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Assessment and reform of greywater reuse policies and practice: a case study from Sharjah, United Arab Emirates

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Abstract

This article presents an assessment of one of the earliest greywater reuse (GWR) experiences in Sharjah, United Arab Emirates (UAE). In 2003, the Sharjah Electricity and Water Authority (SEWA) imposed a compulsory GWR program on various categories of new buildings in the city. However, implementation of the program faced significant resistance and setbacks and remained limited to about 200 buildings, representing less than 2% water savings. In the analysis presented in this study, the need for GWR was assessed through analyzing SEWA's water supply and demand projections, conducting a 12-month water use survey of 285,000 Sharjah residents from about 140 nationalities, and identifying the areas in the city with intense water use. In addition, analysis and reforms of the various aspects of SEWA's GWR reuse policies and practice were presented and discussed. Reforming the policy to increase GWR to about 10% water savings can lead to significant reductions in desalinated water consumption and wastewater generation and consequently significant reductions in desalination cost (35 million USD/y), energy consumption (225,840 MWh/year) and CO_2 emissions (120 ton/year). The case study presented in the article can serve as a reference to guide GWR policies and practice, especially for local authorities in developing countries.

Keywords: Compulsory and voluntary GWR; Greywater reuse (GWR); GWR incentives; GWR policies and practice; United Arab Emirates; Water conservation

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Highlights

- Sharjah's water authority's 2003 greywater reuse (GWR) policy proved impractical.
- GWR in Sharjah remained limited to a maximum of 200 buildings since implementation.
- GWR policy guidelines based on 15 years accumulated local experience are presented.
- Study provides valuable GWR policy guidelines, especially for developing countries.

Introduction

The United Nations Educational, Scientific and Cultural Organization (UNESCO) in its World Water Development Report (UNESCO, 2018) estimates that by 2050 about six billion out of the projected 9.4–10.2 billion global population will suffer from water scarcity. The increasing water scarcity is attributed to population growth, rapid economic development and deterioration of water quality (Wang & Zimmerman, 2016; Mason *et al.*, 2018; UNESCO, 2018). In arid and semi-arid regions of the world, conventional water sources, including available surface and ground water resources, are typically not enough to meet the growing demand for freshwater. Therefore, unconventional water sources, such as desalinated water and treated wastewater, are needed to help meet the increasing demand. Increasingly, greywater (GW) is becoming recognized as an important unconventional water source that is directly available to consumers in urban areas. GW comes mainly from showers, bathtubs, and handwashing basins, and may include laundry water (Yu *et al.*, 2013). GW constitutes the larger (50–70%) and cleaner portion of domestic wastewater (Fountoulakis *et al.*, 2016; Kai Siang *et al.*, 2018). Traditional wastewater treatment and reuse systems rely on centralized systems, while greywater reuse (GWR) is decentralized (Vuppaladadiyam *et al.*, 2019). Onsite GW reuse for non-potable purposes, such as toilet flushing, irrigation, car washing and cooling, is gaining increasing interest and acceptance (Couto *et al.*, 2015; De Gisi *et al.*, 2016; Zavala *et al.*, 2016). GWR can also positively contribute towards reducing energy and greenhouse gas emissions related to wastewater management (Domènech & Saurí, 2011; Hossein *et al.*, 2013; Sarkar *et al.*, 2014; Owusu & Teye, 2015).

The Arabian Peninsula is among the driest regions in the world and its countries are facing growing gaps between natural freshwater supply and demand (Odhiambo, 2017). The Gulf Cooperation Council (GCC) countries of the Arabian Peninsula (Saudi Arabia, United Arab Emirates, Kuwait, Qatar, Bahrain and Oman) are highly dependent on desalination and groundwater to meet the ever-increasing water demand (Lambert & Lee, 2018). The six GCC countries, which are oil producing countries, account for about 50% of the global seawater desalination capacity (Lattemann & Höpner, 2008). Desalination, however, comes at a significant cost related to brine and chemical discharges, greenhouse gas emissions and high energy demand (Dawoud & Al Mulla, 2012). Therefore, water conservation and use of unconventional water resources are essential strategies for such countries (Sarkar *et al.*, 2014; Owusu & Teye, 2015).

Experience with GWR in the Arabian Gulf region remains in the early stages. Vuppaladadiyam *et al.* (2019) reported significant GWR efforts in Jordan in collaboration with the World Health Organization (Ercin & Hoekstra, 2014). In the region, in 2003, the Sharjah Electricity and Water Authority (SEWA) was the first to initiate a compulsory GWR program for large water consumers in Sharjah city, United Arab Emirates (UAE). Sharjah's GWR program faced many challenges that resulted in rolling back the compulsory requirements, however, the experience demonstrated high potential for success provided there was adaptation of appropriate policies and regulations (Shanableh *et al*., 2012). Internationally, GWR is practiced in many countries, but the policies, regulations, participation and socio-economic and technical challenges vary widely (Mizyed, 2013). Therefore, it is essential to develop local GWR policies and regulations that are consistent with the local needs and requirements.

The obstacles and setbacks faced by the Sharjah GWR program, which limited participation to a maximum of about 200 installations during the past 17 years, motivated a team from SEWA and the University of Sharjah (UoS) to assess the current GWR policies and practice and propose modified GWR policies and guidelines for Sharjah. This article presents an assessment of Sharjah's GWR experience and proposed reforms based on accumulated experience and international practice.

Methodology

Assessment and reform of the GWR program in Sharjah was conducted by a joint team from Sharjah Electricity and Water Authority (SEWA) and the University of Sharjah (UoS) following the steps outlined in Figure 1. The methodology described in Figure 1 involves three main tasks as described in the following subsections.

