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# Spatio-temporal effects of fertilization in Anhui Province, China

**Qinpu Liu · Yuling Guo · John P. Giesy**

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**Abstract** In order to understand the status and trends in spatio-temporal variations and effects of using inorganic, chemical fertilizers, indexes of hazards of fertilization, including the Fertilization Environmental Hazard Index (FEHI), and fertilization environmental safety threshold were developed and used to evaluate potential for hazards of fertilization and thus sustainability of the use of artificial, exogenous inorganic fertilizers in Agriculture in China. An example case for Anhui Province, China, is presented. Anhui Province is one of the primary agricultural provinces in China, with serious eutrophication of surface

Q. Liu (✉) · Y. Guo
Institute of Resources Use and Environmental Assessment, School of Bio-chemical and Environmental Engineering, Nanjing Xiaozhuang University, 3601 Hongjing Road, Nanjing 211171, People's Republic of China
e-mail: liuqinpu@163.com

Y. Guo
e-mail: gyl600008871@163.com

J. P. Giesy
Department of Veterinary Biomedical Sciences, Toxicology Program Faculty, Toxicology Centre, University of Saskatchewan, 44 Campus Drive, Saskatoon, SK S7N 5B3, Canada
e-mail: JGiesy@aol.com

J. P. Giesy
Department of Zoology, and Center for Integrative Toxicology, Michigan State University, East Lansing, MI, USA

J. P. Giesy
Department of Biology & Chemistry and State Key Laboratory in Marine Pollution, City University of Hong Kong, Kowloon, Hong Kong, SAR, China

J. P. Giesy
School of Biological Sciences, University of Hong Kong, Hong Kong, SAR, China

J. P. Giesy
State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing, China

waters due to non-point source pollution from application of fertilizer in agriculture. The FEHI increased from 0.57, which represented little hazard in 1990 through 0.65 (medium hazard) in 1995 to 0.77 (serious hazard) in 2012. Based on increases in this index and current trends in use of chemical fertilizers, it is predicted that rural aquatic environments of Anhui Province will continue to be affected by cultural eutrophication. Among 16 regions, there were two regions in Anhui Province classified as being at extreme hazard due to over-fertilization, seven regions being at serious hazard and six regions being at moderate hazard. Extreme hazard of pollution due to excess nitrogen (N) was predicted for two regions, and hazard was extreme for five regions due to excess phosphorus (P), and the predicted hazard from potash (potassium; K) was serious for eight regions.

**Keywords** Fertilization intensity · Spatio-temporal effect · Fertilization Environmental Hazard Index · Fertilization environmental safety threshold · Anhui Province

## 1 Introduction

Since the green revolution began in the 1950s, increasing inputs of inorganic fertilizers, organic manures and pesticides have become the principal means of attaining yields and indirectly, greater production of livestock, both globally and in China (Sun et al. 2012). In 2013, yield of crops of cereals in China reached $6.02 \times 10^8$ t (tonnes), which is twice as great as the production of $3.03 \times 10^8$ t that was achieved in 1978. During the same period, application of inorganic fertilizers increased 6.7-fold from $8.84 \times 10^6$ to $5.84 \times 10^7$ t, with average applications of 486 kg/ha of cropland in 2013. Rapid increases in economic activities as measured by the gross domestic product (GDP) have provided the fiscal means for farmers in China to buy more inorganic fertilizers to improve yields of crops. China is now the largest producer and user of synthetic fertilizers in the world. It consumed one-third of all of the inorganic fertilizers applied in the world. The mass of fertilizer used per unit area in China is more than three times greater than the average for the rest of the world (Ding and Zang 2009). However, this agro-chemical-based intensive agriculture has contributed substantially to emission of greenhouse gases $CH_4$ and $N_2O$, and the entry of pollutants (excessive nitrogen and phosphorus) into soils and water bodies, which has resulted in serious degradation of the natural surface waters due to cultural eutrophication (Smil 1997; Diaz and Rosenberg 2008; Gilbert et al. 2010). Concentrations of nitrogen (N) and phosphorus (P) in larger rivers, especially the Yangtze, Yellow and Huai, have been increasing during recent years (Li et al. 2007; Yu et al. 2010; Zou 2011). The first national pollution census bulletin for China, which was published in 2010, reported that the total mass of N from agricultural non-point source pollution was $2.7 \times 10^6$ t, while that of P was $2.84 \times 10^5$ t, which accounted for 57.19 and 67.27 % in total emissions of these two nutrients, respectively. Surveys conducted in 2012 by the Chinese government found that 70 % of river systems in China suffered from slight or moderate pollution, and eutrophication of lakes was a serious problem in some regions (State Environmental Protection Administration 2013).

