How Efficient Would Demand-Based Water Strategies Be for Qatar?

Sophia Ghanimeh
Environmental Studies Center (ESC), Qatar University, Doha, Qatar
s.ghanimeh@qu.edu.qa

Abstract

Qatar is a water scarce country that heavily relies on seawater desalination. Multiple studies have concluded the need for a more resilient water planning through efficient "demand control" strategies. This study is among the very few attempts to "quantify" the actual impact of such solutions on the water sector. The purpose of this work is to generate "indicative" water usage figures to inform the (non-technical) decision makers and prove the benefits of shifting toward demand-based water strategies. A scenario-based approach was adopted, considering: maintaining status quo (scenario 1), improving the water pricing system (scenario 2), and regulating greywater reuse (scenario 3). Scenario 2 estimates the impact of water tariff increase based on Price Elasticity of Demand in neighbouring countries. Scenario 3 considers imposing on-site greywater reuse as part of the permitting process (for new constructions only). The study forecasted, up to year 2100, the impacts of demand control measures on: (1) domestic water consumption, (2) volume of desalinated water, (3) year by which additional desalination capacity is needed, and (4) year by which wastewater treatment facilities need expansion. It was shown that, by improving the water tariff system, the total domestic water consumption is reduced by up to 27% (equivalent to 16-19% reduction in total demand for desalinated water). As a result, the need to expand the water desalination facilities and the wastewater treatment infrastructure is delayed substantially: 15-20 years and 15-30 years, respectively. Also, regulating greywater reuse may reduce domestic water consumption by up to 6%.

Keywords: Demand-Side Water Management; Domestic water demand; Water tariffs; Greywater reuse

1 Introduction

Qatar suffers from acute freshwater scarcity, having renewable freshwater resources of 29 m^3/capita/year (2015), which is far below the global water poverty threshold of 1000 m^3 (Alhaj et al., 2017; Alsheyab & Kusch-Brandt, 2018). Yet, the country has one of the highest residential water consumption rates in the world. This is partially attributed to: (1) the hot weather, leading to a high need for water, and (2) high economic capacity of the country, making access to high-cost desalinated water affordable, among other factors. Considering the anticipated increase in population and living standards, and the expected changes in climate toward a hotter weather, the demand for residential freshwater in Qatar is expected to increase with further deficit in the water balance.

In fact, due to climate change, Qatar's mean annual rainfall has already fallen below its long-term average value of 84.9 mm/year and the mean annual temperature has increased by 0.3°C over the past four decades. Climatic projections predict a further increase in temperature of 2.3–5.9°C by 2100 (PSA, 2018; MDPS, 2018)

On the other hand, Qatar has the third largest natural gas reserve in the world and exports more than 20% of the world's liquefied natural gas (Kim et al., 2020). The high national income allowed Qatar to meet domestic water demand using expensive desalination technologies and to distribute it to the consumers at a heavily subsidized rate (Baalousha & Ouda, 2017; Ibrahim & Shirazi, 2021).

With increasing water demand and limited freshwater supply, water demand control has been applied as a tool in integrated water resources management to balance demand and supply (Arfanuzzaman & Rahman, 2017; Xiao, 2017). Consequently, water-scarce countries have developed strategies and technologies for water conservation and increased water use efficiency (Liu et al., 2020). Several studies have addressed the potential of water conservation in households using water-saving plumbing fixtures, greywater, and rainwater harvesting. Also, the role of adequate water pricing as an economic tool for improved efficiency of water use has been investigated globally (e.g., Huang et al., 2010; Rinaudo et al., 2012; Rivers & Groves, 2013; Smith & Al-Maskati, 2007; Srouji, 2017).

In Qatar, projects that have been implemented to reduce domestic water consumption were limited to changing plumbing fixtures and promoting water saving and efficient use through conservation programs and awareness campaigns (Alghool et al., 2019). In addition, Qatar General Electricity and Water Corporation “KAHRAMAA” reduced the leakage of the water distribution network to 4% by 2016 (Kamal et al., 2021) and deployed 17,000 water meters in households, with plans to make them smart by 2024. These newly installed devices, however, are unlikely to monitor and bill more than 7.3% of households in 2020 (Hussein & Lambert, 2020).

In contrast, this study investigated the possibility of reducing residential water demand through: (1) improved water pricing, and (2) on-site greywater reuse. While these approaches are widely known to reduce household-level water demand, their actual impact on residential water needs in Qatar remains to be quantified. Even though water demand control strategies have been long advocated, the policy makers need to know how efficient those would be. In this respect, this study provides a high-level estimation of the extent of change expected upon applying demand-based strategies, specifically improved water pricing and enforcement of greywater reuse.

