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Spatially explicit estimation of soil denitrification rates and land use effects in the riparian buffer zone of the large Guanting reservoir

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ABSTRACT

An important function of riparian ecosystems, usually characterized as nitrate-loaded wetland environments, is nitrogen removal by denitrification. Riparian buffer zones around large dams and water reservoirs are also recognized as hotspots for emission of nitrogen (N_2) and nitrous oxide (N_2O), the latter being a strong greenhouse gas. Research has proven that land use has an important effect on soil denitrification. A spatial landscape-scale approach for analyzing denitrification processes and land use effects can therefore be considered important for an adequate assessment and management of NO_3^- losses and N_2O emissions in riparian ecosystems.

In this study, we couple a soil denitrification process model with remote sensing data and techniques to analyze the spatial and temporal dynamics of soil denitrification in the riparian area of the Guanting reservoir, an important water supply of Beijing, China. SPOT-5 and Landsat TM5 satellite data were used to interpret the spatial land surface information and derive model parameters. A laboratory-scale anaerobic incubation experiment was used to estimate the soil denitrification model parameters for the different soil types. Modeling results were compared and validated with data from a nearby experimental N_2O emission research site. The overall average soil denitrification rate (SDR) of the Guanting riparian basin was 32.45 mg N m^{-2} d^{-1} during the simulation period from March to September 2007, with a maximum of 370.49 mg N m^{-2} d^{-1} appeared in August and the minimum of 0.02 mg N m^{-2} d^{-1} in March. Bottomland and wetlands had large SDR's, with an average daily rate of 80.20 and 136 mg N m^{-2} d^{-1} respectively. Forest, grassland and shrub showed lower values, with average daily rates of 25.21, 18.77 and 16.59 mg N m^{-2} d^{-1} respectively. The modeling results also indicated that farmland and orchards had a relative high SDR (34.09 and 33.25 mg N $m^{-2}d^{-1}$ respectively), with large fluctuations observed between June and August due to agricultural practices. As soil denitrification rates and N_2 and N_2O emissions showed to be strongly correlated to the different land use practices, this could be taken into consideration when planning best management strategies for non-point source pollution control and greenhouse gas mitigation.

1. Introduction

As a unique terrestrial aquatic ecotone, the riparian landscape is very important to improve water and habitat quality (Naiman and Decamps, 1997). Since the 1970's, the functioning of riparian ecosystems is gradually been understood and their importance is well accepted today. In many countries, riparian buffer zones are used in ecological engineering (Kuusemets and Mander, 1999; Syversen, 2005). However, most ecological engineering practice today is still based on local site-by-site planning solutions, which can eventually lead to more problems in the near to long-term, especially in dynamic riparian landscapes. A "landscape-scale" approach for riparian ecosystem management can therefore be considered as important, and it can be effective to control nonpoint source (NPS) pollution at larger and or river basin scale.

The riparian ecological system has some essential functions, one being a key factor in decreasing the nitrogen loads in surface runoff, soil water and groundwater (Peterjohn and Correll, 1984; Jordan et al., 1992; Lin et al., 2004; Nina, 2005). We usually recognize three main biological processes to remove nitrogen in riparian zones: (1) uptake and storage in vegetation, (2) microbial immobilization and storage in the soil, (3) microbial conversion to gaseous forms of nitrogen. Lowrance et al. (1997) highlighted that gaseous emission is the main form for nitrogen removal in riparian zones especially by soil denitrification.

Denitrification is a complex microbial-based process in the nitrogen (N) cycle; nitrate is transformed into gaseous N form, first as the greenhouse gas N_2O which may be further reduced to non-toxic N_2 gas. Based on a review of ^{15}N field N balance studies, Hauck (1981)

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estimated that, on average, 30% of fertilizer ^{15}N was removed by soil denitrification. However, one of the byproducts of denitrification is N_2O (Angela et al., 2006), which is a strong greenhouse gas (IPCC, 1996; Flessa et al., 2002). So, denitrification can also be considered partly as the source of an environmental burden. From the aspect of total watershed ecological health, this means that for appropriate management of the riparian zones, it is crucial to study the spatial and temporal effects of denitrification on the nitrogen balance in riparian systems.

It has been shown nowadays that landscape characteristics have a large effect on soil denitrification and N_2O emissions. Most research on nitrogen balances and denitrification originates from agriculture research and management (Aurélie et al., 2007). For example, converting cropland to grassland would reduce the greenhouse gas emissions (Desjardins et al., 2005). By performing a laboratory investigation on N_2 and N_2O emissions in arable soils, Liu et al. (2007) indicated that there is greater potential for N_2 or N_2O loss from no-till soils than conventionally tilled soils. However, neither the landscape nor the function of agriculture and riparian system are very different, it's more necessary to make clear how and quantify the land use effect on riparian soil denitrification.

Soil denitrification depends on environmental conditions such as oxygen and water content, temperature, and pH. In principle, it can be measured, in lab or in situ, but these methods have drawbacks. So, a number of different approaches have been used to develop denitrification models in N cycling. Most models are site specific, and do not apply to the basin scale, such as the DNDC model (Li et al., 2000; Liu et al., 2006), the EPIC model (Sharply and Williams, 1990), the SWAP model (van Dam et al., 1997) and REMM model (Inamdar et al., 1999). In fact, there exists no model that can describe the riparian soil denitrification process at an appropriate and sufficiently high spatial scale. It's therefore necessary to develop methods to quantify the soil denitrification progress and improve the riparian basin management at the landscape-scale.

