pollutant (maximum acceptable concentration C_{max} in mass/volume) and its natural concentration in the receiving water body (C_{nat} in mass/volume).

The BOD load from production or export in the MENA region that is used in the calculation of GWF because of production or export was estimated as follows:

BOD load from crude oil production or export:

BOD_{load} = annual estimated volume of wastewater generated from crude oil production or export in MENA × typical BOD value for crude oil wastewater

The typical BOD value for crude oil wastewater was obtained from Wang et al. (2004).

Results and interpretations

Water usage and wastewater generated because of production

The total annual estimated volumes of water required for the six industries in the MENA region are summarized in Table 3 for the year 2011. Saudi Arabia has the highest requirement because of the crude oil and refining industry sector. For the export industries, the volume is approximately 4.26×10^9 m³, which can be calculated from the last row in Table 3. As an illustration, the total annual

water withdrawal in the MENA region for agricultural and domestic purposes is 2.60×10^{11} and 2.69×10^{10} m³, respectively (FAO AQUASTAT (2000–2014), the data on which the total annual withdrawal is based are for different years ranging from 2000 to 2006). The crude oil and refining industry sector represents 77.5% of the total water required, and is followed by the fertilizer sector, which represents 21.7%. Figure 1 shows the annual wastewater volumes (year 2011) of the five relevant export industries that range between 0×10^6 and 540×10^6 m³. Note that the pig iron industry does not produce effluent and the fertilizer industry has the highest volume.

Net VW export and WWGE

Net VW for all industries (year 2015)

The indirect pressure that EU28 imposes on the water resources of MENA countries and the region as a whole is summarized in Table 4. Iraq and Saudi Arabia are the largest net VW exporters because of the export of crude oil and refined petroleum products. The net VW export from the studied industries of the MENA region ranges from 0 to 1.3×10^8 m³, and it is approximately 3.0×10^8 m³ for the 20 countries, which is a sufficient volume to satisfy the water demands of approximately 5.5 million people (total MENA population in 2015 was 423.6 million people, world bank data on total population for the year 2015). The export of crude oil represents approximately 2.59×10^8 m³ of the industrial net VW export from this region, followed by the export of phosphatic/nitrogenous/mixed fertilizers, which is approximately 6.5×10^7 m³. The greatest impact is observed on the Saudi Arabian hydrological system, where the net VW export represents approximately 1.6% of the actual renewable water resources and desalination capacity. The influence in Kuwait and Libya is noticeable (1.0% for both countries), but in the other countries, it is much smaller. However, the overall water demand by industry in Kuwait, the UAE, Saudi Arabia, Oman, Qatar, Bahrain, and Libya contributes from 3 to 25% of the total actual renewable water resources and desalination capacity, which emphasizes the pressure of the industrial sector on the local water supply.

WWGE (year 2015)

The estimated WWGE volumes are shown in Fig. 2, which indicates that the fertilizer industry has the highest and the potash industry the lowest. For the fertilizer industry in Morocco and Tunisia, the WWGE represents 86.0% of the total volume for the fertilizer industry in all relevant MENA countries.

Table 3 Water usage because of production by the six exporting industries in 10^5 m³/year

Country	Industry					
	Crude oil (year 2011)	Refineries (year 2011)	Fertilizers (year 2011)	Potash (year 2011)	Pig iron (year 2011)	Olive oil (year 2011)
Algeria	847.0	279.3	59.02	–	90.0	0.6
Bahrain	–	157.4	–	–	–	–
Djibouti	–	–	–	–	–	–
Egypt	376.4	447.0	1442.9	–	–	1.9
Iran	2478.1	851.6	640.3	–	–	–
Iraq	2381.5	395.7	–	–	–	–
Israel	–	136.6	270.5	142.5	–	0.5
Jordan	–	–	–	99.7	–	–
Kuwait	1733.6	581.0	145.0	–	–	–
Lebanon	–	–	23.5	–	–	0.3
Libya	220.7	235.0	14.6	–	–	–
Morocco	–	96.1	4634.6	–	–	3.1
Oman	605.2	43.8	–	–	–	–
Palestinian territories	–	–	–	–	–	0.2
Qatar	542.3	113.1	–	–	–	–
Saudi Arabia	16,389.0	1810.7	1202.5	–	–	–
Syria	–	–	186.0	–	–	3.8
Tunisia	43.7	2.5	544.1	–	–	1.9
UAE	1718.5	480.0	87.4	–	–	–
Yemen	–	–	–	–	–	–
Total	27,335.8	5629.3	9250.0	242.2	90.0	12.0

