Study on the Evaluation of Heavy Metal Pollution in Soil of Tea Plantations in Karst Mountain Areas Based on GIS

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Abstract. To understand the soil environment quality of tea producing region in Plateau Mountainous area, the evaluation model of heavy metals pollution in soil was built by adopting both the single pollution index method and Nemerow multi-factor index method combined with ArcGIS Geostatistical Analyst and Model Builder Geoprocessing, which realized the modeling and automation of the soil environment quality. The content levels and spatial distribution characteristics of heavy metals such as Hg, As, Cd, Pb and Cr were analyzed though choosing typical research area. The results showed that Nemerow multi-factor index was 0.502, belonging to clear level and all the mean values of soil heavy metal elements belonged to clear level. The coefficient variation of Pb was the biggest, which indicated that the external pollution was remarkable. The correlation coefficient of Cd and Pb was the biggest, presenting a character of the same source of pollution. The high content of Cd was distributed in the north. There were different degrees of point source pollution of heavy metals in parts of the east, north and west, and there was no soil heavy metals pollution in the south.

Introduction

The quality and safety of agricultural product producing area have been highly concerned and valued by the governments of all countries owing to the source of agricultural products. With the continuous development of China's tea industry, the quality and safety of tea producing area have become the most fundamental guarantee and lifeline for the sustainable development of tea industry. Agricultural environmental pollution, especially the problem of heavy metal pollution in soil is becoming more and more prominent, which make heavy metal pollution of tea plantation in soil take more and more attention [1] [2] [3]. The growth of tea plant can't be separated from the soil, and the enrichment of soil heavy metals enter the food chain and threaten human health [4]. The study of soil pollution usually focus on the drastic spatial variation region[5], and Wang Daxia, Zhou Guolan, Li Ling, Zhang Hui, etc. have carried out mathematical statistic analysis study on soil heavy metals in typical tea plantation in succession [6][7][8][9]. In addition, Yuan Xu, Wang Xue, etc. have studied the spatial distribution characteristics and variation of soil heavy metal content in tea plantation in Rizhao City and Meitan County by means of the combination of Geostatistical Analysis and GIS[10][11].

An important tea producing county in plateau mountain area was selected as study area, which is located in the slope zone of Hunan and Guangxi hilly basin transitional zone with undulating hills and ravines crossbar. Low and middle mountain landform make up 90.50% of the total area and the vertical climate difference is obvious. Most of the study area features subtropical monsoon climate, and the annual average temperature is 14-15℃, the annual rainfall is 1310mm with annual average relative humidity is 80%. The area is covered by yellow-red soil, yellow soil, yellow brown soil, and mountain shrub soil. All above makes it has many advantages to develop tea industry. Shrouded by the clouds and mists, sufficient moisture, low air pressure, long sunshine duration and other features of plateau mountain areas provide a good growth condition for tea, and the complex topography and hydrology system offer a favorable condition for the relocation diffusion of heavy metals in soil.

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Studying the quality of soil environment of plantations and exploring the pollution sources and spatial distribution characteristics of soil heavy metal are conducive to controlling pollution sources and conducting soil bioremediation. In order to provide a scientific evidence for the comprehensive prevention and control of heavy metals in soil and a reference for the planning and construction of green tea plantations, the pollution status of soil heavy metals are sized up by combined with GIS Geoprocessing (GP).

Materials and Methods

Sampling and Analyzing. According to the basic geological, topographic features and tea plantation distribution characteristics, the soil sampling points were increased to 343(Figure 1). The sampling depth of soil was 0～20cm, and the location of sampling points was recorded by handheld GPS. Five kinds of soil heavy metals content such as Hg, As, Cd, Pb, Cr in soil samples were detected through Diffusive Gradients in Thin-Films technique (DGT) and Excel file which contains latitude, longitude coordinates of sampling points, toponym information, pH, and each heavy metal element content of sampling points.

