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Cause Analysis and Prediction of the Groundwater Level in Jinghuiqu Irrigation District

Wangxiong Tao, Jie Zhang, Jianying Wang

College of Environmental Science and Engineering, Chang'an University, Xi'an, China
Email: 741821194@qq.com, 1518163721@qq.com, 460887996@qq.com

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Abstract

Groundwater environment evolution can comprehensively reflect groundwater dynamics. Based on the relationship between the groundwater system and the external environment in Jinghuiqu irrigation district, adopting the Principal Component Analysis method, variation characteristics of environmental factors including climate and human activity and their impact on groundwater were systematically analyzed. The results show that groundwater level in Jinghuiqu irrigation district has been significantly dropped in nearly 34 years; the reduction of surface water irrigation use, which reduced the amounts of groundwater recharge and destroyed the water balance, is considered as the most direct cause for falling of regional groundwater level. Besides, reduction in precipitation, increase of evaporation also accelerated the declining of the groundwater level at some extent. Finally, a predicting method of groundwater depth based on BP neural network is developed. The experimental results show that the predicting model can reasonablely predict the groundwater level in Jinghuiqu irrigation district with a high precision.

Keywords

Jinghuiqu Irrigation District, Groundwater Level, Cause, Prediction, BP Neural Network

1. Introduction

As a result of the complex water-related activity, groundwater system in irrigation district is vulnerable to the external environment. In recent years, with the influence of climate change and human activity, groundwater cycle condition in the irrigation district has been changed greatly [1] [2]. The imbalance of groundwater intensified. Groundwater level of large areas are declining, the area of dropdown hopper was expanding, and the resulting series of environmental and geological problems such as regional land subsidence and ground fissures, which has posed a serious threat to the agricultural production and ecological safety in the irrigation district [3] [4]. Therefore, it is very urgent to study the response of groundwater dynamic to environmental changes in irrigation district.

Jinghuiqu irrigation district, located in Shaanxi Province, is an important grain and cotton production base in

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Guanzhong area. The weather is continental semi-arid with the average annual precipitation of about 538.9 mm and the average annual potential evaporation is 1212 mm [5]. In recent years, groundwater in the irrigation was over-explicated year by year to solve the conflict of water supply, which has caused a continual decline of the groundwater level. The research systematically analyzed the impact of climate change and hanuman activities on groundwater level dynamics and it responses, which is aimed to relieve the groundwater level fall timely and realize sustainable exploitation of water resource in the irrigation district.

2. Driving Forces Analysis and Response of Groundwater Depth

2.1. Climatic Factors and Its Quantitative Analysis

As one of the main recharge sources in irrigation district, the change of precipitation have a significant impact on groundwater dynamics. From 1953 to 2010, the annual precipitation in Jinghuiqu irrigation district appeared a significantly falling trend, while evaporation is an unnotable increasing trend (**Figure 1(a)**). In the 1950s, the average annual precipitation and evaporation in the irrigation district were 551.8 mm and 1277.4 mm, however, after 1990s, the average annual precipitation has turned into 457.7 mm, which has been reduced by 17.1% compared with the 1950s, while the evaporation is 1297.3 mm with an increase of 1.6%. Taking R/S method to predict the future trend of the precipitation and evaporation [6], the result show that both of the Hurst coefficient H > 0.5, which indicates precipitation in Jinghuiqu irrigation district will continue to decrease and evaporation will continue to increase in a future period.

2.2. Anthropogenic Factors and Its Quantitative Analysis

Mining or artificial groundwater recharge can change groundwater dynamics. With the increasing size and extent of human exploitation in groundwater, the impact of anthropogenic factors on the region's groundwater supply and drainage conditions becomes more and more prominent. As a typical large-scale irrigation district, farming activities in Jinghuiqu are very fierce, as well as the agricultural water demands is very large, which accounts for 90% of the total water consumption. Water supply source in Jinghuiqu irrigation district mainly