– This industry is either not present in the relevant country or is present and does not export to EU28

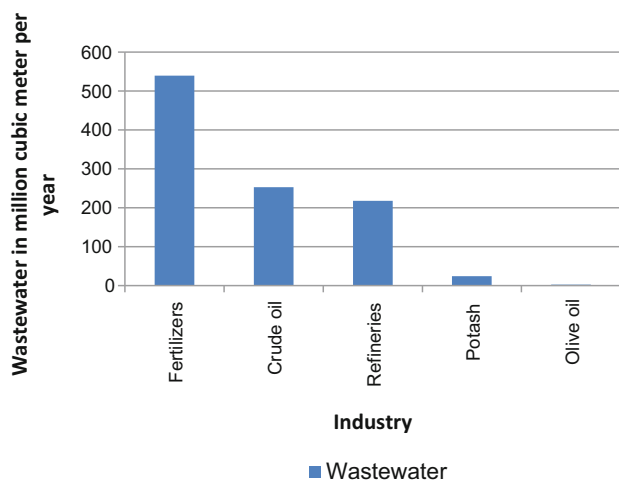


Fig. 1 Annual wastewater volumes generated from the five exporting industries within the MENA region in 2011

GWF

Figure 3 shows the GWFs of the studied MENA industries (GWF for production and export are for the years 2011 and 2015, respectively). The GWF related to production is

highest for crude oil and lowest for potash (the GWF of the pig iron industry is zero, because this industry does not produce effluent). The GWF related to production for the six industries is 111.8×10^9 m³/year. As a comparison, the Nile annual average river discharge measured at six stations is 55.49×10^9 m³/year (Center for Sustainability and the Global Environment Gaylord Nelson Institute for Environmental Studies, University of Wisconsin-Madison, Global River Discharge Database 1976–1987). Average annual value is based on the time period 1976–1987). If it is assumed that these five industries discharge their effluents into the Nile River, the pollution assimilation capacity of the latter would be consumed. Furthermore, the BOD concentration of the Nile would not remain below the ambient BOD water quality standard of that basin.

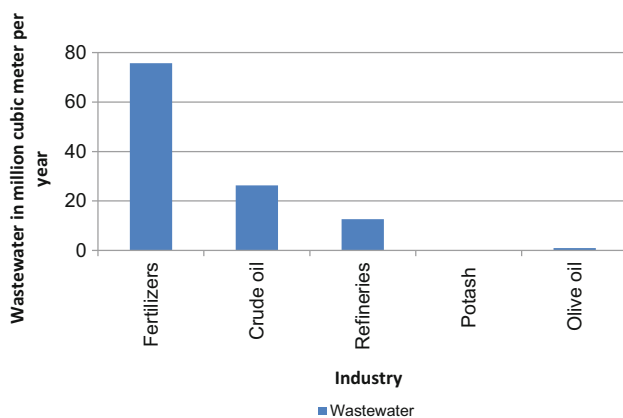
Discussion

Water and VW

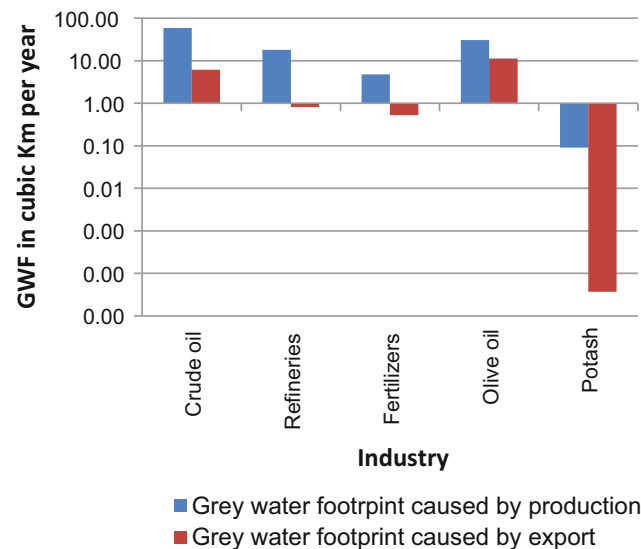
This study focuses on estimating the water requirements and wastewater generation of six relevant export industries

