AN ARTIFICIAL NEURAL NETWORK MODEL FOR MULTI-STEP-AHEAD PREDICTION OF DAILY GROUNDWATER LEVELS

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1. INTRODUCTION

Groundwater is one of the major sources of supply and its efficient management prevents water shortage-related problems such as water rationing and groundwater overexploitation[1]. In order to develop optimal policies for groundwater operation, it is usually necessary to predict variables such as groundwater levels.

This study aims at presenting an Artificial Neural Network (ANN) model for predicting daily groundwater levels up to three days ahead. The procedure is applied to the groundwater system of Matsuyama City, Japan. Scarcity of water is a periodical problem faced by this city and thus accurate predictions of groundwater levels are essential for an adequate management[2].

2. STUDY SYSTEM

Matsuyama City's water supply system is composed of a multipurpose reservoir and a set of 26 unconfined wells located around Shigenobu River, which is the main river of its hydrographic basin. The groundwater of Shigenobu River together with Ishitegawa Dam reservoir is used for supplying all the water needs of the city. Ishitegawa Dam is also used for irrigation and flood control in the region. The layout and location of the water supply system of Matsuyama City is shown in Figure 1.

3. ANN MODEL

An ANN model trained by the back-propagation algorithm is employed for predicting daily groundwater levels. The methodology is applied to Minamitakai observation well, whose water table is used as basis to operate the groundwater system of Matsuyama.

(1) Architecture and topology

The architecture of the network is formed by the input layer, one hidden layer and the output layer. The input layer is composed of three neurons, which are the previous groundwater level $L(t\text{-}1)$, current groundwater level $L(t)$, and forecasted precipitation $P(t+1)$. The number of neurons in the hidden layer is determined based on a trial-error procedure. The best training results were achieved with four neurons in the hidden layer. The one-day-ahead groundwater level $L(t+1)$ is the single neuron of the output layer. The network topology is constrained to be feed-forward, i.e., the connections are allowed from the input layer to the hidden layer and from the hidden layer to the output layer. The network topology is depicted in Figure 2.

The tan-sigmoid function is chosen as the activation function of the hidden neurons. A linear activation function is used for the output neuron.

(2) Training process

The original data (input and targets) are conveniently scaled before the training in order to improve the efficacy of the ANN. The scaling approach consists of normalizing the inputs and targets so that they will have mean and standard deviation equal to zero and one, respectively[3]. The training is performed by the back-propagation algorithm, which has been successfully applied to water resources systems[4]. In this approach, the Levenberg-Marquardt (LM) algorithm is used for the back-propagation training. A detailed explanation of LM algorithm is provided by Hagan & Menhaj[5]. The training process stops by means of the *Early Stopping Method*[3].

4. ANN-BASED MULTI-STEP-AHEAD PREDICTION PROCEDURE

The predictions of groundwater levels up to three days ahead are done by means of the calibrated ANN model, which provides the prediction for one step ahead. The

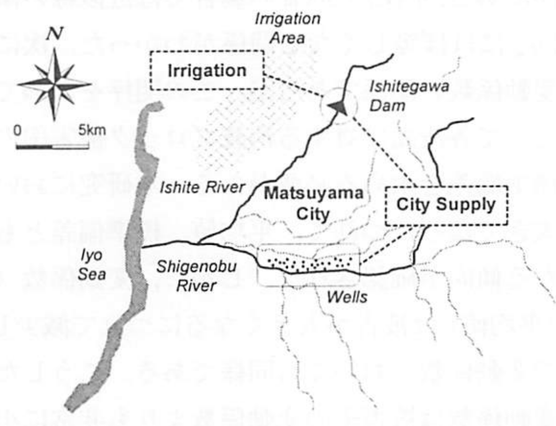

Figure 1 Layout and location of the study system.

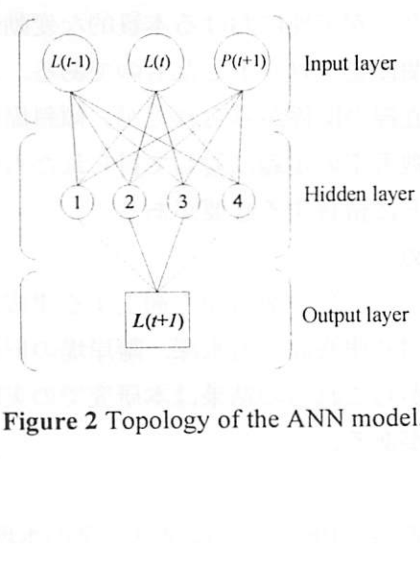

Figure 2 Topology of the ANN model.

procedure consists of applying the ANN model successive times in order to obtain predictions for all three days ahead. In view of the fact that meteorological short-range forecasts are normally accessible, the daily precipitation values up to three days ahead are assumed to be reliable. The basic steps for the multi-step-ahead prediction of groundwater levels are shown in Figure 3.