Need for GWR in Sharjah

Assessment of need for GWR in Sharjah involved assessing the water use in Sharjah, the need for greywater reuse and the past GWR experience in Sharjah. Initially, data on the average monthly and yearly temperature and rainfall during the period 2003–2019 were compiled and analyzed to indicate the hot dry climate of Sharjah. In addition, data from Sharjah Electricity and Water Authority (SEWA) indicating actual and projected water supply and demand for Sharjah for the period 2012–2025 were obtained and analyzed. SEWA also provided results of a 12-month water use survey of about 285,000 residents from about 140 nationalities living in apartments or detached dwellings in

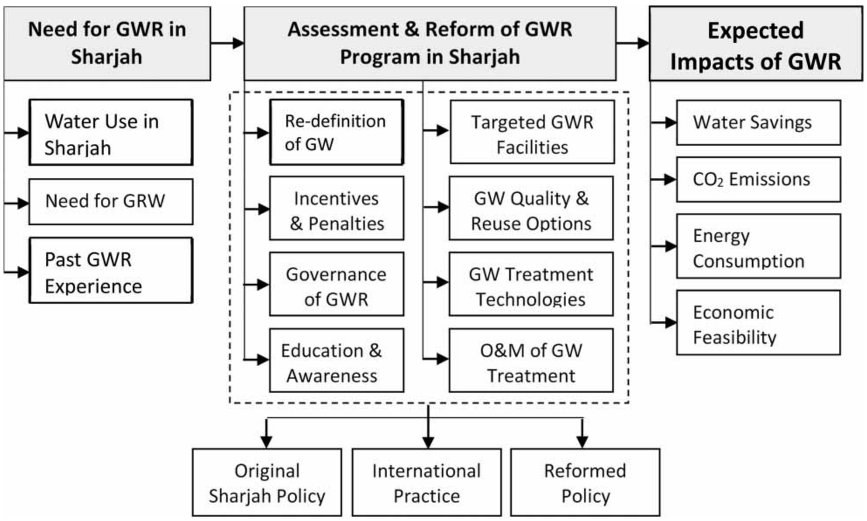

Fig. 1. Methodology framework.

Sharjah. SEWA has direct access to consumers' records and water meters, which enabled SEWA to survey a large portion of Sharjah's population. Finally, a water use heat map was developed to identify the areas in Sharjah with the highest water use and GWR potential.

Assessment and reform of GWR program in Sharjah

The second phase of the study (Figure 1) involved assessment and reform of the GWR program in Sharjah. Assessment and reform addressed various aspects of the program, including definition of GW, facilities targeted for GWR, GWR options and associated water quality, appropriate GW treatment technologies for Sharjah, operation and maintenance requirements of GW treatment systems, penalties and incentives associated with GWR, governance of GWR, and community education and awareness requirements. Modifications to each aspect of the GWR program were based on past experience in Sharjah and international policies and practice (Figure 1).

Potential impact of GWR reforms

The third phase of the study (Figure 1) considered the potential impact of reforming the GWR program on water savings, CO_2 emissions, energy consumption and economic feasibility. The assessment was based on various GWR expansion scenarios assuming water savings ranging between 2 and 10% and associated reductions in desalination costs, energy consumption and CO_2 emissions.

Results and discussion

Need for GWR in Sharjah

Water use survey. To assess GWR potential, SEWA conducted a domestic water use survey in Sharjah City that considered the nationalities of users and type of residence. The survey covered a large portion of Sharjah's population as SEWA owns and has direct access to water meters installed in buildings and keeps relevant customers' records, including nationalities. The survey included old and new buildings and was based on readings of water meters installed in surveyed buildings. The survey was conducted over a 12-month period and included about 285,000 residents from about 140 nationalities classified in Table 1 into seven categories. The expatriate population of the Sharjah is highly diverse but the majority of the population is of Asian origin, with residents from India, Pakistan and Bangladesh constituting about 50% of the population. Users of Middle Eastern origins are classified in Table 1 into two categories, citizens of the GCC countries, including citizens of the UAE, and Middle Easterners from other countries. The variety of cultural backgrounds of water users is an important consideration in terms of acceptability of GWR.

As illustrated in Figure 2, the data show that the water consumption in 2018 was in the range of 100–150 liters per capita per day (L/c/d) for apartments and 200–610 L/c/d for villas. The water consumption was dependent on both nationality and type of residence. For example, the water consumption of GCC citizens in the Middle East reached 610 L/c/d compared to 430 L/c/d for North Americans. For residents of apartments, the highest water consumption was also for the GCC Middle Easterners while the lowest was for South Americans who live in apartments. The higher water consumption in detached villas compared to apartments may be attributed to the fact that detached villas typically have green front and back yards that require frequent irrigation and that the residents of

Table 1. Summary of SEWA's water 2018 users' survey – nationalities and type of residence.

Regional nationality	Villas	Apartments	Total
Asian	2,308	138,582	140,890
M. East (non GCC)	2,580	73,150	75,730
M. East (GCC)	44,621	14,362	58,983
African	206	4,836	5,042
European	558	2,220	2,778
N. American	148	1,205	1,353
S. American	0	271	271
Totals	50,421	234,626	285,047

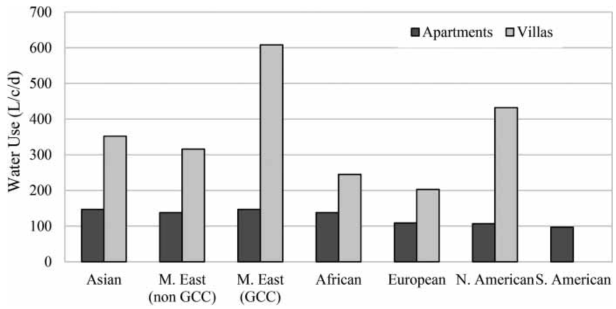

Fig. 2. Average daily water consumption according to regional nationalities and type of residence in Sharjah in 2018.

detached villas are mostly UAE citizens who receive water at a subsidized rate. The overall weighted average water consumption for those surveyed was approximately 220 L/c/d. Another survey of water use based on water bills (Shanableh *et al.*, 2018) also indicated wide variations in residential (apartments) water consumption in Sharjah, ranging between 150 to more than 400 L/c/d.

In addition to indicating rates of water consumption, the results of the survey illustrate the challenge of applying a uniform GWR policy to a highly diverse population of consumers in terms of water consumption and socioeconomic backgrounds. For example, UAE citizens who reside mostly in detached villas and receive water at a highly subsidized rate may not be motivated to implement GWR to reduce water consumption and water charges. On the other hand, owners of apartment buildings may not be motivated to install and operate GWR systems due to negative perceptions, increased liability and lack of financial incentives in the current policy. Water charges on the other hand may not be of major concern to low water consuming tenants of small or shared apartment residential units.

