A Risk Assessment Model for Soil Heavy Metal Pollution in Yunnan Province Based on the Analytic Hierarchy Process

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Abstract. This paper presented a model based on the analytic hierarchy process (AHP) to evaluate the pollution problem of Yunnan Province. The results show that the sample points meet the general requirements (in and below the pollution risk), accounting for 75% of the total. In the serious points exceeding the standard, the points with high pollution risk account for about 95%, and the classification is more complicated. It is necessary to invest in a larger workload in the later stage for detailed classification, and the super high risk point accounts for about 5%.

1. Introduction
In this paper, the analytic hierarchy process (AHP) is used to evaluate the soil pollution degrees. The pollution risk is usually set as the target layer and the pollution items are used as the sub-target layer. The pollution levels are used as the criterion layer. The effect index of each pollution item on soil quality is obtained. Finally we propose a model for assessing the risk of soil comprehensive heavy metal pollution in practice.

2. Background and method
The soil pollution is directly related to the people's living and food safety. In economic development, attention to soil pollution has become an indispensable part.

The soil environmental quality assessment methods commonly used in wild mainly include Nemerow comprehensive pollution index method, weighted average pollution index method [1], potential ecological hazard index method [2], fuzzy mathematics method [3], Grey clustering method, and Geographic Information System (GIS) [4,5], Geo-statistical evaluation method [6], etc. In practical areas, it is necessary to establish models related to actual needs and evaluate soil pollution risks for practical needs.

In this paper, the detailed analysis and analysis data of agricultural land in Yunnan Province is used as the data source. The analytic hierarchy process (AHP) is used to calculate and analyze the weight of each impact factor, and then the grading evaluation result is used as the calculated value of each element. Finally, the calculation result provided a method for classifying the risk value of the sample points to evaluate the soil environmental risk.

2.1. The analytic hierarchy process
Analytic Hierarchy Process (AHP) is a method for analyzing the joint effects of multiple sub-items on a target. It is widely used in target systems with hierarchical interlaced evaluation indicators, and the target value is difficult to quantify the decision-making problem.

For a specific target, the parameters that affect the target are enumerated. The parameters of the parameters and the parameters affecting the parameters are listed at the level, and the layers are progressive. The evaluation matrix is constructed for each layer of influence factors, and the evaluation matrix is used. To calculate the weight of each layer, the analytic hierarchy process is to treat a complex multi-objective decision problem as a system, decompose the target into multiple targets or criteria, and then decompose into several levels of multiple indicators, and calculate by qualitative index fuzzy quantization method. Hierarchical layers were sorted singly and in all, as a systematic method for optimizing decision made with goals and multiple schemes.

In order to evaluate the combined effects of soil heavy metal content on land quality, we introduced the analytic hierarchy process to model existing land pollutants. The analytic hierarchy process is used for soil pollution assessment. The pollution risk is usually targeted to the target layer. As the sub-target layer, the item is used as the criterion layer. Through the progressive relationship, the effect index of each pollution item on soil quality is finally obtained, and the pollution risk of a certain sample of soil is finally evaluated.

According to the requirements, the sample is modeled in three layers, which are the target layer (risk assessment), the sub-target layer (six heavy metal indicators), and the criterion layer (pollution level), as shown in Figure 1.

Among them, the target layer is soil pollution risk assessment, the sub-target layer is six heavy metal elements, and the criterion layer is (clean, normal, light pollution (Light P), moderate pollution (Medium P), and severe pollution (Severe P).

The heavy metal pollution classification evaluation table is introduced as a scoring standard which regarded as expert evaluation on the elements of the sub-target layer, as shown in Table 1. The table divides the evaluation level of each sub-goal into 5 levels, and uses the unique rating result relative to each sub-goal as the expert evaluation result.

| Table 1. the heavy metal pollution classification evaluation table/ mg·kg⁻¹ |
|---|---|---|---|---|---|---|
| Clean | 0.1204 | 23.35 | 0.0920 | 74.88 | 28.37 | 83.68 |
| Normal | 0.2523 | 36.09 | 0.2592 | 99.54 | 40.63 | 116.75 |
| Light P | 0.6000 | 150 | 0.4500 | 150 | 120 | 240 |
| Medium P | 1.4000 | 350 | 1.0500 | 350 | 280 | 560 |

Figure 1. The AHP model for the soil pollution Risk in Yunnan.
3. Experiments and results

In this experiment, the data was preprocessed and put into a hierarchical model for calculation. Finally the results were presented.

3.1. Data source

This paper uses the second soil detailed investigation (hereinafter referred to as the second-tuned investigation) analysis results of Yunnan Province as a data source. The second-tuned detailed soil survey made a detailed sampling investigation and analysis of the soil in Yunnan Province, and comprehensively presented the parameter information of the overall heavy metal content of agricultural land in Yunnan Province. The information is accurate and reliable, and has great reference value. According to the relevant policies of the Ministry of Environmental Protection, after the detailed investigation is completed in 2020, the second-tuned investigation results will be disclosed to the public.

The calculation model uses six heavy metal elements (Cd, Pb, Hg, Cr, Cu, Zn) that have a greater impact on the human body in the second-tuned investigation results as the sub-target layer for evaluation.

3.2. Data preprocessing

Because the sample points are large and discrete, the data and expert evaluation criteria are first normalized.

