The transboundary ecocompensation in eastern china environmental sciences essay

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Abstract

The first transprovincial watershed ecocompensation pilot project has been implemented in Xin’anjiang River Watershed between Anhui and Zhejiang Province, China, in order to solve the problem of transboundary pollution and ensure sustainable use of water resources. Models have been proved to be effective tools for identifying the majority environmental objectives, especially for the watershed management of agricultural non-point sources pollution. The Regional Nutrient Management (ReNuMa) model was employed to model and interpret the main environmental problem (nitrogen contamination) generated within Tunxi Catchment, the headstream of Xin’anjiang River Watershed. With the plenty of available data and parameters, ReNuMa simulated stream flow, sediment and dissolved nitrogen (DN) load well in monthly scale for both calibration (2000 to 2006) and validation (2007 to 2010) period. Particulate Nitrogen (PN) and total nitrogen (TN) load were also estimated after all of the parameters were determined, respectively. Source apportionments of various forms of nitrogen load were performed for both annual and monthly outputs, which illustrated the contribution proportion of each pollution source and characterize temporal variations caused by natural and anthropogenic factors linked to seasonality. The results of the application of the relatively simpler, convenient ReNuMa model for policy-makers showed usefulness to plan nitrogen management strategy in the upstream catchment to reduce the nitrogen load draining to the downstream, so as to gain mutual benefits from the ongoing transprovincial watershed ecocompensation pilot project.

Key words: Ecocompensation; Generalized Watershed Loading Functions (GWLF); Nitrogen; Regional Nutrient Management (ReNuMa); Xin’anjiang River

1 Introduction

China’s water crisis is receiving worldwide attention [1] (Yang, 2013). As one of the several health lakes, Thousand-island Lake (artificial reservoir with waters area of 573 km2) is an important drinking water source of Zhejiang Province, as well as Yangtze River Delta (China's most economically developed area) region's strategic reserve reservoir and ecological security barrier. However, with the rapidly development of regional economy, the water quality of Xin'anjiang River (Anhui Province), which provides about two thirds of the fresh water flowing into the lake, showed a slow deterioration trend in recent years, especially for the total nitrogen (TN) index. Monitoring results showed that TN concentrations increased by 34. 5% in Jiekou monitoring station (the junction station of the two provinces) from 2001 to 2008. The excess nitrogen could lead to eutrophication and hypoxia in water bodies [2] (Han, 2009) and connected with various humans health risks, such as blue baby syndrome and non-Hodgkin lymphoma [3] (Knobeloch, 2000). Watershed eco-compensation mechanism and policy has been proven effective for equal distribution of ecological benefit and economic benefit between protectors and beneficiaries, damage and victims [4] (Zhang, 2007). Fortunately, under the concern and coordinating of multiple government agencies, the first transprovincial watershed ecocompensation pilot project has been put into implementation in March, 2011, China. 300 million Yuan RMB per year was supported by central finance to Anhui Province for pollution control of Xin'anjiang River Watershed, and 100 million was bet between Anhui Province and Zhejiang Province for whether the water quality of Jiekou station reach the reference value (average of the recent three years monitoring results) or not. The goals of the project were to inspire pollution controls of upstream government and balance efficiency and equity during economic developing, finally to ensure mutual benefit of the fresh water. Therefore, identifying nutrient sources and characterizing the timing of nutrient load is essential for developing effective watershed management strategies for upstream government to ensure sustainability of the water resources. Watershed simulation models are commonly considered to be essential tools to evaluate the nutrient and sediment loading to surface waters and lakes [5] (Evans, 2002) and account for the integrated impacts of hydrological cycle and land use pattern to nutrient yield [6] (Ning, 2006). A key criterion for model selection is whether the data required to support the model exist for the watershed in question and if the model output could satisfy the user's demands, particularly for supporting decision-making processes [7] (Sha, 2013). In this paper, Regional Nutrient Management (ReNuMa) [8, 9], (Hong and Swaney, 2007; 2008) model was selected to estimate hydrological and nitrogen load in a typical catchment (Tunxi catchment) of the Xin'anjiang River Watershed, because of its simplicity also facilitates the conversation between policy-makers and scientists [10] (Wu, 2007). The content of this study included: (1) data compilation for the model running; (2) evaluation the performance the model by calibration and validation process using the monthly stream flow, sediment and DN load; (3) source apportionment of nitrogen load, using the annual and monthly modeling outputs, and (4) give some targeted suggestions for the policy-maker of the eco-compensation pilot project.

