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Predicting groundwater level fluctuations with meteorological effect implications—A comparative study among soft computing techniques

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ABSTRACT

The knowledge of groundwater table fluctuations is important in agricultural lands as well as in the studies related to groundwater utilization and management levels. This paper investigates the abilities of Gene Expression Programming (GEP), Adaptive Neuro-Fuzzy Inference System (ANFIS), Artificial Neural Networks (ANN) and Support Vector Machine (SVM) techniques for groundwater level forecasting in following day up to 7-day prediction intervals. Several input combinations comprising water table level, rainfall and evapotranspiration values from Hongcheon Well station (South Korea), covering a period of eight years (2001–2008) were used to develop and test the applied models. The data from the first six years were used for developing (training) the applied models and the last two years data were reserved for testing. A comparison was also made between the forecasts provided by these models and the Auto-Regressive Moving Average (ARMA) technique. Based on the comparisons, it was found that the GEP models could be employed successfully in forecasting water table level fluctuations up to 7 days beyond data records.

1. Introduction

Groundwater excluding the polar ice caps and glaciers (Raghunath, 2003) is a precious and widely distributed water resource of the earth. From a utilization perspective, agriculture (irrigation) is the greatest user of water accounting for 80% of all consumptions. Bedside agricultural consumptions, groundwater is the significant source of drinking, domestic and industrial water worldwide. In order to make an effective water resources management system, it is necessary to predict groundwater level variations with acceptable accuracies. Groundwater levels are subjected to variations due to differences between the supply and release of groundwater, gaining/loosing streamflow variations, tidal effects, urbanization, earthquake, land subsidence and meteorological phenomena as well as global climatic changes (Todd and Mays, 2005). The effective meteorological phenomena in groundwater level fluctuations include atmospheric pressure (which produces considerable fluctuation in confined aquifers), wind blowing over the top of the water wells (which causes minor fluctuations in groundwater level), frost, precipitation (e.g. rainfall) and evapotranspiration. Meanwhile, rainfall causes minor fluctuations wherever surface/subsurface losses of rainfall or travel time for vertical percolation are sizeable. However, in adequately permeable aquifers, the response of groundwater level to rainfall may be rapid, so, rainfall can be considered as a good indicator for groundwater level fluctuations in such aquifers (Todd and Mays, 2005).

So far, many investigations have been achieved to predict groundwater level fluctuations. Some of them are physically based numerical models used to characterize the groundwater flow in aquifers and some are empirical applying (Box and Jenkins, 1976 and Hipel and Mc Leod, 1994) models to produce time series of water table depths. However, the physically based models need a large quantity of accurate data and since the physical properties of groundwater can never be ascertained with absolute accuracy, unavoidable discrepancies between the model and the real world system reduce simulation accuracy hindering efforts to appropriately manage the groundwater resources (Coppola et al., 2005). Also the empirical time series models have their own limitations, because they are not adequate when the dynamical behavior of the hydrological system changes with time (Bierkens, 1998). In the recent years, the use of Artificial Intelligence (AI) approaches [i.e. Genetic Programming (GP), Artificial Neural Networks (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Support Vector Machine (SVM) techniques] in water resources issues has become viable.

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In hydrologic research field, ANN models have been developed and applied to predict diverse water resources variables for an effective water management. Rizzo and Dougherty (1994) used ANNs to characterize the aquifer properties. Coulibaly et al. (2001) used ANNs for modeling of monthly groundwater level fluctuations. Coppola et al. (2005) applied ANNs for accurate prediction of potentiometric surface elevations. Nayak et al. (2006) investigated the potential of ANN for forecasting groundwater levels in an unconfined aquifer. Szidarovszky et al. (2007) introduced a hybrid ANN-numerical groundwater flow model for improving numerical model predictions by constraining the numerical solution with ANN-predicted values. Coppola et al. (2007) applied a combination of ANN modeling with multi-objective optimization for complicated real-world groundwater management problems. Yoon et al. (2007) used ANNs to forecast solute breakthrough curve in unsaturated porous media. Feng et al. (2008) applied ANNs to investigate the effects of human activities on regional groundwater levels. Also, many researchers have reported that the SVM approach is successfully applied to hydrologic problems and their performance is comparable or superior to ANN (Khalil et al., 2006; Gill et al., 2007; Yoon et al., 2010).

ANFIS technique has been applied in complex dynamic hydrological modeling (Hong and White, 2009) and groundwater depth fluctuations modeling (Kisi and Shiri, 2012).