Anhui is a province of China, rich in agricultural resources. It is a national fundamental region for production of grain, cotton, food oil, meat and fresh water products. In 2012, total output of grain was $3.3 \times 10^7$ t. A total of $3.3 \times 10^6$ t of inorganic fertilizer was used at an average rate of 797.1 kg/ha, which is 1.66-fold greater than the national average. While several studies on non-point pollution of farmland and surface waters in Anhui have focused on trace metals (Zhu et al. 2007; Xu and Chang 2008; Fan et al. 2010), little has been done relative to hazards posed by chemical fertilizers. Here, the concepts of

Fertilization Environmental Hazard Index (FEHI) and fertilization environmental safety threshold (FEST) are presented and used to evaluate hazards of farmland fertilization in order to identify serious eutrophication due to agriculture that is not sustainable.

## 2 Materials and methods

### 2.1 Study area

Anhui Province is located in eastern China with latitude from N29°41′ to N34°38′ and longitude from E114°54′ to E119°37′, and covers $1.4 \times 10^5$ square kilometers accounting for 1.45 % of total surface area of China. The province is crossed in the north by the Huai River and in the south by the Yangtze River, with alternating areas of plains, hills, mountains, lakes and low-lying areas. The north of the province is part of the North China Plain, while the north-central areas are part of the Huai River watershed. Both of these regions are flat and densely populated with intensive, advanced agriculture. The land becomes more uneven further south, with the Dabie Mountains occupying much of southwestern Anhui and a series of hills and ranges cutting through southeastern Anhui. Chao Lake, the fifth largest fresh water lake of China, with an area of about 800 $km^2$, is located in the center of the province,

Compared to its eastern neighbors, Zhejiang and Jiangsu Provinces, Anhui has lagged in economic development, specifically industrialization, with a per capita GDP in 2012 of ¥ 25,920 ($4,249 USD). It is also a primary agricultural region with cultivated land of $4.2 \times 10^6$ ha and rural population of 53 million people, which accounts for 77 % of total population of Anhui. There are 16 sub-administrative regions, each with distinctive geographic and economic conditions.

### 2.2 Collection of data

Most of the data used in this analysis came from the 2013 Anhui Statistical Yearbook (Bureau of Statistics of Anhui 2013), which is compiled by the Bureau of Statistics of Anhui Province, and the document of Eco-county, Eco-city, Eco-province Construction Indexes (Revised Draft) from the former State Environmental Protection Administration issued in 2007. Some of the data were compiled from the 2013 China Statistical Yearbook (National Bureau of Statistics of China 2013) and 2013 Anhui Statistical Yearbook.

### 2.3 Methods

Assessment of hazards posed by application of inorganic, chemical fertilizations was based on an evaluation of the status and trends in potential damage and threats to human health, economy and ecological system, and the decision of management. Here, the concept of total Fertilization Environmental Hazard Index ($\mathrm{FEHI}_t$) is presented (Eqs. 1–2).

