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An inventory analysis of rural pollution loads in China

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Abstract Rural pollution has attracted increasing attention over the past decade for its important consequences on surface and groundwater quality. This is particularly so in China due to the wide and effective control of industrial and municipal wastewater discharges over the past decade. Based on the discussion of rural activities in China, this paper develops a new method of inventory analysis through the definition of elementary unit (EU). This inventory analysis approach is then applied to estimate the total rural pollution loads of COD, TN and TP, as well as their spatial distributions in China. Further analysis is also conducted to investigate the correlations between rural pollution loads and agricultural production outputs, as well as population. It is found that China's agriculture is developing largely at the cost of environment quality, and a high population, as well as the increasing demand for agricultural products, is one of the dominant driving forces. The constructed EKC, which describes the relationship between rural pollution loads and agricultural income, also reveals that current agricultural development in China is mostly far from de-locked from the environmental problem.

Keywords China; elementary unit; inventory analysis; rural pollution loads

Introduction

Rural pollution has attracted increasing attention over the past decade for its important consequences on surface and groundwater quality (e.g. Boers, 1996; Agrawal, 1999; etc.). In most developed countries, rural pollution has become a leading contributor to water quality impairment. In the USA, for instance, agricultural pollution accounted for 47.9% of the water quality problem in 2000 (USEPA, 2002). In the UK, rural pollution was responsible for 50% of phosphorus inputs and 71% of nitrogen loads to surface water in 2002 (DEFRA, 2004). It is projected that in OECD countries, nitrogen and BOD loading to waterways from agriculture will increase by more than 25% in year 2020 (OECD, 2001).

In China, with the wide and effective control of industrial and municipal wastewater discharges over the past decade, pollution loads from rural activities are also becoming increasingly dominant in affecting water quality (Li *et al.*, 2000; Zhang *et al.*, 2004). In the 'Three Lakes', which are the key national pollution control watersheds, for instance, it is estimated that 50–70% of total nitrogen (TN) and 40–52% of total phosphorus (TP) came from rural pollution in the Chaohu lake watershed (Zhang *et al.*, 1999; Yan and Bao, 2001); while in the Dianchi Lake catchment, rural pollution has caused 30–53% and 30–60%, respectively, of TN and TP loads (Guo and Yan, 1999; Jiang, 2000; Xing *et al.*, 2004), and in the Taihu Lake basin, rural activities contributed 40–90% and 38–90%, respectively, to the TN and TP loads (Fan *et al.*, 1997; Tao, 1998; Li *et al.*, 2000; Zhang *et al.*, 2004). Similar findings were also observed in other studies, including the Miyun reservoir in Beijing, the Yuqiao reservoir in Tianjin, the Erhai catchment in Yunnan province, and the Dianshanhu basin in Shanghai (Bao and Ma, 1997).

In spite of the increasing importance of rural pollution in China, there has been no clear picture of rural pollution characteristics, including its major components, the scale of the problem, as well as its spatial intensity, and the differences across China. There

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could be three reasons for this. First, pollution loads from rural activities are usually discharged to the environment as non-point or diffuse sources in the sense that they occur over an extensive area of land and are subject to the random occurrence of meteorological events (Novotny and Chesters, 1981). Second, rural land use in China is considerably fragmented and dynamic, which is predominantly decided by millions of individual farmers. Third, China has a lack of storm runoff monitoring data, as well as water quality data in rainfall seasons. Estimation of rural pollution loads has thus become a major challenge to set up a national pollution control strategy.

This paper is directed towards a rural pollution load assessment in China through a specifically developed inventory analysis. The concerned pollution loads include chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP), and involve all major rural activities. Note that pesticide pollution will not be considered in this paper due to a lack of data availability. In the next section, the inventory analysis methodology is presented with focus on discussion of the classification and definition of elemental rural activities. This is followed by a description of data sources and major results in Sections 3 and 4, followed by the conclusions.

Method and data

An inventory analysis, which emphasizes on relative long-term and average pollution loads, is an inexpensive and manageable alternative to providing quantitative information on rural pollution. Early methods of inventory analysis can be traced back to the 1970s for developing the relationship between land use and pollution loads based on field experiments (e.g. Novotny and Chesters, 1981; Beaulac and Reckhow, 1982; Rast and Lee, 1983; Kronvang *et al.*, 1996; EEA, 1998;), or the dependence of storm water quality upon different sources of pollution loads (Zhu *et al.*, 1985).

