

# Ecological niche suitability model with an application in Taojiang land use planning

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**Abstract**—Ecological suitability analysis is an important step in ecological planning. It applies the basis to establish a sound development planning. In this paper, by applying multi-dimension niche concept, an ecological niche suitability (ENS) model was developed. The ENS model, combined with geographical information system (GIS) and spatial simulation, was used to analyze regional resources and environmental features, and identify the suitability of regional resource and environment to regional development. An application of the ENS model in Taojiang agricultural land use planning is presented.

**Keywords**, ecological suitability, land use planning, GIS.

## 1 Preface

Ecological suitability analysis is an useful way to understand the relation between regional development and regional resource and environment. It can help us to establish an environmental sound regional development planning (McHarg, 1969; Steiner, 1984; Ouyang, 1993a). Since MchHarg developed the overlapping method (McHarg, 1969) to evaluate ecological suitability in ecological planning, there have been many studies on ecological suitability model or quantity evaluation methods (Rowe, 1977; Rose, 1978; Steiner, 1984; McPherson, 1987; Ouyang, 1993b). However, most of these work are quality and limiting factor models. In this paper, in applying multi-dimension niche concept, an ecological niche suitability (ENS) model is developed. The ENS model, combined with geographical information systems (GIS) and spatial simulation, is used to analyze regional resource and environmental features, and identify the suitability of regional resource and environment to regional development. An application of the model in Taojiang agricultural land use planning is presented.

## 2 Methods of land suitability analysis

### 2.1 Ecological niche and resource demand of regional development

Niche was first coined by Grinnell in 1917 to describe the place of an organism in the environment. Grinnell pointed out the California thrasher was dependent on a certain set of physical factors and biotic factors in the environment and that factors together

defined the niche of the species (Grinnell, 1917). Elton placed emphasis on the function of an organism in relation to other organisms; an animal's "place in the biotic environmental conditions" (Elton, 1927). Hutchinson extended the concept as "Super-volume niche", which was defined as an *n*-dimensional hypervolume in the environment. Each dimension represents one kind of essential resource to this niche volume (Hutchinson, 1957). The multi-dimension niche concept can apply a theoretic bases to describe organisms' utilizing resource gradients in their habitats.

In regional development, all kinds of development programs, such as urban extension, transportation line align, certain crop distribution and so on, depend on a certain set of physical factors, resources, social and economic conditions. The resource and environmental requirement build up the multi-dimension "niche" of regional development.

### 2.2 Relation of agricultural activities to regional resources

According to agricultural production processes and their relation to physical environment and resources, the requirement of agriculture on resources can be divided into three types (Fig. 1)

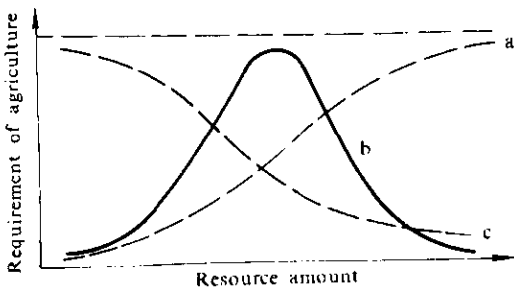


Fig. 1 The relation of the requirement of agriculture to resources

(1) The quality and quantity, or both, of resources must meet the lowest requirement of agriculture, and the richer the resources, the better it is to agriculture (Fig. 1a).

(2) The requirement of agriculture on resources is a kind of scale with low and high limitation in resource gradients. The amount or the quality of the resource below its low limitation or exceed its up limitation will become the limiting factor for the agriculture (Fig. 1b).

(3) The lower the value of the environment, the better it is to agriculture (Fig. 1c).

### 2.3 Land use suitability analysis

In regional development planning, the environmental sound development program is established on the basis of analysis of the capacity of regional resource and environment, and their compatibility to the resource demand of development.

Once the relation between the requirement of agriculture and resources and environment, and the current situation of the resource and physical environment are defined, the following models can be employed to analyse the land suitability.

