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Spatiotemporal patterns of non-point source nitrogen loss in an agricultural catchment

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Abstract

Non-point source nitrogen loss poses a risk to sustainable aquatic ecosystems. However, non-point sources, as well as impaired river segments with high nitrogen concentrations, are difficult to monitor and regulate because of their diffusive nature, budget constraints, and resource deficiencies. For the purpose of catchment management, the Bayesian maximum entropy approach and spatial regression models have been used to explore the spatiotemporal patterns of non-point source nitrogen loss. In this study, a total of 18 sampling sites were selected along the river network in the Hujiashan Catchment. Over the time period of 2008–2012, water samples were collected 116 times at each site and analyzed for non-point source nitrogen loss. The morphometric variables and soil drainage of different land cover types were studied and considered potential factors affecting nitrogen loss. The results revealed that, compared with the approach using the Euclidean distance, the Bayesian maximum entropy approach using the river distance led to an appreciable 10.1% reduction in the estimation error, and more than 53.3% and 44.7% of the river network in the dry and wet seasons, respectively, had a probability of non-point source nitrogen impairment. The proportion of the impaired river segments exhibited an overall decreasing trend in the study catchment from 2008 to 2012, and the reduction in the wet seasons was greater than that in the dry seasons. High nitrogen concentrations were primarily found in the downstream reaches and river segments close to the residential lands. Croplands and residential lands were the dominant factors affecting non-point source nitrogen loss, and explained up to 70.7% of total nitrogen in the dry seasons and 54.7% in the wet seasons. A thorough understanding of the location of impaired river segments and the dominant factors affecting total nitrogen concentration would have considerable importance for catchment management.

Keywords: Non-point source nitrogen; Bayesian maximum entropy; River distance; Spatial regression; Spatiotemporal pattern

1. Introduction

Non-point source nitrogen pollution is a leading cause of degraded water quality and impaired aquatic ecosystems (Carpenter et al., 1998; Sun et al., 2013). Remedial actions require the identification of impaired river segments and dominant factors affecting nitrogen loss. Despite the extraordinary effects of remedial actions, non-point source nitrogen from agricultural catchments remains one of the pollutants most difficult to monitor and regulate due to its diffusive nature, budget constraints, and resource deficiencies (Yang and Jin, 2010). Furthermore, non-point source nitrogen loss is contingent on catchment characteristics, including land use, soil, and topography, and is thus typically episodic and highly localized (Donner, 2003). Variations in catchment characteristics often result in variations in ecological and hydrological conditions, thereby altering the production, transport, and delivery of pollutants to rivers (Cundill et al., 2007). A thorough

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understanding of impaired river segments and the dominant factors affecting non-point source nitrogen loss would have considerable importance for catchment management.

Many studies have discussed methods for predicting non-point source pollution along impaired river segments (Bhaduri et al., 2000; Xiao and Ji, 2007). One method is to employ geostatistics-based approaches that use the principle of correlation among similar data points to derive values at unmonitored locations (Ignaccolo et al., 2014). Traditional geostatistical methods, such as the kriging and cokriging techniques, use a Euclidean metric to calculate distances between the monitoring points. However, these techniques are all linear estimators (Castillo-Santiago et al., 2013). It is often the case that the parameter of interest behaves nonlinearly. The spatiotemporal Bayesian maximum entropy approach is an extension of the linear geostatistical method that was developed as a non-Gaussian and nonlinear estimator (Christakos, 1990). This method provides a rigorous mathematical framework to process a wide variety of knowledge bases characterizing the spatiotemporal distribution and monitoring data available. However, many studies have only examined ambient environmental parameters that were not inherently restricted by the river network configuration. The river plays an important role in the movement of non-point source nitrogen. Hoef et al. (2006) showed that a flow-weighted covariance model using the river distance is more accurate than a model using the Euclidean distance. On the other hand, Cressie et al. (2006) compared the Euclidean distance model and flow-weighted covariance model and found that the Euclidean distance model performed better.

Multivariate statistical models have been widely used to quantify the relationship between catchment characteristics and nitrogen in rivers. Despite their great potential for investigating catchment characteristics to determine the causes of pollution, the use of conventional statistical methods also presents particular analytical challenges. One important obstacle is the inability of these methods to address the problem of auto-correlated data, particularly in cases with few observations (Yuan, 2004; Yan et al., 2013). Spatial data exhibit autocorrelation, which leads to difficulties in meeting the assumptions and requirements of conventional regression techniques. Spatial regression models, especially spatial lag regression models, incorporate spatial dependence in the form of lag and have proven useful for detecting spatial patterns in river water quality (Ye et al., 2007).

The present study was undertaken against this background. The specific objectives were (1) to estimate the non-point source nitrogen at unsampled locations with limited monitoring data, (2) to distinguish the impaired river segments, and (3) to determine the main factors affecting non-point source nitrogen loss.

2. Study area and methods

2.1. Study area

This study was conducted in the Hujiashan Catchment, which is located in the Hanjiang Basin of central China, between the latitudes of 32°44′N and 32°49′N and longitudes of 111°12′E and 111°15′E. The catchment has a drainage area of approximately 23.9 km^2 (Fig. 1) and the population is estimated at 2300 in the residential lands. Elevations within the catchment range from 258 m to 702 m. The catchment is characterized by a subtropical monsoon climate, with a mean annual temperature of 16.1°C and annual precipitation varying between 800 mm and 1000 mm. More than 80% of the rainfall occurs from May to October (Li et al., 2009), which induces nitrogen loss due to the effect of runoff. To account for seasonal variation, non-point source nitrogen data were divided into two categories: data in dry seasons (i.e., November to April) and data in wet seasons (i.e., May to October). Soil types are dominated by purple soil and yellow-brown soil according to the Chinese soil classification system (NSSO, 1998), corresponding to Alfisols and Inceptisols, respectively, in *Soil Taxonomy* of the Unites States (USDA-NRCS, 1999).

2.2. Data processing

2.2.1. Nitrogen data

The dominant land cover in the Hujiashan Catchment includes forests (49.8%), croplands (45.9%), residential lands (2.1%), grasslands, and water bodies (Fig. 2). Combining land use maps and field investigations, we found that croplands and residential lands are concentrated along the river network and there are no drained farmlands. Fertilizers, including ammonium nitrate and phosphate, are applied to the croplands. Methane tanks have been built by every household and there

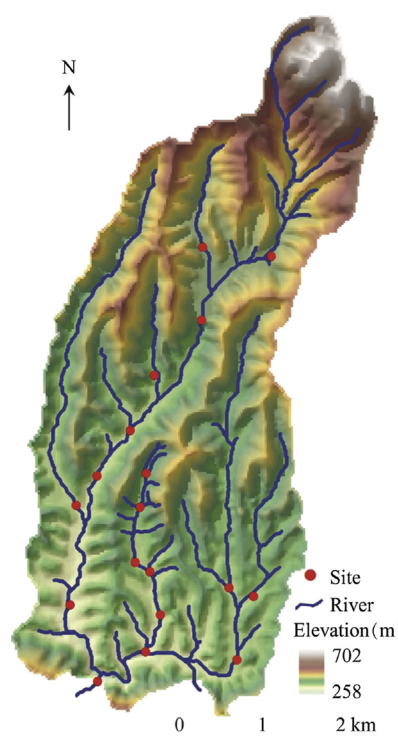

Fig. 1. DEM image of study catchment and monitoring sites.