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# Residential water and energy nexus for conservation and management: A case study of Tianjin

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ABSTRACT

As an important part of energy use in the water end-use system, the energy consumption of urban household water use is typical to illustrate the nexus of water and energy. Considering its urban size and population, Tianjin is studied by questionnaires for residential water use and estimated energy intensity. This paper analyzes water-related energy use by studying water end-use data from 504 households and considering family-related impact and technical factors of water appliances. Results show that clothes washing and shower constitute the largest part of water end-use and water-related energy consumption, respectively. Overall simulation assesses the impact of technological improvements, behavioral modification and water-use decrease in household water-related energy use. It indicates that energy saving could reach to $1.69 * 10^{10}$ KWh per year which accounts for 24% of total energy consumption for non-production purposes, which indicate saving water could lead to saving energy. Correlation analysis are used to analyze the relative effects of factors on household water and energy use. The ratio of hand washing and frequency of shower have significant correlation respectively with water end-use and water-related energy consumption, particularly in the parched north. It is suggested to focus on considering the full cost about water resource, strengthening the development of water saving and energy-efficient water appliances, and enhancing the publicity of water saving in the next step. This paper demonstrates the linkage between water and energy in urban water end-use system, thus providing a decision-support tool for water conservation and management.



## Introduction

In order to efficiently use such limited resources as water and energy, water–energy nexus is subject to the value more and more [1]. Water and energy could be coupled in intimate ways, water is utilized to harness, extract and produce energy, while energy is consumed in the processes of water extraction, treatment, distribution and disposal [2,3]. Recognizing the integration of water and energy for planning has become

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increasingly accepted by international institutions, national governments and businesses [4]. In urban system, water supply and sanitation services provided by urban water and wastewater utilities consume a considerable amount of energy [5]. Many advanced techniques and experience have been accumulated in the field of household water and energy use [6]. As a result, enormous energy consumption is associated with water utilization in urban water system and has highlighted the interdependences of water and energy.

Residential energy consumption was responsible for 13.6% of the globally total energy consumption in 2011 [7]. However, residential energy demand will continue to grow rapidly due to urbanization. Al-Ghandoor analyzed the energy and exergy utilizations in residential sectors by using detailed end-use models [8]. Yun et al. found occupant behavioral aspects and socio-economic aspects (e.g. house income) were critical in terms of energy consumption, in particular for heating and cooling [9]. Min et al. built a regression-based statistical framework to simulate space heating, cooling, water heating and appliance energy end-use by using Residential Energy Consumption Survey (RECS) data [10], and presented the significance of energy efficiency development. In China, residential energy consumption constitutes the second largest part of energy use category. Zhang et al. studied the difference of residential energy consumption between urban and rural areas in Jiangsu Province [11], and revealed the energy efficiency effects played an important role in reducing urban residential energy consumption. However, these studies did not consider the impact of water use on energy consumption.

Nowadays, sustainable urban water consumption has become a critical issue due to water scarcity, and residential households have the potential to conserve water such as across discretionary end uses [12]. In order to develop effective household demand management programs, there are many studies about understanding the factors that influence household water use, such as climate/seasonal variability, incentives (e.g. tariff structure and pricing on water technologies), regulations and ordinances, property characteristics (e.g. house size, energy efficiency of household appliances), household characteristics (e.g. family size, family income, water supply technology), and personal characteristics (e.g. desire to conserve water, knowledge about how to conserve water) [13–16]. Based on prior research, this paper should conduct a survey on water consumption from the perspective of residents' attitudes and behaviors, water appliance stock efficiency, water pricing structures and government management system on water resources.

Energy consumption of urban water systems is strikingly huge when the energy use of water abstraction, water treatment, water distribution, tap water consumption and waste water treatment are all calculated [17]. There have been many studies on water-energy relationship in urban water system since 2000. Wilkinson presented a methodology for analyzing the energy intensity of California's water system, and assessed the multiple potential benefits through integrated water-energy efficiency measures [18]. Kahrlet al. focused on the energy implications of water use in China based on an analysis of economy wide resource flows using China's input–output tables [19]. Hardy et al. explored the water-energy nexus in Spain and offers calculations for both the energy used in the water sector and the water required to run the energy sector [20]. Plappally et al. surveyed the available literature on energy intensity for water use in the municipal and agricultural sectors and divided the processes into several stages [21]. Debra et al. presented the WEN tool to quantify the water and energy portfolios associated with a community's water-energy nexus and the influence of geographic location on resources [22]. However, these studies ignore energy use of residential water end-use, and energy consumption during the residential water end-use is high which has a great potential for water and energy saving.

As for residential water and related energy in water end-use, Kenway et al. calibrated a model for water, water-related energy and costs of a specific family household in Brisbane, Australia [23]. In China, Lu took the case of household water use in Beijing to build a mathematical model of energy intensity of household water use through analyzing the characteristics of household water use [24]. Shen et al. estimated energy intensity of household water use in nine cities through experiments and questionnaires on energy consumption in household water use [25]. Based on the current research, a theoretical framework of residential water and related energy has been constructed, although there are still some shortcomings, such as lacking of measured data and the incomprehensive analysis of residential water use. Saving water in the tap water supply sector could generate maximum energy-conserving effects at least cost, which is an efficient measure for water demand side management.

It has always been an important target for Tianjin to reduce water use and energy consumption due to its water shortage and environmental problems. First, its residential energy consumption, which accounts for about 11% of final energy consumption, has been rising during last decades due to its growing population. Second, Tianjin is severely affected by water shortages, so saving water has become crucial to manage well water resources. This paper adopts a calculation model of energy intensity for residential water use based on data from questionnaire survey in Tianjin. It focuses on analyzing its structure and discussing the influencing factors by calculating the amount of household water-related energy consumption. This study is innovative in terms of introducing the energy consumption analysis to the urban water end-use analysis, which is fundamental for water-energy nexus in urban water system. From water demand side management to water-energy nexus understanding, it is useful to integrate management of water and energy and to expand the potential of energy conservation on the basis of saving water and increasing the utilization efficiency of water and energy in cities.

## Study area and method

### *Study area*

Tianjin is a municipality directly under the central government of China. Located in the northeastern part of the North China Plain, 38°34′N to 4°15′N, 116°43′E to 118°04′E, it is an economic and logistics center of the Bohai Rim region [26]. It is