2 Materials And Methods

2.1 Water Demand Forecast

Water demand was projected up to year 2100 using multi-linear water demand regression models developed by Kamal et al. (2021) for the domestic, commercial, governmental, and industrial sectors in function of population, gross domestic product (GDP) and rainfall (Table 1). Acknowledging that other factors would also affect water demand forecasts, these models are considered adequate to illustrate the intensity of the impact of demand-side management – leading to further future investigations in this direction.

The overall water demand met by desalination was estimated as the sum of demand by each sector, adjusted to include the losses of the desalinated water distribution network (currently stabilized at 4%). In addition, the following consumption patterns were adopted: (1) 20 MCM/year of the domestic water demand are regularly supplied by groundwater abstraction from domestic and municipal wells, (2) 0.18 MCM/year of the industrial demand are met by groundwater withdrawal from industrial wells, (3) the commercial sector is fully supplied by desalination, and (4) around 60% of governmental water demand (including landscaping) is met by desalination while the rest is met by treated sewage effluent (PSA, 2018).

Next, the regression models were used to forecast (up to 2100) the water consumption volumes by sector under various demand scenarios. The United Nation’s world population forecasts were adopted, which include lower 95%, median, and upper 95% probabilistic projections (UN, 2019). Qatar's GDP growth was assumed to be 1.5% (Foure et al., 2012). Median annual precipitation forecasts were adopted from the Coupled Model Inter-comparison Project Phase 6 (CMIP6) projections for the following Shared Socioeconomic Pathways: SSP1–1.9, SSP1–2.6, SSP2–4.5, SSP3–7.0, and SSP5–8.5 (CCKP, 2021).

Table 1: Regression equations adopted to forecast water demand

SECTOR	Regression Model	Adjusted R^2	F-Statistic, ρ-Value ($\alpha < 0.05$)
HOUSEHOLD	$Hh = 30.57771 + 147.53605Pop - 0.07729GDP - 0.40296Rnf$	0.9507	65.22 ; 1.759×10^{-5}
COMMERCIAL	$Cm = -55.89256 + 81.96694Pop - 0.34341GDP + 0.05626Rnf$	0.7077	9.071 ; 0.008269
GOVERNMENT	$Gv = -103.39541 + 73.59485Pop - 0.4746GDP + 0.663756Rnf$	0.7282	9.932 ; 0.006451
INDUSTRY	$In = 4.63937 - 0.32591Pop + 0.02608GDP + 0.02805Rnf$	0.6026	6.054 ; 0.0234

2.2 Scenario 1 – Status Quo

The future residential water consumption, under status-quo conditions, was estimated using the multi-linear regression model for household water demand (Table 1). Demand values were then distributed between expatriates and nationals, considering that annual per capita domestic water use by nationals is seven times higher than that of expatriates (Pandit & Osman, 2016). The present-day demographic constitution of the Qatari population was adopted, consisting of 88% expatriates and 12% nationals (Baalousha & Ouda, 2017). The total volume of collected wastewater was calculated as 40% of the water demand met by desalination (PSA, 2018).

2.3 Scenario 2 – Improved Water Pricing

The water tariff in Qatar is structured per block. The latter represents incremental ranges of household consumption. The first (lowest consumption) block corresponds to less than 20 m^3/cap/month, priced at 1.51 USD/m^3 of consumed water for expatriates and delivered at no-charge for Qataris. Most of the residential use in Qatar falls within that first block. To note that the actual cost of water production is estimated at 2.74 USD/m^3 (KAHRAMAA, 2021; PSA, 2018). There is no official statistical data providing the number of water users and water consumption, segregated per tariff block or nationality. Therefore, this study assumes a constant average consumption rate per capita (Alrefai, 2020).

The principle of price elasticity of demand (PED) was adopted to estimate the impact of increasing water tariffs on residential water consumption. The midpoint method for elasticity (Equation (1)) was used to detect the impact on both nationals' and expatriates' consumption (Srouji, 2017):

$$PED = \left| \frac{(Q_1 - Q_0)/(Q_1 + Q_0)}{(P_1 - P_0)/(P_1 + P_0)} \right| \qquad (1)$$

where P_0 and P_1 represent the initial and new marginal water price, respectively, Q_0 is the initial water demand value, and Q_1 is the new water demand value.

