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## Spatial distribution of Heavy Metal contents in farmland soils by different spatial interpolation methods: A case study of a farmland in Lanping County, Yunnan Province

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# Spatial distribution of Heavy Metal contents in farmland soils by different spatial interpolation methods: A case study of a farmland in Lanping County, Yunnan Province

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**Abstract.** The spatial interpolation method is of great significance for the spatial distribution of heavy metals in soil and the prevention and control of pollution. However, different interpolation methods are applied to predict the accuracy of different heavy metal pollution distributions in small-scale areas with a single farmland. There is no relevant argument. Taking a farmland (96000m<sup>2</sup>) in Lanping County, Yunnan Province, Yunnan Province as the research object, 144 surface soil samples were collected and the contents of Pb and Cd in soil were determined by ICP-MS. The deterministic spatial interpolation method and geostatistical Kriging interpolation method were used to investigate the accuracy of different interpolation methods and the distribution characteristics of Pb and Cd in soil. The results show that the optimal interpolation methods for heavy metals Pb and Cd in polluted farmland are 0-order ordinary Kriging interpolation method, and the content of Pb and Cd in the soil is relatively accurate. This study will provide important basic information for the identification of spatial distribution characteristics of different heavy metals in small-scale areas with a single farmland, which will help to comprehensively evaluate the function of spatial interpolation to identify spatial distribution information of heavy metals.

## 1. Introduction

At present, China's farmland polluted by heavy metals has reached 20 million hectares, accounting for 1/6 of the country's total cultivated land [1-3]. Heavy metals are toxic, easy to enrich and difficult to degrade through biological or abiotic processes in the environment, thus affecting the safety of agricultural products and even threatening human health. At present, the control and restoration of heavy metal pollution has become one of the key tasks of environmental pollution prevention and control in China in the near future [4].

The primary condition for carrying out heavy metal pollution control and restoration work is to understand the spatial distribution characteristics of various heavy metals in the soil [5]. The identification of heavy metal spatial distribution information in real work mainly relies on sparse sampling analysis work and spatial interpolation method for evaluation [6]. When the existing sparse



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sampling conditions cannot be improved, the reasonable selection of spatial interpolation methods is particularly critical, and it will directly affect the accuracy of the spatial distribution characteristics of heavy metal regions [7]. The spatial interpolation method is to use the spatial pattern information on a set or a certain scale set to predict the value of the unobserved data position and merge the incomplete spatial data to realize data integration, which is a data estimation through the measured sampling points. It includes deterministic spatial interpolation and geostatistical spatial interpolation, where deterministic interpolation includes inverse distance weighted interpolation, global polynomial interpolation, local polynomial interpolation and radial basis function interpolation [9], geostatistical space Interpolation method (mainly Kriskin interpolation) mainly includes Ordinary Kriging (normal Kriging, OK), Simple Kriging (Simple Kriging, SK), Universal Kriging (Pan Kriging, UK), Disjunctive Kriging (Dissolving Kriging, DK), etc. [10]. The spatial interpolation method overcomes the shortcomings of using traditional statistical methods to study the spatial variability of soil properties, and can provide more detailed spatial distribution information of heavy metals in soil, which greatly promotes the progress of heavy metal pollution control and restoration in regional soils [11, 12].

Since the 1980s, China has been engaged in the study of spatial variability of soil heavy metals and spatial interpolation techniques, but most of them have studied with a single semivariogram and Kriging interpolation method [13]. For example, six kinds of interpolation methods, such as Ordinary Kriging, Simple Kriging, Lognormal Kriging, Universal Kriging, Disjunctive Kriging and inverse distance weighting, are used to estimate the mercury content in the non-stationary region, and comprehensively compare various internal conditions. The prediction error, statistical eigenvalues and interpolation result distribution maps of the interpolation method are compared to the best interpolation method [14, 15]. For a soil with heavy metal pollution, repairing and improving the soil requires understanding the content of heavy metals in the soil, and there is a precise spatial distribution map of heavy metals. By comparing the different interpolation models and parameters in the same interpolation method, the best model and parameters in the same interpolation method are obtained. Then, the best models in different interpolation methods are compared for longitudinal comparison to determine the optimal. The spatial interpolation model and the obtained spatial distribution map are obviously more accurate [16].