In terms of GW generation per fixture, SEWA estimates that GW generated from washing basins, showers and baths constitutes approximately 33% of the total use. With laundry water, GW makes more than 50% of the total water use. Based on an average domestic water use of 220 L/c/d in Sharjah, GW generation without laundry water amounts to about 66 L/c/d and with laundry water about 110 L/c/d. Clearly, GWR can satisfy the demand for toilet flushing, estimated in Sharjah to be 27% of the water use (about 54 L/c/d), which can lead to significant water savings.

Spatial distribution of water use. Figure 3 depicts SEWA's 2018 water use intensity map in the city of Sharjah. The high-water use intensity parts of the city are located near the two coastal lagoons that are

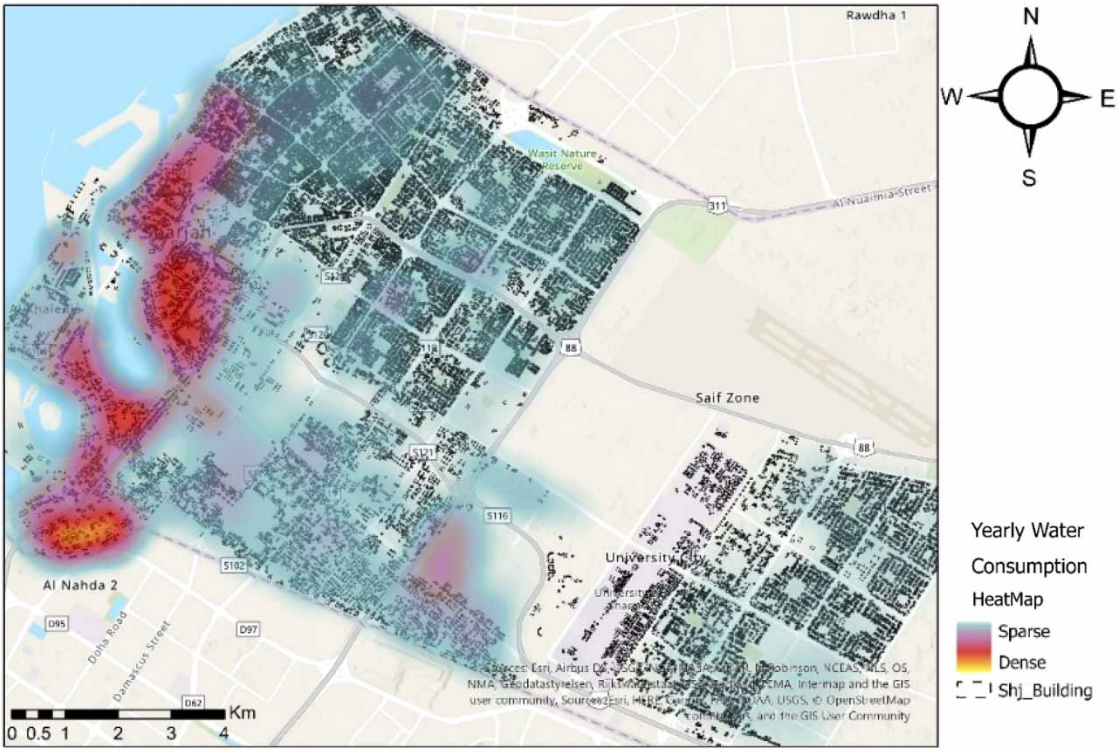

Fig. 3. SEWA's 2018 heat map of annual water consumption in Sharjah.

surrounded by high-rise buildings. The inland middle intensity areas consist of the university city, industrial areas, and parts of the old city that contain multi-storey buildings. On the other hand, the low water use intensity areas consist mainly of detached villas occupied by locals. In fact, most of Sharjah's current 1.3 million residents live in apartments in multi-storey buildings (Table 2). Therefore, expansion of GWR in the high intensity areas can account for a significant part of GWR in the city. In fact, GWR as makeup water in cooling towers of air-conditioning systems proved highly feasible in high-rise buildings in Sharjah (Shanableh *et al.*, 2020).

Need for GWR in Sharjah. The UAE has hot summers, with mean maximum temperatures reaching as high as approximately 50 °C in summer (Figure 4). The mean monthly temperature is about 27 °C and

Table 2. SEWA's Estimate of buildings stock and population in Sharjah.

Item	Approximate value
Number of multi-storey buildings	6,500
Number of apartments	250,000
Number of villas	25,000
Residents of apartments	1,000,000
Residents of villas	300,000

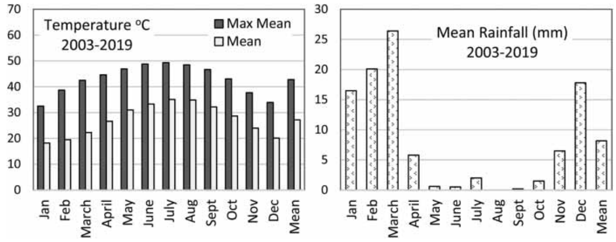

Fig. 4. Temperature and rainfall monthly and yearly means during the period 2003–20019 at Sharjah Airport (*Data source:* National Center of Meteorology, June 2020).

the maximum mean temperature is about 43 °C. The rainy season extends between November and April with the mean annual rainfall being less than 100 mm (Figure 4). In fact, the UAE is classified as one of the most water stressed countries and is highly dependent on desalination to meet water demand. According to the UAE official portal, last visited on 20 December 2020, the country has about 70 major desalination plants accounting for about 14% of the world's desalination capacity.

In addition to the water scarcity, the total per capita water consumption in the UAE (including residential, agriculture, commercial, and industrial usage) is typically reported to be 550 liters per day (UAE Ministry of Environment and Water 2015). In addition, the UAE residents are known to be among the highest consumers of bottled water, which comes mostly from desalination. Clearly, saving water is of strategic importance to the country as the population continues to grow rapidly, groundwater resources are increasingly being depleted, and desalination is expensive and generates brines and undesirable greenhouse gas emissions.

The 2019 Sharjah water demand of approximately 0.43 Mm^3/d (Figure 5) was supplied by SEWA from various sources that included: 20% imports from Abu Dhabi, the capital of the UAE; 5% from wellfields; and 75% from desalination. Based on a projected 5% increase in water demand and 2018 as a baseline, SEWA projects a water shortage of approximately 45% in 2025 (Figure 5). To meet projected deficit, SEWA's options include massive investment in additional desalination and water infrastructure capacity, water conservation, and utilization of unconventional water sources, such as GW and reclaimed wastewater. In Sharjah, wastewater treatment and reuse are managed by the Sharjah Municipality (SM) while GWR is managed by SEWA. SM uses treated wastewater extensively for greening of Sharjah landscapes, with excess effluent discharged to the sea during the rainy season.