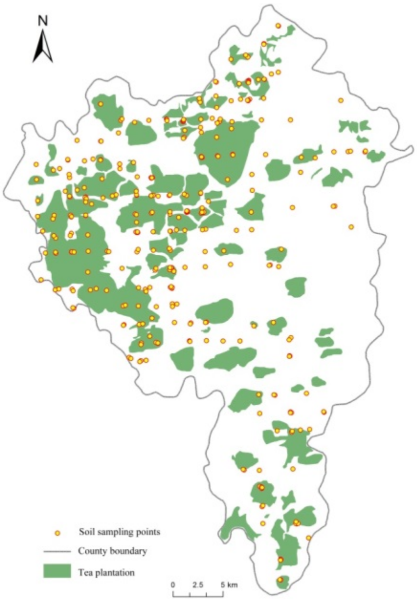

Fig.1 Distribution map of soil sampling points in the study area

Evaluation Criterion. By adopting both the single factor index method and Nemerow multi-factor index method, the pollution of soil heavy metals has been evaluated. Evaluation of single factor index method evaluates the cumulative pollution degree of a certain heavy metal elements in accordance with certain soil environmental quality standards, while Nemerow multi-factor index method considers both the mean pollution value of single heavy mental element and the effects of high concentrations of pollutants on environmental quality. The Eq.1 for the single factor pollution index method:

$$P_i = C_i / S_i \tag{1}$$

In the Eq.1: P_i refers to the environmental quality index of pollutant I, C_i is the measured value of the pollutant *i* (mg / kg), S_i is the evaluation criteria of pollutant *i* (mg / kg).

The Eq. 2 for the Nemerow pollution index:

$$P_n = \sqrt{\left(P^2{}_{\max} + P^2{}_{\text{ave}}\right) / 2} \tag{2}$$

In the Eq.2: P_n is the soil comprehensive pollution index, P_{max} is the maximum value of the mean value of single pollution index, P_{ave} is the mean of the average value of single pollution index.

Soil environmental quality assessment uses the II class standard values of *Environment quality standard for soils (GB15618-1995).* Soil rating adopts *Procedural regulations regarding the environment quality monitoring of soil (NY / T 395-2000),* the grading standards of which are as follows: $P_n \leqslant 1.0$ means non pollution, $1.0 < P_n \leqslant 2.0$ means mild pollution, $2.0 < P_n \leqslant 3.0$ means moderate pollution, and $P_n > 3.0$ means heavy pollution.

Table 1 The classification standards of soil pollution (NY/T 395-2000)

mg/kg

Classification	Indicators of pollution level	Pollution grade	Pollution level
1	$P_n \leq 0.7$	Safety	Clean
2	$0.7 < P_n \leq 1.0$	Warning line	Slight cleaning
3	$1.0 < P_n \leq 2.0$	Mild contamination	The content of soil pollution exceeds the background value and be seen as mild contamination
4	$2.0 < P_n \leq 3.0$	Middle pollution	Soil and crops are moderately polluted
5	$P_n > 3.0$	Heavy pollution	Soil and crops are seriously polluted

Analytical Method. The traditional statistical analysis can only show the overall characteristics of the variables, and cannot quantitatively reflect the randomness, correlation, structure and other specific factors. Based on regional variables, Geostatistical analysis studied the correlation and dependence of the data with the help of variation function, carried out optimal interpolation of data, and simulationed the discreteness and wave properties of the information. The change range of the sample value and the distance between the samples were considered, which makes up the deficiency of the traditional statistics in Spstial Analysis.

The discreteness and the normal distribution characteristics of date were more important for Kriging method. When the coefficient of variation was big, the result had big error. But at the same time, the IDW (Inverse Distance Weighting) method was accurate. The spatial interpolation precision of soil was very major to the assessment of heavy metal pollution in soil to GIS. Laslett believed that for the PH of the IDW had better interpolation results than Kriging method[12], Gotway agreed by testing soil organic matter and nitrogen (N) [13]. The data of soil heavy metals was highly dispersed in the study area, and the normal distribution was poor, the IDW method was suitable. The information of Hg，As, Cd, Pb, Cr in the soil had high dispersion, the data could obey normal distribution but there also were some point of departure through Log transform processing (Figure 2).