In this paper, the deterministic interpolation method and geostatistical Kriskin interpolation method are used to compare the interpolation precision and parameters to study the spatial distribution characteristics of Pb and Cd in farmland soil. Based on the analysis data of heavy metal content in farmland soil samples collected in the region, SPSS19.0 software was used to statistically analyse the soil heavy metal content to obtain the optimal spatial interpolation method, and the spatial interpolation characteristics of heavy metal in small-scale farmland were selected by reasonable spatial interpolation method. Identification provides a theoretical basis.

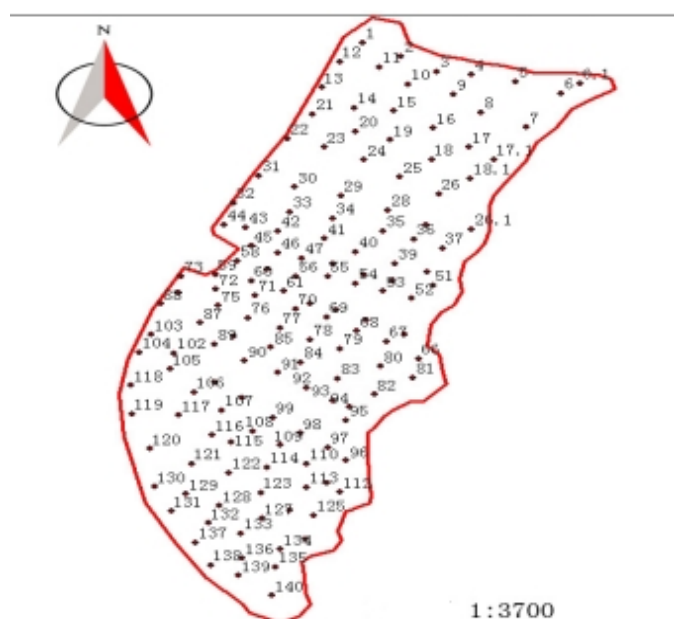
## **2. Research methods**

### *2.1. Survey area overview*

The study area is located in Lanping County of the Lancang River Basin. The Minjiang River originates from the Qingyan Mountain in Lanping County of Nujiang Prefecture. It is located in the south of the “Three Rivers Confluence Area” in the northwest of Yunnan Province. It is an important tributary of the Lancang River, and its upper stream flows from north to south through the northwest of the Lanping Jinding Lead-Zinc Mine. Jinding Town is the location of the Lanping Jinding Lead-Zinc Deposit, which has the largest proven reserves of lead-zinc deposits. The Lanping Jinding lead-zinc mine is 3.5 km east of Jinding Town. The proven reserves are: 2.53×10<sup>6</sup> t, zinc: 1.30×10<sup>6</sup> t, cadmium: 1.7×10<sup>5</sup> t, associated and symbiotic components and arsenic. , sulfur, iron, antimony, bismuth, silver, antimony, etc. The years of mining and smelting of lead-zinc mines have caused heavy metal pollution to the surrounding environment, the Lancang River waters and the farmland soils of the Lancang River Basin, which seriously hindered the sustainable development of agriculture and harmed the health of organisms.

## 2.2. Soil sample collection

The two sides of the strait are paddy soil, texture weight, low organic matter content, and soil compaction, mainly planting rice, wheat and corn. Considering the characteristics of cultivated land and crops in the study area, adhering to the principle of optimal monitoring, and taking into account the uniformity of sample points, priority In the representative areas that reflect the regional soil environmental quality, the sites in the area with pollution sources are encrypted and sampled to achieve a comprehensive reflection of soil heavy metal pollution in the study area [16]. According to the above-mentioned layout principle, 144 sample points were arranged in the study area according to the plum blossom shape, and 144 samples of soil samples were obtained. The schematic diagram of the point layout is shown in Fig.1.



