

Research Article

Analysis and Prediction of Annual Runoff for Fen River Basin

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Abstract: The runoff characteristics of Fen river basin was analyzed first. According to the runoff data of 1960-2000, autocorrelation analysis method was used to determine model input variables and then radial basis function artificial neural network was used to recognize the relationship between previous annual runoff and later annual runoff. The developed prediction model was used to predict the annual runoff of 2001 to 2015 of Fen river basin. The result shows that: the predicted annual runoff was similar to the observed annual runoff, which means high prediction accuracy; the developed radial basis function artificial neural network model can be used for annual runoff prediction of Fen river basin. The research results are of great importance for water resource planning and management.

Keywords: Annual runoff prediction, fen river basin, radial basis function artificial neural network

INTRODUCTION

The runoff forming process is the fundamental part of the water cycle and the runoff is the basic element of water balance. Based on the objective laws of hydrology, runoff prediction is the task to predict the future flows and provide the foundation of the water resource scientific dispatching.

Mid to long term runoff prediction is non-engineering measures which can make people take early measures the overall arrangement when dealing with flood and drought control, water storage and water abandon, as well as water contradiction between different departments. Mid to long-term runoff prediction research is still at the exploratory stage at present. Grey system theory (Xi *et al.*, 2006) fuzzy algorithm (Chen *et al.*, 2007) and neural network (Lu *et al.*, 2012) are commonly used method for runoff prediction; different methods have different advantages, disadvantages and applicable conditions. For example, grey system theory is useful to the system with poor information, however, they are un-useful to the system with some internal information known and part information is unknown. Fuzzy algorithm is suitable for the description of widespread uncertainty and has powerful nonlinear mapping ability. Back Propagation Artificial Neural Network (BPANN) has strong robustness and memory ability, but has slow convergence rate and it is easy to fall into local convergence. Radial Basis Function Artificial Neural Network (RBFANN) could accomplish the complicated non-linear mapping.

It also achieves faster convergence and can avoid becoming trapped in a local optimum compared with BPANN. There are has been no research use radial basis function artificial neural network for mid to long term runoff prediction.

As an extension of the previous researches, radial basis function artificial neural network was used for recognizing the relationship between previous annual runoff data and later annual runoff data at Fen river area, China. The developed model was then used for predicting the annual runoff of this area.

INTRODUCTION OF FEN RIVER BASIN

Fen River is the second largest tributary of Yellow river. Fen River has the longest process and largest basin area in Shanxi province, which is known as the people's mother river of Shanxi province (Li, 2012; Li and Zhao, 2011) The Fen River originates from Leimingsi spring of Wuning town, Xinzhou city in northern part of Shanxi province.

From north to south Fen River flow through Xinzhou, Taiyuan, Jinzhong, Lvliang, Linfen and Yunyu *et al.*, a total of 6 cities, 34 towns, finally flow into Yellow River in Hejin town of Yuncheng city. The main river has the length of 695 km and the area of 39471 km².

Physical geography

Meteorology: The Fen River basin is located in middle latitude semiarid, subhumid climate transition zone, which belongs to the warm temperate continental

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monsoon climate, mainly influenced by the polar continental air mass and subtropical marine air, with four distinct seasons. The annual average temperature of Fen River basin is 6.2-12.8°C, the annual average wind speed is 25 m/sec, average annual humidity is 50-60%, average annual evaporation is 1567-2063 mm and average annual frost-free period is 140-200 days. The summer is hot and winter is cold and the temperature of spring is higher than autumn.

The average annual precipitation of Fen River basin is 434-528 mm, with the large variation in a year. The precipitation is large in winter and summer and is small in spring and autumn. Annual precipitation concentrated in the flood season July to September, with the average precipitation of 298.4 mm, accounting for 62% of average annual precipitation and the heavy rain and rainstorm are concentrated in July and August.

Precipitation has a large inter-annual variation, with maximum value of 794.5 mm and minimum value of 240.6 mm, the value ratio is 3.30. Precipitation distribution trend is: for all the north, south, west and east sides, where it is mountain, it is high and for the middle area, it is low. This precipitation temporal and spatial distribution is the main reason that resulted in drought, flood and soil erosion (Li, 2012; Yuan, 2009).

