Study on spatial variability of soil nutrient and the evaluation of soil quality based on GIS

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Abstract. In this study, geostatistics and GIS were applied to analyze the spatial variability of soil nutrient and the soil quality combined with the research variability property and spatial data in research area. The purpose of this paper is to study the spatial variability regulations between soil quality conditions and soil nutrient. The results show that the spatial variability degree of organic matter (OM), total nitrogen (TN), available potassium (AK), available phosphorus (AP), alkaline nitrogen (AN) and pH is 42%, 33%, 31%, 67%, 58% and 13%. pH is weak variability, TN and AK is low variability, all OM, AP and AN are moderate variability. The spatial distribution of soil nutrient is different, but there are some relationships in partial area.

1. Introduction
Soil quality refers to the ability to maintain production within the ecosystem, ensure environmental quality, and promote healthy behaviors of animals and humans. Since the soil is a time-space continuous variant with high spatial heterogeneity, a certain range of flow causes many soil nutrients to be spatially uneven [1]. The study of spatial variability of soil nutrients is the basis for managing soil nutrients and rational fertilization. Therefore, it is necessary to study the spatial variability of soil nutrients in the research area to understand the spatial distribution of soil nutrients. Soil quality and soil nutrient variation research are of great significance for improving the quality of cultivated land, promoting agricultural modernization and ensuring food security.

At the end of last century, the spatial variability of soil changed from qualitative description to quantitative research. Geostatistical methods were also introduced, combined with Kriging interpolation and GIS spatial analysis techniques further. Xudong Guo [2] used geostatistical theory and GIS technology to study the spatial variability of five nutrients of soil surface alkaline nitrogen, total nitrogen, available potassium, available phosphorus and organic matter in Zunhua City, Hebei Province. It is found that the spatial auto-correlation of five nutrient elements is moderately auto-correlated, but the scale of spatial variation is different, and the range of isotropic is also different. Guitang Liao [3] applied the combination of geostatistics, GIS and multivariate statistical analysis to quantitatively and comprehensively evaluate the soil fertility quality of Mengdingshan tea garden.

Based on the existing research, this study takes Baofei Town, Renshou County, Sichuan Province as the research area, and uses geostatistical analysis and ArcGIS spatial analysis module through field investigation, sampling analysis and data collection. The spatial variability of soil nutrients such as soil
OM, TN, AK, AP, AN and pH in Baofei Town can be explored, and the distribution of soil nutrients can be achieved generally and spatially.

2. Research area, data sources and research methods

2.1. Research area
Baofei Town is located in the southeast of Renshou County, Meishan City, with north latitude 29°49′06″ and east longitude 104°17′53″. The cultivated area of the whole area is 1573.4 hectares. The main crops are rice, wheat and rape, and its soil type is mainly for paddy soils, the climate type belongs to the subtropical monsoon humid climate. The fertilization structure is mainly based on chemical fertilizer, and the organic fertilizer in parallel. The organic fertilizer is mainly farmyard manure and green manure. Baofei Town is selected as a research area to analyze the spatial variability of soil nutrients, which can provide reasonable suggestions for agricultural production planning and layout for urban and rural interlaced areas, effectively alleviating the contradiction between land and economic development.

2.2. Data sources
This study takes Baofei Town as the research area. There are a total of 65 samples in the whole area. GPS technology is used to collect the soil samples. The sampling points ensure the typicality and representative area of various crops, while taking into account the uniformity principle of spatial distribution. All samples are naturally air-dried, and the impurities are removed and ground for the determination of soil physical and chemical properties.

This study focuses on the spatial differentiation of pH, OM, N, P, K in soils, and soil samples include soil OM, TN, AK, AP and pH values. The specific analysis methods: OM is treated by high temperature external heat potassium chromate oxidation external heating method, TN is alkali diffusion method, AP is sodium bicarbonate extraction-molybdenum anti-colorimetric method, AK is acetic acid Ammonium extraction method, pH value is determined by potentiometry [4].