**Figure 1.** Sampling point map

## 2.3. Determination of soil samples

Weigh 0.2g of soil sample in the Teflon digestion tank, add 1mL hydrofluoric acid (40%, excellent grade pure), 4mL nitric acid (65%, excellent grade pure) and 2mL hydrogen peroxide (31%, Aladdin) After being placed in a microwave digestion apparatus for digestion, the digestion is completed and the acid is digested into a 100 mL colorimetric tube and diluted 100 times in a digestion tank. After shaking well, 10 mL is taken from the colorimetric tube in the sample bottle. The content of Pb and Cd in soil samples was determined by ICP-MS (NexION 350X, American PE Company) [9].

## 2.4. Data Processing

The software used in data processing and analysis in this paper is: IBM SPSS statistics19.0 software, ArcGIS10.2 software (ESRI Company), GS+ version 9.0 software.

## 2.5. Determination of the optimal model

The comparison of the fitted models is usually based on comparing the average error, root mean square error, and mean standard error of different models, and then selecting the best fit model from different fitting models according to the optimal model selection principle. . In general, we want the prediction error to be unbiased and optimal, and the average prediction error should be close to zero, but the average error is affected by the data size, so the closer the standard average error (ie, the prediction error divided by the predicted standard deviation) is. The better the 0. By evaluating the uncertainty of the error to check whether the prediction error is optimal, this can be measured by predicting whether the standard error is valid. When the average standard error is close to the root mean square prediction error,

indicating that the prediction standard error is valid, then the standardized mean square the root error should be close to 1, and the predicted uncertainty can be correctly evaluated when the normalized root mean square error is close to 1. Therefore, the selection principle of the optimal model is summarized as: Mean Standardized (MS) is closest to 0; Root-Mean-Square Standardized Error (RMSSE) is closest to 1; Root mean square error (Root-Mean-Square-Error, RMSE) is close to and minimum with Average Standard Error (ASE).

### 3. Results and analysis

#### 3.1. Overview of soil pollution in the study area

The basic statistical characteristics of the soil samples in the study area are shown in Table 1. The logarithmic conversion of lead (Pb) and cadmium (Cd) in soil is log-normal. The pH range of the soil in the study area was 4.36 - 5.96. The environmental quality standard of lead (Pb) and cadmium (Cd) in the soil of Table 1 was grade II ( $\text{pH} < 6.5$ ). The content of Cd was sampled. All the areas studied at the point exceeded the standard, and Pb exceeded the standard in the research area of the sampling point. Through actual investigation of the local area, there may be two reasons: (1) the sewage contaminated by the mining area is not treated directly to irrigate the farmland; (2) The road for transporting minerals is near the sampling point, and it is polluted by dust and dust during transportation.

**Table 1.** The statistical results of Cd and Pb in farmland surface soils

Project	Cd	Pb
Minimum value / ( $\text{mg}\cdot\text{kg}^{-1}$ )	2.66	81.40
Maximum / ( $\text{mg}\cdot\text{kg}^{-1}$ )	16.96	379.14
Mean $\pm$ standard deviation Poor / ( $\text{mg}\cdot\text{kg}^{-1}$ )	5.03 $\pm$ 2.90	138.97 $\pm$ 58.03
National soil environmental quality Standard Class II ( $\text{pH} < 6.5$ )	0.3	80
Edible agricultural product production ring , Environmental quality assessment standard	0.3	80
Local soil background value	1.7	54.98
Soil PH	4.36 ~ 5.96	4.36 ~ 5.96
Skewness coefficient	1.20	1.08
Kurtosis coefficient	4.00	3.92
median	4.07	116.42
Coefficient of variation (%)	57.6	41.7
Distribution type	lognormal distribution	lognormal distribution

#### 3.2. Comparison of deterministic spatial interpolation methods

The two heavy metals were spatially interpolated using different deterministic spatial interpolation methods. The results are shown in Tables 2 and 3. When the Cd inverse distance weight interpolation method has a power of (P) of 3, the RMSE is the smallest<sup>[16]</sup>. Priority is given to the RMSPE minimum principle, and the interpolation effect is best when Cd inverse distance weight interpolation is  $P=3$ . The global polynomial interpolation method of Cd has the smallest RMSE when the order of the polynomial is 3, and the best when the order of the polynomial is 3; the local polynomial interpolation method has the smallest RMSE when the order of the polynomial is 0; the radial basis function interpolation method, The RMSE of the inverse high-order surface function is the smallest, and the interpolation effect is optimal. The order of RMSE values is: 0 local polynomial interpolation (1.46) < radial basis function interpolation (1.49) <  $P = 3$  inverse distance weight space interpolation (1.50) < global polynomial

interpolation (1.52)), In the deterministic spatial interpolation method of Cd elements in farmland soils, the interpolation effect of 0 local polynomial interpolation method is the best.