Hydrology: The elevation of Fen River source is 1670.0 m. and the elevation of Fen river mouth is 368.0 m. The length of Main River is 412.7 km and the bending coefficient of Fen River is 1.68. The river basin can be divided into three parts according to the topography and geomorphology characteristics, which is downstream, middle stream and upstream. Upstream is from Heyuan to the Lancun of Jiancaoping district in city of Taiyuan, middle stream is from the Lancun to the Shitan of Hongdong town and downstream is from Shitan of Hongdong town to entrance of Yellow River. Fen River has more than 100 tributaries and 59 of them have more than 30 km² basin area and Hong River, Dongzhan River, Jian River, Yangxing River, Ciyao River, Xiangyu River, Wuma River, Longfeng River, Lao River, Tuanbo River have basin areas between 500-1000 km² and Lan River, Xiao River, Changyuan River, Wenyu River, Shuangchi River, Honganjian River, Hui River have basin areas larger than 1000 km². The average annual runoff is 2.067 billion m³ and the distribution in a year is uneven, flood season runoff accounted for the proportion of 55-62%. Because most of the precipitation is contributed in flood season, sediment transport amount of flood season is large and soil erosion is very serious.

Topography and geomorphology: The Fen River basin has a general trend of north south high low, east and west sides are high, while intermediate is low. From mountainous area to a basin terrain gradually drops, or a dustpan shape of tilt. The main river is from

north to south through central Shanxi province and tributary water system is developed between two mountain ranges. The mountain formed after Yanshanian orogeny, Himalaya movement fracture is development and geological structure produced and developed on the basis of ancient tectonic movement, thereby form the existing basin topography and geomorphology. The basin geomorphology can be divided into loess hilly and gully region, earth-rocky mountainous area and river terrace area. Overlooking the river basin topography and geomorphology, north-south is long, while east-west is narrow, north - south is about 413 km long, east-west is about 188 km width. Fen River is flow through the syncline fault basin, east and west sides of watershed area is the higher mountainous area, eastern part is Taihang Mountain, while western part is Lvliang Mountain; average height is more than 1500 m (Li, 2012; Yuan, 2009).

Introduction of water resources: The average annual surface water resource quantity of Fen River basin is 2.07 billion m³ and the average annual groundwater resource quantity is 2.41 billion m³ and the surface water and groundwater repeated quantity is about 1.8 billion m³, average annual total water resources is about 3.36 billion m³. There are 3 large-size reservoirs and 13 medium-size reservoirs, with the control basin area of 14736 km², accounting for 38% of the total basin area, the total reservoir capacity is 1.44 billion m³; there are also 50 small-size reservoirs, with the total control area of 15317 km², total reservoirs capacity 1.45 billion m³. There are Leimingsi spring, Lancun spring, Jinsi spring, Hongshan spring, Guozhuang spring, Guangshengsi spring, Longzisi spring and Gudui spring *et al.* in Fen River basin, these karst springs have a average flow rate of 28.7 m³ and the annual runoff is 902 million m³, which is the main component of Fen River runoff (Li, 2012; Yuan, 2009).

RUNOFF CHARACTERISTIC ANALYSIS OF FEN RIVER BASIN

The Fen River basin has a large south to north span, due to the affect of climate, topography and other factors; the runoff distribution is of great difference in this basin. When Shitan hydrology station is used as the limit of upper-middle reach and lower reach, the annual runoff characteristic (1960-2000) can be concluded as in Fig. 1.

