



Riverine nitrogen loss in the Tibetan Plateau and potential impacts of climate change



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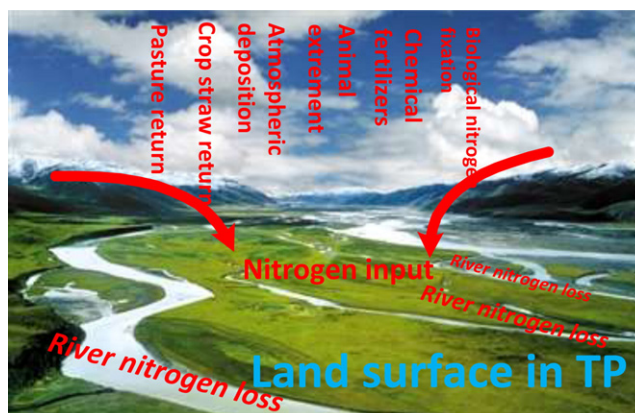
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HIGHLIGHTS

- We analyzed the riverine nitrogen discharges in the Tibetan Plateau.
- About 2.7×10^5 Mg/year was lost through riverine discharges.
- Changes of hydrologic processes would affect the future riverine nitrogen outflows.

GRAPHICAL ABSTRACT



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ABSTRACT

The Tibetan Plateau (TP) has been the subject of study on water circulation and global climate change. Given the environmental processes related to water outflows, there could be massive nutrient losses in the land surface of TP. In this study, we analyzed the nitrogen discharges of the major rivers flowing out of the TP based on the 5-year monitoring data. According to our calculation, the majority of nitrogen outflows were discharged through the upper Yangtze River and upper Huanghe River, representing ~29% and ~17% of total riverine outflows, respectively. In the entire nitrogen deficit in TP land surface, about 2.7×10^5 Mg/year was lost through riverine

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discharges. Due to the global warming, the changes of hydrologic processes in TP would possibly accelerate the riverine nitrogen outflows in the future.

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1. Introduction

As the “Asian Water Tower,” the Tibetan Plateau (TP) is the most important water source for the major rivers in Asia (Immerzeel et al., 2010). There are more than 100 rivers with catchment area > 2000 km² in this region, among which 20 have drainage areas > 10,000 km² (He and Feng, 1996). The area of the outflow region in the TP is 124.32×10^4 km², accounting for >50% of the entire plateau land surface (Cao et al., 2005). About 1.4 billion people depend on rivers that originate from the TP and Himalayas region (Immerzeel et al., 2010; Zhang et al., 2012a). Because of its role as a major water source and unique geographic location, TP has been the subject of research on water circulation and global climate change (Huang et al., 2008, 2009; Immerzeel et al., 2010; Li et al., 2014). The local hydrologic processes are being largely affected by the rapid climate change in this region (Immerzeel et al., 2010; Wang et al., 2013; Lutz et al., 2014; Song et al., 2015).

Precipitation, snow and glacial melt water are the main water sources of rivers in the TP (Lutz et al., 2014). The contribution of local precipitation to river water flows is >50%, and glacier and snowmelt water make up 8–27% (Lutz et al., 2014). Most studies have focused on glaciers in this region because they are sensitive to global warming (Immerzeel et al., 2010; Zhang et al., 2012a). With the climate change, most TP glaciers shrank ~10% from 1970 to 2000 (Zhang et al., 2012a, b). Glacier melt can positively influence local precipitation by increasing evapotranspiration (Du and Ma, 2004). With glacier melt and precipitation increase, more runoff from rivers flowing out of the TP can be expected in the future (Zhang et al., 2012a).

Considering the environmental processes related to water outflows, there could be massive nutrient loss from the TP land surface, which could have a negative impact on the fragile ecological systems of the region. Currently, there have been several studies related to the major ions and trace elements (i.e., Cd, Ni, Hg and Cu) in TP watersheds, and most have concluded that water bodies have been undisturbed by human activities (Huang et al., 2008, 2009). However, few studies have been carried out on nutrient concentrations in the rivers and corresponding riverine nutrient outflows. With massive industrial production of chemical nutrient fertilizers, human activities have substantially altered the global nutrient cycles (Sanchez and Swaminathan, 2005; Galloway et al., 2008; Rockstrom et al., 2009; Canfield et al., 2010; Gu et al., 2013). The increasing nutrient release to the environment has caused a huge burden on environmental systems in most regions (Galloway et al., 2008; Rockstrom et al., 2009). However, the nutrient deficit in land surfaces with little human activity is becoming another environmental issue (Galloway et al., 2008). The nutrient deficit in the land surface has limited the growth of plants and led to a dramatic deterioration of the ecosystem, such as grassland degradation and soil erosion (Matassa et al., 2015).

