Challenges to wastewater reuse in the Middle East and North Africa

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Abstract

Faced with increasing water scarcity, policy-makers in the Middle East and North Africa are increasingly interested in tapping non-conventional water resources, such as recycled wastewater, to meet demands for water. Yet despite its perceived advantages, few countries have succeeded in developing extensive, successful and safe reuse, despite considerable innovation in the water sector. This paper argues that much of the relative failure to expand reuse in MENA can be linked to incentive problems in wastewater management. A simple conceptual model is applied to explore how demand among different users interacts with water supply to produce different reuse cases. The economics of these cases are discussed with reference to data on water pricing and wastewater management. The analysis shows that a variety of constraints inhibit formal reuse of wastewater in MENA, including problems related to the cost of reuse, problems associated with low demand for reclaimed wastewater, the widespread lack of effective price signals and cost recovery in the water sector, and challenges in structuring the financing of reuse.

Keywords: Wastewater recycling; Middle East and North Africa; water scarcity; water management

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1. Introduction

With 14 of 20 nations classified as being in water deficit in 2010, freshwater scarcity in countries in the Middle East and North Africa (MENA) is acute (FAO 2010). Projections of population growth suggest that four of the remaining MENA countries are likely to join that group over the next half century (United Nations 2010). There is also growing consensus among scientists that climate change will reduce precipitation and increase temperatures in MENA countries; both of these trends seem likely to increase stress on regional water resources (IPCC 2007).

Faced with this increasing scarcity, MENA governments, decision-makers and planners have become increasingly interested in tapping non-conventional water resources, such as recycled wastewater, and desalinated brackish or salt water, to meet demands for water. Of these options, wastewater reclamation is often touted for its "inherent" benefits, including: augmentation of water supplies through replenishment of ground or surface waters; preservation of better quality water resources for high-value uses such as potable water; environmental protection obtained through improved wastewater management and reduced surface water abstractions, and postponement of costly investments in water storage and desalination (Scott et al. 2004; Asano et al. 2007).

Yet despite such perceived advantages, few countries have succeeded in developing successful and safe wastewater reuse programs, even as many have demonstrated considerable innovation in the water sector in general (Bucknall et al. 2007). This paper builds on previous work to argue that much of the relative failure to make greater use of reclaimed wastewater in MENA can be linked to incentive problems related to managing the externalities associated with wastewater discharges (Kfouri et al. 2009). Because these externalities have rarely been fully accounted for, it remains difficult to encourage investment in safe reuse. Agents who discharge wastewater rarely if ever bear the high cost of its conveyance and treatment to reuse standards, and irrigators, who themselves do not pay the full cost of water supply, have little economic reason to opt for recycled water unless they have no choice.

We develop a simple conceptual model that includes two types of agents: the first, a high-value water user (perhaps a municipal / industrial user), and the second, a low-value water user (for example an irrigator). This model is used to explore the conditions that make widespread wastewater reuse a challenge in MENA, and present a series of policy-relevant cases for expansion of reuse. In the first case, water users are free to choose among alternative supplies (one taken from the natural environment and the second being recycled wastewater), which are differentiated by price and perceived quality, and constrained in total quantity.[2] Reuse in this case is limited because of the low demand for recycled water relative to that for conventional water. In the second and third cases, users cannot choose between alternatives. The water is either mixed with conventional supplies to create a single homogeneous product that is delivered to users (Case 2), or it is allocated separately to users by a water manager who can limit access to alternative supplies (Case 3). The economics of these cases are discussed with reference to data on water pricing and wastewater management and treatment in MENA.

The paper is organized as follows. The next section presents data and simple calculations that establish the context of wastewater reuse in the MENA region. Section 3 discusses Case 1, which is the most dominant in MENA. Section 4 then presents and discusses Cases 2 and 3. Section 5 synthesizes observations on the general potential of reuse, and develops a set of policy recommendations for furthering it. Section 6 concludes.

2. Current wastewater reuse in MENA

Experience with wastewater reuse – here defined as the recycling of *treated* wastewater back into a country's water balance following use – in the MENA region is widespread.[3] This recycling

[2] Note that the emphasis on "perceived quality" is important because it is possible for treated recycled water to be at least as good, if not better than conventional sources, at least with regards to official water quality standards, if advanced treatment processes such as reverse osmosis are used. Even so, there are understandable objections to using recycled water for drinking purposes.

[3] *Unplanned* wastewater reuse is also common in MENA and the developing world, despite health concerns. This is when untreated sewage is applied onto agricultural lands or discharged into the environment from which it is again withdrawn for consumptive uses. The economic implications of unplanned and planned reuse are very different, as will be discussed in Sections 3 and 4.

can be direct, meaning that storage and conveyance infrastructures transport effluents from treatment works straight to the site of application, or indirect, when treated wastewater is discharged into surface waters or aquifers. Kfouri et al. (2009) review published and unpublished works and find that nearly all countries in MENA are involved in some such reuse, albeit with varying levels of success. Even today, most documented initiatives of wastewater reuse remain pilot initiatives, suggesting that the challenge of scaling up this technology has not fully been met.

One important reason for this appears to be the presence of two important hurdles that impede the potential for planned reuse applications: the low rates of a) collection and b) treatment of wastewater in the region (see Table 1). The Wastewater Reuse Index (WRI; rate of actual over potential reuse) depends on both of these factors as well as the fraction of treated wastewater that is actually recycled. Thus, insufficiency in any one of these dimensions drives down reuse rates. The hurdles preventing collection and treatment of wastewater are partly financial: investments in piped sewerage and wastewater treatment are very expensive, costing about $1.1 per cubic meter, or roughly half of the total cost of water delivered to households (Whittington et al. 2009).[4] The hurdles are also partly economic: unlike the case of piped water, for which incentives are aligned because households must pay to obtain services, most of the benefits of sewerage are diffuse health and aesthetic gains that only accrue to the community as a whole. In several MENA countries, high percentages of the population in dense urban areas still use septic tanks or other on-site sanitation systems (data from the Joint Monitoring Program (JMP) of the World Health Organization (2010)).

[Table 1 about here]

Indeed, evidence from around the developing world shows that sewerage lags well behind coverage with other municipal services, such as piped water, electricity, and telephones (Komives et al. 2003). The average level of piped water coverage across MENA countries is

[4] All costs and data reported in this paper have been normalized to 2010 $US.

about 80% (ranging from 28% in Yemen to 100% in Israel and Kuwait), while sewerage is only about 60% (ranging from 12% in Yemen to nearly 99.6% in Kuwait, see Table 1 Column C).[5]

Sewerage at least removes wastewater from the immediate household and community environment, but wastewater treatment is even further removed from water consumers; its benefits mainly accrue to people living in low-lying urban areas or downstream of large municipalities. In MENA, much of the wastewater collected via sewerage receives minimal or no treatment prior to discharge on land or into the sea or other surface water bodies (Table 1 Column D). This reality of limited treatment applies even more strongly for septage pumped from on-site systems when they fill up; though data on this do not exist, it is likely that a greater proportion of wastewater from on-site systems is discharged outside of the conventional wastewater treatment system. In the absence of strong government enforcement or regulation of wastewater discharges, individuals will not take account of the externalities associated with wastewater conveyance investments and treatment. Upstream users have little incentive to treat wastewater discharges which pollute downstream water supplies, compromising the ability of downstream locations to use recycled wastewater safely and effectively. The private level of investments in sewage conveyance infrastructures and treatment plants will therefore be well below the social optimum.

