A Bayesian network approach for predicting groundwater level (Case study: Qazvin aquifer)

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ABSTRACT

Excessive use of groundwater resources has put the aquifers in critical situations. This study provides a framework for using the Bayesian network for groundwater level estimation and aquifer hydrograph analysis. Five variables, temperature, the groundwater level in the previous month, groundwater withdrawal, aquifer feeding, and rainfall were used as input variables, and the groundwater level in the current month was used as an output variable in the Bayesian network simulations. A 10-year statistical data, 8 years data for model training and 2 years data for model validation, were used. The Bayesian network model was implemented and analyzed in three explicit, clustering and two- and three-month delay states. Explicit simulation results showed that most of the wells have a good correlation between the simulation and observed data. Clustering results were less accurate than explicit ones. In the third case, two and three months delay data was used to simulations. The results showed that the correlation between observed and simulated groundwater levels decreased. At 1, 2 and 3 months delay statues, Root Mean Square Error was 1.87 m, 3.76 m, and 6.42 m, respectively. Therefore, the one-month lag time was chosen for the simulations and aquifer hydrograph was used to evaluate and estimate total aquifer variations. The results indicate the appropriate accuracy of the aquifer parameters estimation.

KEYWORDS

Bayesian network, Clustering, Groundwater level, Qazvin aquifer, Simulation

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1. Introduction

Excessive exploitation of groundwater in conditions where it is not possible to harvest surface and groundwater in combination, has caused irreparable damage to water resources. Therefore, planning to identify the current state of aquifers is important.

In the last decade, the use of the Bayesian network model for forecasting in various fields of water engineering, including integrated water resources management in the catchment [1], groundwater quality [2], drought forecast [3], River flow forecasting [4], and groundwater modeling [5] have been developed. Choubin et al. [6] evaluated the application of regular Bayesian neural networks to model groundwater levels. Their results showed that this model has a very good performance in modeling the groundwater level. Molina et al. [7] proposed a decision support system based on the dynamic Bayesian network (DBNs) to assess the aquifer affected by groundwater use and climate change. The use of a Bayesian network in decision networks due to the nature of input data and their uncertainty could increase the accuracy of work.

2. Methodology

In this study, the groundwater level in the Qazvin aquifer has been simulated by using the Bayesian network intelligent method based on probability reception.

2.1. Study area

The study area of the Qazvin aquifer is located in the northwestern half of the salt lake catchment area. The area of the alluvial aquifer is 3683 square kilometers. The average groundwater level dropdown in the 15-year period (1996-2011) was 1.33 meters per year. There are 56 observation wells in this area that have a 10-year time series of groundwater level data that were used for modeling. Figure 1 shows the location of these observation wells in the Qazvin aquifer.

2.2. Model validation

The model was validated using four statistical methods including R square, Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Predictive accuracy index (P).

2.3. Identifying the input parameters to the Bayesian network and how to model

Temperature, rainfall, aquifer feeding, groundwater abstraction, and water level in the previous month were identified as sensitive parameters for the model and used to predict the water level in the current month. The structure of the Bayesian network using the HUGIN model was compiled and modeled as Figure 2.

