Simulation on Agricultural Non-point Source Pollution Based on SWAT Model in Dahuofang Reservoir Catchment, China

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1. Introduction

Non-point source pollution is gaining concern increasingly due to the wide range, randomness and difficult control. China has paid attention to the agricultural non-point source pollution (ANSP), especially for the pollution prevention in the important reservoirs and water source regions and undertaken some correlated researches. Currently, the integration of remote sensing, geography information systems, global positioning systems (3S) and non-point source pollution mechanism model is the main method for ANSP research. There are some representative large-scale continuous distributed mechanistic models such as soil and water assessment tool (SWAT), agricultural non-point source (AGNPS) model and so on. These models can be used to simulate mechanisms and processes of non-point source pollution accurately, which are important methods to promulgate the spatial and temporal distribution of pollution and to identify pivotal source areas (Fenghua et al., 2006). SWAT model has become one of the most widely used non-point source pollution model because of its reasonable structure, high efficiency of operation, and user-friendly (Gessese et al., 2008). According to domestic and international researches, SWAT model was used in the fields of hydrological simulation, water resources assessment, non-point source pollution and nutrient migration and others (Rostamian et al., 2008; Santhi et al., 2001; Lei, 2007)

Dahuofang reservoir is an important drinking water source of Liaoning province, which was listed as one of nine national water sources. It is a typical valley reservoir, which provides domestic water and industrial water for 7 cities such as Shengyang, Daliang Fushun and so on. The total capacity of reservoir is 21.87×10^8 m^3; the area of basin is 5347km^2. There are there main rivers in study area named Hun River, Suzi River and She River as shown in Fig.1. In recent years, the ANSP is increasingly serious due to the using of large amount of fertilizer and pesticide and discharge of abundant livestock manure and rural domestic wastewater. The exceeding standard rate of annual average value of total nitrogen (TN) and total phosphorus (TP) are 100% and 85.7%. In previous studies, researchers only focused on planting pollution based on SWAT, this study also considers livestock and rural life simultaneously. The results of the research will provide basic support to the establishment of the early-warning platform, and the formulation of controlling technologies and management policies of the ANSP.

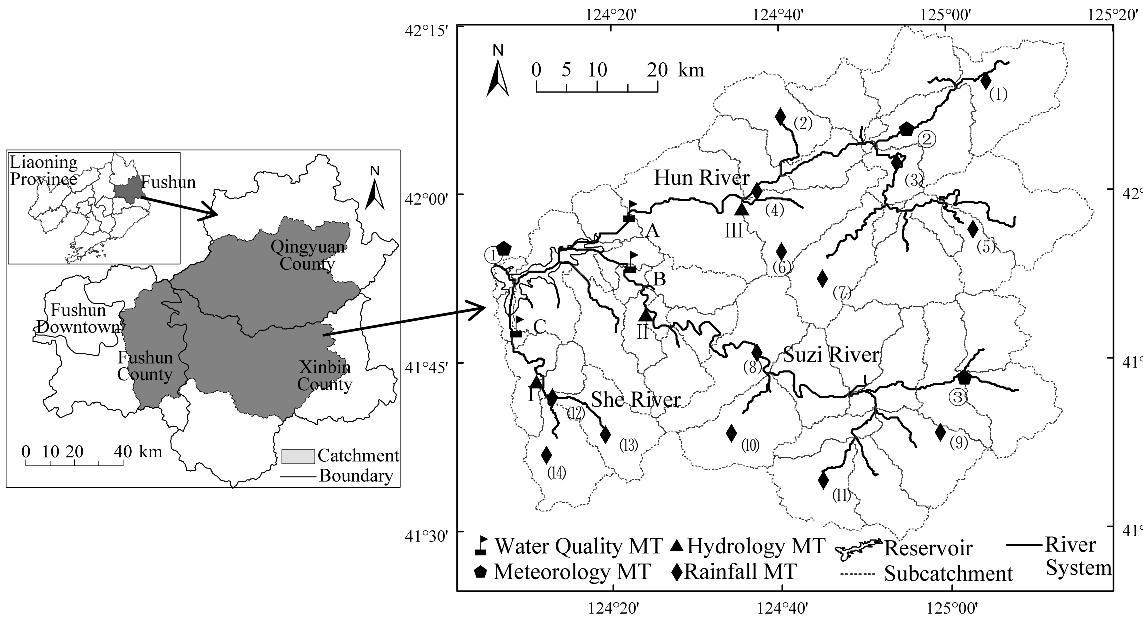

Fig.1. Study area location and meteorological, hydrologic, water quality monitoring sites

2. Methodology

The load of TN and TP discharged from livestock and poultry breeding and rural life was estimated by using export coefficient method, the data was input SWAR model, and then making a comprehensive analysis of the load of pollutants discharged from planting, livestock and poultry breeding and rural life and pollution law.