Given that the water PED has not been determined for Qatar, it was assumed equal to that of the

United Arab Emirates (UAE) – being a neighbour country with closely similar geographic, climatic, demographic and socio-economic setups. UAE imposed higher tariffs in 2015, charging expatriates near 4 times more than nationals who received water at 75% subsidy. Based on the change in residential water consumption within a year of implementing the reforms, an average PED of -0.23 for nationals and -0.33 for expatriates were reported (Srouji, 2017).

Assuming the same tariff increase in Qatar, nationals would pay 0.7 USD/m^3 of domestic water (subsidy of 75% as opposed to 100%) while expatriates would pay at least the full cost of water (2.74 USD/m^3). The household water demand was calculated accordingly. To note that this study assumes 100% collection of water bills – which is currently no more than 51% for expatriates and 8% for nationals (Hussein and Lambert, 2018).

2.4 Scenario 3 – Greywater Reuse

Separating greywater for reuse at the home or building level is considered a viable method to reduce the residential demand for freshwater. A recent survey proved that Qatari residents are willing to reuse treated greywater instead of desalinated water for landscaping (85-92%), toilet flushing (72-83%) and car washing (72-83%) (Lambert & Lee, 2018). Nonetheless, omitting the diluted fraction of the wastewater (that is greywater) presents drawbacks on the efficiency of the sewage treatment system due to higher concentrations of organic materials and settleable solids, among other factors. This would require reassessment and upgrading of operating system; but this is not considered within the scope of this study.

To estimate the impact of on-site greywater reuse, a minimum of 20% reduction (saving) in residential water demand was adopted. This is based on the findings of Alghool et al. (2019) for a prototype greywater reuse system implemented in a residential villa in Qatar. An upper limit of 50% saving in water demand was adopted. This is based on the findings of global studies, showing that residential water consumption can be reduced by 30-59% by greywater reuse (e.g., Kuwait: 30%, Syria: 35%; Kenya: 33-54%, Australia: 33-59%) (Samayamanthula et al., 2019).

Considering that retrofitting all households in Qatar would not be practically or economically viable, it was assumed that greywater reuse systems are implemented only in future constructions. This can be achieved by making greywater reuse system a mandatory requirement of the construction permit. The household construction growth rate and number of water users in new residential units was projected in function of the overall future population, based on the 2015 (latest) national census of population, housing and establishments (MDPS, 2016). The annual volume of water savings was calculated cumulatively for the new households, starting 2025.

3 Results And Discussions

3.1 Water Demand under Status Quo

Under the current conditions of water pricing in Qatar, residential water demand could reach 435-729 MCM by 2100. The volume of desalinated water required to meet total demand is projected at 598-1165 MCM by 2100, for the different population estimates. Following the median 95% population trend, total demand is anticipated to exceed the current supply capacity of the desalination plants (830 MCM/year) by 5%-11% between 2070-2100. Expanding the desalination units would then be required before 2040. As for the 95% upper population forecasts, expansion of the desalination capacity is anticipated around 2035, with demand exceeding supply by 40% in 2100 (Table 2).

Similarly, wastewater generation is expected to reach the current treatment infrastructure capacity (353 MCM/year), under the median population estimates, between 2060-2080. For the upper 95% population projections, wastewater generation could increase to 449 MCM in 2100, thus surpassing the treatment capacity by 27%. Expansion of the wastewater collection and treatment infrastructure would then be required before 2045 (Table 2).

Table 2: Impacts of maintaining status quo

	Lower 95% population forecasts *(% increase with respect to 2022)*	**Median population forecasts** *(% increase with respect to 2022)*	**Upper 95% population forecasts** *(% increase with respect to 2022)*
Residential Water Demand in 2050 (Mcm/Year)	522 (+16%)	558 (+24%)	591 (+31%)
Residential Water Demand in 2100 (Mcm/Year)	435 (-4%)	578 (+28%)	729 (+62%)
Volume of Desalinated Water Needed by 2050 (Mcm/Year)	816 (+26%)	885 (+37%)	950 (+47%)
Volume of Desalinated Water Needed by 2100 (Mcm/Year)	597 (-8%)	875 (+35%)	1164 (+80%)
Year by Which Upgrade of Desalination Capacity is Needed	None	2040	2035
Volume of Wastewater Generated by 2050 (Mcm/Year)	315 (+21%)	341 (+32%)	366 (+41%)
Volume of Wastewater Generated by 2100 (Mcm/Year)	230 (-11%)	337 (+30%)	449 (+73%)
Year by which Upgrade of Wastewater Treatment Capacity is Needed	None	2060	2045

3.2 Impact of Improved Water Pricing

Residential water demand is expected to drop by 27% following the implementation of the proposed tariff reforms, reaching 315-529 MCM by 2100 under all population projections, while the total water consumption could decrease by 16%-19% (485-977 MCM in 2100). Therefore, the current supply capacity of the desalination units is exceeded by 18% in 2100 only for the upper 95% population projections, and the desalination infrastructure should be expanded starting 2055 (Table 3).

