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Research papers

Modified control strategies for critical source area of nitrogen (CSAN) in a typical freeze-thaw watershed

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ABSTRACT

The management of critical source areas of diffuse nitrogen (CSANs) remains challenging in freeze-thaw areas due to the different N loss characteristics in different hydrological conditions and seasons. To address these challenges, a modified strategy was proposed in this study using the Soil and Water Assessment Tool (SWAT) to simulate diffuse N loads in the study catchments. Specifically, the spatial and temporal variations of CSANs caused by differences in precipitation and seasons were considered. In addition, the selection of best management practices (BMPs) was selected according to BMP performance and their seasonal characteristics in diffuse N control. The diffuse N load formed during freeze-thaw seasons accounts for approximately 50% of the annual diffuse N load. The diffuse N load discharged to rivers was higher in wet conditions than dry conditions by 127.4% and 181.5% during freeze-thaw seasons and growing seasons, respectively. The spatial distribution of CSANs was more sensitive to differences between freeze-thaw and growing seasons. Among BMPs, buffer strips (BS), no tillage (NT) and reducing N fertilizer applications (RNFA) all showed differences in their diffuse N removal efficiency under different hydrological conditions and seasons, while reforestation operations were not affected by these factors. The benefit of reforestation operations was lower in flatter areas. When areas with slopes greater than 2 degrees were reforested, the average N removal efficiency of the 1st CSAN could be as high as 82.4%. In the 2nd CSAN, the average N removal efficiency of BS was relatively constant across freeze-thaw seasons. Across growing seasons, the N removal efficiency of BS in wet years was 8%-10% higher than in dry conditions due to the lower percentage of lateral flow. The average N removal efficiency of NT was higher during freeze-thaw seasons and lower during growing seasons with average values of 9.3% and 6.1%, respectively. The N control efficiency of RNFA 10% and RNFA 20% (a 10% or 20% reduction in fertilizer application, respectively) was highest during dry growing seasons with average N control efficiencies of 9.6% and 17.8%, respectively. This study is expected to improve diffuse pollution control in cold areas and to improve the understanding of how N removal efficiency of BMPs responds to variations in hydrological conditions.

1. Introduction

Water degradation caused by excess nitrogen (N) inputs is the most pressing water-quality issue in intensive agricultural areas (Huang et al., 2014; Shen et al., 2014; Rathnayake, 2015). Diffuse N loads vary spatially and temporally on both local and regional scales, affected by interactions among hydrological processes, land-use patterns, terrain and human activities (Ouyang et al., 2013; Zhang et al., 2016; Milledge et al., 2012; Valipour, 2016a). To overcome the challenges presented by the spatiotemporal variance of diffuse N loads, traditional diffuse N control strategies must be modified, especially in freeze-thaw areas. To improve the management of diffuse N pollution in cold areas, a modified strategy is developed to improve the identification of critical source areas of diffuse N (CSAN) and the selection of best management practices (BMPs).

Sub-basins with vulnerable soil and water conservation capacities and fragile ecosystems are often termed critical source areas (CSAs) (Shore et al., 2014), which typically have a high transfer risk and mobilization potential for N (Huang et al., 2013). Recent

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studies indicate that CSAs are sensitive to changes in hydrological conditions (Chen et al., 2014; Viero and Valipour, 2017). Specifically, land-use patterns, agricultural management, soil texture and other underlying surface properties can all affect how N loss responds to changes in hydrological conditions (Thomas et al., 2016; Yannopoulos et al., 2015). Inter-annual variation in precipitation also contributes to variation in the distribution of CSAs (Tsuzuki, 2015) due to the inherent spatiotemporal heterogeneities of catchments (Jordan et al., 2012). In cold regions, both the freeze-thaw cycles and distribution of precipitation play an important role in the transfer of diffuse N (Urakawa et al., 2014; Han et al., 2010; Iwata et al., 2010). In some mid-high latitude areas of the northern hemisphere, the freeze-thaw period could be attributed to the majority of diffuse N load (Liu et al., 2013a). However, in the traditional framework, the CSANs were identified based on annual diffuse N load and a method neglects the spatiotemporal variance of the CSAN (Fig. 1). Therefore, considering the tight connection between hydrological condition and nitrogen loss, rather than focusing solely on annual precipitation, it is important to analyse the impact of seasonal hydrological conditions on CSAN distributions.

Seasonal variation in N loss presents another challenge for controlling diffuse N pollution. During the growing season, N loss from intensive agricultural areas is mainly composed of soluble synthetic N fertilizer and eroded soils (Buckley and Carney, 2013; Vagstad et al., 2004). During the freeze-thaw season, the crop residues, which are crushed and incorporated into the soil surface, become the main potential source of diffuse N in this period (Liu et al., 2014a). Constrained by the frozen soil, N cannot be exported to water-bodies through lateral flow. The undecomposed crop residues are stored in the surface soil and are later flushed away by snowmelt at the end of the freeze-thaw season (Tiessen et al., 2010). The different seasonal characteristics of diffuse N pollution creates additional uncertainties in CSAN identification and management.

