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Research article

The role of the water tankers market in water stressed semi-arid urban areas:Implications on water quality and economic burden

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ABSTRACT

Population growth and development are associated with increased water demand that often exceeds the capacity of existing resources, resulting in water shortages, particularly in urban areas, where more than 60% of the world's population resides. In many developing communities, shortages often force households to depend on water tankers amongst other potential sources for the delivery of water for domestic and/or potable use. While water tankers have become an integral part of the water supply system in many countries, the sector is often unregulated and operates with little governmental supervision. Users are invariably unaware of the origin or the quality of purchased water. In an effort to better assess this sector, a field survey of water vending wells and tankers coupled with a water quality sampling and analysis program was implemented in a pilot semi-arid urban area (Beirut, Lebanon) to shed light on the environmental and socio-economic impacts of the water tanker sector. Total dissolved solids (TDS), chloride (Cl^-), and microbial loads exceeded drinking water quality standards. While TDS and Cl^- levels were mostly due to saltwater intrusion in coastal wells, tankers were found to be a significant source of total coliforms. Delivered water costs varied depending on the tanker size, the quality of the distributed water, and pre-treatment used, with a markup of nearly 8–24 folds of the public water supply and an equivalent economic burden of 16% of the average household income excluding environmental externalities of water quality. The study concludes with a management framework towards consumer protection under integrated supply and demand side measures.

1. Introduction

Urban water distribution systems are increasingly under stress as a result of increased water demand spurred by population growth and economic development, and lately exacerbated by climate change (Vörösmarty et al., 2000; McDonald et al., 2011). In general, surface water is collected and distributed through a public water supply network that may be complemented by groundwater extraction, water tankers, and/or bottled water in the event of water shortages or deterioration in water quality. Water tankers in particular, also known as cisterns, are a common mean of transporting water from wells or springs to communities lacking infrastructure or deprived of water sources (World Health Organization (WHO) and United Nations Children's Fund (UNICEF) 2006).

Water conveyance using tankers occurs in both developed and developing communities, largely in response to water shortages or during emergencies. In developed economies, water transport tends to be of a short-term nature relied upon in response to emergency cases such as water pipes freeze (Arasmith, 2011) or used to supply isolated rural communities (NNEPA, 2010). Conveyance under both conditions occurs in accordance to governmental regulations and international standards (Council of the European Union, 1998; Massachusetts Department of Environmental Protection (MDEP) 2008; Sundaram et al., 2009; Vancouver Coastal Health Authority (VCHA) 2009; DWI 2010; CDPH 2010; NNEPA 2010; MDEQ 2011; SGV 2011; USEPA 2011; WHO 2011; CDPHE 2013; MDDELCC 2013; SoCDPH 2014). On the other hand, in many developing countries, tankers are used to supplement water shortages in urban areas that 1) do not receive enough water from the public network (MDEP, 2008; TNN, 2010), or 2) during special events such as the pilgrimage in Mecca (Mihdhdir, 2009), or 3) even incorporated within the national water delivery network system such as the case of Nigeria, where up to 78% of the water in the dry season is supplied by tankers

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(Nnaji et al., 2013). Whether used for emergencies or to supplement chronic shortages, water distribution by tankers remains a common practice (Table 1) that is largely unregulated particularly in developing communities causing health risks and economic burdens.

In this study, a semi-arid urban area (Beirut, Lebanon) was considered to assess water quality of tankers, to quantify their economics as a supplementary domestic water source, and to develop a management framework to assure safe water quality at a reasonable cost.

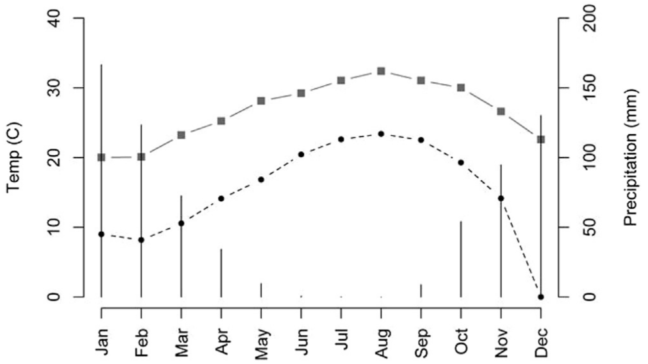

Fig. 1. Minimum (dotted black solid circles) and maximum monthly (solid grey squares) temperatures along with monthly precipitations (solid black vertical lines) from the Beirut International Airport. Data was collected between 1990 and 2010.

2. Materials and methods

2.1. Study area and field survey

Population growth and excessive urbanization in the study area (Beirut, Lebanon) have resulted in chronic public water shortages, with municipal water supplied for only three hours per day during the dry summer season and with many locations not receiving any water (Ministry of Environment, 2011). As such, households resort to the purchase of water through water tankers transporting the water from unregulated private wells located mostly at the outskirt of the city with little information available on the sector, specifically regarding the number of wells being tapped and the number of tankers delivering water to households. In an effort to better characterize the sector, tankers and wells were surveyed using close-ended and structured questionnaires that were administered to tanker drivers and well owners through face-to-face interviews. The costs associated with water pumping, distribution and vending were solicited to quantify the economic burden of water delivery using tankers on consumers.

2.2. Water sampling and quality analysis

Groundwater wells used by the tankers were sampled in December 2013, April 2014, and then again in October 2014, in an effort to capture the seasonal variation in water quality (Fig. 1). Water samples from the tankers were concurrently collected with samples from wells to assess if tankers had an effect on the water quality of the distributed water. The groundwater samples were collected directly from the pipe attached to the wellhead, while samples from tankers were collected from their corresponding outlets. Prior to well and tanker sampling, outlets were disinfected by flame and water was left to run for 1 min to avoid the collection of stagnant water in the supply hose. Samples were transported to the Environmental Engineering Research Center (EERC) at the American University of Beirut (AUB) for laboratory analysis in accordance to Standard Methods for the Examination of Water and Wastewater. The samples were tested for physiochemical and microbiological indicators (Table 2) to assess water quality in comparison to national (Ministry of Environment, 2011) and international standards (USEPA, 2009; WHO, 2006; WHO, 2011).