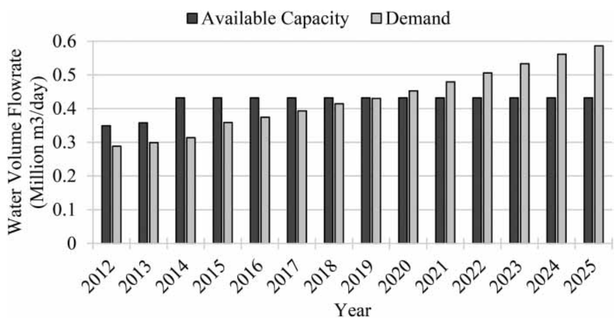

Fig. 5. Water supply and demand in Sharjah (Water Department – SEWA, 2018).

On the other hand, SEWA is concerned with reducing the domestic demand for freshwater. In fact, and although SM and SEWA do not closely coordinate their water supply and wastewater policies, GWR has the potential to reduce the load to the currently overloaded main wastewater treatment plant in Sharjah.

Despite potential, achieving significant water savings from GWR proved to be a major challenge in Sharjah. Currently, the GWR program in Sharjah is limited to new buildings and achieves less than 2% water savings. Increasing savings requires a significant increase in the level of community participation in GWR through engaging owners of existing buildings, offering adequate incentives and education and awareness. For example, if the surveyed water users in Table 1 (285,000 users, or about 22% of Sharjah City population) were to participate in GWR, then the water savings would reach approximately 12% of household water demand. Furthermore, GWR can reduce energy consumption and emissions associated with water supply. Based on reported electricity and CO_2 emissions factors (Krarti & Dubey, 2018), a 12% water saving due to GWR may reduce CO_2 emissions by approximately 150 tons/year and save electricity by about 300 MWh/year.

Assessment and reform of GWR program in Sharjah

Sharjah's 2003–2019 GWR experience. In 2003, SEWA proposed a compulsory GWR program on large water consumers (i.e. shopping centers, houses of worship, hotels, furnished apartments, schools, factories, government buildings, car washing facilities, multi-storey buildings, and labor housing). The program was motivated by principles and practical considerations of conservation, efficiency, sustainability, social responsibility and long-term perspectives (Al Leem, 2015). Since implementation in 2004, the program faced resistance and suffered major setbacks. In 2014, SEWA rolled back the compulsory requirements and made it optional except for hotels, furnished apartments and residential/commercial buildings that use open cooling tower systems. The main GWR challenges related to lack of readiness in terms of community awareness and education, lack of experience, lack of economic incentives, negative perceptions and lack of capacity to monitor and audit systems and enforce the requirements (Shanableh *et al*., 2018). Consequently, the level of community participation in the GWR program remained limited despite the compulsory requirements between 2004 and 2014.

GWR in hotels for landscape irrigation and in rental properties for cooling tower applications proved to be feasible and desirable by owners. On the other hand, landlords of rental properties considered the GWR requirements for toilet flushing to be a burden from financial and operational points of view. Owners of such buildings could not pass the full cost of GWR to tenants through raising rent nor could they share savings with their tenants. Furthermore, the market was not ready for a sudden implementation of the compulsory requirements. As per the conducted field visits and interviews with stakeholders, early system installations suffered from a variety of negative experiences, such as faulty installation of plumbing systems, use of improper systems and materials, poor design of treatment facilities, lack of adequate operation and maintenance, negative perception due to odor emissions, insufficient supervision, lack of certification of systems and components, and difficulties with program enforcement. Even properly installed GWR systems suffered setbacks with owners shutting down such systems to save money. Overall, the number of GWR installations in Sharjah since program initiation remained limited to approximately 200 installations, which amounts to less than 2% of the residential water use. The current program limits GWR requirements to new large buildings, but increasing participation requires engaging owners of existing buildings. For example, achieving water use reduction of approximately 12% requires the participation of around a quarter of Sharjah's population of about 1.2 million.

The dominant culture in Sharjah imposes purity restrictions on reuse of water previously mixed with human waste. The Sharjah community, however, remains not adequately educated on the differences between GW and wastewater, nor aware that religious scholars allow reuse of treated wastewater for non-potable purposes (Faruqui *et al.*, 2001). Negative perceptions are enforced by negative GWR experiences. For example, poorly designed and operated GWR systems in the city typically result in complaints about odors emitted from treatment units.

On the other hand, successful GWR installations in Sharjah achieved significant water and financial savings in the range of 25–40% (Shanableh *et al.*, 2018, 2019). Such installations involved the use of GW as makeup water in HVAC cooling towers and landscape irrigation in schools and hotels. In all successful applications, GWR systems proved to be financially beneficial to owners, while unsuccessful applications added financial and operational burdens to owners.

Modified GWR program in Sharjah

Re-definition of GW. Sharjah's program considered water collected from showers, bathtubs and hand-washing basins as GW and excluded laundry and kitchen waters. Internationally, GW definition varies among countries, states or cities with respect to including kitchen water (Yu *et al.*, 2013). Laundry water may include lint, dirt, oil and grease, soaps, detergents and other compounds that requires more complex treatment. Therefore, laundry water was excluded from GW in the 2003 Sharjah GWR program. Furthermore, the demand for GWR in buildings may be lower than available GW and therefore collection and treatment of laundry water may not be necessary. For example, reusing GW for toilet flushing may require a significant part of the GW available in any building, but not necessarily all the available quantity. Nevertheless, SEWA recommended that the plumbing infrastructure be designed for collecting and treating all potentially available GW, including laundry water. This recommendation is to ensure that the GWR infrastructure is available for potential policy changes or technological advancements that may either mandate GWR or make it attractive to tenants and landlords in Sharjah.