Similarly, increasing water tariffs is expected to reduce the volume of generated wastewater to 187-376 MCM by 2100 (a drop of 16%-19%). Consequently, expanding the wastewater treatment infrastructure would not be needed before 2075 under upper 95% population forecasts (Table 3).

Hence, higher water tariffs could reduce the pressure on desalination plants by stabilizing water demand below their current supply capacity and delaying the need to expand the desalination and water supply infrastructure by 15-20 years within the time horizon 2025-2100. This would also alleviate the pressure on the wastewater treatment infrastructure by delaying the need for expansion by 15-30 years.

Table 3: Impacts of increased water tariffs

	Lower 95% population forecasts *(change with respect to status-quo)*	**Median population forecasts** *(change with respect to status-quo)*	**Upper 95% population forecasts** *(change with respect to status-quo)*
Residential Water Demand in 2050 (Mcm/Year)	379 (-16%)	405 (-10%)	429 (-5%)
Residential Water Demand in 2100 (Mcm/Year)	315 (-30%)	420 (-7%)	529 (+17%)
Volume Of Desalinated Water Needed by 2050 (Mcm/Year)	682 (+5%)	741 (+14%)	797 (+23%)
Volume Of Desalinated Water Needed by 2100 (Mcm/Year)	485 (-25%)	726 (+12%)	977 (+51%)
Year by Which Upgrade of Desalination Capacity is Needed	None	None	2055
Volume of Wastewater Generated by 2050 (Mcm/Year)	263 (+1%)	286 (+10%)	307 (+19%)
Volume of Wastewater Generated by 2100 (Mcm/Year)	187 (-28%)	280 (+8%)	376 (+45%)
Year by Which Upgrade of Wastewater Treatment Capacity is Needed	None	None	2075

3.3 Impacts of Greywater Reuse

The impact of reusing treated greywater in future households on residential water consumption was studied (Table 4). Based on the local figure of 20% reduction in residential water consumption, the total volume of recycled greywater could amount to 4-18 MCM in 2100 for the different population estimates, reducing domestic demand to 424-683 MCM. However, by achieving 50% savings in household water use, similar to global rates, the total volume of reclaimed greywater could reach 11-46 MCM. Overall, greywater reuse has the potential to save up to 6% the country’s domestic water demand.

Table 4: Impacts of greywater reuse

	Lower 95% population forecasts	**Median population forecasts**	**Upper 95% population forecasts**
Freshwater Savings in 2050 (Mcm/Year)	4-11	7-17	9-24
Freshwater Savings in 2100 (Mcm/Year)	4-11	9-21	18-46
Reduction in Domestic Water Demand (%)	1% - 2.5%	1.5% - 3.7%	2.5% - 6.3%

4 Conclusions and Recommendations

Qatar is a water scarce country, relying mainly on desalination to supply the water needed for domestic usages. Reducing the demand on domestic water would reduce both the expenses and the environmental impacts of the water management system. This study revealed that increasing water price could substantially lower residential water consumption (by up to 27%) and delay the need to expand the desalination infrastructure (past the year 2055). On the other hand, integrating greywater treatment and reuse (in new constructions only) could save up to 6% of the household water demand. Based on these findings, specific actions are recommended to transition into a more sustainable demand-side water management scheme.

The observations made in this paper are based on high-level assumptions and averaged rates. They are fairly accurate for a paradigm shift and informed strategic decisions. Yet, in order to produce high-accuracy forecasts, the following future work is recommended:

- Elaborate water metering that captures water consumption patterns, categories and variables needed to calculate location-specific PED values and forecast water demand based on socio-economic variables and climatic changes; and
- Conduct a detailed technical and social analysis to evaluate the potential of reusing greywater in various residential applications and allow spatial and temporal estimation of water savings across the country.

References

Alghool, et al. (2019). "Perspectives on dual-purpose smart water power infrastructures for households in arid regions", Electric power conversion, Găiceanu Marian, IntechOpen, London, 113–130.