In addition, ionic ratios such as the Simpson Ionic Ratio of $Cl^-/(HCO_3^- + CO_3^{--})$ and the Jones Ratio (Na^+/Cl^-), computed according to Darnault and Godinez (2008), were used to assess the level of contamination by seawater intrusion (Ekhmaj et al., 2014; El Moujabber et al., 2006; Lee and Song, 2007). Simpson ratios less than 0.5 are indicative of good water quality. Ratios ranging from 0.5 to 1.3 suggest slightly contaminated water, ranges from 1.3 to 2.8 indicate moderate contamination, between 2.8 and 6.6 indicate harmfully contaminated waters, and those between 6.6 and 15.5

Table 1
Global examples of water tanker distribution.

Continent	Country	State/city	Reason
Africa	Burkina Faso	Ouagadougou [a]	Network shortage
	Ghana	Ashanti [b]	Limited access to piped-water
	South Africa	Mpumalanga [c]	Network shortage
America	Canada	Manitoba [d]	Water delivery
	Caribbean islands	Dominican Republic [e]	Network shortage
	United States of America	Alaska [f]	Freezing weather conditions
Asia	Bangladesh	Dhaka [a]	Limited access to piped-water
	Indonesia	Jakarta [a]	Limited access to piped-water
	Pakistan	Karachi [a]	Limited access to piped-water
	Philippine	Manila [a]	Limited access to piped-water
	South Korea	Seoul [a]	Limited access to piped-water
	Thailand	Bangkok and Chonburi [a]	Limited access to piped-water
Europe	Great Britain	England and Wales [g]	Emergencies or water piping fixtures
	Spain	Barcelona [h]	Severe droughts
Oceania	Australia	State of Victoria [i]	Water delivery

[a] Kejjlen and Mcgranahan, 2006.
[b] Nauges and Stand, 2013.
[c] Duse et al., 2003.
[d] MHPU, 2013
[e] Dos Anjos, 1998.
[f] Arasmith, 2011.
[g] DWI, 2010.
[h] Keeley, 2008.
[i] State Government of Victoria (SGV), 2011.

Table 2
Tested water quality indicators with corresponding analytical procedures (APHA-AWWA-WEF, 2012).

	Quality Indicators	Well Water	Tanker Water	Analysis	Methods of Reference	Purpose
Physical	pH	✓	✓	Electrometry	4500-H^+ B	Physiochemical analysis
	Conductivity	✓	✓	Electrometry	2510 B	
	TDS	✓	✓	Gravimetry	2540 C	
Chemical	Calcium Hardness	✓	✓	EDTA Titrimetry	3500-Ca B	
	Total Hardness	✓	✓	EDTA Titrimetry	2340 C	
	Alkalinity	✓	✓	Titrimetry	2320 B	
	Chlorides	✓	✓	Argentometry	4500-Cl^- B	Levels of salinity
	Nitrates	✓	✓	Colorimetry	4500-NO^{3-} B	Indicators of pollution by fertilizers or sewage
	Sulfates	✓	✓	Colorimetry	4500-$SO4^{2-}$	
	Bromide	✓		Colorimetry	4500 Br^- B	Assess the hydrochemistry of the water
	Potassium	✓		Flame Photometry	3500-K B	
	Sodium	✓		Flame photometry	3500-Na B	
Microbiological	Total Coliform (TC)	✓	✓	Membrane filtration	9222 D	Triggers adverse health effects on humans
	Fecal Coliform (FC)	✓	✓	Membrane filtration	9222 D	

point to highly saltwater contaminated waters (Arslan, 2013; Ekhmaj et al., 2014; El Moujabber et al., 2006; Liu et al., 2003). As for the Jones ratio, seawater contamination is implied when levels drop below 0.86 (Darnault and Godinez, 2008). Other molar ratios such as the Ca^{++}/Na^+, HCO_3^{--}/Cl^-, SO_4^-/Cl^-, Mg^{++}/Cl^- and Ca^{++}/Cl^- (Arslan, 2013; El Moujabber et al., 2006; Pulido-Leboeuf et al., 2003; Mondal et al., 2011) were also used to cross check the outcome of the Simpson and Jones ratios.

2.3. Statistical analysis

Field questionnaire data were sorted and entered into the Statistical Package for the Social Sciences: SPSS version 16.0 (SPSS Inc, 2007) and into the R statistical software (R Core Team, 2015). Determinants affecting the delivery cost of water were assessed in an effort to establish correlations between quality, price, and the quantity of the water delivered to the consumer. Seasonal changes in well water quality were tested for statistical significance, using the repeated measures ANOVA test, given that the same wells were sampled over time. The test accommodates for within-well variability while testing for inter-sampling variability. Pairwise t-tests with Homs's adjusted p-values were conducted to identify differences of significance between seasons. Note that the log transformation was applied on all tested variables, except for pH and Bromides, in an effort to normalize the data. Bromides were square root transformed given the presence of a zero value. The Friedman Rank Sum Test, which represents the nonparametric equivalent of the one-way ANOVA with repeated measures, was used to analyze fecal and total coliform data. The test accounts for built-in dependency in data, the presence of zeros, and right-censored data (Too Numerous to Count (coliforms >300)). When the null hypothesis for the Friedman Rank Sum test was rejected, post-hoc comparisons were conducted to identify differences of significance between seasons.

