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Net anthropogenic phosphorus inputs (NAPI) index application in Mainland China

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HIGHLIGHTS

- ▶ We studied phosphorus input more reasonable by taking seeding P into consideration.
- ▶ We analyzed spatial and temporal variation of phosphorus input in Mainland China.
- ▶ We analyzed the main components of net P input and their change.
- ▶ Fertilize phosphorus is the largest source of net anthropogenic phosphorus input.
- ▶ The primary factor of net anthropogenic phosphorus input change is total population.

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ABSTRACT

This study provides a new understanding on sources of P, which may serve as a foundation for further exploration of anthropogenic effects on P input. Estimation of net anthropogenic phosphorus input (NAPI) was based on an inventory of phosphorus (P) fertilizer use, consumption of human food and animal feed, seeding phosphorus and non-food phosphorus net flux. Across Mainland China, NAPI had an upward trend from 1981 to 2009, which reflects development trend of the population and economic. NAPI for years 1981, 1990, 2000 and 2009 are 190 kg P km^{-2} yr^{-1} (1.8 kg P per person yr^{-1}), 295 kg P km^{-2} yr^{-1} (2.5 kg P per person yr^{-1}), 415 kg P km^{-2} yr^{-1} (3.1 kg P per person yr^{-1}) and 465 kg P km^{-2} yr^{-1} (3.4 kg P per person yr^{-1}), respectively. On a geographical basis, NAPI per unit area is lower in northwest Mainland China than in southeast Mainland China with the largest NAPI of 3101 kg P km^{-2} yr^{-1} in Shanghai, while NAPI per person is in reverse with the largest NAPI 7.7 kg P per person yr^{-1} in Tibet. P input of fertilizer is the largest source of NAPI, accounting for 57.35–83.73% (109–390 kg P km^{-2} yr^{-1}) of the total NAPI, followed by non-food P and P in human food and animal feed. Year 2000 was a critical point where P changed almost from net input to output. Grain production rate per unit mass of fertilizer showed an obvious downward trend. The primary factor in relation to the change in NAPI is total population.

1. Introduction

Regional nutrient pollution is divided into point source pollution and non-point source pollution. Point source pollution is generated from sewage outlets, so it is relatively easy to identify and control. Non-point source pollution has complicate formation process, spatial variability, long latent cycle, and so on (Straalen and Gestel, 2008), and its severity is being gradually revealed in recently years. China is one of the countries in the world with rapidest population and economy growth. In the past thirty years, population and economy growth has brought about many environmental issues (Hu et al., 2011a, 2011b; Wu et al., 2011), among which the nutrient non-point source pollution is a relatively serious one. Even though some technology has been used to control nutrient non-point source pollution, the effect is imperceptible because the control actions have been merely focused on end-control engineering projects, such as establishment of sewage farm, artificially-reclaiming of wetland at bayou or watercourse (Liu et al., 2010; Guan et al., 2011). Therefore, investigation on pollutant sources and implementation of source-control policies is indispensable.

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Eutrophication is a kind of water pollution caused by excessive nutrients. Phosphorus (P) is one of the main pollution elements of eutrophication. P emission from different pathways and sources is a key issue concerning the protection of water quality and sustainable watershed management practices (Lowrance et al., 1985; Rivera et al., 2007; Neset et al., 2008).

The nutrient input to the watershed is mainly caused by human activities (Leeben et al., 2008), such as crop cultivation, livestock breeding, human excretion, household garbage and so on. Many researchers have focused their attention on the evaluation of pollutant loadings by human activities. Jordan and Weller (1996) put forth the concept of net anthropogenic nitrogen input (NANI), which refers to the difference between the total amount of N produced from applied fertilizer, N fixation and atmospheric deposition and the total amount of N exported from food and feed in the watershed ecosystem. The study of McIsaac et al. (2001) shows that NANI is more sensitive to the N flux in the watershed, i.e. a slight change in NANI may result in a great change in riverine N content. Russell et al. (2008) also conducted a relevant investigation on net anthropogenic phosphorus input (NAPI = P Fertilizer + P Feed + P Food + Non-food P), pointing out that NAPI is an important index for predicting the P pollution in watershed. The theories provide useful research methods for investigation on nutrient input (Bristow et al., 2008; Kelderman et al., 2009; Li et al., 2011; Obour et al., 2011; Han et al., 2011). In addition, nutrient element in seed is always mentioned in researches on agricultural nutrient balance, but it is seldom taken into consideration in NAPI research (OECD, 2001; Feng and Fang, 2006; Fang et al., 2007). Therefore, we introduced a comparatively reasonable way of studying P input by taking P in seed into consideration, that is, NAPI = P fertilizer use + P in seed + P in human food and animal feed + non-food P.

