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## Greywater reuse in the water-scarce Gulf Region

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**Abstract.** Treated wastewater has emerged in many countries as a component of the water stream and a way to supplement, primarily, landscape and agricultural irrigation. Several European and Asian states have, in addition, promoted the use of greywater in the interior of buildings. Regulations for greywater reuse are, by and large, not in place and quality standards for different types of application are in evolution. At the same time constructed wetlands as stand-alone or as part of the wastewater treatment system have shown promise as a way to improve wastewater effluent, while upgrading ecosystem and aesthetic aspects of a site. Gulf countries, such as the United Arab Emirates (UAE) are faced with natural water scarcity, exorbitant water demands, beyond their renewable resources and desalination capacities, overloaded wastewater treatment systems that have resulted in releases of untreated wastewater in the marine environment, and increasing populations and expanded economic activities that would further accentuate existing water problems. The current article discusses these issues and, given the public reluctance in the UAE to accept interior greywater reuse, it focuses on the applicability of constructed wetlands in the Gulf region and their potential to enhance irrigation streams and landscape appeal.

### 1. Introduction

The Gulf region countries have average annual precipitation that ranges from a minimum of 72 mm in Bahrain to a maximum of 114 mm in Kuwait and evaporation rates that exceed 2 m and can even reach 4 m per year [1]. The region is experiencing rapid economic and cultural transformations, as well as tremendous demographic pressures with multi-million population cities being constructed in locations where just a few decades ago small communities, consisting of a few thousand people, stood. Availability of water has surfaced as a critical link to their transitioning to modern states, with water being intimately linked not only to the drinking needs of the increasing population, but also to the energy needs for desalination, which in 2010 had reached 76% of the global desalinated seawater capacity, and to the security needs to maintain a minimum local food production, currently not exceeding 10% of the market demand [2]. The intense economic development and the subsequent energy needs have led to disproportionate, to their population, greenhouse gas emissions with Iran, Saudi Arabia, the United Arab Emirates (UAE), Qatar, and Kuwait being in the top 40 polluting countries with 672, 635, 232, 130, and 104 MtCO<sub>2</sub>, respectively [3].

In the Middle East the top daily domestic water consumption was reported in 2017 by the Environment Agency Abu Dhabi (EAD), UAE at 590 lt per capita per day [4], a similar number reached in 2014 by Bahrain, with Qatar and Kuwait, at 500 lt/capita/day, following close after the top



two water-consuming Gulf countries. These four GCC countries compared very poorly with, for example, the average domestic water use in USA of about 300 lt/capita/day, Sweden with about 140 lt/capita/day, Germany at 117 lt/capita/day [5], the UK's target for new homes of 125 lt/capita/day [6], or other countries in the Arabian Peninsula, such as Oman and Saudi Arabia, which consumed about half of the above quantities at 260 lt/capita/day.

In the Emirate of Abu Dhabi, UAE the high water use by agriculture, forestry, and parks, at over 2,300 Mm<sup>3</sup>/year or about 71% of the total water consumption, the high salinity of the groundwater, the existence of over 100,000 wells that have resulted in groundwater levels drops of about 50m, and the environmental impacts of desalination have led to calls for, among others, metering of farm water (UAE Law No 5 of 2016 on Groundwater Organisation) and increased reuse of treated wastewater. The latter constitutes an area where significant water savings can be accomplished since only 51% of the treated wastewater gets to be recycled and also since only 28.6% of the desalinated water returns to the sewerage system, despite the extensive sewerage coverage in the Emirate [4].

The aim of the current paper is to evaluate the use of grey water as a source of irrigation for landscaping and other uses in desert cities, and to analyse the applicability of constructed wetlands and to assess their feasibility in the Gulf region.

## 2. Greywater: uses, regulations, and technologies

Greywater is broadly defined as that wastewater that is generated by homes and offices that does not contain fecal contamination. Strictly speaking this excludes only toilet water (sewage or black water) and includes all waste streams from the kitchen, dishwashers and washing machines, sinks and bathtubs. In most studies the term is used to describe only the low organic content wastewater from washbasins and the drains of showers and bathtubs, and it excludes the wastewater from kitchen sinks, dishwashers, and washing machines that contains higher organic load. The preference to use a narrower definition is based on the fact that several water quality parameters, such as BOD<sub>5</sub>, COD, P<sub>total</sub>, N<sub>total</sub>, total coliforms, and E.coli are exhibiting lower values if only the wastewater from washbasins, showers, and baths is considered than if the wastewater from the kitchen and the washing machines is also included [5].