$$\mathrm{FEHI}_t = \sum_{i=1}^{n} W_i \cdot \mathrm{FEHI}_i \tag{1}$$

$$\mathrm{FEHI}_i = \frac{\mathrm{FI}_i}{\mathrm{FI}_i + \mathrm{FEST}_i} \tag{2}$$

where $\mathrm{FEHI}_t$ denotes the total Fertilization Ecological Hazard Index, which is the sum of component hazard factors multiplied by weighting factors; $\mathrm{FEHI}_i$ represents a single factor (*i*) for an individual constituent of fertilizers, such as N, P or K; $W_i$ is the weight of each factor with values between 0 and 1. $FI_i$ is the fertilization intensity of i factor, that is the mass of fertilizer i applied on the per unit of cultivated land area (kg/ha); $FEST_i$ is the fertilization ecological safety threshold of a single factor, which means the maximum mass of a fertilizer applied to soil to maximize productivity without adverse effects on the environment (kg/ha). The net volume of fertilizer is the mass of N, P or K in the forms of N, phosphate ($P_2O_5$), potash ($K_2O$), respectively.

Values of $FEHI_t$ (or $FEHI_i$) range from 0 to 1.0. When $FEHI_t$ is equal to 0.5, $FI_i$ is equal to $FEST_i$, where fertilization of cropland is at the critical point of environmental safety, above which adverse effects would be expected to occur. When $FEHI_t$ is nearly 1.0, fertilization intensity ($FI_i$) of fertilizer greatly exceeds the environmental safety threshold ($FEST_i$). That is, pollution due to excess application of fertilizer would be extremely serious. When $FEHI_t$ approaches 0, use of inorganic fertilizer is nearly 0 and $FI_i$ is less than the $FEST_i$. This is referred to as organic agriculture, in which addition of inorganic fertilizer is not contributing to cultural eutrophication. Environment hazard (or safety) can be assessed by the magnitude that $FEHI_t$ deviates from 0.5. According to the folds of fertilizer mass greater or less than the FEST, classification of environmental hazards from "safety" to "extreme hazard" can be divided into 6 classes (Table 1).

## 3 Results and discussion

### 3.1 Temporal trends in indexes due to use of fertilizer in Anhui Province

Before calculation of Fertilization Environmental Hazard Indexes (FEHI), the threshold FEST must be determined. In this assessment, 250 kg/ha was used as the threshold $FEST_t$, because the Chinese government considers it to be the standard for assessment of eco-county in China (Ministry of Environmental Protection of P.R.C. 2009). Because the appropriate proportions of N, P and K for most crops is 1:0.5:0.5, values of $FEST_i$ for N, P and K are 125, 62.5 and 62.5, respectively. According to their magnitudes of harm to the environment when overused, 0.35, 0.55 and 0.10 are defined as $W_i$ for N, P and K, respectively. Using models of fertilization environmental hazard assessment, yearly fertilization intensities ($FI_i$) were calculated for Anhui Province for the period 1990–2012. This information was then compared with annual yields of grain, cotton and food oil (Fig. 1).

Amounts of fertilizer applied, expressed as both the total and normalized to area, has been steadily increasing in Anhui Province from 1990 to 2012. The total amount of

**Table 1** Classes of Fertilization Environmental Hazard Index (FEHI)

| Class | FEHI | Indication of degree | Criteria |
|---|---|---|---|
| 5 | >0.80 | Extreme hazard | Mass of fertilizer greater than four times of FEST |
| 4 | 0.76–0.80 | Serious hazard | Mass of fertilizer less than four times of FEST |
| 3 | 0.66–0.75 | Medium hazard | Mass of fertilizer less than three times of FEST |
| 2 | 0.51–0.65 | Minimal hazard | Mass of fertilizer less than twice and greater than one FEST |
| 1 | 0.35–0.50 | Relative safety | Mass of fertilizers less than one FEST |
| 0 | <0.35 | Safety | Mass of fertilizers less than half of FEST |