Rich countries like Kuwait and Bahrain, which have managed to create effective systems for collecting and treating nearly all of their wastewater, can more easily benefit from reuse, because the financing of reuse does not entail paying for missing components of wastewater management. In contrast, countries like Egypt, Iraq and Yemen, with relatively low rates of sewerage, or Libya, Lebanon and Morocco, which treat very little of their wastewater, have a steeper road to climb.[6] Similarly, additional complications occur where operation and maintenance of conveyance and treatment infrastructures is neglected, as these may stop

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[5]All data presented in this section should be treated with caution, as they are somewhat inconsistent across years and countries. But while specific estimates for particular countries may be inaccurate, it seems safe to say that the situation of incomplete sewerage, lower treatment of sewerage, and even further reduced reuse rates generally applies across the region. Some of the numbers are not far from estimations based on more detailed wastewater accounting surveys conducted in specific countries; see for example Abu-Madi (2004).
[6]Morocco has however been moving quickly to expand wastewater treatment capacity (see: http://www.globalwaterintel.com).

producing recycled water that meets the standard for reuse. All of these issues confront the locations where *unplanned* reuse is most prevalent. Some analysts argue that economic calculations for reuse projects require that "…only the marginal cost of wastewater recycling (additional treatment, storage, and distribution) be considered, excluding the cost of wastewater collection and treatment" (Lazarova et al. 2001). However, this is only true if these services are in place and functioning in the absence of the recycling investment (Kfouri et al. 2009).

In order to better understand these potential financial barriers, let us briefly consider the costs of conveyance and treatment of reuse (Table 2). Sewerage costs vary substantially as a function of urban density, topography, and the nature of the housing stock, but Whittington et al. (2009) estimate that conveyance infrastructures cost on average US$0.8 per cubic meter of water delivered. These costs can be substantially reduced, to US$0.3/$m^3$, by using condominial sewer technologies, but the use of such low-cost technologies would limit the potential for wastewater reuse to zones very near to collection sites (perhaps urban landscaping or gardening). The costs of wastewater treatment also depend on the technology that is used, the quality of water required before discharge, and the availability of land. Lee et al. (2001) estimate average treatment costs to be US$0.65/$m^3$ (range 0.57–0.90); estimates from Whittington et al. (2009) and others are somewhat lower at $0.3/$m^3$ (see Table 2). These high costs imply that financing wastewater collection and treatment though wastewater reuse initiatives will be extremely challenging unless the marginal product of reused water is high. In some instances, wastewater conveyance and treatment together may even exceed the $0.5-1.5/$m^3$costs of alternative options such as desalination. The other important cost of reuse, which will vary across supply alternatives depending on the relative distances to the reuse sites, is re-distribution of treated water. This cost varies from US$0.10-0.50/$m^3$, and represents a lower bound on the cost of reuse in places where sewers and treatment are already in place.

[Table 2 about here]

The fact that the WRI is low in so many MENA countries with water scarcity problems (for example in Bahrain, Libya, Egypt, Morocco and Tunisia) suggests that there may be factors besides the lack of wastewater conveyance and treatment that restrain reuse in the region (Table 1 Column F). It could be related to the demand for recycled water, whether because a) the marginal product of reused water is lower than the cost of delivering it, b) the prevailing prices for alternative sources are highly distorted (due to subsidies for irrigators), or c) users are sensitive to real or perceived differences in quality between conventional and reuse supplies. Financial barriers may also play a part, given that the infrastructures for distribution of recycled water require investment in capital intensive civil works like irrigation canals or piped water systems. To frame these issues, the next two sections develop and apply a simple conceptual model to illustrate a number of simple realities facing the reuse sector in MENA.

3. Characterizing the dominant reuse situation in MENA

This section develops a simple static model of markets for conventional and reused water in order to characterize the dominant reuse situation in MENA. The model includes two types of agents: a high-value water user who is sensitive to real or perceived water quality and requires tertiary treatment prior to reuse, and a less quality-conscious, low-value user who requires a lower level of treatment. Though the description focuses on these two types, the conclusions obtained could be applied and extended to a larger and more diversified set of agents. In the MENA context, the differentiation in user types applies across sectors, for example irrigation (low-value) versus municipal / industrial (high-value), as well as within sectors, for example, for low-value grain-producers versus high-value growers of fruits and vegetables.[7]

3.1. The gap between supply and demand for water

In most MENA countries, the price for raw (untreated) water from conventional water supplies is very low or zero, until the capacity limit ($\bar{Q}$) is reached, after which no more water is available. The high and low-value user types have demand for water from the conventional water supply D_H and D_L, respectively, such that total demand $D_T = D_L + D_H$. If the price of raw water from conventional sources is ${p_1}^*$, the total demand is ${q_1}^*$, and there is no shortage (Figure 1).

[7] A complete graphical presentation of the model applied below can be found in technical notes available online in the ERF working paper series, available at: http://www.erf.org.eg/

However, if the price of the water is $p_2{}^*$, total quantity demanded $q_2{}^*$ is greater than $\bar{Q}$, and there is water shortage $\varepsilon_2 = q_2{}^* - \bar{Q}$.[8] This is the typical situation in MENA.

[Figure 1 about here]

There are several ways of addressing this shortfall. The first is to raise the price of water until the total quantity demanded falls below $\bar{Q}$. Though data on water tariffs are limited, in most MENA countries, indeed throughout the world, water is priced well below the full cost of supply, particularly in the low-value agricultural sector.[9] Table 3 summarizes the range of prices charged for irrigation and domestic water that were found through this research, as well as an estimate of the marginal cost of raw water supply (Columns 2 through 4). This marginal cost generally includes the cost of maintaining storage and conveyance infrastructures, but does not include the cost of capital depreciation or treatment and distribution of potable water to municipal and industrial users.

[Table 3 about here]

Fees levied to irrigators for agriculture are low and typically even zero. In the MENA countries with the largest surface water irrigation systems (Egypt, Iran, Lebanon, Morocco and Syria), charges vary from annual land levies (in Egypt, Lebanon and Syria), where the price of marginal units consumed is zero, to a fraction of the water supply cost (in Morocco and Iran). For groundwater, farmers typically pay only pumping costs (up to about US$0.30/m^3). In addition, MENA governments have often provided generous subsidies for installation of groundwater pumping equipment, and fuel (Bucknall et al. 2007). These policies do little to encourage water conservation. No MENA countries use scarcity pricing even though water scarcity is supposedly acute. Only Israel engages in serious demand management: a) charging farmers close to the full cost of supply; and b) monitoring, metering and charging for groundwater abstractions at the

[8]Note that there may be additional costs associated with providing finished water to high-value users, which are generally reflected in differentiated and higher prices for that sector. For simplicity, in this paper we only include the price of raw water, before such finishing treatment.

[9]The most complete may be Global Water Intelligence's annual tariff survey; see: http://www.globalwaterintel.com.

same rate as surface water use. Thus, even if the quality of reused water were good, it seems unlikely that irrigators would opt for recycled water over conventional surface supplies unless they had no choice but to use the former, and reuse can only compete with groundwater pumping where the latter is expensive.

Several MENA countries also charge among the lowest rates in the world for municipal water, for example Saudi Arabia, Egypt, Libya, Qatar and Yemen. Additional and separate charges for wastewater management are relatively rare in the region and usually do not come close to the full costs of services documented above (Table 4, data from Global Water Intelligence 2010). Only in Dubai and Jerusalem, and perhaps Tel Aviv and Ramallah, do the combined tariffs come close to the total costs of high quality services. These low tariffs help to explain why sewerage and coverage rates with wastewater treatment are so low in MENA. Increasing this coverage is not impossible; indeed, the recent rise in tariffs in large Moroccan cities coincided with a large push to improve wastewater management, and further rate hikes are anticipated to sustain this progress. Other large cities in MENA, though clearly not all, have also seen recent increases in rates for water and wastewater management (Table 4). In some MENA countries, domestic and municipal water users pay tariffs that approach the costs of supply and treatment to drinking water standards (Table 3). In particular, cost recovery appears high for municipal piped water systems in Israel, Jordan, Oman, and the United Arab Emirates, which have average tariffs ranging from \$0.70-1.45/m^3. Utilities in Tunisia, Morocco, Kuwait, Algeria and Lebanon also recover a large proportion of their operating costs (these average rates are hard to calculate without additional data, due to the increasing block tariff structures that prevail).

