Spatial Structure Change Analysis of Cultivated Soil Nutrients in Urban Fringe of North China

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Abstract. Spatial structure analysis is beneficial to guide soil nutrients management. This paper developed a method for spatial structure of soil nutrients and analyzed these change characteristics from 2000 to 2007 using geographic information system (GIS) technology for Daxing district of Beijing, China. The results of spatial structure were obtained and occupied space proportions of total kjeldahl nitrogen (TN), alkali-hydrolyzable nitrogen (AN), organic matter (OM), available phosphorus (AP) and available potassium (AK) were 0.33, 0.22, 0.25, 0.03, 0.16 for 2000 and 0.32, 0.25, 0.23, 0.03, 0.17 for 2007, respectively. The change characteristics and influence factors for spatial structure of soil nutrients were systematically analyzed. Increased soil nutrients were exhibited three belts on the whole, whereas decreased soil nutrients were located in other regions. Natural factors and human activities drove these changes of soil nutrients. This study provides a reference for future related research.

Keywords: Soil nutrients, Spatial structure, Principal component analysis, Geographic information system, Urban fringe

1 Introduction

In the long-term agricultural production and human activities, soil is a renewable resource and plays an important role in maintaining the balance of agricultural ecology and environment [1]. Soil nutrients are key factors for regional food safety, grain yield and agricultural sustainable development [2].

Since the 1970s, a large number of researches on soil nutrient have been developed by domestic and foreign scholars using geostatistical methods [3]. Numerous studies have been developed to focus on predicting spatial variability of soil nutrients based on different Kriging methods from different spatial scales [4]. These studies are including two issues: spatio-temporal variation of soil nutrients and quality evaluation of soil nutrients [5, 6, 7, 8, 9]. However, scarce researches focus on the spatial structure analysis of soil nutrients now. Geographic information system (GIS) technology can effectively solve the relation between spatial data and attribute data of soil nutrients, and coupling with statistical methods can reveal the spatial structure of regional soil nutrients. Therefore, the objectives in the paper are to present a method for spatial structure of soil nutrients by principal component analysis (PCA) and analyze these change characteristics from 2000 to 2007 using geographic information system (GIS) technology.

2 Study Area

Daxing district of Beijing is in the urban fringe of North China between longitude 116°13'-116°43' E and latitude 39°26'-39°51' N. The study area is shown in Figure 1. Daxing district covers an area of 1,036 km^2. The district is characterized by alluvial plains. The district is rich in foods, vegetables and fruits. Additionally, agricultural cropping patterns and crops in this district are winter wheat-summer corn, spring corn, winter wheat, and so on.

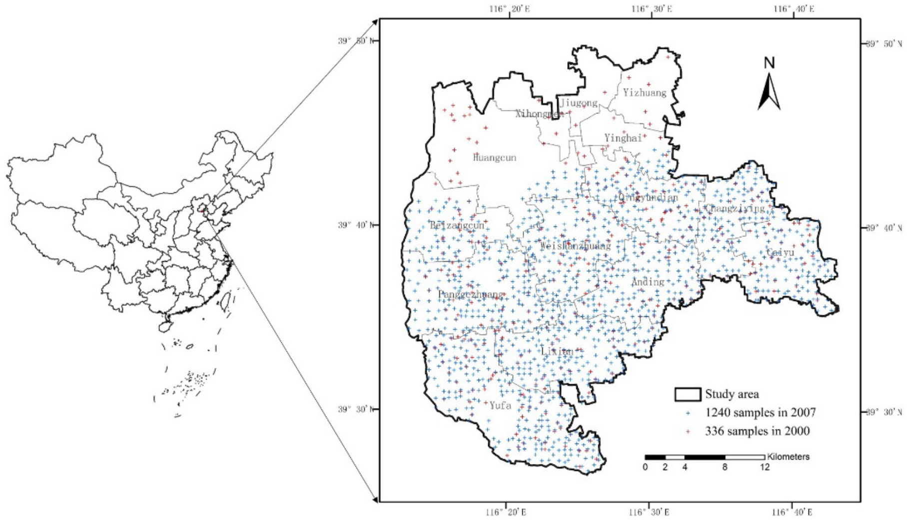

Fig. 1. Daxing district in Beijing

3 Data and Methods

3.1 Soil Sampling Data

In this study, two projects of soil sampling were achieved in 2000 and 2007, respectively. The surface soil with 0-20 cm depth were obtained in the sampling collection process. Each sampling had about 1 kg of mixed soil. Total 336 and 1,240 soil samples were collected for 2000 and 2007, respectively. Five soil nutrients including TN, AN, OM, AP and AK were selected for chemical analysis.