2.4. Economic implications

The tankers' net profits were estimated from the survey data collected on the price of water set by well owners, the cost of water distribution for the tankers, and charges paid by consumers at the delivery point. Consumer estimated losses were then compared to charges set by the public authority on supplying water. The economic burden on consumers was then highlighted by comparing the additional charges paid to of water tankers to the monthly average household income.

2.5. Management framework

A management framework was developed with the aim to regulate water vending towards providing consumer protection and ensuring quality water at a reasonably affordable price. The framework defines control measures with determinants pertaining to water supply monitoring and distribution.

3. Results and discussion

3.1. Sector characteristics

The field surveys identified 24 filling points, some with up to three wells per location, summing up to 33 privately owned wells (Fig. 2). The identified wells supplied water to 34 tanker operators, with some owning multiple tankers that deliver water to the study area. The response rate for the administered questionnaires was relatively high (92 and 100% for the well and tanker owners, respectively). None of the surveyed wells were authorized or regulated for domestic water distribution (twenty-one held an agricultural license, three belonged to car wash stations, two were licensed for industrial use, and six had no license). All wells were accessible by road and most were located within residential areas in close proximity to the coast (within 100–2330 m from the seashore). Some wells were near rivers[1], while others were within petroleum stations[2]. The wells date from as far back as 1913 to as recent as 2013. Their depths ranged between 5 and 125 m below ground. None had provisions for monitoring water quality or pumping rates, which precluded the direct measurement of the amount of water being pumped. Instead, the reported number of tankers filled was used as a proxy to estimate the average daily pumping rates, which varied by season. It exceeded 2000 m^3/day/well in the summer and declined down to 80 m^3/day/well in the winter, with operations being a function of demand rather than of recharge rates.

Since some operators owned multiple tankers, the administered questionnaires represent data collected from 34 operators running 100 tankers. The tankers' capacity ranged between 1.2 and 30 m^3[3], with a median of 20 m^3. Most tankers (89%) were made of steel, including galvanized and painted cisterns, with the rest being either stainless steel (10%) or plastic (1%). Given the lack of

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[1] Wells W6, W7, W8, W9, W10, W11, and W12 were between 24 m and 650 m away from Beirut River, while well W24 was 70 m away from Antelias drainage.

[2] Wells W2, W4-5, W10, and W22.

[3] The estimate is based on the following: 100*(4.5 $/day)*(30 days/month)/(833 $ month).

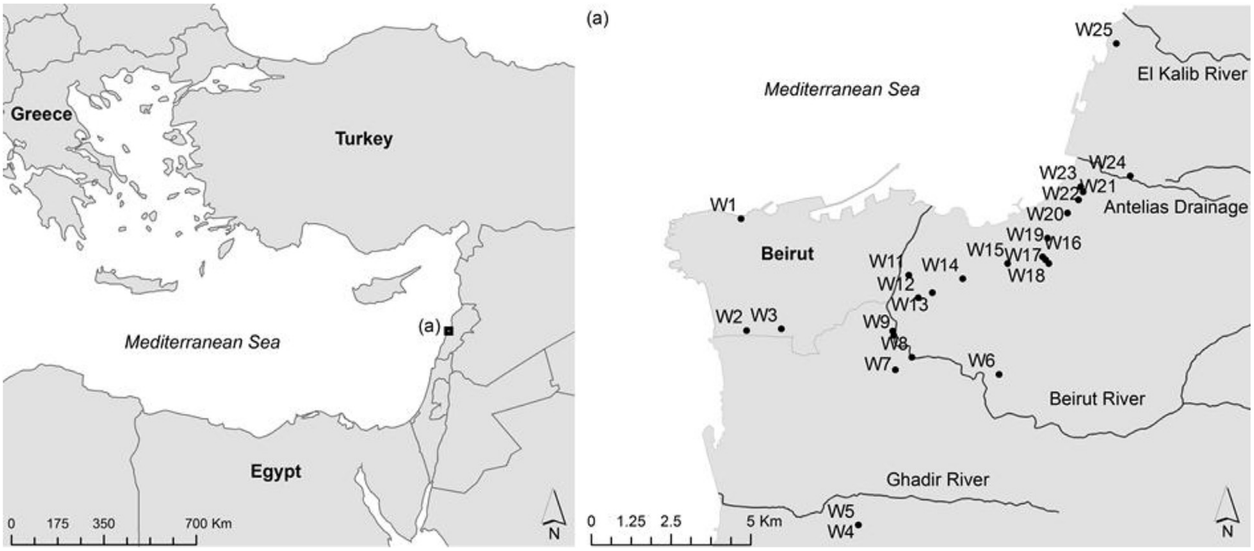

Fig. 2. Locations of filling points.

regulatory monitoring, 27% of tankers reported that they were never cleaned, 12% reported to practice sand suction occasionally, 12% reported regular rinsing with water, and the rest (49%) indicated that they underwent water cleaning with common household detergents (Fig. 3). Similarly, most tankers (94%) did not adopt water treatment prior to distribution. Only two tankers reported adding chlorine capsules to the tanks after each filling. The capsules were provided by serviced hospitals. Four stainless steel tankers were equipped with cotton filters at their outlets. Well operators did not operate onsite treatment, except at one location that had a reverse osmosis system and another that had a sand filter. Both charged an additional fee for treating the water, with tankers given the option to fill prior to or after treatment.

The daily number of trips conducted by a single operator in the summer season varied between 1 and 50 trips/day, whereas in the winter, the number of trips did not exceed 20 trips/day, with many operators (18) becoming inactive from December to April. The total amount of water distributed during the summer season by the surveyed tankers was estimated at ~32,600 m^3/day, generating more than 395 trips/day. In the winter, the total amount of water supplied decreases by nearly 78.3% (~7000 m^3/day), generating about 70 trips/day.