Controlling N loss in CSANs has become a consensus priority (Shen et al., 2015; Giri et al., 2014), aimed directly at mitigating the diffuse N pollution caused by agricultural activities. A widely accepted approach has been the implementation of individual or combined BMP measures in all CSANs (Du et al., 2014). However, this is a simple method that does not consider differences in contamination levels among sub-basins or in the applicability of BMPs in different seasons (Syversen, 2002; Woznicki and Nejadhashemi, 2012; Roseen et al., 2009). Therefore, a more specific method for selecting and placing BMPs, accounting for the complicated regional climate characteristics and hydrological processes of cold areas, is required to mitigate diffuse N pollution.

As mentioned above, the traditional method for the identification and management of CSAN is a generalized method without considering the dramatic changings of temperature and precipitation in freeze-thaw areas. Overlooking the spatial variance of the CSAN in different seasons may result in inaccurate identification or the omission of the CSAN, which could appear only under certain circumstances (dry, normal and wet seasons). The defects could further lead to the improper layout of BMPs and overestimation of N removal efficiencies. In this paper, an modified method was proposed to improve the watershed management of freeze-thaw areas that highlights the combined the impact of hydrological conditions and seasonal alterations on the CSAN identification. Moreover, the placement of BMPs was also modified considering both their N removal efficiency and adaptability to seasonal alterations. Based on the modified framework, a case study was carried out for a freeze-thaw agricultural area, using the Soil and Water Assessment Tool (SWAT, a semi-distributed hydrological model) to simulate diffuse N loads and evaluate the performance of BMPs. Specifically, the detailed objects of this study are threefold: 1) provide a modified framework suitable for managing diffuse N pollution in cold areas; 2) analyse how the spatiotemporal distribution of CSAN responds to changes in seasonal hydrologic conditions; and 3) explore seasonal differences in the performance of typical

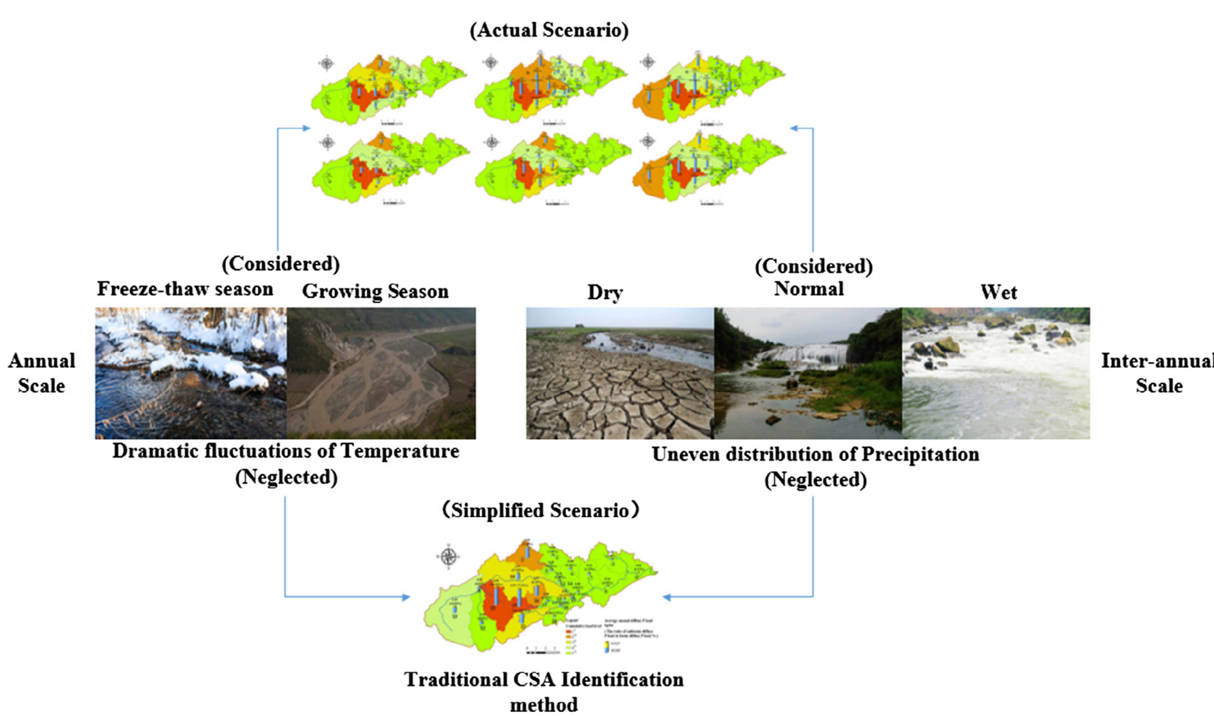

Fig. 1. The defects existed in the traditional CSA identification method.