The methodology of inventory analysis in this study is based upon the same concept as those applied above, yet redeveloped to be consistent with rural activities in China. In addition to fertilizer runoff, the other important rural pollution sources include livestock waste, agricultural organic solid waste (e.g. straws and vegetable remains), rural sewage, and municipal wastes. This is based on three aspects. First, livestock in China are mostly kept on a small scale (e.g. less than 10% slaughtered pigs come from livestock with more than 200 swine in stock per year) and is not subject to effective pollution regulations being in practice. Second, due to the improvement in rural life, the traditional utilization of agricultural wastes is gradually decreasing, and they are increasingly dumped along the riparian of surface waters and washed away into the water-body by storm runoff. Third, given the fact that rural water demand and domestic wastes has increased rapidly in recent years, there is still a widespread lack of infrastructure in the countryside; rural sewage and waste are also important sources of pollution loads in China.

Inventory analysis is based on the definition of the elementary unit (EU) of rural pollution sources, which is a computable, independent, and homogeneous minimal pollution discharge unit. Table 1 presents the list of EU in this study with due consideration of data availability and requirements of the policymaker. It is organized through a four-tier of structure, i.e. activity, class, unit, and indicator.

This proposed method is a ‘top-down’ approach, which builds up links between rural activities and pollution emissions. Its basic idea is very easy to understand.

$$TEL = \sum EL_{activity} = \sum\sum EL_{class} = \sum\sum\sum EC_{unit} * EUA \tag{1}$$

As Equation (1) presents, total emission load (TEL) from rural pollution is the sum of that produced by each activity ($EL_{activity}$, including fertilizer runoff, livestock, agricultural

Table 1 List of the elementary unit of rural pollution sources in China

Activity	Class	Unit	Indicator
Fertilizer runoff	Nitrogenous fertilizer	N fertilizer use for grain crops	Fertilizer consumption per planted area (kg N/ha)
		N fertilizer use for vegetables and melon	Fertilizer consumption per planted area (kg N/ha)
		N fertilizer use for other crops	Fertilizer consumption per planted area (kg N/ha)
	Phosphate fertilizer	P fertilizer use for grain crops	Fertilizer consumption per planted area (kg P_2O_5/ha)
		P fertilizer use for vegetables and melon	Fertilizer consumption per planted area (kg P_2O_5/ha)
		P fertilizer use for other crops	Fertilizer consumption per planted area (kg P_2O_5/ha)
Livestock	Cattle	Cattle and cow	Year-end total number (head)
	Pigs	Pigs	Slaughtered number
	Sheep	Sheep and lamb	Year-end total number
	Poultry	Poultry	Slaughtered number
Agricultural organic waste	Grain crops	Rice	Yield (kg)
		Wheat	Yield (kg)
		Corn	Yield (kg)
		Beans	Yield (kg)
		Tubers	Yield (kg)
	Economic crops	Oil-bearing crops	Yield (kg)
		Cotton	Yield (kg)
	Horticulture crops	Vegetables/fruits	Planted area (ha)
Rural sewage	Rural wastewater	Person	Rural population (person)
Rural wastes	Rural Solid waste	Person	Rural population (person)

organic waste, rural sewage, and rural wastes), and $EL_{activity}$ is the sum of that from each class (EL_{class}). EL_{class} is calculated by multiplying the elementary unit amount (EUA) from national statistics by measured pollutant discharge by individual unit, which is the so-called 'emission coefficients (EC_{unit})' of each EU. If several EUs were identified in one class, for example the class of nitrogenous fertilizer, emission load of this class is the sum of discharge from each EU group. The emission coefficients of each EU are derived from a comprehensive survey of various field experiments, and more detailed discussion can be found in Lai *et al.* (2004).

The proposed inventory analysis is spatially conducted at the provincial level in 2003, with the whole of China divided into 33 areas, excluding Hong Kong, Macao, and Taiwan. The relevant data of rural activities were collected from a number of national databases including China Statistic Yearbook (CBYB), China Rural Statistical Yearbook (CRSYB), and China Agricultural Statistical Yearbook (CRSYB).

