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Vertical and horizontal distribution of soil parameters in intensive agricultural zone and effect on diffuse nitrogen pollution

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ABSTRACT

Understanding the spatial relationships of diffuse agricultural pollution with soil properties at a sub-basin scale is an innovative way to characterize the pollution yield. The objectives of this study was to identify the interaction of soil parameters with diffuse nitrogen (N) loading at spatial-vertical directions, which provide an optional method to assess the diffuse N pollution. The diffuse N loading of a sub-basin was simulated with the Soil and Water Assessment Tool with the consideration of land use (upland and paddy rice). Soil properties were analyzed in terms of eight parameters by employing a 1.5 km-grid soil sampling process at two depths across multiple sub-basins. The spatial soil properties were interpolated for each sub-basin. The spatial distributions of total nitrogen (TN), iron (Fe), manganese (Mn), and cadmium (Cd) exhibited the same pattern at two soil depths, but the vertical patterns of available nitrogen (AN), soil organic carbon (SOC), sulfur (S) and lead (Pb) varied. Overlaying the diffuse N loading and land use distribution, it was found that the sub-basins of upland and paddy rice were primary contributors. The diffuse N discharged from upland sub-basins was about 50% lower than that from paddy rice. The correlation analysis of soil variables with diffuse N indicated that the top layer had a stronger relationship with the diffuse N than the subsurface, which had more direct impact on the pollution. A partial least squares (PLS) regression analysis was employed to identify the key soil variables in surface layer. The analysis indicated that the metal parameters (Fe, Mn, Cd, and Pb) were the important factors for diffuse N loading. However, the TN in the paddy rice was the principal predictor. With the soil property information, the diffuse N yield from the two types of farmlands can be assessed in a simplified way. The developed method in this paper is flexible and efficient, which also is compatible with results of the SWAT model.

1. Introduction

Diffuse (or non-point-source) pollution from agricultural area is a main source of water quality degradation and a regulatory priority due to huge loading (Schreiber et al., 2001; Prasad et al., 2004). Water quality in agricultural basins is frequently degraded by nitrogen (N) discharge during cultivation (Jégo et al., 2008). It is difficult to express the diffuse agricultural pollution generated by a basin using traditional point-source pollution monitoring methods, such as pollution concentration and flow monitoring (Mbonimpa et al., 2014). Consequently, temporal-spatial pattern identification has been the subject of many studies, leading to the development of methods such as statistical analysis and distributed models (Giupponi and Vladimirova, 2006; Mouri et al., 2011). However, these methods ultimately rely on huge quantities of monitoring and spatial data (Ouyang et al., 2008). In this paper, the spatial relationships of soil properties with diffuse N loading are identified and applied to assess the spatial loading, which is a more effective measurement than regular modeling for watershed pollution assessment.

In the last decade, attention has shifted from agricultural production to diffuse pollution because of its effect on ecosystems. Control of diffuse N pollution from agricultural sources is regarded as an urgent environmental protection issue related to water safety (Hadas et al., 1999; Panagopoulos et al., 2012). Previous studies have shown that the diffuse N load varies under different land use conditions (Kersebaum et al., 2003; Ouyang et al., 2013a). Under similar land use condition, the diffuse N loading shifted within and between rainfall events, crop cultivation and soil properties (Braskerud, 2002; Fricks et al., 2009). The N transfer in soil is

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affected by the physico-chemical aspects, water content profiles, and microbial community (Cliff et al., 2002). In recent years, several routine field monitoring methods have been applied to obtain a reliable quantitative information on N leaching under diverse conditions (crop types, fertilization and cultivation practices) (Garnier et al., 2010). This field monitoring is labor-intensive and can only identify the load at the field and small sub-basin scales.

Monitoring water quality variation at the outlet of agricultural basin is a basic way to understand diffuse N pollution discharging to the water bodies. The influences of land use, agricultural practice, and climate change on diffuse N yield have been observed (Ouyang et al., 2010; Praskievicz and Chang, 2009). However, regular monitoring cannot assess high temporal resolution loading variance over a long term period or basin larger than one million hectare (Mbonimpa et al., 2014). To better characterize the temporal and spatial variations of diffuse N pollution of basin, the physically based models with geographical information system and remote sensing data have been employed in recent decades (Birkinshaw and Ewen, 2000). The temporal-spatial pattern of pollution loading can be simulated by models using different approaches that can also determine critical source areas (Trevisan et al., 2010).

