Sensors and Materials, Vol. 37, No. 1 (2025) 261–268
MYU Tokyo

S & M 3905

Analysis of Geographic Suitability of Chinese Medicine Based on Analytic Hierarchy Process-Fuzzy

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(Received August 9, 2024; accepted January 21, 2025)

Keywords: evaluation of suitability of Chinese medicine, geographic analysis, indicator system, analytical hierarchy process, fuzzy comprehensive evaluation

In this paper, geographic analysis methods in geographic information systems were applied to study and practice the ecological suitability influencing factors of traditional Chinese medicine resources. On the basis of the theory and methods of traditional Chinese medicine resource ecology, statistical ecology, and geographic analysis, the meaning and content of the ecological suitability of Chinese medicine resources were generally described. The indicator system of the ecological suitability of Chinese medicine resources was established. The analytic hierarchy process (AHP) was adopted to quantitatively and reasonably evaluate the impact of relevant indicators in the indicator system. The solution for the analysis and evaluation of suitability, which combines the AHP-Fuzzy method with geographic analysis methods, was proposed, and the geographic suitability analysis and ecological suitability evaluation models were established. The traditional Chinese medicine geographic suitability analysis system was designed and implemented on the basis of the Browser/Server framework to display the results of evaluation and analysis by 3D visualization. Experiments showed that the analysis results and the actual medicine's plant growth are basically consistent, and the method for creating an indicator system and geographic analysis model was proved to be feasible and reasonable from a practical viewpoint.

1. Introduction

The description of the ecological suitability of traditional Chinese medicine refers to the matching between the optimal ecological factors necessary for the growth and development of traditional Chinese medicine in a certain natural area and the ecological conditions in the study area.(1) The scientific evaluation and rational planning of the ecological suitability of traditional Chinese medicine resources are crucial for achieving the effective protection and sustainable utilization of these resources. At present, research on the ecological suitability analysis of traditional Chinese medicine has made some progress,(2,3) but there is still significant room for development in terms of research object coverage, technological innovation, and interdisciplinary

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https://doi.org/10.18494/SAM5292

ISSN 0914-4935
https://myukk.org/

cooperation. Some studies mainly focus on a few traditional Chinese medicine resources that have important economic or medicinal value, without universality, which increases the workload of suitability analysis and reduces the flexibility of the work.[4–7] The application of new technologies and interdisciplinary integration are gradually deepening, and the demand for the periodic monitoring of traditional Chinese medicine ecology is becoming increasingly significant.[8–10] Therefore, in this study, we aim to integrate multidisciplinary theories and technologies such as traditional Chinese medicine resource ecology, statistical ecology, and a geographic information system (GIS) to construct a comprehensive and systematic framework for evaluating the ecological suitability of traditional Chinese medicine resources.[11–15] In terms of evaluating the suitability of traditional Chinese medicine, a combination of geographic analysis and statistical analysis methods is adopted, fully considering the 3D spatial characteristics of traditional Chinese medicine suitability analysis. Research on an extensible theoretical method and technology is of considerable practical significance.

2. Construction of Indicator System of Ecological Suitability of Chinese Medicine

2.1 Process of constructing suitability indicators for Chinese medicine

The establishment of the indicator system consists of the following four steps: first, proposing the research questions; second, establishing the set of ecological suitability factors for Chinese medicine; third, collecting relevant data for suitability analysis; and finally, constructing the suitability indicator system.

2.2 Selection of suitability indicators

First, the Delphi method was used to consult experts opinions on the evaluation indexes of the suitability of alternative Chinese medicines, determining the specific candidate indicators. After the indicators are determined, principal component analysis (PCA) is conducted on the basis of the actual types of Chinese medicine, aiming to simplify the indicator system and reduce its dimensionality.

The selection process primarily involves listing all factors that may affect the growth and development of Chinese medicine (i.e., all candidate indicators). By the Delphi method, these indicators are compared and selected one by one, adhering to the principle of prioritizing relevance, to determine the final set of factors for the indicator system.

After the selection process, the indicators related to Chinese medicine suitability are categorized into five major classes: climate impact factors, atmospheric impact factors, soil impact factors, topographic impact factors, and biological impact factors. Each major category can be further divided into several subfactors.