Results and discussions

Total rural emission loads and their spatial distributions in China

It is estimated that COD, TN, and TP emission loads from rural activities in China in 2003 are approximately 9.5, 6.0, and 1.0 million tons, respectively. Note that the COD discharged from industries and municipalities in China were 5.12 and 8.22 million tons, respectively (SEPA, 2004). Although the former is the amount without consideration of pollution control due to a lack of applied countermeasures, and the latter is the one discharged from treatment facilities should three be one, pollution loads from rural activities are indeed the dominant component in China's pollution sources. Figures 1 to 6 present the spatial distributions of pollutant loads and their intensities across China. As given in the figures, the provinces of He'nan, Shandong, Sichuan, and Hebei are

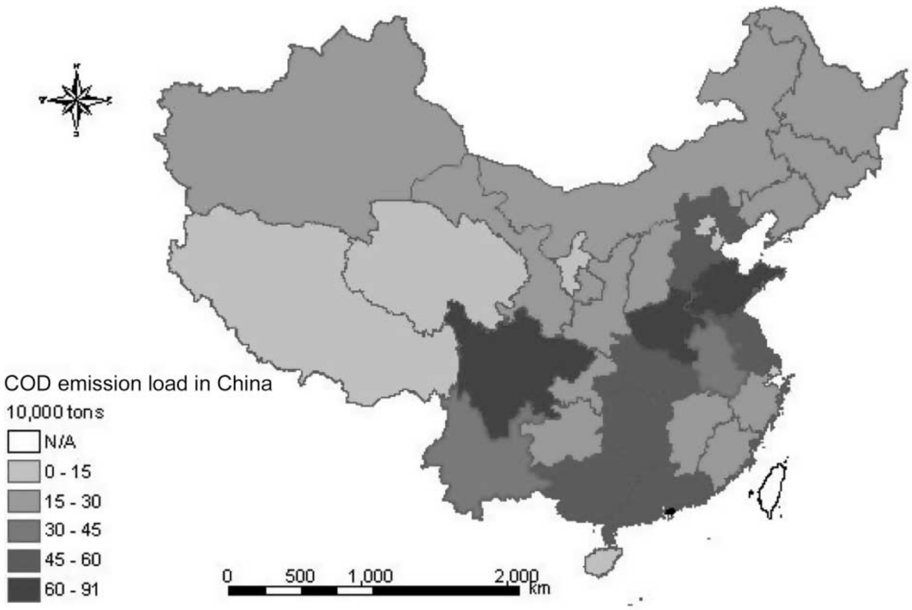

Figure 1 COD emission loads in 2003

the top producers of rural pollution loads and their COD, TN, and TP loads account for 31%, 31%, and 32% of national totals, respectively. The results are consistent with the fact that the four provinces are major agricultural areas with a large rural population. 29% of grain crops and 31% of vegetables, for instance, were produced in the four provinces, and their rural population is 29% of the total in China.

Given the fact that rural pollution can and should be accommodated mostly by agricultural land, pollution loads per agricultural land (i.e. the sum of cultivated and pasture areas) are a practical indication of the severity of rural pollution. As seen in Figures 4 to 6, the most polluted provinces are Guangdong, Fujian, Hainan, Hunan, and Shanghai,