The purpose of this paper is to calculate net anthropogenic phosphorus budgets in Mainland China, which includes: (a) researching the spatial distribution and temporal variation of net P input; (b) analyzing the main components of net P input and their change; and (c) discussing the relationship between the typical socioeconomic factors and net P input. To some extent, this paper overcomes the difficulties in quantifying P sources and introduces a more reasonable way for studying P input.

2. Methods

2.1. Study sites

China is the fourth largest country in the world (after Russia, Canada, and the USA). It is situated at 4° to 53°30′ North Latitude and 73°40′ to 135°05′ East Longitude and is bordered by Russia, India, Afghanistan, Bhutan, Myanmar, Kazakhstan, North Korea, Kyrgyzstan, Laos, Macau (semi-autonomous), Mongolia, Nepal, Pakistan, Tajikistan, and Vietnam. China covers about 9.6×10^6 square km. The population of China is about 13.7×10^8 (as of December, 2010). With highlands in the west and plains in the east, from the Tibetan Plateau and other less-elevated highlands rise rugged east–west trending mountains, and plateaus interrupted by deep depressions fanning out to the north and east. China is composed of 23 provinces, 5 autonomous regions, 4 municipalities, and 2 special administrative regions. The study region in this paper is Mainland China, namely, Taiwan province, Hongkong and Macao special administrative regions are excluded. Therefore, with each administrative region as a research unit, there are 31 research units in total (see Fig. 1 and Table 1).

We obtained the data from the National Bureau of Statistics of China. Land cover was derived from satellite images of Ministry of Land and Resources of the People's Republic of China. We calculated net P input values for years 1981, 1990, 2000 and 2009.

2.2. NAPI estimation approach

NAPI was estimated by accounting for the anthropogenic P input in each unit. We quantified input of P in each unit, most of which are derived from human activities: fertilizer use, seeding, human food and animal feed, and non-food P.

2.2.1. P fertilizer use

Current management practices in agricultural production are highly dependent on intensive fertilizer use, so fertilizer use is one of the important sources of NAPI. We obtained data on the amount of applied P fertilizer within each research unit from the National Bureau of Statistics of China. Estimates of fertilizer application are available for each research unit. P fertilizer contains 12% −18% of P_2O_5 (Liang, 1999; Gao et al., 2001). Total P fertilizer application was converted to kg P by multiplying by 436.4 kg P per ton P_2O_5.

2.2.2. Seeding P

We chose vegetable and seven main agricultural crops to estimate seeding P in each research unit. The vegetable was represented by cabbage since the value of seeding P was slightly different between different kinds of vegetable. Seeding P per unit area for each crop type has been reported by Agricultural Technology Promotion Center of China (1999) (see Table 2). The data on cultivation area of each crop type were obtained from the National Bureau of Statistics of China. Seeding P was estimated by multiplying P input of seed per unit area for each crop type by cultivation area in each research unit.

2.2.3. Net P input in human food and animal feed

Humans and animals require a great deal of food and feed during their lives, so net P in human food and animal feed is also an important component of NAPI. Human food and animal feed are associated with input/output P of agricultural products. With a few exceptions, we used the general method introduced by Jordan and Weller (1996), who quantified the net input of P as:

net input in food and feed = food and feed consumption of human and animal – animal production for human consumption – crop production.

We obtained data on human population and crop and animal production from the National Bureau of Statistics of China. Each item, as well as the final result, in this method is presented by research unit data.

2.2.3.1. Food and feed consumption. Human consumption of P in food was estimated by multiplying the number of inhabitants in each research unit (see Table 2) by per capita intake of 0.52 kg P per year (Wu, 2005). P consumption per individual animal was then multiplied by the number of each animal type in each research unit. We chose the values of consumption as reported by Wu Shuxia (2005) and the values of the percentage P excreted as reported by van (1998). We assumed all animals were completely formula fed, i.e., 80% from corn and 20% from pasture (Li, 2007).

2.2.3.2. Crop production. We chose vegetable and 14 main agricultural crops to estimate P production in each research unit. The vegetable was represented by cabbage since phosphorus content was slightly different between different kinds of vegetable. We calculated P content in the crop harvest in each research unit. P content ($g\ kg^{-1}$) for each crop type has been reported by Wang (2003) (see Table 2). We assumed that pests, spoilage, and processing caused a 10% loss for all crops (Jordan and Weller, 1996).