2.3 Structure of suitability indicator system for Chinese medicine

The ecological suitability indicator system for Chinese medicine resources has the characteristics of multiple indicators and hierarchical structure. Therefore, a hierarchical

structure can be adopted to simplify complex problems by decomposing the suitability indicators into individual layers, ultimately forming a three-level structure. In this study, the five major categories of factors are divided into 17 subfactors that can be directly used for analysis, establishing a three-level logical structure suitability indicator system to evaluate the ecological suitability of Chinese medicine.

On the basis of the analysis of environmental factors affecting the ecological suitability of Chinese medicine and the actual data results, we established the indicator system shown in Fig. 1.

3. Ecological Suitability Analysis and Evaluation Research

In this section, we describe the construction of a geographic analysis model and an evaluation model for Chinese medicine suitability, enabling the effective application of spatial data such as Chinese medicine patch data and patch environmental survey data in suitability analysis and evaluation. This serves to support decision-making in the management of Chinese medicine zoning.

3.1 Method for determining indicator weights

We used the analytic hierarchy process (AHP) to determine the weights of each ecological indicator.[9] The calculation steps are as follows:

(1) Calculate the weights of the first-level indicators.
(2) Calculate the weights of each indicator in the second-level indicator layer.
(3) Calculate the composite weights of the second-level indicator layer.

For the weights of the 17 indicators for Chinese medicine suitability analysis, their feature vectors were calculated and normalized, calculating the weights of the topographic, meteorological, atmospheric, soil, and biological indicators.

The method for constructing the Chinese medicine indicator system in this study has been well applied to the geographic analysis of Chinese medicine resource suitability. Here, we illustrate this using an example from a county in Shanxi Province. We obtain the environmental factor parameters for each growing area of the Chinese medicine and calculate the indicator weights as shown in Table 1.

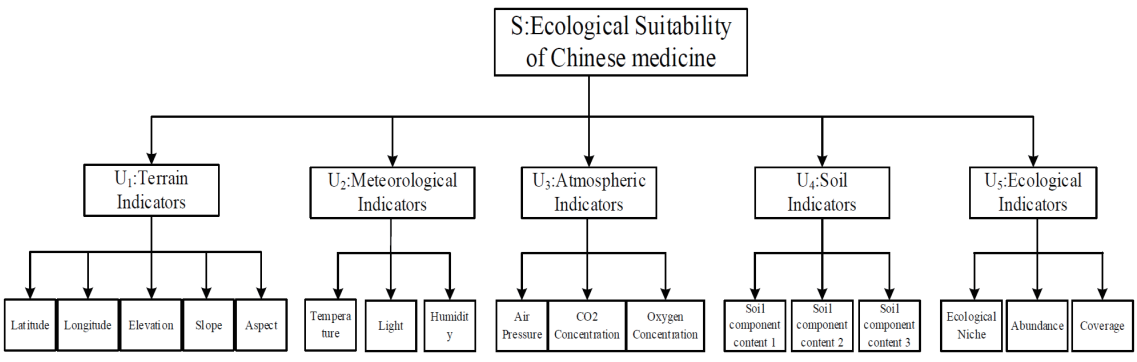

Fig. 1. Indicator system structure graph.

Table 1
Weights of indicator system.

Objective Layer	Criterion Layer	Weight	Indicator Layer	Weight
Resource Ecological Suitability	Terrain Indicators	0.212	Latitude	0.110
			Longitude	0.142
			Surface Elevation	0.315
			Surface Slope	0.164
			Surface Aspect	0.269
	Meteorological Indicators	0.274	Temperature	0.413
			Light	0.385
			Humidity	0.202
	Atmospheric Indicators	0.152	Air Pressure	0.187
			CO_2 Concentration	0.362
			Oxygen Concentration	0.451
	Soil Indicators	0.223	Soil Nitrogen Content	0.478
			Soil Phosphorus Content	0.522
	Ecological Indicators	0.139	Chinese medicine Ecological Niche	0.413
			Abundance	0.251
			Coverage	0.336

3.2 Ecological and geographic suitability analysis model

We established a GIS database by preprocessing the surveyed factor data and the field-mapped Chinese medicinal herb patches through spatial interpolation and vectorization methods. Then, we established a reasonable ecological indicator system and suitability analysis model. Through GIS spatial overlay and integrated calculations using data on the growth of Chinese medicinal herbs and various factors, we can use the yield and quality of Chinese medicinal herbs as criteria to express the degree of suitability. A Chinese medicinal herb suitability evaluation model was established, and scientifically valid recommendations for Chinese medicinal herb zoning were proposed for different regions.[16,17]