For type I,

$$X_{ij} = \begin{cases} 0 & \text{when } S_i < D_{ijmin}; \\ \frac{S_i}{D_{ijopt}} R_i & \text{when } D_{imin} \leq S_i \leq D_{ijopt}; \\ R_i & \text{when } S_i > D_{ijopt}. \end{cases} \quad (1)$$

In Equation (1),  $X_{ij}$  is the suitability index of *i* resource or environmental factor to

$j$  agricultural activity,  $S_i$ , the current value of  $i$  resource or environmental factor,  $D_{ijmin}$ ,  $D_{ijopt}$  and  $D_{ijmax}$ , the required lowest, optimized and maximum value of a given agricultural activity to  $i$  resource or environmental factor respectively to  $j$  agricultural activity, and  $R_i$ , the guaranteed index value of the resource and environmental factor above certain value.

For type II,

$$X_i = \begin{cases} 0 & \text{when } S_i < D_{ijmin} \text{ or } S_i > D_{ijmax}; \\ \frac{S_i - D_{ijmin}}{D_{ijopt} - D_{ijmin}} R_i & \text{when } D_{ijmin} \leq S_i \leq D_{ijopt}; \\ \frac{D_{ijmax} - S_i}{D_{ijmax} - D_{ijopt}} R_i & \text{when } D_{ijopt} < S_i < D_{ijmax}. \end{cases} \quad (2)$$

For type III,

$$X_i = \begin{cases} R_i & \text{when } S_i \geq D_{ijmin}; \\ \left(1 - \frac{S_i - D_{ijmin}}{D_{ijmax} - D_{ijmin}}\right) R_i & \text{when } D_{ijmin} < S_i \leq D_{ijmax}; \\ 0 & \text{when } S_i > S_{ijmax}. \end{cases} \quad (3)$$

As agricultural development depends on multi-resources, environmental factors and their combination, it is usually determined by the limiting resource or physical environmental factors. According to Shefold' limiting factor principle, the comprehensive suitability of land can be got by following model.

$$X_j = \left( \prod X_{ij} \right)^{1/n}. \quad (4)$$

In Equation (4),  $X_j$  refers to comprehensive suitability index of resources and environmental factors to  $j$  agricultural activity.

### 3 Taojiang land suitability analysis

#### 3.1 Taojiang physical environment and natural resource

Taojiang County, Hunan Province, China, locates at the geographic transition between Dongding Lake Plain and Xuefeng Mountain. The total area of Taojiang is 2063 square kilometer with 789000 people in 1991, and about 91% of the total population is in the countryside.

##### 3.1.1 Geographical condition

Taojiang is a hilly county. Its topography is very complex with steep slopes. Mountain land is about 27.3% of total area, hilly land about 44.1%, and plain land about 26.4%, and about 3% of watershed.

Zijiang River, one of the four main rivers in Dongding Lake water system with 21.83 billion cubic meter of the stream-off annually, goes through the county. There are three main local rivers, all of them flow into Zijiang River in the country.

In Taojiang, there are seven types of soil, among which, the red soil covers 76.8% of the county. The rice paddy soil, a kind of soil developed by rice cultivation, takes more than 80% cultivated land. About 84.4% of land is loam and clay loam texture. In 96% land, the soil organic matter concentration is less than 3.5%.

### 3. 1. 2 Climate resource and climate features

Taojiang belongs to wet monsoon sub-tropic climate. The total radiation is 102.7 kcal per square centimeter per year. Annual average temperature is 16.6°C, and there are more than 6000°C accumulative temperature. The cold month is January with the average temperature 4.3°C, and absolutely lowest temperature -15.5°C. Both radiation and temperature reach its peak values in July, 17.4 Kcal/cm<sup>2</sup> · a and 28.9°C, respectively. The annual preperception is 1553 mm, April, May and June three months take 42% of total annual rainfall, sometimes one day rainfall is 200—300 mm. In general, Taojiang has rich radiation, temperature and water resources, and most of them distribute from April to October, the season of crop plantation, although they vary with spatial and annual distribution because of the monsoon climate and complex topographic features.

### 3. 1. 3 Vegetation

There are no primary forests in Taojiang. All of the vegetation are either secondary or artificial forests. In Taojiang, there are about  $3.63 \times 10^4$  ha bamboo forest with about 48.5 million bamboo, which is in the first position in Hunan Province and the third in China. Taojiang is one of the main bamboo production counties in China.

