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Water demand forecasting by trend and harmonic analysis

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ABSTRACT

Water demand forecasting in water supply systems is one of the basic strategic management tasks of water supplying companies. This is done using specially designed water consumption models which generate data necessary for planning operational activities. A high number of water demand forecasting methods proposed in the literature points to the complexity and significance of the problem for current operation of water supplying companies. However, it must be observed that no universal method applicable to any water supply system has been developed so far. In addition to this, there is no method which could be considered referential relative to other methods. For this reason, it is necessary to continue the research on forecasting methods enabling effective forecasts based on suitably selected sets of input quantities. This paper proposes a solution for water consumption forecasting in a water supply system, wherein hourly water consumption is determined by trend analysis and harmonic analysis. Trend analysis consists in estimating parameters of models for individual phases of a cycle, while harmonic analysis is based on the assumption that a time series consists of sine and cosine waves with different frequencies known as harmonics. In addition, relationships between structural parameters of individuals harmonics and ambient temperature are investigated using the least squares method.

1. Introduction

Water demand forecasting is one of the key tasks of water supplying companies to ensure proper standards of service together with reduced operational costs, including, in particular, that of electric energy required for pumping, usually prevailing in the total economic calculation [1,2]. Water demand forecasting is done using water consumption models specially developed for this purpose. Forecasting data

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obtained with such models are then used to manage, control and modernize the existing water supplying infrastructure, as well as to design new elements of the system [3,4]. Water consumption standards are also used to create computer-simulated models reflecting hydraulic conditions in water-pipe networks. Such simulations are usually performed using time and space averaged values of these standards. Spatial averages are determined by grouping specific consumers and assigning water consumption to water-pipe network nodes, while time averages are calculated as the averages of temporary values of water consumption at nodes. A correct model for forecasting variations in water consumption will additionally facilitate identification and control of leakages in the water supply system by comparing real and simulated water demand [5–7].

Despite numerous solutions for optimizing water supply infrastructure management reported in the literature, there is a continuous search for verified water demand forecasting models as effective tools for the operational management of a water supplying company. For example, in paper by Loska et al. [8] two subsystems are presented, which create an integrated control and management system for water supply network. The development of forecasting models for the above applications is not an easy task due to the complex, deterministic and random nature of water consumption [9]. Water consumption forecasts can refer to different time intervals depending on its aim [10]. As for current and short-term forecasts generated one up to several hours in advance, short-term forecasting is usually used exclusively in algorithms for simulating water distribution system operation and developing an optimal strategy for the management of water delivery processes [11,12]. The output value of the model can refer to both daily and hourly flow if the forecasting of pump control and tankage management is planned. Water consumption models predominantly assume hourly time intervals, although there are studies in which shorter intervals (e.g. 15 min) are used [13], the fundamental input parameters of such water demand forecasting models being historical data regarding water consumption, temperature, precipitation [14–16] and seasonal factor [28] according to which there is a significant difference between water consumption during the summer and the rest of the year. An alternative solution to short-term forecasts are long-term forecasts which are usually applied to plan and design water supply infrastructure, as well as to manage the company's property [15,17].

Given their diversity, water demand forecasting models can be classified according to different criteria, one of them being a division into linear and nonlinear models [18]. Widely used linear models include univariate time series analysis and autoregressive integrated moving average (ARIMA) models [19–22]. These methods are widely used due to their simplicity and practical use in operational activity. The methods for forecasting hourly water consumption time series (ARIMA models and exponential smoothing of time series methods) meet the practical rule of easy availability of output data for forecasting, including predicators. However, they do not omit any external variables and are solely based on chronological sequences of observations from the direct past [23]. Autoregressive integrated moving average (ARIMA) models reflect static and dynamic properties of stationary series and certain classes of non-stationary series interpreted as the result of white noise passing through a discrete, finite-dimensional linear filter. They can be used for current and short-term forecasts of time series regarding water consumption, however the accuracy of their results is often unsatisfactory. Forecast results are usually made more accurate by describing and transforming the raw data by Fourier transform [12].

Widely used nonlinear methods for water demand forecast modelling include: nonlinear regression models, bilinear models, threshold autoregressive models, ANN-based models, fuzzy logic, extended Kalman filter and genetic programming, and model trees [4,14–16,24–26]. Artificial neural networks (ANNs) can be used to analyse many variables simultaneously, hence it is possible to develop a model even if solving the problem is exceptionally complex. The disadvantages of neural networks include difficulty in determining structural parameters, long time of learning, and lack of clear interpretation [1,4,11,14,27].

Among the many new multivariate regression methods, particular attention should be paid to Support Vector Regression (SVR) [29,30]. The algorithm of this method consists in determining a linear function. The nonlinearity of this method results from the fact that observations about a set of learning data are transformed to a new space with a much greater dimension by a non-linear transform. One of the advantages of multivariate regression is the fact that it does not require the user to verify the assumptions concerning the distribution of diagnostic variables. The application of this method enables reduction in forecasting errors regarding observations from the test data set. Moreover, this method is resistant to noise occurrence in the set of learning data. Unfortunately, its operation is automated to a great extent, resembling that of a "black box", and the results can be interpreted only to a small degree. The stages of the learning process and validation required for data tuning are complicated here, too [31,32].

Fontanazza et al. [3] proposed dividing regressive model-based forecasting methods into 5 categories: regression analysis, time series analysis, computational intelligence approach and stochastic models. Time series models can contain long-term, cyclical and short-term ingredients. Artificial intelligence comprises artificial neural network (ANN) models, fuzzy logic, and agent-based models [3]. In recent years, hybrid models based on earlier developed methods have been effectively used, for instance, the support vector regression method based on Fourier time series proposed by Brentan et al. [33]. In turn, Romano and Kapelan [34] proposed a new method for water demand forecasting based on time series analysis and evolutionary artificial neural networks (EANNs). A survey of methods for modelling water consumption in different time intervals was also given by Qi and Chang [35] as well as House-Peters and Chang [9]. The abundance of water demand forecasting methods points to the complexity and significance of the problem. It must be noted that there is no universal method which could be applied to any water supply system. In addition to this, there is no method which could be regarded as referential in relation to other methods. In light of the above, it is necessary to continue research on forecasting methods, a particular challenge for mathematical forecasting models being here long-term forecasts based on correctly selected sets of input data. This stems from the fact