Study on the migration law of biogenic substances under different scheduling schemes of reservoirs

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Abstract. In order to study the migration process of biogenic substances in river basins under reservoir regulation and quantify the migration characteristics of nitrogen and phosphorus pollution in the middle and lower reaches of the Lancang River cascade reservoir basin. This article constructs a simulation model for the migration of biogenic substances in the Lancang River Basin based on the SWAT model, and preliminarily simulates the migration process of nitrogen and phosphorus in the basin. The results indicate that the model has good applicability in the Lancang River basin, with the NSE coefficient of 0.76 and the R^2 coefficient of 0.78. Moreover, there is a roughly positive correlation between nitrogen and phosphorus production and rainfall distribution in the basin, but rainfall is not the only factor determining the distribution of nitrogen and phosphorus pollution load. By inputting different reservoir regulation schemes into the reservoir regulation module, the migration processes of nitrogen and phosphorus in various sections of the watershed under natural conditions, conventional regulation, power generation regulation, and ecological regulation schemes are calculated. The results indicate that the conventional and power generation scheduling schemes have a significant impact on the migration of total nitrogen and phosphorus in the watershed, leading to a certain retention and accumulation effect of nitrogen and phosphorus in the reservoir. However, the ecological scheduling scheme to some extent reduces the impact of reservoir scheduling on the migration of biogenic substances.

Keywords: Biogenic material migration; Reservoir regulation; SWAT model; Hydrological simulation.

1. Introduction

The SWAT model was developed by the Agricultural Research Center of the United States Department of Agriculture in the 1990s, which can effectively simulate hydrological processes such as runoff, non-point source pollution and soil erosion in the watershed [1,2]. With the continuous updating of the model, the combination with GIS improves the efficiency of the model in data management, extraction, output expression, etc. [3], and has been widely used in watershed runoff simulation and non-point source pollution research [4,5].

The Lancang River originates in southwestern China and flows through three provinces of Qinghai, Tibet and Yunnan. The size of the basin is 167400 square kilometers, and the undulations are intense. The source material of the basin is mainly from the urban industrial point source in Qinghai, Tibet and Yunnan, and the non-point source pollution from livestock and poultry breeding, agriculture and natural soil and water loss. After the source material enters the river, it is transported to the drainage outlet of the basin under the control of the reservoir, so it is very important to quantify the migration characteristics of nitrogen and phosphorus pollution in the cascaded reservoir basin of the middle and lower reaches of the Lancang River.

2. Data and Methods

2.1 Data materials

The data required for building the model are spatial data and observational data. Spatial data include Lancang River Basin Digital Elevation Model (DEM), land use data (Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences), and soil data (China Soil

dataset of the World Soil Database). The observation data are the daily meteorological data of Atmospheric Assimilation Dataset (CMADS) from 2008 to 2016 and the hydrological and water quality measured data of Yunjinghong Hydrology Station, an outlet station of the basin, from 2008 to 2014.

2.2 SWAT model construction

On the basis of digital elevation, land use, and soil data, a spatial database of the Lancang River Basin is constructed through GIS platform processing. Then, a SWAT model is constructed using meteorological data such as daily rainfall, temperature and wind speeds from 2008 to 2016 using the Atmospheric Assimilation Dataset (CMADS v1.0) [6]. The SWAT model uses diurnal time continuous calculation to divide the basin into multiple sub-basins, which in turn are divided into multiple hydrological response units (HRUs) [7]. The smallest unit of computation consisting of a unique land-use type and soil type superimposed is called HRU [8].

2.3 Multi-objective scheduling scheme for reservoirs

According to the typical regulation rules of cascade reservoir groups with different objectives, four typical regulation schemes of reservoir are adopted, including natural conditions, conventional reservoir regulation rules, optimal power generation regulation rules and ecological optimal regulation rules. The regulation scheme under natural condition is to consider the balance control of the reservoir according to the inlet and outlet. The conventional reservoir dispatching rule is to consider the regulation of cascade reservoir group and run according to the design dispatching diagram. The power generation optimal and ecological optimal dispatching scheme is a reservoir dispatching operation mode considering the maximum power generation and the optimal ecological target.

