Environmental Modelling & Software 103 (2018) 52–61

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Assessing the significance of tourism and climate on residential water demand: Panel-data analysis and non-linear modelling of monthly water consumptions

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ARTICLE INFO

Article history:
Received 18 May 2017
Received in revised form
8 January 2018
Accepted 13 January 2018

Keywords:
Water demand modelling
Residential water uses
Tourism
Climate
Correlation analysis
Panel-data

ABSTRACT

The concentration in time and space of tourists and of specific water-demanding touristic activities can add considerable pressure on available water supplies in coastal regions.

The impact of tourism has not been adequately addressed in the water demand literature, especially at sub-annual scale: the present study includes the role of tourism on the monthly water demand in a set of Mediterranean coastal municipalities in a panel data framework.

The influence of both climatic and touristic drivers on the water demand is investigated through a correlation analysis, thus deconstructing the seasonal variability of the consumption, and the development of both linear and non-linear models. The results demonstrate the improvement allowed by non-linear over linear modelling and the value of the information embedded in both climatic (in particular temperature daily maxima and minima and number of rainy days) and touristic determinants as drivers for the water demand at sub-annual scale.

1. Introduction

In Mediterranean regions, inherently affected by water scarcity conditions, the gap between water availability and demand is expected to further increase in the near future due to both climatic and anthropogenic drivers.

In particular, the high degree of urbanization and the concentration of population and activities in many coastal areas is often severely impacting the water availability also for the residential sector, especially in the dry summer season, when the demand is maximum and the water availability is minimum (EEA, 2010), confirming that socio-economic, in addition to climatic, changes will be the most important driver of shifts in future municipal water demand (Parkinson et al, 2016).

Water demand forecasting is the primary requirement for managing and planning of water supply systems. Short-term forecasting over the coming days, weeks or months, allows to optimise operational water management decisions (reservoir storages, emergency measures during water scarcity periods, etc.) and to help estimate revenues from water sales and short-term expenditures (i.e. energy pumping costs). Long-term forecasting allows instead to plan the investments on water supply and distribution systems, such as accessing new water sources, developing new treatment plans or enhancing the distribution networks.

Many water utilities still assume that the demand will evolve simply as a product of per-capita demand and a projection of population, whereas the predictive power of such methods is inadequate under changing conditions. It is therefore now acknowledged that in order to obtain reliable demand forecast, it is important evaluating, understanding, and modeling the factors that influence water use over both short-term and long-term intervals" (AWWA, 2013).

Urban water demand is guided by complex interactions between human and natural system variables at multiple spatial and temporal scales.

In the past, many studies have focused only on economic and other policy variables that can be decided by policy-makers and water utilities, so that their future evolution is known, but there is the need to keep into account also the factors that are not controlled by the water utilities and are characterized by an uncertain evolution.

Climate is certainly one of such factors: a large number of studies (see Section 2.1) have analysed the causal relationships

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https://doi.org/10.1016/j.envsoft.2018.01.011
1364-8152/

between the demand and a number of different climatic variables and have developed urban demand models that include such drivers in the explanatory variables.

These models can successively be used by the water utilities to forecast the future water demand as a function of the predicted evolution of the meteorological variables, consisting in either long-term climate change scenarios or short-term seasonal forecasts.

As far as the impact of climate change and variability is concerned, understanding and modelling the influence of meteorological factors on urban demand is the first step for assessing the long-term pressure on the water supply system due to expected climatic scenarios. This approach is followed, for example, by Goodchild (2003); Babel et al., 2014; Haque et al., 2015b who first set up demand models driven by meteorological factors and then provide in input the same drivers obtained from climate change scenarios.

Analogously, for the purpose of operational management decisions, identifying the role of the whether variables in a monthly water demand model would immediately allow the inclusion of inputs deriving from weekly to seasonal meteorological forecasts (even if such numerical weather predictions are still affected by very large uncertainties over lead-times longer than a few days), thus resulting in improved short-term water demand forecasts: Tian et al. (2016) have recently proposed, for the first time, the use of weekly weather forecasts in input to a water demand model.

A full understanding of which variables are significant is a necessary prerequisite for improving the demand models. In coastal regions (but not only there), a very important factor in addition to climatic determinants is the influence of tourism on water use: such factor has not been adequately addressed in the literature so far and is generally neglected in water demand analyses.

