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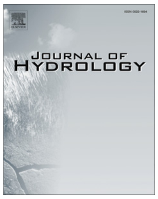

Research papers

Diffuse nutrient losses and the impact factors determining their regional differences in four catchments from North to South China

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ABSTRACT

Diffuse nutrient loss mechanism is complicated and shows remarkably regional differences due to spatial heterogeneities of underlying surface conditions, climate and agricultural practices. Moreover, current available observations are still hard to support the identification of impact factors due to different time or space steps. In this study, an integrated water system model (HEQM) was adopted to obtain the simulated loads of diffuse components (carriers: runoff and sediment; nutrient: total nitrogen (TN) and total phosphorous (TP)) with synchronous scales. Multivariable statistical analysis approaches (Analysis of Similarity and redundancy analysis) were used to assess the regional differences, and to identify impact factors as well as their contributions. Four catchments were selected as our study areas, i.e., Xiahui and Zhangjiafen Catchments of Miyun Basin in North China, Yuliang and Tunxi Catchments of Xin'anjiang Basin in South China. Results showed that the model performances of monthly processes were very good for runoff and good for sediment, TN and TP. The annual average coefficients of all the diffuse components in Xin'anjiang Basin were much greater than those in Miyun Basin, and showed significantly regional differences. All the selected impact factors interpreted 72.87–82.16% of the regional differences of carriers, and 62.72–71.62% of those of nutrient coefficients, respectively. For individual impact factor categories, the critical category was geography, followed by land-use/cover, carriers, climate, as well as soil and agricultural practices in Miyun Basin, or agricultural practices and soil in Xin'anjiang Basin. For individual factors, the critical factors were locations for the carrier regional differences, and carriers or chemical fertilizer for the nutrient regional differences. This study is expected to promote further applications of integrated water system model and multivariable statistical analysis in the diffuse nutrient studies, and provide a scientific support for the diffuse pollution control and management in China.

1. Introduction

Diffuse nutrient losses play a critical role in the deterioration of aquatic environment, which have polluted nearly half of global water bodies and the percentage is even larger in developing countries (White et al., 2009; Zhai et al., 2014). Being a rapid developing country with large agricultural land, China is also facing severe water pollution issues in major rivers and lakes. Contribution of diffuse source is up to 81% for nitrogen and 93% for phosphorus (Ongley et al., 2010). Since the mid-1990s, Tai, Dianchi and Chao Lakes have been the top priority lakes of environment restoration (Zhou et al., 2015). However, the water pollution is still a serious problem. The diffuse nitrogen and phosphorus losses are estimated to be about 64% and 33% of total received nutrients within the Tai Lake, 44.5% and 26.7% in the Dianchi Lake, 74% and 68% in the Chao Lake, respectively (Ongley et al., 2010; Shen et al., 2012). It is increasingly accepted that the nutrient losses are considerable

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pollutant sources and should be of great concern in China (Ongley et al., 2010; Lai et al., 2011; Shen et al., 2012; Ouyang et al., 2013). It is essential and crucial to estimate the nutrient loss load, identify critical loss source regions and impact factors for the environmental improvement and management.

The nutrient loss mechanism is complicated at large scales due to the dispersiveness and diversity of pollutant sources (Lai et al., 2011; Zhai et al., 2014; Ouyang et al., 2014a,b). The regional heterogeneities of climate, underlying surface conditions and agricultural management practices also result in the remarkable regional differences of nutrient losses. In the existing studies, both field experiments and mathematical modelling were adopted to depict the nutrient loss mechanism (Bechmann et al., 1998; Vagstad et al., 2004; Liu et al., 2013). However, scale issue and many uncontrollable conditions were involved in the filed experiments (Wickham et al., 2006; Shen et al., 2012). Massive investments of manpower, physical and financial resources should also be needed, particularly at large scales (Liu et al., 2013). In contrast, mathematical modelling is powerful to describe complicated relationships among precipitation, runoff and water quality variables based on the existing conditions of hydrological and nutrient cycles. It can also make full use of the available databases and estimate the nutrient losses at high spatial and temporal resolutions, which is benefit to identify critical loss regions and impact factors of diffuse pollutants. Numerous models have been developed and applied globally, such as empirical export coefficient (Uttormark et al., 1974), CREAM (Foster et al., 1980), AGNPS (Young et al., 1989), HSPF (Bicknell et al., 1997), ANSWERS (Bouraoui and Dillaha, 1996) and SWAT (Arnold et al., 1998). However, the simulation performance of existing model, especially for soil nitrogen and carbon simulation, is one of critical issues in the diffuse pollutant studies (Gassman et al., 2007; Zhang et al., 2016b).