Alhaj, et al. (2017). "A review of Qatar's water resources, consumption and virtual water trade", *Desalination and Water Treatment, 90*, 70–85.

Alrefai, B. Mohammad (2020). "Price elasticity and determinants of residential water consumption in Al Ain region", Master's thesis, United Arab Emirates University.

Alsheyab, Mohammad A.T. & Kusch-Brandt, Sigrid (2018). "Potential recovery assessment of the embodied resources in Qatar's wastewater", *Sustainability,10*, 9, 3055.

Arfanuzzaman, Md. & Rahman, A. Atiq (2017). "Sustainable water demand management in the face of rapid urbanization and ground water depletion for social–ecological resilience building", *Global Ecology and Conservation, 10*, 9–22.

Baalousha, H. M. & Ouda, O. K. M. (2017). "Domestic water demand challenges in Qatar", *Arabian Journal of Geosciences, 10*, 537.

CCKP. (2021). "Qatar-Climate projections". https://climateknowledgeportal.worldbank.org/country/qatar/climate-data-projections. Accessed 9 August 2022

Foure, et al. (2012). "The great shift: Macroeconomic projections for the world economy at the 2050 horizon, CEPII Working Paper No. 2012-3.

Huang, et al. (2010). "Irrigation water demand and implications for water pricing policy in rural China", Environment and Development Economics, 15, 3, 293–319.

Hussein, H. & Lambert, L. A. (2020). "A rentier state under blockade: Qatar's water-energy-food predicament from energy abundance and food insecurity to a silent water crisis", *Water, 12*, 4, 1051.

Ibrahim, A. J. & Shirazi, N. S. (2021). "Energy-Water-Environment Nexus and the Transition towards a Circular Economy: The Case of Qatar", *Circular Economy and Sustainability, 3*, 835–850.

KAHRAMAA, (2021). "Tariff". http://www.km.com.qa/customerservice/pages/tariff.aspx.

Accessed 2 September 2022

Kim, et al. (2020). "Swing suppliers and international natural gas market integration", *Energies,13*, 18, 4661.

Lambert, L. A. & Lee, J. (2018). "Nudging greywater acceptability in a Muslim country: Comparisons of different greywater reuse framings in Qatar", *Environmental Science & Policy, 89*, 93–99.

Liu, et al. (2020). "Individual Water-Saving Response Based on Complex Adaptive System Theory: Case Study of Beijing City, China", *Water, 12*, 1478.

MDPS. (2016). "Analysis of the results of population, housing and establishments census 2015", Ministry of Development Planning and Statistics, Doha, Qatar.

MDPS. (2018). "Qatar Second National Development Strategy: 2018-2022", Ministry of Development Planning and Statistics, Doha, Qatar.

Pandit, M. & Osman, Mohammed (2016). "Expats use seven times less water than Qataris", Zawya, Business. https://www.zawya.com/en/business/expats-use-seven-times-less-water-than-qataris-dab28c3l. Accessed 3 June 2022.

PSA (2018). "Water statistics in the state of Qatar 2017", Planning and Statistics Authority, Doha, Qatar.

Rinaudo, Jean-Daniel, Neverre, N. & Montginoul, M. (2012). "Simulating the impact of pricing policies on residential water demand: a Southern France case study", *Water Resources Management*, *26*, 7, 2057–2068.

Rivers, N. & Groves, S. (2013). "The Welfare Impact of Self-Supplied Water Pricing in Canada: A Computable General Equilibrium Assessment", *Environmental & Resource Economics, 55*, 419–445.

Samayamanthula, D. R., Sabarathinam, C. & Bhandary, H. (2019). "Treatment and effective utilization of greywater", *Applied Water Science*, *9*, 90.

Smith, M. & Al-Maskati, H. (2007). "The effect of tariff on water demand management: implications for Bahrain, Water Science & Technology: *Water Supply*, *7*, 4, 119–126.

Srouji, H. (2017). "The impact of residential water price increases and subsidy reductions on elasticity of demand in Abu Dhabi city", Master's thesis, Harvard Extension School.

UN (2019). "World population prospects 2019". https://population.un.org/wpp/Download/Standard/Population/. Accessed 3 June 2021.

Xiao, Y. (2017). "Basin-wide Water Demand Management: Transfers and Compensation among Competing Users". UWSpace.

Cite as: Ghanimeh S., "How Efficient Would Demand-Based Water Strategies Be for Qatar?", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0159