3.2. Water quality analysis

Groundwater samples across all sampling rounds exhibited a pH between 5.6 and 7.9 (Table 3). The TDS levels exceeded the 600 mg/L threshold level in 63%, 86% and 85% of samples collected in rounds 1, 2, and 3, respectively. Similarly, the chloride threshold (250 mg/L) was exceeded 59% in round 1, 50% in round 2, and 61% in round 3. While TDS and chloride levels were expected to decrease in the wet season, an exceptionally dry year led to minor improvements in quality. Measured nitrate levels were below the WHO permissible limit of 50 mg/L for NO_3^- (WHO, 2006; 2011) for sampling rounds 1 and 2. In round 3, around 9% of samples exceeded the NO_3^- standard. Similarly, the WHO permissible sulfate level of 250 mg/L, was exceeded in 13% of samples collected in round 1, 4% in round 2, and 19% in round 3. Lastly, total coliforms were present in all samples of rounds 1 and 2 and in ~80% of samples in round 3. As for fecal coliform 30–36% of sampled wells tested positive across the three rounds. Note that several filling points were located in close proximity to residential buildings, which raises the risk of wastewater infiltration from sewage collection systems to nearby wells.

The Simpson ratio, $Cl^-/(HCO_3^- + CO_3^{--})$, which is an effective

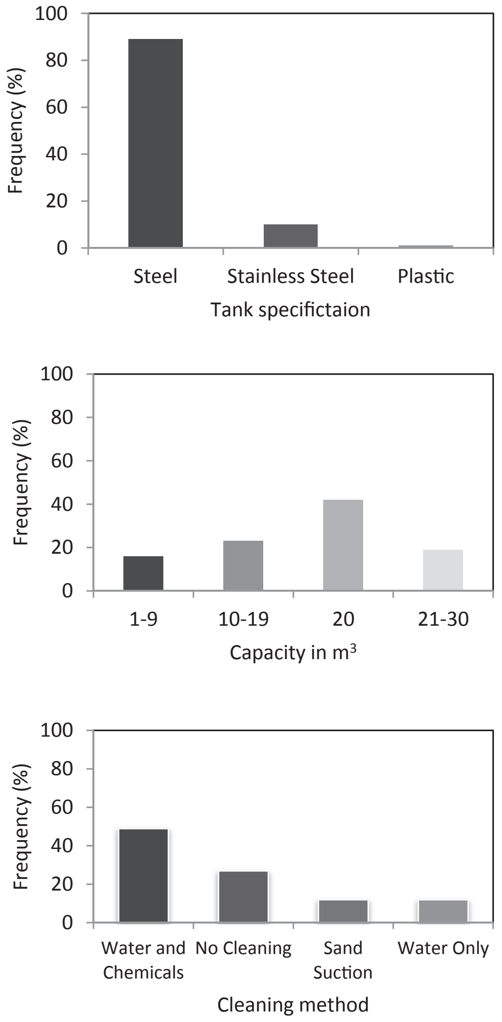

Fig. 3. Tankers characteristics.

Table 3
Summary of the analytical results at filling points.

Round	Parameter tested	Range	Mean	Drinking water standards			Standard exceedance number of samples (%)
				USEPA	WHO	MoE Lebanon	
1	FC (CFU/100 ml)	0–140	10.82	0	0	0	7 (31.8)
	TC (CFU/100 ml)	4 - TNTC	N/A	0	0	0	22 (100)
	pH	6.21–7.49	7.01	6.5–8.5	6.5–9.5	6.5–9.5	0 (0)
	TDS (mg/L)	310–7530	1638	500	600	500	14 (63.64)
	Chlorides (mg/L)	27.4–4920	752.5	250	250	200	13 (59.1)
	Nitrate (mg/L NO_3^-)	7.6–41	19.22	44	50	50	0 (0)
	Sulfates (mg/L SO_4^-)	7–475	121.4	–	250	250	3 (13.63)
2	FC (CFU/100 ml)	0–180	16.36	0	0	0	8 (36.36)
	TC (CFU/100 ml)	19 - TNTC	N/A	0	0	0	22 (100)
	pH	6.75–7.76	7.13	6.5–8.5	6.5–9.5	6.5–9.5	0 (0)
	TDS (mg/L)	217–7283.8	1516.7	500	600	500	19 (86.36)
	Chlorides (mg/L)	16.43–3400	564.2	250	250	200	11 (50)
	Nitrates (mg/L NO_3^-)	17.3–49.4	18.37	44	50	50	0 (0)
	Sulfates (mg/L SO_4^-)	12–340	99.2	–	250	250	1 (4.54)
3	FC (CFU/100 ml)	0–1632	84.66	0	0	0	7 (33.33)
	TC (CFU/100 ml)	0 - TNTC	N/A	0	0	0	17 (80.95)
	pH	5.64–7.85	7.04	6.5–8.5	6.5–9.5	6.5–9.5	1 (4.76)
	TDS (mg/L)	405–15,560	3266.19	500	600	500	18 (85.71)
	Chlorides (mg/L)	29.7–8240	1469.36	250	250	200	13 (61.90)
	Nitrate (mg/L NO_3^-)	3.4–55.5	21.25	44	50	50	2 (9.52)
	Sulfates (mg/L SO_4^-)	7–1050	190.29	–	250	250	4 (19.05)

indicator towards the quantification of the level of salinization in water, reached 100 in some wells indicating the severity of deterioration in tapped aquifers (Fig. 4). Similarly, the Jones ratio (Na^+/Cl^-) indicated a similar pattern of salinization at the sampled wells. Table 4 categorizes the wells based on quality using the two ratio indices. Saltwater intrusion appears to have increased over the sampling time, with most samples collected in round 3 exhibiting the largest deterioration. While aquifer replenishment in the wet season (round 2) diminishes saltwater intrusion, the improvement does not appear in all wells.