2 Materials and Methods

2. 1 The Study Catchment

The Tunxi catchment is situated in Huangshan City, south of Anhui Province, Eastern China, and covered an area of approximately 2, 674 km2 (Fig. 1). The outlet of the catchment is in Huangkou station, Tunxi District, which is the confluence of two tributaries. Then the river flows approximately 385 km draining towards Thousand-island Lake through the Jiekou station. The catchment spans six counties and the land use was quite spatially heterogeneous. Forest and shrubs (77. 26%) dominated the catchment, followed by farmland (18. 04%), grassland (3. 66%), residential area (0. 68%) and water body (0. 35%). The elevations ranged from 71m to 1599 m, with the average slope of 16. 1 degree. The mean annual rainfall was close to 1700 mm, over 78% of which precipitated from February to August. Uneven rainfall over seasons has resulted in high flow rate but much nutrients and sediment loss in spring and summer, which may cause high risk to the water resource. Fig. 1

2. 2 The ReNuMa Model

The ReNuMa model is a hydrologically-driven, quasi-empirical model designed to estimate nutrient fluxes at mixed-use of mesoscale watersheds (up to several thousand km2). The hydrology and sediment yield are calculated in the same way as in the classic GWLF (Generalized Watershed Loading Functions; Haith and Shoemaker 1987) [11] model, which are generated on a daily basis and summed over time to estimate monthly and annual load. Runoff from each land use is parameterized using a variation of the SCS (Soil Conservation Service) curve number (CN) formulation; erosion is generated using the USLE (Universal Soil Loss Equation). An important variation in ReNuMa is the introduction of Net Anthropogenic Nitrogen Inputs (NANI, Hong and Swaney, 2007; 2011) [12] and land-use-specific response functions to estimate N concentrations in runoff water [13, 14] (Aber et al., 2003; Billen et al., 2000). Atmospheric nitrogen deposition, fertilizer applications, nitrogen fixation and denitrification, and human septic system effluents were all considered in ReNeMa model. Nitrogen load to the stream involve in dissolved and particulate forms. The dissolved nitrogen (DN) load consists of rural runoff N flux from each land use, groundwater N flux, deposition N flux, point source N flux, and septic N flux. The particulate nitrogen (PN) load consists of rural sediment N flux and urban washoff N flux from each land use. The ReNuMa modeling platform is the visual basic macro language of Microsoft Excel [8, 9] (Hong and Swaney, 2007; 2008). The excel platform permits easy generation of graphical display of time series and other relationships between inputs and output variables. The model also has a powerful capability in parameters calibration and uncertainty analysis, utilizing the embedded Excel Solver add-in [8, 9] (Hong and Swaney, 2007; 2008) and Monte Carlo uncertainty assessment method, respectively. These characteristics of the ReNuMa model are suitable for a region with limited data and no history of model applications [7] (Sha, 2013), as well as a potential tool for policy-maker according to the outputs processing.

2. 3 Input Data

The ReNuMa model input data were consisting of a series of monitoring data and lump parameters. Table 1 showed an overview of measured data, as well as the data processing. Table 1 [15-17]Based on the 2010 Agricultural Yearbook of Huangshan City, as well as the area weight of the involved six counties, the areas of the land use types in this catchment were shown in Table 2. The farmland contained paddy, grain and cash crops; tea plant was typical local economic crop scattered over the forest and shrubs. Table 2Only the NH4+ concentration of wet deposition and corresponding rainfall recorded from two stations in 2012 were obtained to estimate annual atmosphere nitrogen deposition. Based on the Xing’s [18] (2002) and Zhao’s [19] (2009) research near the study area, the value 2. 0 of NH4: NO3 ratio was assumed to estimate nitrogen in wet deposition. It was also assumed that dry deposition fraction was 0. 5 [9, 20] (Hong, B. and Swaney, D., 2008). Then, the yearly atmospheric N deposition, 14. 7 kg/ha, was determined. Two human population groups of septic systems were distinguished in this catchment: population served by short circuit systems and normal septic systems. A " people buffer zone" along the river of 500 m [7] (Sha, 2013) was set up using ArcGIS 9. 3 and the people within which were assumed as the number served by short-circuited septic tank, while the others were assumed to be served by normally-functioning systems. Monthly of agricultural land nitrogen fixation amount and denitrification loss rate of different land use were estimated based on the publications (Table 3), especially referring to the researches near study area [18, 21-24] (Boyer, 2002; Breemen, 2002; Hofstra, 2005; Xing, 2002; Liu, 2008). The growing season was assumed to correspond to months during which mean air temperature is at least 10 °C (March to November for this study). Sediment delivery ratio (SDR) was calculated using the relationship [11, 25] (Vanoni, 1975; Haith, 1987): where b was the area of the catchment (km2). The initial values of the rest important parameters were based on the ReNuMa and GWLF User Manual or literatures survey (Table 4), which were calibrated using the corresponding monitoring data. Table 3Table 4

