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# Using a nitrogen-phosphorus ratio to identify phosphorus risk factors and their spatial heterogeneity in an intensive agricultural area

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ABSTRACT

High phosphorus risk in intensive agricultural regions, which threatens an increasing number of water bodies within the regions, is driven by the nitrogen-phosphorus ratio (N:P ratio). The mechanism remains unclear, however. Most nutrient studies are based on local-scale field trials, which failed to identify the geographical factors that drive phosphorus accumulation at the larger scale of a watershed. To address this issue, we adopted a large-scale, remote-sensing-driven model to simulate the N:P ratio in the soil of the Sanjiang Plain, one of the most important commercial grain bases of China. A grid-random sampling method was employed to test the validity of the model. The results show that 35% of the higher N:P ratios were converted to lower ratios in old cultivated land where the concentration of soil phosphorus increased by 1–2 times over 11 years (2000–2010); however, in the new cropland cultivated from forestland, grassland and wetland, 18% of the lower N:P ratios were converted to higher ratios, with soil phosphorus concentration increased slightly. Higher N:P ratios come from greater nitrogen input into the new cropland soil, which reduces soil pH and then enhances phosphorus accumulation, thus increasing the phosphorus risk. We find that the variation in land-use types and the excessive input of anthropogenic fertilizers are the two dominant factors influencing the N:P ratio. Intensive anthropologic activities changed traditional knowledge on the relationship between the N:P ratio and phosphorus accumulation, and further necessitated large-scale research on nutrients in intensive agricultural regions. The finding can shed new light on phosphorus management and non-point source pollution control in intensive agricultural areas.



## 1. Introduction

Phosphorus (P) application has received global attention in recent decades because phosphorus is key to agro-ecosystems, crop production and food security (Smith et al., 2005; Delgado-Baquerizo et al., 2013), and because of its significant influence on water eutrophication and non-point source pollution (Jarvie et al., 2012; Wang et al., 2012). Phosphorus risk means the risk of phosphorus pollution of water bodies will increase if there is excessive P accumulated in the soil, although P is a limiting factor in terrestrial and aquatic ecosystems (Wang et al., 2016; Ulén et al., 2016; Wei et al., 2016). There is ample information available on the negative influence of excessive P accumulation on cropland soil that is caused by the migration of P to water bodies through runoff and leaching, and the associated critical risk to water quality and eco-environmental safety (Chen et al., 2010; Lou et al., 2015). The two key factors that induce P risk are anthropogenic fertilizer inputs to soil and land-use changes (e.g., forestland or wetland converted to cultivated land), and their primary purpose is crop production for ever-increasing populations (Nesme et al., 2012; Jiang et al., 2012).

The N:P ratio is an important indicator for detecting nutrient limitations in soil and vegetation, and it also predicts freshwater and estuary eutrophication (Chiaudani and Vighi, 1974; Koerselman and Meuleman 1996; Elser et al., 2009). Sustained external P inputs and variations in land use not only cause the buildup of P in soil but they also disturb the original N:P ratio, which in turn significantly influences phosphorus accumulation (Vitousek et al., 2010; Ouyang et al., 2013a). Many studies have explored the N:P ratio in parallel terrestrial ecosystems (e.g., soil

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(Domburg et al., 2000; Nesme et al., 2012) and plants (Ågren et al., 2012; Ramoelo et al., 2013)), and aquatic ecosystems (e.g., water (Elser et al., 2007; Carpenter, 2008) and algae (Sañudo-Wilhelmy et al., 2001; Edwards et al., 2011)). The studies have provided a clearer understanding of the formation and mechanisms that cause variation in the N:P ratio in terrestrial and aquatic ecosystems and add knowledge about the relationship between nitrogen and phosphorus in the process of soil formation and land use change. However, the relationships between the disturbed N:P ratio, P accumulation and P risk are not well understood, especially in areas with intensive agriculture.

Two methods are used to obtain the N:P ratio: the first uses soil chemistry (Pathak et al., 2010) and can generate a precise N:P ratio from sampling in a small study area; the second method utilizes a simple statistical model, e.g., a budget equation (Nesme et al., 2012; Wang et al., 2014), and it can generate an N:P ratio based on large-scale mass data collection, although it is difficult to obtain continuous spatial data for the N:P ratio. The two methods provide the basis for examining the N:P ratio at multiple scales, from the plot scale (Adu-Gyamfi et al., 2007; Watson and Matthews, 2008) to the watershed scale (Domburg et al., 2000) and the global scale (Penuelas et al., 2013), and focus more on chemical experiments and mass samples in a local area. However, these traditional methods are unable to explore the factors driving the large-spatial-scale variation of the N:P ratio in agricultural areas. Remote sensing (RS) technologies can be potentially applied to the simulation of the dynamics of nitrogen and phosphorus (Nesme et al., 2012; Wang et al., 2012), because of their distinct advantage in retrieving information from earth's surface at multiple temporal-spatial scales. This technology can be applied to obtain geo-information directly (e.g., a land-use map) and used in physically based non-point source pollution models (Gassman et al., 2007).