[Table 4 about here]

Raising water prices further to achieve cost recovery in MENA countries would go a long way towards reducing the quantity of water demanded to levels below the volume of available renewable resources. If water demand still exceeded water availability at cost recovery prices, water rates could be raised further to internalize the scarcity value of the resource. No additional water would need to be supplied; users willing to pay less than this equilibrium price, at the intersection of $\bar{Q}$ and D_T (Figure 1), would no longer buy water. Higher water and sewer rates could also indirectly facilitate reuse, by lowering financial pressure on utilities and/or the public sector, allowing for more investment in wastewater treatment. In fact, such investments may be justified from a social welfare perspective if improved wastewater management delivers net benefits. There is widespread dissatisfaction with the existing quality of water and sanitation services in MENA countries, and a general willingness to pay more for such improvements. In Palestine, 83% of respondents from five Gaza governorates were willing to pay increased fees for services that met the WHO standards for water quality (Al-Ghuraiz and Enshassi 2005). Average WTP was about US$0.71 per m^3 for higher-quality services, close to the cost of such services, and much more than actual average payments of $0.26/$m^3$ (LEKA 1997). These data from relatively poor communities support the idea that wastewater management may be underprovided in many MENA countries. Without this investment, however, the cost of safe, planned reuse in most locations in MENA will far exceed the cost of conventional supplies (including the cost of treatment which more than doubles the cost of reuse).

Raising water rates is often politically unpalatable, however. The agriculture sector and the poor would likely bear the brunt of higher water prices, and governments that tout the benefits of improved food security and protection for the poor have usually been unwilling to risk the political backlash that high water rates might entail (Perry 2001). Thus, a second solution is to use non-price rationing devices, i.e. reducing the reliability of water delivery to selected users or to the population as a whole, to allocate water or simply to drive down demand. Unfortunately, the costs of a policy of reduced reliability are often high, and its success in reducing demand may be less than anticipated. Individual water users faced with low supply reliability routinely invest in storage tanks or increase pumping of groundwater in order to maintain water consumption during periods of interrupted supply (Rogers et al. 2002). Low reliability may also create health risks for water consumers, due to problems associated with pressure fluctuations in the distribution system, or of storing water for extended periods at the point of use. Other coping behaviors include wasteful irrigation practices (flooding one's fields whenever possible), or delaying investments in conservation technologies like drip irrigation that rely on dependable services.

A third and more politically attractive solution is to identify and develop new, alternative supplies of water. In most MENA countries, available surface and groundwater sources have long been tapped, and the remaining possibilities for expanding supply are often limited to reuse and desalination. Desalination is costly ($0.5-1.5 per m^3without accounting for distribution costs), energy-intensive, and polluting (due to brine by-products), and can only be financed with large subsidies or payments by very high-value users (United Nations 2001; Kfouri et al. 2009). The high costs of desalination, combined with the promise of improved wastewater management and treatment, explains much of the attraction of wastewater reuse.

3.2.Low demand for recycled water in MENA

For recycled wastewater to be considered viable, however, three important conditions must be met. First, the cost of wastewater reuse – which will vary depending on the extent to which wastewater processing is developed in a particular location, as discussed above – should not exceed the price that users are willing to pay for it. This is the typical context that precludes most private investment in planned reuse.[10] On the other hand, users rarely pay the full cost of water supply in MENA, and governments have repeatedly shown that they are willing to subsidize water and wastewater services for key sectors such as the urban poor and irrigators. As a result, the gap between willingness to pay (WTP) and the full cost of supplying recycled wastewater does not itself explain the challenges facing reuse. A second condition then, is that the private cost borne by a user buying reused water (the tariff for recycled water) must not exceed her WTP (otherwise she will not buy it). Third, users buying recycled water must also be the ones who would increase their consumption at the prevailing price for conventional water supplies, but who cannot do so because of shortage. Otherwise, excess demand will remain, as new (and different) users emerge, perhaps in the low-value sector. In other words, those suffering shortfalls must be content to use at least some recycled wastewater in place of the water they lack from the conventional source. This is not generally true in most MENA countries because water source choice among all users is preserved, which results in a situation where only limited reuse is feasible.

[10]There are of course exceptions, but they seem to be for very special cases and depend on creative institutional arrangements, for example irrigation of a golf course in Benslimane, Morocco (Lahlou, 2005).

It is tempting to think that reuse can alleviate water shortage simply because there is excess demand at the prevailing prices for water, and because the theoretical quantity of reused water is large enough to make up some or all of this deficit. All that is needed is additional subsidy to facilitate reuse, which is just an extension of the policies that maintain low water prices. But there is an important flaw in this reasoning. When the price for conventional water is artificially low, what becomes relevant is the demand for reused water conditional on those prevailing prices. Because willingness to pay is suppressed by low water rates for alternative supplies, it is often the case that reuse will not be attractive. This may be particularly true when the specific water units foregone by users due to water scarcity are also the units for which the willingness to pay for reuse demand is below the existing price. Consumers, especially high value users, will continue to not consume these units because reused wastewater is perceived to be of lower quality. Furthermore, because consumers in developing countries are often accustomed to coping with unreliable water supply, they may find a wide variety of ways to avoid using low quality water.

One source of information on how irrigators might react to reuse water comes from farm productivity data. Many supporters of reuse suggest that crop yields can be improved, or that fertilizer costs can be decreased, owing to the nutrients present in the water (Neubert & Benabdallah 2003). However, the Drainage Water and Irrigation Project (DWIP) in Egypt has produced data related to the use of three types of water – fresh surface water, mixed surface and reused water (from upstream irrigated areas as well as municipal discharges), and pure reuse of drainage water – that shows that productivity declines with increasing concentration of recycling, for a variety of cereal crops as well as cotton (DWIP 1997). Such data should of course be interpreted with caution. In Egypt, much wastewater is simply released untreated into irrigation systems, and reuse of "treated" water would perhaps not be similarly damaging (though wastewater treatment does not solve salinity problems). It could also be that the farms irrigated with mixed or drainage water are different from those with access to fresh water sources along other dimensions that are important in determining crop yields (such as farmer effort, use of inputs like labor and fertilizers, soil fertility and climate), or that some salinity-tolerant crops would better tolerate recycled water.

