## Title

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PERSPECTIVE

# Is Gray Water the Key to Unlocking Water for Resource-Poor Areas of the Middle East, North Africa, and Other Arid Regions of the World?

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**Abstract** Support for the use of treated gray water as an alternative water resource in the Middle East and North Africa is high, especially given the lack of religious restrictions against its use, but several obstacles have kept application of treated gray water near 1 % in some areas. The largest of obstacles include the cost of treatment and the ambiguity surrounding the health safety of gray water and treated gray water. This paper aims to provide an overview of current gray water practices globally, with specific focus on household-level gray water practices in the Middle East and North Africa region, and highlight the need for cost reduction strategies and epidemiological evidence on the use of household-level gray water and treated gray water. Such actions are likely to increase the application of treated gray water in water-deprived areas of the Middle East and North Africa.

**Keywords** Gray water · Health · Middle East · Epidemiology · Wastewater · MENA

## INTRODUCTION

Water scarcity is a well-documented global phenomenon that is burdening available water resources, especially in water-deprived regions like the Middle East and North Africa (MENA). Aquifer salinization and pollution are leading to the degradation of water resources and the situation is expected to worsen with growing populations and climate change (Qadir et al. 2009; Droogers et al. 2012). Additionally, challenges in coping with water demands are leading to shortages in food and energy according to recent reports by the United States Intelligence Community (USIC 2012). To mitigate this deteriorating situation, countries in the Middle East have turned to fossil water (water trapped in deep underground aquifers), virtual water (water or water-intensive foods acquired through international trade), and desalinization of seawater to meet rising water demand, but these methods can be extremely expensive and in many cases unsustainable (Issar 2007; Shuval 2007). For some oil-rich countries in the Middle East, ranking among the highest in gross domestic product worldwide, the issue of cost is not as significant, but for others the costs associated with mining fossil waters, importing water-intensive products, or building and operating seawater desalinization plants can be prohibitive. For this reason, attention has shifted towards more sustainable cost-effective methods.

## CHARACTERISTICS AND INCENTIVES OF GRAY WATER

Countries in the MENA region are increasingly turning to gray water (GW), which is wastewater generated from domestic activities such as laundering, dishwashing, and bathing, to meet rising water demands. GW comprises 50–75 % of residential wastewater and is distinct from black wastewater, which is collected from toilets (Eriksson et al. 2002; Friedler 2004). There are many incentives for using this water resource. At the household-level there are several potential economic incentives that include: reducing the amount of monthly income allocated to purchasing water for irrigation, decreasing the frequency of evacuation of cesspits due to the decreased quantity of household wastewater, decreasing the demand for chemical fertilizers, increasing the overall quantity of water possible for irrigation, and increasing the potential for higher biomass yields in crops (Gross et al. 2007; Abu-Madi et al. 2010; Alfiya et al. 2013).

Reusing waters of lesser quality, like GW, can also have national- or regional-level impacts. Adopting GW recycling practices on a large scale may lower freshwater demands and decrease groundwater extraction rates by up to 30–50 %; this can result in a decrease in the risk of aquifer salinization (Jeppesen 1996). In places with centralized sanitation, using GW at the household or community level may reduce the quantity of influent wastewater to often over-burdened wastewater treatment facilities (Bino et al. 2010). Recycled GW can also be used after treatment to artificially recharge aquifers (Bouwer 2002; Koussis et al. 2010a, b). In coastal regions, artificial recharge with treated gray water (TGW) can be a way of providing positive pressure to decrease salt water intrusion into aquifers and provide a larger supply of brackish groundwater (a mixture of salt water and fresh groundwater), which is more energy efficient to desalinate compared to seawater (Koussis et al. 2010a, b).

## CONCERNS FOR USING GW

Despite these advantages, there are many concerns for using GW.