Greywater contains biodegradable organic matter from, among others, hair, skin, and bathing products, as well as some coliform bacteria from washing the body's anal part. Phosphorus is coming from detergents for cloth washing and dishwashing, whereas nitrogen originates mainly from kitchen wastewater. The change in detergent composition has reduced significantly in some countries, such as Sweden, the P-level to half (to 2 g/person/day) the last fifty years. Depending on the use of the narrow or the broad definition, the country, and the region, greywater can range from a low of 30% to almost 80% of the wastewater stream of a house, respectively [5,7]. Because of the biodegradable matter it contains, greywater, if left untreated, can result in foul-smelling and potentially lethal gases (sulfates (SO<sub>4</sub><sup>2-</sup>) and hydrogen sulphur (H<sub>2</sub>S)) produced during anaerobic decomposition.

Greywater uses depend on whether this has been treated or not. If greywater is immediately diverted, with storage, if at all, for only a few hours, then it can be used for restricted irrigation. If greywater is filtered and treated to remove suspended matter and rendered colourless and odourless, and after being disinfected, it can potentially be used for toilet flushing, irrigation and gardening, and industrial applications. Treatment systems can be decentralized for a single house, or centralized, collecting and treating the greywater from more than one house.

In the European Union greywater falls under the classification of domestic wastewater, for which the conditions and limits of the *European Directive on Urban Waste Water Treatment 91/271/EEC* on treatment and discharge to receiving waters apply [8]. The European Commission published a briefing in June 2018 that it would proceed with legislation specifically addressing water reuse in agricultural irrigation [9]. This proposes four classes of reclaimed water quality as shown in table 1.

**Table 1.** European Commission's proposed reclaimed water quality classes [9].

Wastewater class	Crop category	Irrigation method	Treatment process	E.coli cfu/100ml	BOD <sub>5</sub> mg/l	TSS mg/l
A	Food crops that come into direct contact with reclaimed water or are consumed raw	All methods	Secondary, tertiary, and advanced treatment	<10	<10	<10
B	Processed food and non-food crops, crops for milk or meat-producing animals, and crops in non-direct contact with reclaimed water	All methods	Secondary and tertiary treatment	<100	25	35
C	Industrial, energy, seeded crops	Drip-irrigation only		<1000		
D		All methods		<10,000		

For greywater used in toilet flushing some European countries, such as Germany, have utilized the standards set in Annex I of the *European Directive 2006/7/EC on Bathing Water* [10,11], thus requiring for total coliform bacteria values below 100/ml, for fecal coliform bacteria less than 10/ml, and for the bacterium *Pseudomonas aeruginosa*, which is found in pools, Jacuzzis, and other wet environments, and which is antibiotic-resistant and can infect damaged or reduced immunity tissues a value below 1/ml. Additional criteria include values of BOD<sub>7</sub> and oxygen saturation as measures of the self-life of greywater [5,11]. In Germany greywater recycling systems inside buildings must be approved by the Health Office to guarantee that no cross-contamination with the public drinking water system would occur. Cost recovery of these systems was found to be between 5 to 7 years and the most widely used are those that employ advanced wastewater treatment followed by UV disinfection [11]. In France, where greywater is understood in its broad context (i.e., excluding only the wastewater from toilettes and urinals), collection, treatment, and reuse of greywater is not approved for domestic purposes. ANSES (French Agency for Food, Environmental and Occupational Health & Safety) conducted a four year study and concluded that installation of non-potable water systems inside dwellings can pose cross-contamination risks to the public water system. ANSES recommended that regulations for greywater reuse are considered only for specific locations subject to repeated water shortages and for uses, after treatment, that are limited to toilette flushing; watering of green areas, exempting vegetable gardens and agricultural irrigation; and outdoor surface washing, excluding high-pressure washing [12]. It must be borne in mind that in France the 30-year annual average precipitation ranged from a minimum of 515 mm in the southeast to a maximum of 1,451 mm in the southwest part of the country, and additionally, that this country has 7.5 billion cubic meters of water stored in reservoirs, compared to the UAE's 16 million cubic meters of dammed water [13,14].