There is however other evidence that suggests that the demand for reclaimed wastewater is generally lower than it is for alternative sources of fresh water. The first source of evidence is in the fees charged for reused water (summarized in Table 3). Yemen and Syria do not charge farmers anything for recycled water (Bazza 2003; Baquhaizel and Mlkat 2006); prices in Kuwait are also very low (US\$0.07/m^3) relative to the cost of supply (Fadlelmawla 2009). The Tunisian experience with wastewater reuse offers an especially cautionary story. There, the government mandated a price of US\$0.02/m^3 for farmers using recycled wastewater, in an effort to stimulate reuse (Lahlou 2005; WHO 2005). This price is only a fraction of the US\$0.08/m^3 price for already heavily-subsidized irrigation water, and yet farmers continue to show reluctance to use this alternative water (Bahri and Brissaud 1996; Shetty 2004; Boubaker 2007). We can conclude that the demand for recycled water, conditional on low prevailing prices for conventional water, is extremely low in Tunisia. Only in Morocco is there a single pilot case of pricing of recycled water at close to the marginal cost of supply, for irrigation of a golf course for which the alternative of municipal drinking water is much more costly (Lahlou 2005).[11]

Preference studies confirm that perceptions of quality are important. Evidence from contingent valuation and other studies suggests that users are often willing to pay a premium for high-quality water and sanitation. In one Kuwaiti study, households were willing to pay more for domestic water supply if they were assured that it did not contain recycled water (Dolnicar and Saunders 2006). Studies in Qatar and Jordan have found that households express concern over reuse that is used for growing agricultural products (Ahmad 1991; Mrayyan 2005; Pasch and Macy 2005). In Crete, forty percent of farmers are not willing to pay anything for recycled water and only 18% of farmers are willing to pay as much for it as for fresh water (average WTP is about 55% of the prevailing rate for conventional water) (Menegaki et al. 2007). One alternative that is sometimes advanced for cheaper wastewater reuse, which is to provide only basic treatment, is not viewed favorably by farmers because it precludes certain uses and involves crop

[11]More generally, the availability of high quality alternatives, and thus the concept of the conditional demand curve (Section 3), is important. Tunisian farmers who have no choice between using reclaimed wastewater and high salinity groundwater, and Palestinian farmers facing acute water scarcity, do not object to paying for reuse (Shetty, 2004; Khateeb, 2001).

restrictions. Nearly half of farmers in Jordan and Tunisia say they would not be willing to pay anything for such water (Madi and Braadbaart 2002).

When conventional and recycled water sources are kept separate, additional subsidies will thus typically be necessary to achieve reuse goals and to drive the price of recycled water well below that of conventional water. Such policies have had limited success in countries such as Tunisia, and have further increased the cost recovery challenge of reuse. They also impose real economic costs. Considering that prevailing prices are already usually below the cost of supplying water from relatively high quality sources, it is easy to understand why reuse may not fulfill its promise.

3.3. Observations on the typical reuse situation in MENA

Based on these realities, this section closes with the following list of general observations about the typical context of wastewater reuse in MENA countries. First, it seems that few countries in MENA charge anything close to the full cost of piped water supply. Thus, when source choice is preserved (as is most typical), the relevant concept of demand for reuse is the conditional demand curve, given the low prevailing price for conventional sources.

Second, as we have seen, there is evidence from several countries that conditional demand for recycled water is very low. As long as users have a choice between conventional and recycled water, it will be hard to achieve extensive reuse, since users will continue to attempt to use conventional sources unless very large subsidies are given to users of recycled wastewater. The economics of reuse as typically practiced in MENA will not be favorable as long as water rates remain so far below the cost or scarcity value of water.

Third, in most MENA countries, sewerage and wastewater treatment are currently limited, so the costs to achieve safe, planned reuse are likely to be considerably higher than the cost of conventional supply. Under the existing political economy of water supply, wastewater reuse is likely to impose net welfare costs on society, except where it displaces more expensive desalination, where non-negotiable (and non-tradable) water rights impose very high costs on high-value users (at the benefit of low-value users), or where the costs of improper wastewater disposal are high. Of course, if this last condition holds, investment in improved wastewater management should not depend on reuse.

Fourth, cost recovery is lower in the wastewater management sector than it is for the supply of irrigation and drinking water, so there is a tendency for treatment systems to be poorly operated and maintained. This leads to widespread unplanned reuse (for example in Egypt and Syria), which reinforces perceptions that recycled water is low in quality and should be provided to users free or at very low prices. Wastewater pumped from on-site systems often contributes to unplanned reuse when it is evacuated into water bodies or dumped directly onto agricultural land. It is important to note that this type of unplanned reuse is considerably cheaper than the reuse we describe above because it is contingent on fewer infrastructure investments (e.g., in sewers, treatment infrastructure, and conveyances for redistribution). Yet unplanned reuse comes with environmental and health costs. In addition, water availability decreases as pollution increases. This in turn heightens scarcity, since there is little demand for highly contaminated water.

4. Options for facilitating reuse in MENA

There are two management strategies that enable much greater reuse of wastewater. The first is the case of indirect reuse, where recycled water is mixed with conventional water supplies. The second is when recycled water is supplied to specific user types via separate systems. This section explores these cases and relates them to existing policies in MENA countries. It closes with the presentation of a typology grouping countries according to the three policy cases explored in this paper. In this typology, Case 1 is the typical limited reuse situation. Cases 2 and 3 are the two strategies described below.

4.1. Reuse facilitated by mixing of recycled water with conventional supplies

The most obvious solution to the problem of differentiated and suppressed demand for reuse is to restrict water source choices for users. One way of implementing this strategy is to mix treated wastewater directly into conventional surface water supplies. Water suppliers then collect and distribute water tapped from this augmented volume of water. The incremental cost of adopting this approach varies from a cost of nearly zero, if sewage treatment exists and treatment facilities are located next to discharge sites, up to the cost of sewerage and treatment plus disposal, when these are insufficient and discharge sites are far away. Some of the MENA countries with the most successful reuse policies, for example Jordan, pursue this blending strategy by discharging wastewater effluents to surface water reservoirs.

One complication of this strategy is that the demand for mixed water may decrease, if water users perceive that this mixing degrades water quality. This will be particularly acute where treatment is inadequate to remove contaminants of concern to farmers or other users (e.g., salinity). The cost of water to high-value users may also increase since additional treatment, or a shift to expensive alternatives like desalination or deep aquifers, may be necessary to achieve water quality standards in certain sectors. In the long run, industries requiring highly treated water might not locate where source water quality is judged to be poor. The reduced demand for mixed water is reflected in debates over how reuse affects crop yields and export, since export markets for high-value fruits and vegetables may reject potentially contaminated crops. To be sure, the agricultural sector in Jordan has been affected by this debate (Mrayyan 2005; Pasch and Macy 2005).

4.2. Reuse under separate provision of recycled water to specific user types

A second strategy for solving the excess demand problem, while protecting the highest-value water users most sensitive to water quality, is to mix wastewater effluents into conventional sources and then pursue a policy of differentiated water delivery.[12] Recycled, adequately-treated wastewater is delivered only to systems supplying low-value users, via connections to existing

[12]As a practical matter, it will always be difficult to eliminate mixing between wastewater and "conventional" water supplies. In most cases it is less costly to discharge treated effluents into the environment, such that it will end up in surface waters or aquifers. This mixing is in fact the norm for point sources of wastewater in industrialized countries that achieve full treatment.

conveyance networks or targeted recharge of sources that serve those systems exclusively. Such targeting has been applied successfully in Israel and in the richer Gulf states, where wastewater treatment is already very high.

Assuming that demand decreases somewhat given concerns over quality, targeted reuse will increase water consumption and augment water supplies unless the low-value demand for recycled water is also very low. In contrast to case 2, the low-value user cannot choose to consume unmixed conventional water. Any conventional water that remains after high-value use is simply blended with the recycled water that is provided to the low-value user.

4.3. Efficiency implications of successful wastewater reuse policies

An important question is whether the approaches to reuse described above actually deliver economic benefits to the societies they serve; i.e. whether they are efficient relative to the status quo. Given the highly subsidized water rates in MENA countries, there is reason to be doubtful about this. Indeed, water shortages in many places may actually serve to reduce welfare losses since the units foregone by consumers may be among the ones for which supply costs already exceed benefits.

The efficiency implications of wastewater reuse depend on the following set of factors:

1. The gap between price and supply cost for conventional and reused water (i.e. the size of water subsidies);
2. The price elasticity of demand (i.e. the extent to which these subsidies result in inefficient allocation of water resources);
3. The extent to which the supply constraint prevents high-value water use, due to high scarcity value or cost of alternatives, or preferential allocation to low-value uses; and
4. The extent to which reuse can help spur investment in socially beneficial, but undersupplied, sanitation and wastewater treatment.