### Health Concerns

- Households with individuals who are carriers of infectious disease or who perform practices such as bathing babies and laundering diapers may be at greater risk for spreading the disease as a result of GW reuse (Rose et al. 1991; Eriksson et al. 2002; Ottoson and Stenstrom 2003; Friedler 2004; Gross et al. 2005; Maimon et al. 2010).
- Variations in personal/household-level behavior such as frequency of showering, laundering, use of personal care products and household chemicals, and the original quality of domestic water all impact household effluent quality and render it nearly impossible to expect a common GW effluent quality across households (Rose et al. 1991; Casanova et al. 2001; Eriksson et al. 2002). Households of families with children, for example, are more likely to have higher levels of fecal coliforms (Rose et al. 1991) and households improperly disposing of products containing compounds such as medications, household cleaning supplies, and heavy metals may expose individuals to endocrine disruptors if constituents are consumed (Eriksson et al. 2002).
- Levels and types of GW contamination depend on the household source it originates from; using water from laundering clothes versus bathroom water, for example, may increase enteropathogenic disease burden by up to 1000-fold in some places (Rose et al. 1991; Friedler 2004; O'Toole et al. 2012; Barker et al. 2013).
- Because enteric pathogens most commonly occur in GW when an individual contributing to a system is a carrier, using GW in multiple household systems might be more dangerous than in an individual household (Maimon et al. 2010). Multiple household systems provide a larger pool of susceptible individuals to overlap with a contributing infectious disease carrier and subsequently increase the likelihood that infections are proliferated into new hosts.
- In arid regions, evapotranspiration and low household water consumption can further concentrate GW constituents and lead to regrowth of pathogens (Friedler 2004; Halalsheh et al. 2008; Dalahmeh et al. 2011).

### Environmental Concerns

- Accumulation of chemicals such as boron or chlorine may damage plants (Gross et al. 2005).
- Long-term irrigation with waters high in salts and alkalinity can compromise soil structure and fertility and cause toxicity in plants (Gross et al. 2005; Qian and Mecham 2005).
- Irrigation with GW containing food matter, grease, and surfactants may create hydrophobic soils that prevent soil infiltration, cause odors, and attract vectors (Gross et al. 2005; Morel and Diener 2006; Travis et al. 2010; Dalahmeh et al. 2011).
- Non-effective treatment or the improper disposal of antibiotic substances into the environment through GW may lead to the development and dissemination of microbiological resistance (Pruden et al. 2013).

The above factors, the decentralized nature of GW production, and the general lack of education on proper production and use of GW make monitoring the safeties of GW challenging.

## REUSE GUIDELINES AND TREATMENT

To reduce health risks, international and national guidelines for GW use have been established (Nazzal et al. 2000; WHO 2006; USEPA/USAID 2012). All guidelines are based on threshold levels of risk for specific biological, physical, and chemical indicators. These guidelines recommend practices such as using GW only on trees or forage crops or if used on vegetables requiring a minimum number of days between last irrigation, harvest, and consumption of these products. Some have argued that current guidelines do not accurately characterize the health risks associated with wastewater reuse and have disparaged the fact that current standards fail to account for environmental risks (Shuval et al. 1997; Maimon et al. 2010). For this reason guidelines are periodically updated.

In addition to guidelines, treatment has also been pursued as a method for reducing the risk of using GW. GW treatment is often integrated into centralized sewerage systems that funnel effluent from individual households, either separated from black water or not, into one location where it can be treated and reused at the central level. In urban and peri-urban settings this type of system has been used with success. In Cyprus, for example, this schema effectively treats GW for injection into coastal aquifers to prevent aquifer desalinization and provide a more cost-effective source of water for desalination (Koussis et al. 2010a, b). In less densely populated areas, however, the utility of centralized systems is still in question. Water recycling projects in Egypt have attempted to adapt centralized models in rural settings without achieving the same level of success (Abd El Gawad and Butter 1995). Reliable consumption of water (~100 lpcd) and the high cost of implementing conventional sewers can prove to be major constraints for expansion of sewer services to small rural communities (Bakir 2001).

As an alternative to centralized treatment, since 2000 multiple organizations have assisted in the implementation of hundreds of gray water treatment units (GWTUs) in many rural resource-poor areas of the MENA region. The goal of implementing GWTUs is to allow for the retention of household-level incentives for using GW while avoiding the risks of using raw GW and the costs of wastewater transportation in centralized treatment collection, which account for 80–90 % of capital costs and over 65 % of annual operational costs (Bakir 2001). Although design features of GWTUs vary, most of the units installed in the region use gravity to allow GW to pass from the household into a multi-stage treatment unit that contains chambers for suspended solid settling, anaerobic degradation by up-flow through a gravel medium, and sometimes "polishing" sand or an activated carbon filter (Fig. 1). Other types of GWTUs include mechanical processing, UV disinfection, sand filtration, or filtering through organic composts such as mulches and barks (Friedler et al. 2006; Morel and Diener 2006; Li et al. 2009; Dalahmeh et al. 2011; Ghaitidak and Yadav 2013). GWTUs process GW with varying levels of effectiveness, but many can significantly decrease the concentration of total suspended solids (TSS) (>70 % and in some systems >90 %),