### 3. 2 Taojiang land use suitability

Different types of agricultural activities and crop patterns have different basic requirement and different influence and response to ecosystems. A comprehensive ecology based land use suitability analysis must consider both the natural condition and the requirement for rural social development. In the analysis for Taojiang County the multi-dimensional ecological niche suitability model is used to estimate suitability classes for each of five types of potential land developmental plan. These broad categories include citrus fruit orchards, bamboo, tea, tilled crops and forest land. Previously developed land, residential land and area used for commerce or industry are eliminated from consideration for land use development.

#### 3. 2. 1 Citrus land suitability

Citrus is one of the most economically beneficial cash crops produced in Taojiang County. In general the climate in the whole region is adequate to support citrus production. The county has tried over three decades to support peasant-farmers to develop citrus, but it has been forward that due to natural conditions some areas of the county are susceptible to periods of frost. This is especially true for much of the prime agricultural area in the Taohuajiang Valley in eastern Taojiang County where periodic frosts have caused great damage to citrus crops in recent years. The factors influencing land suitability for citrus are local topography, microclimate, slope and present land use. As seen from these results, area near surface water are in general most suitable for citrus. Other suitable areas distribute mainly along the Zijiang River and in the south-eastern basin plain area. The factors, niche suitability matrix (Table 1) and final suitability for citrus development are shown in Fig. 2 and Fig. 3, respectively.

**Table 1 Suitability matrix for citrus**

Factor	Most suitable	Suitable	Unsuitable
Topography	Flat land	Hilly land	Mountainous land
Microclimate	Near surface water	Others	Frost zone (valley)
Slope	0—15%	15%—25%	More than 25%
Current landuse	Others	Not applicable	Built-up areas, water