Provided that an estimate on the expected touristic fluxes is available (for example through one of the many tourism demand forecasting models available for the tourism industry) also such variables might be directly used in input to the proposed model, to obtain a more accurate water demand forecast.

The present work, for the first time, introduces the use of the time-series of the monthly tourists' overnight stays as an additional explanatory variable to model monthly urban water demand, in order to provide knowledge on the combined impacts of climatic and touristic factors.

The case study refers to a set of cities in Italy, where sub-annual analyses are so far not reported in the literature, and in particular to the most economically developed coastal region in the country.

In such and similar contexts, the proposed water demand models may be successively used by water utilities to derive more accurate water demand forecasts based on the available climatic and touristic evolution scenarios.

2. Factors driving urban water demand

There is abundant theoretical and empirical literature on urban water demand modelling, at different spatial (household to municipal) and temporal (hourly to multi-yearly) scale: the readers may refer to House-Peters and Chang (2011) or Donkor et al. (2014) for comprehensive reviews of concepts and models.

A variety of determinants (exogenous inputs) may have an impact on water demand and have been considered in the literature, in addition to information on previous consumptions (endogenous input): structural and geographical variables, such as household or building/landscape features, and socio-economic variables, such as population characteristics, water price and consumer income, water use behaviour.

The majority of the above variables are not subject to seasonal fluctuations (or, even when not negligible, such sub-annual fluctuation is generally not recorded) and are considered to change at annual scale, allowing to analyse inter-annual variability only.

For modelling the overall behaviour of the demand over time, it is, instead, necessary to take into account not only factors that change from year to year (interannual), but also the factors that have a seasonal (or monthly) variation, in order to capture also the infra-annual expected variations in the demand, such as climatic variables and tourism.

2.1. Influence on water demand of climatic drivers

When analysing a sub-annual behaviour and the objective is to assess the reasons for seasonal changes in the demand, the main influence is generally attributed to climatic variables (rainfall, temperature, evapotranspiration), as demonstrated by a very large number of studies analysing and modelling the role of such variables (see, among the many others, Zhou et al., 2000; Gutzler and Nims, 2005; Gato et al., 2007; Wong et al., 2010; Bakker et al., 2013, and, in particular, Chang et al., 2014 and Haque et al., 2015a also present excellent reviews on the use of climatic determinants).

It is in fact expected that weather conditions do influence the intensity and/or the frequency of important water-demanding activities, both indoor, such as showers and other personal hygiene practises, and outdoor, such as garden/plants irrigation but also car and street washing, or swimming pool use.

Temperature and rainfall variables are the most frequently adopted in water demand modelling, also due to the good availability of such measures/estimates. On the other hand, derived variables, such as evapotranspiration estimates, are relevant for only a part of the above mentioned water-consuming activities (i.e. irrigation activities for evapotranspiration factors).

Temperature and rainfall can be adopted in several forms in the water demand modelling (see Haque et al., 2015a): temperature indexes may be based on mean values or on daily maxima and minima, or on the numberof days exceeding a certain threshold. In the same way, rainfall indexes may include total rainfall depth, the number of rainy days or rain events or the duration between the events.

Identifying the temperature and rainfall indexes more suitable for each specific water demand modelling analysis is therefore still an open problem and, even more important, the outcomes of previous studies on the impact of climatic variables are not always in agreement.

Some studies found that the demand is both positively related to the temperature and negatively related to the rainfall (Maidment and Miaou, 1986; Lyman, 1992; Corral et al., 1998; Olmstead et al., 2007; Ruijs et al., 2007).

Other authors (Nauges and Thomas, 2000; Martins and Fortunato, 2005; Haque et al., 2015a; 2015b) showed that high temperatures increase the demand, but did not find a significant effect of the precipitation.

On the contrary, in the case studies analysed by Zhou et al. (2000), Klein et al. (2007) and Schleic and Hillenbrand (2009) precipitation was more important than temperature.

In particular, it seems that the touristic vocation of the study area may play an important role in assessing the importance of the meteorological variables and in understanding their influence: in fact, in not touristic cities, rainfall and temperature may do not exert a significant weight on the water demand (see Martinez-Espiñeira, 2002a,b).

Or actually, in some cases it was even found a “wrong” sign, that is a negative correlation, between temperature and consumption: this happened when considering areas that are not highly touristic (or at least not during the summer season), like the city of Zaragoza