Table 4 Water and net VW statistics for MENA countries

Country	Net VW exported (10 ⁶ m ³ /year) (year 2015)	Net VW export/water used (%)	Total actual renewable water resources (10 ⁹ m ³ /year) ^a (year 2014)	Desalination capacity (10 ⁶ m ³ /year) ^b (year 2015)	Net VW export/(total actual renewable water + desalination capacity) (%)	Water used for industry/(total actual renewable water + desalination capacity) (%)
Algeria	41.8	32.7	11.7	1034.7	0.3	1.0
Bahrain	0.0	–	0.1	399.3	–	3.1
Djibouti	0.0	–	0.3	–	–	0.0
Egypt	–3.4	–	58.3	525.4	–	0.4
Iran	–18.4	–	137.0	375.2	–	0.3
Iraq	75.0	27.0	89.9	337.9	0.1	0.3
Israel	7.0	12.8	1.8	821.1	0.3	2.1
Jordan	–1.8	–	0.9	97.7	–	1.0
Kuwait	13.9	5.7	0.0	1365.7	1.0	17.8
Lebanon	–10.3	–	4.5	8.8	–	0.1
Libya	10.9	23.2	0.7	439.5	1.0	4.1
Morocco	52.9	11.2	29.0	135.3	0.2	1.6
Oman	–1.5	–	1.4	653.6	–	3.2
Palestinian Territories	0.0	–	0.8	10.6	–	0.0
Qatar	1.7	2.7	0.1	741.9	0.2	8.2
Saudi Arabia	125.2	6.5	2.4	5437.8	1.6	24.8
Syria	1.4	7.4	16.8	0.0	0.0	0.1
Tunisia	9.7	16.4	4.6	91.3	0.2	1.3
UAE	–3.4	–	0.2	3429.1	–	6.4
Yemen	–0.8	–	2.1	26.0	–	0.0
Total	300.0	7.0	362.5	15,930.9	0.1	1.1

^a Source: FAO AQUASTAT^b Source: GWI-Desaldata (desalination capacities for Lebanon and Syria are for the year 2013)**Fig. 2** WWGE for the five exporting industries of the MENA region for the year 2015

in some countries of the MENA region. The goal is to select and analyze important industries that export goods to EU28 (the classification of export and non-export

**Fig. 3** Grey water footprints for MENA industries because of production and export. GWF for production and export is for the years 2011 and 2015, respectively