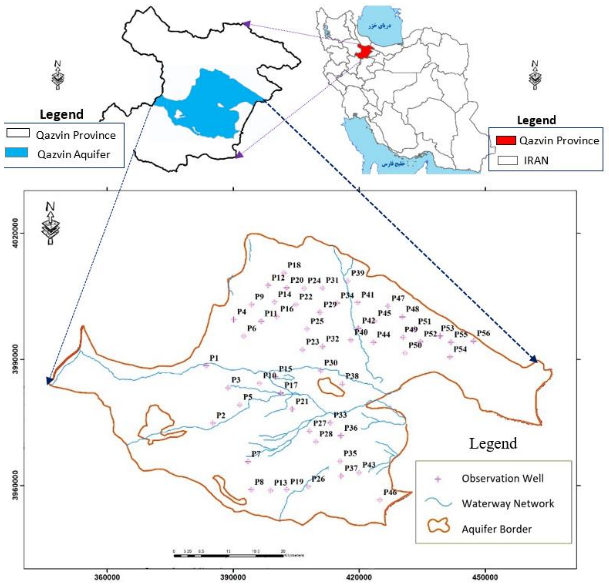

Figure 1. Location of observation wells in Qazvin aquifer

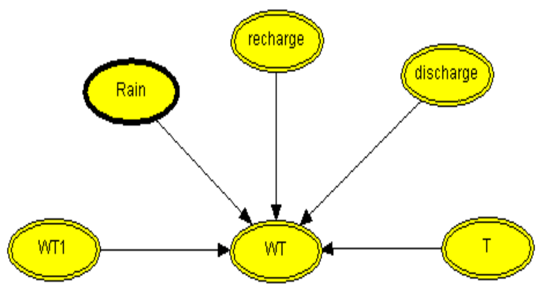

Figure 2. Modeling parameters using Bayesian network

3. Results and Discussion

3.1. Simulation of groundwater level in the explicit state

If the data from the previous month in the aquifer were used to estimate its groundwater level in the simulation model, the results showed that there is a good agreement between the observed and simulated groundwater level in most observation wells. In this case, 39 observation wells have a correlation coefficient above 90%, which indicates the appropriate accuracy of the Bayesian network for simulation in the monthly time step with a delay of one month before.

3.2. Groundwater surface simulation in clustering mode

Results of the clustering model showed that most observation wells have less very low accuracy in simulation. Therefore, the clustering method is inaccurate compared to the explicit mode. In general, the results indicate that the clustering model cannot enter data for simulation. It is worth mentioning that Kardan Moghaddam and Roozbahani [8] and Ebrahimi et al. [9] also expressed the accuracy of the clustering method lower than the explicit method in simulating the groundwater level using the Bayesian network.

3.3. Simulation of groundwater level in explicit state with time delay

Groundwater level simulation was performed in Qazvin aquifer using Bayesian network with 2 and 3 months ago data. For example, the observed and predicted groundwater levels for an observation well were shown in Figure 3. As can be seen, the one-month delay was more accurate than the other two modes and provided good results.

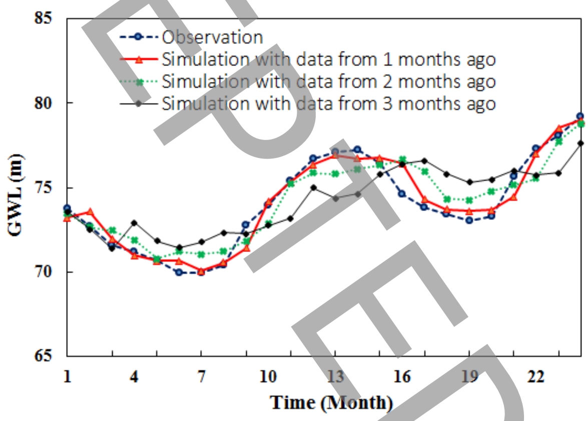

Figure 3. Comparison of observational and simulated groundwater levels with Bayesian network in 2-year statistical period in observation well 9

4. Conclusions

In this study, the Bayesian network model was evaluated in three modes of using explicit, clustering, and explicit approaches with time delays of one, two, and three months to predict groundwater level in the Qazvin aquifer. Five parameters of precipitation, temperature, aquifer recharge, aquifer discharge, and groundwater level in the previous month were defined as input variables and groundwater level in the coming month as output variables. In the case of explicit mode, the results showed that the correlation coefficient between the observed and simulated groundwater level was 0.82 and the RMSE was estimated to be 1.87 m. In this case, the Bayesian network has the appropriate accuracy in simulation in the monthly time step with a delay of one month before. The simulation accuracy in the clustering mode was less than the explicit mode. The general analysis of the results showed that with increasing the time delay, the correlation coefficient between the observed and simulated results decreases. So that the average correlation coefficient in the time delay of one month is equal to 0.82, in the delay of two months is 0.73 and in the delay of three months is 0.64. Also, the RMSE is 1.87 m, 3.76 m, and 6.42 m in one, Two, and three-month delay, respectively. Therefore, the longer time of data interval for prediction has the lower accuracy of the simulation results. In general, groundwater level prediction has better results in the Qazvin aquifer by using a delay time step (one month) in the Bayesian network model.

5. References

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