Journal of Hydrology 389 (2010) 373–380

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Long-term vegetation landscape pattern with non-point source nutrient pollution in upper stream of Yellow River basin

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ARTICLE INFO

Article history:
Received 24 September 2009
Received in revised form 22 April 2010
Accepted 10 June 2010

This manuscript was handled by L. Charlet, Editor-in-Chief, with the assistance of Peter Wolfgang Swarzenski, Associate Editor

Keywords:
Non-point source pollution
Nutrient pollutants
Landscape pattern
SWAT
Yellow River basin
Tempo-spatial dynamics

SUMMARY

Grassland, forest, and farmland are the dominant land covers in upper catchments of the Yellow River and their landscape status has direct connection with dynamics of non-point source (NPS) pollution. Understanding the correlations between landscape variables and different formats of NPS nutrients pollutants is a priority in order to assess pollutants loading and predicting the impact on surface water quality. The regional vegetative cover in 1977, 1996, 2000 and 2006 was determined by classifying historical multi-temporal Landsat imagery and clipping data from the National Landcover Database. The landscape pattern is expressed means of metrics such as patch density, edge density, fractal distribution index, all of which were calculated by FRAGSTATS. The soil and water assessment tool (SWAT) was used to analyze and visualize the fate of NPS nitrogen and phosphorus loads in diverse formats from different land cover types in different years. Statistical analysis indicated that the grassland landscapes played a major role in NPS nutrient pollution dynamics and grassland patch edges benefited pollution control. However, the presence of more forest and farmland lead to more NPS nitrogen emissions. It was found that grassland areas reduced nitrogen loss and had a multi-function role in the nutrient pollution process. Farmland was the direct source of organic nutrients, but did not have great impacts on sediment P and soluble N loadings. Forest areas contributed NPS nutrients pollution loading. The statistical models derived in this study can be used to estimate watershed NPS nutrient pollution losses. These equations can help identify pollution sources and suggest appropriate and effective solutions for planing basin management practices.

1. Introduction

During the last several decades, and in spite of considerable efforts to reduce point source pollution, water quality often has not improved significantly. This may be due to the contribution of non-point sources (NPS) of pollution in both developed and developing countries (Leone et al., 2009). The major NPS pollutants are nitrogen (N) and phosphorus (P), and they are the leading causes of water degradation in rivers and lakes. Nutrient losses from farmland, grassland and forest are important factors limiting water quality (Ribarova et al., 2008; Munodawafa, 2007). Long-term NPS nutrient pollution modeling plays a critical role in environmental management and for determining the value of vegetation in limiting NPS pollution.

With the increasing importance of prevention and protection of natural water resources, a number of studies have been carried out to assess NPS pollution (Duchemin and Hogue, 2009). The fate of NPS nutrient pollutants is critical in water quality modeling. Nutrients are delivered to water bodies from multiple sources, each having different transport and composition characteristics. The variation of spatial–temporal patterns of NPS pollution produces different impacts (Edwards and Withers, 2008). Inputs of nitrogen in a watershed are derived from atmospheric deposition, mineral N pools of top soil, and fertilization. Furthermore, ammonia, mediated by microorganisms can mineralize from soil organic matter. NPS nutrient pollutants have two modes of transportation, namely by being dissolved in water and associated with the transportation of soil particles. Nitrogen can be found in various forms: molecular N, organic N, ammonium N, nitrite N and nitrate N (Maillard et al., 2008). N reduction and loss can result from denitrification, uptake of plants, percolation, lateral flow, and surface runoff. P is less mobile than nitrogen because it is less soluble, and, in general, losses via overland flow are affected by surface soil P concentrations and land management practices (Bowes et al., 2008).

Field research on nutrient pollution is both expensive and time consuming. Because of the temporal and spatial variability in processes, regular monitoring requires a large investments. As a result, watershed-scale modeling of NPS pollution has become useful and popular (Easton et al., 2008). Physically based watershed modeling

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doi:10.1016/j.jhydrol.2010.06.020

can take into consideration most of the factors that cause spatial and temporal variation in NPS pollutant loads. Several modeling systems can simulate hydrologic processes, soil erosion, and nutrient transport via surface runoff, interflow, and groundwater flow, as well as in-stream nutrient cycling at the catchment scale. Several models have been applied to estimate nutrient loadings in watersheds (Viotti et al., 2002; Cho et al., 2008). Among the NPS pollution simulation models, the soil and water assessment tool (SWAT) can integrate local weather variables, soil properties, topography, vegetation and land management scenarios.

Vegetation cover status has been recognized as major factor contributing to watershed NPS nutrient movement (Bouldin et al., 2004). However, little attention has been paid to long-term watershed responses of NPS nutrient pollution on vegetation and landscape variations. In this research, we simulated watershed organic N, nitrate N, sediment P and organic P over 4 years and correlated them to the corresponding areas of the three major types of vegetation in the study area. This paper reports on a pilot attempt to employ the SWAT model system and other geospatial technologies to explore impacts of vegetation landscape patterns on NPS nutrient pollution loads. The findings demonstrate the influence of landscape patterns on NPS nutrient pollution dynamics provide insights into watershed NPS nutrients loss processes and allow to prediction of watershed NPS nutrient pollutant loads. In brief, the two key aims in this paper are: (i) use temporal land cover data to simulate long-term variations of NPS nutrients pollution in upper catchments of the Yellow River; and (ii) characterize the correlation of NPS nutrients losses with vegetations' landscape patterns.