2.1 Export coefficient method

Export coefficient method, proposed in the early 1970s, was mainly used to study the relationship between land use and eutrophication of lakes. Johnes also considered livestock, population and other factors (Johnes, 1996). This model has been further improved and was widely used. Equation as fallow:

$$L = \sum_{i=1}^{n} E_i \left[A_i \left(I_i \right) \right] + P \tag{1}$$

Where: L is the loss amount of pollutant (kg), E_i is the output coefficient of pollution source i, A_i is the area of land use i, the amount of livestock i, or the population, I_i is the input load from pollution source i, P is the load of pollutants input from rain.

According to 'National Drinking Water Source Protection Plan', the export coefficients of TN discharged from night soil and domestic wastewater for one person are 0.83 and 1.83 kg•a^{-1}, and TP is 0.08 and 0.16 kg•a^{-1}. The coefficients of livestock breeding were determined based on statistic data from 'Animal Health Supervision Authority'. The TN export coefficients of unit cattle, pigs, sheep and chickens are 10.58、0.57、0.91and 0.03 kg•a-1, TP is 0.31、0.14、0.05 and 0.005 kg•a^{-1}.

The study area was divided into 12 sub-regions according to the spatial distribution of rural population and livestock and poultry farms, pollutants output port were established in each sub-region. The output load of pollutants in each sub-region was dispersed based on the rainfall of 12 months. Finally, the temporal and spatial discretization results were input SWAT model.

2.2 SWAT model

SWAT is watershed scale simulation model, which is developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (Neitsch et al, 2002). Spatial data include DEM resolution ratio30m×30m, land use and soil type map scale 1:50000, and water system map. Attribute data mainly consist of meteorological data and soil data. The monthly data of precipitation was collected from Qingyuan, Zhangdang and Xinbin meteorological station from 1986 to 2009, which is used to establish the weather generation routines. The daily data of precipitation and air temperature was collected respectively from 14 precipitation monitoring sites and 3 meteorological monitoring sites from 2001 to 2009 as shown in Fig.1. The data used to construct soil attribute data base was collected from 'Fushun Soil'.

SWAT model extracted water system within watershed based on DEM. 45 sub-watersheds were formed by means of the fixed area of catchment and outlet of the watershed as shown in Fig.1. According to the 6% threshold of land use and the 12% threshold soil type, the whole watershed was divided into 277 hydrological response units (HRU), and then loading meteorological data and the results of discretization. Initial simulation was implemented in SWAT VIEW interface.

Relative error δ, determination coefficient r^2 and Nash-Suttcliffe coefficient E_{ns} were used to evaluate the applicability of model and to calibrate SWAT model. Equations are as follow:

$$\delta = \frac{\overline{Q_{\mathrm{m}}} - \overline{Q_{\mathrm{o}}}}{\overline{Q_{\mathrm{o}}}} \times 100\% \tag{2}$$

$$r^2 = \frac{\left[\sum_{i=1}^{n} \left(Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}}\right)\left(Q_{\mathrm{m},i} - \overline{Q_{\mathrm{m}}}\right)\right]^2}{\sum_{i=1}^{n} \left(Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}}\right)^2 \sum_{i=1}^{n} \left(Q_{\mathrm{m},i} - \overline{Q_{\mathrm{m}}}\right)^2} \tag{3}$$

$$E_{\mathrm{ns}} = 1 - \frac{\sum_{i=1}^{n} (Q_{\mathrm{o},i} - Q_{\mathrm{m},i})^2}{\sum_{i=1}^{n} (Q_{\mathrm{o},i} - \overline{Q_{\mathrm{o}}})^2} \tag{4}$$

Where: $Q_{o,i}$ is measured value, $Q_{m,i}$ is simulation value, $\overline{Q_{\mathrm{o}}}$ is the average measured value, and $\overline{Q_{\mathrm{m}}}$ is the average simulation value.