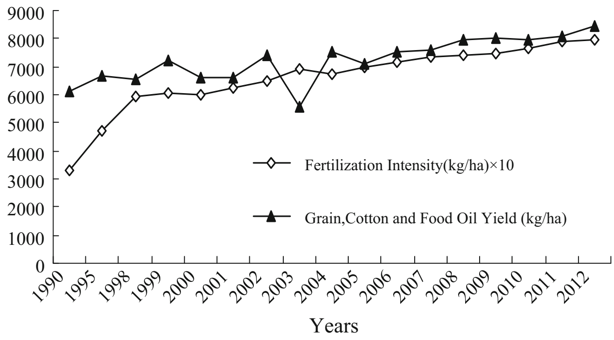


**Fig. 1** Trends of fertilization intensity and sum yields of grain, food oil and cotton products

fertilizer used increased from $1.45 \times 10^6$ t in 1990 to $3.3 \times 10^6$ t in 2012. Fertilization intensity (*FI*), where the total amount of fertilizer applied was normalized to the area farmed, increased from 333 to 797 kg/ha in the same period. Both total amount of fertilizers and $FI_t$ increased, while the sum of yields of grains, food oil and cotton products increased by 38 % from 6,123 to 8,475 kg/ha (Fig. 1). This analysis suggests that it is likely that the amount of fertilizer used will continue to increase into the future, a result that is consistent with the conclusions of other studies (Hu and Zhao 2007; Zhao and Cheng 2011; Sattari et al. 2012).

Due to the "law of diminishing returns" of land, increasing rates of use of fertilizer have been greater than rates of production of grain, food oil and cotton. Efficiency of use of fertilizers, which is the product yield per unit of fertilizer, has been decreasing, while the FEHI has been increasing (Fig. 2). The FEHI increased from 0.57 ("minimal hazard") through 0.65 in 1995 ("medium hazard") to 0.77 ("serious hazard") in 2012. According to the current trend of fertilizer use, FEHI will soon exceed 0.8, which indicates "extreme hazard."

## 3.2 Spatial variation of FEHI in Anhui Province

Using the models of fertilization environmental hazard assessment, $FEHI_t$ and $FEHI_i$ ($FEHI_N$, $FEHI_P$, $FEHI_K$) were calculated and ranked for each region of Anhui (Table 2).

Two regions, Tongling and Huainan of Anhui Province, were classified as being at "extreme hazard" from over-fertilization. Seven regions, Bengbu, Hefei, Xuancheng,

