The Environmental Capacity of Hun River, Liaoning Province, China

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Abstract. Based on the environmental functional area allocation, point and non-point sources, hydrology and water quality data of Hun River, SWAT model is built and used to calculate the hydrological, water quality and environmental capacity processes in the river channel. The results showed: (1) When the upstream water quality concentration was limited to the grade III of the national surface water quality standard, the environmental capacity of total phosphorus (TP) in Hun River is about 582.01 t/a. (2) According to the results of water environmental capacity in different water periods, the environmental capacity of Hun River is seriously overloaded in the flood season, although annual value is satisfied the standard. For the strong driving effect on the pollutants transport in the river by the intense rainfall in flood season, the concentration in flood season exceeds the water quality standard of grade III. (3) To strengthen the environmental management of Hun River, it is necessary to monitor non-point sources in the cultivated land, standardize the fertilization measures, and improve the rural sewage pipe networks and related facilities.

1. Introduction

Water environmental capacity refers to maximum mass of pollutants that a water volume can hold under the given environmental objectives [1,2]. The capacity is related to water quality goals, water environmental properties, and the characteristics of pollutants, as well as the flow discharge mode and spatial-temporal distribution of the pollutants [3, 4]. Presently, the computational methods of water environmental capacity mainly include the formula method, trial-and-error method, system optimization method, probabilistic dilution model (PDM) method, and uncertainty analysis method[5]. Among them, the formula method is clear in conception, easy to compute, widely applicable, and also able to couple with hydrologic, hydrodynamic, and water quality models to improve the calculated results.

In recent years, with rapid growth of local industrial and agricultural economy and urban expansion in the Hun River Basin, it has faced double impact of the original agricultural non-point source pollution (ANPSP) and the increasing urban point source pollution, which might be worsened by poor-quality water discharged from wastewater treatment plants in flood events and direct discharge of partly domestic sewage near Hun River branches [6-8]. Degraded water quality of Hun River not only affected the local residents, but also had an important impact on the drinking water source of Dahuofang Reservoir [9,10]. The water quality in Hun River was vulnerable to factors such as natural rainfall, runoff...
and dynamical pollution loads driven by human activities. \[11,12\]. Therefore, study on water environmental capacity in Hun River Basin is prerequisite to solution of the problem of water environment deterioration within the basin. In this paper, the water quality process of Hun River Basin was firstly calculated using the Soil & Water Assessment Tool (SWAT) model. Secondly, the non-point source pollution load in the basin was determined, and the water environmental capacity of each sub-basin of Hun River was calculated. Lastly, countermeasures for the pollution control in the river basin were proposed, and more rational distribution, pollutant emission and reduction methods discussed according to the water environmental capacity in different periods.

2. Data and Methods

2.1 Overview of the Studied Area

Hun River is 415 km long, covering a watershed area of $2.35 \times 10^3$ km$^2$ (E120º 20'~125º 15', N41º 30~41º 15'). Its spatial distribution is as shown in figure 1. The study area located in the temperate zone controlled by the continental monsoon climate in East Asia. The annual mean temperature is 5~7 °C and the mean annual precipitation is 760~790 mm.

2.2 Computational formula of Water Environmental Capacity

Considering the functional division of water environment in Hun River Basin, SWAT software was adopted to generalize the natural river sub-catchments and the river network in the study area. There are 20 sub-catchments divided in Hun river basin. The water environmental capacity of the minimum space unit (sub-catchment) in the study area was calculated. The formula is as follows:

\[
W = 86.4[(Q_0 + q)C_S \exp\left(\frac{kx}{86400u}\right) - C_0 - Q_0]
\]  

(1)
In the formula, $W$ is the water environmental capacity (kg/d) of the segment; $Q_0$ is the designed inflow (m$^3$/s) of the segment; $C_S$ is the standard concentration of pollutants (mg/l) in the segment; $C_0$ is the concentration of pollutants (mg/l) in the segment; $k$ is the coefficient of pollutant degradation (d$^{-1}$) in the segment; $u$ is mean flow velocity (m/s) in the segment; $x$ is the length of the segment (m); and $q$ is the branched flow (m$^3$/s) in the segment.