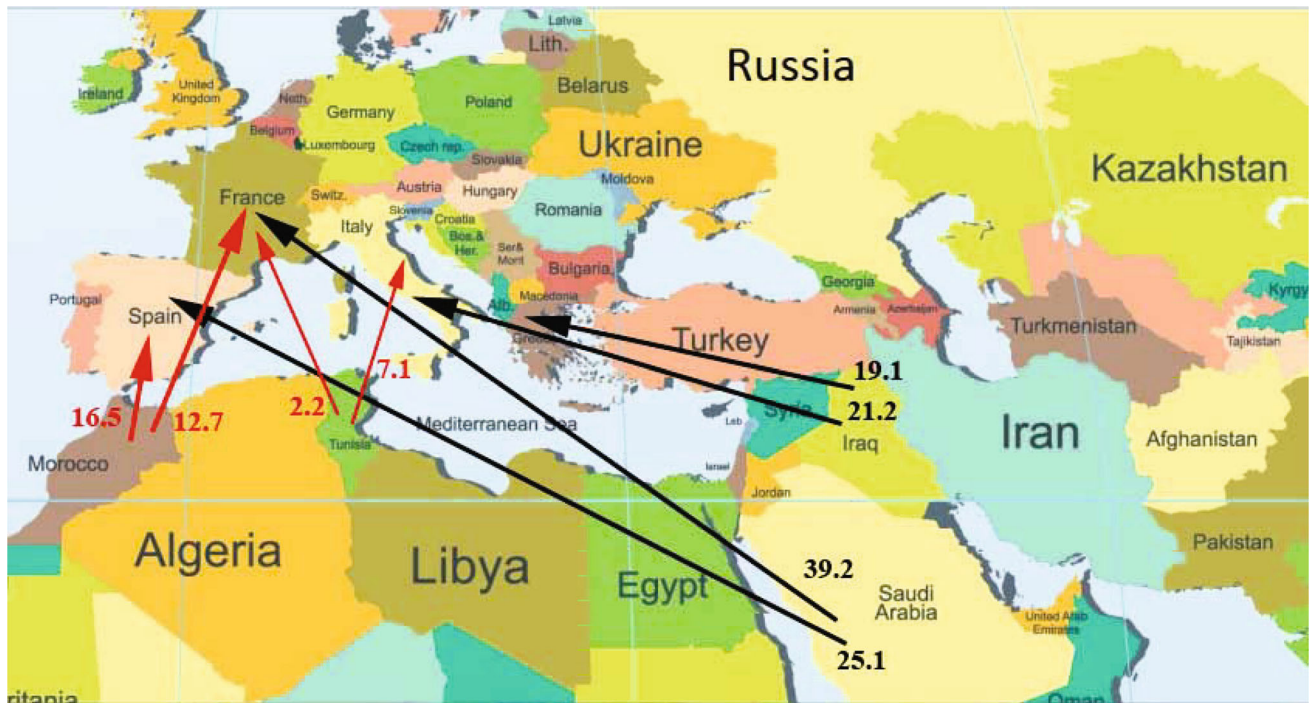


Fig. 4 Net VW export from four MENA exporting countries to four EU28 countries in terms of crude oil (black) and diammonium phosphate mixed fertilizer (red). The numbers represent millions of cubic meter of net VW exported in 2015 (map reference: Alhadef 2015)

industries has been based on the UN Comtrade database for the year 2015) and quantify/evaluate the indirect pressure that EU28 poses on the MENA hydrological system.

The export industry that is most relevant in terms of water demand within MENA is that of crude oil. As previously shown, the estimated water usage for this industry is approximately $2.73 \times 10^9 \text{ m}^3$. The water required to repressurize oil fields is the primary use for this industry. For example, it is common practice in large parts of North Africa to use freshwater from the regionally extensive Cretaceous aquifer as injection water for oil reservoir pressure maintenance (Hardisty 2010), whereas Libya repressurizes its oil fields using freshwater from Nubian sandstone and analogous aquifers, and it is estimated that this withdrawal exceeds $75 \times 10^6 \text{ m}^3$ (Hardisty 2010). Moreover, countries in the Middle East also use water for pressure maintenance. For example, the largest oil field in Saudi Arabia (Al-Ghawar) uses approximately $4.06 \times 10^8 \text{ m}^3$ of treated sea water annually for pressure maintenance (Durham 2005). Therefore, in Libya and Saudi Arabia, more than $4.81 \times 10^8 \text{ m}^3$ of water is used annually for injection purposes. In addition, the Al Furat Petroleum Company of Syria uses water from the Euphrates River as well as oilfield produced water to maintain the pressure of these fields controlled by this company (Al Furat Petroleum Company Website 2006).

Regarding VW, the indirect water use by EU28 is primarily caused by the import of crude oil, refined petroleum

products, and fertilizer goods, which amounts to 99.82% of the total indirect water use attributed to EU28 countries through the import of the six studied commodities. This finding is based on estimations calculated from many statistical data sources (e.g., UN Comtrade, Fertilizer Statistical Yearbook 2011 of the Arab Fertilizer Association, US Energy Information Administration). In this regard, Fig. 4 shows the net VW flows from four MENA countries to four EU28 countries for the year 2015. Iraq and Saudi Arabia are the largest net VW exporters in terms of crude oil, whereas Morocco/Tunisia are the largest net VW exporters in terms of diammonium phosphate.

Pollution

The threat of pollution imposed on the environment by the six relevant industries is also considered. Therefore, the GWF pollution related to production and export, the pollution characteristics, certain liquid emission effects, and the emissions mitigation practices in certain MENA countries is highlighted and discussed in this section. With regard to pollution caused by production, the highest polluter is the crude oil industry, and is followed by olive oil industry. The ratio of $\text{GWF}_{\text{export}}$ to $\text{GWF}_{\text{production}}$ ranges between 0 and 37%, with the olive oil industry having the highest percentage (36.75%) and potash having the lowest (0.04%). The pollution of water bodies caused by production is relevant for crude oil, refined petroleum, olive

oil, and fertilizers, although it could be considered negligible for potash (see Fig. 3). The pollution caused by exports is relevant for the crude oil and olive oil industries, because their annual combined GWFs represent 92.8% of the total from the export of all goods ($GWF_{\text{export}}/GWF_{\text{production}}$ were calculated based on information from numerous sources which can be found in the supplementary material).

