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Comparison of spatial interpolation methods for mercury content in soil of contaminated farmland in Tongren

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Abstract. Taking mercury-contaminated farmland in Tongren city, Guizhou province as study area, we conducted five interpolation methods, including inverse distance weight, radial basis function, global polynomial, local polynomial and kriging, for the collected soil mercury content data. The interpolation results were evaluated by cross validation. The results indicated that the five methods can accurately reflect the spatial distribution characteristics of the study area and the interpolation effect and precision of kriging method are optimal. In kriging method, the accuracy of removing second-order trends is highest, and the interpolation effect of exponential model is the best. The variation function model of kriging method shows that soil mercury content in this region is mainly affected by natural factors, but less affected by random factors.

1. Introduction

Limited by sampling techniques and cost, studies on the distribution of soil mercury content are usually based on limited sample data. Spatial interpolation technology can transform discrete data points into coherent data surfaces through certain functions, so as to effectively predict the data distribution in unknown space. Thus it has been an important method to evaluate soil heavy metal pollution [1].

Different types of geographical element data have different distribution, processing methods, pollution simulation requirements, so the accuracy evaluation of interpolation method is not consistent [2]. Some scholars believe that kriging's interpolation accuracy is higher than that of inverse distance weight and spline function interpolation [3, 4, 5], while others draw the opposite conclusion [6, 7]. It is very necessary to select the most suitable interpolation method by comparing different interpolation results for specific areas. In this paper, 5 interpolation methods were used to interpolate mercury content of contaminated soil in Tongren city, Guizhou province by using Arcgis geostatistical interpolation. Results and accuracy of different interpolation methods were compared, and the optimal interpolation method was selected to provide a basis for accurately reflecting spatial distribution characteristics of soil mercury content.

2. Materials and methods

2.1. Study area

The study area is located in the township of Wawu dong, Bijiang district, Tongren city, Guizhou province. It is an agricultural area on the right bank of Siqan dam. It is the largest agricultural grain and oil producing area in Wawu township, with a total area of about 2.345 square kilometers. The main irrigation water and drinking water in this area all come from tiaowu rive which is polluted by mercury. When heavy rain or rainstorm, the drop height make a large amount of mercury wastewater and slag into the river channel. The water overflowed the dam and flooded the land, causing mercury pollution in the soil of the area. At the same time, the dust containing mercury settled into the soil, which also caused the soil mercury pollution in this area.

2.2. Data

Sampling sites were selected according to the natural distribution of fields in the study area. One sample was collected for each field from surface soil (about 0-20cm depth). The total mercury content in soil samples was determined by aqua regia digestion and cold atomic fluorescence method.

Phantom 4 DJI UAV is used to photographed the study area. The image mosaic was obtained by stitching multiple images. Google image and ENVI software was used to conduct geography registration of UAV images. The distribution of sampling sites was shown in figure 1. Mercury levels were higher in areas near the river bank and lower in arears farther offshore.

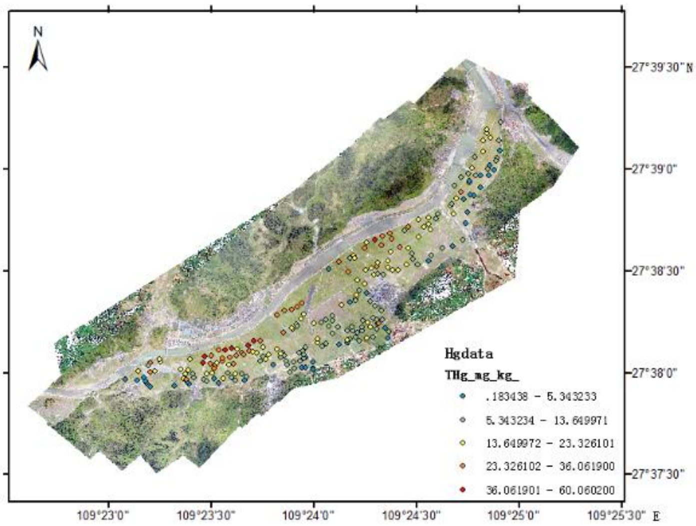

Figure 1. Sampling sites distribution map

2.3. Interpolation method

2.3.1. Kriging interpolation. Kriging interpolation is the most widely used in geostatistics at present.. Kriging method contains ordinary kriging, Pan Kriging. This study chose ordinary kriging method. The variation function includes spherical model (SPH), Gaussian model (GS), exponential model (EXP), hole effect model (HE), K - Bessel function model (KB), trigonometric (TR) function model.