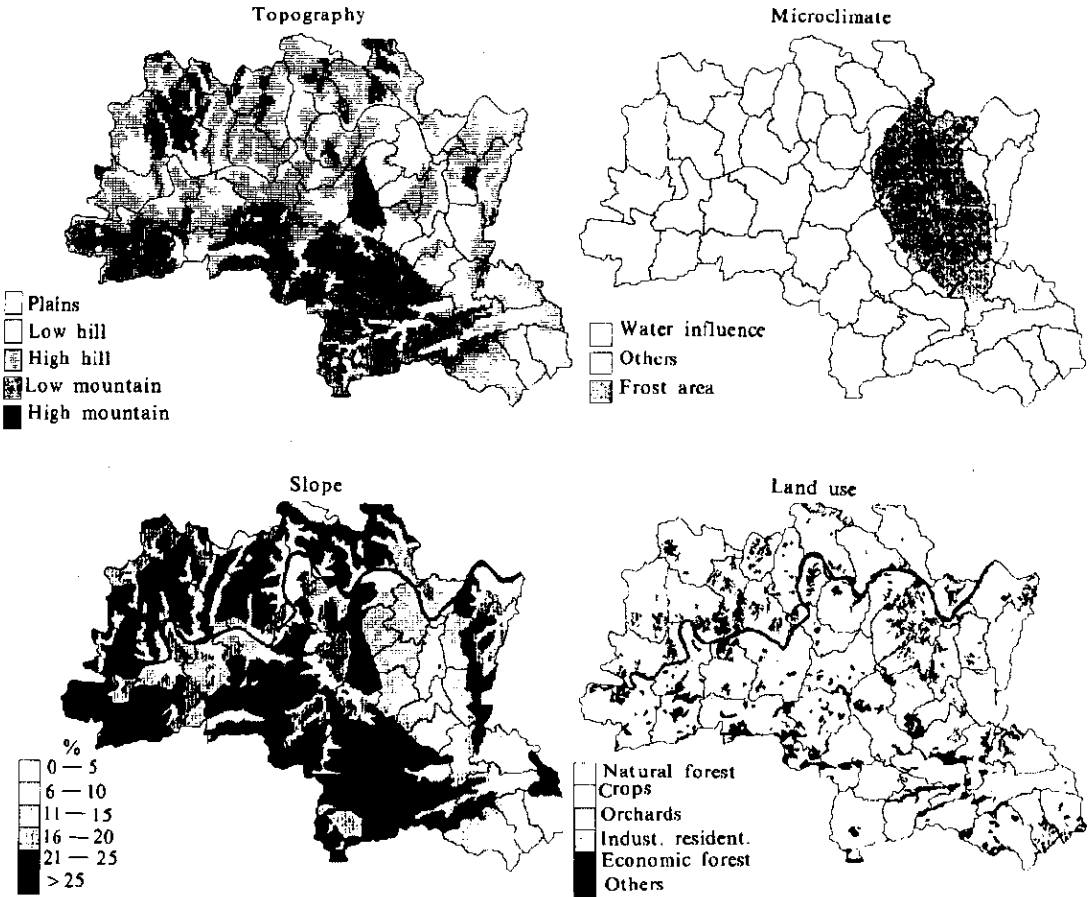


Fig. 2 Base factors for citrus suitability analysis

3. 2. 4 Field crops land suitability

Land suitability for field crops is related to climate conditions, 10 C accumulated temperature, rainfall, soil character (texture and organic matter content), erosion potential, flood risk, draught frequency, and topography. The results of this analysis in-

dicates that about 25300 hectares have the highest suitability for this type of development. The most appropriate land for crop production distribute mainly in the lower valley area south of Zijiang River, adjacent to Taohuajiang River, near some banks of the Zijiang River and in the southeastern part of Taojiang County. Unsuitable areas are in the more mountainous areas, especially in the southwestern part of the country.

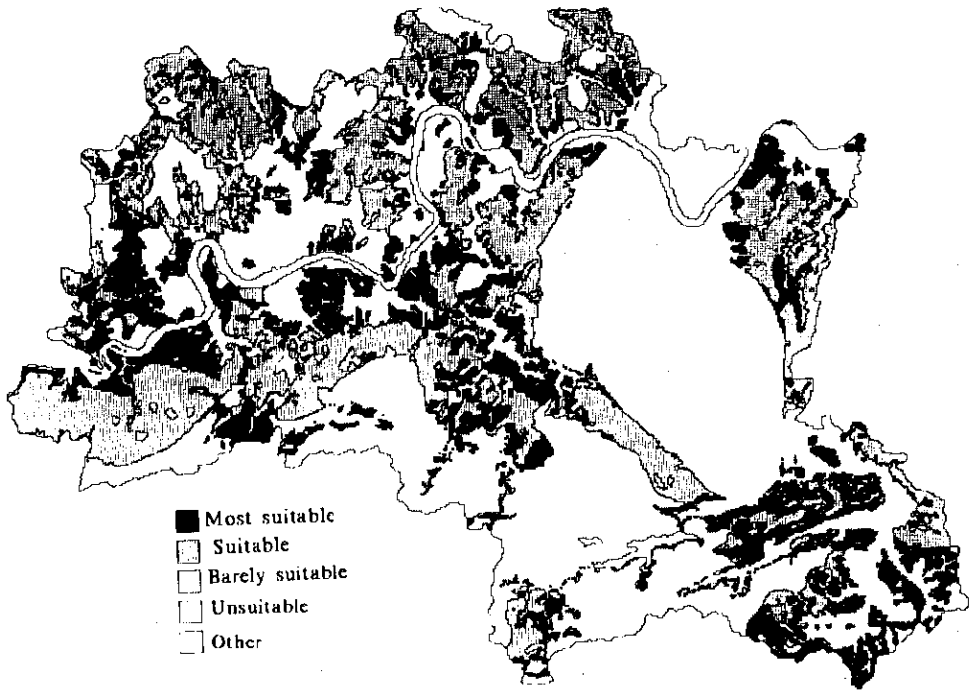


Fig. 3 Taojiang County citrus suitability analysis results

### 3. 2. 2 Bamboo land suitability

Bamboo is one of the renewable resources with large potential and multi-use in Taojiang County. The overall climate conditions everywhere in Taojiang are very suitable for bamboo, so its development is mainly determined by the soil parent material and present land use, as well as transportation facility, if development of commercial bamboo forests is to be decided. Results of the niche suitability analysis indicate that 94000 hectares are suitable for bamboo, of which 32000 hectares are in the "most suitable" category. The area most preferable for economic development of bamboo are in towns and villages of Songmutan, Shaoshan, Sanguanqiao, Wutan and Luojiaping, these areas, generally, have good physical conditions and transportation facilities.