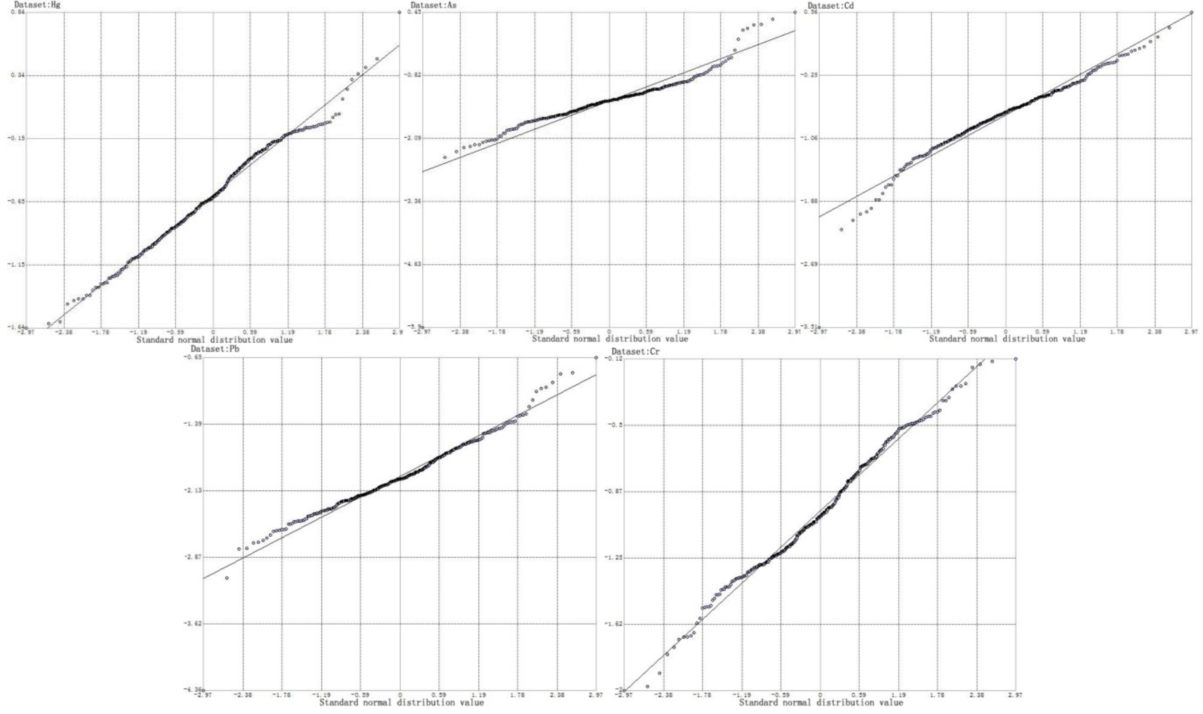

Fig.2 QQ-Plot

IDW (Inverse Distance Weighted) assumes that the distance is closer to the sample position of soil properties more similar. And the impact of known samples to unknown sample point is smaller with the distance longer. Weighted was depended by the distance between the interpolation points. Eq. 3 is as follows:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i(S_i) \tag{3}$$

In the Eq. 3, $\hat{z}(s_0)$ was the predicted value at S_0, N was the number of surrounding prediction computation process used to predict spotting points, λ_i was the weight of every point in calculation process for predicting, this value was reduced with the distance between the sample and the predicted point increasing, $Z(s_i)$ was measured value at S_i.

Model Building

Coordinate System Transformation. Model builder builds geography processing tool flow through Visual Programming Language (VPL) rather than Text Programming Language (TPL). In a complete GIS workflow, geographic modeling was finished by using system and custom tools, running Geoprocessing tools in sequence according to the pattern of workflow, and controlling the flow of model by using loop statement and conditional statement.

```
# Process: Make XY Event Layer
tempEnvironment0 = arcpy.env.outputCoordinateSystem
arcpy.env.outputCoordinateSystem= "GEOGCS['GCS_WGS_1984',DATUM
['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',0
.0],UNIT['Degree',0.0174532925199433]]"
arcpy.MakeXYEventLayer_management(Input table data, Longitude, latitude, Output GPS points,
Spatial Reference, "")
arcpy.env.outputCoordinateSystem = tempEnvironment0
# Process: Create Custom Geographic Transformation
arcpy.Project_management(Output GPS points, Output projection file, Output coordinate system,
"WGS84-1940", Input coordinate system)
# Process: Definition projection
arcpy.DefineProjection_management(Projection output, coordinate system)
```

The model consists of input data, spatial processing tools and output evaluation results three parts. Arc-Toolbox provides a rich set of input and output feature, raster, dataset and other spatial data types and options, making it available to deal with input and output data simply and rapidly through the compilation of custom tools. It is necessary to transform the coordinate system to realize standardization map shows and operation of source data and target data. Enter the soil sample data, translate them into shapefile through the creation of XY event and then customize object coordinate system. The key source code is as follows:

```
# Process: Make XY Event Layer
tempEnvironment0 = arcpy.env.outputCoordinateSystem
arcpy.env.outputCoordinateSystem= "GEOGCS['GCS_WGS_1984',DATUM
['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwich',0
.0],UNIT['Degree',0.0174532925199433]]"
arcpy.MakeXYEventLayer_management(Input table data, Longitude, latitude, Output GPS points,
Spatial Reference, "")
arcpy.env.outputCoordinateSystem = tempEnvironment0
# Process: Create Custom Geographic Transformation
arcpy.Project_management(Output GPS points, Output projection file, Output coordinate system,
"WGS84-1940", Input coordinate system)
# Process: Definition projection
arcpy.DefineProjection_management(Projection output, coordinate system)
```