3. Analysis of Results

3.1 Calibration and Verification of SWAT model

The calibration period was from 2009 to 2013, and the verification period was from 2014 to 2016. According to figure 2, the predicted average monthly runoff at Beikouqian station fitted well with the measured value. Comparison between the measured and simulated TP loads at Nanzamu station are presented in the figure 3 and it indicated the excellent accuracy of the predicted model.

3.2 Predicted results of Water Environmental Capacity

Combined with the predicted flow discharge and pollutants concentration at the outlet section of a sub-catchment by the SWAT model, the water environmental capacity of different function zones in Dahuofang basin was calculated by the high-water, the normal-water, and the low-water period. In addition, it also required to keep accordance with functional zoning of surface water environment and local water quality goals. The result of the spatial distribution of calculated water environmental capacity is shown in figure 4.
The water environmental capacity of TP in the upper waters of the Hun River was 582.01 t/a. It showed the significant seasonal variation including: 1) the largest in the high-water period, followed by the normal-water period, then the low-water period. Continuous moderate and heavy rains will increase river flow, raise the river level, strength the flow the turbulence, and thus change the self-purification capacity of the water body and influence the water environmental capacity of TP; therefore, differences in precipitation has an effect on water environmental capacity at some degree. According to figure 4, water environmental capacity is also proportional to the length, width, and depth of the sub-channel in the segment, the longer the river, the larger the water environmental capacity. Longer river means longer transport time, better mixing of pollutants faster dilution and more ratio of degradation, and therefore it has the larger pollutant carrying capacity than short river.

Based on the predicted TP concentration in each section of Hun River Basin and flow discharge in the sub-basins, integrated with the water environmental capacity in 2013 selected as the referent year, the amount of pollutant reduction in each sub-basin was calculated by the high-water period, the normal-water period, and the low-water period respectively, which is given in the figure 5.

The concentration of TP in each section of Hun River Basin was calculated, and the pollutant emission of its sub basin was predicted. The actual discharge of Hun River basin was 521.65 t/a. In annual temporal scale, the TP water environmental capacity of Hun River was 60.36 t/a. In terms of annual scale, there is still a surplus of 60.36t/a in the TP water environmental capacity. However, the seasonal difference of water environmental capacity in Hun River is obvious. The number of sub-catchments with water environmental capacity overload is 60%, 30% and 20% during high-flow period, normal-water period, and low-flow period respectively. The results showed that the TP emission in most of the sub basins of Hun River exceeded the purification capacity of the water body in the wet season, and the Hun river basin was dominated by crop planting and livestock breeding, and the main pollutant
source was non-point source. The use of nitrogen and phosphorus fertilizer and the livestock breeding contributed a lot to the environmental phosphorus pollution. Non-point source pollutants especially the particulate phosphorus is mainly transported into rivers through the runoff driven by the rainfall. During the dry season, most of the pollutants are deposited and accumulated in the soil and it is not easy to transport into the river, but the rainfall in the flood season will rush this accumulated TP into the rivers and then makes the TP in the water exceed the standard. Although the environmental capacity of Hun River Basin is relatively large in normal and dry periods because of the low pollutant concentration. the accumulation of pollutants in the dry season may have the adverse effects on the carrying capacity in flood season. Therefore, it is necessary to regulate the fertilization measures and fertilization amount to reduce TP emission in the future.

4. Conclusion

In this paper, the water environment capacity in Hun River Basin is predicted at different hydrological periods using well verified SWAT model. Main conclusion is listed as follows: There are obvious differences in the water environment capacity in different water periods. The pollutant concentration makes the TP overload rate of the basin in the high and low water period. Therefore, the corresponding measures should be taken according to different period. For example, the average TP reduction amount should not be less than 10.17 t/a in the wet season. To improve the water quality level, it is necessary to strictly control of pollutant load in accordance with the water environmental capacity in each sub-catchment, and implement zero or less pollutants emission in sub-basins compared to the surplus environmental capacity. In order to achieve this object, some methods should be adopted. For example, the standard fertilization measures for the farmland, the renewed rural sewage pipe network collection system and supporting measures should be taken to improve the efficiency of domestic wastewater recovery etc.

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