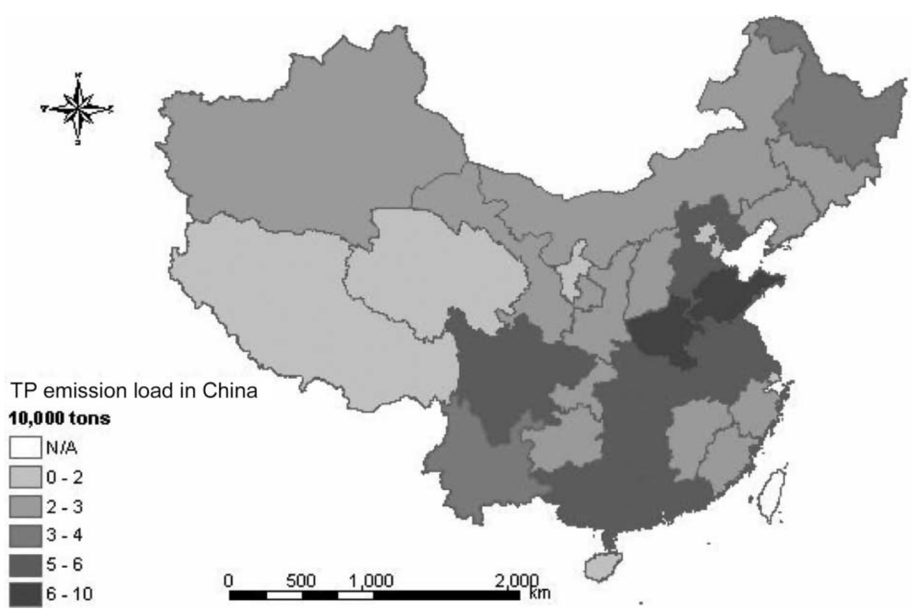

Figure 2 TN emission loads in 2003

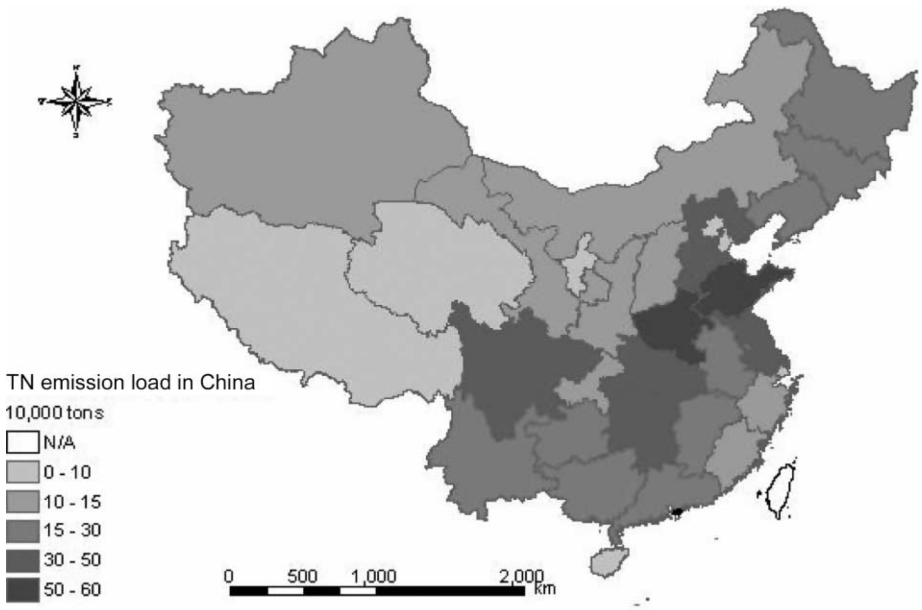

Figure 3 TP emission loads in 2003

which are different from the ones based on the total loads. They are characterized by a high population density and rapid urbanization, and their COD, TN, and TP emission load per agricultural land is 6–8 times the national average, and 100–200 times the least polluted ones (e.g. Tibet, Qinghai, Inner Mongolia, and Xinjiang). This result reveals the considerable dual pressures of urbanization to rural production and environment in China, the discussion of which we now turn to.

