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Energy use for water provision in cities

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ABSTRACT

Energy demand for urban water supply is emerging as a significant issue. This work undertakes a multi-city time-series analysis of the direct energy use for urban water supply. It quantifies the energy use and intensity for water supply in 30 cities (total population of over 170 million) and illustrates their performance with a new time-based water-energy profiling approach. Per capita energy use for water provision ranged from 10 kWh/p/a (Melbourne in 2015) to 372 kWh/p/a (San Diego in 2015). Raw water pumping and product water distribution dominate the energy use of most of these systems. For 17 cities with available time-series data (between 2000 and 2015), a general trend in reduction of per capita energy use for water provision is observed (11%–45% reduction). The reduction is likely to be a result of improved water efficiency in most of the cities. Potential influencing factors including climate, topography, operational efficiency and water use patterns are explored to understand why energy use for water provision differs across the cities, and in some cities changes substantially over time. The key insights from this multi-city analysis are that i) some cities may be considered as benchmarks for insight into management of energy use for water provision by better utilising local topography, capitalising on climate events, improving energy efficiency of supply systems, managing non-revenue water and improving residential water efficiency; ii) energy associated with non-revenue water is found to be very substantial in multiple cities studied and represents a significant energy saving potential (i.e. a population-weighted average of 16 kWh/p/a, 25% of the average energy use for water provision); and iii) three Australian cities which encountered a decade-long drought demonstrated the beneficial role of demand-side measures in reducing the negative energy consequences of system augmentations with seawater desalination and inter-basin water transfers.

1. Introduction

Energy is used in every stage of water supply, abstraction, conveyance, treatment and distribution. In future, more energy is expected to be required to adapt water systems to meet increasing demand, regulatory requirements and the effects of climate change (Rothausen and Conway, 2011). In places with increasing water scarcity, alternative water sources such as inter-basin water transfers, desalination, potable water recycling and decentralised sources are being considered or utilized to meet increasing water demands and/or to cope with drought (Hussey and Pittock, 2012). Most of these alternative supply sources are more energy-intensive than traditional options such as dams and aquifers (Stokes and Horvath, 2006). This can represent a significant increase in greenhouse gas emissions and therefore, may be inconsistent with climate change mitigation policies. In addition, rising energy use can represent a financial risk to water utilities and communities (Kenway and Lam, 2016). For instance, the electricity cost for providing urban water services in Australia was forecast to increase five-fold over 2010 levels by 2030 (Cook et al., 2012).

Energy use for urban water provision has been studied extensively from different perspectives such as to understand direct energy impacts (Nogueira Vilanova and Perrella Balestieri, 2015; Sanjuan-Delmás et al., 2015), to quantify the embodied energy impacts (Amores et al., 2013; Mo et al., 2011; Stokes and Horvath, 2006) and to explore future scenarios (Lundie et al., 2004; Shrestha et al., 2011; Twomey Sanders, 2016). In addition to these particular studies, energy use in urban water systems has been previously reviewed in literature. Plappally and Lienhard (2012) reviewed energy use for the whole water cycle, while Loubet et al. (2014) provided a review of LCA studies for urban water systems.

Most of the published work comprises studies of a single region. There are very few multi-regional studies on energy for water.

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Abbreviations

kWh/p/a	Energy use expressed as kilowatt-hour electricity use per person per year
kWh/kL	Energy intensity expressed as kilowatt-hour electricirty use per kilolitre water supplied
L/p/d	Water use expressed as litre of water use per person per day

Siddiqi and Anadon (2011) assessed the inter-dependence of the water and energy systems in the Middle East and North Africa, and Sanjuan-Delmás et al. (2015) statistically analysed a sample of 50 municipalities in Spain to assess their energy use in water supply networks. A multi-regional study is valuable because it can help to identify best practice and support inter-city learning, especially between cities with similar geophysical environments (Kennedy et al., 2009). Multi-regional studies also provide a better understanding of the impacts of geospatial conditions on water management decisions (Mo et al., 2014). Decker et al. (2000) emphasised the need to broaden the study of individual cities into systematic cross-city comparisons. Furthermore, most of the studies reviewed present a "snapshot" of a single year. Studies considering the influence of time on water-related energy use are not currently evident in the literature (Kenway et al., 2011).