5. APPLICATION AND RESULTS

The historical data utilized in the procedure contain 13 years of daily data (1991-2003). The ANN model was calibrated using the data from 1991 until 2001 and tests were carried out over the years 2002 and 2003. The model calibration used the *Early Stopping Method* and, therefore, the calibration data set was divided in two subsets: the first was used for the ANN model training (1993-1999), and the second for validation (2000-2001), which specifies when to stop the network training. After the calibration of the ANN model, the sequential generation of groundwater levels was carried out as described in section 4.

The correlation (r) and bias (B) statistical indexes were used as criteria for evaluating the performance of the ANN-based multi-step-ahead prediction procedure. A perfect prediction, which is unlikely to happen, would have $r = 1$ and $B = 0$.

The test results between observed and predicted groundwater levels up to three days ahead are displayed in Figure 4. The respective correlations and biases were calculated and are also presented in Figure 4. The results were shown to be very reliable and presented slight decreases of accuracy for longer daily steps. As a consequence, this procedure may be an important support for a better management of the groundwater system of Matsuyama.

6. CONCLUSIONS

The ANN-based multi-step-ahead prediction procedure was shown to be trustworthy and, therefore, very appropriate for short-term prediction of groundwater levels as long as accurate short-range forecasts of precipitations are available. In conclusion, this model may produce reliable data for the application of techniques to the sustainable management of Matsuyama's water supply system.

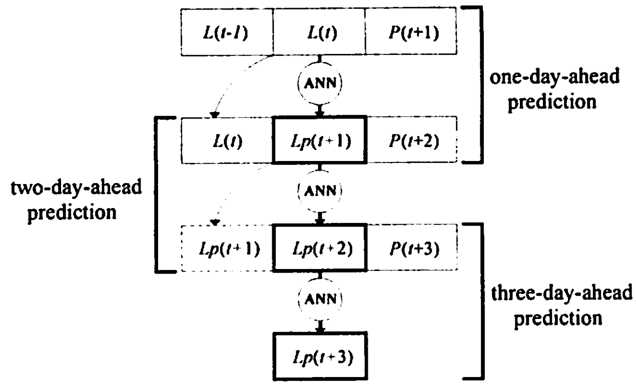

Figure 3 Steps for predicting groundwater levels up to three days ahead.

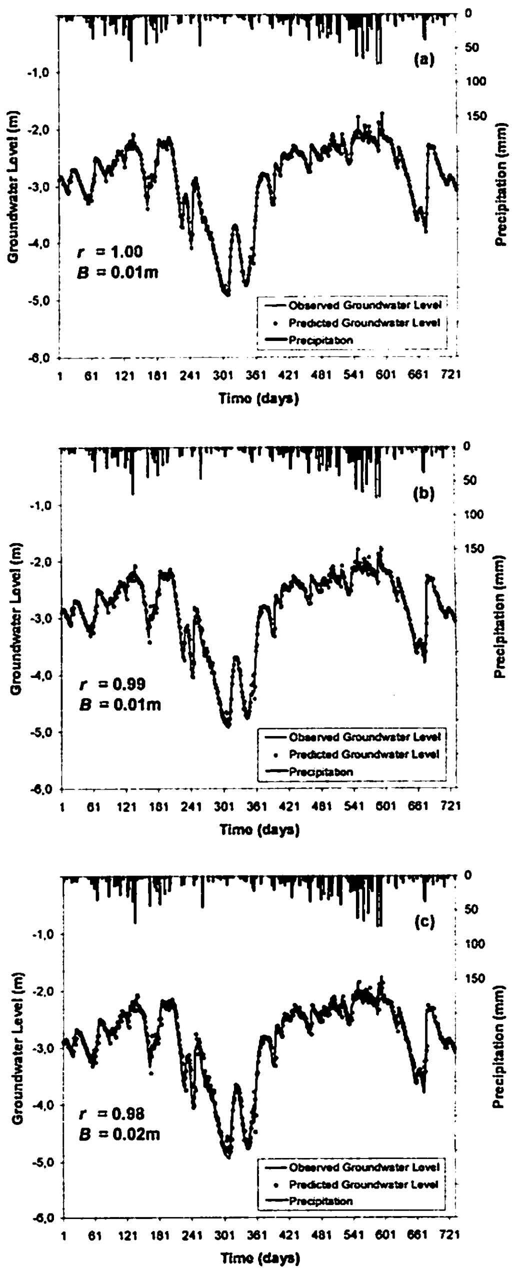

Figure 4 Comparison between observed and predicted groundwater levels for (a) one day ahead, (b) two days ahead and (c) three days ahead.

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