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Quantification of the urban water-energy nexus in México City, México, with an assessment of water-system related carbon emissions

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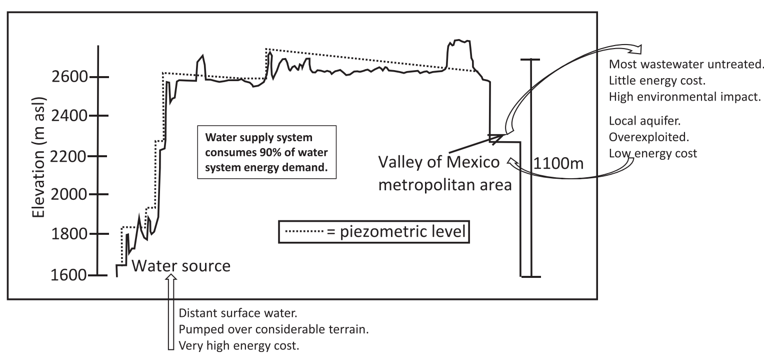
HIGHLIGHTS

- The water system related energy use and climate impact of Mexico City is presented.
- Water supply is responsible for ~90% of energy consumption in the system.
- Wastewater treatment is limited with concomitant low energy/carbon impact.
- Water savings measures may lead to major reductions in energy use and carbon impact.
- A switch to greener energy fuels would cut carbon impacts.

GRAPHICAL ABSTRACT



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ABSTRACT

Global urbanisation will put considerable stress on both water and energy resources. While there is much research at the national and regional levels on the energy implications of water supply (the urban water-energy 'nexus'), there is relatively little at the city scale. This literature is further diminished when attempting to account for the climate impact of urban water systems. A study of the urban water-energy-climate nexus is presented for México City. It is shown that 50% of México City water comes from a local aquifer with a further 30% deriving from energy-intensive surface sources which are pumped over considerable topography. The water supply system consumes 90% of the water system energy demand, and is responsible for the majority (90%) of the CO_2e emissions. In the wastewater sector, 80–90% is discharged with no or little treatment, with correspondingly low energy demand. The small fraction that is treated accounts for the majority of energy use in the wastewater sector. This study shows the uncertainty in energy demand and CO_2e emissions when reliant on secondary data which considerably over/under-estimate energy use compared with primary data. This has implications when assessing energy and carbon budgets. Three water savings options are assessed for their impact on energy and CO_2e emissions reductions. Considerable reductions in water supply volumes and concomitant energy consumption and CO_2e emissions are possible. However the extent of implementation, and the effectiveness of any implemented solutions depend on financing, institutional backing and public support. An additional measure to reduce the climate impact is to switch from traditional to renewable fuels. This work adds city-level quantification of the urban water-energy-climate nexus, allowing policy makers to discern which water-system elements are responsible for the greatest energy use and climate impact, and are better equipped to make targeted operational decisions.

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1. Introduction

Global urbanisation prospects suggest that by 2050 up to seven billion people may live in urban areas (UN, 2014). This is equivalent to the entire global population today. Seven billion urban residents imply a considerable increased demand on water service provision and by extension energy demand. One pressing global challenge is how to sustainably provide seven billion urban residents with suitable water and energy services that also offer a respectable standard of living. This issue is much more complex than it may initially appear as it is well known that water and energy, especially in urban areas, are intimately linked (Kenway et al., 2011; Sanders and Webber, 2012; Lenouvel et al., 2014; Lenhart et al., 2015), and should not be thought of as two separate systems. Energy is required to pump, treat and deliver freshwater and to treat wastewater, while water is extensively used in the energy sector for extraction, processing and in cooling for example (e.g. Olsson, 2012). As a pertinent example, at present about 12% of primary energy consumption in the US is related to the water sector (Sanders and Webber, 2012) and current estimates state that between 2 and at least 8% of global energy use is in the water sector (Olsson, 2012; WWAP, 2012). Together, and especially in the water service cycle in cities, they form one interconnected system, with changes in one impacting the other (e.g. Kenway et al., 2014).

General information regarding energy and water usage and their relationships are available, especially in terms of national, regional or global average values. For example the World Energy Council (2010) report global averages for the water required for primary energy extraction. Likewise the DOE (2006) report global averages for water used in different electricity generation methods. At the national and regional scale, studies have investigated the general trends between water in the energy sector and vice-versa (e.g. Fthankis and Kim, 2010; Rasmussen, 2012; Sanders and Webber, 2012; Davies et al., 2013; Koch et al., 2014).