IDW and Modeling. Based on shapefile of custom coordinates, IDW interpolation was done. Samples in the calculating process of forecast values for weight is influenced by the parameter P, so must set the power, radius and pixel model parameters. When running the model, the parameters can be adjusted. According to *Procedural regulations regarding the environment quality monitoring of soil (NY / T 395-2000)*, the IDW interpolation weight classification variables interval: $P\leqslant 0.7$,$0.7 < P \leqslant 1.0$, $1.0<P\leqslant 2.0$, $2.0<P\leqslant 3.0$，$3.0<P$. The reclassification of the raster file transfered vector and smoothed. The model parameters set up the layer sign system, which was conducive to the rapid mapping and evaluation of the level of heavy metal pollution in tea producing areas. The main source code is as follows:

```
# Process: IDW
tempEnvironment0 = arcpy.env.extent
arcpy.env.extent = "289969.98333151 2734169.6961513 331003.254337288 2793380.1895 2098"
arcpy.Idw_3d(Input point elements, Z_ value field, Interpolation file output, Pixel size, "2", "VARIABLE 12", "")
arcpy.env.extent = tempEnvironment0
# Process: Reclassify
arcpy.Reclassify_3d(Output interpolation file, "Value", Classification parameter, Output file, "DATA")
# Process: Converts rasters to polygons
arcpy.RasterToPolygon_conversion(Output file, Converts rasters to polygons, Simplified surface, "VALUE")
```

The evaluation model of heavy metal pollution in soil of tea plantation generated through workflow, as shown in Figure 3.