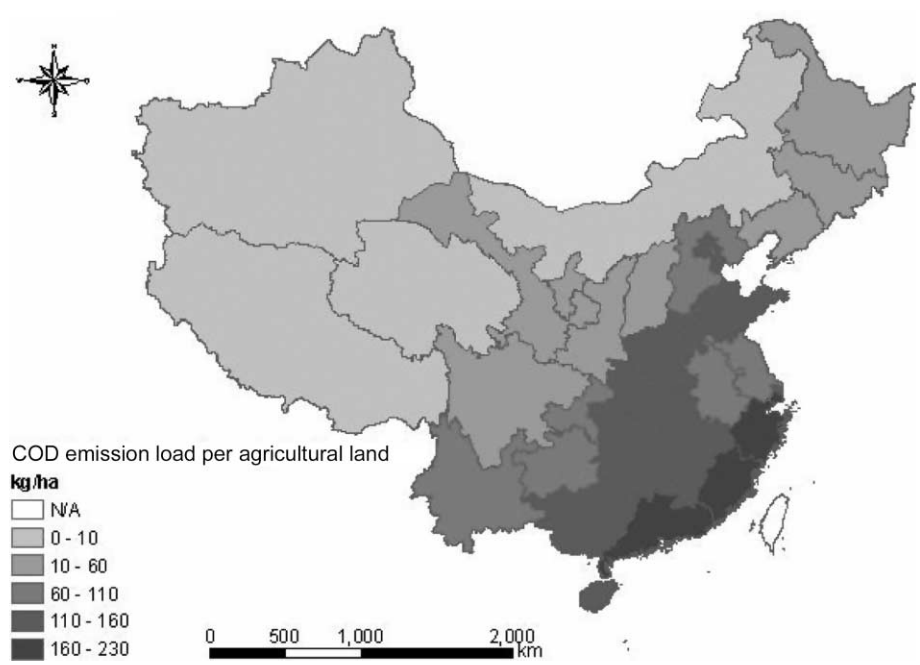

Figure 4 COD emission loads per agricultural land in 2003

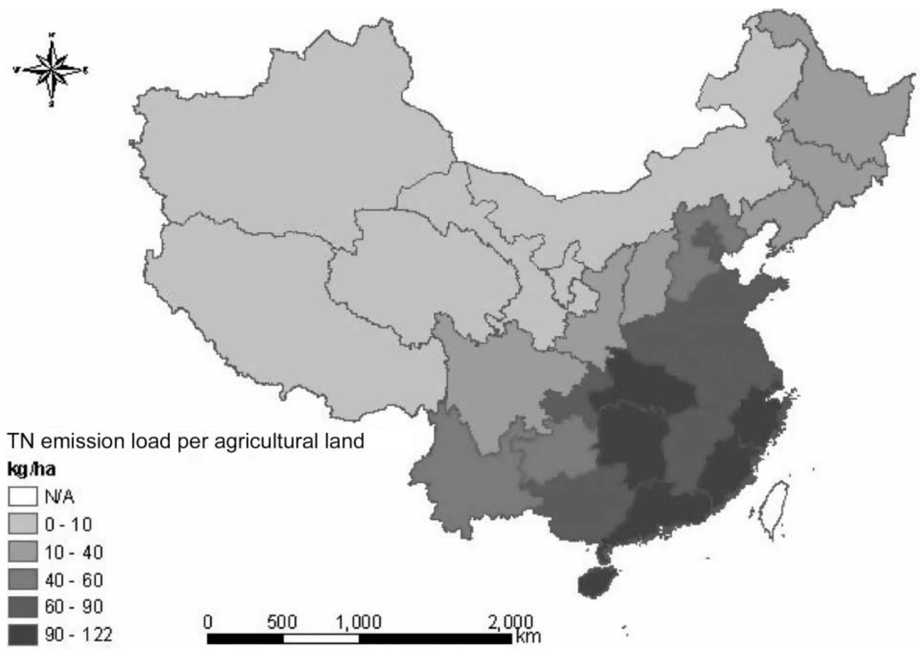

Figure 5 TN emission loads per agricultural land in 2003

Agricultural development and rural pollution

Figure 7 shows the relationship between agricultural outputs and different rural pollution loads, in which highly positive correlations are available (e.g. $R^2 > 0.85$). This reveals that agricultural development in China is far from de-locked from the environmental problem and is largely at the sacrifice of an increasing environmental pressure. In the past 20 years, agriculture in China has been under a considerable change due to the wide