3. Results and Analysis

3.1 Hydrological and water quality simulation results

According to the model calibration and verification results, the fitting effect between the observed value and the simulated value is good, in which the decisive coefficient R^2 is 0.78, and the Nash-Suttcliffe efficiency coefficient NSE is 0.76, both of which are greater than 0.5. It can be seen that the SWAT model has good applicability in the Lancang River Basin. The model parameters are returned to the original model to run the calculation, and the simulation results are written into the database, and the data is analyzed. Based on the results in the database, the spatial and temporal distribution patterns of rainfall, total nitrogen and total phosphorus in the 19 sub-basins divided by the SWAT model can be obtained.

Due to the large amount of output data, 2014 is chosen as a typical year for analysis. As shown in Figure 1, the spatial distribution of precipitation, total nitrogen production, and total phosphorus production in the Lancang River Basin in 2014 are shown. It can be seen from the figure that the distribution of nitrogen and phosphorus production in the basin is similar to that of precipitation, and the nitrogen and phosphorus production in the region with high precipitation is relatively large. The spatial distribution of precipitation is very uneven, showing a decreasing trend from southwest to northeast. The load distribution of total nitrogen and total phosphorus is similar, and the pollution in the lower reaches of Yunnan River is more serious, which is due to the increase of pollution load and accumulation in the lower reaches of Lancang River. At the same time, it can also be seen that precipitation is not the only factor that determines the loss of non-point source pollution load.

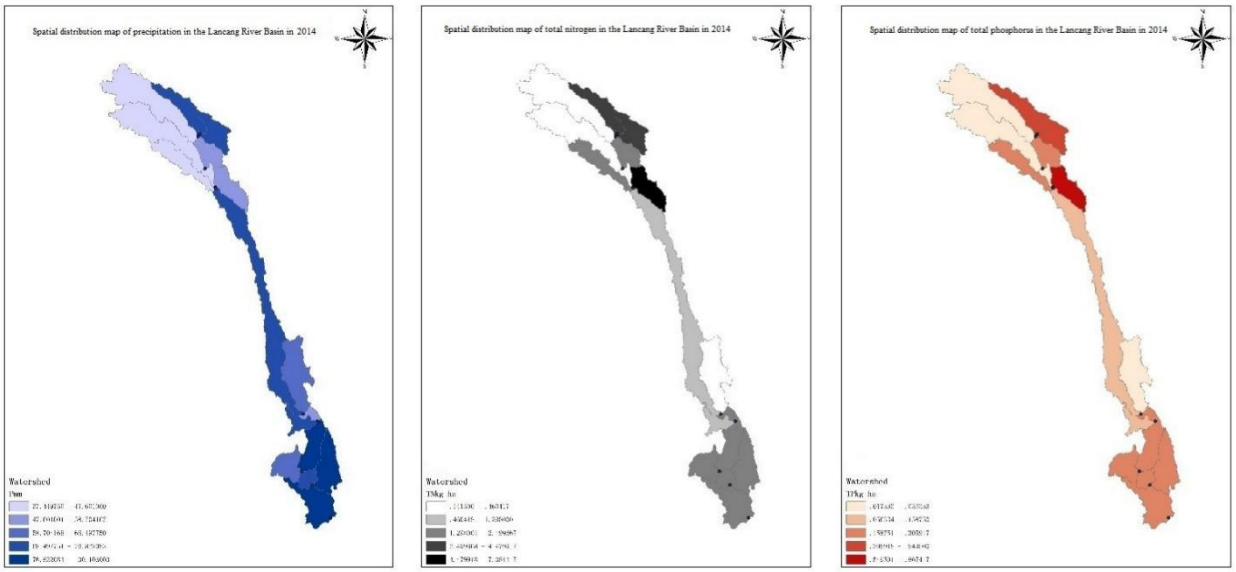

Fig. 1 Spatial Distribution of Precipitation, Total Nitrogen Production, and Total Phosphorus Production in the Lancang River Basin in 2014

3.2 Four kinds of reservoir discharge schemes

In this paper, Xiaowan and Nuozhadu reservoirs, which have strong regulation performance in the basin, are mainly considered to be included in the reservoir joint operation and control. Through calculation, the outflow processes of Xiaowan and Nuozhadu reservoirs during conventional regulation, optimal power generation regulation, and ecological optimal regulation in 2014 are obtained, as shown in Figure 2.