3.2 Household Survey Data

In this study, questionnaires and field investigations were implemented in Daxing district. All of the 274 households from 14 villages of 6 towns including Anding, Beizang, Lixian, Panggezhuang, Qingyundian and Weishanzhuang were surveyed and interviewed among the farmers in agricultural activities. The information collected in this survey mainly included land use, planting pattern, cropping systems, fertilization structure, population and economic incomes, and so on

.

3.3 Methods

Spatial Interpolation and Standardized of Soil Nutrients. Kriging method was used for spatial interpolation of TN, AN, OM, AP and AK based on ArcGIS 9.3 software for Daxing district in 2000 and 2007. Classification and gradation were achieved according to the *Standard for Classification and Gradation of Soil Nutrient in Beijing* (Beijing Soil and Fertilizer Station, 2006) and included three classes of high, medium and poor grades. The results are shown in Table 1.

Table 1. The grades of soil nutrients for Daxing district.

Grade	TN (g/kg)	AN (mg/kg)	OM (g/kg)	AP (mg/kg)	AK (mg/kg)
High	>1.00	>90	>20	>60	>125
Medium	0.65-1.00	45-90	10-20	15-60	70-125
Poor	<0.65	<45	<10	<15	<70

Soil nutrients of TN, AN, OM, AP and AK were lack of comparability because of these different dimensions and units, so fuzzy membership function model was adopted to standardize five indicators of soil nutrients. The higher of the index manifested the much higher levels of the factor, but the utility of this factor also tended to a constant factor when it rose a certain critical value. S-type fuzzy membership function model was selected in this study, and membership value was from 0.1 to 1.0. The calculation formula was defined as:

$$F(x)=\begin{cases}1.0 & x \ge U \\ 0.1+0.9\times\dfrac{x-L}{U-L} & L \prec x \prec U \\ 0.1 & x \le L\end{cases} \tag{1}$$

Where *F(x)* is membership value, and *x* is original value. *U* is the upper inflection point of function, and the value is demarcation point of high and medium grades in Table 1. *L* is the lower inflection point of function, and the value is demarcation point of medium and poor grades in Table 1.

Spatial Structure Analysis of Soil Nutrients. Principal component analysis (PCA) was adopted for spatial structure analysis of regional soil nutrients in urban fringe of North China [10, 11].

The calculation method for the spatial structure of soil nutrients indicators was achieved.

(1) Correlation coefficient matrix of soil nutrients indicators standardized was calculated to obtain eigenvalues, eigenvectors and variance contribution rate corresponding eigenvalues.

(2) The first *t* principal components that cumulative variance contribution rate was greater than 85% were selected to integrate original data information. Variance contribution rate was defined as:

$$C=(C_1,C_2,\ldots,C_t) \tag{2}$$

(3) The first *t* eigenvectors were adopted and standardized using:

$$A = (A_1, A_2, ..., A_t) = \frac{(U_f - \min(U_f))}{(\max(U_f) - \min(U_f))} \tag{3}$$

Where *U* was eigenvectors, and *f* was from 1 to *t*.

(4) The overall contribution rate of each factor was calculated using:

$$P = \frac{C \times A^T}{\sum_{i=1}^{t} C_i} \tag{4}$$

(5) *P* was standardized as:

$$W = \frac{P_j}{\sum_{j=1}^{t} P_j} = (w_1, w_2, ..., w_n) \tag{5}$$

Where w_j was the spatial structure proportion of *j-th* soil nutrients indicator.