2.3. Research methods

2.3.1. Semi-variogram function and its theoretical model. The semi-variogram function is a tool function for studying spatial variability in geostatistics and is used to characterize the spatial variability structure or spatial continuity of random variables. When the mean of random variables does not change with position Z, and its covariance Cou [Z(x), Z(y)] depends only on the distance between sample points x and y, i.e., the random variable satisfies the second-order stationary hypothesis. The half variance function can be expressed as half of the variance of the Z(x) increment of the regionalization variable. The general expression is:

\[ r(h) = \frac{1}{2} \text{var}[Z(x) - Z(x + h)] \]  

(1)

The calculation formula is:

\[ r^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x) - Z(x + h)]^2 \]  

(2)

In the equation, h is the sample spacing, N(h) is the logarithm of all the points of the sample distance.

The semi-variogram function has three important parameters: the nugget value, the range, and the base value. The nugget value is caused by the measurement error and the variability of soil properties within the minimum sampling interval. C indicates that the range reflects the spatial variability of soil properties. The magnitude of the range shows the regionalization variable to affect the size of the range. The abutment value refers to the semi-variance maximum value existing in different sampling intervals, reflecting the a priori variance of the regionalized variable. The value points calculated by the semi-
variogram function are plotted on the semi-variogram showing the relationship between h and r(h). The curve equation used to fit the semi-variogram is called the semi-variogram function theoretical model [5].

2.3.2. Kriging. Also known as spatial local estimation or spatial local interpolation, kriging is one of the two main contents of geostatistics. It is based on a number of the measured sample data in the limited neighborhood of the sample to be estimated, and carefully considers the shape, size and spatial positional relationship of the sample points, their spatial positional relationship with the sample to be estimated, and the variogram function. After the structural information, a linear unbiased optimal evaluation of the value of the sample is estimated [6].

3. Results and analysis

3.1. Statistical Analysis of Soil Nutrients

The coefficient of variation (C· V) is a statistic of the degree of variation in the study variable, which is the ratio of the standard deviation to the mean. The soil nutrient content of the sampling points is statistically analyzed. The statistical results show in Table 1. The coefficient of variation of AP is the largest, at 67%. The second is AN, and the coefficient of variation of pH is the smallest, at 13%. According to the coefficient of variation grade classification criteria: when C· V >100% is a strong variation, when 40%<C· V < 100% is a medium variation, when 10%< C· V <40% is a low variation, when C· V <10% is a weak mutation. Therefore, pH is a weak mutation, TN and AP are low-variation, OM, AP, and AN are all moderately mutated. The coefficient of variation of nutrient content in soil reflects the degree of dispersion of soil nutrients, which is affected by factors such as fertilization structure, application rate and nutrient movement in soil. The coefficient is mainly affected by fertilization, such as P. While crops have high absorption and mobility, generally, variation coefficient is relatively small, such as N.

Table 1. Variation coefficient of soil nutrient contents.

| Soil nutrient | Min. value | Max. value | Avg. value | Standard deviation | Variation coefficient | Variation degree |
|---------------|------------|------------|------------|--------------------|-----------------------|------------------|
| pH            | 5.40       | 8.40       | 7.21       | 0.93               | 0.13                  | weak             |
| OM (g/kg)     | 5.40       | 42.80      | 19.87      | 8.39               | 0.42                  | moderate         |
| TN (g/kg)     | 0.57       | 2.21       | 1.37       | 0.45               | 0.33                  | low              |
| AK (mg/kg)    | 42.00      | 185.00     | 111.02     | 34.40              | 0.31                  | low              |
| AP (mg/kg)    | 4.30       | 111.00     | 27.30      | 18.16              | 0.67                  | moderate         |
| AN (g/kg)     | 0.10       | 98.77      | 55.85      | 32.31              | 0.58                  | moderate         |