The water resource quantity through Fen River to Yellow River is different in different year. From 1960-2000, the largest exit water quantity is 3.45 billion m³, which is exist in 1964; the smallest exit water quantity is 260 million m³, which is exist in 1987; average annual exit water quantity is 1.28 billion m³. The main characteristic of Fen River is uneven annual distribution, most of the runoff is concentrated in the

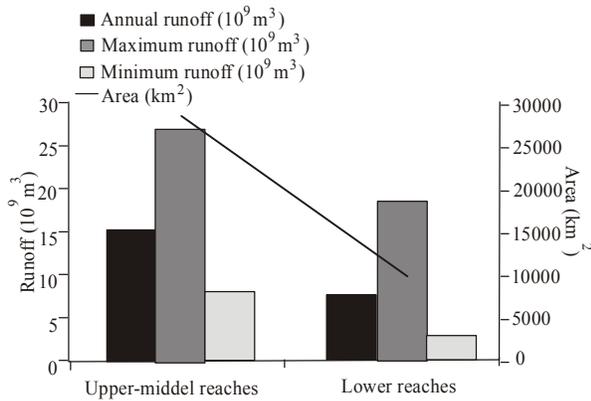


Fig. 1: Runoff characteristic of Fen River basin

flood season (June to September), which account for 55-62% of annual runoff. And the more abundant water year, flood season runoff concentration degree is higher, such as Fen reservoir in abundant water year flood season runoff accounts for 77.5% of annual runoff.

In addition, the runoff is negative growth when the river flows through the city due to the water resources demand of the city. For example, the area of Lancun station is 7705 km², and the runoff of Lancun station is 88.98 million m³; while the area of Erba station is 14030 km² and the runoff of Erba station is 10.23 million m³. The area of Erba station is nearly twice of the Lancun station, while the runoff of Erba station is only a quarter of the runoff of Lancun station. The reason of the runoff decrease is that when Fen River is flowing through Taiyuan city, the industrial and agricultural production and living water resources demand directly reduce the inflow water of downstream hydrologic station. The cutoff phenomenon is very serious, especially in Jinzhong basin area. Although there are many reasons, but it is mainly resulted by human activities.

ANNUAL RUNOFF PREDICTION AT FEN RIVER BASIN

Radial basis function artificial neural network: Introduction of radial basis function artificial neural network: Radial basis function artificial neural network is a class of forward-feed neural network that uses radial basis function as activation functions. It is widely used in classification, function approximation and regularization (Kegl *et al.*, 2000). Radial basis function artificial neural network finds an increasing engineering application because of its fast convergence and high stability (Moradkhani *et al.*, 2004).

Structure of radial basis function artificial neural network: Radial basis function artificial neural network

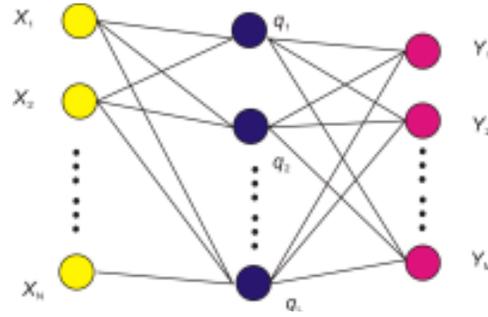


Fig. 2: Structure of radial basis function artificial neural network

is a 3-layered feed forward network consisting of input layer, hidden layer and output layer. While it uses a nonlinear transformation from input layer to hidden layer via a radial basis activation function, the transformation from hidden layer to output layer is linear. The structure of radial basis function artificial neural network is in Fig. 2.

In Fig. 2, X_p ($p = 1, 2, \dots, T$) is a T dimensional input vector. Thus the output of the neurons in the radial basis function artificial neural network hidden layer is assumed as:

$$q_i = \Phi(\|X - c_i\|) \tag{1}$$

where

- c_i = The center associated with the i^{th} neuron in the radial basis function hidden layer
- $i = 1, 2, \dots, L$, where L is the number of hidden units
- $\|X - c_i\|$ = The norm of $X - c_i$ which is usually Euclidean and represents the distance between the input vector X and center c_i
- $\Phi(\cdot)$ = A radial basis function that achieves a unique maximum at point c_i

With increase of $\|X - c_i\|$ $\Phi(\cdot)$ rapidly attenuates to zero. In terms of given input variables, only a small fraction of the variables near the center are activated (Chen *et al.*, 1991).