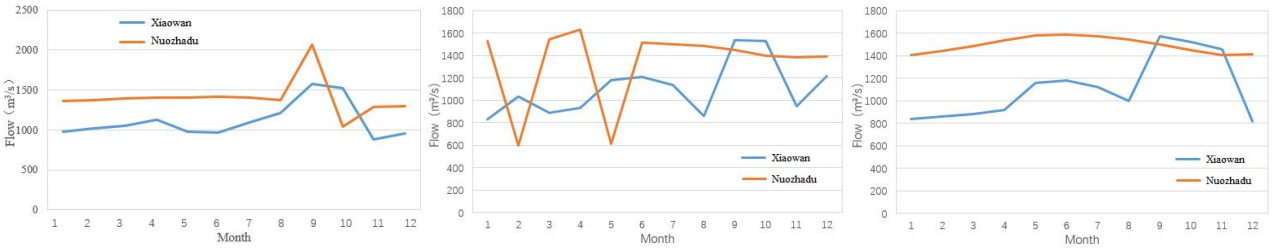

Fig. 2 Flow Process Diagram of Xiaowan and Nuozhadu Reservoirs for Conventional Dispatching, Optimal Power Generation Dispatching, and Ecological Optimal Dispatching in 2014

3.3 Analysis of migration results of biogenic materials under different schemes

On the basis of the original SWAT model under natural conditions, by adding two reservoirs, Xiaowan and Nuozhadu, and inputting the basic parameters of the reservoir and the monthly average outflow of the reservoir under different reservoir regulation schemes into the model, the model is driven by meteorological data to obtain the results of the migration of biogenic substances in the Lancang River Basin under different regulation schemes.

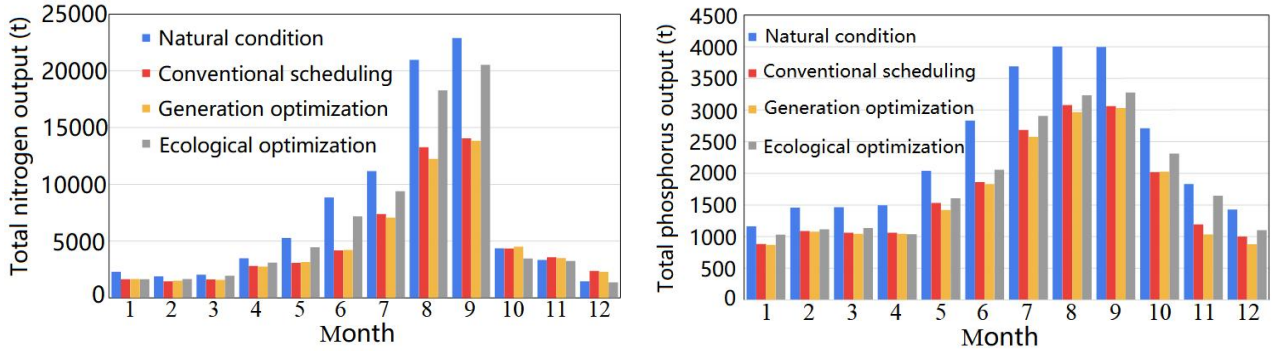

Fig. 3 Process diagram of total nitrogen and total phosphorus output in Xiaowan Section in 2014