Other molar ratios (Ca^{++}/Na^+, HCO_3^-/Cl^-, SO_4^{-}/Cl^-, Mg^{++}/Cl^- and Ca^{++}/Cl^-) ascertained seawater intrusion in groundwater aquifers. Fig. 5 depicts these ratios as a function of Cl^- levels. The Ca^{++}/Na^+ ratio is a measure of seawater intrusion, with low values indicative of saltwater intrusion. The increase in the Cl^- levels is coupled with a decrease in the Ca^{++}/Na^+ ratio across the three seasons ($R^2 = 0.45$; log-log relationship). The negative slope in the Ca^{++}/Na^+ ratio is a direct reflection of the increase in sodium levels originating from the sea. Similarly, the variation in the ratio HCO_3^-/Cl^- with respect to the Cl^- concentration exhibited a negative correlation ($R^2 = 0.87$; log-log relationship). For every 10% increase in Cl^- molar equivalent, the HCO_3^-/Cl^- ratio decreases by 9.5%. A similar relationship was observed for the Ca^{++}/Cl^- molar ratio with respect to Cl^- ($R^2 = 0.81$; log-log relationship). The molar ratio of SO_4^{-}/Cl^- showed a negative correlation with Cl^- ($R^2 = 0.65$; log-log relationship). The negative slope indicates that for every 10% increase in Cl^- molar equivalent, there is a decrease of 5.5% on average in the SO_4^{-}/Cl^-. A similar pattern was also observed between the Mg^{++}/Cl^- ratio and the Cl^- concentration ($R^2 = 0.71$; log-log relationship). All molar ratios consistently indicated that excessive pumping is inducing acceleration in saltwater intrusion at tapped wells. Moreover, the relationship between log Cl^- and the log ratios appeared to be stable over the three sampling rounds.

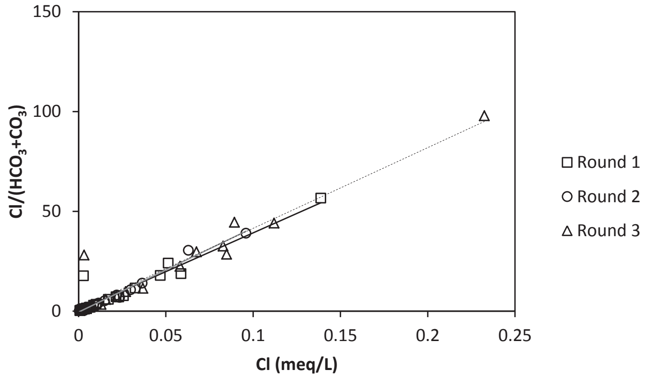

Fig. 4. Correlation between $Cl^-/(HCO_3^- + CO_3^-)$ and Cl concentration (meq/L). Black solid line represnts the trendline for Round 1; Solid grey line represnts the trendline for Round 2; dashed line represnts the trendline for Round 3.

3.3. Statistical analysis

Statistically significant differences were observed between the three sampling rounds (Table 5). Seasonal variations of chlorides and EC were significant ($p\text{-value} < 0.05$); the post-hoc comparison showed that levels measured in rounds 1 and 3, and rounds 2 and 3 were significantly different. Similarly, calcium and total hardness levels exhibited significant seasonal variations ($p\text{-value} < 0.05$). In terms of potassium and TDS, statistically significant differences were observed between rounds 1 and 2 on one hand, and rounds 2 and 3 on the other ($p\text{-value} < 0.05$). The seasonal variation for sulfates was only statistically significant between rounds 2 and 3 (p-value of 0.0118). Bromide levels were statistically different across all sampling rounds. The FC levels did not show statistically significant differences across the three rounds. However, seasonal differences were statistically significant (p-value of 0.00044) for total coliforms. Post-hoc comparison showed that TC levels measured in Round 3 were different from those measured in Rounds 1 and 2 but the difference between Rounds 1 and 2 was not significant.

Well samples were matched with their corresponding tankers to assess the impact of the latter on the quality of the delivered water. As such 19 filling points were compared with 30 tankers in terms of Fecal and Total Coliform, chlorides, TDS, nitrates and sulfates. Paired t-tests were conducted on the log transformed concentrations of TDS, nitrates, sulfates, chlorides, and fecal coliforms in an effort to assess if the quality of the water varied between the wells and their corresponding tankers. The differences were not

Table 4
Water contamination by seawater based on the Simpson and the Jones ratios.

Seawater contamination		Round 1	Round 2	Round 3
$Cl^-/(HCO_3^- + CO_3^{--})$	Good quality <0.5	W10, W24, W25	W8, W10	W10, W24, W25
	Slightly contaminated by seawater <1.3	W8, W13, W17, W18	W4, W12, W15, W17, W24, W25, W18	W26
	Moderately contaminated by seawater <2.8	W11, W15,W16	W11, W15	W8, W11, W16
	Harmfully contaminated by seawater <6.6	W19, W20, W22	W7, W19, W20, W22	W15, W20
	Highly contaminated by seawater <15.5	W7, W9, W21, W23	W6, W9, W21, W23	W7, W9, W19
	Highly contaminated by seawater >15.5	W2, W3, W4, W6	W2, W3,	W2, W3, W4, W6, W21, W22, W23
Na^+/Cl^-	Seawater contamination <0.86	W2, W3, W4, W6, W9, W13, W16, W19, W21, W22, W23	W2, W4, W17, W18, W24, W25, W26	W2, W4, W6, W7, W8, W9, W11, W12, W13, W14, W15, W16, W17, W19, W20, W21, W22, W23, W24, W25, W26

statistically different at the 95% significance level (p-value of 0.24, 0.25, 0.22, 0.33, and 0.31 respectively). This highlights the importance of the wells with regard to pollution levels. While overall, the difference in Fecal Coliforms was not significant, 8 tankers had higher concentrations than their source water, a strong sign of lack of hygiene in the filling and/or the cleaning procedures. The main