The inverse distance weight interpolation method of Pb has the smallest RMSE when the power of the parameter (P) is 3, and the best when P=3; the global polynomial interpolation method has the smallest RMSE when the order of the polynomial is 3, and the interpolation effect is the best; The polynomial interpolation method has the smallest RMSE and the best interpolation effect when the order of the polynomial is 2. The radial basis function interpolation method has the smallest RMSE of the tension spline function and the best interpolation effect. The order of RMSE values is: 3rd order global polynomial interpolation method (30.91) < local polynomial interpolation method (33.01) < radial basis function interpolation method (33.14) < P=3 inverse distance weight space interpolation method (33.77), which is studied Among the deterministic spatial interpolation methods of Pb elements in regional farmland soils, the interpolation effect of the 3rd global polynomial interpolation method is the best.

**Table 2.** Predictive errors of deterministic interpolation method of Cd in Farmland Soil

Interpolation method	Parameter	Mean difference ME	Root mean square error MRSE
Inverse distance weighted interpolation method,	P=1	0.0144	1.58
	P=2	0.0145	1.52
	P=3	0.0108	1.50
Global polynomial interpolation	3	-0.0007	1.52
	4	0.0055	1.56
	5	-0.0036	1.60
Local polynomial interpolation	0	0.0265	1.46
	1	-0.0265	1.47
	2	0.0184	1.49
Radial basis function interpolation	Rule spline function		
	High-order surface function	0.00006	1.56
	Anti-high-order surface function	-0.0022	1.73
	Thin plate spline function	0.0092	1.49
	Tension spline function	-0.0093	1.90
		0.0004	1.54

**Table 3.** Predictive errors of deterministic interpolation method of Pb in Farmland Soil

Interpolation method	Parameter	Mean difference ME	Root mean square error MRSE
Inverse distance weighted interpolation method,	P=1	-2.876	34.62
	P=2	-2.489	33.98
	P=3	-2.250	33.77
Global polynomial interpolation	3	0.0607	30.91
	4	0.401	31.91
	5	0.553	33.06
Local polynomial interpolation	0	-2.087	33.56
	1	3.517	33.38
	2	0.075	33.01
Radial basis function interpolation	Rule spline function		
	High-order surface function	-0.972	33.23
	Anti-high-order surface function	0.124	34.45
	Thin plate spline function	-2.120	33.31
	Tension spline function	0.505	36.79
		-1.133	33.14

### 3.3. Comparison of Geostatistical Kriging Interpolation Methods

The closer the arithmetic mean (Mean) of the measured error is to 0, the more unpredictable the predicted value. Since the value of Mean is affected by the size of the data, in practice, the average standard value (Mean Standardized, MS, the standardized value of Mean) can be examined. The closer the index is to 0, the better; the root mean square standard error (Root-Mean-Square Standardized Error, RMSSE) is closest to 1, indicating the more accurate the standard error; the Root-Mean-Square-Error (RMSE) is close to the Average Standard Error (ASE) The smaller, the smaller the error between the predicted value and the measured value [17].

It can be seen from Table 4, Table 5 and Table 6 that the three Kriging interpolation methods of geostatistics are compared using the principle that ME is closest to 0 and RMSE is the smallest (priority), and the heavy metal elements Cd and Pb in the soil are studied in a trend-free effect. The interpolation effect of ordinary Kriging is the best; the four Kriging interpolation methods of geostatistics are compared by the principle that ME is closest to 0 and RMSE is the smallest (priority), and the Pb element of soil is applied by the universal Kriging interpolation method of constant trend effect. The interpolation effect is optimal; the ME Kriging interpolation method is compared with the principle that the ME is closest to 0 and the RMSE is the smallest (priority), and the interpolation effect of the second-order trend effect extraction Kriging interpolation method is applied to the soil Cd element excellent.

