Research on Relationship of Total Nitrogen Concentration and Runoff in the Xiangxi River Basin

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Abstract. The response relationship between pollutant and flow rate is very important and is one of the key factors for the reasonable simulation of the model for a basin. The basin land use type, soil types, weather, vegetation distribution, soil and water loss situation are taken as the influence factors to explore its concentration change in migration of pollutants in relation with the response of the flow in Xiangxi River watershed. Emphasis was put on the effects of nitrogen pollutants based on the mass conservation equation combined with the total nitrogen concentration of pollutants. Relationship between total nitrogen pollutants and flow of three types of response relation is preliminary established. Measured data of total nitrogen from 2014 to 2017 are used for verification and error analysis. Results show that the power function is the best relationship, while the logarithm function is the second one, and the exponential function is the third one through trend coincidence, fluctuation range and error analysis. This study is helpful to understand the response relationship between pollutant concentration and discharge in small watershed, so it can also be used for pollutant prediction in small watershed without measured data.

1. Introduction

Water pollution has become one of the most important eco-environmental problems faced by human beings. Many scholars at home and abroad have conducted an increasing number of studies on the migration/loss of non-point source pollutants in basin, and thus developed many semi-distributed hydrological models[1-4]. These semi-distributed hydrological models on the hydrological response unit based on the mathematical physics equation of hydrological model are set up to simulate the runoff process, the water quality simulation principle mainly include first order kinetics equation, Chemical, Runoff and Erosion from Agricultural Management System (CREAMS) model[5], the QuAL-2K one-dimensional steady-state water quality model[6], etc.

A proper interpretation of the principle of pollutant loss is the prerequisite condition for a reasonable simulation. Even in the current sophisticated software, the response relationship between pollutant and flow rate has not been solved successfully, and the coefficient of pollutant loss and the parameters that
characterize watershed characteristics are not yet clear. Liu Yusheng used HSPF model to simulate water quality indexes in Dianchi Lake basin, and found that the accuracy of water quality simulation was lower than that of hydrological simulation[7]. Gao Xiaoxi et al. evaluated the rainfall and water quality indicators through SWAT model, and concluded that the rainfall and water quality indicators were positively correlated, but the functional relationship between the two processes was not clearly explained[8]. Therefore, it is necessary to conduct further analysis on the principle of pollutant migration and loss in a specific basin, so as to simulate the future trend more accurately. Taken Xiangxi River watershed as the research basin, the response relationship between runoff and pollutant is established by the statistical forecast methods combined with principle of mass balance considering digital elevation data, land use and vegetation distribution[9]. Finally, the response relation equation which is more suitable for Xiangxi River is constructed. The study is intended to explore the reasonable responding function type between the flow rate and pollutant concentration firstly, and then to provide scientific reference for the rapid calculation and early warning of pollutants concentration in small watershed.

2. Materials and methods

2.1. Study area and data resource
Xiangxi River basin, located in the west of Hubei Province, is the first-level tributary of the Three Gorges Reservoir of the Yangtze River. The geographical location (figure 1) of the basin is 30.57’N ~ 31.34’N, 110.25’E ~ 111.06’E, the total basin area is 3099 km², with annual runoff 1.956×10⁸ m³, annual average flow 63.5 m³/s, and annual average precipitation 900~1200 mm (mainly from May to September). In Xiangxi River basin, the severe area of soil and water loss exceeds 2700 km², and the degree of erosion is moderate[8]. The main sources of nitrogen non-point source pollution concentration in Xiangxi River basin are land use, animal husbandry and residential pollution sources[10]. The elevation data of this paper adopts STRIMV3.1 90m Digital Elevation Model (DEM) data, which is derived from national geographic data spatial cloud (http://www.gscloud.cn/). The daily rainfall data are from the National Meteorological Data Center (http://data.cma.cn/), and the data of Xiakou station from 2014 to 2017 are adopted. The daily flow discharge flow data during 2014-2017 at Changshaba station were collected from the same monitoring station, which was measured by the Environment Monitoring Center of Hubei Province. Watershed land use type, vegetation coverage selection 2015 Landsat remote sensing data, soil type data were downloaded from Chinese soil science database (http://vdb3.soil.csdb.cn/).

Figure 1 Location of the Xiangxi River basin
2.2. Model construction and validation methods

2.2.1. Soil erosion model calculation. The Universal Soil Loss Equation (USLE) [11] is used to calculate the soil erosion in Xiangxi River watershed, which is taken as the impacted factor on watershed non-point source pollutant characteristics. The empirical expression of USLE is:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]  

(1)

where \( A \) represents the daily average soil loss, \( t/(hm^2\cdot day) \); \( R \) represents the daily rainfall erosivity factor value, \( MJ\cdot mm/(hm^2\cdot day) \), and the daily erosion kinetic energy per unit area; \( K \) represents the value of soil erodibility factor, \( t/(MJ\cdot mm) \); \( L \) represents the slope length factor; \( S \) represents the slope factor; \( C \) represents the preparation coverage factor; \( P \) represents the soil and water conservation measure factor; \( L, S, C \) and \( P \) factors are dimensionless. The parameters calculation refer to Liu, N.[12]. The spatial distribution of \( A \) value is calculated by multiplying the spatial distribution of various factors, and the value of \( A \) at the outlet of the basin is obtained (figure 2).

