

Fruit tree suitability assessment using GIS and multi-criteria evaluation

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Abstract The application of a Multi-Criteria Evaluation (MCE) approach to identify suitable areas for the production of banana, lichee and longan in Southeast of Fujian Province in China was presented. Climate, terrain and soil databases were used to integrate GIS coverage. Because of the varied topography of Fujian Province, the yearly average temperature and minimum temperature were modeled through Digital Elevation Model (DEM) for the whole region. The evaluation factors of slope, aspect were derived from DEM through ARCGIS 3 software. Relevant criteria for this fruit trees and suitability levels were defined. This information was used to obtain the criterion maps, which in turn were used as input into the MCE algorithm. Suitability evaluation result map was produced using weighted linear combination and AHP method programmed by ESRI software Arcobjects and Visual Basic language. Land use/cover map and distribution map of fruit trees of 2001 were gained using ERDAS Image 8.5 software by means of a supervised classification from Landsat TM images. These land use/cover and the suitability maps were crossed to identify differences and similarities between the present land-use and the suitable areas for banana, lichee and longan.

Key words: fruit tree suitability evaluation; multi-criteria evaluation; Digital Elevation Model; GIS

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0 Introduction

Under the pressure of ever-increasing population, resources shortages, and degradation of ecological environment, it was an essential trend to scientifically and reasonably exploit the mountainous areas. Fujian Province is a mountainous area. The problem of selecting the appropriate land for the cultivation of a certain agricultural product is a long-standing and mainly empirical issue. The increased need for high-quality food production and the shortage of resources stimulate a need for sophisticated methods of land evaluation to decision makers in their roles to both preserve highly suitable lands and satisfy producers' demands for increased profits.

Geographic Information System (GIS) has universally been used for land suitability evaluation of multiple crops and fruit trees^[1-3]. In the process of land suitability evaluation, many variables are involved and each one should be weighted according to their relative importance on the optimal growth

conditions for the specific land-use. The issue was expressed as multi-criteria decision problem because several criteria should be evaluated. Multi-criteria decision-making could be understood as a world of concepts, approaches, models and methods that aid an evaluation according to several criteria. The main purpose of the Multi-Criteria Evaluation (MCE) techniques is to investigate a number of alternatives in the light of multiple criteria and conflicting objectives^[4]. Researches show that the integration of analytic techniques designed to work with MCE problems within GIS could give more functionality to the user^[5] and it is a powerful approach to land suitability assessments^[6].

Some researches have been conducted using MCE-GIS combined method in selecting disposal sites for natural hazards^[7], habitat suitability modeling^[8,9] and geo-environmental evaluation for urban land-use planning^[10], etc. However, MCE-GIS integration has not been utilized in China to solve problems related to specific agricultural topics, such as in the case of identifying suitable areas for specific fruits. The suitability evaluation of fruit trees in the southern mountainous areas of Fujian Province was conducted based on DEM and GIS using a multi-criteria evaluation (MCE) approach.

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2 Method

2.1 Study area

Zhangzhou region, is located between latitude 23° 01' N and 25° 13' N and longitude 116° 53' E and 118° 09' E, the southern part of Fujian Province, southeast of China. This area includes nine counties and two boroughs. The total area of Zhangzhou region is approximately 12897 km². The climate is characterized as south semi-tropic zone. The yearly average temperature is 21 °C. The frost-free time is 318~349 days per year. The yearly average sunlight is over 2000 hours. The yearly average precipitation is about 1500 mm.

The general procedure followed in this study can be outlined as follows: 1) Obtaining and preparing databases, including interpolation of climate point data and its adjustment; 2) Digital processing of the Landsat TM image; 3) Integrating land suitability assessment results and Landsat TM land use information.

