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Estimation of Non-point Source Pollution in the Pingqiao River Basin of China based on a Spatial Source Hydrograph Separation Approach

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Introduction

Non-point source pollution (NPS) contributions became major causes of water quality degradation in Chinese rivers and lakes. Lake Taihu (2338 km^2), which is located in the Yangzi River Delta, is the third largest freshwater lake in China. In the past 20 years, with rapid social and economic development, Lake Taihu has been suffering severe water quality deterioration and eutrophication problems. With recent effective abatement of point source pollution, it was estimated that at least more than 50% of the total pollution loads were generated by NPS in the Taihu Basin[1)].

Our study area, the Pingqiao River Basin (22.3 km^2), is a small-scale river basin located in the upstream of the Taihu Basin. The water quality of the Pingqiao River Basin is closely related to the drinking water safety of Liyang City (0.76 million people, 2015) and the sustainable development of local economies of the Taihu Basin.

Recently, an NPS modelling based on spatial source hydrograph separation approach by a distributed hydrological model (Rainfall-Runoff-Inundation (RRI) Model) and Time-Space Accounting Scheme (T-SAS) was proposed[2)]. This proposed NPS modelling outputs time series of NPS nutrient loads exported from different spatial zones (land-uses); the hydrological model used is fully physically-based; the water quality sub-model is more empirical based thus it has simpler calculation process and lower demand of data than distributed water quality models; the calculation basis of NPS nutrients i.e. source runoff concentration, is based on field measurement or inversely estimated. This NPS modelling was applied at the Pingqiao River Basin for a storm event study using inversely estimated source runoff concentration with applicability verified[2)].

In order to quantitatively study the long-term NPS issues of the upstream area of the Taihu Basin, this study applies the hydrograph-separation-based (spatial source) NPS modelling at the Pingqiao River Basin for a one-year simulation to estimate the NPS export features in terms of different spatial zones (land-uses) and proposes targeted countermeasures for NPS control and management based on our simulations and the local conditions and limitations.

Method

We consider that the NPS nutrient loads in stream is a mixing of NPS nutrient loads from each spatial zone. This model simulates the NPS nutrient loads exported from each spatial zone and the NPS nutrient concentrations in streams. The spatial zone is considered as three land-use types (urban, agriculture and forest) and the stream runoff is mixed by runoff originated from each land-use. If we assume that the source runoff concentration does not vary temporally within a short period nor by flow mixing as the biochemical reaction can be negligible due to the comparatively short travel time in streams, the following mass conservations should be satisfied:

$$f_{A1}C_{A1} + f_{B1}C_{B1} + \cdots + f_{Z1}C_{Z1} = C_{ST1}$$

$$f_{A2}C_{A2} + f_{B2}C_{B2} + \cdots + f_{Z2}C_{Z2} = C_{ST2}$$

$$\vdots$$

$$f_{An}C_{An} + f_{Bn}C_{Bn} + \cdots + f_{Zn}C_{Zn} = C_{STn}$$

where f_A is the contribution rate of flow discharge which originates from spatial zone A; C_A is the source runoff concentration of NPS nutrient of spatial zone A; C_{ST} is stream flow concentration of NPS nutrient; A, B, ……, Z represent different spatial zones (e.g. A: urban, B: agriculture, C: forest; n_Z=3); n_Z is the number of spatial zones; 1, 2, 3, …… n represent temporally different stream samples.

Among the equations above, discharge contribution rates (f_A, f_B, and f_C) are obtained from spatial-source-based separated hydrograph by the RRI model and T-SAS. The source runoff concentrations (C_A, C_B, and C_C) are estimated by field measurement at selected typical source runoff points.

Results and discussions

The one-year simulation (2014/12/1 ~ 2015/11/30) estimated 79,010 kg of total nitrogen (TN) and 1,670 kg of total phosphorus (TP) export. The annual export coefficients in 2015 of TN and TP were estimated to be 3,543 kg/km^2 and 75 kg/km^2. Simulated stream nutrient concentrations showed satisfactory agreement with the observations as the RMSE and RE of TN is 0.77 mg/L and 19.6% and the RMSE and RE of TP is 0.051 mg/L and 34.3% in summer (**Fig.1**). The simulated NPS loads had satisfactory agreement with the observed loads for both TN and TP particularly in the precipitation and discharge concentrated summer (shown within the grey dashed lines in **Fig.2**). 50.6% and 27.3% of TN were contributed in summer and spring, and 45.2% and 33.8% of TP were contributed in summer and autumn. Our results well reflected the effects of runoff and farming activities on the seasonal nutrient load characteristics.

The targeted countermeasures were proposed based on simulation results and local conditions. The drainage system and sewage treatment improvement were given the first priority because the urban area (5.3% of total area) had the highest contribution rate of TN (15.3%) and TP (26.9%). For the agricultural area, 30% reduction of current chemical fertilizer use was estimated to reduce 9,576 kg of TN export in the selected year. Forest suffering severe deforestation and soil erosion contributed 44.3% of TN and 36.6% of TP, thus afforestation on steep slopes is considered necessary and urgent.

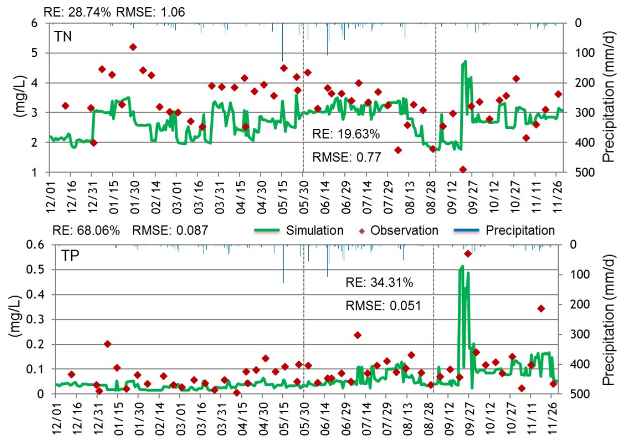

Fig.1: Stream NPS nutrient concentration simulation and validation

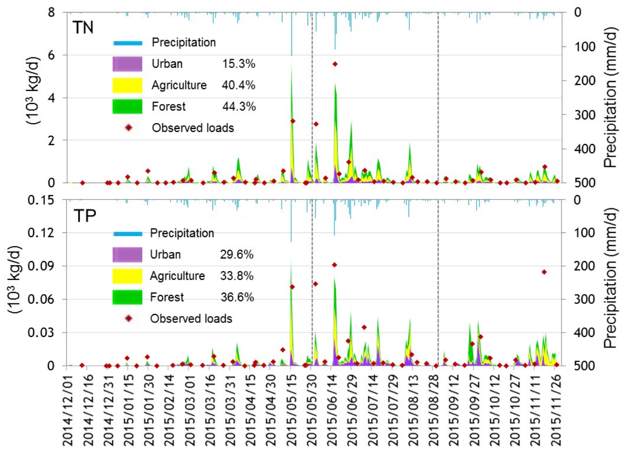

Fig.2: Long term simulation of NPS nutrient loads

References

1) Jiangsu Province of China : *Implementation plan of comprehensive control of water environment in the Taihu Basin of Jiangsu*, 2013, in Chinese.

2) Xue, H., Sayama, T., Takara, K., He, B. and Duan, W. L. : Hydrograph-separation-based non-point source pollution modelling in the Pingqiao River Basin, China, *Annual Journal of Hydraulic Engineering, JSCE*, Vol. 73, No. 4, 2017. (in print)