3.3 Ecological suitability assessment

The establishment of an ecological suitability model (Fig. 2) primarily involves creating a relational framework based on the required ecological factor data and the results of quantitative analysis. This framework defines the numerical values of parameters that link ecological factors to overall suitability, thus forming a comprehensive evaluation model.[18]

In this system, spatial geographic analysis is used to analyze the ecological environment for the growth of Chinese medicinal herbs in order to identify the most suitable areas for their cultivation. Vector data spatial analysis is then employed to overlay the identified growth regions with administrative boundaries, enabling a more detailed analysis of the administrative scope of suitable areas.[7]

(1) Determine the evaluation object set: P = Ecological Suitability of Chinese Medicine Resources, and construct a two-level evaluation indicator set U.
(2) Define the linguistic rating domain, i.e., establish the evaluation set: $V = \{V1, V2, ..., V4\}$ = {Most Suitable, Secondarily Suitable, Generally Suitable, Not Suitable}.

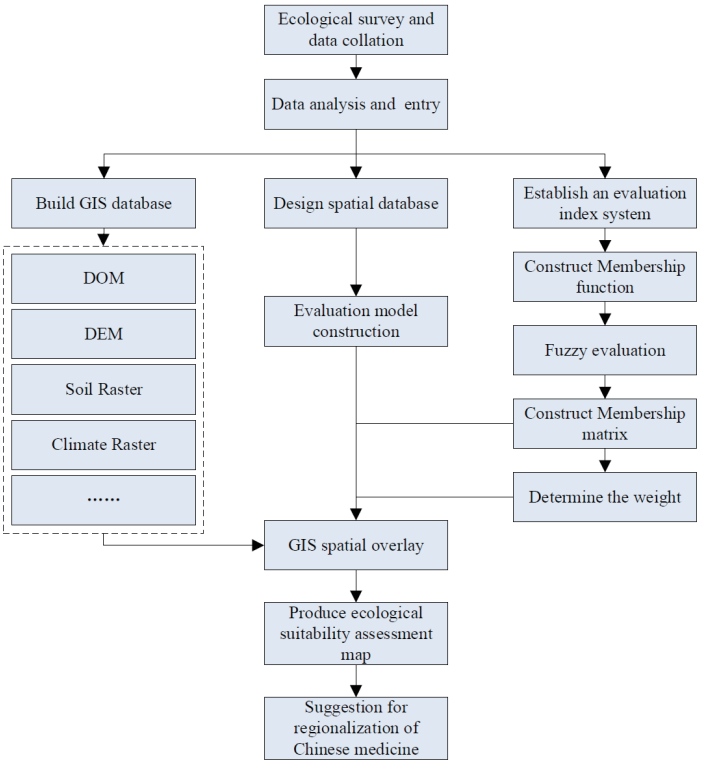

Fig. 2. (Color online) Suitability model establishment and analysis process diagram.

On the basis of differences in regional environmental conditions, we divided the regions into four different levels, as shown in Table 2.

Through the established suitability evaluation model, the calculated quantitative suitability values determine which numerical range within the evaluation set the suitability value falls into, and the evaluation result is then assigned the corresponding level of the evaluation set. In Fig. 3, the upper part shows the suitability analysis results for a certain Chinese herbal medicine growing region, whereas the lower part presents actual verification data. The comparison between the upper and lower parts of the figure indicates that the indicator system established in this study and the geographical analysis results for suitability align well with the actual situation.

4. Experiment and Analysis

4.1 Overall platform architecture

The platform designed in this paper adopts a Browser/Server (B/S) architecture. The system structure is mainly composed of four layers, namely, client layer, application layer, service layer, and data layer, as shown in Fig. 4. The data layer adopts a multi-source data integration approach, integrating spatial grid data, Chinese herbal medicine statistical data, Chinese herbal medicine patch vectors, and component base data, thereby establishing an integrated database for research on the ecological suitability of Chinese medicine resources.

Table 2
Classification of suitability evaluation set.

Suitability Level	Code	Meaning
Most Suitable	*V*1	Environmental factors are in optimal condition, with no limiting factors for the growth and development of Chinese herbal medicines.
Secondarily Suitable	*V*2	Environmental factors are suitable for the growth of Chinese herbal medicines, but to a lesser degree than the most suitable level.
Generally Suitable	*V*3	Environmental factors impose moderate restrictions on the growth of Chinese herbal medicines.
Not Suitable	*V*4	Environmental factors severely limit the growth of Chinese herbal medicines, making them unsuitable for planting.