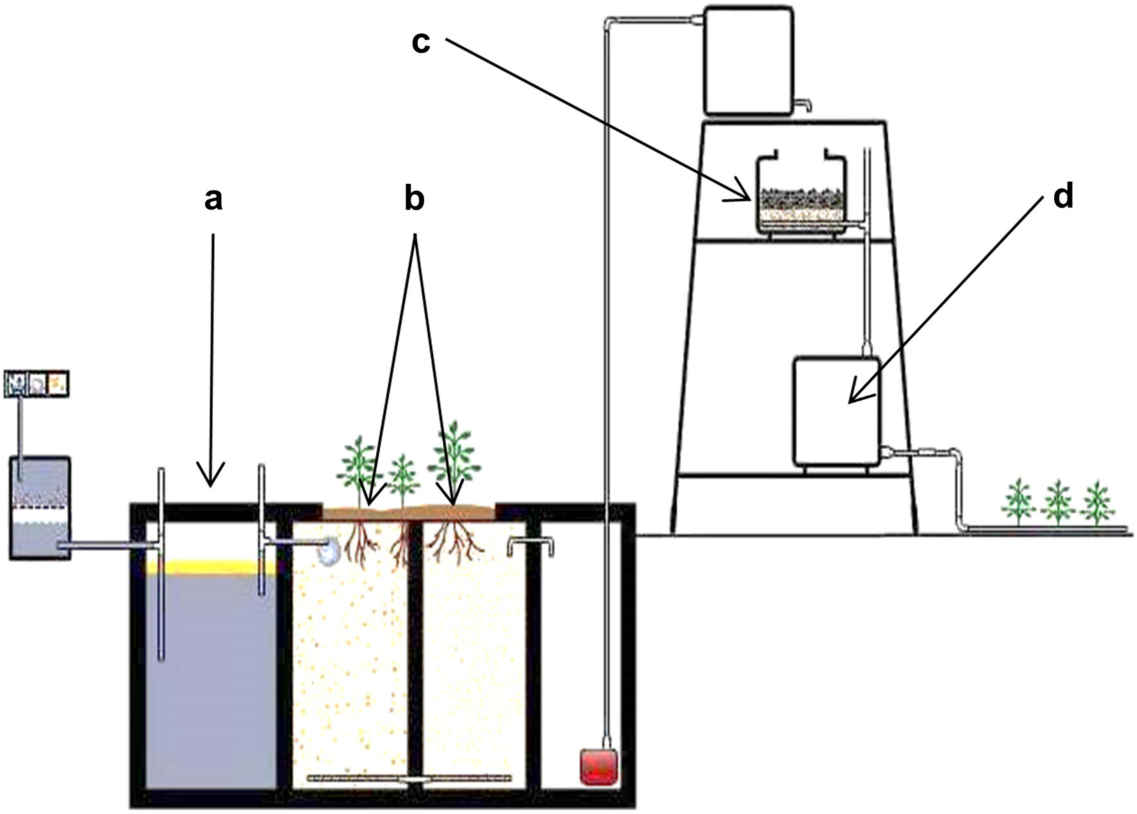

**Fig. 1** Palestinian Hydrology Group's GWTU scheme composed of an initial settling tank (**a**), two anaerobic gravel-based filter tanks (**b**), a charcoal filter (**c**), and a reservoir to store water until used for irrigation (**d**)

chemical oxygen demand (COD) (>70 %) and biochemical oxygen demand (BOD) in water (>90 %) (Friedler et al. 2006; Morel and Diener 2006; Gilboa and Friedler 2008; Halalsheh et al. 2008; Winward et al. 2008; Li et al. 2009; Ghaitidak and Yadav 2013). If designed with the right controls and maintained properly, GWTUs can be deemed safe for environmental and human health (Alfiya et al. 2013).