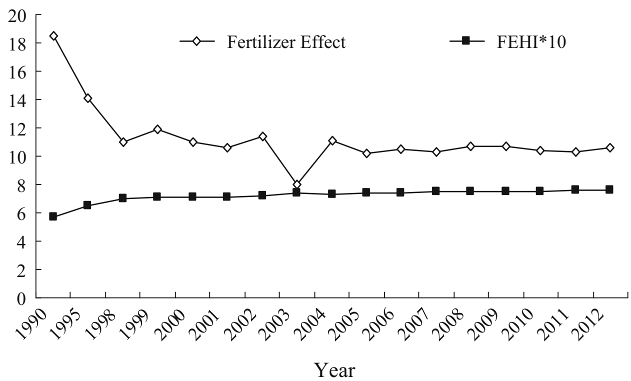


**Fig. 2** Trends of fertilizer effect and Fertilization Environmental Hazard Index (FEHI)

**Table 2** Fertilization Environmental Hazard Index ($FEHI_t$) among regions of Anhui Province in 2012

| Regions | Total fertilizers | | Nitrogen (N) | | Phosphate ($P_2O_5$) | | Potash ($K_2O$) | |
|---|---|---|---|---|---|---|---|---|
| | $FEHI_t$ | Hazard degree | $FEHI_N$ | Hazard degree | $FEHI_P$ | Hazard degree | $FEHI_K$ | Hazard degree |
| Chizhou | 0.71 | Medium | 0.76 | Serious | 0.66 | Medium | 0.76 | Serious |
| Bozhou | 0.71 | Medium | 0.66 | Medium | 0.74 | Medium | 0.74 | Medium |
| Suzhou | 0.73 | Medium | 0.74 | Medium | 0.72 | Medium | 0.75 | Medium |
| Fuyang | 0.73 | Medium | 0.71 | Medium | 0.75 | Medium | 0.75 | Medium |
| Ma'anshan | 0.74 | Medium | 0.74 | Medium | 0.75 | Medium | 0.75 | Medium |
| Huangshan | 0.74 | Medium | 0.81 | Extreme | 0.70 | Medium | 0.74 | Medium |
| Huaibei | 0.75 | Medium | 0.74 | Medium | 0.75 | Medium | 0.76 | Serious |
| Liuan | 0.76 | Serious | 0.79 | Serious | 0.74 | Medium | 0.75 | Medium |
| Anqing | 0.76 | Serious | 0.75 | Medium | 0.78 | Serious | 0.77 | Serious |
| Wuhu | 0.78 | Serious | 0.80 | Serious | 0.77 | Serious | 0.74 | Medium |
| Chuzhou | 0.78 | Serious | 0.76 | Serious | 0.80 | Serious | 0.75 | Medium |
| Xuancheng | 0.79 | Serious | 0.79 | Serious | 0.79 | Serious | 0.77 | Serious |
| Hefei | 0.79 | Serious | 0.78 | Serious | 0.80 | Serious | 0.79 | Serious |
| Bengbu | 0.80 | Serious | 0.80 | Serious | 0.81 | Extreme | 0.78 | Serious |
| Tongling | 0.82 | Extreme | 0.79 | Serious | 0.83 | Extreme | 0.80 | Serious |
| Huainan | 0.84 | Extreme | 0.83 | Extreme | 0.86 | Extreme | 0.79 | Serious |
| Average | 0.77 | Serious | 0.77 | Serious | 0.77 | Serious | 0.76 | Serious |

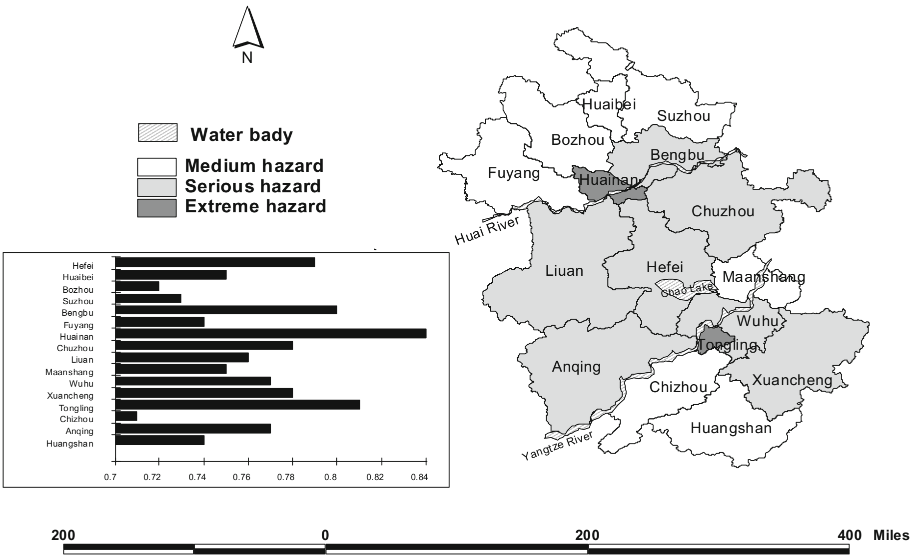


**Fig. 3** Distribution of hazards (FHRI) due to NPK pollution

Chuzhou, Wuhu, Anqing and Liuan were classified as being at "serious hazard." Hazards of the rest six regions were classified as "medium hazard" (Fig. 3). Two regions of Huainan and Huangshan were classified as being "extreme hazard," and nine regions were