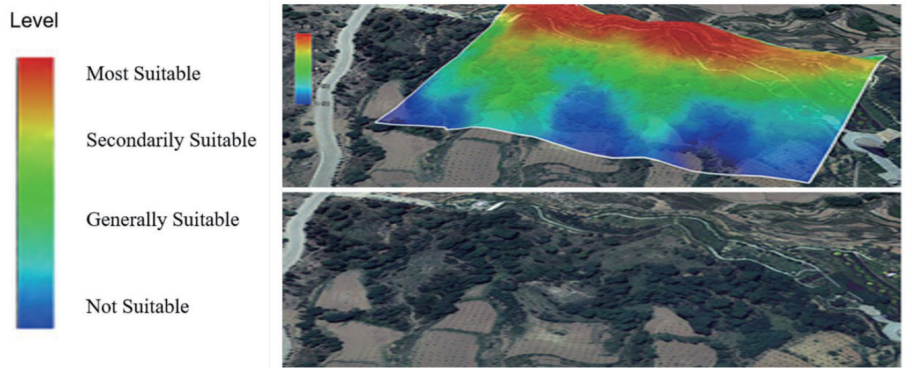

Fig. 3. (Color online) Contrast between original image and suitability analysis results graph.

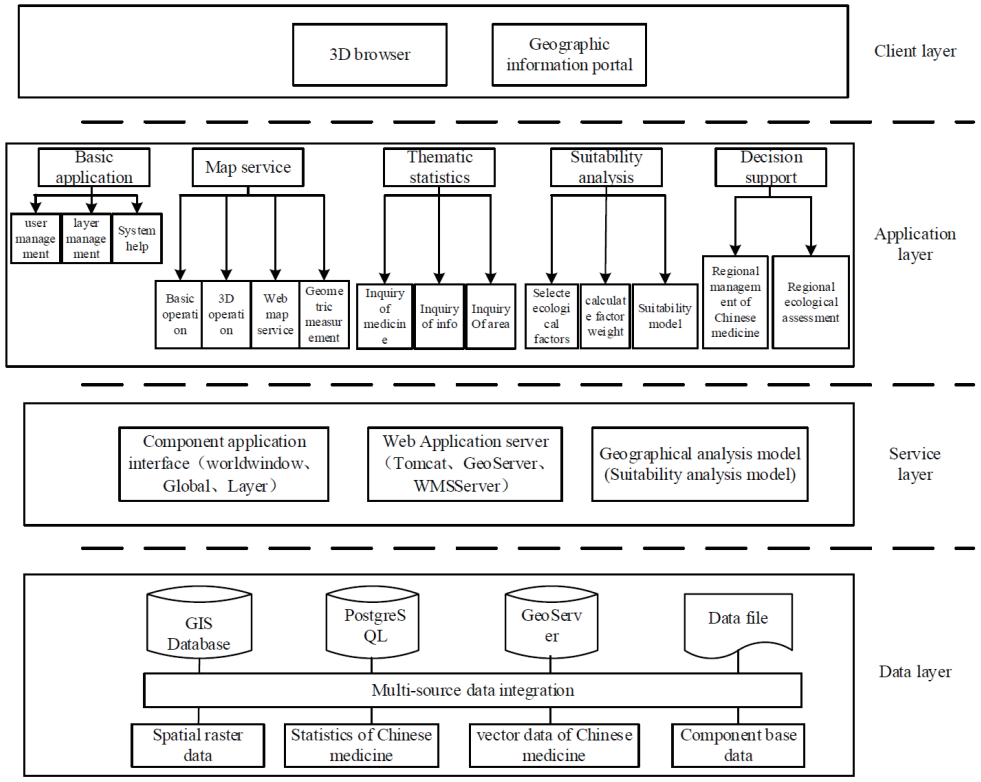

Fig. 4. System architecture diagram.