## APPLICATION AND PERCEPTIONS

Many governments in the MENA region are optimistic about adopting widespread use of wastewater in any form, but currently application remains low in most areas. In the Palestinian West Bank, there are modest goals of reaching as much as 30 % of all wastewater being treated and reused in irrigation over the next few years, but currently application remains only near 1 % (PNA 2011). Regional per capita estimates of wastewater treated annually at the municipal level are available by country in Fig. 2. Several countries in the region such as Bahrain, and Kuwait have relatively large quantities of municipally treated wastewater, while others including Iran and Lebanon have been slow to adopt, with per capita water treatment estimates remaining near 1 $m^3$ $year^{-1}$ $pop.^{-1}$ (Fig. 2). Although patterns of treatment and reuse vary widely by nation, regional

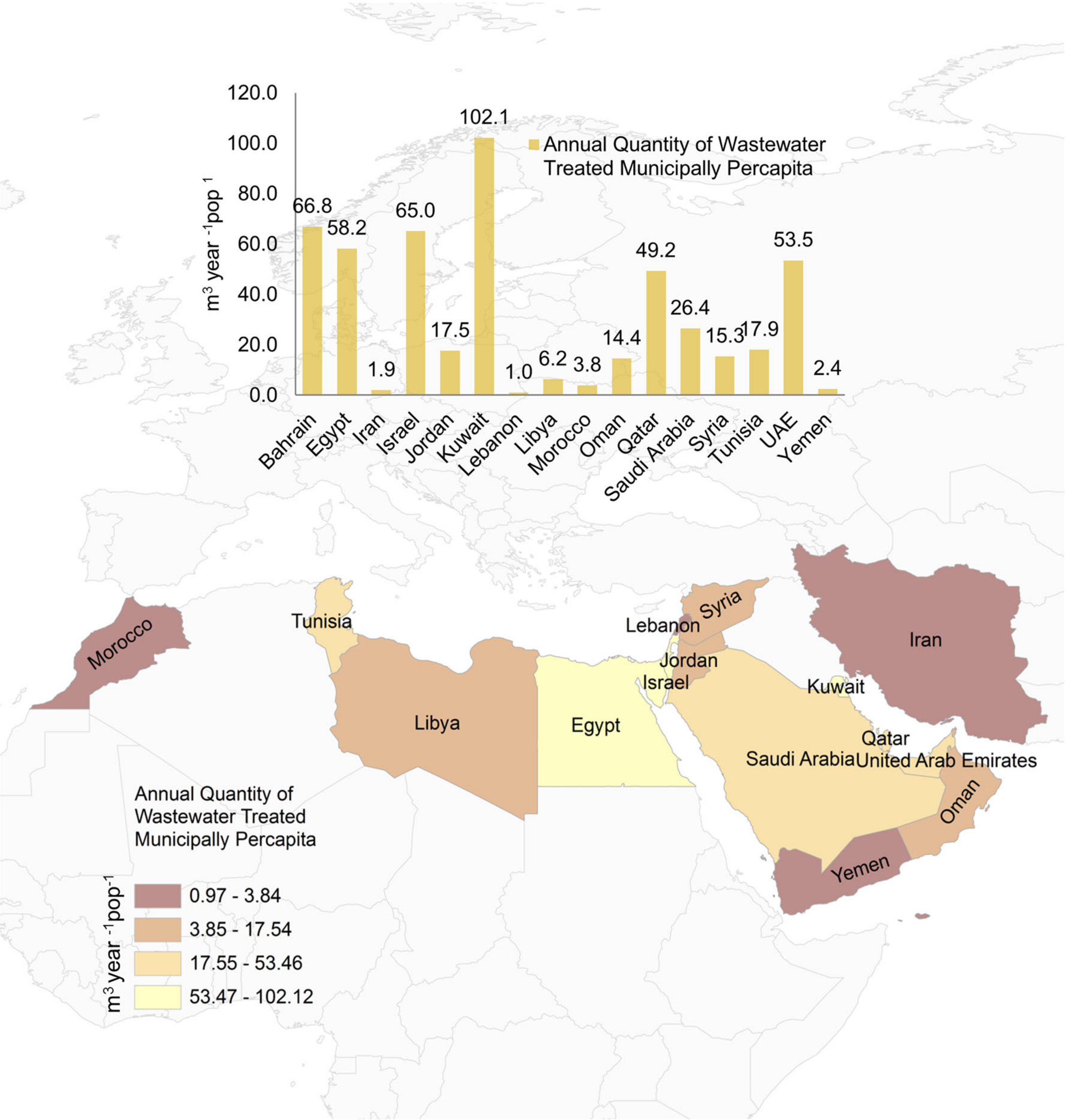

**Fig. 2** Annual quantity of wastewater treated municipally per capita in the MENA region (1998–2011). GW generally constitutes 50–75 % of all wastewater (Eriksson et al. 2002; Friedler 2004). Palestinian Occupied Territories are not shown and are not accounted for in Israel estimate. Estimates are taken from the most recently available year. *Source* FAO (2013) and USEPA (2004)

estimates indicate that 13.24 $km^3$ of wastewaters (including both gray and sewer waters) are produced every year, but only 35.7 % of this water is actually treated at the municipal level and reused (Qadir et al. 2009). This indicates that approximately 64.3 % or 8.49 $km^3$ of all wastewater in the region is going unused or is used without treatment, underscoring the massive potential for this resource.