Remote sensing (RS) technology has long been considered a promising source of information for landscape management decisions (Johannsen and Barney, 1981; Leal, 2002).With the rapid development of RS technology in 20th century; the RS tech. was applied in so many fields, for the technical advances of making spatially variable application. Kerstin et al. (1993) estimated the N_2 emission in soil by remote sensing of thermal infrared at different moisture levels. Chen et al. (2000) developed an algorithm using reflectance from a remotely sensed color photograph to predict soil organic carbon.

Examining soil denitrification process in the context of the landscape, using an appropriate spatial resolution (e.g. 5–10 m), will improve our ability to manage riparian landscapes to balance the NO_3^- losses from soils and N_2O emissions, implementing sustainable riparian ecosystems, while addressing concerns surrounding non-point source pollution and greenhouse effects. This study couples remote sensing data and methods to a simple denitrification and soil water balance and soil temperature process model. It aims (1) to build a spatially explicit soil denitrification model, applicable at basin scale,

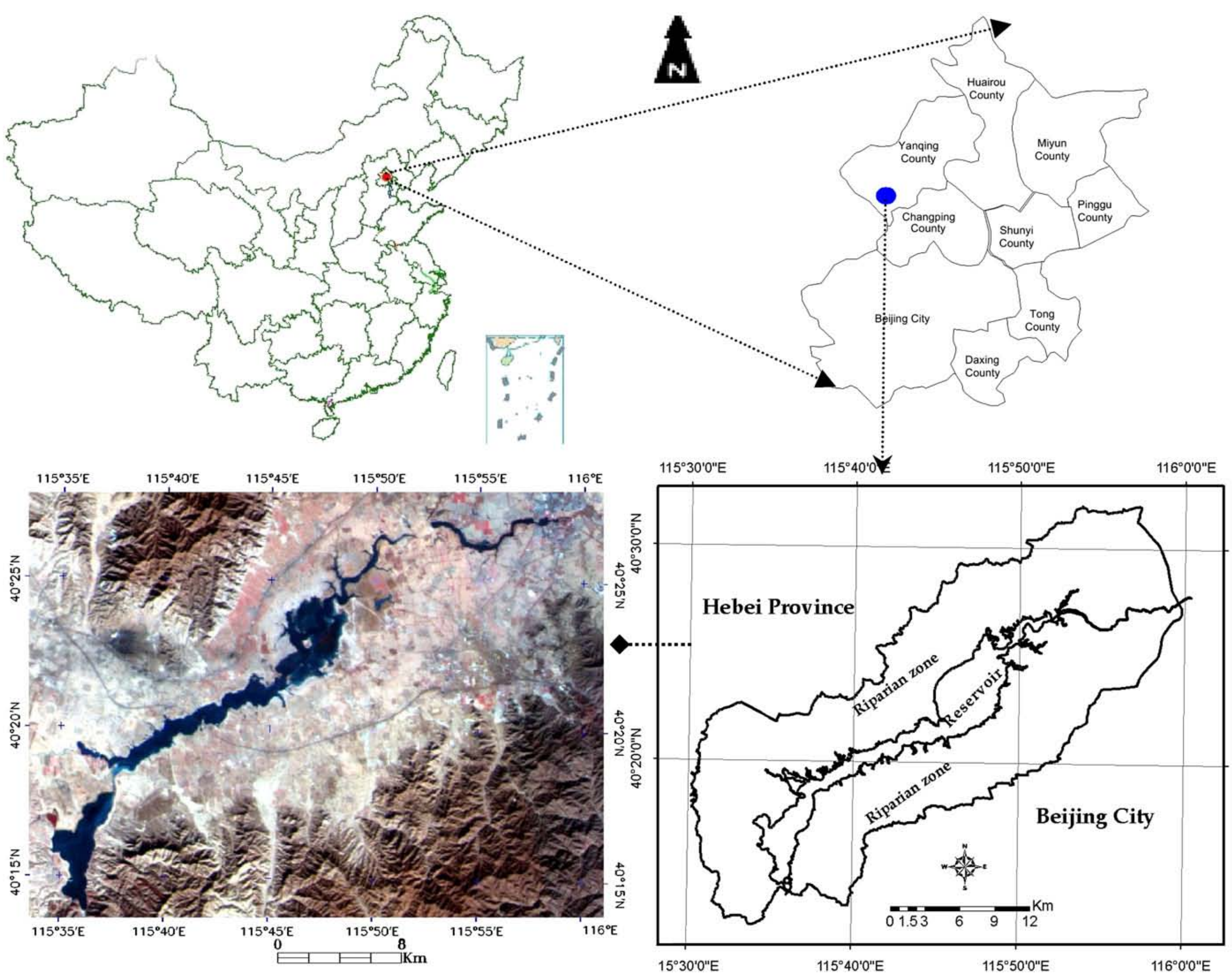

Fig. 1. Location of the research area in north-east China and the Guanting reservoir.