The liquid emissions of crude oil, refined petroleum, and olive oil industries have been selected for the purpose of investigating the pollution. The value of the production GWF in Fig. 3 has been used as the criterion for the selection: the latter emissions display the largest three values in Fig. 3. The liquid effluents from the crude oil, refined petroleum, and olive mill industries have their own characteristics. The effluent from crude oil production contains a complex mixture of inorganic compounds (silt, salts, scale salts, Naturally Occurring Radioactive Materials, and metals) and organic compounds (heavy or light crude oils, and acid gases) (AlAnezi et al. 2012); the effluent from refineries contains high concentrations of toxic derivatives (oil and grease, phenols, sulfides, cyanides, suspended solids, and nitrogen compounds, as well as heavy metals such as iron, copper, selenium, zinc, molybdenum, etc.) (Nwanyanwu and Abu 2010); and the acidic dark-colored effluent from olive oil mills contains phytotoxic and biotoxic substances (Niaounakis and Halvadakis 2006).

The produced water from crude oil production contains BOD values ranging from 50 to 1400 ppm, in which oil and grease are the main pollutants of concern (Wang et al. 2004). The continuous discharge of formation water into a freshwater environment could cause major damage to aquatic and agricultural resources (Obire and Amusan 2003). This is probably the case for oilfield production sites in MENA. For example, the Saudi Arabian Oil Company (ARAMCO) deals with the formation water from crude oil production along with the gas and oil. The three streams are sent to a separation plant where the formation water is separated from the other two streams and afterwards directed to a treatment plant (The Oil Drum 2009), although there is no information on the method of treatment. Another example is the practices in dealing with the formation water in Kuwait. The produced water from the oil fields in North Kuwait was disposed in lined or unlined pits. It is not mentioned whether this water was treated or not. The groundwater in Kuwait was found to be contaminated due to these practices (Al-Rashed et al. 2010). A final example is that of Oman which paid attention to the groundwater pollution due to the disposal of produced water in the shallow water bearing strata in the past. The latter country has prohibited this practice and all the

formation water disposals are being switched to deeper bearing strata (Hirayama et al. 2002).

Refineries generate polluted wastewater that contains BOD levels of approximately 150–250 ppm (Pollution Prevention and Abatement Handbook, World Bank Group 1998). The ineffectiveness of refinery wastewater treatment causes these effluents to become dangerous and leads to the accumulation of toxic compounds in the receiving water bodies, which has potentially serious consequences for the ecosystem (Nwanyanwu and Abu 2010). This is most likely the case for the refineries in the MENA region. For example, wastewater from the Homs Refinery in Syria is subject to only simple physical treatment (separation of floating oil) before its discharge into the Orontes River (The Arabic Network for Human Rights Information 2007), and the wastewater from each of the three refineries in Kuwait is discharged into the Arabian Gulf (Kuwait National Petroleum Company (KNPC) Annual report 2006–2007), and although this water is treated, there is no information on the method of treatment. Oil and grease are the most critical parameters observed in Kuwait's refinery liquid emissions (KNPC Annual report 2006–2007). The application of oil-refinery effluent over a prolonged period on certain types of soil has been reported to cause an increase in the soil's heavy metal content (Zn, Fe, Cu, Mn, Cr, Pb, and Ni), with levels potentially accumulating to toxic levels, which could make the soil become phytotoxic (Rajesh et al. 2009). Such changes should be a cause for concern in countries that use refinery wastewater for irrigation, such as in Jordan (Mohsen and Jaber 2002).

The high BOD value of olive mill wastewater causes it to have high organic loads, and it is classified as among the strongest industrial effluents (Niaounakis and Halvadakis 2006). The pollution load of olive mill effluent has been reported to be 5–10 or even 25–80 times larger than that of domestic sewage (Boari et al. 1984; Schmidt and Knobloch 2000). In Morocco, most of the latter wastewater is discharged directly or through the public sewage system in its raw form without any treatment. These actions pose serious environmental problems. In Lebanon, it is also discharged in raw form to water bodies (7% of the total), applied to land (30% of the total), and discharged to the sewage system (27% of the total) (Hamdan 2009). Values for the non-biodegradable COD for olive oil mill wastewater using different biological treatment technologies have previously been reported by Yeşilada et al. (1999); Gonçalves et al. (2009); Ammary (2005); Hamdi et al. (1992). Yeşilada et al. used seven strains of fungi as treatment, and the lowest value was 4.46 g/l. However, Gonçalves et al. used six different yeasts as treatment, and the value ranged from 53.4 to 122.6 g/l. Hamdi et al. applied three biological treatment steps in series and obtained a value of 13.64 g/l,

whereas Ammary used an anaerobic sequencing batch reactor to obtain 2.7 g/l.