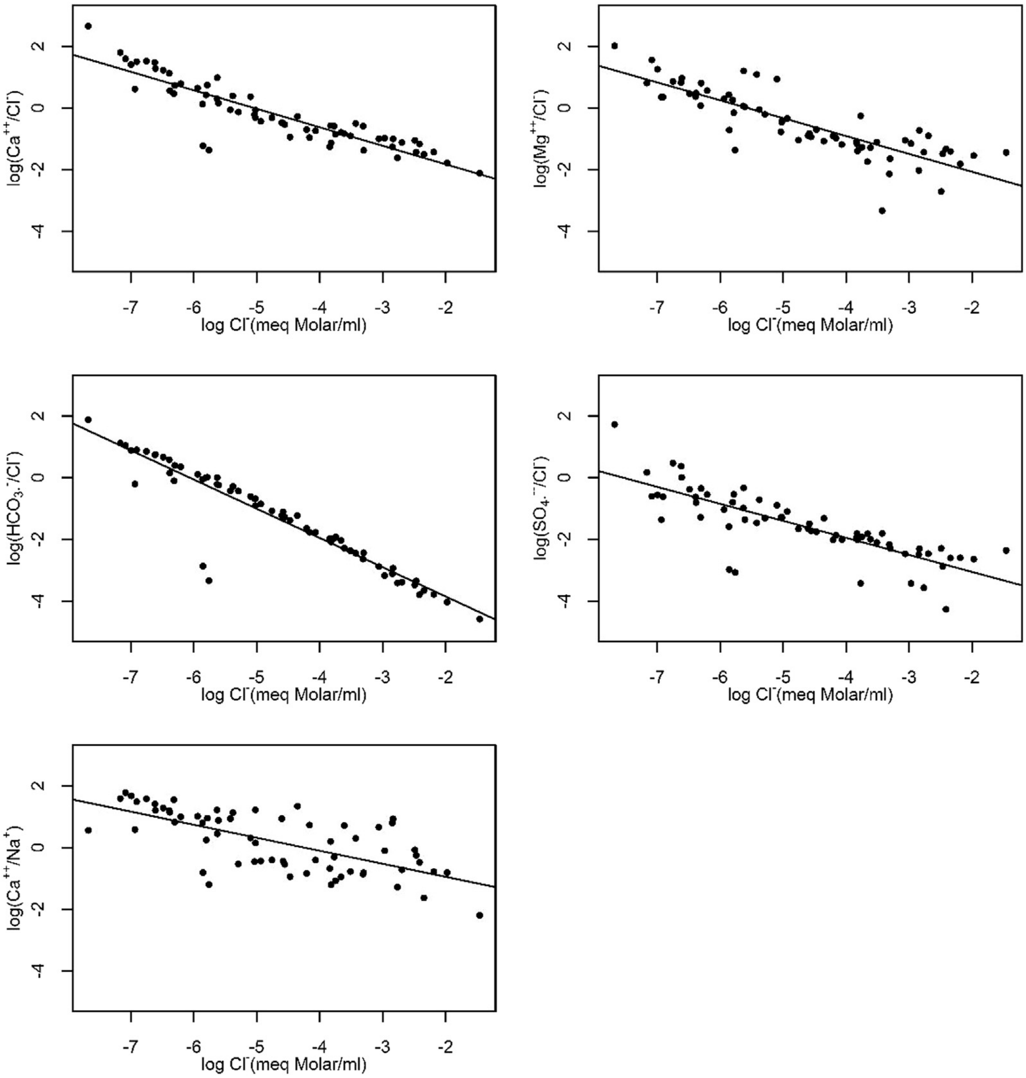

Fig. 5. Molar ratios of groundwater parameters versus Cl^- concentration (meq/L).

Table 5
Statistical difference between the seasonal variation (values report p-values).

Parameters	Repeated MeasuresANOVA	Difference S1–S2	Difference S1–S3	Difference S2–S3
Chlorides	5.34E-04	0.13	8.5E-04	4.18E-03
Calcium Hardness	2.74E-04	9.9E-03	0.11	2.4E-03
Magnesium Hardness	No significance			
Total Hardness	1.12E-03	1.48E-02	0.33	3.8E-03
Alkalinity CO_3	No Significance			
Alkalinity HCO_3	No significance			
PH	No significance			
EC	3.97E-05	0.16	2.3E-05	1.6E-03
TDS gravimetry	9.43E-04	1.1E-03	1.1E-03	0.84
Nitrates	No significance			
Sulfates	1.18E-02	0.37	6.7E-02	2.7E-02
Sodium	No significance			
Potassium	2.62E-11	2.1E-06	5.10E-07	0.44
Bromide	2.08E-12	7.50E-05	6.60E-10	7.50E-05
Parameters	Friedman rank Sum test	Difference S1–S2	Difference S1–S3	Difference S2–S3
Fecal coliform	No significance			
Total coliform	4.4E-4	0.15	2.01E-03	2.8E-05

Shading highlights statsitically signficant results.

variability in the water quality between tankers and wells was found in the Total Coliform (TC) concentrations. Due to the right censorship of the TC data, a parametric *t*-test could not be used. Replacing censored data with the upper detection limit is well known to bias the results from a *t*-test. As such, the non-parametric Wilcoxon signed-rank test for paired data was adopted. The test treated the data as ordinal and thus is capable of handling ties between paired entries. For the TC data, there was strong evidence to indicate that the TC values in the tankers were significantly higher than the values recorded in their corresponding wells (p-value < 0.05), suggesting that the tankers are an important source of coliform bacteria contamination. These results indicate that either the tanker material or the operators' hygienic practices do not conform to international standards of water transport and are introducing bacteria to the source water. Table 6 compares the analytical results between the wells and tankers for the dry season and shows the variability in quality.