Implementing a wastewater reuse policy can be considered to have three separate effects which can potentially decrease welfare. First is the demand effect. When the demand curve shifts downward because of low perceived water quality, the change in consumer surplus from conventional to reuse units will be negative. The second effect is due to the expansion of supply, which allows consumption of low-value units further along the demand curve. This expansion effect will have a negative welfare impact when water is priced below the full supply cost, which is the norm rather than the exception in the MENA region, as discussed above. The third effect stems from the cost of reuse. If additional investments are needed for collection, treatment, or disposal of recycled water into receiving waters (note these also pertain to disposal), the net loss on all units beyond the original supply constraint and below this supply cost, will increase by this incremental amount.[13]

An additional problem from concurrent subsidization of both conventional and recycled water supply is related to the sustainability of these systems. Insufficient funding for collection and treatment of wastewater can lead to long-term deterioration of water networks, increasing pollution in receiving water bodies, and further effects on water demand (Myers and Kent 1998). "Unplanned" reuse could therefore conceivably reduce the quantity of water that is available, and thus intensify water scarcity. In this case, the welfare implications of reduced demand will be particularly large, without even considering ecological costs.

For all of these reasons, greater reuse will often result in welfare losses. But whether or not efficiency suffers will depend on the gap between price and supply cost (i.e. the size of the water subsidies) and the price elasticity of the demand curves (i.e. the extent to which these subsidies result in inefficient allocation of water resources). It is not hard to imagine situations in which wastewater recycling might increase social welfare, as depicted in Figure 2.

The simplest case that may lead to welfare improvements is when supplies are so tight that the scarcity value of water rises above the cost of supplying recycled water, such that relaxing the supply constraint inevitably leads to welfare gains.[14] This may result when there is extreme water

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[13] Note that this also applies to the reuse of sewage from on-site systems, though the costs of such reuse may be lower since it does not require the construction of sewers and may be used locally.

[14] Of course, there may still be net losses even when the scarcity value is high, if relaxing the supply constraint leads to consumption of much more water below the cost of supply.

stress (Panel A) or when the rights of low-demand users q_l are prioritized above those of high-value users q_h, leading to large inefficiencies (Panel B). Both of these situations can lead to gains even when the cost of reuse is higher than the cost of the fully-utilized conventional supplies. In some such circumstances, society could even invest in desalination at cost c_d and still experience gains (Panel B).

[Figure 2 about here]

The third situation in which welfare gains are possible is when the net social cost of recycled water c_r is lower than the cost of conventional supplies c_c, such that the economic inefficiency from water subsidies can be reduced (Panel C). This is unlikely in MENA (except perhaps in the higher-income Gulf States or for targeted, localized reuse applications), because sewerage and wastewater treatment rates are typically low, and because treated effluents are seldom connected back to water supply systems. Finally, welfare gains may also result when the social benefits of expanded wastewater collection and treatment outweigh their costs, such that joint wastewater and reuse projects deliver large positive externalities (Panel D). As MENA countries continue to develop economically, it seems likely that more locations will find improved wastewater management to be an attractive proposition, as evidenced by recent efforts to improve wastewater management in countries such as Morocco. It may also be the case that MENA countries are not investing in wastewater management at the socially efficient level.

In all four panels of Figure 2, the higher cost incurred for reuse c_r (relative to the prevailing price p_2*) does imply welfare losses on water units consumed beyond the point where marginal benefits equal this cost. Whether area B (losses) is larger than area A (gains) will depend on the shape of the demand curves and the incremental cost of safe water reuse. Furthermore, these four cases may apply to varying degrees in MENA countries where water scarcity is acute and current water policy protects low-value users. In MENA, the agriculture sector remains the largest water user (Figure 3), in large part owing to low or zero water rates for irrigators (see next section)

[Figure 3 about here]

4.4. Summary typology of wastewater reuse in MENA

In general, most MENA countries can be grouped as falling under the typical context (Case 1) with limited reuse (Table 5). These countries tend to have low water rates, particularly for irrigators, and, with a few exceptions, relatively limited wastewater treatment. Jordan, with its fairly well-developed wastewater collection and treatment infrastructure, pursues the most active re-mixing strategy for wastewater recycling (Case 2). If Case 1 countries were to achieve higher levels of wastewater treatment, they could presumably pursue a similar remixing strategy. With the exception of Bahrain and Syria, trends in the fraction of wastewater that is treated (as a proportion of that produced) have mostly been positive in MENA countries. And though these trends indicate that wastewater treatment is expanding (especially given population growth and the concomitant increase in production of wastewater), treatment rates vary widely and progress has generally been very slow (Figure 4).

Even with re-mixing of treated and conventional surface water, though, gains might be limited due to quality concerns. Indeed, the overall water balance under Case 2 might improve only marginally since re-mixing of untreated wastewater ("unplanned" reuse) already occurs, particularly in Egypt, Syria, Morocco and Yemen. Israel also does some re-mixing, but tends to favor more targeted reuse (Case 3), as do the richer Gulf States. Tunisia manages only limited, targeted reuse, in large part because the pricing of water and demand for reused water are not favorable to widespread reuse. In Case 3 countries, irrigators and urban landscapers are the primary users of recycled water.

[Table 5 about here]

[Figure 4 about here]

5. Policy recommendations

Working from these observations, it is possible to offer several recommendations for improving the potential of wastewater reuse in MENA countries.

First, reuse policy at the strategic, national level has an important role to play. A policy of remixing treated water into conventional supplies (as practiced in Jordan), or supplying low-value agricultural users exclusively with recycled or mixed water (as done in Israel and in many Gulf countries) is more likely to be successful than one which preserves user choices with respect to water sourcing. The availability of alternatives is an important factor in reducing demand for recycled water.

Second, countries that have achieved complete or near complete cost recovery in water and wastewater management (Israel, the UAE, Oman, Jordan to some extent, and increasingly, Morocco) are better positioned to leverage the potential of reuse, because they have already internalized these costs. Under these conditions, reuse should be aggressively pursued using one of the strategies listed above, as it will certainly be cheaper than desalination, and may lead to general improvements in welfare as the scarcity value of water rises above the incremental cost of reuse.

Third, before wastewater reuse can really take off, there is an urgent need for MENA governments to solve the free-riding problems in the wastewater sector. Inadequate upstream sanitation which leads to pollution of water resources (a local public good), imposes very large costs on downstream communities. Upstream users have little incentive to pay for sewerage and treatment other than the removal of waste from the local neighborhood, so governments should work to invest when the balance of wider social costs and benefits is favorable. Indeed, it is likely that the social optimum in many MENA countries involves higher levels of wastewater treatment, although more research and valuation work is warranted to better understand the benefits it would provide. As long as government regulators and institutions allow upstream users to pollute water resources at little to no cost, however, the existing situation will persist; expecting wastewater reuse to solve this problem is unrealistic because it does not address underlying problems with incentives.

Finally, in countries that provide large subsidies to users of water and sanitation services, the promotion of reuse alone may actually decrease social welfare, given the inefficiencies associated with overuse of water at low prices. It may also exacerbate water quality and scarcity problems due to poor operation and maintenance of infrastructures and increased discharges of untreated wastewater. In these countries, targeted opportunities for wastewater reuse probably exist, especially if low value users' water rights are protected and impose high costs on higher-value users. But a national policy to stimulate reuse is likely to face practical resistance from users and financial difficulties due to insufficient funds to provide the subsidies needed to stimulate demand. Such countries, which often promote equity by charging low water rates, should carefully consider that improved cost recovery and efficiency in the water sector would itself promote conservation and probably enhance social welfare. Water tariff reform can lead to greater infrastructure investment and reduced wastage, and it need not create hardship for the poor if appropriate tariff structures and/or cross-subsidies can be developed.