Outputs of the k^{th} neuron in radial basis function artificial neural network output layer are linear combinations of the hidden layer neuron outputs as:

$$y_k = \sum_{i=1}^L w_{ki} q_i - \theta_k \quad (k = 1, 2, \dots, M) \tag{2}$$

where,

- w_{ki} = The connecting weights from the i^{th} hidden layer neuron to the k^{th} output layer
- θ_k = The threshold value of the k^{th} output layer neuron

Training method of radial basis function artificial neural network: Radial basis function artificial neural network training is performed in two stages:

Table 1: Input and output variables of the runoff prediction model

Input variables	Output variables
$Q_{t-1}, Q_{t-2}, Q_{t-3}, Q_{t-4}, Q_{t-5}, Q_{t-6}$	Q_t

Table 2: Accuracy analysis of the prediction model

RMSE ($10^8 m^3$)	MAE ($10^8 m^3$)
0.55	0.47

- From input layer to hidden layer needs calibrations of the center vectors c_i and the radial bias function width parameter σ_i . Unsupervised algorithms are often used to train center vectors c_i and width parameters. Centre vectors c_i are obtained via random center selection or self-organizing center selection. Radial bias function width parameter σ_i is then calibrated using clustering algorithms such as the k-means algorithm.
- Then from hidden layer to output layer requires calibration of connection weights w_{ik} . Supervised algorithms (pseudo inverse technique or least squares technique) are often used to train connection weights w_{ik} .

Development of annual runoff prediction model in typical station at Fen River basin:

Introduction of Lancun station: Lancun station is located in the Upper-middle reaches of Fen River, in 22.5 km northwest of Taiyuan city (112°26' E, 38°00' S). The control basin area of Lancun station is 7705 km², the average width of the basin is 36.1 km and the average annual runoff is 14.3.cm³/s.

Input variables determination using autocorrelation method: It is necessary to determine the input variables before the prediction model is develop (Bodri and Čermák, 2001; Dahamsheh and Aksoy, 2009). Autocorrelation method determines the input variables by calculating the autocorrelation coefficient between the observed and predicted annual runoff (Monserud and Marshall, 2001; Sarkar *et al.*, 2002).

Indeed, the annual runoff of this year is in fluced mainly by the annual runoff of previous n years. Therefore, an autocorrelation was used to determine the n value according to the runoff data of 1960 to 2000 at Lancun station. The autocorrelation result showed that n is 6, which is to say the annual runoff of this year is in fluced mainly by the annual runoff of previous 6 years. The runoff prediction model consists of 6 input variables and 1 output variables (Table 1).

Runoff prediction model development with radial basis function artificial neural network: The annual runoff data of 1960 to 2000 make up 35 sets input output data. These input output data were divided into 2 parts: training data with previous 30 data and validation data with later 5 data. The annual runoff prediction

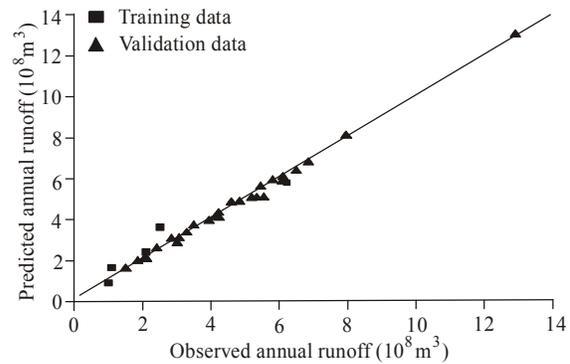


Fig. 3: Observed annual runoff vs. predicted annual runoff with radial basis function artificial neural network model in Fen River basin

model was built with radial basis function artificial neural network method on the platform of MATLAB 7.0. The trained radial basis function artificial neural network prediction model consist 6 input neurons, 30 hidden neurons and 1 output neuron.