In this study, runoff and sediment were calibrated firstly, then nitrogen and phosphorus. The order of time calibration is annually, monthly and daily calibration. The date of runoff and sediment used to calibrate and verify was collected form Nanzhangdang, Zhanbei, and Beikouqian hydrology monitoring sites. The simulation values of nitrogen and phosphorus were calibrated by using the data from Taigou, Gulou and Beizahmu water quality monitoring sites. The time for model preheating is 2005, for calibration is from 2006 to 2007, for verification is from 2008 to 2009. The spatial distribution of hydrology and water quality monitoring sites was showed in Fig.1. The results of calibration and verification were showed in Table 1 and Fig.2.

Table 1 Evaluation on the results of calibration and validation of runoff, sediment, TN and TP

Simulation period	Item	Average monthly measured value	Average monthly simulation value	δ%	E_{ns}	r^2
Calibration period	Runoff (m^3/s)	31.12	29.53	-5.13	0.85	0.86
	Load of sediment (t)	5069.23	4756.39	-6.17	0.91	0.92
	Load of TN (t)	181.62	194.16	6.09	0.66	0.71
	Load of TP (t)	10.02	11.46	14.37	0.69	0.68
Verification period	Runoff (m^3/s)	21.19	22.63	6.81	0.84	0.85
	Load of sediment (t)	3142.23	3619.35	15.18	0.69	0.74
	Load of TN (t)	153.34	159.46	3.99	0.67	0.69
	Load of TP (t)	7.85	8.52	8.58	0.73	0.68

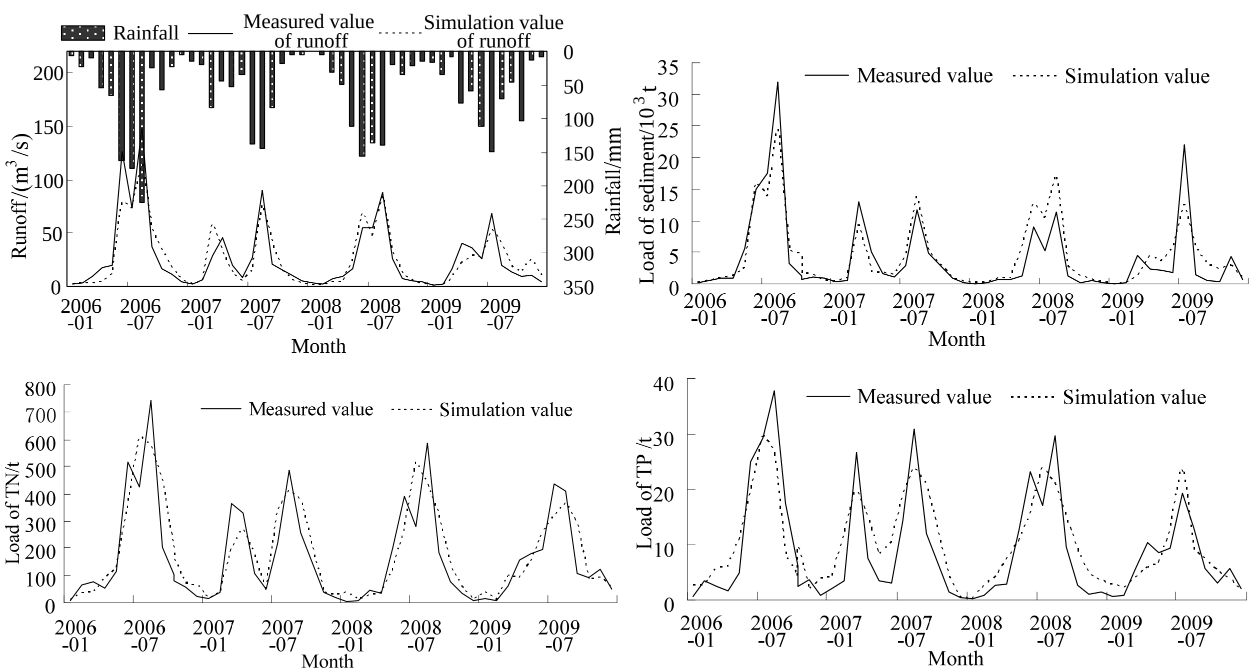

Fig.2 Simulated and observed value of monthly runoff, sediment, TN and TP

3. Results and analysis

According to Table 1, the simulation index δ, E_{ns} and r^2 all reached the requirement. The simulation effect of runoff was good, E_{ns}>0.80，r^2>0.80. The simulation effect of sediment in calibration period is better than in verification period. The simulation index of TN and TP are all higher than 0.65. The applicability of SWAT in this study reached the standard.