2.3.2. Deterministic interpolation. Deterministic interpolation creates the fitting surface by the similarity between various points or the smoothness of the entire surface [4], including global polynomial interpolation and local interpolation, among which local interpolation includes inverse distance weight interpolation, radial basis interpolation and local polynomial interpolation. Global polynomial interpolation use all data points to fit a polynomial mathematical equation to conduct interpolation. Local interpolation uses adjacent data sites to estimate the value of unknown sites.

2.4. Verification method
In this study, the cross validation function in Arcgis was used to evaluate the accuracy. Specific indicators for cross-validation are mean prediction error (ME), root mean square error (RMSE), mean relative error (MRE), standardized mean error (MSE), standardized root mean square error (RMSSE), and average standard error (ASE).

3. Results and analysis

3.1. Kriging method

3.1.1. Trend analysis. The mercury content in study area first rises and then decreases from north to south, showing an inverted u-shape and obvious second-order trend. There is a weak second-order trend from west to east, which increases first and then decreases. Meanwhile, taking the exponential model and the gaussian model as examples, the effects of different trends on interpolation accuracy are compared. In the exponential function, the root mean square error and mean relative error of the second order trend removed is minimal. The mean relative error of the second order removed in gaussian function is the minimal and the root mean square error is also relatively low. In the two models, the normalized root mean square error of the second order removed is closest to 1, and the mean standard error is closer to the root mean square error. Considering comprehensively, the interpolation accuracy of removing the second order trend is the highest.

3.1.2. Comparison of different variogram models. The interpolation accuracy of different variogram models is compared under the removal of second order trend. The ME of the six methods is between 0.06 and 0.11. RMSE is between 6.47 and 6.65, among which, the RMSE of exponential model is lowest. The MRE ranged from 0.346 to 0.372. The MSE is 0.0054~0.0097.The RMSEE ranges from 1.0064 to 1.0907, and the exponential model is closest to 1, far lower than other models. The ASE of the exponential model is the highest, but it is closest to RMSE. The ME and MRE obtained by the exponential model are small, and the MSE and RMSE are the lowest among the six methods, and the RMSE is close to the ASE. Therefore, the accuracy of exponential model is highest.

3.1.3. Comparison of model parameters of different variogram. The relevant parameters of the variogram can reflect the spatial variation characteristics of the data, and the ratio of partial sill to sill can reflect the strength of spatial correlation (Table 1). The ratio is between 58% and 74% in the six variograms, which shows the strong spatial correlation. The premise of kriging method is that the data have spatial correlation, which indicates that the data can be interpolated by kriging method.

The nugget effect represents the variation characteristics between samples, and the stronger the nugget effect is, the more the variation between samples is caused by random factors. The nugget effect of the six variograms is between 26% and 42%, indicating that it is less affected by random factors. The anisotropy ratio of the 6 variograms is greater than 1, indicating that the spatial distribution of Hg has significant anisotropy. The HE and TR models show that the greater the influence of random factors, the less anisotropy. The weaker the nugget effect is, the more significant the anisotropy is, because anisotropy is mainly controlled by natural factors, such as surface runoff, rainfall, wind, etc., and is less affected by random factors such as human beings activities.

Table 1. The parameters of different variogram

variogram	nugget value	partial sill	sill	nugget effect	Partial sill/sill	Anisotropy
SPH	21.12	51.93	73.05	28.91%	71.09%	2.420
EXP	20.47	57.11	77.58	26.38%	73.62%	1.670
GS	28.52	43.81	72.33	39.43%	60.57%	2.433
HE	28.94	40.67	69.61	41.57%	58.43%	1.978
K-Bessel	28.10	44.51	72.61	38.69%	61.31%	2.368
TR	21.92	50.49	72.41	30.27%	69.73%	2.473

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3.2. Comparison of different interpolation methods

Mean prediction error, root mean square error and average relative error are used to compare the accuracy of the five interpolations. The mean prediction error, root mean square error and mean relative error of the five methods are 0.01~0.13, 6.4~6.9 and 0.32~0.42, respectively (Table 2). The mean prediction error and root mean square error of local polynomial interpolation are the lowest among several methods. Two of the three indexes of global polynomial method and kriging interpolation are relatively low. The interpolation accuracy of inverse distance weight is the lowest. Considering these three evaluation indexes, the accuracy of local polynomial interpolation is the highest.