Accuracy analysis of annual runoff prediction model at Fen River basin:

Using the developed radial basis function artificial neural network prediction model to predict the annual runoff of the 5 validation data. The prediction accuracy was measured with Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE) (Table 2), which are calculated as follows (Wu *et al.*, 2010; Yang *et al.*, 2009; Wang, 2008; Jia and Yang, 2000; Wang, 2000):

$$RMSE = \sqrt{\frac{1}{n} \sum_{t=1}^n (Q_t - \hat{Q}_t)^2} \tag{3}$$

$$MAE = \frac{1}{n} \sum_{t=1}^n |Q_t - \hat{Q}_t| \tag{4}$$

where,

Q_t = Observed annual runoff

\hat{Q}_t = Predicted annual runoff

The closer the RMSE and MAE is to zero, the higher the accuracy is.

The scatter diagram of the observed annual runoff vs. predicted annual runoff with the developed models are in Fig. 3, which shows how the observed versus the predicted annual runoff scatter around the 1:1 perfect line together, the closer the scatter is to the line, the higher the accuracy is. Figure 4 is the time series of the observed and predicted annual runoff and Fig. 5 is the prediction error. Figure 3 to 5 and Table 2 demonstrated that the developed radial basis function artificial neural network prediction model has a high fitting accuracy, which can be used for annual runoff prediction.

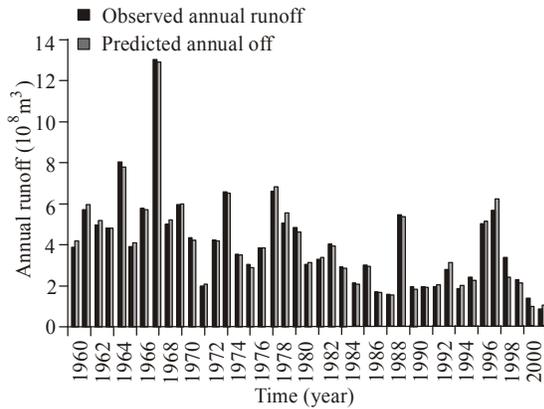


Fig. 4: Time series of observed and predicted annual runoff in Fen River basin

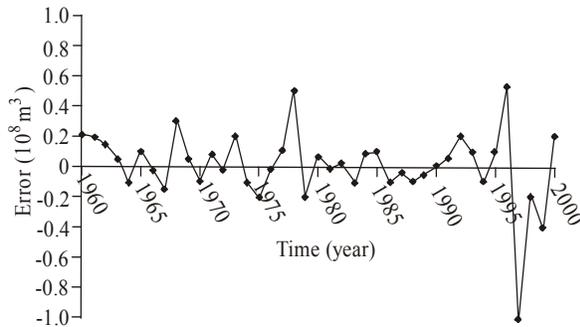


Fig. 5: Prediction error of annual runoff in Fen River basin

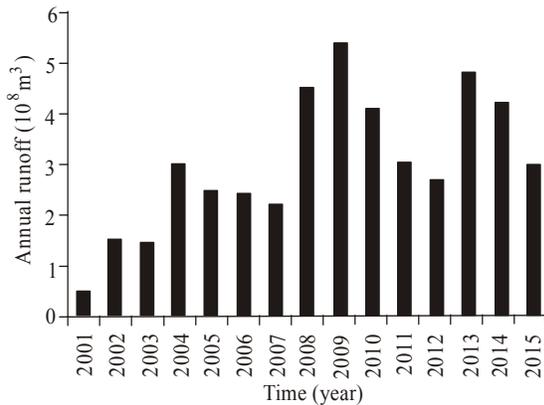


Fig. 6: Annual runoff prediction results at Lancun station

Annual runoff prediction at Lancun station: The developed radial basis function artificial neural network prediction model was used for annual runoff prediction of 2001 to 2015 at Lancun station and the prediction result was in Fig. 6.

CONCLUSION

Autocorrelation analyses were used to determine the input variables of the prediction models first and the

analyses results showed that given annual runoff was influenced mainly by the annual runoff of 6 previous year. Radial basis function artificial neural network was used in this study to build the prediction models. The predicted annual off was compared with the observed annual runoff and the result showed that the developed radial basis function artificial neural network model has high predicted accuracy. Therefore, radial basis function artificial neural network model is used to predict the annual runoff of 2000-2015. These prediction results are of great importance to disaster prevention.

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