This multi-city study quantifies, compares and analyses the direct energy use of water supply systems (i.e. source to tap) for a sample of 30 cities (including time-series for 17 of the cities studied). It aims to i) illustrate the historical performance of water use and direct energy use for water provision in the sampled cities using a new water-energy profiling approach, and ii) improve our understanding of some of the determining factors (i.e. climate, topography, water use pattern and operational efficiency) for variations between cities and temporal changes in some cities.

The major contributions of this work are i) Compilation and analysis of the most up-to-date energy use for water provision data (where available) in a large set of cities, ii) Performance of a time-series water-energy analysis for a sub-set of these cities to explore the trends and lessons learned, iii) New insights from a rare multi-city analysis, and iv) Illustration of the results with a water-energy profiling approach. Collectively, the work could support inter-city learning and help guide benchmarking of urban water systems, helping cities to transition towards greater water and energy efficiency.

2. Materials and methods

2.1. Data collection and compilation

Urban water use, energy use or energy intensity of water supply systems and population data were collected for 30 cities (Table 1). These cities, with a range of population size (>500,000) and water supply sources, were chosen based on availability of data, especially the energy demand for water provision. The most up-to-date data

Table 1
List of cities studied.

City/region[a]	Country	Studied year(s)[b]	Population[c]	Major water sources[d]				
				River/lake	Constructed reservoir	Inter-basin water transfer	Groundwater	Desalination
Brisbane	Australia	2002–2014	2,275,000		✓			○
Melbourne	Australia	2001–2015	4,377,000		✓	○		○
Perth	Australia	2002–2015	1,961,000		✓		✓	✓
Sydney	Australia	2002–2014	4,755,000		✓	○		○
Rio de Janeiro	Brazil	2014	5,913,000		✓			
Salvador	Brazil	2014	2,700,000		✓			
São Paulo	Brazil	2003–2014	26,075,000		✓			
Toronto	Canada	2006, 2011–2013	2,772,000	✓				
Beijing	China	2011	18,585,000		✓		✓	
Tianjin	China	2011	12,648,000		✓		✓	
Copenhagen	Denmark	2008–2010, 2012–2014	575,000				✓	
Berlin	Germany	2010	3,438,000				✓	
Ahmedabad	India	2009	5,578,000	✓				
Bangalore	India	2013	8,444,000			✓		
Bhopal	India	2009	1,798,000	✓	✓		✓	
Delhi	India	2009	16,788,000	✓				
Jamshedpur	India	2005–2009	860,000	✓				
Osaka	Japan	2005–2014	2,686,000		✓			
Sapporo	Japan	2007–2014	1,928,000		✓			
Tokyo	Japan	2000–2003, 2005, 2009–2014	13,257,000		✓			
Yokohama	Japan	2004–2007, 2009–2014	3,712,000		✓			
Mexico City	Mexico	2013	8,894,000			✓	✓	
Oslo	Norway	2001–2010	584,000	✓				
Cape Town	South Africa	2010	3,655,000		✓			
Bangkok	Thailand	2004–2011	8,001,000	✓				
Denver	U.S.A.	2007–2014	1,172,000		✓			
Los Angeles	U.S.A.	2003–2015	3,988,000			✓	✓	
San Diego	U.S.A.	2003, 2007–2015	1,326,000			✓		
San Francisco	U.S.A.	2014	837,000		✓			
Tampa	U.S.A.	2010	657,000		✓			

[a] Considering metropolitan regions, Table 1S (Supplementary Material) includes the regions considered for some of the cities.
[b] Depending on data availability.
[c] Considering population served by water mains in the latest studied year. References can be found in Table 1S (Supplementary Material).
[d] Water sources are considered to be major if they contribute to more than 10% of the local water supply. River/Lake: with natural water bodies; Constructed reservoir: with artificial water bodies upstream; Inter-basin water transfer: sourcing water from distant river basins; Groundwater: with underground aquifers; Desalination: reverse osmosis; ○ to be operated in dry years. References can be found in Table 1S (Supplementary Material).

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