Table 2. The accuracy of different interpolation methods

Index	Inverse distance weight	Radial Basis function	Global polynomial	Local polynomial	Kriging
ME	0.1365	0.1057	0.0293	0.0137	0.0810
RMSE	6.8848	6.7001	6.7581	6.4365	6.4705
MRE	0.4188	0.4090	0.3296	0.3835	0.3689

The spatial distribution of mercury content obtained by 5 different interpolation methods are generally consistent, with higher near the river bank and lower far from the river bank. The highest values appear in the southwest and the lowest in the eastern edge. One of the causes of mercury pollution in this area is that mercury-polluted rivers overflowed the dykes and flooded the land during heavy rainfall. As a result, mercury levels are higher near the river bank and lower away from it. At the same time, the parameters of kriging's variogram show that there is little random variation in this region and the distribution of mercury content is mainly affected by natural factors. The five interpolation methods can accurately reflect the spatial distribution of the study area, and the kriging variogram can well describe its spatial variation characteristics.

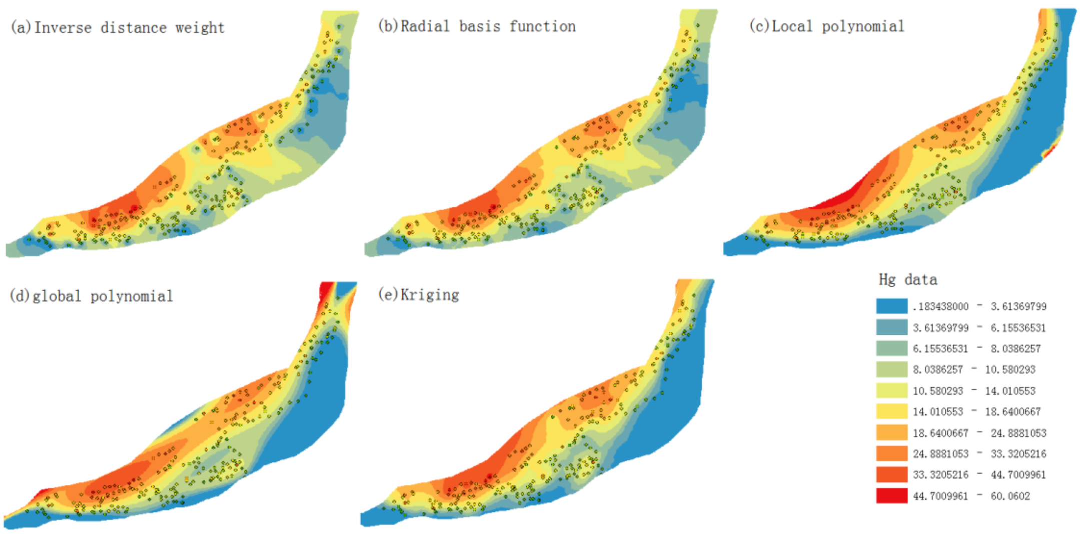

Figure 2. Interpolation image

It can be seen from the interpolation image that the interpolation effect of the inverse distance weight is similar to that of the radial basis function. The inverse distance weight has a good description of local details. But it is sensitive to the extreme value, thus induces the serious bull's eye phenomenon. The radial basis function shows moderate performance to the overall trend and local trend. The global polynomial can reflect the global trend but not local trend, the interpolation result is too smooth. The local polynomial interpolation is more dependent on local variation. Compared with global polynomial interpolation, it can better reflect local spatial differences. Kriging interpolation has good performance for both local and global spatial changes.

The interpolation accuracy is not consistent with the interpolation results image. The accuracy of local polynomial and kriging interpolation is higher. The two interpolation methods can well reflect the general trend and local trend. But the transition between the sample values of the local polynomial is abrupt, the flatness and connectivity are not as good as the kriging interpolation. The radial basis function can well reflect the global and local variation, but the accuracy is not high. Considering the interpolation results and precision evaluation indexes, kriging interpolation method has the best interpolation effect for mercury content in this region.

4. Conclusion

The mercury content of soil in the study area showed a trend of higher near the river bank and lower away from it, because that the mercury-polluted rivers overflowed the dykes and flooded the land. All the five interpolation methods could well reflect this trend, among which kriging interpolation could describe the spatial variation characteristics more accurately.

The reflection of kriging interpolation in general trend, anisotropy and spatial variability cannot be replaced by deterministic interpolation, and it is suitable for geographical elements with structural and random features, so the interpolation effect on soil mercury content is the best. The interpolation results are influenced by different factors such variation range and geographical factors. In order to improve the interpolation accuracy, it is necessary to develop reasonable sampling strategies according to the specific situation of the research area to control experimental errors and ensure the accuracy of data. Descriptive statistical analysis also should be conducted on the data to find out the distribution rule, so as to select the optimal spatial interpolation method.

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