6. Conclusions

Previous research has shown that a variety of constraints inhibit formal reuse of wastewater in MENA. These include problems related to the incentives and cost of reuse, problems associated with reduced demand for reclaimed wastewater, the widespread lack of effective price signals and cost recovery in the water sector, and challenges in structuring the financing of reuse. This paper has explored some of these incentive problems by using simple, conceptual models, and then relating these to country-specific data on wastewater coverage and water prices.

Some of the key constraints that inhibit more widespread wastewater reuse have been identified in this paper, and a number of actions that countries can pursue to improve its prospects have been proposed. These include improving cost recovery by raising water tariffs, extending wastewater management and treatment, and pursuing targeted or national reuse opportunities that are appropriate given the existing levels of development and sustainability in the sector. National policies for reuse will do little good as long as economic incentives and financing constraints are aligned against them.

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Tables and Figures

Table 1. Sewerage coverage in urban and rural areas, and wastewater treatment and reuse rates in the Middle East and North Africa

Country	**Sewerage rate to piped network** (% of households connected)			D. **Treatment rate** (% of collected wastewater by volume)	E. **Treatment rate** (Est. % of wastewater by volume)[a]	F. **Reuse efficiency** (% of treated wastewater by volume)	G. **WRI** (Est. % of all wastewater by volume)[b]
	A. Urban	B. Rural	C. Overall				
Algeria	92	50	77	46	40	Na	Na
Bahrain	Na	Na	77	73	49	16-20	10
Egypt	74	18	42	57	52	24	12
Iran	39	5.3	30	78	21	Na	Na
Iraq	39	3.3	28	30	17	Na	Na
Israel	99.5	95	98	Na	90	99	89
Jordan	67	4.0	56	98	53	76	40
Kuwait	Na	Na	>99	Na	78	63	49
Lebanon	Na	Na	66	81	23	50	11
Libya	54	54	54	24	13	100	13
Morocco	86	2.8	53	20	18	6	1
Oman	53	17	44	34	27	66	18
Palestine	67	12	54	Na	Na	Na	Na
Qatar	Na	Na	78	100	78	50	39
Saudi Arabia	44	7	37	93	69	40	27
Syria	96	45	72	Na	40	78	31
Tunisia	79	8.9	54	77	68	20	14
UAE	93	63	87	Na	87	25	22
Yemen	42	0.4	12	66	8	40	3

Notes:
Na: Data not available
[a] Estimate from Aquastat (2014) data: Wastewater volume treated / Wastewater produced; If estimates were not available, this is estimated as Sewerage rate*Treatment rate (Column D), assuming that production rates are similar across connected and unconnected households.
[b] Authors estimate: Wastewater volume treated)*Reuse efficiency (Column E)*(Column F).
WRI = Wastewater Reuse Index.
Sources: Authors' calculations using data from Aquastat database (FAO 2014), Kfouri et al. (2009), Jimenez and Asano (2008), *Global Water Intelligence* (http://www.globalwaterintel.com), and country reports from the JMP (World Health Organization and UNICEF 2014).

Table 2. Costs of wastewater collection, treatment, and reuse

Component	**Cost/m³ (US$)**	**Notes**	**References**
Conveyance to treatment works	0.30–0.80		Whittington et al. (2009)
Non-mechanized secondary treatment	0.15–0.25	Necessary for restricted reuse	WHO (2005), Shelef & Azov (1996), Haruvy (1997), Amami et al. (2005)
Aerated secondary treatment/activated sludge	0.30–0.35	Lower land requirement	Kamizoulis et al. (2003), Shelef & Azov (1996), Shelef (1991), Haruvy (1997)
Tertiary treatment (in addition to secondary)	0.10–0.22	Necessary for unrestricted reuse	Shelef & Azov (1996), Haruvy (1997), Shelef et al. (1994)
Distribution	0.10–0.50		Shelef et al.(1994)
Total	0.25–2.00	Treatment and conveyance	Shelef et al. (1994), Lee et al. (2001), Whittington et al. (2009)

Notes: All costs in US$2010.

Table 3. Range of user fees for water from conventional and reuse sources for irrigators, and for domestic users

Country	**Conventional irrigation tariff** ($/m^3, unless otherwise noted)	**Other farm water supply costs** ($/m^3, unless noted)	**Domestic water tariff** [a] ($/m^3)	**Marginal cost of raw water** ($/m^3)	**Recycled water tariff** ($/m^3)	**Original Sources for data**
Algeria	0.03	None	0.16, 0.53 (Avg = 0.51)	0.26	Na	Laoubi & Yamao (2008); Maliki et al. (2009)
Bahrain	None	Pumping cost (0.01-0.27)	0.08, 0.26	Pumping cost	Na	FAO (1997); Qamber (2003); Basheer et al. (2003)
Egypt	None	Annual tax (~$3.5/fed-yr)	0.05	Na	Na	Bazza & Ahmad (2002); Malashkhia (2003); Kebiri (2010)
Iran	0.04	Pumping cost	0.06 (Avg)	0.32	Na	Moghaddasi et al. (2009)
Iraq	Na	Pumping cost	0.01	Na	Na	Razzaq (2010)
Israel	0.20-0.32	Pumping cost	1.06 (Avg)	0.30	No difference	Becker (2002); Markou & Stavri (2005); Global Water Intelligence (2009a)
Jordan	0.01-0.06 (Avg = 0.03)	Pumping cost	0.70	0.37	No difference	Bazza & Ahmad (2002); Dinar & Mody (2004); Venot et al. (2007); Arabiyat (2007); The Jordan Times (2010)
Kuwait	None	Pumping cost	0.58	Na	0.07	Fadlelmawla (2009); FAO (2010)
Lebanon	None	Annual tax ($7-400/hA-yr)	0.15-0.51	Na	Na	ESCWA & UNDP (2002)
Libya	None	Pumping cost only	0	Na	Na	Global Water Intelligence (2009b)
Morocco	0.02-0.07	Pumping cost < 0.21	0.24-0.95	0.02-0.13	0.07 – 0.29	Bazza & Ahmad (2002); Choukr-Allah & Hamdy (2008), Benabderrazik & Doukkali (2003)
Oman	None	Pumping cost	1.75	Na	Na	FAO (1997); Omezzine & Zaibet (1998)
Palestine	Na	Pumping cost	0.26	Na	Na	Al-Ghuraiz & Enshassi (2005)
Qatar	None	Pumping cost	No charges for nationals	Na	Na	FAO (1997)
Saudi Arabia	None	Pumping cost	0.03, 0.04	Na	Na	FAO (1997); Gulf News (2010)
Syria	None	Annual levy	0.07, 0.20	Na	0 (unplanned)	Bazza & Ahmad (2002)
Tunisia	0.08	Pumping cost	0.3, 0.4	0.10-0.19	0.02	Dinar & Mody (2004); Easter & Liu (2005); Mourad (2010)
UAE	None	Pumping cost	1.37	Na	Na	FAO (1997)
Yemen	None	Pumping cost (0.07-0.27)	0.06	Pumping cost	0 (unplanned)	FAO (1997); Bazza & Ahmad (2002)

Na: Data not available (no information found). All costs in US$2010.
[a] Most countries utilize increasing block tariffs, so it is difficult to derive an average tariff without information on the consumption per household. Therefore, prices for the first two blocks are listed, except where average tariffs are known and reported.

