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Assessment of global nitrogen pollution in rivers using an integrated biogeochemical modeling framework

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ABSTRACT

This study has analyzed the global nitrogen loading of rivers resulting from atmospheric deposition, direct discharge, and nitrogenous compounds generated by residential, industrial, and agricultural sources. Fertilizer use, population distribution, land cover, and social census data were used in this study. A terrestrial nitrogen cycle model with a 24-h time step and 0.5° spatial resolution was developed to estimate nitrogen leaching from soil layers in farmlands, grasslands, and natural lands. The N-cycle in this model includes the major processes of nitrogen fixation, nitrification, denitrification, immobilization, mineralization, leaching, and nitrogen absorption by vegetation. The previously developed Total Runoff Integrating Pathways network was used to analyze nitrogen transport from natural and anthropogenic sources through river channels, as well as the collecting and routing of nitrogen to river mouths by runoff. Model performance was evaluated through nutrient data measured at 61 locations in several major world river basins. The dissolved inorganic nitrogen concentrations calculated by the model agreed well with the observed data and demonstrate the reliability of the proposed model. The results indicate that nitrogen loading in most global rivers is proportional to the size of the river basin. Reduced nitrate leaching was predicted for basins with low population density, such as those at high latitudes or in arid regions. Nitrate concentration becomes especially high in tropical humid river basins, densely populated basins, and basins with extensive agricultural activity. On a global scale, agriculture has a significant impact on the distribution of nitrogenous compound pollution. The map of nitrate distribution indicates that serious nitrogen pollution (nitrate concentration: 10–50 mg N/L) has occurred in areas with significant agricultural activities and small precipitation surpluses. Analysis of the model uncertainty also suggests that the nitrate export in most rivers is sensitive to the amount of nitrogen leaching from agricultural lands.

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1. Introduction

Increasing world population has resulted in higher food and energy demand and consumption over the past half century (United Nations, 1996). Human activities have greatly accelerated and enlarged the natural cycles of nutrients and nitrogen in the soil, water, and atmosphere. Through activities such as fertilizer application, fossil fuel consumption, and leguminous crop production, humans have more than doubled the rate at which biologically available nutrients enter the terrestrial biosphere in comparison to pre-industrial levels (Galloway et al., 2004). One of the most important nutrients in this respect is nitrogen, which is an integral component of many essential plant nutrients. However, while nitrogen is an essential nutrient that plays important roles in increasing crop yields and quality, it is also a major pollutant in terrestrial ecosystems (Baker, 2003; Oenema et al., 1998; Schepers et al., 1995). Excess nitrogen used in fertilization has disturbed the biogeochemical nitrogen cycle of natural ecosystems, resulting in stratospheric ozone depletion, soil acidification, eutrophication, and nitrate pollution of ground and surface waters (Davis and Koop, 2006; Ding et al., 2006; Hantschel and Beese, 1997; Rijtema and Kroes, 1991). Water quality degradation associated with nitrate leaching from agricultural soils is an important environmental issue worldwide (Galloway, 1998, 2000; Galloway and Cowling, 2002; Galloway et al., 1995). Losses of nitrogenous compounds in the atmosphere and aquatic systems have inverse impacts not only on human health and global warming, but also on natural and agricultural terrestrial and aquatic ecosystems. The effects of agricultural diffuse source nitrogen pollution on water quality and aquatic ecosystems have received considerable research attention in recent years (Howarth et al., 2002; Hudson et al., 2005). Nitrogen pollution is one of the major pollutants, yet it is difficult to estimate because its sources are widely spread. In addition, both natural and anthropogenic emitters are responsible for nitrogen pollution (He et al., 2009a and 2009b). For example, natural reactions of atmospheric forms of nitrogen can result in the formation of nitrate and ammonium ions. In addition, the large anthropogenic sources of septic tanks, application of nitrogen-rich fertilizers, and agricultural processes have greatly increased the nitrate concentration, particularly in groundwater. Since the characteristics of each river basin is different, the relative contribution from each emitters has to be analyzed based on the database of land use, population, agricultural fertilizer, industrial production, livestock, etc.

To date, research on the nitrogen cycle has primarily focused on the river basin scale (Dumont et al., 2005; Seitzinger et al., 2005). Very few national- or global-scale studies exist (Dumont et al., 2005), and prediction of nitrogen export is still insufficient (Seitzinger et al., 2005). In addition, most large- or global-scale nitrogen studies have treated entire river basins as the basic unit and, as a result, the calculated nitrogen leaching or nitrate concentration mainly reflects the amount of nitrogen in river outlets (Bouwman et al., 2005a; Harrison et al., 2005; Howarth et al., 2002; He et al., 2009b). Detailed information on nitrogen leaching or nitrate concentration in individually distributed grids is lacking in the current literature. Furthermore, global nitrogen cycle models have relied on calculated amounts of nitrogen fertilizer application based on yearly statistical databases for each country. Monthly nitrogen fertilizer application amounts have not been available for global-scale study.

The aim of this study was to estimate the global nitrogen loading from point and nonpoint sources separately and apply an integrated biogeochemical model to nitrogen export for global rivers. The nitrogen fertilizer application amount and nitrate leaching were first calculated for each grid box, measuring 0.5° by 0.5°, using the process-based N-cycle model. In this article, we present an initial overview of the integrated modeling framework, including the structure, database, and model results. Section 2 presents the methodology, and Section 3 discusses the database for the point and nonpoint sources. The integrated simulation using the above model and database is discussed in Section 4.

2. Method

2.1. Integrated modeling framework

This study proposed an integrated biogeochemical modeling of global nitrogen loads from anthropogenic and natural sources. The global runoff was simulated by a land surface model driven by atmospheric forcing in an off-line mode (Fig. 1). Then, the nitrogen load (NL) from different sources such as crop, livestock, industrial plant, urban and rural population were calculated by applying datasets of fertilizer utilization, population distribution, land cover map, and social census. The number of livestock and population in each country was collected from national census database. The

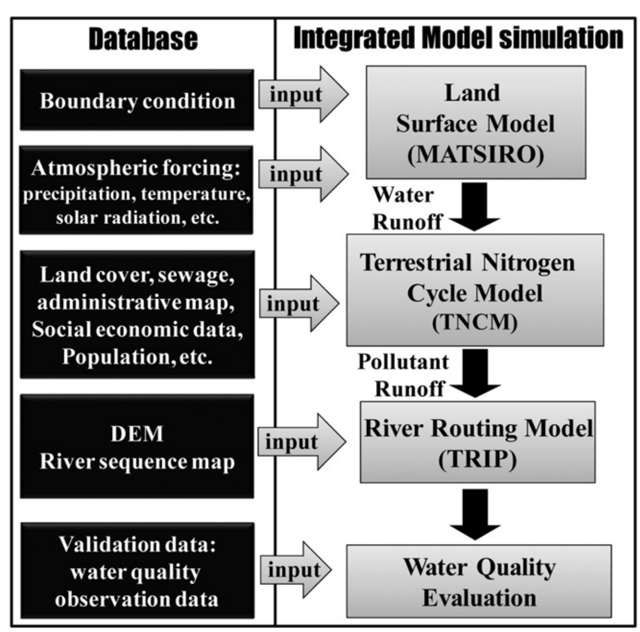

Fig. 1 – Integrated modelling framework for calculating global terrestrial nitrogen load and rivers' nitrogen concentration.