The application of GP (i.e. Gene Expression Programming, GEP) to modeling time-series of groundwater levels is also limited. Shiri and Kisi (2011) used time series of measured groundwater levels for predicting groundwater level fluctuations.

The main purpose of the present study is to analyze the performance of the GEP, ANFIS, ANN and SVM techniques in daily water table elevation forecasting using the daily water table as well as rainfall data. The predictions of the models were compared with those of observed values using a detailed statistical analysis.

2. Materials and methods

2.1. Data analysis

In the present study, daily groundwater level (h) and rainfall (R) data for Hoengchon Well in Republic of Korea were deployed. Fig. 1 shows the geographical position of the studied site. Daily groundwater level values used in this modeling exercise are the averages of 24 hourly measurements, while corresponding daily precipitation values are the total precipitation measured over the 24-h period. Automatic groundwater level loggers for the National Groundwater Monitoring Network (NGMN) are inspected and calibrated every two months to ensure high quality data. One of the objectives for installation and operation of NGMN is to establish a natural background database of groundwater levels across Korea that is not affected by pumping. Thus, most of NGMN stations have been installed in areas where the affect of groundwater extraction on groundwater level fluctuations is minimal. Therefore, this variable was not considered a relevant model input in this study. In contrast, because precipitation is the primary and most critical variable affecting short-term groundwater level fluctuations within the study area, data collected from a rainfall station located near the Hongcheon station (with distance of 500 m) was used as input to the models.

It is noted that different disciplines require the processing and applying of data at various time intervals, according to the degree of desirability and necessity for different applications. For instance, daily groundwater depth data are important in irrigation scheduling in arid and semi-arid region, where the water is scarce, especially in the period when the water consumptive use of plants are high (Shiri and Kisi, 2011).

The applied data comprise the observations for eight years (from 1st January 2001 to 31st December 2008), from which those of the first six years have been used for training the applied models and the last two years have been reserved for testing. Table 1 summarizes the geographical position of the Hoengchon Well and aquifer characteristics. From the well vertical profile listed in Table 1, it is seen that the rainfall water can easily recharge the groundwater, and the response time is very short. Consequently, rainfall and evapotrasnpiration can be considered as a good indicator for analyzing groundwater level variations. Groundwater level data have been measured as height above the mean sea level, by using a pressure sensor. Using the meteorological data of the studied region during the same period, the potential evapotranspiration (ET) values were calculated by global FAO56-PM model (Allen et al., 1998). Fig. 2 displays the observed time series of groundwater level and rainfall during the study period. From the figure it can be observed that the highest groundwater level (during the study period) occurs in the 17th

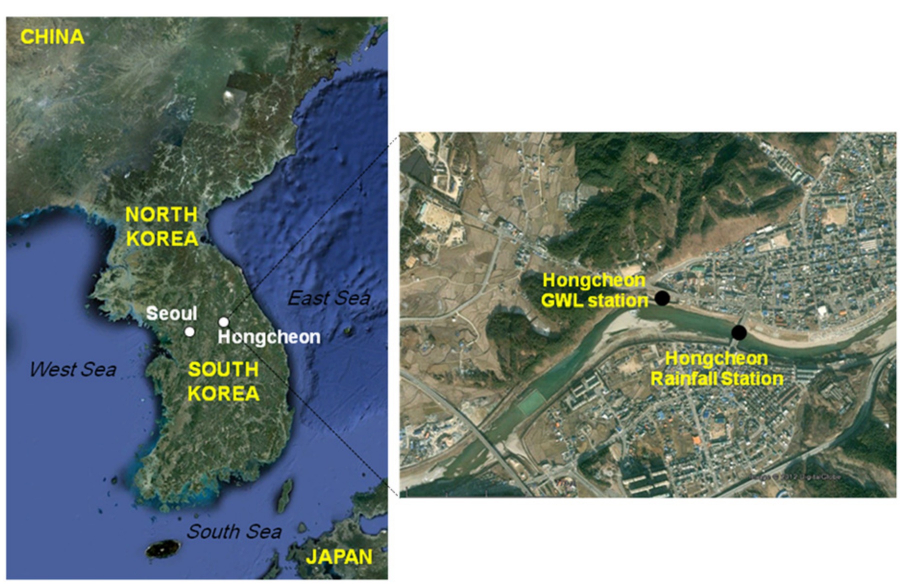

Fig. 1. Map of situation of the studied site (Hongcehon Station- Korea).