3.1 Temporal analysis of ANSP

The load of sediment, TN and TP that flowed into reservoir were showed in Table 2. The load of sediment, TN and TP in 2007 was larger than other years with the maximum rainfall 850mm. The load of TN that flowed into reservoir was decreased from 2155.83t to1685.15t from 2006 to 2009. The annual average load of sediment, TN and TP can be calculated as 82.65×10^3 t, 1873.49 t and 81.97 t.

Table 2 Annual variation of ANSP input the reservoir from 2006 to 2009

Year	Rainfall/mm	Runoff/10^6m^3	Load of sediment/10^3t	Load of TN/t	Load of TP/t
2006	850.40	1416.81	108.22	2155.83	95.79
2007	639.60	1032.43	71.95	1878.32	77.38
2008	714.40	1034.76	84.16	1774.67	81.11
2009	694.60	875.51	66.29	1685.15	73.60
Average	724.75	1089.88	82.65	1873.49	81.97

The monthly load of pollutants was compared with water quantity that flowed into reservoir, as shown in Fig.3. Determination coefficient r^2 of sediment, TN and TP with water quantity input reservoir was 0.94, 0.89 and 0.88. Generation and migration of Sediment were closely related with surface hydrological cycle, which were strongly impacted by the spatial distribution of rainfall and runoff. The generation of ANSP and the migration of the pollutants are substantially influenced by the runoff, precipitation and the generation of sediment. The loss of sediment, nitrogen and phosphorus was up to the maximum in July and August each year, accounting for 67.91%, 42.64% and 44.42% of the annual loss amount respectively, because of the strength of rainfall and soil erosion increasing, sediment transport capacity was increased by large runoff.

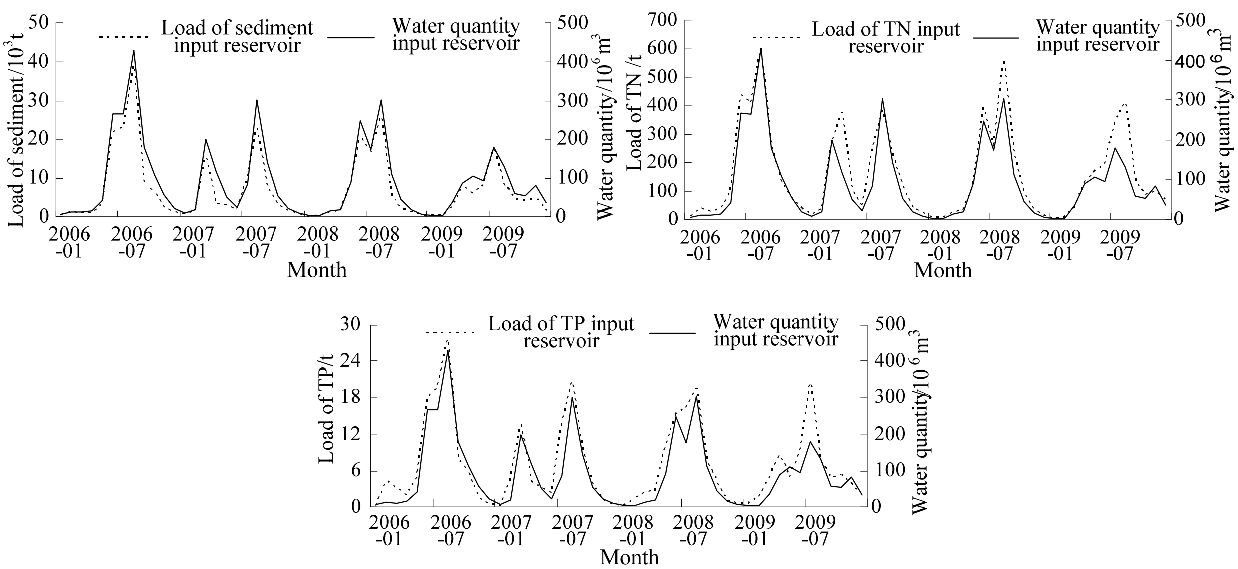

Fig.3 Variation of the load of sediment, TN and TP with water quantity input reservoir