Facilities targeted by the GWR program

SEWA's initial GWR regulations of 2003 made it compulsory on owners of large new buildings to install and operate GWR facilities. Noticeably, the 2003 GWR program categories did not address small water users in detached and semi-detached residential dwellings, nor imposed requirements on existing buildings. In 2014, SEWA changed the requirements and adopted a mixed, compulsory/optional approach, with the compulsory requirements maintained on hotels, furnished apartments and residential/commercial buildings that employ open cooling tower systems for air conditioning.

Internationally, GWR is generally optional rather than compulsory. Voluntary GWR may be promoted through provision of incentives (Cupp & Nichols, 2011), such as rebates, tax deductions, grants and permit exemptions (City and County of SF, 2012). Certain authorities may also require landlords to install dual plumbing systems to accommodate future GWR (Yu *et al.*, 2016). In Tokyo, the government enforces GWR in buildings with an area more than 30,000 m^2 or with potential reuse of 100 m^3/day (McIllwaine, 2003). In Andalusia, Spain, hotels were initially obliged to install GWR systems but the requirements were relaxed in 2008 upon the requests of many hotel managers (Domènech & Saurí, 2010).

SEWA should not limit the GWR program to large consumers and new buildings but should include existing buildings and small facilities such as detached dwellings and townhouses. Clearly, the GWR requirements of small consumers should differ from large consumers in terms of required approvals, treatment requirements, allowed uses of GW, incentives, operation and maintenance, and reporting other relevant requirements. Therefore, and to simplify governance and facilitate implementation of GWR in Sharjah, it is recommended to follow the example of the Department of Health of the Government of Western Australia (Department of Health, Government of Western Australia, 2011) and to classify the GWR systems in Sharjah into small ($<5\ m^3$/day), such as detached dwellings, townhouses and small houses of worship, and large ($>5\ m^3$/day), such as commercial and residential buildings, hotels, shopping centers, educational institutions, large houses of worship, and government facilities.

The Sharjah compulsory GWR requirements for cooling in new buildings proved acceptable and beneficial to owners and therefore the program may remain unchanged. For older buildings with HVAC cooling towers, it is recommended that SEWA adopts an optional approach with adequate incentives to encourage owners to retrofit their building with GWR systems. On the other hand, it is recommended that GWR for toilet flushing and restricted irrigation be optional for existing and new buildings with owners supported by incentives, on a case-by-case basis, technical assistance and education to encourage participation. For owners-occupiers of buildings, the benefits can be realized from savings in water charges, with additional incentives potentially offered by SEWA in the form of reduced charges proportional to reduction in consumption. On the other hand, owners of rental properties in which GWR is used for toilet flushing may not benefit from the savings achieved by their tenants unless they raise rent, which may not be attractive to tenants. Therefore, SEWA may structure the water charges such that owners share savings with tenants and offer rebates to such owners based on GWR efficiency.

GW use categories and water quality requirements

The available GWR options in Sharjah include irrigation, dust control, toilet flushing, restricted irrigation and cooling in HVAC systems. SEWA currently applies one set of water quality (WQ) requirements for all GWR options (Table 3). Such requirements may be unnecessarily restrictive and costly. Internationally, WQ requirements are linked to intended GWR options (Table 3), and SEWAS should adopt a similar approach for Sharjah. It is recommended that SEWA adopts three sets of WQ requirements for GWR for non-potable purposes as follows: (1) General WQ for subsurface irrigation, (2) Advanced WQ for surface irrigation, and (3) High WQ for toilet flushing and cooling towers in residential buildings. In all cases however, GWR to irrigate raw-edible crops must not be allowed in Sharjah. The prohibition was a requirement in the original SEWA policy and is expected to remain a requirement in Sharjah for the foreseeable future. Such a prohibition is common in the region (McIlwaine, 2010) and relates to negative community perceptions and lack of general awareness of the differences between GW and wastewater. Additionally, the following GWR requirements in the current SEWA GWR program should be maintained:

- should not be stored for long to avoid excessive growth of microorganisms;
- should not be used for irrigation of small domestic planters;
- should not be used for irrigation of plants or vegetables that are eaten raw; and
- should not come in direct contact with humans.

Table 3. Proposed GWR options and corresponding WQ limits.

	Sharjah GWR WQ Requirements				UK				WA		Canada
	Current	Recommended			(Hoare Lea, 2013)				(Gov. of WA 2011)		(MoH, 2010)
Parameter	All	SSI[a]	SI[b], DC[c], CW[d]	TF[e], OCT[f]	SA[g]	TF[e]	GW[h]	L[i]	HR[j]	Low	TF[e]
pH	6–8	Direct Diversion System that	6–8	6–8	5–9.5				6.5–8.5	6.5–8.5	–
BOD (mg/L)	≤10	includes screening and	<20	<10	–	–	–	–	–	–	≤20
COD (mg/L)	≤50	filtration with no storage	<100	<50	–	–	–	–	–	–	–
TSS (mg/L)	≤10	allowed	<30	<10	–	–	–	–	–	–	≤20
Total Coliform (MPN/100 mL)	≤100		<100	<100	10	1,000	1,000	10	–	–	–
Fecal Coliform (MPN/100 mL)	≤5		<5	<5	–	–	–	–	–	–	–
R. Chlorine (mg/L)	0.5–1		0.5–1	0.5–1	–	–	–	–	–	–	–
E. coli, (cfu/100 mL)	–		–	–	N/A	250	250	N/A	<1	<1,000	≤200
Turbidity (NTU)	–		–	–	<10	<10	N/A	<10	<2–5	–	≤5

[a]SSI: Sub-surface irrigation.
[b]SI: Surface Irrigation.
[c]DC: Dust Control.
[d]CW: car washing.
[e]TF: Toilet Flushing.
[f]OCT: Cooling Towers.
[g]SA: Surface Application.
[h]GW: General Wash.
[i]L: Laundry.
[j]HR: High Risk.

Appropriate GW treatment technologies for Sharjah

The main GW pollutants include suspended solids, hair, oil and grease, nutrients, dissolved organic matter, surfactants, dyes and microorganisms (Roccaro *et al.*, 2013; Braga & Varesche, 2014). Initially, basic granular activated carbon (GAC) was used for GWR treatment in Sharjah (Figure 6(a)). Between 2005 and 2011, SEWA introduced improvements to GAC systems through inclusion of screens and hair strainers and requiring provision of make-up water, system automation, automatic diversion of influent and effluent to sewers and coagulation prior to filtration. In 2012, SEWA approved ultrafiltration (UF) systems (Figure 6(b)) in selected buildings and in 2014 SEWA demanded the use of UF systems, which proved more reliable than GAC systems, in high-rise buildings. Currently, GAC systems are mostly used in schools and labor campus while UF systems are used in multi-storey buildings (Shanableh *et al.*, 2018).