4 Results and Discussion

4.1 Spatial Structure Proportions and Distributions of Soil Nutrients

Soil nutrients standardized for Daxing district were analyzed by principal component analysis in 2000 and 2007, respectively. Table 2 and Table 3 show the calculated results of principal component analysis. The first two principal components were selected to calculate spatial structure proportion because of their cumulative variance contribution rates were both greater than 85% in 2000 and 2007, respectively. Table 4 shows the calculated results and the spatial structure proportions of TN, AN, OM, AP and AK in Daxing district were 0.33, 0.22, 0.25, 0.03, 0.16 for 2000 and 0.32, 0.25, 0.23, 0.03, 0.17 for 2007, respectively. The results showed that contents of nitrogen, organic matter, potassium and phosphorus in the soil of Daxing district were highest, high, low and lowest levels, respectively.

Table 2. Eigenvalues for PCA of soil nutrients in Daxing district.

Year	PC	Eigenvalues	Cumulative variance contribution rate, %
2000	PC1	0.1151	76.40
	PC2	0.0165	87.32
2007	PC1	0.2247	81.03
	PC2	0.0283	91.23

Table 3. Eigenvector matrix for PCA of soil nutrients in Daxing district.

Year	PC	Eigenvector matrix				
		TN	AN	OM	AP	AK
2000	PC1	0.666494	0.45314	0.487503	-0.06254	0.329968
	PC2	0.452376	0.26201	0.195713	0.201007	-0.80498
2007	PC1	0.632707	0.500107	0.450137	0.023445	0.382625
	PC2	0.259954	0.072094	0.295811	0.232617	-0.88635

Table 4. Spatial structure proportions of soil nutrients.

Proportion	TN	AN	OM	AP	AK
2000	0.33	0.22	0.25	0.03	0.16
2007	0.32	0.25	0.23	0.03	0.17

A spatial structure of certain indicator was the product of this indicator and its spatial structure proportion, and all of the indicators' spatial structure were combined into spatial structure of regional soil nutrients in Daxing district of Beijing. Spatial structure distributions of soil nutrients in 2000 and 2007 were exhibited in Figure 2 and Figure 3, respectively. The process was performed in ArcGIS 9.3 software.