4.1 Spatial analysis of ANSP

The study area was divided into four sub-basins to analyze the contribution rate of pollutants to the reservoir as shown in Table 3. The data in Table 3 was the annual average value from 2006 to 2009. According to Table 3, there was 522.63×10^6 m^3 water that flowed into reservoir from Hun River basin, as the biggest contributor, also Hun River basin has the greatest contribution rate of the ANSP, the contribute rate of pollutants was more than 40%, followed by Suzi River basin and She River basin, The small river basins around the reservoir have the least contribution rate. Hun River basin as the biggest contributor has a large population with biggest output value of farming and livestock breeding.

Table 3 Contribution rate of water quantity and ANSP from different basins

Item	Water quantity (10^6m^3)	CR of Water quantity (%)	Load of sediment (10^3t)	CR of Load of sediment (%)	Load of TN(t)	CR of Load of TN (%)	Load of TP(t)	CR of Load of TN (%)
Hun River basin	522.63	47.95	40.77	49.33	966.28	51.58	43.37	52.91
Suzi River basin	482.11	44.23	35.18	42.57	802.35	42.83	33.82	41.26
She River basin	52.72	4.85	3.22	3.88	83.75	4.46	3.05	3.72
Small river basins	32.42	2.97	3.48	4.22	21.11	1.13	1.73	2.10
Total	1089.88	100	82.65	100	1873.49	100	81.97	100

4. Conclusion

According to the results of calibration and verification based on the monitoring data of hydrology and water quality, the r^2 of monthly runoff and sediment was higher than 0.74, the E_{ns} was higher than 0.69. The SWAT model after being calibrated can be used in this study area. By simulation of SWAT model total amount of TN, TP and average sediment load that flows into Dahuofang Reservoir can be calculated as 1873.49t, 81.97t and 82.65×10^3t. The generation and migration of ANSP was substantially influenced by the rainfall and runoff. The loss of sediment, TN and TP was up to the maximum in July and August each year, accounting for 67.91%, 42.64% and 44.42% of the annual loss amount respectively. Spatially, Hun River basin contributed the greatest of the ANSP, followed by Suzi River basin and She River basin; the small river basins around the reservoir have the least contribution rate.

A comprehensive command of the source, generation, distribution and inflow of the ANSP in the study area and the dynamite change of precipitation can be acquired. The results of the research will provide basic support to the establishment of the early-warning platform, the conservation of the water quality in the water source region and ecological security.

Reference

Fenghua, H., Shengtian, Y., 2006. The Theoretical Method and Application of Non-point Source Pollution Model. China Environmental Science Press. 3-10.

Gessese, A., Yonas, M., 2008. Prediction of Sediment Inflow to Legedadi Reservoir Using SWAT Watershed and CCHEID Sediment Transport Models. Nile Basin Water Engineering Scientific Magazine. 1:65-74.

Rostamian, R., Jaleh, A., Afyuni, M., et al, 2008. Application of a SWAT Model for Estimating Runoff and Sediment in Two Mountainous Watersheds in Central Iran. Hydrology Science Journal. 53(5):977-988.

Santhi, C., Arnold, J.G., Williams, J.R., et al, 2001. Validation of the SWAT Model on Large River Basin with Point and Non-Point Sources. Journal of the American Water Resources Association. 37(5):1169-1188.

Lei, Y, 2007. Water Quantity Simulation of the Zhangweinan Basin Based on SWAT Model. Journal of Jilin University: Earth Science Edition. 37(5):949-954.

Johnes, P.J., 1996. Evaluation and Management of the Impact of Land Use Change on the Nitrogen and Phosphorus Load Delivered to Surface Waters: the Export Coefficient Modeling Approach. Journal of Hydrology. 183: 323-349.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., et al, 2002. Soil and Water Assessment Tool User's Manual Version 2000. Texas Water Resources Institute. 12-472.