Policies to mitigate water scarcity in the MENA region

By 2050, it is estimated that all countries in the MENA region (except Iraq) will be subject to water scarcity (Michel et al. 2012), and one of the primary causes is population growth. Despite using the media to encourage birth control, such as in Jordan, a 15.5% increase in Jordan's population occurred from 2010 to 2014 (World Bank Data on total population for the time period from 2010 to 2014). In addition, the remaining MENA countries also experienced an increasing trend in population in the same time period. For example, by 2050, it is expected that Iraq's population will more than double (2.6-fold) and Syria's population will increase by 50%. In addition, migration related to the warfare occurring in Syria and Iraq has also increased the pressure on the limited water resources of certain MENA countries. Jordan is strongly influenced by this with 2 million immigrants from Syria and Iraq living in this country counting 6.98 million inhabitants (World bank data on total population 1995–2015) and substantially increasing the pressure on its limited water resources. To alleviate this pressure, it is suggested that Jordan follows a policy of acquiring as much aid as possible from international organizations and requesting that the immigrants return home as soon as the conditions in their countries improve.

Because the trend for the future is an increase in the population of the MENA region, the solution for managing its limited water resources is to implement integrated water resources management (IWRM) policies. The latter have been applied in Egypt, Jordan, and Yemen. In January 2005, Egypt issued a national water resources plan based on the IWRM concept, and this plan focused on conserving current water resources instead of finding new sources (i.e., bolstering supply). Jordan has successfully implemented the latter concept, and it has been using Islamic teachings since the early 1990s to increase the public awareness of water conservation within the context of IWRM (Michel et al. 2012). Yemen also attempted to incorporate the latter into its national water policy in the past decade and plans have included the involvement of farmers in water management and teaching IWRM in 2004 in Sana University (Michel et al. 2012). Because of the current political unrest, an IWRM would not help Yemen, because this requires a strong government and stable conditions.

Bolstering water supplies is a problem in the MENA region, because large projects, such as dam construction, river diversions, and sea water desalination, focus on the supply side of water management. The MENA water policies should be implemented to support methods/

projects that focus on water conservation, such as the use of drip irrigation for agriculture.

Encouraging bilateral IWRM-based agreements between MENA countries that share water resources helps to improve the stewardship of these resources through cooperation. An example of such an agreement is represented by the sharing of the Disi aquifer, which is a groundwater resource, between Jordan and Saudi Arabia. However, there is a dispute regarding this aquifer that has not been resolved, and there is a silent pumping race between these two countries in which each is attempting to obtain the greatest amount of water from the aquifer without cooperation (Allen 2010).

Despite water management strategies that are implemented in countries of the MENA region, they still need more water resources. This is why policies are currently followed to build several projects of sea water desalination. The latter are now in their phase of construction. In Jordan, for example, there is the Red Sea Desalination Project at Aqaba which will produce 80–100 million m³ of desalinated sea water in its initial phase of commercial operation in 2018 (Jordan Valley Authority 2014). This desalinated water will be shared between Israel, Jordan, and Palestinian Authorities. Egypt will be constructing a desalination project consisting of five plants in the Egyptian governorate of South Sinai with a combined production capacity of 60,000 m³/day (Construction Review Online 2016). Kuwait Fund for Arab Economic Development will support construction of this project by raising funds totaling up to 98.6 million US \$ in form of loan (Construction Review Online 2016). A final example is the Al Khafji Solar Saline Water Reverse Osmosis (Solar SWRO) Desalination Plant near the Kuwait border in Saudi Arabia, due to be completed in 2017, is set to be the world's largest facility of its kind. The plant will be capable of treating 30,000 m³ of water every day, which can supply over 100,000 people daily (Living water 2016).