In contrast to the careful assessment of risks and limitations of greywater use in European countries, practices in several developing countries include the indiscriminate use of untreated wastewater, even for farming. For example, in the Gujarat state, India, villages around the state's major cities were found to use treated and untreated wastewater for farming irrigation [15]. The problem is acute in some African countries, which suffer from both water scarcity and poor sanitation conditions, and where the lack of sewage networks (figure 1) results in grey and black water directly impacting the groundwater.

China, after having faced urban water shortages and the continuous decline of the quality and quantity of its surface and ground waters, conducted pilot studies and established national water quality standards on urban wastewater reuse, which distinguish four major classes of application: landscape enhancement, groundwater recharge, farmland irrigation, and industrial water. This allowed the use of treated wastewater, which reached about 1.66 billion cubic meters in 2008. Despite the widespread wastewater reuse since the early 2000s it is recognized in China that this may lead to long-

term salt accumulation in the soil; pollute groundwater with heavy metals, nitrates and phosphates, and low-concentration toxic substances; and when non-tertiary treated wastewater is used, pathogens may be introduced in the food chain, thus endangering human health [16].



**Figure 1.** Somaliland: scarcity of water (left); public toilette (right) (photos by the authors).

Constructed wetlands [17] are simple, inexpensive, and environmentally friendly solutions where wastewater is being distributed in the constructed wetland, where filtration/sedimentation and biological and chemical decomposition occur. They have become a popular means (figure 2) of dealing with relatively small quantities of municipal wastewater providing at the same time an aesthetic appeal to the surrounding area. In some countries constructed wetlands are used as part of the full wastewater treatment cycle, albeit with limitations to the functioning of the wetlands during the winter months [18,19]. The state of constructed wetlands in the UAE is discussed in the next section.



**Figure 2.** Constructed wetland, Taiwan (photo by the authors).

### 3. Methodology

Our methodology consists of providing a brief overview of the water quality and quantity issues in the UAE with emphasis on the state of wastewater reuse in this country. The regulatory framework regarding treated wastewater reuse in the UAE and the limitations and risks associated with this are discussed. Finally, potential areas of application of greywater reuse and in particular of constructed wetlands, which may prove to be appropriate for this country, are analysed.

### 4. Recycled water and constructed wetlands in the UAE

Despite the limited renewable water resources, which together with desalination cover less than fifty percent of the water demand, there seems to be limited public awareness of the criticality of the water situation in the UAE. Based on an extensive survey about 45% of the respondents asserted that a water

shortage will not occur in this country with 35% believing that fresh water was abundant. There were clear preferences for using recycled water in construction, car wash, and landscape/garden/farm irrigation with acceptance levels exceeding 60%, while negative attitudes to these uses were limited to about 10% of the respondents. In contrast, direct contact, such as treated effluent discharge in areas of swimming, or for home use met with great reluctance, which in some cases reached a 50% disapproval rate [20]. These attitudes are reflected in Abu Dhabi's design and construction sustainability regulations where points are awarded to communities that utilize recycled water for exterior landscape irrigation, but no stipulation is made for interior greywater use [21]. No details on recycled water quality requirements, or monitoring of recycled water quality parameters for exterior use are provided in the regulations, which presents the risk of poor application of the standards and may lead to discrediting the practice of wastewater reuse. All of these point to a strong need to conduct extensive water awareness campaigns in this country.