3.4. Economic burden

Based on the collected data, the cost of water pumping to the well operator varied between 0.034 and 0.75 ($US/m^3) depending on well depth. The price of water set by well owners varied by tanker size. For large tankers, prices ranged between 0.08 and 0.11 ($US/m^3), while the prices for small tankers ranged from 0.20 to 1.23 ($US/m^3). The cost of water distribution ranged between 0.49 and 7.92 ($US/m^3), with an average of 2.56 ($US/m^3). The water price that consumers paid on delivery differed depending both on the distance from the filling point and on the location of the water holding tanks in the building (if it is on the roof or on the ground). The price of water paid for filling tanks on the roof was often greater than filling tanks on the ground. A comparison between the actual cost of the water and the price paid for water tankers shows that the tankers' profits for delivering water to ground tanks ranges between 16 and 414%, while profits for roof delivery ranges between 61 and 729%. Moreover, a comparison between the price paid by a consumer for 1 m^3 delivered by a tanker and the cost for municipal water (0.42 $US/m^3) indicates that the markup for the consumer ranges between 760 and 2410%, highlighting the significant economic burden, excluding environmental externalities associated with health impacts resulting from poor water quality or with increased saltwater intrusion due to over-pumping (potential damage to household appliances by using saline water for domestic purposes). Considering that 70% of households generates an average of 833$ per month (Abou Khaled, 2014), and a water consumption rate of 0.16 m^3/capita/day (Ministry of Environment, (2011)), a family of four persons pays during the period of shortage, an additional 4.5 $/day for water, or 16%[3] of their income excluding environmental externalities associated with poor water quality of tankers in the form of cost of potential illness, damage to household appliances, and or the purchase of bottled water that is invariably used for drinking purposes.

Table 6
Summary of the analytical results of wells and tankers during the dry season.

Parameter tested	Outlet	Range	Mean	Drinking water standards			Standard exceedance by N samples (%)
				USEPA	WHO	MoE–Lebanon	
FC (CFU/100 ml)	Well	0–140	10.42	0	0	0	6 (31.57)
	Tanker	0–146	8.32				14 (46.66)
TC (CFU/100 ml)	Well	4–TNTC	7 TNTC	0	0	0	19 (100)
	Tanker	13–TNTC	22 TNTC				30 (100)
TDS (ppm)	Well	145–2700	989.68	500	600	500	12 (63.15)
	Tanker	76.2–2580	1054.17				22 (73.33)
Chlorides (mg/L)	Well	27.4–2080	510.83	250	250	200	9 (47.36)
	Tanker	28.9–2075	564.39				18 (60)
Nitrate (mg/L NO_3^-)	Well	7.6–25.3	16.65	44	50	50	0 (0)
	Tanker	7.8–27.9	16.54				0 (0)
Sulfates (mg/L SO_3^-)	Well	7–280	106.84	–	250	250	1 (5.26)
	Tanker	6–270	100.87				2 (5.88)

3.5. *Management framework*

Similar to many developing urban communities, tankers and wells in the pilot area appear to be completely unregulated or do not abide by existing regulations pertaining to well and tanker permitting as well as compliance with water quality standards. At a governance level, worldwide practices envisage several institutions/agencies to be responsible for managing the water sector in terms of quality, cost, protection, and enforcement. In the pilot area, none seems to be involved with regulating or monitoring tankers or enforcing well permitting processes or ensuring quality water. Accordingly, it is imperative that a management framework targets the regulatory and institutional context to organize wells and tankers alike including the establishment of monitoring requirements and providing consumers with a potable water supply at a reasonable price. The main elements for such a plan are detailed in the Supplemental Material. Clearly, the implementation of such a framework will naturally require the involvement of various regulatory, protection and enforcement agencies.

Given the ongoing operation and need for water, decision makers cannot shut down water vendors without providing an immediate alternative to avoid social conflicts. The control of water vending under the governance of existing institutions is preferable over establishing a new regulatory board that is invariably not readily accepted and would inevitably delay implementation processes. Existing regulatory institutions can link private service providers to the government system to ensure compliance with standards and tariffs. Considering that the end user has little means of verifying the safety of the water they purchase, information dissemination programs may aid consumers in selecting the best available source from existing wells and tankers. *In the short-term* (Fig. 6), regulatory issues in relation to licensing, water quality and cost monitoring towards consumer protection can be addressed by water establishments responsible for water distribution to ensure that water service providers are following best practice and safety guidelines for wells and tankers and that the water quality is periodically monitored.

In the long term (Fig. 7), given the chronic nature of water shortage, it is imperative to adopt an integrated approach of supply and demand side measures within a comprehensive management framework coupled with detailed guidelines for the water vending sector targeting licensing, inspection, maintenance, and monitoring procedures and requirements for wells and tankers with corresponding record keeping and penalties (See Supplemental Material). Smart metering with tariff restructuring based on usage, promotion of water conservation practices and incentives for water saving appliances are vital demand side measures indispensable for sustainable water consumption and proper resource management. On the other hand, reducing unaccounted-for-losses in the water supply network, currently estimated at 50% in the study area (Ministry of Environment, 2011), remains a priority measure that can save invaluable water resources. Rainwater harvesting, benefiting from surface runoff (storm water) along coastal areas, as well as reuse of treated grey water or wastewater, despite associated sensitivity in terms of social acceptance, can also be considered in the framework. Other supply management methods, discussed in national plans, including the construction of a series of dams as well as conveying water from rural areas, could prove viable in the medium to long term when population growth and high consumption rates require boosting available water resources. The latter is considered in parallel to demand side and other supply side measures such as unconventional sources (i.e. desalination, water harvesting, water reuse and wastewater recycling).