A variety of technologies can be used to treat GW for reuse (Fountoulakis *et al.*, 2016; Oh *et al.*, 2018; Vuppaladadiyam *et al.*, 2019). Typical pre-treatment steps include screening, straining and aerated equalization storage, with post-treatment consisting of disinfection. The main treatment consists of either GAC, UF, biological treatment followed by sedimentation and possibly filtration or membrane biological reactors. Diversion GWR systems for sub-surface irrigation may utilize screens, strainers and filters without storage. Authorities can either specify GW treatment systems (i.e. prescriptive approach) or approve systems that can meet the required WQ (i.e. performance-based approach), or a combination of both (Can *et al.*, 2014; Farajzadehha *et al.*, 2015; Daghrir *et al.*, 2016). In Singapore for example (PUB, 2014), it is obligatory to utilize biological treatment combined with advanced filtration and disinfection for applications that pose potential risk to human health. In some Australian states (Government of WA, DoH, 2011), authorities focus on demonstrated performance through testing, validation and monitoring.

For Sharjah, it is recommended that SEWA: (1) utilizes a mixed prescriptive/performance-based GW treatment system; (2) continue to certify treatment systems; and (3) issue design, health and safety, and operation and maintenance guidelines for GW systems. SEWA should specify the minimum pre-treatment and post-treatment system components, with the main treatment step being performance-based. It is also recommended that GW treatment systems be modular in design to match the level of buildings' occupancy. SEWA should also allow third parties to build and operate GW treatment systems for profit.

Operation and maintenance of GW treatment systems

In Sharjah, the owners of GWR systems are responsible for operating and maintaining their GW treatment systems. SEWA requires monthly reports to ensure achievement of the required WQ. However,

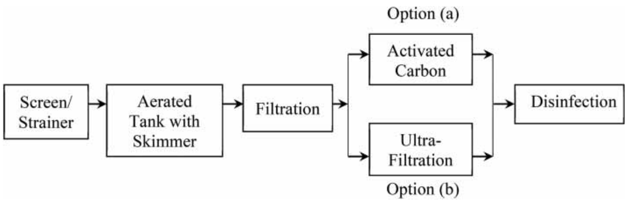

Fig. 6. Current GW treatment systems in Sharjah: (a) activated carbon; (b) ultra-filtration.

SEWA does not monitor treated GW quantities nor requires maintenance reports. To cut costs, owners may rely on unqualified building attendants and security personnel for operation and may require cheap materials and spare parts, which results in frequent shutdowns and failure of GW facilities. In fact, bad odours and frequent complaints from tenants result in shutdowns and abandonment of treatment systems in Sharjah.

International practice demands that owners of complex systems adequately operate and maintain GW treatment systems through engaging the services of qualified operators (City and County of SF, 2012) in addition to complying with manufacturer's instructions and approval conditions issued by local councils (DWE – NSW, 2008). In Sharjah, it is recommended that SEWA issues general operation and maintenance guidelines and requirements, provide educational and training opportunities for personnel, provide incentives for well maintained and operated systems, and demand that suppliers provide training to operators of new systems. A set of proposed guidelines and requirements for Sharjah are provided in Table 4. Owners can sign contracts with specialized firms to operate and maintain GW treatment systems as well as benefit from build-own-operate-transfer (BOOT) schemes, whereby BOOT companies install, operate and maintain treatment systems on behalf of owners following SEWA requirements. SEWA, however, should certify all service contract companies and BOOT arrangements.

Incentives and penalties

At the time SEWA introduced the compulsory GWR program in 2003, it was assumed that savings in water consumption can pay for cost of GWR systems. However, analysis of Sharjah's experience revealed that some owners and tenants benefited significantly while others lost due to the ownership and tenancy situation in Sharjah (Shanableh *et al*., 2018). For example, owners of buildings who use GW as makeup water in HVAC cooling towers made significant savings while their tenants, who supplied the GW, did not benefit from the savings. On the other hand, owners of rental properties who

Table 4. Proposed operation and maintenance guidelines and requirements for Sharjah.

O&M Related Issue	Small GWR Systems	Large GW Systems	SEWA
Third party O&M arrangement (if applicable)	N/A	✓	
Owner/tenant O&M arrangement (if applicable)	✓	✓	
Operator certification by SEWA	N/A	✓	
Submission of quarterly WQ reports	N/A	✓	
Submission of GWR quantity records	N/A	✓	
Submission of evidence of annual inspection	✓	✓	
O&M record keeping	✓	✓	
O&M manuals/procedures	✓	✓	
Sampling and sample handling procedures	✓	✓	
Health and safety procedures	✓	✓	
Incidence documentation and reporting	✓	✓	
Readiness for audits	✓	✓	
Certification of WQ analysis and service companies			✓
Incentives for effective O&M			✓
Education and training opportunities for O&M personnel			✓
Regular inspection/auditing of installed systems			✓

installed GWR systems for flushing toilets incurred losses as the market reality did not allow proportional increases in the rent while their tenants benefited from savings in their water bills. Table 5 provides a summary of the current financial gains/losses associated with GWR in Sharjah.

As for the penalties, the SEWA 2003 program included penalties for failing to install and adequately maintain GWR systems. However, owners either resisted the installation of compulsory GWR systems and opted for paying penalties, installed off-line GWR systems to avoid penalties, sought exemptions from penalties, or used other ways to avoid the requirements. In NSW, Australia, failure to obtain required installation and operation approvals carry penalties and local councils can issue on the spot fines (DWE – NSW, 2008).

Internationally, a variety of incentives are offered to owners of GWR systems depending on the size and complexity of GW installations. San Francisco City, USA, for example offers financial assistant grants for single and multiple buildings projects (City and County of SF, 2012). In Arizona, USA, Tempe City offers rebates to residents (City of Tempe, 2018) while Tucson City offers reimbursement for installation of a permanent GW irrigation system in residential dwellings (City of Tucson, 2018). In Cyprus, the government generously subsidizes GW treatment systems (Sofroniou & Bishop, 2014).

