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Assessing the applicability of the Bartlett-Lewis model in simulating residential water demands

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Abstract

This paper presents the set-up and application of the Bartlett-Lewis clustering mechanism to simulate residential water demand at fine, i.e. sub-hourly, time scales. Two different variants of the model, i.e., the original and the random-parameter model, are examined. The models are assessed in terms of preserving the main statistical characteristics and temporal properties of demand series at a range of fine time scales, i.e., from 1-min up to 15-min. The comparison against the typical Poisson rectangular pulse model showed that clustering mechanism enables a better reproduction of demand characteristics at levels of aggregation other than those used in the fitting procedure.

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1. Introduction

The high temporal and spatial variability of water demand poses extra difficulties in the efficient planning and management of water distribution and sewerage systems [1,2]. To cope with this uncertainty stochastic simulation techniques are usually employed to generate a large number of possible realizations of demand events across a wide

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range of time and spatial scales, from minute to days and from the household to the DMA. Recently, the rising deployment of smart metering technologies, by providing high resolution data from households, enables the implementation of a "bottom-up" approach [3] that allow the demand series at higher temporal and spatial scales to be obtained by aggregating the demands from individual users. In this context, a special focus is given to the development of models that reproduce the statistical properties and the stochastic structure of water demand at individual user level. In this paper our focus is on fine time scales (i.e., sub-hourly) which are the temporal resolution of interest in water quality modelling of the peripheral parts of a network. In these parts the qualitative characteristics of water and the flows in the pipes are directly affected by the high variability of residential water demand [1,4].

At fine time scales, the stochastic modelling of residential water demand has been studied with the use of the Poisson [5–10] and Poisson-cluster processes [11–13]. The main representative of the first category is the Poisson rectangular pulse (PRP) model [6]. It represents the demand mechanism via rectangular pulses that occur in continuous time according to the Poisson point process. Each rectangular pulse is associated with a random duration and intensity that follow specific probability distributions. In the initial formulation of the model, pulse durations and intensities are assumed mutually independent variables and independent of the arrival process. Recently, a model variant that introduces correlation between the intensity and duration was proposed by Creaco et al. [10].

In the Poisson-cluster processes, the events are formulated via clustered rectangular pulses. In this case, two different Poisson processes are used to specify the time origins of clusters and the origins of pulses within clusters, respectively. Rodriguez-Iturbe et al. [14,15] first studied two alternative types of clustering, the Bartlett-Lewis and Neyman-Scott process, after observing the weakness of simple PRP-type models to reproduce the statistical characteristics of rainfall at multiple time scales. The main difference between the Bartlett-Lewis and Neyman-Scott mechanism lies in the way that pulse origins are distributed within a cluster. Transferring the clustering concept into demand modelling, the assumption of representing the consumption events through sequences of pulses, rather via individual pulses, seems more consistent with the actual demand mechanism, i.e., sequences of different water use activities are performed sequentially or simultaneously in the house [11]. Alvisi et al. [11] first examined the applicability of the original Neyman-Scott rectangular pulse (NSRP) model to simulate the total water demand at different fine time scales (i.e, from 1-min up to 15-min) of a small group of households. The Neyman-Scott model was later used by Alcocer-Yamanaka et al. [13,16]. On the contrary, the Bartlett-Lewis clustering process has never been studied for the residential demand modelling. Furthermore, a direct comparison between the Poisson and the Poisson-cluster models is not available in the literature.

This study presents the set-up and application of the Bartlett-Lewis rectangular pulse model to simulate the water demand of a single-household, as it is recorded via the smart meter. Specifically, two different variants of the model, i.e., the original and the random parameter model, are examined. To fully evaluate the clustering mechanism against individual pulse processes, the Bartlett-Lewis models were compared to the original PRP model with independent pulse intensities and durations. The assessment of the models was conducted in terms of preserving the main statistical characteristics and temporal properties of a demand series from a household in Athens, at a range of fine time scale, varying from 1-min up to 15-min.

2. Model description

2.1. The Poisson rectangular pulse model

The Poisson Rectangular Pulse model was initially proposed to simulate rainfall events [14], while the model used later in the modelling of water demand [6]. In the PRP model, event origins occur according to a Poisson process with rate λ. Each pulse i has a random intensity x_i and a random duration w_i that follow a specific probability distribution. Different probability distributions have been used to describe pulse characteristics depending on what is best fitted to the observed data. Regarding pulse intensity, the two-parameter Weibull distribution was assumed by Garcia et al. [8], while the normal [7], log-normal [17] or exponential [1,12] distributions have been also used. The exponential distribution has been mainly used for pulse duration [1,7,8,12] while log-normal distribution seems also valid [9,17].