It becomes a new direction for the diffuse pollution models to get the detailed description of soil nutrient processes by coupling soil biogeochemical models. Krysanova et al. (1998) modified SWAT based on hydrological components from SWAT and nutrient components from MATSALU model. Pohlert et al. (2006) integrated a physically based biogeochemical model (DNDC) into SWAT to predict the nitrogen loads in a mountainous catchment, Germany. Deng et al. (2011) extended DNDC framework with some fundamental hydrological features (i.e., surface runoff and soil erosion) by incorporating SCS curve and MUSLE functions. Zhang et al. (2016b) proposed an integrated water system model (HEQM) by considering multiple water-related processes in hydrology, biogeochemistry, water quality and ecology, as well as the interference of human activities. All of these studies demonstrated that the simulation performances of both hydrological and nutrient components were improved by incorporating advantageous functions of the hydrological models and soil biogeochemistry models. Integrated hydrological and biogeochemical modelling would be an effective approach to well capture the nutrient loss processes and their spatial-temporal distribution at the catchment scales.

Furthermore, the identification of critical impact factor has been conducted (Ficklin et al., 2010; Lee et al., 2010; Shrestha et al., 2011; Wu et al., 2012; Jiang et al., 2014; Ouyang et al., 2014a). The widely-used approach in the existing studies was to find the differences between the graphs of observed or simulated nutrient loads at some typical cross-stations, then identify the main impact factors and obtain their contributions. All the analyses focused on the variations of nutrient loads at the station scale, rather than the regional scale. Moreover, the current available observations were not sufficient to support this study because of their different sampling time or space steps. For example, runoff was usually observed at daily scale, but water quality concertation was observed once or twice a month in China. Although the distributed models could provide the synchronous simulations, the spatial distribution characteristics as well as the spatially heterogeneities of impact factors were underused.

Multivariable statistical analysis has strong advantages to identify the main dependent variables from numerous multivariate data sets, and to quantify their contributions to the changes of independent variables (Anderson, 1958). The typical models are multivariate analysis of variance (MANOVA), redundancy analysis (RDA), canonical correspondence analysis (CCA), all of which are widely used in the ecological sciences, medicine, financial and marketing, and so on (Hair et al., 2006). A large number of applications also existed in the studies of hydrology and environmental observations or simulations, such as univariate analyses of extreme events (Favre et al., 2004), water quality governing (Kim et al., 2005; Cloutier et al., 2008), regional hydrological classification (Wolock et al., 2004; Zhang et al., 2012) and impact assessment of dam regulation (Matteau et al., 2009; Zhang et al., 2016b). Ouyang et al. (2013, 2014b) adopted the *F*-test, correlation test, RDA and a diffuse pollution model (SWAT) to analyze the interactions of vegetation patterns with diffuse pollution, but these studies were restricted to find the relationships between diffuse pollution and landscape dynamics, rather than numerous potential factor sets. The impact factor contributions were not quantified.

The purpose of this study was to use integrated water system model for the diffuse nutrient simulation, and multivariable statistical analysis for the identification of the impact factors and their contributions to pollution loads. The specific objectives were: (1) to apply an integrated hydrological-biogeochemical model (HEQM) to capture the detailed regional characteristics of runoff and nutrient losses in the different catchments from North to South China; (2) to assess the regional differences of runoff and nutrient by the Analysis of Similarity method (ANOSIM); (3) to identify the critical impact factors and assess their contributions for the individual catchments or basins by the rank analysis method (e.g., RDA, CCA).

2. Material and methods

2.1. Study area

Miyun Basin (40°20′-41°36′N, 115°25′-117°30′E) of North China, and Xin'anjiang Basin (29°21′-30°13′N, 117°36′-118°57′E) of South China were selected as our study area (Fig. 1). In these regions, Miyun and Xin'anjiang Reservoirs are main drinking water sources for Beijing and Hangzhou cities, respectively. They are the good vegetation regions with the major land use of forest and grass. Each of the river basin with two major catchments, Xiahui and Zhangjiafen Catchments of Miyun Basin, Yuliang and Tunxi Catchments of Xin'anjiang Basin, was considered for the further study in this paper. Table 1 summarized the general characteristics of these four catchments.

The underlying surface and climate conditions are quite distinct between Miyun and Xin'anjiang basins. In Miyun Basin, the whole area is 15,369 km^2 (Xiahui Catchment: 5340 km^2; Zhangjiafen Catchment: 8506 km^2). It belongs to the cold climate region with dry winter and hot summer (dwa) according to Köppen climate classification (Peel et al., 2007). The annual average precipitation and temperature are around 480 mm and 10 °C, respectively. The major soil types were alfisol and semi-alfisol. In Xin'anjiang Basin, the whole area is 5843 km^2 (Yuliang Catchment: 1599 km^2; Tunxi Catchment: 2670 km^2). It belongs to the temperate climate region with hot summer but without dry season (cfa) (Peel et al., 2007). The annual average precipitation and temperature are around 1800 mm and over 15 °C. The major soil types were ferralsol and primitive soil.

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