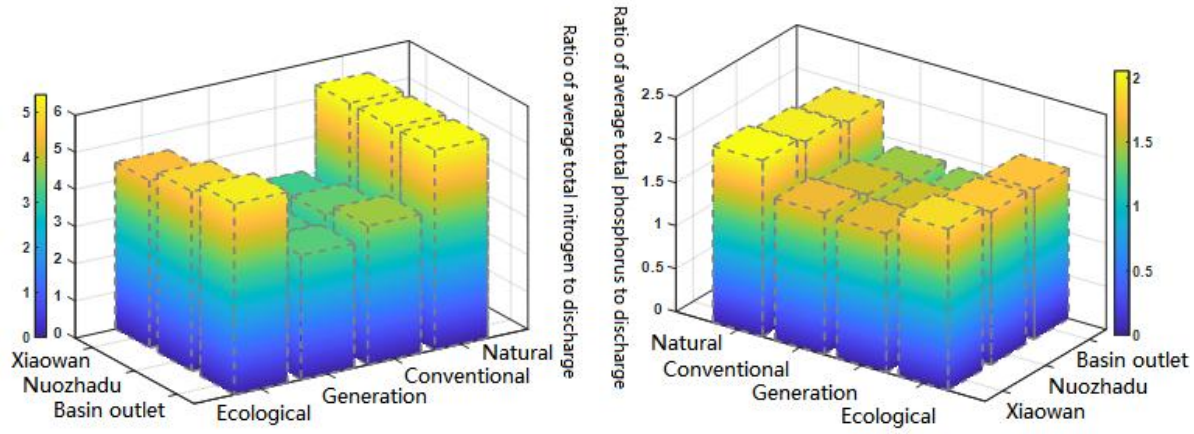

Fig. 4 Variations of total nitrogen and total phosphorus along different scheduling schemes

As shown in Figures 3 and 4, from the perspective of time distribution, the total nitrogen and phosphorus output in the watershed is generally smaller than that in the non flood season. This may be due to the increase in nitrogen and phosphorus production during the flood season, and the migration of biogenic substances is directly proportional to the flow rate; From the perspective of spatial distribution, there is no significant change in the total nitrogen and phosphorus levels along the Lancang River channel under natural conditions. However, under the conditions of cascade reservoir scheduling, the spatial distribution of total nitrogen and phosphorus levels is affected, and the output of total nitrogen and phosphorus levels in the cross-section is reduced, indicating that reservoir scheduling has a certain retention and accumulation effect on nitrogen and phosphorus; Finally, from the perspective of different scheduling schemes, it is found that the total nitrogen and phosphorus output of the basin is the highest under natural conditions. Conventional scheduling rules and power generation scheduling rules have a significant impact on the migration of total nitrogen and phosphorus in the basin, especially during the flood season when there is a sudden decrease. The ecological scheduling rules proposed in the study have to some extent reduced the impact of scheduling on the migration of biogenic substances, which is more conducive to the migration of biogenic substances compared to conventional scheduling rules and power generation scheduling rules.

4. Summary

This article constructs a simulation model for the migration of biogenic substances in the Lancang River Basin based on the SWAT model, and calibrates and verifies the model. The results showed that the NSE coefficient and R^2 index of the model are 0.76 and 0.78, respectively, indicating that the model has good applicability in the simulation of the Lancang River Basin. By returning the parameters to the original model for simulation calculation, the spatiotemporal distribution patterns of precipitation, nitrogen, and phosphorus in the watershed are obtained. The results show that there is a roughly positive correlation between nitrogen and phosphorus production in the watershed and rainfall. Rainfall gradually decrease from the southwest to the northeast, and the distribution of total nitrogen and total phosphorus loads in the downstream Yunnan section of the river is severely polluted, it also shows that precipitation is not the only factor that determines the load loss of non- point source pollution.

By studying different joint scheduling schemes for cascade hydropower stations in the basin, four different reservoir regulation schemes are obtained, including natural conditions, conventional scheduling, power generation scheduling, and ecological scheduling. The migration patterns of total nitrogen and total phosphorus in the Lancang River basin are obtained by inputting different scheduling schemes into the calibrated model. Under natural conditions, the total nitrogen and

phosphorus output in a watershed is the highest. Conventional and power generation scheduling schemes have a significant impact on the migration of total nitrogen and phosphorus in the watershed, leading to a certain retention and accumulation effect of nitrogen and phosphorus in reservoirs. The ecological scheduling scheme reduces the influence of reservoir scheduling on the migration of source materials to a certain extent, which provides a reference for ecological scheduling in the Lancang River basin. It is also of great significance for protecting the ecological environment of the basin and reservoir area and studying the spatiotemporal distribution and migration laws of biogenic substances in the basin.

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