Table 4. Wastewater tariffs in select major cities in the MENA region in 2010[a]

City	Piped water supply (US$/m^3)	Trend[b] (2007-2010)	Wastewater management (US$/m^3)	Trend (2007-2010)
Overall average cost estimate (from Table 2 and Whittington et al. (2009))	0.35 - 0.85	Na	0.5 - 1.3	Na
Algiers, Algeria	0.16 - 0.52	No change	0.03	No change
Manama, Bahrain (2009)	0.07 – 0.22	No change	None	Na
Alexandria and Cairo, Egypt	0.05 – 0.07	-23%	0.02	+23%
Baghdad, Iraq (2008)	0.002 – 0.005	No data	None	No data
Tehran, Iran (2007)	Based on dwelling size	No data	None	No data
Jerusalem, Israel	1.87	+50%	Na; combined tariff	Na
Tel Aviv, Israel	1.29 – 1.45	+50%	0.33	No change
Amman, Jordan	0.70	No data	Na; combined tariff	Na
Casablanca, Morocco	0.76 – 0.80	+2.4%	0.19	+160%
Rabat, Morocco	0.65 – 1.85	+5.7%	0.18-0.32	+19%
Muscat, Oman	1.22	-11%	Na; combined tariff	Na
Ramallah, Palestine (2009)	1.22 – 1.37		0.32	
Jeddah and Riyadh, Saudi Arabia	0.03 - 0.04	No change	None	Na
Damascus, Syria (2009)	0.06 – 0.17	-30%	0.02	No change
Tunis, Tunisia	0.29 - 0.39	+5.1%	0.09	No change
Dubai, United Arab Emirates (2009)	2.15 – 2.50	No change	0.36	Separate tariff only in 2010

Data from Global Water Intelligence (2010), in 2010 US$. Trends however are in nominal terms. Na = Not applicable

[a]Cost estimate ranges are based on high and low cost technology options discussed in Whittington et al. (2009); ranges for cities represent prices in first two consumption blocks of the increasing block tariff.

[b]Reported trend is for lowest consumption block only.

Table 5. Typology of MENA countries according to reuse situation

	Case 1: limited or unplanned reuse only	Case 2: Extensive mixing of recycled water	Case 3: Targeted provision of recycled water
Countries	Unplanned: Egypt, Syria, Morocco, Yemen Limited: Bahrain, Iraq (?), Iran, Lebanon, Libya, Tunisia	Jordan Israel (limited)	Israel (mostly) Few schemes in Tunisia Heavily subsidized: Qatar, Kuwait, Oman, Saudi Arabia, UAE

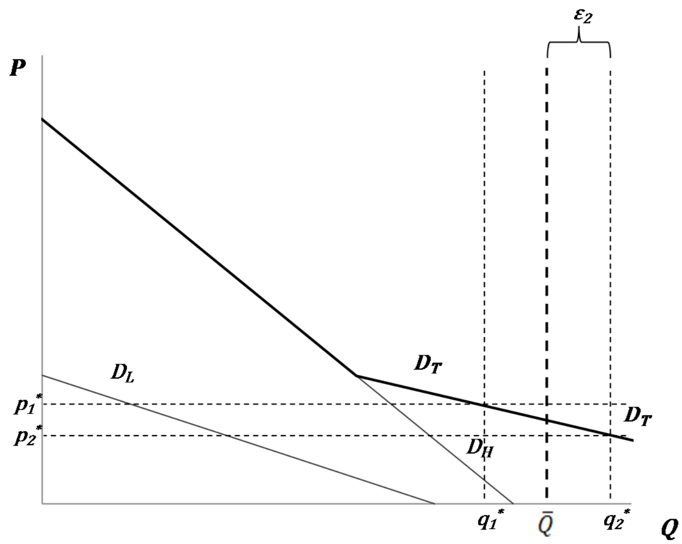
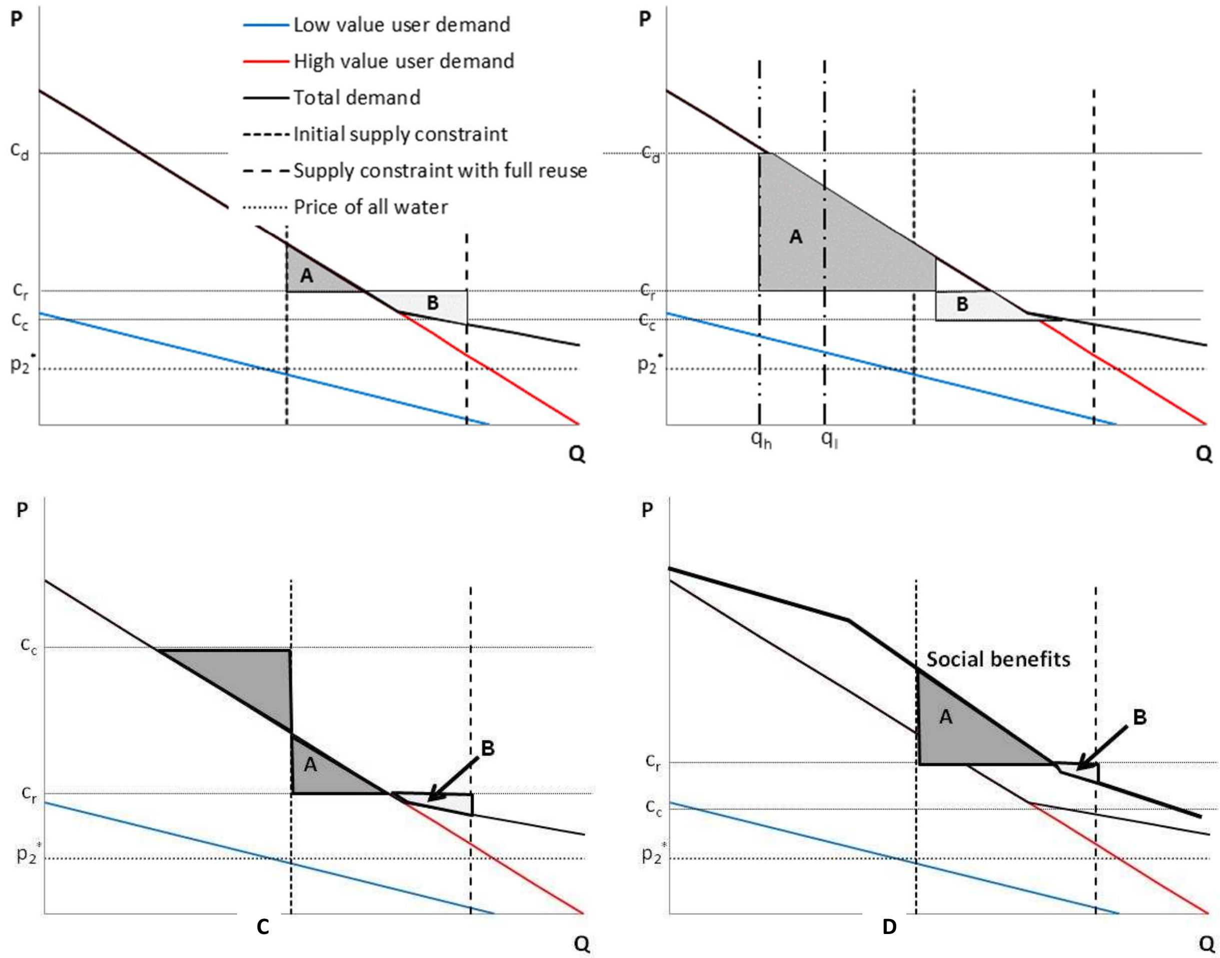


Figure 1. Demand for raw water from the natural environment (the conventional source) for two users, one high-value and the other low-value



Notes: Panel A: scarcity value of water exceeds cost of supply; Panel B: quotas or water rights inefficiently protect low-value uses; Panel C: Reuse is much cheaper than conventional supply; and Panel D: Reuse delivers positive externalities by fostering better management of wastewater, as shown by the Social Benefits curve. In all cases, net gains are shown by Area A, net losses are shown in Area B.