Several household-level studies have also reported low treatment levels of wastewater despite high perceptions of using TGW in many areas. Abu-Madi et al. (2010) estimated that 6 % of the West Bank received partial treatment of wastewater even though 72 % of households sampled in Ramallah, West Bank were willing to implement GWTUs and use TGW for household practices if treatment was effective. A similar survey in Oman reported that 76.4 % of their respondents were willing to use GW for gardening, 53.3 % for washing cars, and 66.3 % for flushing toilets, but currently per capita treatment levels remain low in Oman (14.4 $m^3$ $year^{-1}$ $pop.^{-1}$) compared to other countries in the MENA region (Jamrah et al. 2008).

Some success in achieving positive perceptions of GW in the Middle East has been possible through religious endorsement (Farooq and Ansari 1983; CLIS 1998). Water purity is a topic of great scholarly discussions based on the teachings of Islam, which is the major religion of the MENA region. There are many levels of purity of water according to Islam. The purity of water pertains to its level of mixture with other components. If not mixed with any chemical, impurity, or contaminant that change its physical qualities (such as taste, smell, or color) this is called “Mutleq,” or pure water, and can be found in water sources such as rain, surface water, or groundwater. Mutleq water can be used for drinking, washing, and religious purification purposes. Water that is mixed with any other component to the degree that has changed its smell, color, or taste, such as the case of GW, is called “Muthaf”, or added water, and is not considered pure water and cannot be used to clean impurities. For this reason, GW cannot be used for religious cleanliness, such as in the performing of ablution before prayers. Many other juristic details are allotted to water for human use and consumption. Any non-human consumption of water, such as that used for irrigation, does not undergo scrutiny to require it reach the level of Mutleq water, making it possible to religiously endorse the use of GW by Muslims if it is not used for human consumption or contact. If treatment is verifiably effective in removing impurities such as scent, smell, and taste, TGW has even been endorsed for drinking purposes and in such cases it can be elevated to the Mutleq status for human use from an Islamic perspective (CLIS 1998).

## OBSTACLES TO ACHIEVING WIDESPREAD USE OF TGW

### Cost

While positive perception and religious endorsements of TGW are growing, an obstacle that continues to be faced is the cost of treatment, even at the household-level. The principle costs of both centralized and decentralized GW treatment are the initial costs of developing sewer systems, restructuring piping to separate GW from other wastewater, and constructing treatment facilities. At the household-level, costs of GWTU implementation in the Middle East have been estimated to range from 261 to 600 USD, depending on the type of GWTU, and approximately 39–100 USD annually for maintenance costs over the lifetime of the GWTU (Gross et al. 2007; Bino et al. 2010). While these costs may seem insignificant they often become a burden for low-income households (Qadir et al. 2009).

Despite the incentives of using TGW, in more resource-poor areas the purchase of a GWTU at the current price can be hard to justify for a household that is largely surviving off the crops they grow and for this reason many farmers may be unwilling to make the switch from using fresh water. A study of farmers across the Palestinian West Bank, for example, indicated that 42 % of respondents would only be willing to use treated wastewater as a replacement for freshwater if the cost was significantly less than freshwater, and 32 % indicated that they would only use treated wastewater if it were provided free of charge (Shaheen 2003).

### Health Uncertainty

Cost barriers are not the only factor leading to low application; health concern and perceived risk are reported as leading barriers to widespread use of recycled wastewaters, including GW (Jamrah et al. 2008; Dolnicar et al. 2011). In 2008 Jamrah et al. found that among respondents in Oman that rejected the use of GW, 87 % indicated that their personal safety was a reason for rejection of GW, and 46.7 % of the entire sample reported that using GW was harmful to human health. Similarly, among respondents in a sample from the Palestinian West Bank, 64 % of males and 47 % of females reported concerns for waterborne disease from using GW even if they were currently using it (Hassan et al. 2010). The challenge from a global health perspective is whether the perceived risks of individuals in these studies and others like them are actualized risks that pose a public health threat.