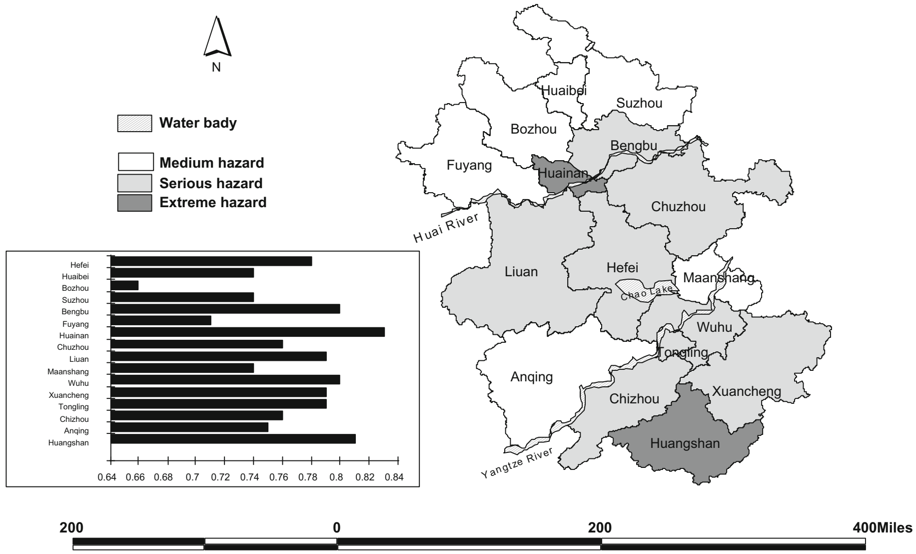


**Fig. 4** Distribution of hazards ($FEHI_N$) due to N pollution

classified as "serious hazard" due to pollution with N (Fig. 4). Three regions, Huainan, Tongling and Bengbu, were classified as being "extreme hazard," due to pollution with P (Fig. 5). No regions were classified as being "extreme," but eight regions were classified as being "serious," and the rest of eights regions as being "medium" due to pollution with K (Fig. 6). Hazards posed by non-point pollution, due to use of inorganic, chemical fertilizers in Anhui Province, are serious, especially for P due to its cause of entrophication of lakes. This causes undesirable changes in ecology, resulting in a decline in the provision of eco-services, often with serious economic consequences (Syers et al. 2008).

## 3.3 Effects of overuse of chemical fertilizers on the environment of Anhui Province

Excess fertilization can eventually cause deterioration of soil, pollution of air and water, poor quality agricultural products and in some cases result in adverse effects on health of people, such as methemoglobinemia caused by nitrite ($NO_2^-$). Excess N in surface and groundwater mainly originates from farmland, on which excess inorganic fertilizers are applied (Zou 2011). According to monitoring of soils in Mengcheng County in Bozhou, Anhui Province, sponsored by the local government, pH of soil has been decreasing since 1985. On average, pH of soil decreased from 8.2–8.4 in 1985 to 7.2–7.7 in 2003 with the least pH of 6.1. Thus, pH has decreased 0.7–1 units within 8 years. By 2006, the mean pH of soil was 6.56, with a minimum of 4.57, which is a decrease of 1 U within 3 years (Table 3). This trend in pH is mainly due to overuse of fertilizer (Zhang and Hu 2008).

The main reason for the decreasing pH is the use of inorganic, chemical fertilizers which contain chlorine (Cl), sulfur (S) and P. These elements can result in leaching of ions, including $Na^+$, $K^+$, $NH_4^+$, $Mg^{2+}$ and $Ca^{2+}$ from soil, which affects ion balance and results in excessive $H^+$. Another reason for acidification is increasing rates of use of fertilizer and lesser efficiency of assimilation by plants. For example, in the vicinity of Chao Lake, the mass of N from fertilizer was 75, 750 and 960 kg/ha in 1960s, 1980s and 2000s,