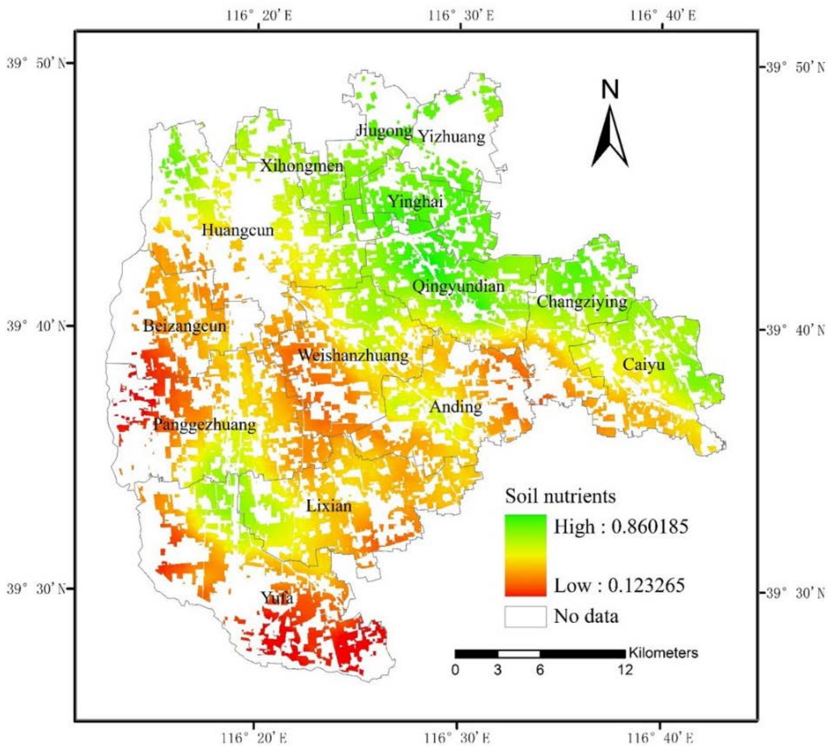

Fig. 2. Spatial structure distributions in 2000

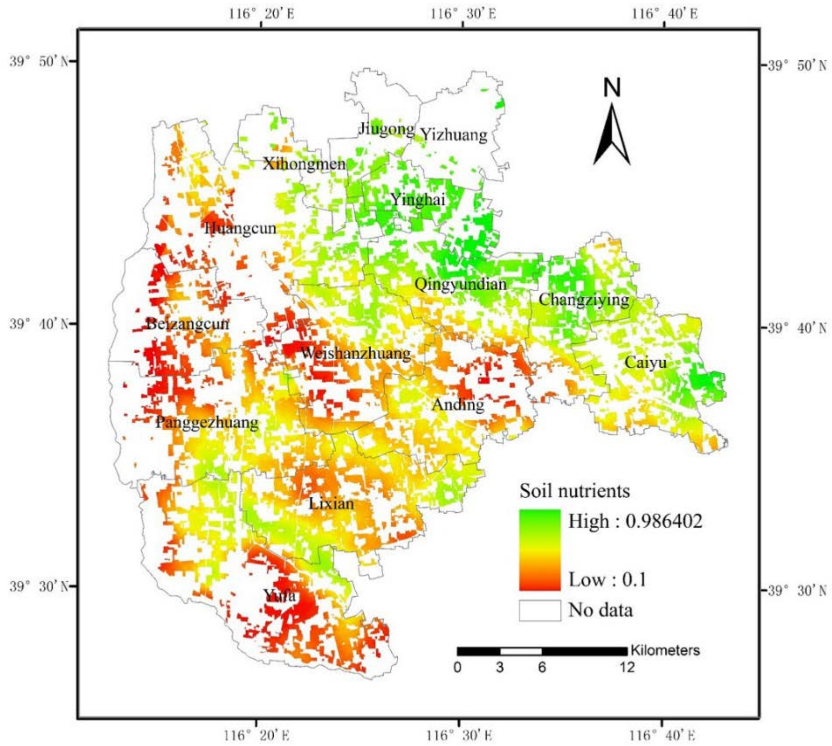

Fig. 3. Spatial structure distributions in 2007

In general, high values of soil nutrients were mainly concentrated in the northeast regions whereas low values were located in the southwestern regions and the central regions of Daxing district.

4.2 Spatial Structure Change Analysis from 2000 to 2007

Spatial structure change analysis of soil nutrients from 2000 to 2007 was achieved using spatial distribution characteristics in 2000 and 2007 based on ArcGIS 9.3 software (Figure 4). Increased soil nutrients were exhibited three belts on the whole including northeast, middle and south belts, whereas decreased soil nutrients were located in other regions. Northeast belt included Caiyu, Changziying and Yinghai towns. Middle belt contained Anding, Weishanzhuang and Panggezhuang towns. South belt included Lixian and Yufa towns.