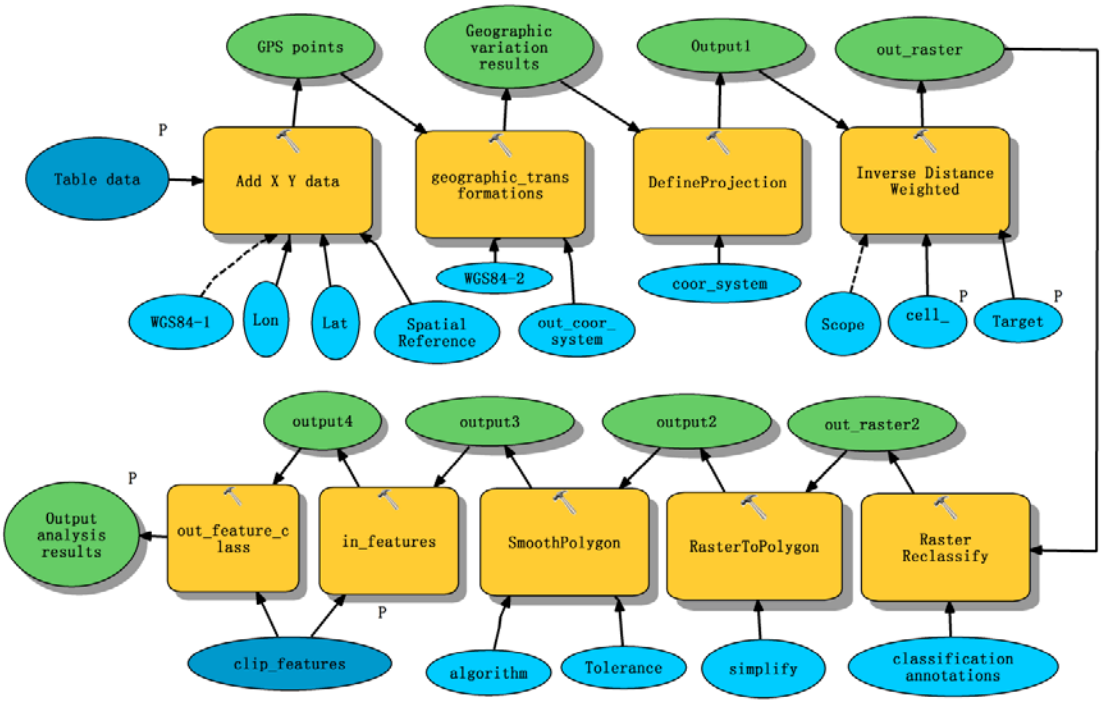

Fig.3 Model interface

Results and Analysis

Descriptive Evaluation of Soil Heavy Metals in Tea Plantation. The mean values of single pollution indexes of soil heavy metals Hg, As, Cd, Pb and Cr are 0.592, 0.291, 0.556, 0.159 and 0.396. which are in clean range respectively. The dispersion degree of variables of the estimated value is in a high level. The variance coefficient order is Pb > Cd >As> Hg >Cr. The amplitude variations of the content of Pb, Cd and As are tremendous, the values of which are 3.2～727.3 mg/kg, 0.009～2.535 mg/kg and 0.11～62.58 mg/kg. The contents of Hg and Cr vary greatly, which are 0.058～0.693 mg/kg, 20.3～133 mg/kg. The data characteristics indicate that the soil of tea plantation mainly influenced by exogenous heavy mental pollution. The exceeding standard rate of soil heavy mental Hg, As, Cd and Pb are 2.91%, 2.040%, 4.664% and 0.291%, which are in clean range according to the II standard of *Environment quality standard for soils (GB15618-1995)*. The comprehensive pollution index of the study area is 0.502 on the basis of Nemero comprehensive pollution index method, resulting that soil heavy mental of tea plantation is clean level.

The correlation test among Hg, As, Cd, Pb, Cr was conducted and Pearson's correlation coefficients among all the variables are shown in Table 3. Very weak correlation was shown between Hg and As, Cd, Pb, Cr. The correlation between As and Cr is greater than that between As and Cd, Pb, the correlation between Cd and Pb showed a weak correlation, which is greater than that between Cd and Cr, showing that Cd and Pb may also be less effected. Very weak correlation was shown between Pb and Cr.

Table 2 Descriptive statistics of soil heavy metals

	Hg	As	Cd	Pb	Cr
Mean (mg/kg)	0.177834	11.65	0.166	39.93	59.432
Maximum (mg/kg)	0.693	62.58	2.535	727.3	133
Minimum (mg/kg)	0.058	0.11	0.009	3.2	20.3
The II standard of *Quality standard for heavy metals in soil* (mg/kg)*	0.3	30	0.3	250	150
Standard deviation	0.07	6.66	0.165	41.03	20.92
Variable coefficient	0.393626	0.571	0.988	1.027	0.352
Exceeding standard rate（%）	2.91	2.040	4.664	0.291	-
Mean square root	0.073	6.536	0.0192	0.178	0.126

Note: * the II standard value of *Environment quality standard for soils (GB15618-1995)*

Table 3 Pearson correlation coefficient of soil heavy metals

	Hg	As	Cd	Pb	Cr
Hg	1	-	-	-	-
As	0.088	1	-	-	-
Cd	0.00289	0.0236	1	-	-
Pb	0.0276	0.0259	0.303	1	-
Cr	0.06	0.182	0.1098	0.132	1

Model Evaluation of Heavy Metal in Soil of Tea Plantation. The quality of the soil environment level distribution map were made(Figure 4), dark green - light green - yellow - orange - red represented the change of soil from clean to heavy pollution. The soil heavy metal pollution in the tea producing area was polluted by point source, and the soil environment in the study area was affected greatly by the external factors. Combined with land-use data, Hg, As, Cd, Pb were all affected by the highway. There was light pollution of Hg in west and north central part where pollution area was 1.564 km^2, and moderate pollution in west where pollution area was 0.0009 km^2. The results showed that Hg pollution is the point source pollution. There was moderate pollution of As which the area was 0.283 km^2. The northeast region was affected by human activity, the eastern part was impacted by the transport and residential area. Cd appeared light, moderate and severe pollution, which has certain connection to the high background. The light polluted area was 0.685 km^2 which distributed in the Midwest of the study area, the source was resident point. Moderate polluted area was 0.64 km^2 in west and north which was affected by the transport and residential area. The moderate and severe pollution regions were irregular spatial distribution, the main reason was located in the transport interchange, the high river density high accelerated the migration and diffusion of heavy metals in the soil, the polluted area was 0.82 km^2. Pb showed light and moderate pollution, which was distributed in the west of the study area. Pb and Cd were affected by the residential area, the spatial distribution characteristics showed that Pb and Cd belonged to the same source pollution. The southern region of the study area was not impacted by heavy metals in the soil.