Other policies of the MENA countries state that their industries should invest and implement the latest techniques and technologies to reduce the water use. For example, they could cooperate with General Electric (GE) in the United States that provided technology to reduce water consumption in a Canadian petroleum refinery (Hydrocarbon Processing 2016) and a Steel producer in Indiana USA (Hardcastle 2016). Regarding the Canadian Petroleum Refinery, GE provided an advanced water recycling technology, which consists of combining a membrane bioreactor and a high efficiency reverse osmosis system to recycle and reuse about 7600 m³ of wastewater a day. After commissioning, the Canadian refinery will reduce its freshwater use by 28% (Hydrocarbon Processing 2016). Moreover, the US Steel producer used a rotary vacuum filter provided by GE to dewater sludge produced by this

company, and the water produced has been reused as make-up to cooling systems (Hardcastle 2016). Another example is a Midwestern refinery in the US, which built an integrated membrane facility on its site for the treatment of multiple water sources (among which are refinery's wastewater and municipal wastewater) to be reused (Close 2016). The membrane facility consisted of microfiltration, nanofiltration, and reverse osmosis membranes. The Midwestern refinery was able to reduce water consumption by about 1.5 million gallons daily (Close 2016). A final example is the two-phase olive oil extraction, which uses less water than three-phase extraction systems (Azbar et al. 2004). This technology should be replaced by three-phase extraction systems currently in use in MENA countries such as Israel. The countries of the MENA region can learn from the Spanish experience where about 90% of olive oil mills use two-phase extraction systems (Spanish Ministry of Environment 2000).

Further methods of mitigating water scarcity problems in the MENA region include policies to encourage the contribution of the private sector in water management. The public sector in many of the latter countries suffers from poor management in the water sector, which could be resolved through cooperation between the private and public sectors to alleviate water scarcity. The MENA governments should implement policies (such as raising water tariffs) that will instill confidence in the private sector, so that their investments in the water sector will be returned within a reasonable time period (return on investment). It is worthwhile to mention that few countries in MENA have succeeded in achieving private sector contributions (Michel et al. 2012).

Finally, it should be mentioned that Islam, as the main religion of MENA countries, could help assist water conservation efforts to a great extent. Islamic law provides detailed information on the subject of water, and it is recognized as a social and political power in that region. Therefore, Muslim societies prefer to receive environmental education from their religious leaders as revealed by surveys (Wickström 2010). Imams could be educated on the water scarcity problem, and they could increase public awareness of water conservation during Friday prayers in mosques, which are among the most efficient locations for providing public education on all topics regarding daily life. However, the responsibility for educating the public on how to best manage water demand should not rest solely on the shoulders of mosques and religious schools; rather, it should be extended to the entire educational system. Islam says that water cannot be owned and it belongs to everyone. If this concept is practically realized, the disputes related to transboundary waters in this region would be resolved. An example of this type of dispute is between Turkey, Iraq, and Syria over the Tigris-Euphrates basin.

Turkey constructed an extensive dam and hydropower project on the Tigris and Euphrates rivers, thus reducing their flows to Iraq by 80% and to Syria by 40% (Kleyn 2012). The Turkish government has stated that it owns these water resources and has the right to manage them according to the water and economic needs of Turkey (Michel et al. 2012). There is also the transboundary water dispute between Egypt, Sudan, and Ethiopia due to the Grand Renaissance Dam that will affect the flow of the Nile River upstream. Although Egypt and Sudan had, and still have, strong opposition to this dam since the beginning of its construction in April 2011, the Ethiopians insist to complete the dam, resulting in diplomatic disputes between the three aforementioned countries. The completion of this dam would have catastrophic effects on Sudan and Egypt. The Egyptian experts claim that its construction would result in a loss of 60% of Egypt's agricultural land, and its share of water resources from the Nile would decrease by 9–12 billion m³ per year (Ezz Al Arab 2015). Naser Faruqi (a leading researcher in water management) suggested solutions to these complex disputes, which is to establish an Islamic council that has the power to judge and mediate resolutions to these disputes between the states that share transboundary waters.