## PERSPECTIVE 1: IS GW AND TGW SAFE FOR HOUSEHOLD-LEVEL USE?

The scientific community has done a sufficient job addressing the possible risks of GW use and the difficulties of monitoring its quality (see list above), but the question that remains unanswered by the scientific community is: "Is GW and TGW safe to use at the household level?" Achieving higher levels of GW treatment and application are dependent upon the answer to this question. While there is some health evidence for or against the use of GW or TGW, there is not enough evidence and it is too discordant to make a non-reticent answer to this question or recommend widespread use. To begin addressing this knowledge gap, we recommend further research in the following two disciplines:

1. *Contaminant enumeration:* Throughout the past several decades there has been discordance in the types of water quality indicators that have been used for evaluating the health risk of using GW. A list of parameters that have been used to measure the quality of GW in 11 studies in the last decade is available in Table 1. Many of these indicators are determined by tests that look specifically for the presence of certain biological pathogens (e.g., *Salmonella*), suspected chemical contaminants (e.g., boron) or suspected physical byproducts (e.g., lead). Other tests, although more commonly used, are less sensitive and indicate only the potential presence of categories contamination, but do not distinguish within that category (e.g., fecal coliforms, COD, TSS). From an epidemiological perspective, tests that measure levels of specific contaminants are more powerful, but these tests are also usually much more costly and are less frequently used. For example, reverse transcriptase-polymerase chain reaction (RT-PCR), which has been used to measure levels of norovirus in GW, is among the most sensitive and specific tests for microbiological assessments, but requires laboratories capable of DNA sequencing to be conducted (O'Toole et al. 2012).
   Recently several studies have attempted to statistically model levels of less easily detectable pathogens such as viruses with less expensive fecal indicators such as *Escherichia coli* and information from prior studies (Ottoson and Stenstrom 2003; Mara et al. 2007; O'Toole et al. 2012). The results of these surrogate measures are promising from a financial perspective and some inconclusive efforts have been made to validate them (O'Toole et al. 2012). More validation studies using surrogate exposure assessments or development of simple cost-effective approaches using new technologies are needed. Consensus on which measures should be used in GW quality studies is also drastically needed to help guide decision makers.
2. *Population-based epidemiological studies:* While there are many studies that have examined the quality of GW, little is known about how GW or TGW use affects a population's health. To the authors' knowledge, there are only two published studies addressing health risks associated with using GW that are performed using a traditional epidemiological approach (Fernandes et al. 2007; O'Toole et al. 2012). Fernandes et al. (2007) used a retrospective cohort design to assess attack rates of accidental drinking water contamination with GW and found that areas that were exposed to contamination with GW had a 54 % higher waterborne disease attack rate than areas that were unexposed. O'Toole et al. (2012) on the other hand found little association between the presence of enteric pathogens in GW used for irrigation and the reported prevalence of waterborne disease. While these studies are informative, they have drastically different designs, assess different routes of exposure, come to drastically different conclusion and neither significantly address the effect that adherence to reuse guidelines and use of treatment have on the health outcomes of the study participants.
   The limiting factors that continue to undermine attempts to conduct observational epidemiologic investigations of GW are the sample sizes and the laboratory and diagnostic procedures required to achieve sufficient power and sensitivity to make inferences at the population level (O'Toole et al. 2012). To circumvent these logistical constraints, many have turned to probabilistic models, such as quantitative microbial risk assessment (QMRA), to determine the excess risk of infectious disease as a result of using GW (Shuval et al. 1997; Ottoson and Stenstrom 2003; Mara et al. 2007; Maimon et al. 2010; Barker et al. 2013). The accuracy of these models depends upon reliability of prior information taken from epidemiological investigations. While these models may be the way of the future, large population based studies are imperative for the provision of substantiated information to fit the statistical models and the validation of their application to examining health outcomes from TGW and GW use. Additionally, while probabilistic models may provide useful evidence for the health effects of GW and TGW use, observational studies can provide information to guide public education programs on the safety of using GW, by focusing on tangible results that are based on observed human behaviors.