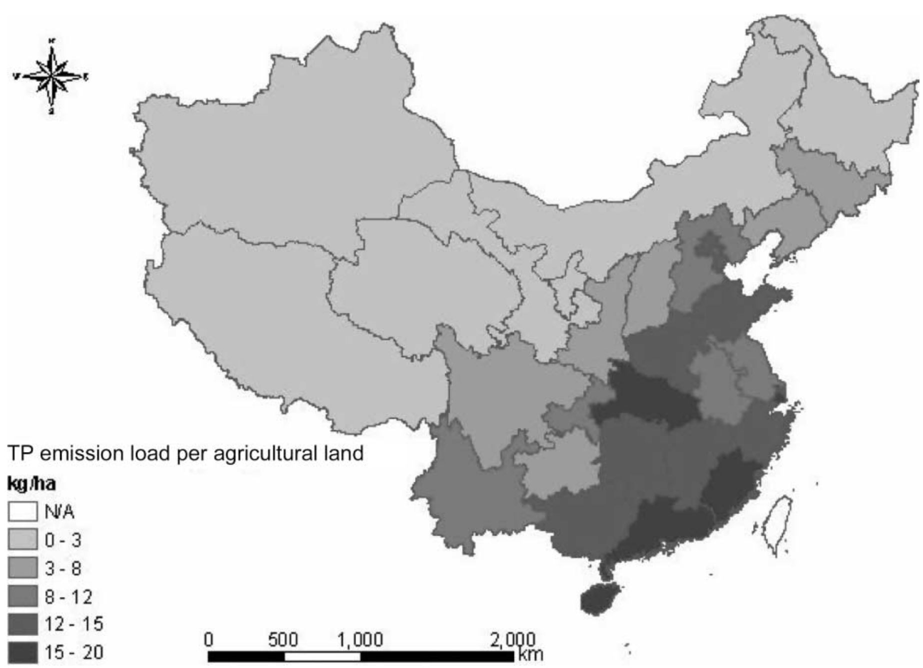

Figure 6 TP emission loads per agricultural land in 2003

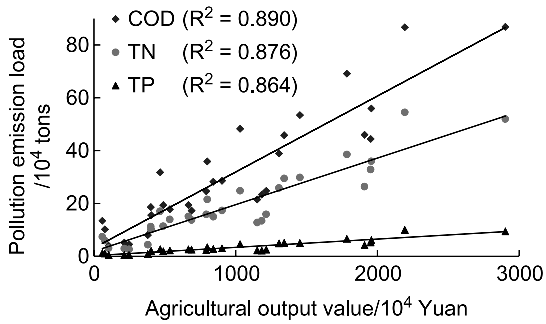

Figure 7 Correlation between pollution loads and gross agricultural output value

practice of intensive agriculture including multiple cropping, intercropping, large scales of livestock production, and over-application of chemical fertilizers.

In some regions, intensification of crop planting and livestock has resulted in a spatial imbalance between nutrient supply and demand. On the one hand, livestock manure is concentrated in confined factories, for which both storage and transportation costs are increased. It is thus difficult for livestock manure to be either directly returned to the soil or utilized in other ways, unless external farm costs could be compensated for. Presently, manure from intensive livestock factories is mostly discharged into nearby ponds or disposal sites, and eventually enters to water-bodies through storm runoff. On the other hand, farmers in intensive farming areas have a high demand for nutrients and have to turn to cheap chemical fertilizers. The average N and P chemical fertilizer applications per cultivation land were 170 kg N ha^{-1} and 104 kg P_2O_5 ha^{-1}, respectively, in China in 2003, which is about twice as high as those in the United States and Europe. Excess dosage of fertilizers, together with improper application practices, has resulted in a low utilization rate, and it is reported that N and P fertilizers are utilized by only 30–35% and 10–20% in China (Zhu, 1998).

As shown in Figure 8, the applied amount of chemical fertilizers (total weight of fertilizer applied, not converted into N or P) is also strongly correlated with the planted areas of grain and vegetables. In particular, the correlation between fertilizer–vegetable as given by R^2 is greater than that between fertilizer–grain. This illustrates that vegetable planting contributes more directly to fertilizer runoff in China. In general, the N fertilizer application of vegetables, melon, and flowers is 569–2 000 kg N ha^{-1}, which is at least 1.2–2 times more than that of grain crops, and even 10 times in some regions (Zhang *et al.*, 2004). Further analysis reveals that application of chemical fertilizers increases more than the vegetable planted area, which suggests that the nutrients are increasingly easy to runoff from vegetable-planted lands.

