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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.

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

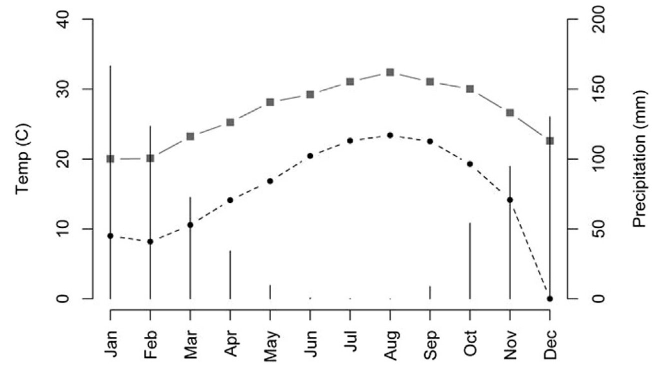

Fig. 1. Minimum (dotted black solid circles) and maximum monthly (solid grey squares) temperatures along with monthly precipitations (solid black vertical lines) from the Beirut International Airport. Data was collected between 1990 and 2010.

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^{2-}) 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.