**Table 1** Measurements used in 11 selected studies of GW characterization or risk assessment (2001–2012)

| Abbreviation | Description | Frequency of use | GW quality assessment |
|---|---|---|---|
| *Chemical and physical* | | | |
| TSS | Total suspended solids | 6 | Casanova et al. (2001), Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), Jamrah et al. (2008), and Winward et al. (2008) |
| TS | Total solids | 2 | Friedler (2004) and Jamrah et al. (2008) |
| TDS | Total dissolved solids | 1 | Jamrah et al. (2008) |
| TFS | Total fixed solids | 1 | Jamrah et al. (2008) |
| TVS | Total volatile solids | 2 | Friedler (2004) and Jamrah et al. (2008) |
| TOC | Total organic compounds | 2 | Friedler (2004) and Jamrah et al. (2008) |
| OM | Organic matter | 1 | Gross et al. (2005) |
| TU | Turbidity | 3 | Casanova et al. (2001), Jamrah et al. (2008), and Winward et al. (2008) |
| – | Ph | 5 | Casanova et al. (2001), Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), and Jamrah et al. (2008) |
| COD | Chemical oxygen demand | 5 | Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), Jamrah et al. (2008), and Winward et al. (2008) |
| BOD | Biological oxygen demand | 6 | Casanova et al. (2001), Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), Jamrah et al. (2008), and Winward et al. (2008) |
| BOD/COD | Biological oxygen demand/ chemical oxygen demand | 1 | Halalsheh et al. (2008) |
| DO | Dissolved oxygen | 1 | Jamrah et al. (2008) |
| EC | Electrical conductivity | 5 | Casanova et al. (2001), Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), and Jamrah et al. (2008) |
| ALKY | Alkalinity | 1 | Jamrah et al. (2008) |
| B | Boron | 2 | Friedler (2004) and Gross et al. (2005) |
| $SO_4$ | Sulfates | 2 | Casanova et al. (2001) and Halalsheh et al. (2008) |
| Cl | Chlorine | 1 | Casanova et al. (2001) |
| TN | Total nitrogen | 1 | Gross et al. (2005) |
| N-kj | Total Kjeldahl nitrogen | 1 | Halalsheh et al. (2008) |
| $NO\text{-}_3$ | Nitrate | 1 | Jamrah et al. (2008) |
| $NH_4$-N | Ammonium (indicated in mg/l) | 1 | Friedler (2004) |
| $NH_3$ | Ammonia | 1 | Halalsheh et al. (2008) |
| $PO^4$-P | Phosphate | 3 | Friedler (2004), Gross et al. (2005), and Halalsheh et al. (2008) |
| FOG | Fat oil and grease | 2 | Friedler (2004) and Halalsheh et al. (2008) |
| MBAS | Methylene blue active substances assay (detects surfactants) | 4 | Friedler (2004), Gross et al. (2005), Halalsheh et al. (2008), and Jamrah et al. (2008) |
| Na | Sodium | 2 | Friedler (2004) and Jamrah et al. (2008) |
| SAR | Sodium absorption ratio | 1 | Gross et al. (2005) |
| $HCO_3$ | Bicarbonate | 1 | Halalsheh et al. (2008) |
| Ca | Calcium | 1 | Jamrah et al. (2008) |
| Mg | Magnesium | 1 | Jamrah et al. (2008) |
| K | Potassium | 1 | Jamrah et al. (2008) |
| ZN | Zinc | 1 | Jamrah et al. (2008) |
| Al | Aluminum | 1 | Jamrah et al. (2008) |
| Pb | Lead | 1 | Jamrah et al. (2008) |
| Cu | Copper | 1 | Jamrah et al. (2008) |
| Ni | Nickel | 1 | Jamrah et al. (2008) |