Figure 2. Four situations in which reuse can lead to welfare gains, in spite of low prevailing water tariffs

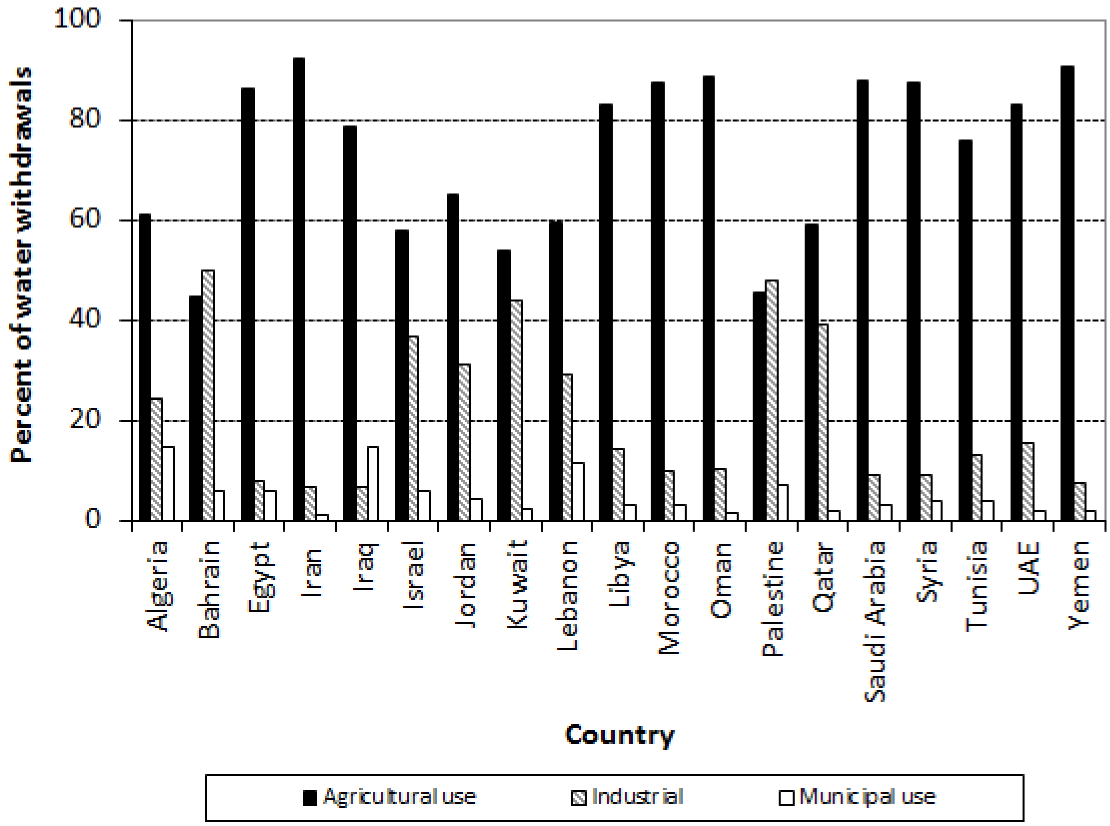


Figure 3. Water consumption by sector in MENA countries (latest data from FAO Aquastat (2014); 2003-2006 for most countries)

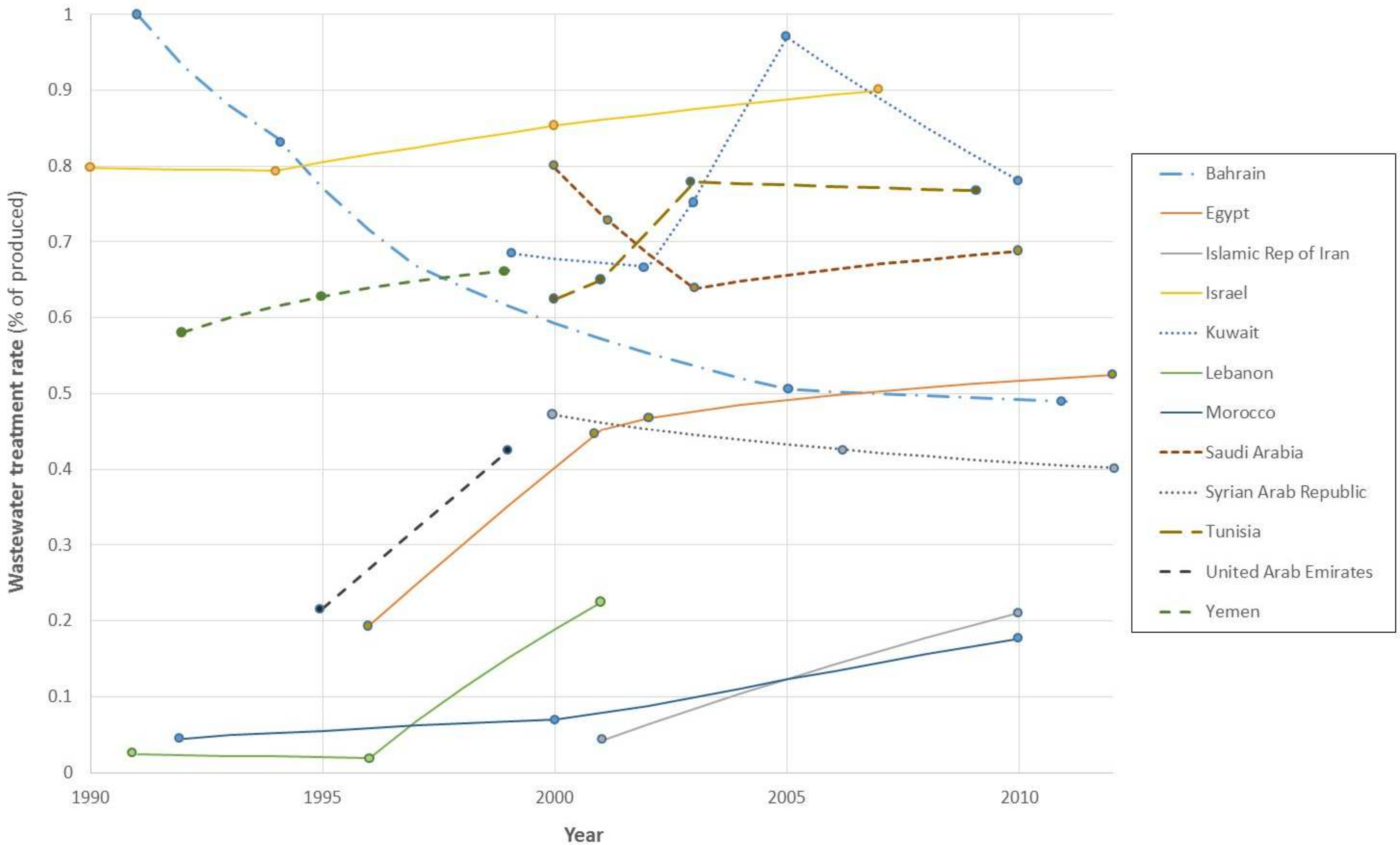


Figure 4. Treatment of wastewater in MENA countries, as a percentage of wastewater produced (Trends are based on calculations using data available in FAO Aquastat (2014), with interpolation between the data points that are shown)