2.2 Database

The evaluation factors databases include climate database, soil database and terrain database. Climate information was obtained from 16 meteorological stations located within and close to the study area. The number of recorded years was from 1972 to 2002. The maps were constructed by means of a distance-weighted average interpolation procedure within ArcGIS 8.3 software. Since latitude and elevation were the important factors affecting the average temperature of large region, Equation 1 was used to simulate the yearly average temperature and minimum temperature. The yearly average temperature and minimum temperature of each raster could be calculated with 1:50000 scale DEM.

$$Y = a * x / 100 + y_1 \quad (1)$$

Where Y is the simulated results of the yearly average temperature and yearly minimum temperature; x is the elevation, m; y_1 is the original interpolated the yearly average temperature and yearly minimum temperature; the content "a" is an empirical parameter, -0.55 referred from some local observed meteorological data. Soil database was obtained from the digitized map of the soil maps such as soil type map, soil organic content. Terrain database, such as the slope and aspect information, was obtained from the Digital Elevation Model (DEM) using ArcGIS 8.3 software. The ecological requirements database of fruit trees was constructed. According to the analysis and the superiority of Zhangzhou region, three types of fruit trees were chosen, namely banana, lichee and

longan. Understanding the ecological requirements of different biological resources was helpful to exploit the superiority of the local biological resources.

2.3 Image processing

Remotely sensed data for this study were Landsat TM images in the autumn of 1998, 2001, corresponding to scene No. 119-043, 120-043 and 120-044. First, these images were geometric corrected using 1:10000 scale digital topographical maps. Since the interpreted land use/cover map of 1998 has been obtained from China CASW data technology corporations, the land use/cover map of 2001 can be obtained through its updating. The change area was detected by contrast of the two years' Landsat TM images. Supervised classification of land use was conducted only on the changed areas. Some fieldwork was conducted to get the training set selection. A system of land use classification was established in which land use was grouped into six categories (paddy field, dry land, woodland, lawn, water body, building land and unused land). Supervised classification with a maximum likelihood algorithm available in ERDAS 8.4 was used. The training polygons were digitized based on GPS data and distributed throughout the study areas. The pixels in the polygons that were selected as representative of each class were plotted in spectral space and a visual check that all classes could be separated in at least one combination of bands. The distribution map of several kinds of fruit tree map was interpreted from Landsat TM image of 2001 following similar procedures, except that it did not require the change detection and was conducted on the whole study area.

2.4 Multi-criteria evaluation

The general procedure of MCE includes several phases. First, the decision making problem was identified and the relevant criteria (factors and constraints)^[10] were established. Factors established in this phase are not unique, but they are the most relevant. Suitability levels for each of the factors were defined. The levels were: 1 (very suitable), 2 (suitable), 3 (moderate suitable), 4 (not suitable). According to the experts' opinion and the bibliography revision, a specific suitability level per factor for banana, lichee and longan were defined (Tables 1, 2, 3). Factor maps were then constructed for banana, lichee and longan fruit. Constraint maps including building land, water bodies were also made.

Then a matrix pairwise comparison was made. One of the most prevalent procedure for MCE is the

Table 1 Specific suitability level per factor for banana

Factor	Most suitable	Suitable	Moderate suitable	Not suitable
Yearly average temperature/ Precipitation/mm	24~ 32 > 2400	15. 5~ 24. 0 or 32~ 35 1800~ 2400	10~ 15. 5 or 35~ 40 1200~ 1800	> 40 or < 10 < 1200
Extremely cold temperature/ Soil organic content/g · kg ⁻¹	> - 2 > 30	- 3~ - 2 20~ 30	- 5~ - 3 5~ 20	< - 5 < 5
Soil texture class Soil pH value	Loam 6. 5~ 7. 5	Sandy loam 4. 5~ 6. 5 or 6. 5~ 7. 5	Clay 7. 5~ 8. 0 or 3. 5~ 4. 5	Other class < 3. 5

Table 2 Specific suitability level per factor for lichee

Factor	Most suitable	Suitable	Moderate suitable	Not suitable
Yearly average temperature/ Yearly 10 accumulated temperature/ A verage temperature of coldest month/ Extremely cold temperature/ Precipitation/mm	21~ 23 7500~ 8300 13~ 17 > - 1 1600~ 2000	23~ 25 or 19~ 21 6500~ 7500 10~ 13 - 2~ - 1 1300~ 1600	25~ 30 or 14~ 19 6000~ 6500 8~ 10 - 4~ - 2 1000~ 1300	> 30 or < 14 < 6000 < 8 < - 4 < 1000
Soil organic content/g · kg ⁻¹ Soil pH value	> 30 5. 0~ 6. 5	20~ 30 4. 5~ 5. 0 or 6. 5~ 7. 0	5~ 20 7. 0~ 8. 0 or 3. 5~ 4. 5	< 5 < 3. 5