**Table 1** continued

| Abbreviation | Description | Frequency of use | GW quality assessment |
|---|---|---|---|
| XOC[a] | Xenobiotic organic compound | 1 | Eriksson et al. (2002) |
| *Biological* | | | |
| TC | Total coliforms | 4 | Casanova et al. (2001), Halalsheh et al. (2008), Jamrah et al. (2008), and Winward et al. (2008) |
| FC | Fecal coliforms | 6 | Casanova et al. (2001), Friedler (2004), Gross et al. (2005), Ottoson and Stenstrom (2003), Halalsheh et al. (2008), and Jamrah et al. (2008) |
| – | Fecal streptococci | 1 | Casanova et al. (2001) |
| – | Fecal enterococci | 2 | Ottoson and Stenstrom (2003) and Winward et al. (2008) |
| – | Coliphages | 2 | Casanova et al. (2001) and Ottoson and Stenstrom (2003) |
| – | Coprostanol | 1 | Ottoson and Stenstrom (2003) |
| – | Cholesterol | 1 | Ottoson and Stenstrom (2003) |
| – | Indicator *E. coli* | 4 | Ottoson and Stenstrom (2003), Halalsheh et al. (2008), Winward et al. (2008), and O'Toole et al. (2012) |
| *ehxA* | Hemolysin gene of *E. coli* | 1 | O'Toole et al. (2012) |
| Typ EPEC | Typical enteropathogenic *E. coli* | 1 | O'Toole et al. (2012) |
| Atyp EPEC | Atypical enteropathogenic *E. coli* | 1 | O'Toole et al. (2012) |
| EAEC | Enteroaggregative *E. coli* | 1 | O'Toole et al. (2012) |
| – | *Staphylococcus aureus* | 2 | Casanova et al. (2001) and Winward et al. (2008) |
| – | *Pseudomonas aeruginosa* | 2 | Casanova et al. (2001) and Winward et al. (2008) |
| – | *Clostridium Perfringens* spores | 1 | Ottoson and Stenstrom (2003) |
| – | *Clostridium* | 1 | Winward et al. (2008) |
| – | *Campylobacter* spp. | 1 | Winward et al. (2008) |
| – | *Compylobacter Jejuni*[b] | 2 | Ottoson and Stenstrom (2003) and Mara et al. (2007) |
| – | *Salmonella*spp. | 1 | Winward et al. (2008) |
| – | *Salmonella*[b] | 1 | Ottoson and Stenstrom (2003) |
| – | *Cryptosporidium Parvum*[b] | 2 | Ottoson and Stenstrom (2003) and Mara et al. (2007) |
| – | *Giardia Lamblia*[b] | 1 | Ottoson and Stenstrom (2003) |
| – | Norovirus GI[c] | 1 | O'Toole et al. (2012) |
| – | Norovirus GII[c] | 1 | O'Toole et al. (2012) |
| – | Enterovirus[c] | 1 | O'Toole et al. (2012) |
| – | Rotavirus[c] | 1 | O'Toole et al. (2012) |
| – | Rotavirus[b] | 2 | Ottoson and Stenstrom (2003) and Mara et al. (2007) |

[a] Assessed potential presence via literature review

[b] Risk of human exposure estimated by surrogate using a statistical model

[c] Assessed using RT-PCR

## PERSPECTIVE 2: A BALANCE OF INCENTIVES FOR IRRIGATING WITH TGW IN SMALL COMMUNITIES

For TGW use to be adopted widely in small communities there is a balance that must first be struck between health, economic, and societal incentives. First, studies are inconclusive about the health risks associated with using GW and TGW at the household-level. The residual doubt leads many to believe that municipal water is much safer than GW. The result is that although many would like to use GW or TGW, they continue to use municipal water for health reasons. Second, individuals who value the economic incentives of using GW are more likely to forgo using TGW compared to raw GW because of the costs associated with acquiring and maintaining GWTUs. When monetary resources are limited and presented with the choice of paying several months wages for a GWTU or using raw GW that is available free of charge, most choose to risk whatever health consequence and proceed with using raw GW. Third, reducing the consumption of groundwater and increasing the efficiency of centralized wastewater treatment facilities are important at the societal level and are worth pursuing at the government or organizational level, but offer only altruistic incentives at the individual level. While farmers may be fully aware of the diminishing water supply in the region, this may not be enough motivation to spend upwards of 300 USD on an alternative water resource. It may be enough motivation to cause them to use a free water source like GW, but it is unlikely that national- and regional-level goals will be accomplished through TGW if the cost of achieving these goals remains on the individual.

## CONCLUSION

To achieve widespread use of TGW in low-income rural communities and to achieve goals of water security through TGW use, first there is a need for large-scale epidemiological studies that examine validated and standardized GW quality indicators, actual human health outcomes from using GW and account for the use of treatment and adherence to guidelines for irrigation throughout time. Second, governments and partnering organizations must seek to lower GWTU construction costs or provide a more expansive subsidization system to make the purchase of a unit cost-effective for subsistence farmers. Societal, religious, and individual-level perceptions of GW are mostly positive but the incentives of purchasing treatment are not valuable enough for subsistence farmers unless provided at a low cost. Given the health uncertainties, education on proper use of GW and TGW according to current guidelines for household-level irrigation with wastewater should be emphasized in areas where GW use continues.

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