2. 4 Calibration and Validation

The model run for a period of 11years, from the 1 January 2000 until the 31 December 2010. The first year of model simulation was used as a spin-up period to allow model to equilibrate to approach reasonable starting values given potentially inaccurate initial conditions [26]. The spin-up data were also repeated for model simulation. Monthly aggregations data from 2000 until 2006 were used for calibration and data from 2007 until 2010 were used for validation, by comparing the simulated and observed time series of stream flow, sediment and DN load for the calibration and validation periods. The first step calibration was done for the hydrological part of the model, such as CN2k and coefficients for groundwater flow (r, s), which strongly influenced the nutrient and sediment loads [27] (Chang, 2001). The next step was to calibrate the parameters associated with nitrogen and sediment load. The USLE parameters and erosivity coefficients groups were the main calibration parameters. Prior to the calibration of vast parameters, a local sensitivity analysis (LSA) was undertaken to determine the parameters that should be calibrated [7]. Two conventional numerical model performance measures were employed to assess the correlation between observed and predicted values of the calibration and validation. The coefficient of determination (R2) indicates the quality of relationship between observed and predicted results, which ranged from 0. 0 (poor model) to 1. 0 (perfect model). The Nash–Sutcliffe efficiency (ENS) determinates the relative magnitude of residual variance compared to the measured data variance [26], which ranged from negative infinity (poor model) to 1. 0 (perfect model) [5, 28] (Nash and Sutcliffe, 1970; Evans, 2002).

3 Results and Discussion

3. 1 Parameters Sensitivity

Generally, sensitivity analysis was done before parameters calibration to improve the calibration efficiency, as well as for inferring effective management options [7 8] (B. Hong and D. P. Swaney, 2007; Sha, 2013). As shown on Figure 2, the LSA results were divided into three classes based on the parameters response to the model outputs. Black bars indicate sensitivity of a 10% reduction in a parameter (lower sensitivity); purple bars indicate the sensitivity of a 10% increase (upper sensitivity). Although the absolute values of sensitivity indices were all below 1. 0, the figures showed that the recession and seepage coefficients were relative more sensitive to the monthly stream flow (Fig. 2-a). Paddy, cash crops and forest land use were more sensitive to the DN load (Fig. 2-b), while shrubs, tea plant and summer monthly (May, June, Fig. 2-c) were more sensitive to the sediment yield. Thus, the policy maker should develop preventive measures aiming at these sensitive factors. Fig. 2Then, the sensitive hydrology transport and nutrient parameters above were calibrated based on the observation data, respectively. Also, it was a trade off between obtaining high ENS and making the calibrated parameter in a reasonably range. The calibrated values of essential parameters were listed in Table 4. Validation of the model was performed after all of the parameters were determined.

3. 2 Model Performance

Model predictions and observations for monthly stream flow, DN load and sediment yield of calibration and validation were compared in Figure 3 and Figure 4. Fig. 3Fig. 4At the monthly time scale for the stream flow and DN, the model's performance indicated excellent predictive capability. Stream flow (presented as water depth in centimeters over the surface area of the catchment) could be predicted fairly well as reflected by the high R2 and ENS values, with 0. 945, 0. 936 for calibration period and 0. 957, 0. 936 for validation period (Fig. 4), respectively. The data points scattered about the 1: 1 line (Fig. 3), with narrow confidence intervals. The observed and modeled DN loads were also matched well for both calibration period and validation period (Fig. 4), although the slopes were not 1: 1. For the sediment yield simulation, model performance degraded somewhat. Observed monthly export of sediment were predicted acceptably by ReNuMa, which R2 and ENS values were equal or greater than 0. 7, although the model overestimated sediment yield at low flows and underestimated at high flows (Fig. 4). Actually, the error of the sediment yield prediction mainly occurred in the peak flow period due to the simple lumped erosion and sediment delivery parameter of the model. In conclusion, the ReNuMa provided very good simulations of stream flow, monthly nitrogen and sediment loads generated at the 2674 km2 of Tunxi catchment.

3. 3 Source apportionment of TN load

The ReNuMa model was run for TN estimated after calibration and validation with data from 2000 to 2010. The annual and monthly outputs were used for source apportionment of nitrogen load and management.