4. Conclusion

Reliance on water tankers is a common adaptation measure in urban areas with chronic shortages in the public water distribution

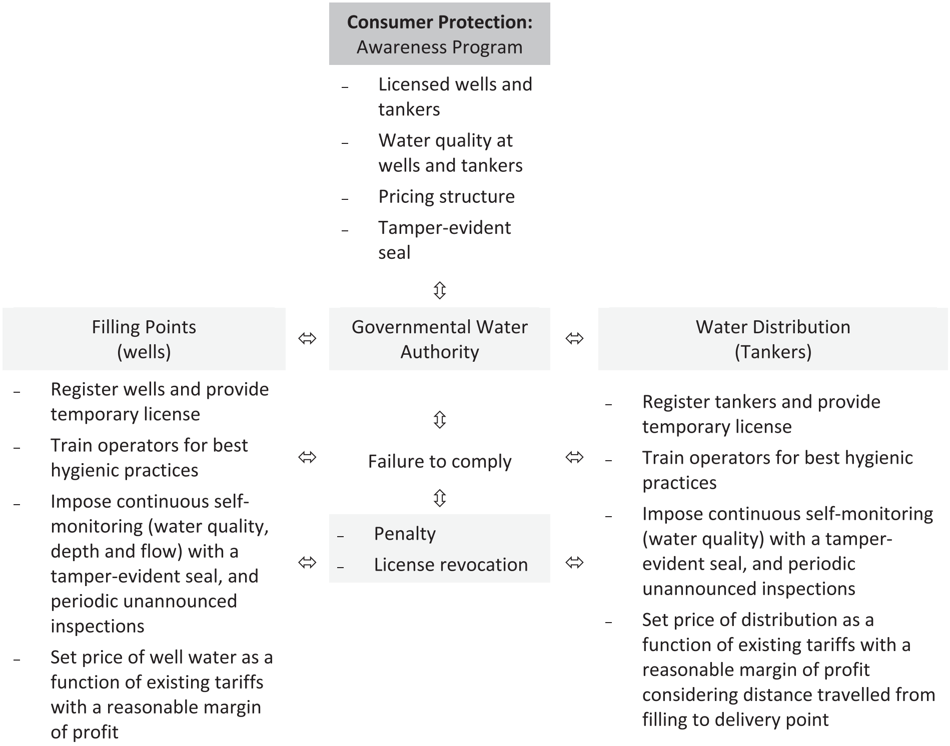

Fig. 6. Short Term control framework.

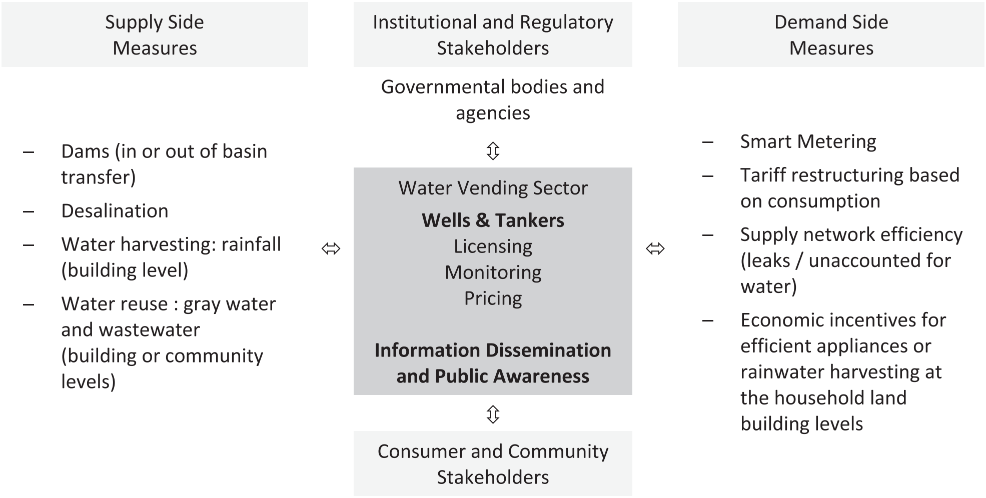

Fig. 7. Long term management framework.

system. The economic burden incurred to receive water from tankers differs depending on the hauling distance, the guidelines set by the community, and the monitoring program among others. Often, private service providers resort to obtain water from unprotected sources and set prices entirely at their discretion, considering factors of supply and demand. Hence, while small-scale water providers can fill a gap in the supply system and contribute towards meeting basic water needs, it is critical to regulate their services to ensure compliance with water quality standards and tariffs. In the pilot area, tankers deliver water at a cost ranging between 3.5 and 11 $\$US/m^3$, which is nearly 8 to 24 times more than governmental fees for water delivered through the public network. The relatively high cost is unjustifiable considering the poor quality of well water being delivered (high TDS in 85% of samples, high chloride in 61% of samples) and the equivalent economic burden as a function of the average household income of 16% the burden of environmental externalities. While wells were the main source of water contamination, tankers proved to be an important source of total coliform, mainly due to the sub-standard tanker material and/or operators' hygienic practices. Moreover, unregulated pumping was found to be a strong promoter of saltwater intrusion, with most wells exhibiting evidence of salinization. The high costs, the promotion of saltwater intrusion, and the impaired water quality of tankers are a direct result of the lack of regulations and monitoring or the lax in the enforcement of existing ones. With the continuously growing water shortage and in the absence of adequate public water distribution capacity, it becomes imperative to recognize and regulate the water vending sector as well as formalize and control its market through a management framework that is fundamental to ensure the provision of safe and affordable water services. This framework can be managed through a monitoring program that continuously assesses the performance of the sector in the context of consumer complaints and protection. The framework can be implemented wisely with control measures gradually undertaken at critical milestones to support and maintain aspired performance at the short and long terms.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2016.11.065.

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