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Assessing the significance of climate and community factors on urban water demand

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Abstract

Ensuring adequate water supply to urban areas is a challenging task due to factors such as rapid urban growth, increasing water demand and climate change. In developing a sustainable water supply system, it is important to identify the dominant water demand factors for any given water supply scheme. This paper applies principal components analysis to identify the factors that dominate residential water demand using the Blue Mountains Water Supply System in Australia as a case study. The results show that the influence of community intervention factors (e.g. use of water efficient appliances and rainwater tanks) on water demand are among the most significant. The result also confirmed that the community intervention programmes and water pricing policy together can play a noticeable role in reducing the overall water demand. On the other hand, the influence of rainfall on water demand is found to be very limited, while temperature shows some degree of correlation with water demand. The results of this study would help water authorities to plan for effective water demand management strategies and to develop a water demand forecasting model with appropriate climatic factors to achieve sustainable water resources management. The methodology developed in this paper can be adapted to other water supply systems to identify the influential factors in water demand modelling and to devise an effective demand management strategy.

Keywords: Urban water; Principal components analysis; Water demand model; Water demand management; Sustainable water resources

1. Introduction

Water scarcity has become a major concern in many countries around the world due to issues such as over extraction of groundwater, inadequate flow in major river systems, water pollution and increase in demand due to growing population and rapid urbanisation (Vörösmarty et al., 2000; Haque et al., 2014a). Furthermore, changing climatic conditions are expected to exacerbate the pressures on water supply systems (House-Peters and Chang, 2011; Misra, 2014; Haque et al., 2015a,b) as catchment water yield is likely to decrease in many parts of the world due to climate changes (Jin et al., 2012; Ficklin et al., 2013; Liu et al., 2013). In order to cope with these challenges and to secure adequate water supply, the implementation of integrated management

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options that include identifying new water sources, increasing the efficiency of existing water supply systems (Postel, 2000) and managing water demand (Arbués et al., 2003; Oduro-Kwarteng et al., 2009) is critical. It is crucial to understand the key influencing factors on urban water demand, which form the basis for developing a reliable water demand forecast model to estimate future water demand.

Urban water demand varies with a range of factors including demographic factors (e.g. population, number of connections and average number of people in a house) (Firat et al., 2009; Fox et al., 2009; Arbués et al., 2010), climatic factors (e.g. rainfall, temperature and evaporation) (Balling and Gober, 2007; Franczyk and Chang, 2009; Cole and Stewart, 2013), and socio-economic factors (e.g. household income and water price) (Arbues and Villanúa, 2006; Franczyk and Chang, 2009; Qi and Chang, 2011). The influence of climatic factors on water demand is of particular importance due to potential higher temperature and reduced rainfall in the future as a result of the changing climate (IPCC, 2007; Babel et al., 2014).

In recent years, another factor has emerged which can be harnessed to reduce urban water use. This is termed as "community intervention programmes" and relates primarily to the employment of water saving measures such as water efficient appliances and rainwater tanks for outdoor water use in homes (Beal et al., 2012; Rahman et al., 2012; Dawadi and Ahmad, 2013; Haque et al., 2013a). These water saving measures are likely to gain increasing importance in managing urban water demand, and hence merits detailed investigations.

Several commonly used techniques have been adopted by water demand studies to identify the influential factors in urban water demand modelling such as regression analysis (Fernandes Neto et al., 2005; Almutaz et al., 2012), artificial neural networks (Firat et al., 2009; Babel and Shinde, 2011), factor analysis (Panagopoulos, 2014) and sensitivity analysis (Babel et al., 2014). Alternatively, another multivariate statistical technique, principal components analysis (PCA) (Gabriel, 1971), can be used to investigate the relative importance of various influential factors in water demand modelling. A biplot, the output from PCA, provides a graphical representation of multivariate data, which facilitates easy identification of the dominant factors. This PCA biplot technique has been adopted in some other types of studies, such as ecology (Basille et al., 2008), environmental studies (Gallego-Álvarez et al., 2013) and water quality analysis (Alias et al., 2014) to identify the influential factors in the modelling. However, application of the biplot technique in identifying the relative importance of various water demand factors is limited.

The objectives of this study are (i) to assess the relative influence of various climatic and community intervention factors on residential water demand using the PCA biplot technique; (ii) to evaluate whether future water demand would be impacted by changing climate or not; and (iii) to recommend strategies to enhance the sustainability of urban water supply management. The results of this study are expected to provide important insights into the influential climatic and community intervention factors in water demand modelling, which will help to plan and develop more effective water demand management strategies (e.g. whether to introduce/continue community intervention programme). Furthermore, this study is intended to generate scientific knowhow that can be used to derive more accurate water demand projections by utilising the useful information on the relative impacts of climatic and community intervention factors on water demand (e.g. whether climatic factors are to be included in the water demand modelling). The findings of this study would be useful in enhancing the sustainability of urban water resources and water supply systems in a given region.

2. Study area and data

Blue Mountains Water Supply System (BMWSS) in New South Wales, Australia was selected as the study area. In the Blue Mountains region, BMWSS provides water to about 48,000 people residing between Faulconbridge and Mount Victoria (Fig. 1). The Blue Mountains region is situated in eastern New South Wales at latitude 33.7°S and longitude 150.3°E. The temperature in the Blue Mountains region is around 7 °C lower than that in coastal Sydney. The average monthly maximum temperature in the study area is around 12 °C and 22 °C in winter (May–August) and summer months (November–February), respectively. The average annual rainfall in the study area is around 1300 mm per year. More details on the BMWSS can be found in Haque et al. (2013b, 2014b, 2015c).

Data on monthly metered residential consumption and number of dwellings were obtained from Sydney Water, the water supply utility, for the period of January 1997–September 2011. From the water consumption data, it was evident that the single residential dwellings (i.e. free standing houses/semi-detached houses) is responsible for about 94% of the residential water consumption while the multiple dwelling sector (i.e. apartment blocks/units) accounts for about 6%.

The list of water demand factors and their brief descriptions are presented in Table 1. Among the eleven factors, five are climatic factors (RF, NRD, MMT, EVP and SE), five are community intervention factors (S_WF, S_DIY, S_WM, S_TR and S_RWT) and the remaining one is the water price factor. These factors were adopted based on their potential influence on water demand. Data on water price and community intervention factors were collected from Sydney Water for the period of January 1997–September 2011. Values for community intervention factors were determined based on the number of dwellings which had installed water efficient appliances and rainwater tanks (i.e. S_WF, S_DIY, S_WM, S_TR and S_RWT). For example, in November 2003, the number of single dwellings with rainwater tanks was 879 and accordingly S_RWT for that month was taken as 879. Meteorological data, such as rainfall, number of rain days,