Annual outputs

The source apportionments of average annual nitrogen were shown in Figure 5. Of the entire TN load, the DN load was the primary pollution source, contributing about 73% in outflow, while the PN load contributed the rest 27%. As clearly shown in Fig. 5-A, the groundwater N load was the primary pollution source, followed by the sediment N, the septic N, the runoff N, the deposition N, point source N and wash off N. ReNuMa was used to model nutrient loading and soil erosion to nonpoint source pollution impacts in the coupled precipitation and human activities systems. Research findings indicate that groundwater was the largest contribution of TN loading. In fact, shallow ground water is susceptible to contamination by fertilizer application derived from the land surface. As water infiltrates downward, nitrate is readily transmitted through soil and can seep into groundwater [29] (Hitt, 2005). In this paper, eight shallow drinking water or irrigation well samples of forest, agricultural and urban land use were analyzed and the results showed that the average DN concentration of groundwater were 6. 77 mg·L-1, and even one sample exceeded 10 mg/L World Health Organization guideline [30] (Spalding, 1993). It should be paid more attention to the groundwater contamination and farmland nutrient management. However, the proportion of groundwater of TN loading might be overestimated here because the groundwater samples were all collected from existed wells, which might be polluted by the surroundings. PN was the second largest contributor that mainly came from soil erosion of all kinds of land use. The proportions of shrub and tea plant contributed to the PN were amazing, of which the sum more than 90% (Fig. 5-B). In fact, Maofeng Tea of the Yellow Mountains is well known at home and abroad, much land areas of shrub or forest were changing into tea plant (i. e. changing forest land use to agricultural land use) driven by the economic interests in recent years. This disturbance of human being activity led to lower-cover vegetation and the soils were prone to be eroded while heavy rainfall events happened. Due to lack of enough statistical yearbook and satellite image map, the land use " trajectory" was not modeled, so it failed to reveal the influence of land use transformation by the human activities. Another important contributor to the TN load was from septic system. Population density in this region was relatively high along the riverbank but there were no sewage networks or enough septic-tank, which caused lots of human sewage and manure production discharged into the river directly when rainfall happened. Fortunately, the sewage pipe networks reconstruction and separation of rainwater and sewage engineering covered the main towns and most densely-populated districts were ongoing under the supervising of Huangshan City government. Runoff N load (one main source of DN load) apportioned to different land use were shown in Fig. 5-C. It was different from PN component ratio. The two agriculture land use, cash crops and paddy were the main sources, contributing 40% and 27%, respectively. These were mainly due to the agricultural activities with overusing fertilizer, but a great deal of them drained into the river because of their high CN2k values, which were 92 and 90 for cash crops and paddy land, respectively. Moreover, most of the farmland land was spread along the river with short hydraulic transmission path into the river and lack of enough riparian zones. The forest land use also contributed 16%, owing to its larger area. Fig. 5

Monthly outputs

Monthly simulation results of ReNuMa model were analyzed to study temporal nitrogen load behavior, in order to provide more targeted decision for eco-compensation project. Component percentages of monthly TN were shown in Figure 6. It clearly showed that the monthly amount and proportions of TN were different. Eighty-nine percent of the PN (soil erosion) occurred from May to July (Plum Rains season), resulting sharply increases of TN load in summer and accounting for more than fifty-five percent of the annual TN load associated with DN load. However, the DN was more important source contributed to the TN load all the year round. Municipal (septic N load) and industrial wastewater discharge (point source N load) constituted constant loads, whereas surface runoff and groundwater were seasonal phenomenon, largely affected by climate within the catchment [31, 32] (Singh, 2004; Shrestha, 2007) and agricultural activities such as seeding and fertilizing. The deposition N load was larger from May to July, which also due to the denitrification of the fertilizer and plentiful precipitation. However, it might be underestimated in this study due to lack of enough wet and dry deposition of nitrogen data, especially for the organic nitrogen. Fig. 6

4 Conclusions

Nitrogen load was directly influenced by the periodic variation of the precipitation and air temperature, as well as the underlying surface conditions. The study area was mountainous and the average slope was 16 degree, which might incurred severe soil erosion in the bare underlying surface and vast nitrogen of different landscapes (especially for the agriculture land) discharged into the river driven by abundant rainfall. Therefore, some suggestion derived by the model should be considered for decision making to improve the water quality for Huangshan City government and better support the ecological compensation pilot program. Firstly, a series of runoff and sediment reduction and retention technologies should be adopted, such as trees planting and grasses growing in riparian buffer zone, contour farming, terraces, conservation tillage, cover crops and crop rotations, etc. [7, 33] (Evans, 2007, Sha, 2013). Secondly, stricter fertilizer applications should be implemented, such as more scientifically based fertilizer management procedures in agriculture. Thirdly, the drainage networks should be reconstructed in the cities and towns with high population density, and waste treatment facilities and other effluent controls should be built in rural areas. Lastly, it is also important to mobilize the whole people's enthusiasm to participate in ecological engineering construction. The ReNuMa model has been successfully applied in the Tunxi catchment of Xin'anjiang River Basin in China. As illustrated by the model calibration and verification results, the model provided reasonably good estimates of monthly stream flow, nitrogen and sediment load of the catchment. Simpler model may be easier for the policymakers or other users to adopt and use as a screening methodology to identify priority watersheds pollution problems and accelerate the implementation with respect to soil erosion and nonpoint pollution controls. More detail monitoring data and reliably parameters will be done to improve accuracy, as well as improvement of the sediment simulation modules of the model in the future.

The ReNuMa model has the potential to be applied and extended in China and in other similar developing countries.

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