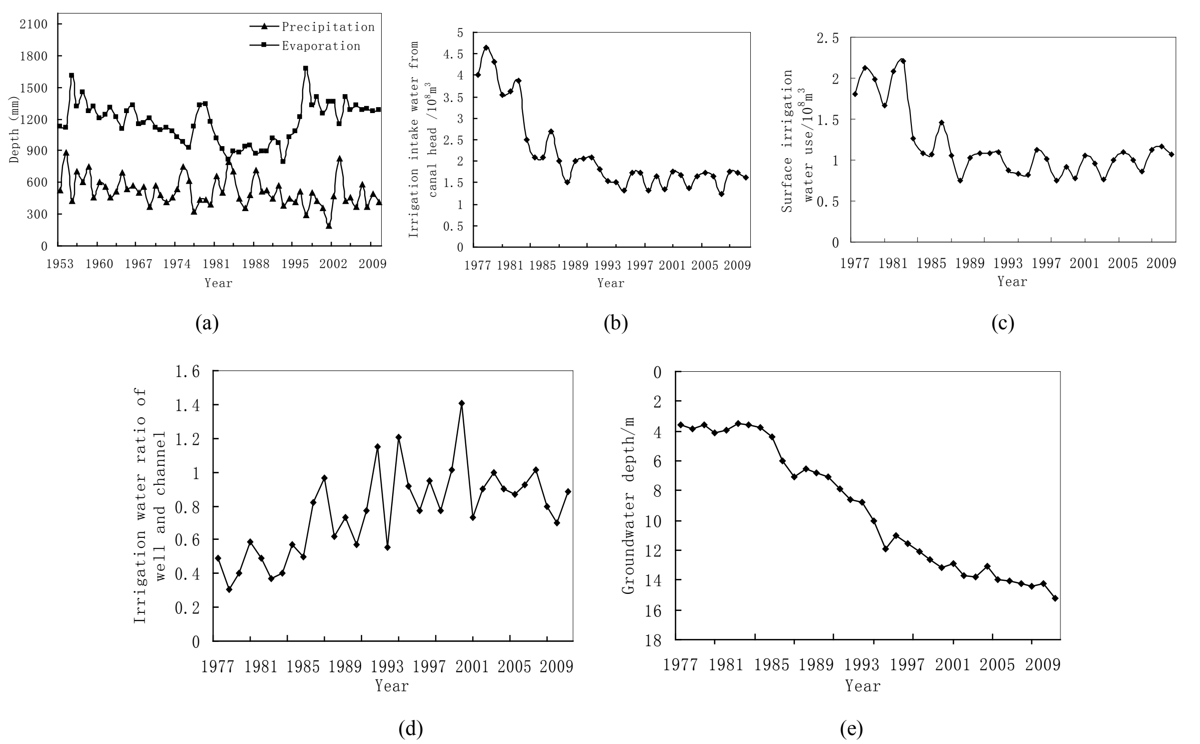

Figure 1. (a) Interannual variations of climatic factors; (b) Intake water from canal head; (c) Surface irrigation water use; (d) Irrigation water ratio of well and channel; (e) Groundwater depth.

consist of the Jinghe river diversion and groundwater exploitation, Thus it can be seen that the proportion of the two parts water supply source plays an important role on the dynamic characteristics of groundwater in the irrigation area.

From 1977 to 2010, the irrigation intake water from canal head and the surface irrigation water use in the irrigation district both showed a falling trend (**Figure 1(b)** and **Figure 1(c)**). Before 1980s, the irrigation intake water from canal head can be more than $4 \times 108\ m^3$, but in the 1990s was only about $1.59 \times 108\ m^3$, which has been reduced by 62.5%; The second is surface water irrigation quantity, approximately from $1.82 \times 108\ m^3$ (1977) to $1.01 \times 108\ m^3$ (2010). As we know, infiltration of surface irrigation water is a major recharge source of the groundwater; therefore, we can infer that a significant reduction of the irrigation intake water, which has been leading to a substantial reduction in groundwater recharge, is a major cause of the severe decline in groundwater level in Jinghuiqu irrigation district in recent decades.

Groundwater pumping is the most direct way of groundwater discharge in irrigation district. At the same time, part of the extracted water in turn recharged the local groundwater by irrigation activities. With the increase of the irrigation water ratio of well and channel (**Figure 1(d)**), the way of surface water irrigation in the 1970s has gradually transformed into the current groundwater irrigation, which means that in the case of the extraction of groundwater has not changed dramatically, the groundwater discharge is relatively increased. Therefore, it can be inferred: It is the combined effects of the increasing groundwater pumping and decreasing irrigation recharge that destroyed the water balance and caused the groundwater level continuing to decline.

2.3. Response of Groundwater Depth

The above analysis shows that, in recent decades, the external environment of the groundwater system in Jinghuiqu irrigation district have undergone a significant change, comprehensive effects of climate change and human activity has resulted in the decline of groundwater level in the irrigation area. The decreased precipitation and increased evaporation, also the reduced amounts of groundwater recharge and the increased amounts of excretion all led to groundwater level dropping gradually, which dropped from 395.4 m to 383.6 m in nearly 34 years (**Figure 1(e)**). In Luqiao and Zhangbu district, two large dropdown hoppers have formed. Meanwhile, destroyed by hanging space, off pump and collapse, 90 percent of the wells built in the 1970s have been scrapped.

2.4. The Principal Component Analysis

Table 1 lists the correlation coefficient between each factor and the groundwater depth, where S1-S7 is the groundwater depth, precipitation, evaporation, accumulative total groundwater exploitation, irrigation intake water from canal head, surface water irrigation quantity and irrigation water ratio of well and channel, respectively. As can be seen from the table, the accumulative total groundwater exploitation has a most closely related degree with the groundwater depth (**Table 1**). The exploitation of groundwater, as a dual identity of recharge and drainage of groundwater, plays the most prominent role on the groundwater level dynamics in Jinghuiqu irrigation district. Besides, the amount of surface water irrigation, as well as the proportion of groundwater and surface water supply, also closely linked with the groundwater water depth. Compared to human factors, the impact of precipitation and evaporation is relatively weak.