3.2. Exploratory data analysis of soil nutrients

Exploratory Data Analysis refers to the exploration and analysis of the obtained raw data, and the distribution characteristics of the data through mapping and the like, which can provide a basis for accurate selection of the analytical model. In this study, the normal QQPlot distribution map is used to detect the data distribution. The exploratory data analysis tool mainly uses the QQPlot distribution map tool provided by ArcGIS, which is a graph made by using the quantile of the distribution, and the existing data can be used. The distribution is compared to the standard normal distribution to analyze and evaluate the existing data. If the data graph is closer to a straight line, it is closer to the normal distribution. The results show that the nutrient data figures are approximately straight under the premise of eliminating local outliers, so OM, TN, AK, AP, AN and pH are basically in accordance with the normal distribution, as shown in Figure 1.
3.3. Analysis of soil nutrient variation based on variogram.

The variogram is a powerful tool for studying spatial distribution characteristics in geostatistics. According to the analysis data of soil nutrient content in different spatial locations, the actual semi-interpolation \( r(h) \) is calculated to generate a semi-variogram, and the semi-variogram is a spatial variability model generated by using the variogram to study the spatial variability of soil properties. It is the basis for geostatistical interpretation of the spatial variability structure of soil properties, and its accurate estimation is the key to the success of spatial interpolation.
According to the semi-variogram of each nutrient, the changes of different sites are irregular and independent, the directionality is not obvious and is different. The semi-variance does not change with the spatial distance, namely, the semi-variance does not change with the spatial distance, that is to say that there is a pure nugget effect. After calculating the r-h diagram, different models were used to fit the soil nutrients, and the parameter values of the model were obtained. The results are shown in Table 2.

Figure 2. Semi-variogram of soil nutrients.
**Table 2. Soil nutrients variation function model and the related parameters**

| Soil nutrient | Theoretical model | Nugget (Co)     | Base value (Co+C) | Nugget effect (%) | Range (m) |
|---------------|-------------------|-----------------|-------------------|-------------------|-----------|
| pH            | E                 | 0.13            | 0.27              | 47.37             | 376       |
| OM            | S                 | 19.04           | 32.73             | 58.15             | 376       |
| TN            | S                 | 0.06            | 0.09              | 67                | 376       |
| AK            | E                 | 0.013           | 0.023             | 34.4              | 330       |
| AP            | S                 | 0.59            | 0.92              | 64.1              | 550       |
| AN            | S                 | 0.69            | 1.12              | 61.6              | 578.5     |

Notes: S is spherical model; E is index model.

It can be seen from Table 2 that the pH and AK are in accordance with the index model, and OM, TN, AP and AN are all in a spherical model. According to the relevant standard: the ratio of the nugget value to the base value is < 25%, indicating that the variable has a strong spatial correlation. Between 25% and 75%, the variable has a moderate spatial correlation. When > 75%, the variable spatial correlation is pretty weak. It can be also found from the nugget effect C0/(C+C0) that six soil nutrients have moderate spatial correlation, indicating that the spatial variation of these properties is the results of interaction of structural factors (such as soil formation factors) and random factors (fertilization farming, etc.). From Table 2, it can demonstrate that the nugget effect of TN is the largest with 67%, indicating that the artificial fertilization activity has a greater impact on it, which weakens the strong spatial autocorrelation effect caused by structural factors.

**4. Conclusions**

This study uses ArcGIS software as a tool, combined with geostatistical theory and method, describes and analyzes the statistical characteristics of soil nutrients, and draws a semi-variogram, and determines a reasonable theoretical model. The conclusions are as follows: the degree of variation of each nutrient is different, pH is weak variable, TN and AK are low-grade variable. OM, AP and AN are moderately variable. However, some regions have certain spatial correlation, which is affected by soil formation factors and fertilization. Through field investigation, it is found that the evaluation results of this study are basically consistent with the actual situation. The soil nutrient distribution caused by agricultural fertilization is not uniform and can be used to guide agricultural production.

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