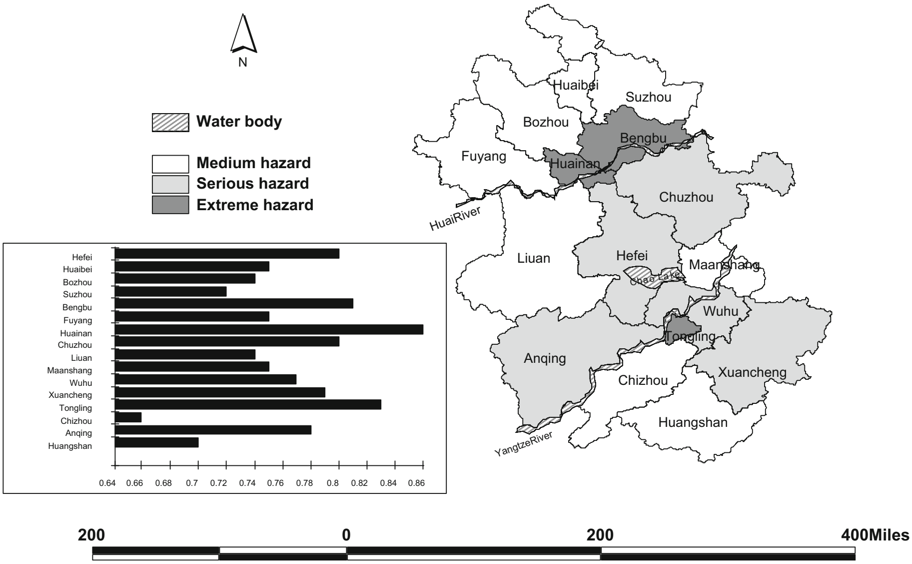


**Fig. 5** Distribution of hazards ($FEHI_P$) due to P pollution

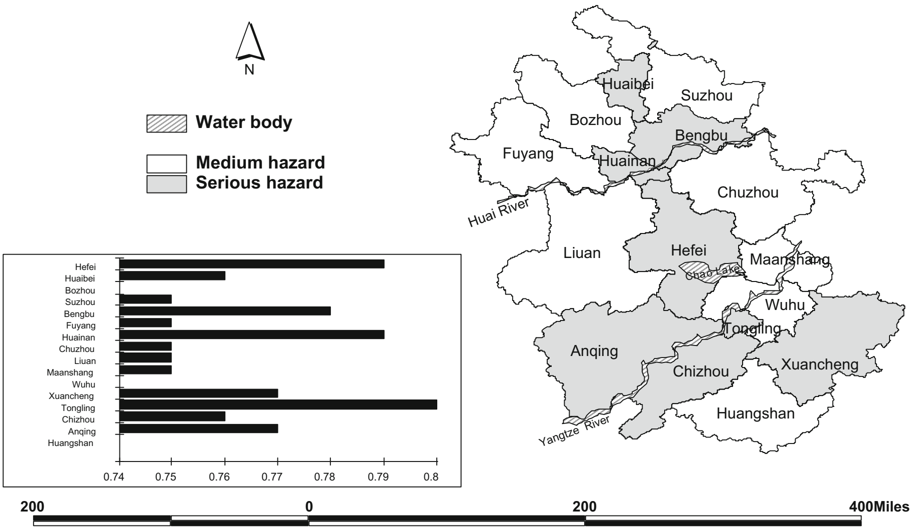


**Fig. 6** Distribution of hazards ($FEHI_K$) due to K pollution

respectively, with the greatest amount of 1,200 kg/ha in 2008 in some areas (Wang et al. 2008). According to the Environmental Protection Bureau of Anhui Province (Bureau of Environmental Protection of Anhui Province 2013), water quality of tributaries to the Huai River in Anhui Provence is moderately polluted. Of the 19 tributary rivers, there were 4 tributaries with minimal water pollution, 3 tributaries with moderate pollution, 12 tributaries with severe pollution. Water quality of Chao Lake was grade IV, with minimal pollution and moderate eutrophication. Among 11 rivers which flow into the Chao Lake, there were 2 rivers that were classified as being moderately polluted, 5 rivers were

**Table 3** Changes of nutrients and pH values of soils in Mengcheng, Bozhou, Anhui Province (Zhang and Hu 2008)

| Year | Total N (g/kg) | Available P (μg/g) | Available K (μg/g) | Soil pH |
|---|---|---|---|---|
| 1985 | 0.86 | 4.8 | 146 | 8.2–8.4 |
| 2002 | – | 16.3 | 117 | 7.2–7.7 (2003) |
| 2006 | 0.94 | 18.5 | 129 | 6.56 |

seriously polluted, and only 4 rivers were deemed to not be polluted. According to the survey on 740 farm families in watershed of Chao Lake (Liu et al. 2008), 90 % of them overused nitrogen fertilizers with unsuitable methods of fertilization, such as spreading fertilizers on the surface of soil, fertilizing crops once a year with unreasonable amounts, which results in non-point source pollution due to runoff, leaching and evaporation.