Total water consumption in 2017 in the Emirate of Abu Dhabi, UAE was about 3,240 Mm<sup>3</sup> with desalination providing about 1,070 Mm<sup>3</sup>, groundwater about 2,000 Mm<sup>3</sup>, and treated wastewater the remaining of the water stream at about 170 Mm<sup>3</sup>. According to EAD the total volume of treated wastewater in 2015 was approximately 335 Mm<sup>3</sup> with about 51% of this being recycled, the remaining being discharged in the Arabian Gulf or the desert. Of the treated sewage effluent about 400,000 m<sup>3</sup> per day (146 Mm<sup>3</sup> annually) are discharged in a relatively shallow and of low velocity channel (South Mussafah Channel), which has resulted to high nutrient levels and to eutrophication conditions there [4]. Treated wastewater released from a major wastewater treatment plant serving the city of Al Ain, the Zakher with capacity 54,000m<sup>3</sup>/day, but operating at peak with double that volume, has resulted in elevation of the groundwater level and the creation of an artificial lake (figure 3), pointing to the need for an environmental impact assessment of this treatment facility.



**Figure 3.** Lake Zakher (photo by the authors).

Treated maximum wastewater capacity has increased since 2012 - when the two major plants, the Mafraq with capacity 260,000 m<sup>3</sup>/day serving the city of Abu Dhabi (AD), and the Zakher, produced almost 95% of the treated effluent - to the current design capacity of 544,000 m<sup>3</sup>/day [22]. The overload in the Emirate's wastewater treatment system prior to 2012 had resulted in releases of poor quality effluent and sludge and in extreme cases to discharges of large quantities of raw wastewater to the marine environment.

Clearly, rational water management in the country involves, as a first priority, aggressive curtailment of the exorbitant water consumption, with emphasis on the domestic and agricultural water use, and concurrent reduction of the water losses, which are of the order of 30% of the desalinated-produced water, which occur in the transmission and distribution network, and which given the relative young age of the network are extremely high, approaching the level of aged European systems. Despite the relative small, in terms of the overall water budget, quantity of the remaining treated wastewater that can be recycled this still exceeds the reservoir capacity of the whole country,

which stands at 120 Mm<sup>3</sup> of water, and the maximum annual recharge in the Emirate's aquifers of about 140-150 Mm<sup>3</sup>, and hence its utilization is vital.

In UAE wetlands have been constructed to deal with small volumes of wastewater and most occupy small areas. The design characteristics of some constructed wetlands are summarized in table 2. Performance data in terms of biochemical oxygen demand (BOD5), Total Suspended Solids (TSS), Nitrogen in terms of ammonium (NH<sub>4</sub>), and Phosphorus in terms of PO<sub>4</sub> are provided in table 3. The variability in the wastewater quality and quantity data that are shown below is not provided in the reference source.

**Table 2.** Design characteristics of UAE's constructed wetlands [23].

Location of Constructed Wetland	Design Characteristics
Mifra, AD	Construction date: 2011; <i>Pre-treatment</i> : sludge filtration & mineralization; reed bed: 2 basins, vertical flow; <i>Biological treatment</i> : reed bed: 1 basin, vertical flow; outflow: 20 m <sup>3</sup> /day; area: 400 m <sup>2</sup>
Anantara, Sir Bani Yas Island, AD	Construction date: 2011; <i>Pre-treatment</i> : bar screen; sludge filtration & mineralization; reed bed: 4 basins (4 × 248 m <sup>2</sup> ), vertical flow; <i>Biological treatment</i> : reed bed: 4 basins (4 × 360 m <sup>2</sup> ), vertical flow; outflow: 62.5 m <sup>3</sup> /day; area: 8000 m <sup>2</sup>
Al Haray, Fujairah	Construction date: 2013; <i>Pre-treatment</i> : bar screen; sludge filtration & mineralization; reed bed: 4 basins (4 × 1,000m <sup>2</sup> ), vertical flow; <i>Biological treatment</i> : reed bed: 4 basins (4 × 1,325m <sup>2</sup> ), vertical flow; outflow: 220-316 m <sup>3</sup> /day; area: 15,000 m <sup>2</sup>
Al Hamra, Ras Al Khaimah	Construction date: 2014; <i>Pre-treatment</i> : bar screen; sludge filtration & mineralization; reed bed: 4 basins (4 × 675 m <sup>2</sup> ), vertical flow; <i>Biological treatment</i> : reed bed: 4 basins (4 × 900 m <sup>2</sup> ), vertical flow; outflow: 150-200 m <sup>3</sup> /day; area: 12,000 m <sup>2</sup>
Al Awir, Dubai	Construction date: 2005; <i>Pre-treatment</i> : settlement tanks; <i>Biological treatment</i> : vertical subsurface flow in reed bed; outflow: 25 m <sup>3</sup> /day; area: 450 m <sup>2</sup>