Against this background, local-level information at the scale of the city is missing in many locations. While there are examples of city-level studies (e.g. Kenway et al., 2014; Lenouvel et al., 2014; Lenhart et al., 2015; Jiang et al., 2016), generally the information can be scarce. Kenway et al. (2014) quantify the impact of different policy decisions on the water-energy future for Melbourne, Australia. Using urban metabolism modelling, they found that a compact urban form would result in greater water savings than a sprawling city. They also show that while desalination will become more important, it still provides a low percentage of total water, but with a high energy cost. Lenouvel et al. (2014) discuss the energy cost that has been, or may be, associated with water independence for Singapore. They show that while Singapore is world-leading in terms of becoming self-sufficient with regard to water supply, this may come at a high energy cost, increasing reliance on energy imports. Using Rotterdam, The Netherlands, as a case study, Lenhart et al. (2015) discuss how by changing the role of local authorities in urban water-energy planning, efficiency in both sectors can be improved, and a greater degree of circularity (repeated re-use of resources) can be achieved. In a more narrowly focussed study, Jiang et al. (2016) show the important contribution of urban residential water consumption to overall energy demand in an urban area, taking Tianjin, China, as an example. They show that through a variety of in-home water savings measures, a significant energy saving city-wide could be achieved. Taking Beijing as a case, Chen and Chen (2016) use system network modelling and input-output modelling to show the energy used for water services in the city. They show the tight coupling of water and energy use for Beijing. Sahin et al. (2016) use system dynamics modelling to show how bulk water imports may change in southeast Queensland, Australia, due to climate and population pressures. These pressures will require water contingency planning in the form of extra transfer of water from a number of sources, all of which will increase the energy requirements in the system. Venkatesh et al. (2014) examine the water-energy relationships in four cities (Nantes, Oslo, Turin and Toronto) to explore some of the main factors that shape and influence the urban water-energy nexus. It is shown that climate, technology and geography play important factors, with local planning also important. In general, academic studies, while very useful in forwarding the concept of the urban water-energy nexus and useful in providing general quantitative results, sometimes lack the fine-scale city-level detail required for practical long-term strategic planning. In such cases, local level information is critical as national or regional level studies smooth over or average out potentially crucial local level information. These differences could have a large impact on the perceived effectiveness of various policy measures, especially regarding urban water-energy, where the interrelations are so tightly coupled.

To this end, this paper presents a detailed study into the urban water cycle of México City in order to provide city-scale detail regarding the urban water-energy nexus. We contribute to the existing literature by providing city-level information on the water-energy nexus using primary data from local water service providers, and showing how tightly connected these systems are. We include analysis on both the water supply system and the wastewater treatment system, considering the city's water cycle. We connect this information to carbon dioxide equivalent (CO_2e) emissions, and therefore to the wider debate surrounding urban expansion and climate change (e.g. WWAP, 2014). While CO_2 is not the only climate forcing gas (e.g. CH_4 and NO_x are also critical climate forcing gases), CO_2e emissions are the focus of this study due to data availability and access issues.

2. Data and methodology

2.1. Study location and water system

This study focusses on the whole water system (supply and treatment) of México City, which is one of the world's largest cities with a rapidly growing population, with very diverse socio-economic characteristics and an extremely complex water system (many supply sources and various levels of treatment) to serve this population. The aim was to explore this system in terms of water supply characteristics and the corresponding energy demand and carbon impacts and also from the wastewater treatment sector to determine the current levels of treatment including energy and carbon implications. Also of interest was examining the extent to which potential water saving measures deemed realistic by local experts could help mitigate a) existing concerns surrounding water supply sustainability and the sinking of the city centre area as a result of overexploitation of the underlying aquifer; b) the energy demands from the system and c) the increasing carbon emissions from this system.

México City (Fig. 1), currently has a population of c. 8.84 million people (CONAGUA, 2013), and has increased from 8.6 million in 2000, 8.7 in 2005 and 8.8 million in 2010. At present, about 72% of the total Mexican population is urban, although there has been significant divergence in the urban:rural divide since the 1960′s (INEGI, 2011). México City itself has an area of 1485 km^2, and is located within the Mexican hydrological administrative region (RHA) XIII. RHA XIII comprises the Valley of Mexico and Tula sub-regions, and crosses three Mexican states (México, Hidalgo and Tlaxcala) and has a total of 23 million people. México City, México State and Hidalgo form the Valley of Mexico Metropolitan Area (ZMVM). In this area, the vast majority of people are concentrated in México City.

A rapid increase in population and population density in México City has led to a recent ongoing deterioration in water services along with considerable overexploitation of water resources. At present, in México City, water supply coverage is about 90%, and per-capita use is estimated between 240 and 360 l cap^{-1} day^{-1}, although this is estimate includes domestic, industrial and service sector demands (CAN, 1997; INEGI, 2000). It is also unclear if these values include non-revenue water. Non-revenue water here refers to all unaccounted for or uncharged for water in the system, both water lost to leakage and all