Currently, TP is being affected by the global warming, and the changes in climate are affecting the hydrologic processes largely, including water outflows in this region (Immerzeel et al., 2010; Wang et al., 2013; Song et al., 2015). Nutrient outflows from the TP rivers have seldom been assessed before. In the present study, we estimated the nitrogen discharges of the major rivers flowing out of the TP. A nitrogen balance model was used to assess the role of riverine nutrient loss from the TP land surface. The potential impacts caused by the climate change and measures of nutrient retention in TP are also discussed.

2. Data and methods

2.1. Study area

The major rivers flowing out of the TP studied were the upper Yangtze, upper Huanghe, Yalongjiang (a major tributary of the Yangtze), Yarlung Zangbo (upper Brahmaputra), Nujiang (upper Salween), and Lancangjiang (upper Mekong) (Table 1 and Fig. 1). From hydrological data obtained in 2008 (Changjiang River Water Conservancy Commission, 2008; Ministry of Water Sources, China, 2008), a total of 4.23×10^{11} m³/year of fresh water flows out of the TP through these rivers. These rivers are the most important water sources for the major rivers in Asia, and also an important part of TP water balance (Zhang et al., 2012a). Among all the selected rivers, Yangtze, Yalongjiang and Huanghe River flow into the plain regions in East China, and the other three rivers flow into the countries in South Asia, as cross-border rivers (shown in Fig. 1). The upper Yangtze River has the maximum flow, with annual water discharge of 1.4×10^{11} m³ (about 31% of the total outflows) (Fig. S1). The minimum annual flow was observed in the upper Huanghe River, at 3.1×10^{10} m³, or 7% of the total (Fig. S1). Annual discharges of the other selected rivers ranged from 3.6×10^{10} to 1.3×10^{11} m³. The majority of the flow of the selected rivers originates from precipitation, glacier, and snowmelt water, which were more sensitive to the climate change (Immerzeel et al., 2010; Lutz et al., 2014). A significant seasonal variation of runoff in the selected rivers was observed, and larger flows always occurred in summer and autumn (Fig. S1). Five major river basins in Asia are fed by the selected rivers, and these basins vary considerably in their characteristics (Table 2). The Yangtze River Basin has the largest population (about 5.8×10^8). The Brahmaputra Basin (downstream of the Yarlung Zangbo River) has the most extensive upstream areas (accounting for ~68% of the total drainage area) and larger glaciated areas than the Yangtze and Huanghe Basins (Raup et al., 2007). The Mekong (downstream of Lancangjiang), Brahmaputra, and Yangtze Basins have a wetter climate than the Huanghe River Basin (Table 2) (Huffman et al., 2007).

2.2. Nitrogen data

Nitrogen data of the selected rivers were collected from monitoring stations near the TP periphery (belonging to the national monitoring network of China, sites shown in Fig. 1). Total nitrogen (TN) concentrations were monitored monthly from 2008 to 2012 at six stations. Due to the difficulty in the sample collections, for the Yarlung Zangbo and Nujiang River, nitrogen monitoring was only done in the typical months of the year or in the recent years. Field sampling was carried out according to the “Technical Specifications Requirements for Monitoring of Surface Water and Waste Water in China (HJ/T 91-2002)”. Water samples of 0.5–1 L were collected and unfiltered water samples were used for TN analysis. As soon as the samples were collected, H₂SO₄ (GR) was added to make pH < 2, to avoid impacts from microbial processes. The samples were kept in the refrigerator before analysis at temperature = 4 °C. Measurement of TN was based on the alkaline potassium persulfate digestion ultraviolet spectrophotometric method (GB 11894-89), with the detection limit of 0.01 mg/L.

2.3. Nitrogen flux estimation

In this study, annual nitrogen discharges were estimated based on the monthly nutrient concentrations and corresponding water flows,

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