The RS-based Ecohydrology Assessment Tool (EcoHAT) (Liu et al., 2009; Wang et al., 2010; Yang et al., 2011; Lou et al., 2015) is an ecohydrological simulation system that can comprehensively simulate regional ecohydrological processes based on physical and chemical mechanisms. It works with remote sensing models to retrieve land surface parameters, providing a spatial data source for ecohydrological process simulation. Driven by remote sensing, EcoHAT takes full advantage of remote sensing to resolve the problem of simulating nitrogen and phosphorus concentrations in the soil at a large scale and over time (Liu et al., 2009). Compared to other models, EcoHAT uses the best features of remote sensing and optimizes its use of public remote sensing products, which makes it easier to run; meanwhile, it can adjust its simulation based on temporal-spatial scales. EcoHAT has been widely used in a variety of settings to calculate nitrogen and phosphorus (Yang et al., 2011; Lou et al., 2015). In this study, the remote sensing data were collected and resolved by EcoHAT, and some parameters were retrieved using remote sensing.

However, existing methods (e.g., soil chemistry or statistical models) cannot obtain a continuous N:P ratio at a large spatial and long temporal scale, which restricts us to know the nutrient limitations in the soil or to understand the risks that result from the continued accumulation of some nutrients (e.g., phosphorus) in the soil. Using a remote sensing driven model, it remains unclear that whether we can find the driving factors for phosphorus accumulation and phosphorus risk from the perspective of geographical space but not from environmental chemistry. The method described here could provide a new model for controlling non-point source pollution and managing the phosphorus in intensive agricultural areas.

The aims of the present study are to: 1) calculate the N:P ratio in the soil using the improved RS-driven EcoHAT model at a regional scale; 2) find the temporal-spatial variations in the N:P ratio and their driving factors; 3) explore the relationship between the N:P ratio and phosphorus accumulation.

## 2. Materials and methods

### 2.1. Study area

The Sanjiang Plain (43°49′55″–48°27′40″N, 129°11′20″–135°05′26″ E) (Fig. 1) is an area of low relief within the Heilongjiang Province of China, with a total area of 108,900 km$^2$, occupying 22.6% of the total

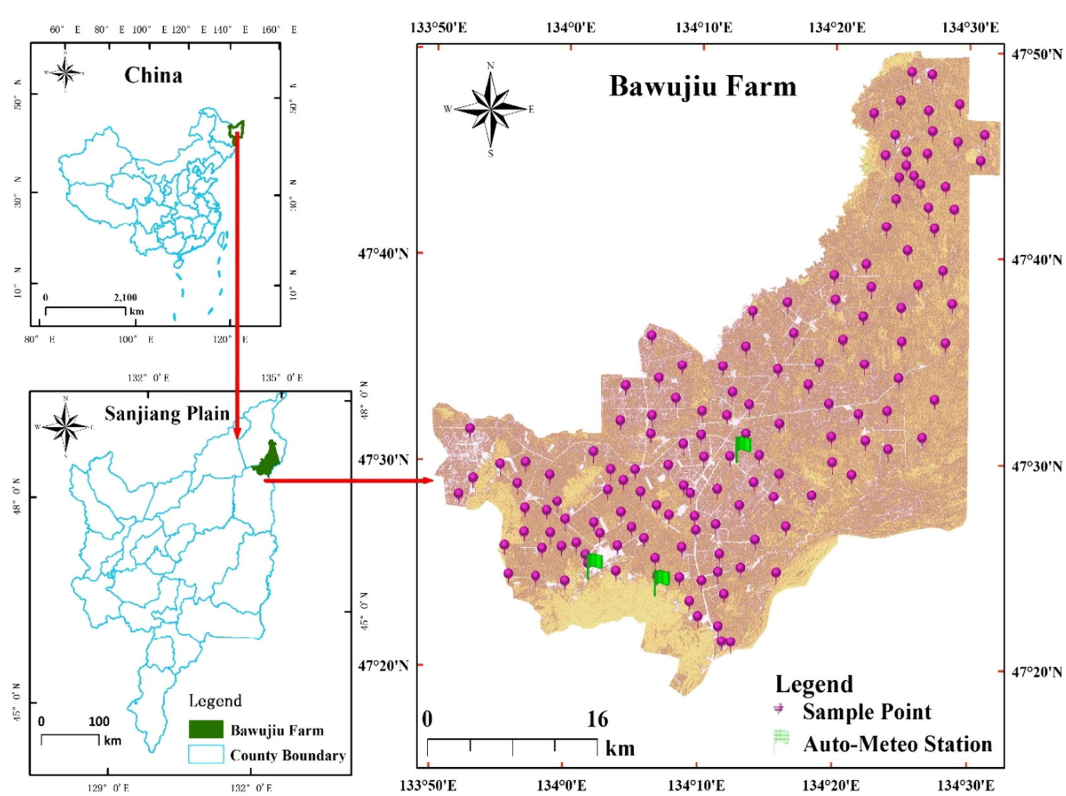


**Fig. 1.** Sanjiang Plain and the Bawujiu Farm in Northeast China.