In this study, potential diffuse N pollution loading was calculated using the Soil and Water Assessment Tool (SWAT), which is a widely applied process-based distributed modeling tool (Grizzetti et al., 2003). SWAT can reproduce the temporal-spatial distribution of basin diffuse pollution and can assess the leaching of N from agricultural sources, taking into considerations the hydrogeologic and land use factors (Gatzke et al., 2011; Ouyang et al., 2009). The SWAT model was employed because of its capability to simulate the water, sediment, and pollution yields of each sub-basin in large and complex ungauged basins (Arnold et al., 1998; Akhavan et al., 2010). The SWAT model also simulates the transformation and movement of N within each hydrological response unit, which delineate watershed into sub-basin with topographic and soils data. The N from fertilizer or manure can be covered as an input during SWAT simulation. The losses of N from soil by crop uptake, surface runoff, lateral flow, percolation and erosion can also be identified by SWAT (Neitsch et al., 2005).

Diffuse N discharge dynamics are determined by soil composition and structure, which may vary at diverse scales (Gutierrez and Baran, 2009). Understanding the spatial relationships of diffuse N pollution yield with soil property parameters in an agricultural basin is not only useful for balancing fertilizer but also for predicting the potential pollution loading in an effective way. The objectives of this research were: (a) to determine the spatial distributions of diffuse N loading and eight soil property parameters at the sub-basin scale and analyze their spatial relationships, (b) to determine which soil parameters can be used to reliably assess the diffuse N loading, and (c) to understand the relationship of soil properties at two depths with the diffuse N loading.

2. Materials and methods

2.1. Study site description

The study basin (149 km^2) is an agriculture-dominant basin located in the Heilong Jiang province in northeastern China (47.25N, 134.02E), (Fig. 1). The annual average rainfall is 583 mm, and most rainfall occurs in the summer. The local agriculture was developed by converting wetlands into farmlands, which has created pollution and environmental concerns. Increased N availability induced by human activities accelerated water quality degradation and affected soil organic carbon dynamics in wetlands (Ouyang et al., 2013b).

2.2. Soil sampling and analysis

The soil samples were collected at the surface (0–20 cm deep) and subsurface (20–40 cm deep) layers between April 22 and April 30, 2011. The 30 sampling sites were selected based on a randomized design of blocks fixed in each 1.5-km grid. The basic physical properties of soil were firstly analyzed and their detailed information was listed in a previous paper (Ouyang et al., 2013a). The soil available nitrogen (AN), total nitrogen (TN), soil organic carbon (SOC), sulfur (S), iron (Fe), manganese (Mn), cadmium (Cd), and lead (Pb) at two layers were measured in the laboratory, which were used for the interaction analysis with the diffuse pollution load.

The TN and SOC were measured using a C/H/N Elemental Analyzer (Euro Vector S.P.A EA3000, Milan, Italy; dry combustion temperature, 900 °C). The soil AN was determined by an NaOH diffusion method (Stanford, 1982), which was the mineral N concentration in soil. The S, Fe, Mn, Cd, and Pb were digested with a mixed acid containing HF, HNO_3 and $HClO_4$ (Kara et al., 1997) and then determined by inductively coupled plasma optical emission spectrometry (ICP-OES, IRIS Intrepid II XSP, Thermo Electron, USA).

2.3. SWAT model preparation

SWAT databases of land use, topography, soil, climate, and agricultural practice were imported. The land use distribution in 2009 was interpreted with Landsat image (Fig. 1). The paddy field was reclassified as paddy rice and the upland was reclassified as soybeans. The agricultural practices of two dominant crops were considered which included the planting and harvest date,

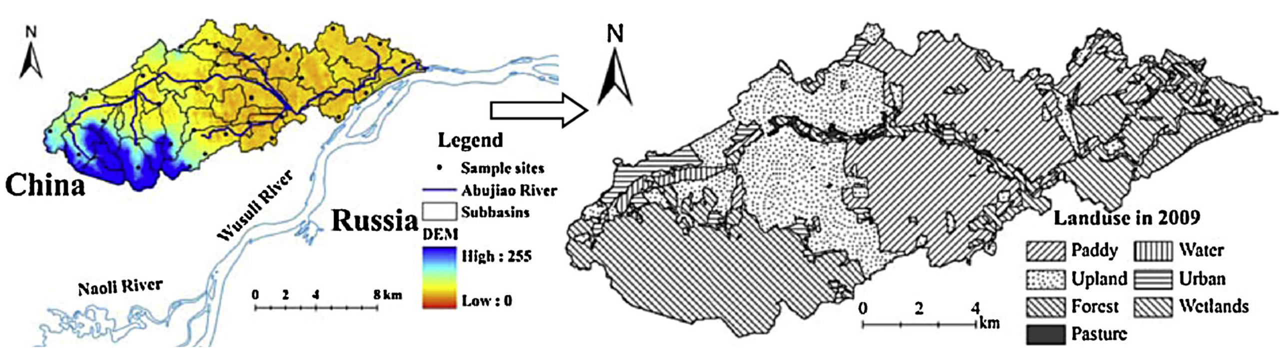

Fig. 1. Location, topography (DEM) with sampling locations, and land use distribution of study area in northeastern China.