![Figure 2 factors relevant to soil erosion and soil erosion modulus](image)

2.2.2 Model prediction. According to the relevant studies on the relationships among the rainfall, flow discharge, soil erosion and pollutant discharge characteristics in Xiangxi River basin, the response of pollutant concentration related to flow at the outlet of the basin indicate a nonlinear relationship. Therefore, the power regression, logarithmic regression and exponential regression are selected in the study respectively. The response relationship is predicted by combining the mass conservation equation, one-dimensional pollutant diffusion equation and relative research [5,7], as shown:

\[ c = aQ_{av}^n \]  

(2)

\[ c = b \log_{\eta} Q \]  

(3)

\[ c = \lambda e^{kQ} + \gamma \]  

(4)

Where Eq. (2): \( Q \) is the daily averaged flow (m³/s) in Eq. (3) and Eq. (4); \( c \) is the daily average concentration (g/m³) in Eq. (3) and Eq. (4); \( a \) is the factor of pollution concentration density in the basin. \( n \) reflects the river basin characteristics, \( \eta \) is the base of the logarithm function, and \( b \) is the drainage coefficient of outlet flow and pollutant concentration in the basin. In Eq. (4), \( \lambda \) is the correlation coefficient between pollution concentration and flow in a river basin. \( k \) reflects the river basin properties. \( \gamma \) reflects the drainage basin characteristics, and the parameter factors of \( a, n, \eta, b, \lambda, k \) and \( \gamma \) are all
2.3. The error analysis

Relative error and Nash–Sutcliffe efficiency coefficient (NSE) are adopted as evaluation parameters used for evaluating the model quality, which is generally used for verifying the simulation results of hydrological models.

\[ R^2 = \frac{\sum (c'_o - c'_m)^2}{\sum c'_o} \]  
\[ E_{NS} = 1 - \frac{\sum (c'_o - c'_m)^2}{\sum (c'_o - \bar{c}_o)^2} \]  

Where \( c_o \) refers to the observed value, \( c_m \) refers to the predicted value, \( c' \) refers to a certain value at time, and \( c \) refers to the total average of observed values. The value of \( E_{NS} \) is infinity to 1, which means the better the model quality and the more reliable the model.

3. Results and Discussion

3.1. Total nitrogen model trend verification

![Figure 3: Power simulation of TN](image)

![Figure 4: Logarithm simulation of TN](image)

![Figure 5: Exponential simulation of TN](image)
The process of nitrogen migration and transformation in soil and water is very complicated. Three types of simulated pollutant values are predicted by three models and principles prediction formulas. The first function is power model: \( c = Q^{(0.14+A)} \). In the simulating of total nitrogen concentration, the daily flow is taken as the base, and parameter \( A \), the soil erosion produced by rainfall, is taken as the power index. The predicted total nitrogen concentration is larger than the measured value. When the index \( A \) is added with 0.14, the simulated value and trend are close to the measured data. The results show the power response relation can represent the relationship between pollutant and flow rate. Figure 3 indicates that the trend of the simulated sequence is basically consistent with the measured value, and the fluctuation range of the simulated sequence is good. The second function is logarithm model: \( c = \log_Q Q^A \), which can be used as the responsive relation in the form of logarithm to simulate the total nitrogen concentration. The flow rate is a variable in the logarithm function, and when \( Q=8 \) the simulated value is approximately approach to the measured data. Figure 4 illustrates that the fluctuation trend of the simulated series is roughly the same as that of the measured values, and the fluctuation range is larger than that of power model. The third function is exponential model: \( c = 1.6 e^{0.0027Q} - 0.2 \), which has relevantly low simulated values with narrow fluctuation range and have bigger deviation compared with the other two functions.

3.2. The error analysis

Table 1. Comparison of the prediction model of TN in Xiangxi River basin

| number | prediction model | \( R^2 \) | \( E_{NS} \) |
|--------|-----------------|--------|----------|
| 1      | \( c = Q^{(0.14+A)} \) | 15.5%  | 0.54     |
| 2      | \( c = \log_Q Q^A \)   | 23.1%  | 0.14     |
| 3      | \( c = 1.6 e^{0.0027Q} - 0.2 \) | 27.6%  | 0.34     |

Table 1 indicates that the relative error of the total nitrogen prediction model is less than 30%. The minimum relative error of total nitrogen power model and logarithm model is 15.5% and 23.1% respectively, and the results is comparatively good. The relative error of exponential model is 27.6%. From the aspect of Nash coefficient, the Nash coefficient of power model is 0.54, which is greater than logarithm model, 0.14, and exponential model, 0.34.

4. Conclusion

In Xiangxi River basin, analysis results of rainfall, geography, environment factors show that the main source of watershed non-point source pollutants is the soil erosion, which is driven by rainfall. In the paper, power function, logarithmic function and exponential function of constitutive relation, the corresponding shape functions and the key parameters are analyzed respectively, and calculation methods are applied in Xiangxi River basin. The total nitrogen power model has a smaller fluctuation range than logarithm model and can fit the measured values with least errors. From the aspect of relative error, power model of total nitrogen in Xiangxi River is the best than the other two models used in the paper. The predicted data of total nitrogen pollutants using to power and logarithm model can effectively control the peak value and enlarge the lower value on Nash coefficient. The fluctuation of power model is not as large as that of logarithm model, which also leads to the higher parameter of logarithm model compared to power model. Both power and logarithmic functions are suitable for long time series simulation. This model can simulate pollutant concentration quickly and provides effective total nitrogen estimation and prediction in river basin near the Xiangxi River. The following work includes verify whether the response relation and related parameters obtained in this paper have a good representativeness in more other basins, and set up model to more suitable for other basins.

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