Owners may consider GWR permitting and compliance requirements as demanding and time-consuming. Therefore, a clear, simple and one-stop service is essential. In Arizona, small GWR systems within premises (<400 gallons/day) can be installed without notifying the authority (DEQ – Water

Table 5. Current building owners gains/losses associated with GWR in Sharjah.

GWR	Users of Property	Who Pays for Water Consumption	Incentives to Owners to Install GWR System	Incentives to Tenants
GWR for Toilet Flushing	Tenants	Owners	✓ None unless rent is increased	Savings if rent is not increased
		Tenants		Savings through reduced water bill
	Expat Owners	Expat Owners	Savings through reduced water bill	–
	Local Owners	Local Owners	✓ Minor savings water is subsidized	–
GWR for Cooling in HVAC Towers	Tenants	Owners	Savings through reduced water bill	✓ None – no return for GW used by owners
	Owners	Owners	Savings through reduced water bill	–
Government/ Public Buildings	Public/Government Employees	Government	Savings through reduced water bill	–
GWR for Irrigation	Tenants	Owners	Savings through reduced water bill	✓ None – no return for GW used by owners
		Tenants	✓ None unless is increased rent	Savings through reduced water bill
	Expat Owners	Expat Owners	Savings through reduced water bill	–
	Local Owners	Local Owners	✓ Minor savings as fresh water is subsidized	–

✓ Identifies loss situations that may require incentives from SEWA.

Pollution Control, 2015). In NSW, Australia, diversion GWR systems do not need permitting (DWE – NSW, 2008).

The proposed GWR incentives system for Sharjah targets the GWR owners' categories in Table 5 who are potentially facing financial loss. In this regard, it is recommended that SEWA may consider offering the following incentives on a case-by-case basis:

- reduction of water connection fee for new buildings;
- reduction of drainage fee for buildings with GWR systems based on GWR volume;
- grants or loans to assist owners cover initial cost of GWR infrastructure;
- rebates to encourage owners of existing buildings retrofit their buildings with GWR systems;
- structured water charges (both base and consumption-based variable charges) that allow owners of rental properties to share savings with tenants through rebates to owners proportional to reduction in consumption.

In addition, SEWA should offer:

- simplified, one-shop stop permitting and reporting system;
- technical assistance and financial feasibility assessment services;
- training for operators;
- certification services for service companies, suppliers and operators;
- educational programs and materials for owners and tenants;
- a rating system for sustainable practices in buildings, including water conservation and GWR.

On the other hand, penalties should be imposed and enforced on violators, including those who operate unlicensed installations, do not comply with the requirements, or those whose practices pose a risk to human health and the environment. Such penalties should be proportional to the nature and extent of violation.

Governance of GWR in Sharjah

Governance of GWR requires permitting, supervision of construction, auditing, certification, commissioning, post monitoring, and coordination among authorities. Currently, SEWA is the only authority that manages GWR in Sharjah, with SEWA employees in charge of defining requirements, approving treatment technologies, receiving and reviewing monthly WQ reports, and inspecting installations. On the other hand, Sharjah Municipality (SM) is in charge of approving and supervising implementation of the building code, including utilities in buildings with SEWA's approval. However, SEWA is not involved in supervising plumbing installations nor in certifying materials and installers. As a result, past GWR installations in Sharjah suffered from faulty plumbing installations and the use of subgrade materials.

Internationally, GW reuse programs are typically governed by local authorities in coordination with authorities concerned with planning, buildings, water supply, sewerage, public health and the environment (Government of WA, DoH, 2011; City and County of SF, 2012; PUB, 2014).

Future governance of GWR may fit best with SM, which is in charge of buildings and wastewater reuse. Furthermore, other authorities should be involved in governance of GWR in Sharjah, including:

(1) Sharjah Health Authority (SHA), (2) Sharjah Environment & Protected Areas Authority (SEPAA), and (3) Sharjah Directorate of Land Planning & Survey (SDLPS). SHA should be involved in GWR permit approval, the setting-up of WQ and monitoring requirements, and handling of public health concerns. SEPAA should be involved in GWR permit approval of irrigation applications, setting-up of WQ and monitoring requirements, and handling of environmental concerns. SDLPS should be involved in GWR permit approval of irrigation applications. The proposed involvement of each of the mentioned authorities is summarized in Table 6. Recommended compliance reporting and record-keeping requirements for Sharjah is presented in Table 7.

Community education and awareness

Despite the passage of over 15 years since initiation of the GWR program in Sharjah, the level of participation remains low and is mostly limited to installations whose owners achieved significant financial benefits. Furthermore, implementation of the GWR program in Sharjah was not accompanied by an adequate educational program to engage all stakeholders. The community remains sceptical of the feasibility, cleanliness and harmfulness of treated GW and is unaware of the differences between GW, black water and wastewater. Poorly operated GWR systems in some buildings exacerbated negative perceptions due to foul odours and observed WQ.

It is SEWA's responsibility, as champion of GWR, to partner with other stakeholders in the community and lead campaigns to enhance public acceptance and reduce negative perceptions of GWR. The potential health and environmental concerns suggest involvement of authorities other than SEWA in educating and raising awareness of the community. In particular, users of premises that have GWR systems must be educated on sources of disease-causing and toxic materials in GW and basics of disease transmission, as well as type of products to use to prevent contamination with recalcitrant and harmful pollutants. Community organizations and leaders must also be engaged to ease community concerns with regard to the cleanliness of treated GW and its suitability for reuse for intended purposes.

Potential impact of GWR program reforms

So far, the impact of the GWR program in Sharjah has been limited in terms of saving water and reducing sewage generation, CO_2 emissions and electricity consumption. The water savings achieved

Table 6. Suggested involvement of authorities in governing GWR in Sharjah[a].

Governance issue	SEWA	SM	SHA	SEPAA	SDLPS
Infrastructure design/materials/installation approval and certification	✓	✓			
Treatment and reuse permit approval	✓	✓	✓	✓	✓
Certification of installations, materials, systems, suppliers and operators	✓				
Inspections, auditing and admin of incentives/penalties	✓				
WQ and monitoring requirements	✓		✓	✓	
Follow-up on public health concerns	✓		✓		
Follow-up on environmental concerns	✓			✓	
Training, certification of operators, education and technical assistance	✓				

[a]In the future, governance of GWR may fit with the Sharjah Municipality (SM).