**Table 4.** Comparison of parameters of different kriging interpolation methods for Pb Cd in soils

Interpolation method	Parameter	Cd	Pb
Ordinary Kriging (OK)	ME	-0.003	-0.850
	MSE	1.516	33.080
	ASE	-0.008	-0.017
	RMSE	1.027	1.127
	RMSSE	1.477	26.129
Simple Kriging (SK)	ME	0.004	-1.604
	MSE	1.456	33.639
	ASE	0.002	-0.038
	RMSE	1.032	1.056
	RMSSE	1.410	28.926
Disjunctive Kriging (DK)	ME	0.004	-1.604
	MSE	1.456	33.639
	ASE	0.002	-0.038
	RMSE	1.032	1.056
	RMSSE	1.410	28.926

**Table 5.** Prediction errors of soil Pb elements under various trend effects

Interpolation method	Trend order	ME	MSE	ASE	RMSE	RMSSE
OK	0	-0.003	1.516	-0.017	1.127	12.612
	1	-0.003	1.518	-0.027	1.128	25.543
	2	-0.008	1.530	-0.041	1.114	24.819
UK	constant	-0.006	1.508	-2.4971	1.095	0.293
	1	-0.019	1.546	0.089	1.004	30.235
	2	-0.019	1.699	-0.062	0.984	36.073
DK	0	0.004	33.639	-0.038	1.056	28.926
	constant	0.004	33.686	-0.039	1.058	28.922
	1	0.008	32.832	-0.055	1.086	27.209
	2	-0.002	32.992	-0.023	1.055	27.151
SK		0.004	33.639	-0.038	1.056	28.926

**Table 6.** Prediction errors of soil Cd elements under various trend effects under various statistical interpolation methods

Interpolation method	Trend order	ME	MSE	ASE	RMSE	RMSSE
OK	0	-0.003	1.516	-0.008	1.027	1.477
	1	-0.003	1.518	-0.009	1.028	1.475
	2	-0.008	1.530	-0.013	1.040	1.472
UK	constnt	-0.006	1.508	-0.004	1.002	1.504
	1	-0.019	1.546	-0.012	1.010	1.528
	2	-0.019	1.699	-0.001	1.002	1.747
DK	0	0.004	1.456	0.002	1.032	1.140
	constant	0.004	1.464	0.002	1.039	1.410
	1	0.008	1.462	0.004	1.046	1.393
	2	-0.002	1.483	-0.004	1.068	1.385
SK	None	0.004	1.456	0.002	1.032	1.410