Table 1. Correlation matrix between each factor and the groundwater depth.

	S1	S2	S3	S4	S5	S6	S7
S1	1.000						
S2	−0.540	1.000					
S3	0.599	−0.463	1.000				
S4	0.978	−0.163	0.510	1.000			
S5	−0.753	−0.054	−0.090	−0.780	1.000		
S6	−0.859	−0.060	−0.257	−0.664	0.963	1.000	
S7	−0.745	0.156	−0.267	−0.720	0.822	0.780	1.000

3. Prediction of Groundwater Depth

3.1. BP Neural Network

BP (Back Propagation) neural network is proposed by a team headed by Rumelhart and McCelland, which has the powerful ability to deal with non-linear interpolation to obtain the mathematical mapping reflecting the internal law of the experimental data [7] [8]. The prediction model contains three parts: input layer, hidden layer and output layer, a classical 3-layer BP net as **Figure 2**.

In the **Figure 2**, X_n is the input vector of n components, H_q is the hidden vector of q components, and Y_m is the output vector of m components (**Figure 2**). As the BP algorithm is very slow when calculating the derivatives of the weights and bias, the conjugate gradient back-propagation method was used to accelerate the computing efficiency. The main idea is to adjust the weights of the network to make total error minimum. In the forward process, the input signals are processed from the input layer to the output layer and the states of the layer's nodes can only influence the states of the next layer's nodes. At the output layer, the value of the output is compared with the anticipant value. If there is any error, the error will be returned along the quondam way, and the weight values of the nodes between layers are modified to reduce the error. So the error will be controlled in the range given in advance.

3.2. Empirical Results of BP Neural Network

Based on the above analysis, groundwater level is affected by many factors. We select the annual precipitation, evaporation, groundwater exploitation, irrigation intake water from canal head, surface water irrigation quantity and irrigation water ratio of well and channel as the input vector, the groundwater level as the output vector. There were 43 samples data from 1977 to 2010. The samples data were divided into two parts: the first 33 samples data for training, the remaining 10 for predicting.

After data processing, a typical three-layered BP network is established. The final structure of BP network model is: 6-15-1, which means 6 input layer nodes, 15 hidden layer nodes and 1 output layer node. The non-linear S function tansig is used in the hidden layer as the neuron transfer function and the purelin function as the output layer neuron prestige linear function. The specific training parameter: the training error is 0.001; the extensive training epoch is 8000; every 500 epochs demonstrates one time. In this model, when the number of hidden layer unit is 15, training results are very good.

Training and prediction results of model are shown in **Table 2**. The average absolute value of relative error of forecasting is 0.67%, which indicates that training and prediction values are good agreement with the actual value. Therefore, it can be concluded that the BP neural network model can reasonably predict the groundwater level in Jinghuiqu irrigation district.

4. Conclusions

Through the analysis in the article, some important conclusions could be summarized:

1) External environment of the groundwater system in Jinghuiqu irrigation district have undergone a significant change in recent years, which resulted in a continual drop of groundwater level from 395.4 m to 383.6 m in

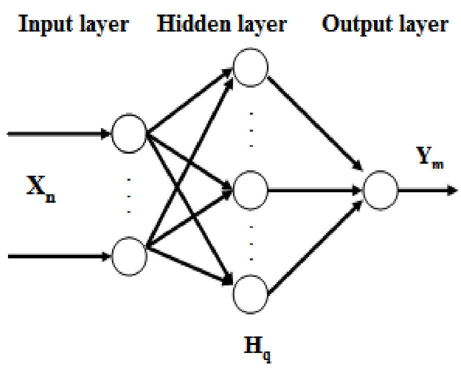

Figure 2. BP neural network architecture.

Table 2. Analysis of training results and predicting results

Year	Observation (m)	Prediction (m)	Absolute error/m	Relative error/%
2001	12.94	12.92805	−0.01195	0.09
2002	13.71	13.66407	−0.04593	0. 34
2003	13.78	13.76993	−0.01007	0. 07
2004	13.09	12.99656	−0.09344	0.07
2005	13.99	14.10596	0.115963	0. 83
2006	14.02	13.98873	−0.03127	0. 22
2007	14.21	14.20163	−0.00837	0. 06
2008	14.41	14.58063	0.170628	1.18
2009	14.28	14.32972	0.049723	0. 35
2010	15.23	15.02816	−0.20184	1.33

recent 34 years; the reduction of surface water irrigation use lessened the amounts of groundwater recharge and destroyed the water balance, which is the most direct reason for the decling of regional groundwater level. Besides, reduction in precipitation and increase of evaporation also accelerate the declining of groundwater level at some extent;

2) BP neural network model was developed to predict groundwater level. The maximum relative error of the predicting results is 1.33% and the minimum is only 0.06% examined by the observed data, which suggests that the model is efficient for predicting the groundwater level in Jinghuiqu irrigation district.

3) At the present stage, diverting more surface water for irrigation to increase the groundwater recharge in Jinghuiqu irrigation district is the most efficient way to relieve the declining of groundwater level.

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