Table 7. Summary of recommended compliance, reporting and record keeping requirements for Sharjah.

	Compliance Requirements	Reporting and Record Keeping Requirements
Small GWR systems for detached dwellings	• Seek SM permit to modify building's plumbing system (for existing buildings) • Apply to SEWA for a 'Permit to Use' before or after the installation of system • Engage only SEWA certified suppliers, plumbers, contractors and diversion/treatment systems • Be ready for inspections/audits as required	• Keep records and receive incentives • Report to SEWA - Modifications/upgrades and termination of operation • Report to SEWA, SHA, SEPAA (where applicable) - Suspected/confirmed health or environmental concerns
Other GWR installations involving GW treatment	• Seek SM permit to modify building's plumbing system (for existing buildings) • Apply to SEWA for a 'Permit to Use' before installation of treatment system • Engage only SEWA certified suppliers, plumbers, contractors and diversion/treatment systems • Seek SEWA's initial permit to operate following system's installation • Seek SEWA's final permit to operate upon demonstration of successful operation • Comply with SEWA's operation AND maintenance requirements for systems, suppliers and personnel and staying ready for audits	• Keep Records: - WQ and Quantity records - System inspection/service reports • Report to SEWA - Extended exceedance of WQ requirements and corrective actions - Modifications/upgrades and termination of operation - Quarterly WQ records • Report to SEWA, SHA, SEPAA (where applicable) - Suspected/confirmed health or environmental concerns

by the 200 current GWR installations represent less than 2% of the domestic water use and a small fraction of the existing buildings in Sharjah (Table 8). A 10% saving on domestic water use requires the participation of 20% of Sharjah residents, which may be the maximum GWR target. In fact, the current GWR policy cannot lead to achievement of significant additional water savings in the foreseeable future as the current GWR program is limited to new buildings and the policy lacks adequate incentives and enforcement. On the other hand, retrofitting existing buildings to implement GWR is a major undertaking for owners and tenants of buildings and requires adequate incentives and education.

The data presented in Table 8 provides an assessment of various GWR expansion scenarios showing increasing water savings from the current of less than 2% to 5.2, 7.8 and 10%. Water savings above 5% are significant and savings in the range of 5–10% can serve as achievement targets for Sharjah. Such water use savings nearly equally reduced wastewater generation and also significantly reduce electricity consumption and CO_2 emissions. The energy consumption for desalination is reported in the range of 4.1–23.4 kWh/m^3, depending on the method of desalination (Sadhwani & Veza, 2008; Laspidou *et al.*, 2012; Jia *et al.*, 2019), and the UAE rate of CO_2 emissions is considered equal to 0.61 kg CO_2/kWh. Based on the desalination energy consumption of 13.8 kWh/m^3 and CO_2 emissions of 7.25 kg CO_2/m^3, a 10% water savings is associated with a 10% reduction in wastewater generation, CO_2 emissions reduction of 120,000 ton/y and energy use reduction of 226,000 MWh/year. Furthermore, and using today's water and

Table 8. Cost/benefit analysis of expansion of GWR in Sharjah.

Current GWR program	2020	Stage 1	Stage 2	Ultimate
Number of GW installations in buildings	200	800	1,400	1,800
Number of people served	40,000	150,000	250,000	360,000
Total population (million people)	1.30	1.45	1.60	1.80
People served/total population (%)	3.1	10.3	15.6	20.0
Water saving[a] (Mm^3/Y)	1.83	6.84	11.41	16.43
Water saved/total domestic use (%)	1.5	5.2	7.8	10.0
Cost of water saving[b] (million USD/Y)	3.8	14.3	23.9	34.4
Cost of sewage disposal saving[b] (million USD/Y)	0.5	2.0	3.4	4.9
Total savings (million USD/Y)	4.4	16.4	27.3	39.3
Desalination CO_2 emissions (kg CO_2/m^3)	7.3			
Desalination energy consumption (kWh/m^3)	13.8			
Reduction in CO_2 emissions (Ton CO_2/Y)	13,230	49,620	82,700	119,080
Reduction in energy consumption (MWh/Y)	25,090	94,100	156,840	225,840

[a]Assuming full recycling of available GW.
[b]Assuming current water and sewage tariffs remain unchanged.

sewage tariffs, the value of saved water and reduced sewage at 10% water use reduction for buildings' owners and tenants can amount to about 40 million USD/y. Such savings are more than adequate to pay for the costs of installation and operation of GWR systems, with return periods on investment of less than 10 years (Shanableh *et al.*, 2020).

Summary and conclusions

The past 17 years of GWR experience in Sharjah demonstrated that compulsory GWR requirements that are not matched with adequate incentives and do not adequately consider the diversity of ownership and reuse options reduce opportunities for participation. The modified program presented in this study include compulsory requirements, with incentives, to install dual plumbing systems in new large buildings. The program also includes incentives to encourage optional retrofitting of existing buildings and optional installation and operation of GW treatment systems. The current SEWA requirements limit GWR to large water consumers, but the modified program calls for allowing GWR in detached and semi-detached residential dwellings. The modified program also calls for adopting a three-tiered GW treatment and water quality requirements matching intended GWR.

Currently, SEWA is the only authority that manages GWR in Sharjah. However, governance of GWR requires collaboration between various authorities, including Sharjah Municipality, Sharjah Health Authority, Sharjah Environment & Protected Areas Authority, and Sharjah Directorate of Land Planning & Survey. The governance of GWR in Sharjah also requires that authorities allocate adequate resources to ensure credible management, monitoring and enforcement of GWR policies.

Education and awareness are critical for the success of GWR in Sharjah. Currently, landlords and owners view GWR as a financial burden and operational risk. Residents are unaware of the differences between GW and wastewater and are sceptical of the cleanliness of GW for reuse in their premises. Operation and maintenance of GWR systems proved to be a major concern in Sharjah. Reliable operation and maintenance requires educated and trained operators and certified service providers coupled with adequate incentives to owners.

The proposal presented in this article is currently under consideration for implementation in Sharjah, with SEWA undertaking community consultation steps to assess the views of the various stakeholders on the proposed system before implementation.

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Data availability statement

Data cannot be made publicly available; readers should contact the corresponding author for details.

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