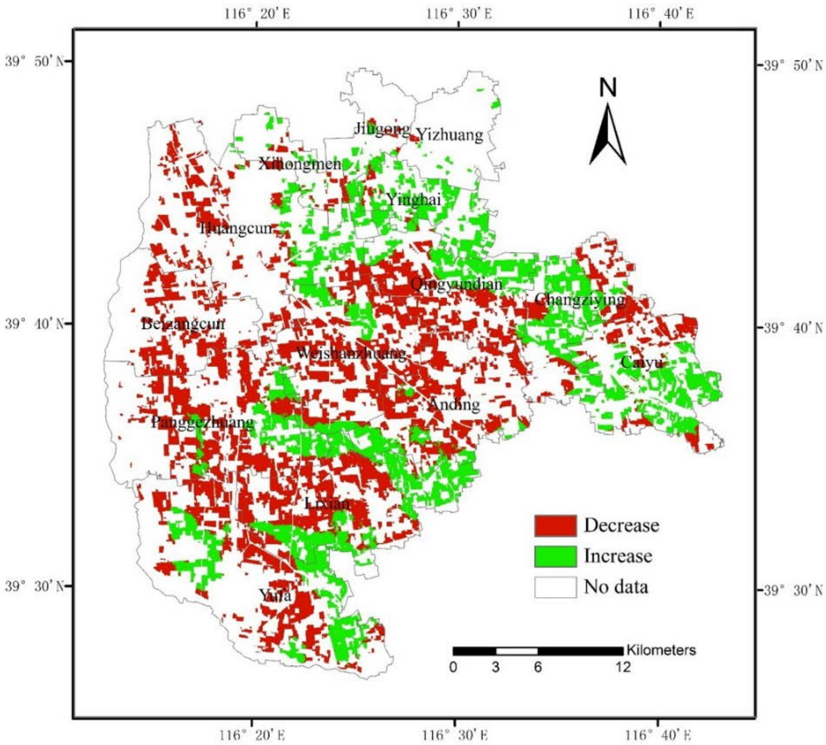

Fig. 4. Spatial structure change of soil nutrients from 2000 to 2007

4.3 Influence Factors Analysis for Spatial Structure Change of Soil Nutrients

The influence factors for spatial structure change in Daxing district were drove by natural factors and human activities. Natural factors included soil type and texture, and location conditions. Human activities were mainly divided into government regulation and planning and household decision behavior.

Natural Factors. Natural factors were one of the important limiting factors for spatial structure change of soil nutrients. Chao soil was major soil type of Daxing district and accounted for more than 95% of the total area. Chao soil was rich in mineral nutrient and lower of available phosphorus content. Light loamy soil in northeast regions with moderate soil texture, good permeability and temperature stability, was conducive to nitrogen absorption and organic matter accumulation. Sandy soil in southwest region with soil temperature change rapid, poor drought resistance and relatively poor nourishment contain, was much more difficult to the accumulation of OM in this study area. The soil particles and the soil nutrients sucking fertilizer properties were poor and not conducive to fertilizer especially for potassium and phosphorus. Daxing district was the nearest district to Beijing downtown and consumed a lot of urban waste, garbage and sewage, so soil organic matter content in urban fringe was increased.

Government Regulation and Planning. Most of the cultivated land in urban fringe were diverted and expropriated because of the rural urbanization construction, which was resulted in decreasing soil nutrients. Increased soil nutrients were associated with Eleventh Five-Year Agricultural Development Planning of Daxing district. Northeast belt of increased soil nutrients coincided with vegetable industry zone and agriculture products distribution zone in Eleventh Five-Year Agricultural Development Planning of Daxing district. Middle and south belts of increased soil nutrients coincided with west muskmelon industry zone in Eleventh Five-Year Agricultural Development Planning of Daxing district.

Household Decision Behavior. According to the actual survey data of farmers, households in Daxing district were attached great importance to nitrogen and potassium fertilizer, and neglected or despised potash and quality organic fertilizer. Agricultural cropping patterns in Daxing district were double cropping and single cropping. Crops with winter wheat-summer corn, spring corn, winter wheat, watermelons, tomatoes and canola were accounted for 80%, 58%, 26%, 13%, 15% and 9%; respectively. Corn, watermelon and vegetables were demand for high nitrogen and potassium, low phosphorus in their growth. About 65%, 26% and 6% of the farmers respectively selected nitrogen fertilization, phosphate and potash as base fertilizer. Accounting for 81% of households chose nitrogen fertilization as top dressing. Additionally, 23% of households selected organic fertilizers in the fertilization process, and 45% of households chose large area straw returning and a large number of nitrogen were assimilated and absorbed by microorganisms.

5 Conclusions

This paper proposed a method for spatial structure of soil nutrients by PCA and analyzed these change characteristics from 2000 to 2007 using geographic information system (GIS) technology in Daxing district of Beijing. The results showed that the occupied space proportions of TN, AN, OM, AP and AK were 0.33, 0.22, 0.25, 0.03, 0.16 for 2000 and 0.32, 0.25, 0.23, 0.03, 0.17 for 2007, respectively. High values of soil nutrients were mainly concentrated in the northeast regions whereas low values were located in the southwestern regions and central regions of Daxing district. The change characteristics and influence factors for spatial structure of soil nutrients were systematically analyzed. Increased soil nutrients were exhibited three belts on the whole, whereas decreased soil nutrients were located in other regions. Natural factors and human activities drove these changes of soil nutrients. In the future, engineering, farming and fertilization methods are comprehensively adopted to improve cultivated soil nutrients for Daxing district.

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