Climate change

The emissions of greenhouse gases into the Earth's atmosphere caused its composition to change resulting in temperature rise (Zereini and Hötzl 2008). Projections show that global warming will be between 1 and 6.3 °C in 2100 (Mosbrugger 2008). Furthermore, predictions say that North Africa's annual average temperature rise due to climatic changes will be higher than the average expected for the planet (Radhouane 2013). North Africa would be particularly affected by droughts that would be more frequent, more intense, and longer-lasting. Several studies indicate (Evans 2010; Kundzewicz et al. 2007; Ragab and Prudhomme 2000) that the precipitation in the MENA region will decrease from 5 to 30%. The predictions also announce a drop of 4–27% in annual rainfall in North Africa (Radhouane 2013). Indeed, Middle Eastern countries experienced precipitation decrease. For example, the overall volume of precipitation in the Lebanese coastal zone has dropped from 914.5 mm in 1976–1977 to 718 mm in 1995–1996. Such a decrease is also seen in the amount of falling snow in the mountainous areas of Lebanon, where it sharply decreased from 499 cm in 1965–1966 to 380 cm in 1995–1996 (Arkadan 2008). Another phenomenon accompanied by climatic change is desertification. The latter is a form of land degradation by which land becomes more arid (Lane 2014). The main cause of desertification is the removal of plant life (United

Nations Convention to Combat Desertification (UNCCD 2014). Plant removal is caused by two dominant reasons; one of them is climatic change (UNCCD 2014), that results in temperature rise and precipitation decrease. This can cause drought conditions and prevents the sustained growth of vegetation (UNCCD 2014). The Mediterranean countries are already suffering from desertification and climatic changes would only exacerbate this phenomenon (Radhouane 2013).

Water resources/reservoirs and their potentialities in the MENA region

MENA has an actual renewable water resource per capita value of about 1100 m³/year (World Bank 2007), which is far below the water security threshold of 1700 m³/year. This region uses more water than it receives each year (World Bank 2007). Ragab and Prudhomme (2000) estimated that Tunisia is using 83% of these resources, and Egypt 92%. Based on the average for 2000–2009, the potential of surface and ground water supply in MENA is 171 and 48 km³, respectively (World Bank 2012). This shows that there is more dependence on surface water for the daily human activities than ground water. Some countries depend on surface water as the main water resource (such as Egypt) others depend on groundwater (such as Jordan). Egypt's main freshwater resource is the Nile River and two groundwater aquifers (the first comprises groundwater in the Nile Valley and Delta, and a second aquifer which is non-renewable in the western desert) (Egypt National Action Program to Combat Desertification 2005). The estimated average annual discharge of the Nile River at Aswan is 84 billion m³, while the annual withdrawal from Nile and Delta aquifers is 6.13 billion m³ (Egypt National Action Program to Combat Desertification 2005). As for Jordan, the surface water is very limited, and therefore, the groundwater is the main water source (Al-Zyoud et al. 2015). Most of the groundwater aquifers in Jordan are overexploited (Jordan Ministry of Water and Irrigation (JMWI) 2013). There are 12 important aquifers in Jordan from which a combined abstraction of about 540 million m³ water has happened in the year 2013 (JMWI 2013). Nine out of the twelve important aquifers in Jordan are overexploited [safe yield of the 9 aquifers: 280.5 million m³ (JMWI 2013), total combined abstraction from these nine basins: 440.8 million m³ (JMWI 2013)].

Conclusions

The water demand and pollution potential of the exporting and non-exporting industries in the MENA region are considerable. The net VW export to EU28 caused by the

net flow of export commodities to EU28 countries increases this pressure. The estimations of water usage and wastewater generation were obtained by applying Arabic-specific figures. The Saudi Arabian hydrological system is under the greatest pressure internally as well as externally (net export to EU28). The pollution from these industries is a cause for concern, especially because of the presumable discharge of their wastewater directly into the environment or through the public sewage system in raw form or with only partial treatment, which occurs for olive mill wastewater in Morocco and Lebanon. Indirect water usage by EU28 countries is most relevant for the crude oil, refined petroleum, and fertilizer industries. In terms of the GWF, water body pollution caused by production water is most relevant for the crude oil, refined petroleum, and olive oil industries. Although, water body pollution caused by the export of goods is also relevant for the crude oil industry and olive oil mills. The MENA industries do not have the technological development and water conservation techniques possessed by EU28 industries. Presumably, there are a number of factors that contribute to water loss in the exporting industries, and effective measures have not been provided to counteract such losses. However, the EU28 and MENA countries should cooperate to reduce industrial water requirements by supporting the implementation of the latest technologies to alleviate the environmental impacts of these industries. This suggestion must be implemented, because the scarcity of water resources in MENA continues to be a cause of concern due to (1) population growth [1.8% in MENA for the year 2015 (World Bank3 2015)]; (2) a lack of precipitation, which reduces the actual renewable water resources per capita by several fold compared with those of water-rich countries; and (3) climate change.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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