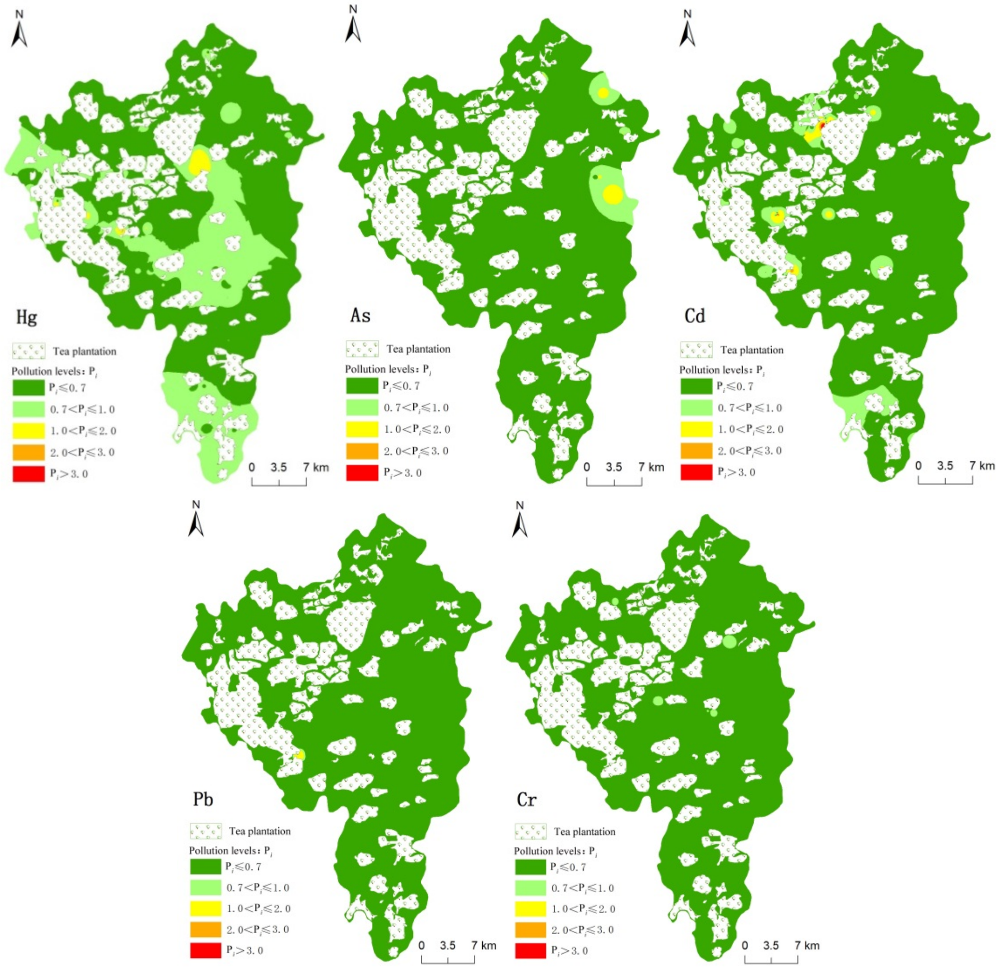

Fig.4 Spatial distribution of soil heavy metals

There were light and moderate pollution of Hg with Pb, light pollution of As, light, moderate and severe pollution of Cd. Combining the landuse data, the polluted area were 0.49%、0.09%、2.63%、0.13% of the tea garden. Cr was clean. The study area had a good ecological environment, which was important for the development of tea industry, but there were still some points has metal exceed the standard problem, soil remediation measures and monitoring efforts should be made, the region which was more vulnerable to the influence of human activity should be monitored.

Conclusion

According to the standards of *Environmental quality standard for soils (GB15618-1995)* and the *Procedural regulations regarding the environment quality monitoring of soil (NY / T 395-2000)*, the Model Builder of ArcGIS was used for visual modeling and the single factor index method and Nemerow multi-factor index method were used for the evaluation. The soil heavy metal pollution assessment model of the tea plantations in plateau mountain areas was constructed, and the visualization of eveluation process of soil heavy metal pollution status was realized. The results indicates that the study area present point pollution which is consistent with the actual situation. With certain practical value, the evaluation model of heavy metal pollution in the soil of tea plantations provides a scientific reference for the related management departments. Because the study area is located in plateau mountain area, there are lots of factors disturbs the scientific evaluation of pollution status of soil heavy metals. There is a need to further explore to introduce some evaluation factors such as soil available heavy metals and detection crop of heavy metals into the model.

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