Table 3 Specific suitability level per factor for longan

Factor	Most suitable	Suitable	Moderate suitable	Not suitable
Yearly average temperature/ Yearly 10 accumulated temperature/ Extremely low temperature/ Precipitation/mm	20~ 23 7000~ 8000 > - 2 > 1500	23~ 25 or 18~ 20 6500~ 7000 - 2~ - 3 1200~ 1500	25~ 30 or 13~ 18 6000~ 6500 - 3~ - 5 1000~ 1200	> 30 or < 13 < 6000 < - 5 < 1000
Soil organic content/g · kg ⁻¹ Soil pH value	> 30 5. 0~ 6. 5	20~ 30 4. 5~ 5. 0 or 6. 5~ 7. 0	5~ 20 7. 0~ 8. 0 or 3. 5~ 4. 5	< 5 < 3. 5 or > 8. 0

weighted linear combination^[11] and the most promising technique is the pairwise comparison developed by Saaty (1977)^[12] in the context of a decisionmaking process known as the Analytical Hierarchy Process (AHP). In this study, factors were rated according to the opinion of fruit experts from the Zhangzhou Agricultural Bureau. The principal eigenvector of the pairwise comparison matrix was computed to produce a best fit to the weight set. The Consistency Ratio of the matrix was calculated and 0.10 or less is acceptable^[13]. Using weighted linear combination (WLC)^[11] with the GIS data layers, a final suitability evaluation result map can be produced through multiplying each criterion by the corresponding weight and then summing these products over all the criteria. The process of AHP and MCE was realized through ESRI software ArcObjects^[14] and Visual Basic programming.

3 Results

3.1 Image processing results

The land use/cover map of 2001 from Landsat TM image is shown in Fig. 1 and the distribution map of fruit trees is shown in Fig. 2. It can be seen from Fig. 1 that most land use type in Zhangzhou region is

woodland, fallow lawn, paddy field, dry land and building land. As it can be seen from Fig. 2 that the banana tree mainly distributed along the Xiangcheng borough, Tianbao and Pinghe county and the lichee and longan tree distributed along the Jiuhu, Zhangpu, Xunxiao, Zhaoan.