3.2.1 Data normalization. The source data distribution is treated as a Gaussian model, and the Gaussian model normalization method (i.e., $t = \frac{x - \mu}{\theta}$ ) is used as the normalization rule. Calculate the mean and variance of the eight heavy metal elements, normalize according to the formula, and then normalize the pH value and the national standard line at the same time to ensure unity.

3.2.2 Expert evaluation table normalization. On the basis of data normalization, assuming that the expert evaluation table item is also attributed to the distribution of the corresponding heavy metal elements, for each heavy metal element, the five threshold values in the expert evaluation table are put into the mean and variance using the corresponding heavy metal elements. In the normalization formula, normalize it. The normalized results are shown in Table 2.

### Table 2. The normalized heavy metal pollution classification evaluation table/ mg · kg$^{-1}$

|             | Cd    | Pb    | Hg    | Cr    | Cu    | Zn    |
|-------------|-------|-------|-------|-------|-------|-------|
| Clean       | -0.94 | -0.24 | -0.24 | -5.55 | -6.28 | -6.65 |
| Normal      | -0.81 | 0.14  | 0.14  | -3.47 | -4.96 | -4.12 |
| Light P     | -0.48 | 0.57  | 0.57  | 0.79  | 3.55  | 5.32  |
| Medium P    | 0.28  | 1.91  | 1.91  | 17.65 | 20.72 | 29.82 |
| Severe P    | 0.85  | 2.93  | 2.93  | 30.3  | 33.6  | 48.2  |

3.3. Calculate the attribution of normalized values

Since the value has been normalized, the original value/excessive value method can be reduced to the addition and subtraction method. The normalized value of a certain scale value of the sample is subtracted from the classification scale, and the attribute is classified according to the left and right. A class classified into five categories of the criteria layer. Attribute values obtained a total of five categories of six.

3.4. Constructing a two-two importance matrix (judgment matrix)
According to the relative importance of each indicator of the factor layer to the target layer, the five-level quantitative scale assignment is used.

According to the established hierarchical structure diagram, construct a pairwise comparison judgment matrix:

\[
A = (a_{ij})_{n \times n}.
\]

The magnitude of each factor \(a_{ij}\) in the judgment matrix is given by a scale method using 1 to 9 and its reciprocal as a measure.

3.4.1 Criteria layer construction matrix. According to actual needs, the criterion layer construction matrix is as follows:

\[
a = \begin{pmatrix}
1 & 1 & 1 & 1 & 1 \\
\frac{1}{3} & \frac{7}{8} & \frac{8}{9} \\
3 & 1 & 1 & 1 & 1 \\
6 & \frac{7}{8} & \frac{8}{9} \\
7 & 6 & 1 & \frac{1}{3} & \frac{5}{3} \\
8 & 7 & 3 & 1 & \frac{1}{3} \\
9 & 8 & 5 & 3 & 1 \\
\end{pmatrix}
\]

3.4.2 Sub-target layer construction matrix. Since the demand side pays equal attention to each heavy metal element, the weight value of each heavy metal element is set to be equal to 1.

3.5. Calculate single sort weight vector and do consistency check
The maximum eigenvalues of the comparison matrix and their corresponding eigenvectors are calculated for the criterion layer, and the consistency test is performed by using the consistency index, the random consistency index and the consistency ratio. If the test passes, the feature vector (after normalization) is the weight vector.

- For the judgment maximum eigenvalues of the matrix A:
  \[
  \lambda_{\text{max}} = 5
  \]
- The eigenvector corresponding to the maximum eigenvalue after normalization:
  \[
  \omega = \begin{pmatrix} 0.028 & 0.048 & 0.153 & 0.269 & 0.500 \end{pmatrix}^T
  \]
- Calculate the consistency indicator
  \[
  CI = \frac{\lambda_{\text{max}} - n}{n-1},
  \]
  Where \(n\) determines the order of the matrix, which indicates 5.
- The calculated consistency index \(CI=0\), which meets the consistency test requirements, can be used as a weight vector, that is, the weight vector can be used as an evaluation index.

3.6. Evaluation results
According to the scores of the selected evaluation price indicators and the weights of the evaluation indicators, the soil pollution risk assessment index is calculated, and the existing data are evaluated according to the soil pollution risk assessment standard (Table 3).
It can be seen from the evaluation results (Figure 3.) that the sample points meet the general requirements (in and below the pollution risk), accounting for 75% of the total. In the serious points exceeding the standard, the points with high pollution risk account for about 95%, and the classification is more complicated. It is necessary to invest in a larger workload in the later stage for detailed classification, and the super high risk point accounts for about 5%.

4. Summary

In this paper, the analytic hierarchy process (AHP) is used to analyze the heavy metal content of the second-turned investigation samples in Yunnan Province. An evaluation model for the degree of mult-metal element exceeding the standard and the hazard risk is proposed. A fourth-order grading method is proposed, which can effectively reflect the sampling point. The degree of the exceeding standard and a reasonable evaluation of the excessive point pollution risk make it easier for the management department to analyze, interpret and formulate the next work plan.

References

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Table 3. Soil pollution risk assessment standard.

| Pollution Risk | Class standard |
|----------------|---------------|
| >1.000         | Super High    |
| 0.500~1.000    | High          |
| 0.260~0.500    | Moderate      |
| <0.260         | Low           |

Figure 2. 3.6. Evaluation results.