### 3. 2. 3 Tea land suitability

Tea is one of the most important labor-intensive cash crops in Taojiang County. Its production depends mainly upon the relation humidity, soil texture, topography, distance from population bases and present land use. The results show that about 53000 hectares are suitable of which only about 8000 hectares are of the most suitable category for tea production.

### 3.2.5 Forest land suitability

The main factors used to determine the suitability of land for forests in Taojiang include topography, soil type and present land use. Since farmland in the county is in short supply, slopes of less than 20% gradient are not considered for forestry development. Results of this analysis show about 123000 hectares (approximately 59% of the total area of the county) are suitable for forests. About 62000 hectares of this land is considered to be in the "most suitable" category and potentially suitable for economic forestry development. The areas which should be considered for this purpose should be closed to local population centers and on less sloped land (in order to avoid erosion damage). Forestry for lumber should be carefully managed by the local government in order to assure that methods are in accordance with principles of sustainability.

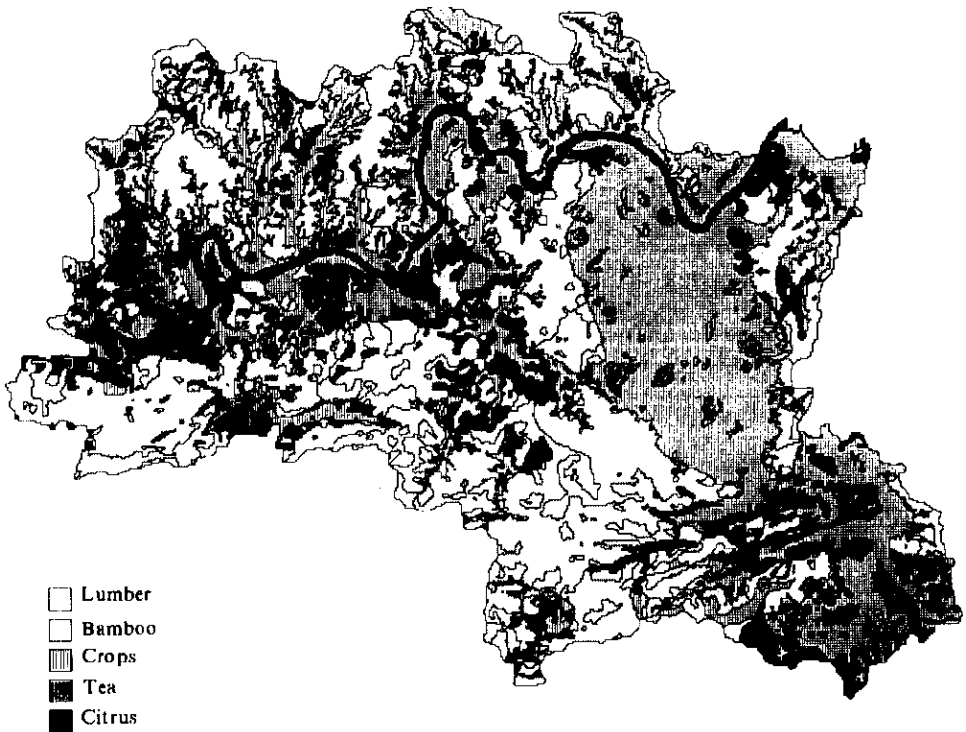


Fig. 4 Taojiang County agricultural suitability analysis results

### 3.2.6 Overall land suitability distribution

A comprehensive land suitability plan was made on the basis of the individual suitabilities as shown above along with economic and social benefits of each type of land use (Fig. 4). Results illustrated show that (i) most of the high quality land are assigned to field crops, which are mainly food crops such as rice, for the sake of food safety, (ii) both for land suitability and economic benefit, bamboo can contribute a main role in Taojiang forest industry, and (iii) some land with steep slope and sensitive to erosion is suitable only for forest or protected area.

## 4 Conclusion

In this paper, a land use suitability model based on niche concept is developed and applied in agricultural land use planning in Taojiang. The results show that applying ecological knowledge and methods, and spatial simulation technique (by aids of GIS) in regional development planning will ensure regional sustainability. It will be a trend in ecological planning.

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