### 3.4 Responsibilities of governments

Excess fertilization has resulted in severe acidification of soil, moderate pollution of the Huai River and entrophication of Chao Lake in Anhui. Thus, overuse of fertilizers is a significant environmental problem there. One reason for the overuse of fertilizers is that farmers do not know how much fertilization is suitable for their crops. Most of them have the misperception that the more fertilizers the greater production. So it is the responsibility of local jurisdictions to offer many kinds of training programs to farmers. Government agencies should send agricultural technicians to the countryside to guideline fertilization applied by farmers. They should inform farmers of the optimal amounts and types of fertilizers to apply, based on the regional soil types and crops. For example, the northern area of Anhui is mostly located in the Yellow-Huai River alluvial plain. There are various types of yellow alluvial soils, most of which have lesser quantities of organic matter should be used with more organic fertilizers to improve soil structures. In the southern part of Anhui, where rice is cultivated along the Yangtze River Plain, it is recommended to use fertilizers such as urea, ammonium chloride, rather than sulfate and nitrate N. There were some successful practices that government helped farmers with technology of fertilizer prescription via soil measurement since 2005. It has been demonstrated that optimal rates of applications of fertilizers would reduce rates of application by 28 kg/ha, which would also maintain optimal productivity. In fact, based on a reduced cost of fertilization while maintaining maximum productivity would result in a net increase in profit of approximately 838 ¥/ha (136.3 $/ha) (Zhao and Cheng 2011). As farmers learn better fertilization practices, they will be better able to assist in protection of the environment, reduce environmental hazards and ensure sustainability of their agricultural practices.

Government agencies should also persuade and assist fertilizer producers to pay more attention to technological innovations by providing farmers with better quality, more effective, slow-releasing fertilizers, such as organic compound fertilizers. Application of mixed organic and inorganic fertilizers is good for quality of both soil and products. Also straws and other residues of crops could be used.

## 4 Conclusions and suggestions

1. Models of evaluating the environmental hazard by over-fertilization, initially set up by authors were applied to assess Anhui agricultural environment. The FEHI increased

from 0.57 (minimal hazard) in 1990 through 0.65 (medium hazard) in 1995 to 0.77 (serious hazard) in 2012. According to the current trend in use of fertilizer, the FEHI will soon be over 0.8, which is extreme hazard. Thus, the rural ecological environment situation of Anhui Province faces serious challenges.

2. Fertilizers were found to be over-used in most sub-administrative regions of Anhui Province. Among 16 regions, two were classified as being extremely at hazard from over-fertilization, seven were classified as being serious, six were classified as being moderate. Two regions were classified as being extremely at hazard due to pollution with N, three were classified as being serious at hazard due to pollution with P, and no regions were classified as being extreme at hazard due to pollution with K. Based on the results of this assessment, environmental hazard posed by non-point source pollution from use of chemical fertilizers in Anhui Province is very serious.
3. Models of assessing fertilization environmental hazard need further improvement in the future. Determination of threshold guidelines for application of inorganic fertilizers should consider the social, ecological and economic factors of agricultural production of various regions in China. The 250 kg/ha of fertilization environmental safety threshold suggested by the Chinese government is very general, but is useful for the control of total amount of fertilizers at provincial or county levels. It gives references of fertilization for policy makers, agriculture producers or farmers. In fact, the situation varies between regions, sites and also between crops, so the FESTs should be different in different places where the amounts of fertilizer used could be higher or lower than 250 kg/ha according to local conditions. And the classifications of fertilization environmental hazard can also be adjusted according to local conditions and requirements for the quality of environment.

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