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ORIGINAL ARTICLE

Prediction of municipal water production in touristic Mecca City in Saudi Arabia using neural networks

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Abstract Accurate forecast of municipal water production is critically important for arid and oil rich countries such as Saudi Arabia which depend on costly desalination plants to satisfy the growing water demand. Achieving the desired prediction accuracy is a challenging task since the forecast model should take into consideration a variety of factors such as economic development, climate conditions and population growth. The task is further complicated given that Mecca city is visited regularly by large numbers during specific months in the year due to religious reasons. This study develops a neural network model for forecasting the monthly and annual water demand for Mecca city, Saudi Arabia. The proposed model used historic records of water production and estimated visitors' distribution to calibrate a neural network model for water demand forecast. The explanatory variables included annually-varying variables such as household income, persons per household, and city population, along with monthly-varying variables such as expected number of visitors each month and maximum monthly temperature. The NN prediction outperforms that of a regular econometric model. The latter is adjusted such that it can provide monthly and annual predictions.

1. Introduction

The forecast of future needs for potable water is important for the planning and management of water resources. The projections of urban water use are required in planning future requirements for water supply, distribution and wastewater systems. In this regard, short-term forecasting is useful for operation and management of existing water supply systems within a specific time period, whereas long-term forecasting is important for system planning, design, and asset management (Bougadis et al., 2005; Davis, 2003). The forecast of water demand is particularly important in regions of limited natural water resources. The county of Saudi Arabia, for instance, is an arid country characterized by a scarcity of its water resources. The country has no perennial rivers or lakes, and its renewable water resources total 95 cubic meters per capita, well below the 1000 cubic meters per

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Nomenclature

H	household size	S	scaling factor
I	income, SR	T	maximum monthly temperature, °C
N	city population, also number of data set	u	input variable
NN	neural networks	V	visitors
m	number of hidden layer neurons	w_j, w_{ii}	bias, input weights
MLP	multi layer perceptron	x	arbitrary variable
p	number of input neurons	X	explanatory variable
q, $q_{\rm m}$	water consumption, monthly water consumption, l/day	y	output variable
$q_{\rm i}$	perceptron weights	$\tilde{y}$	measured output
$Q_{\rm y}$, $Q_{\rm m}$	yearly and monthly total water consumption, m^3/day	Greek letters	
$R_{\rm H}$, $R_{\rm I}$, $R_{\rm N}$	annual growth rate for household size, income and population, respectively	α	intercept of the econometric model
		β	model elasticity
		θ	vector of MLP parameters

capita benchmark commonly used to denote water scarcity. In order to satisfy the needs for a growing population, the kingdom is currently relying on desalination plants to satisfy around half of the water demand. Building desalination plants is, however, a costly and time consuming process. It is therefore of importance that policy makers have a reliable estimate of the long term water demand in order to implement the appropriate capital expenditures in the development plans and to avoid any shortage in the domestic water supply. Similarly, short-term (monthly) water demand prediction is equivalently important for municipal authorities to optimize the water production based on rigorous analysis of the effect of number of visitors on the total water consumption.

Water demand forecasting depends on a number of factors (i.e. drivers or explanatory variables) that affect the demand. These include socioeconomic parameters (population, population density, housing density, income, employment, water tariff, etc.), weather data (temperature, precipitation, etc.), conservation measures as well as cultural factors such as consumer preferences and habits. Various methodologies are available in the literature for water demand forecast. The selection of the forecast methodology is driven in part by the data that can be made available through collective efforts. The methodologies for the forecast include end-use forecasting, econometric forecasting and time series forecasting (Davis, 2003; Khatr and Vairavamoorthy, 2009). End use prediction bases the forecast of water demand on the prediction of uses for water, which requires a considerable amount of data and assumptions. The econometric approach is based on statistically estimating historical relationships between the independent explanatory variables and water consumption, assuming that these relationships will persist into the future. Time series approach, on the other hand, forecasts water consumption directly without having to predict other factors on which water consumption depends (Khatr and Vairavamoorthy, 2009; Zhou et al., 2000).

The econometric approach depends largely on variables that change on a yearly basis or at least cannot be estimated on a monthly basis. Therefore, these types of models can be used only for annual water demand forecast. However, for a city like Mecca, it is important to have a model capable of monthly forecast to account for the varying number of visitors from one month to another during one year. Time series models allow utilizing input variables with different time scales. However, the model may not directly account for physical variables. Therefore, the effect of a specific physical variable on the water demand cannot be quantified.

In this paper, a neural network model based on city population, housing density, personal income, maximum monthly temperature and monthly number of visitors will be developed. Neural networks are proven tools for pattern recognition and trend detection. Usually NNs can be used for data regression with high nonlinearity (Pao, 1989). Other applications of artificial NNs include identification and control of dynamic processes (Narendra and Kannan, 1990) and solution of optimization problems (Hopfiled and Tank, 1985). ANN is also used for water demand forecast by Liu et al. (2003). However, their model was used only for annual water demand predictions. Further theoretical background on the field of artificial neural networks can be found elsewhere (Haykin, 1998; Paliwal and Kumar, 2009).

The proposed NN model has the capability for long term (annual) and short term (monthly) water demand prediction for the city of Mecca, the religious capital of Saudi Arabia. Neural network model is chosen because its structure allows using inputs with mixed time scales. Moreover, the model structure permits utilizing physical variables with specific configuration. Thus the sensitivity of the model output, i.e. water demand, to a definite physical variable can be estimated. A modified econometric model that allows for multi rate prediction will also be developed for comparison purposes. This modified model is an ad hoc combination of the monthly-based and yearly-based variables.

2. Water demand and supply in the city

Mecca city, with a population of around 1.4 millions, has an important religious attraction and a focal point for local and international visitors. The number of visitors varies from month to month and may culminate to double the city population in a single month which puts considerable strains on available water resources. The visitors' quantity has a distinct peak at the 9th and 12th of the lunar calendar. These months correspond to well known religious events which occur each lunar year at the same time. The fluctuating number of visitors puts challenges on the municipal authorities to formulate the