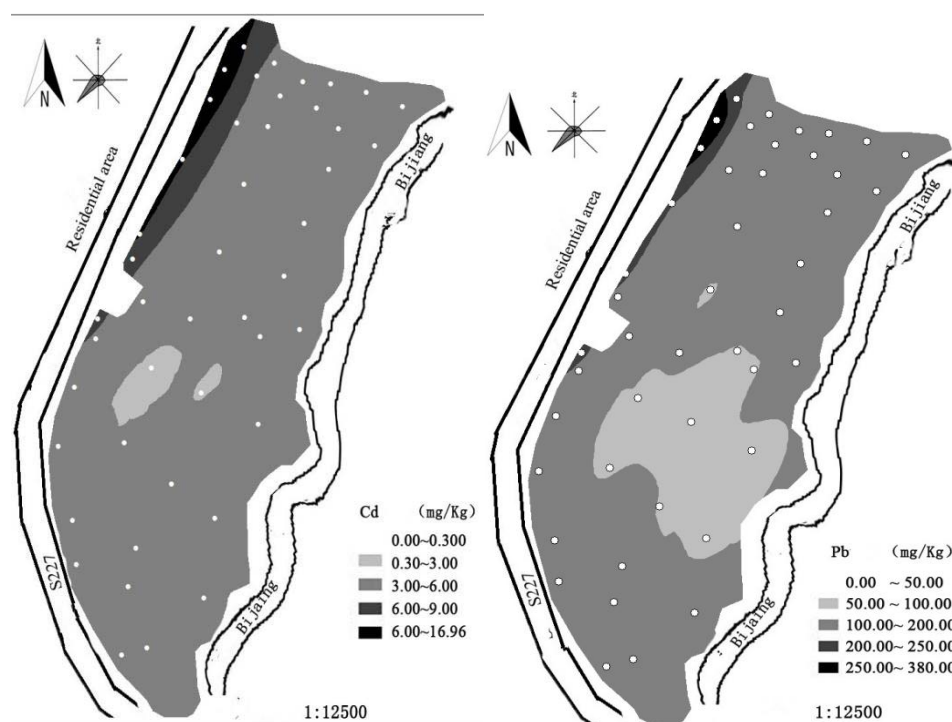


### 3.4. Spatial simulation of heavy metal elements in soil

The same interpolation method is used to obtain the optimal interpolation method of Cd elements: 1) The deterministic spatial interpolation method has the best interpolation effect with 0 local polynomial interpolation method; 2) The interpolation effect with ordinary Kriging is the most effective under the trendless effect. Good; 3) the interpolation effect of the Kriging interpolation method is best when the second-order trend effect is applied under different trend effects.

The optimal interpolation method for Pb elements is obtained by horizontal comparison of the same interpolation method: 1) The interpolation effect of the 3rd global polynomial interpolation method is the best in the deterministic spatial interpolation method; 2) The interpolation effect of ordinary Kriging is applied without the trend effect. Best; 3) the interpolation effect of the universal Kriging interpolation method using the constant trend effect under different trend effects is optimal.

The accuracy and parameters of the three optimal interpolation methods for the two heavy metals Cd and Pb are compared. The optimal interpolation criteria are: average error ME, normalized average error MSE is closer to 0, and root mean square error RMSE is minimum. The average standard error ASE is closest to RMSE, and the normalized root mean square error is closer to 1, and combined with the spatial distribution map, the spatial distribution map with more distinct distribution of heavy metal content is obviously superior. Finally, the optimal spatial distribution map and optimal spatial interpolation method for Cd and Pb in the study area are selected based on the spatial simulation map and interpolation precision. It is concluded that the optimal distribution maps of heavy metal elements Pb and Cd are: 0-order ordinary Kriging interpolation method.



**Figure 2.** Optimal spatial interpolation simulation map of soil Cd and Pb content

## 4. Conclusion

According to the optimal interpolation analysis method selected by the research, the optimal distribution map of heavy metals can be used to predict the distribution of heavy metal pollution in small-scale plots more accurately, which has certain significance for improving contaminated soil. It provides support for the spatial distribution of soil heavy metal content and accurate soil remediation. It can alleviate the problem of excessive heavy metal pollution in soil and agricultural products, and it has certain

guarantees for safeguarding the health and safety of the people and improving the quality of life of local residents Social reality.

(1) Comparison of interpolation effects of deterministic spatial interpolation method: The interpolating effect of the two heavy metals Cd and Pb in the study area with 0 local polynomial and 3 global polynomial interpolation is the best.

(2) Comparison of interpolation effects of different Kriging interpolation methods in geostatistics: The spatial interpolation effects of heavy metal elements Cd and Pb in the study area using ordinary Kriging are the best. Under the different trend effects, the interpolation effect of the Cd and Pb elements with the second-order trend effect extraction Kriging interpolation method and the constant trend effect pan-Kriging interpolation method is the best.

(3) By comparing the spatial interpolation precision of different models or parameters of the same spatial interpolation method and the vertical comparison of different spatial interpolation methods, the optimal interpolation methods for the heavy metal elements Pb and Cd are: 0-order ordinary Kriging Interpolation method, the obtained spatial distribution map is more accurate for the distribution of Pb and Cd in the soil, and has certain significance for the targeted restoration of contaminated soil. It will be the different heavy metal space in the small-scale area with single farmland as the unit. The identification of the distribution features provides important basic information and contributes to the comprehensive evaluation of the spatial int.

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