2. Materials and methods

2.1. Study watershed description

The studied watershed is a part of upper stream of the Yellow River in central China and has a total drainage area of 3,428,447 ha. This area has a typical continental climate, which is cold, dry, and seasonally variable (Fig. 1). The average annual temperature is about −2.3 °C, without a completely frost-free season (Feng et al., 2005). Local topography varies greatly, with altitude between 1700 m and 4991 m. The dominant land covers in this watershed are grassland and forest. The land cover and landscape condition of upper catchments of Yellow River basin have been degraded significantly with rapid socio-economic development and environmental change during recent decades (Jia et al., 2006).

2.2. Research framework

The analytical framework of the research comprises four steps. First, land cover was mapped by classifying multi-temporal Landsat images over 4 year periods, by clipping the data from national basic databases. Then, with the spatial databases, sensitive parameters were selected and the SWAT model was validated for water, sediment, and nutrient yields. The tempo-spatial distribution of watershed NPS nutrients pollution was simulated. Third, the area and landscape patterns of three vegetative covers were calculated and correlated with NPS nutrient pollution. Finally, correlations between NPS nutrient pollution loads and vegetation area and landscape patterns were identified.

2.3. Temporal land cover data

The land cover data act as the bridge between NPS pollution and its response to vegetative landscape pattern According to availability of satellite images and land cover databases, the year 1977, 1996, 2000 and 2006 were selected for simulation. The land cover data in 1996 and 2000 were part of national databases, which were classified from Landsat series images. The accuracy of the land cover was assessed before release. The land cover data in 1977 and 2006 were obtained from Landsat MSS and TM images, which were interpreted by us according to the same classification process used for compiling the national database (Liu et al., 2005). There were no reference data for the interpretation of 1977 images; therefore, no accuracy estimations were implemented. The accuracy assessment of TM based map in 2006 was conducted by site-specific methods whereby points in land cover maps were compared with ground control points (Chen et al., 2006). Eighty-eight control

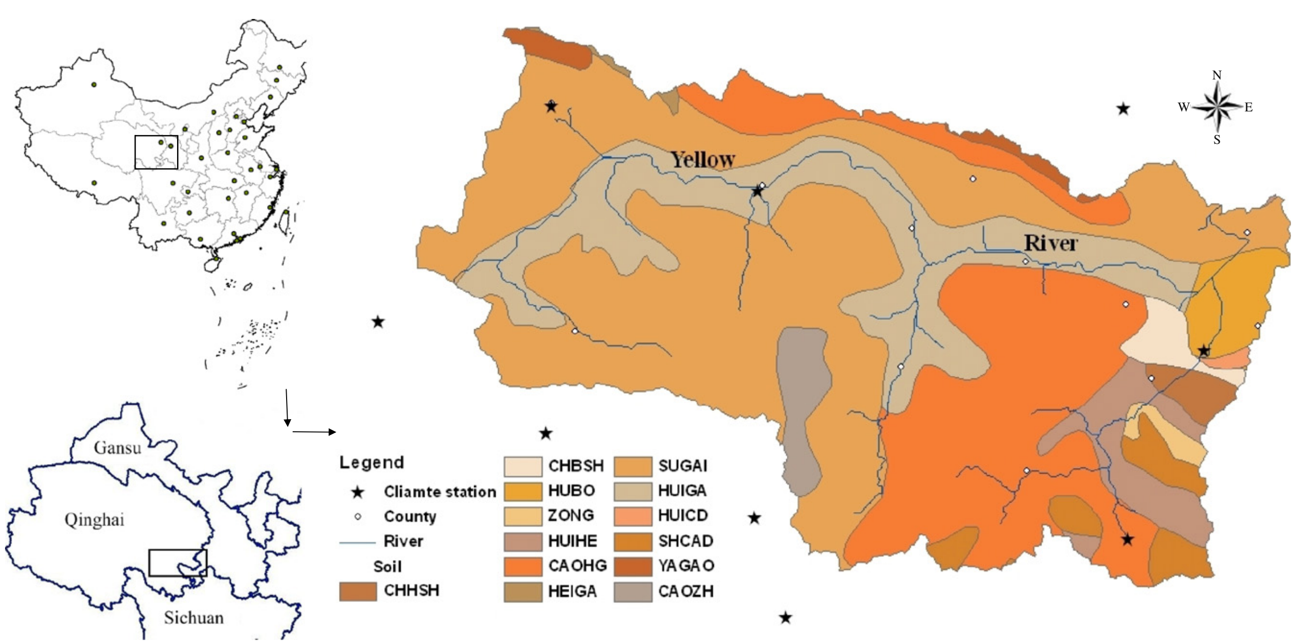

Fig. 1. Location, soil property and climate station distribution of the study area in the upper catchments of the Yellow River basin.