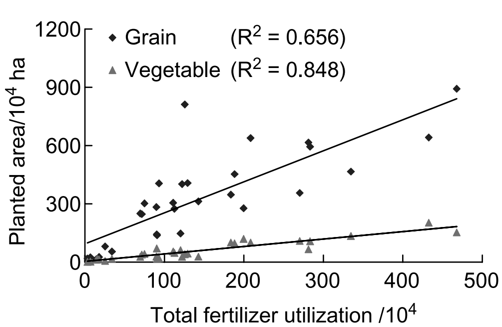

Figure 8 Correlation between applied fertilizer amount and planted area

Population and rural pollution

As shown in Figure 9, there is also strong correlation between rural pollution loads and population, indicating that the high population in China is one of the dominant driving forces of rural pollution. China's population is growing at a rate of about 15 million per year, which has been an increasing challenge to food security. Meanwhile, food preference in China is undergoing a rapid change toward high contents of protein and nutrition. This further increases the demand for grain, vegetables, and meat. To this end, China has developed various policy instruments to promote grain and meat production, the most important of which include multiple cropping, subsidy of chemical fertilizers, and livestock production. Due to the lack of environmental consideration in agricultural policy formation, the effective implementation of these policies leads to a significant amount of agricultural waste discharged from grain, vegetable, and livestock production.

The Environmental Kuznets Curve (EKC) of rural pollution

Another interesting result is shown in the scatterplot of rural pollution loads and agricultural value-added per person (i.e. the average agricultural income per capita). In general, their relationship would follow an inverted U-shaped curve, known in economic terms as the Environmental Kuznets Curve (EKC). It is explained that pollution increases at the early stage of economic development but decreases when the economy is over a certain mature level. Although the EKC is still facing criticism, it is frequently used to identify a country/region's development stage in terms of both income or economic development and environment quality. As shown in Figure 10, it is clear that most provinces in China are at the early stage of agricultural development in the context of environmental performance, and rural pollution will continue to increase. Given the already high level of total rural pollution loads, it is thus urgent for China to set up an effective rural environmental policy to support a sustainable level of agricultural development.

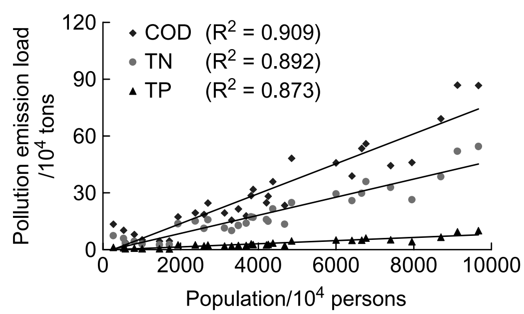

Figure 9 Correlation between pollution loads and population

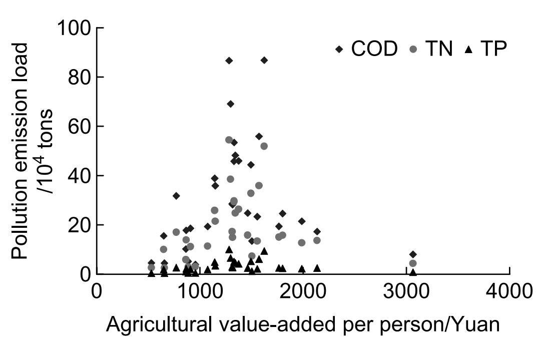

Figure 10 Scatterplot of pollution loads and agricultural value-added per person

Conclusions

Based upon the definition of EU of rural activities, a new method of inventory analysis is developed in this paper to estimate the total rural pollution loads and their spatial distribution in China. Results indicate that rural pollution, which is caused by irrational agricultural practices and inefficient utilization of resources, plays an increasing role in the water environment in China. The total rural pollution loads in China contribute to water quality degradation as much as industrial and municipal wastewater. As opposed to developed countries, rural pollution sources in China are more diverse and include fertilizer runoff, livestock waste discharge, agricultural organic solid waste (e.g. straws and vegetable remains), rural sewage, and municipal wastes. Of the studied 33 provinces in China, the major agricultural regions, such as He'nan, Shandong, Scihuan, and Hebei are the dominant rural pollution producers, and their COD, TN, and TP account for over 30% of national totals. As far as rural pollution intensity per agricultural land is concerned, however, the most polluted provinces are Guangdong, Fujian, Hainan, Hunan, and Shanghai, which have a high population density and rapid urbanization.

Further analysis of correlation between different rural pollution loads and agricultural production outputs indicates that China's current agriculture is developing largely at the cost of environmental quality, and the high population, as well as their increasing demand for agricultural products, is one of the dominant driving forces. This conclusion is consistent with the relationship between rural pollution loads and agricultural income as given by the EKC. Agricultural development in China mostly is far from de-locked from the environmental problem, and a systematic assessment of current agricultural policies is thus required if sustainable agriculture is to be achieved in China.

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