4.2 System implementation and analysis of results

Using the ecological suitability analysis model constructed in this study, we obtained the quantitative relationships between the suitability of a particular Chinese herbal medicine and various influencing factors. This allowed us to conduct an overall evaluation and grading of the ecological environments in different cultivation zones. When implementing zoning management for Chinese herbal medicine cultivation, the first step is to evaluate candidate areas on the basis of environmental standards for suitability derived from the suitability model. Figure 5 shows the suitability evaluation results for the red-selected area. Figure 6 is used to verify the analysis

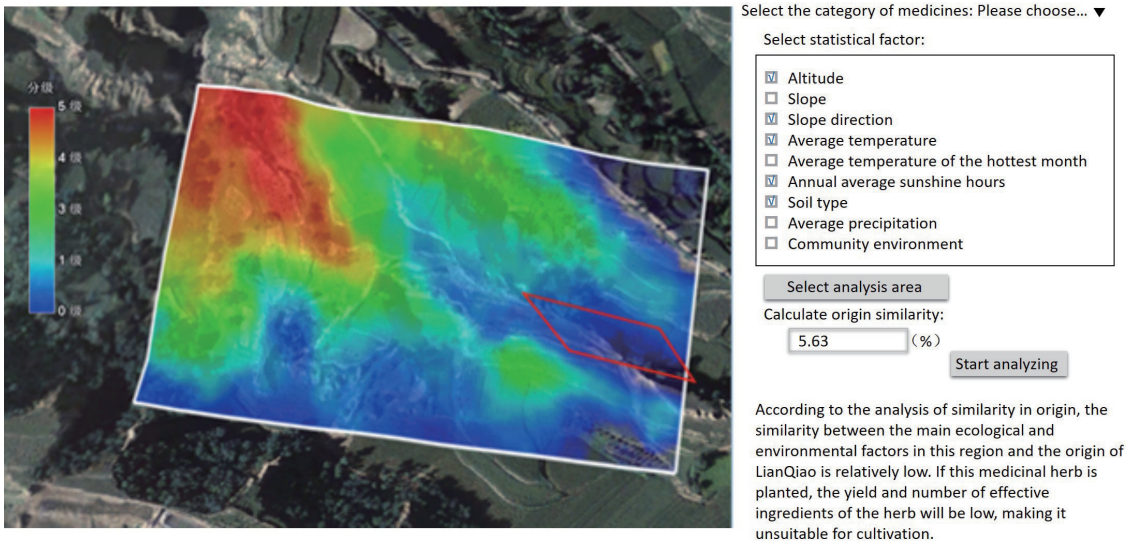

Fig. 5. (Color online) Evaluation for regional planning management.

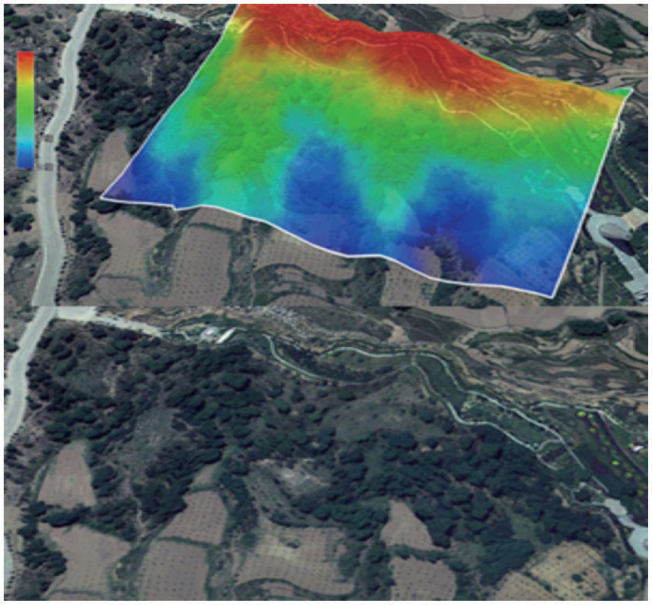

Fig. 6. (Color online) Suitability classification results validation.

results; the top and bottom parts of the figure represent the rendered maps of Chinese herbal medicine growth areas according to different suitability levels and the original images of those areas, respectively. Regions with higher grades have denser growth of medicinal herbs. The comparison shows that the analysis results are largely consistent with the actual situation.

5. Conclusions

Through practical applications of the platform, the feasibility and applicability of the Chinese herbal medicine suitability analysis and evaluation model designed in this study have been validated. By combining GIS technology with methods from fuzzy mathematics, we investigated and analyzed the ecological suitability evaluation of Chinese herbal medicine resources. The evaluation results, after being compared and verified with actual regional data, proved the feasibility of the analytical method and the consistency of the evaluation results with reality.

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