**Table 3.** UAE's constructed wetlands operational data (adapted from [23]).

Wetland	BOD5 (mg/l)			TSS (mg/l)			NH4-N (mg/l)			PO4-P (mg/l)		
	In	Out	%	In	Out	%	In	Out	%	In	Out	%
Mifra	279	5	98	129	10	92	45.4	0.2	99.5	5.53	0.02	99
Anantara	91	10	89	55	3.5	93	22.6	nd	-	2.27	0.36	84
Al Haray	105	9	91	138	6	96	37.8	1.15	97	12.2	0.23	98
Al Hamra	175	7	96	308	5	98	33.4	0.99	97	11.6	0.35	99
Al Awir	67	2	97	47	0	100	3.6	0.7	80	7.0	4.8	31

The vast majority of the constructed wetlands in the UAE and in general in the Middle East are of the surface flow (SF) type. SF constructed wetlands mimic natural wetlands and have a relatively straightforward design and operation, while they can handle variations in flow. Subsurface flow (SSF) wetlands operate by the wastewater remaining below the substrate and they are limited in their performance by the oxygen required for nitrification and the need for relatively uniform flows. Practically, all constructed wetlands in the UAE include a pre-treatment stage that reduces organic loading and controls odors and mosquitoes. Vertical flow in compartmentalized reed beds is the preferred design. Effluent from the constructed wetlands listed above is directly used for irrigation, and in the case of the Al Awir wetland it is also used for road and car washing, and for a fish pond.

## 5. Summary and conclusions

Treated wastewater has become part of the water stream in many countries, utilized for irrigation, landscape enhancement, aquifer recharge, and industrial processes. Greywater, in some European countries, such as Germany, is accepted for interior building use for toilette flushing, and the same practice is accepted in some Asian countries, such as Taiwan.

However, regulations that establish limits on greywater quality parameters for different types of application are lagging technological innovations that have allowed improved wastewater treatment, and with the exception of China that has developed national water quality standards for four reuse classes of urban wastewater, most countries are still in the process of establishing a regulatory framework on greywater reuse.

Gulf countries, as exemplified in this article by the United Arab Emirates, face severe water shortages that are due to the natural hydrologic conditions, the over eighty percent salinity of the groundwater, and the excessive demands on the water system placed by expanded populations and economic activities. To accentuate the situation, which finds four Gulf countries at the top of the global list of water consumption per capita per day, surveys have indicated that a large percentage of these countries' population believe that water is plentiful and combined with the high water subsidies no water savings measures are exercised.

Although wastewater, which constitutes only ten percent of the total annual water budget, cannot on its own resolve the discrepancy between water demand and natural and produced renewable water resources, it can alleviate the pressure on landscape and farming irrigation, which have come to utilize desalinated water. These recycled water uses appear to be acceptable to local populations, whereas the resistance to greywater reuse inside buildings is high, and hence at this stage, it would not be recommended.

Risks involved in wastewater reuse in Gulf countries include the absence of a treated wastewater distribution network that would make it available on a large scale; the lack of public awareness of the water situation in the Gulf countries, which by and large have reserves of a few days; the insufficient regulatory framework on greywater reuse, which although it promotes reuse for landscape application does not provide reused water quality standards; and finally, the lack of systemic risk management.

Constructed wetlands have started to find modest application in the Gulf countries, in the last five to ten years. Most wetlands installed include both a pre-treatment and biological treatment phase and they utilize vertical flow in compartmentalized reed-based cells. Surface flow (SF) is the dominant type of wetland constructed, with only a few cases of subsurface flow (SSF) systems built. Preliminary data have shown excellent removals of DO<sub>5</sub> and TSS as expected, but perhaps surprisingly, all constructed wetlands in the UAE exhibit very high removal efficiencies for nitrogen and phosphorus too.

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