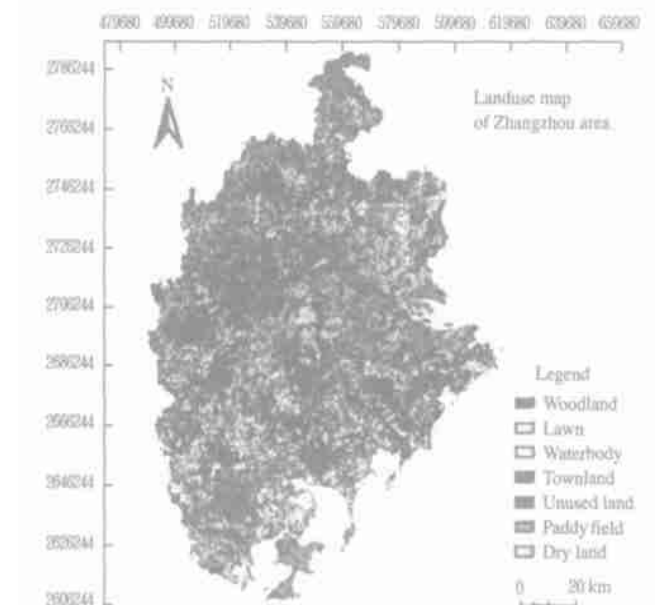


Fig. 1 Land use map from the classification of Landsat TM images

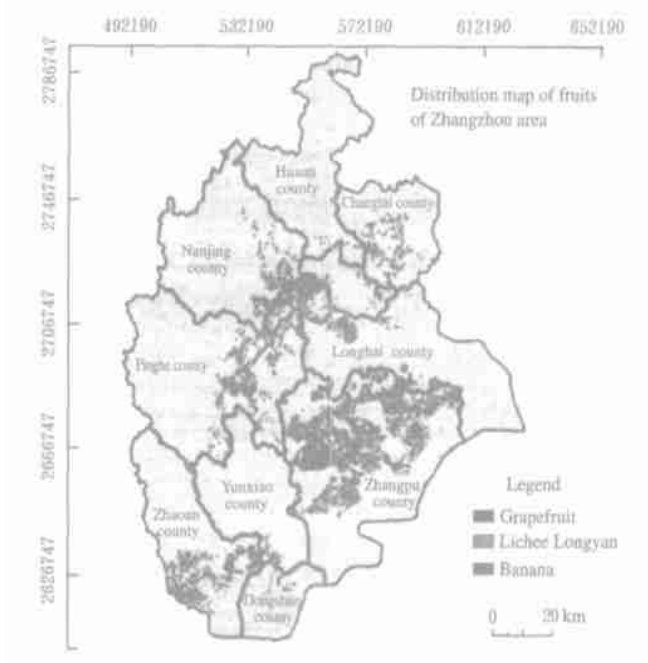


Fig 2 Distribution map of several kinds of fruits

suitability of these several kinds of fruits

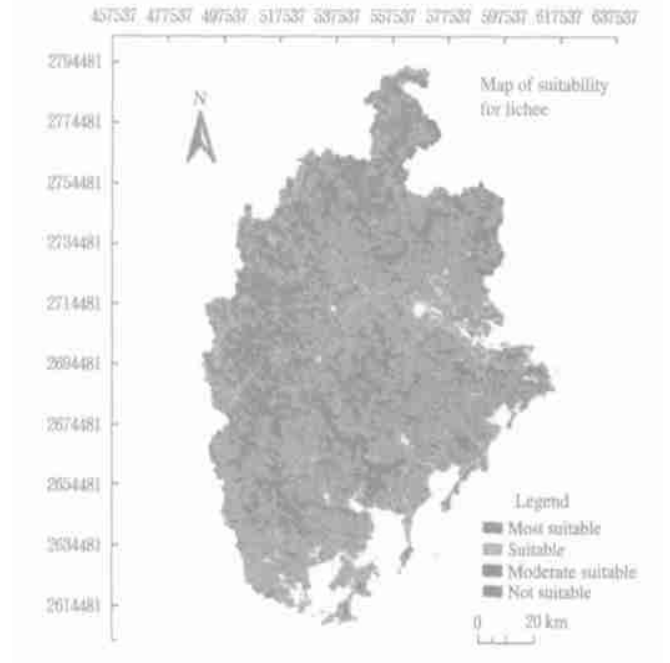


Fig 4 Map of suitability for lichee

3.2 MCE process and overlaying land use/cover and suitability maps for several kinds of fruits

The suitability maps of banana, lichee and longan were obtained through MCE- GIS method. The maps were shown in Fig 3 to Fig 5.

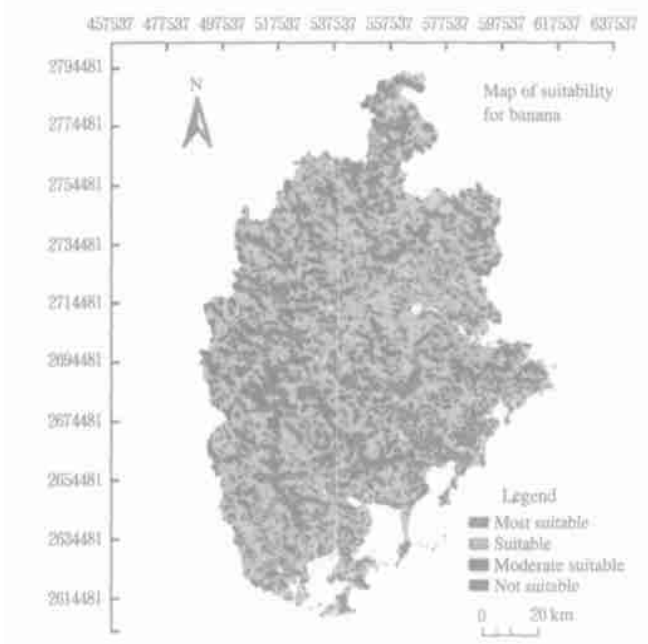


Fig 3 Map of suitability for banana

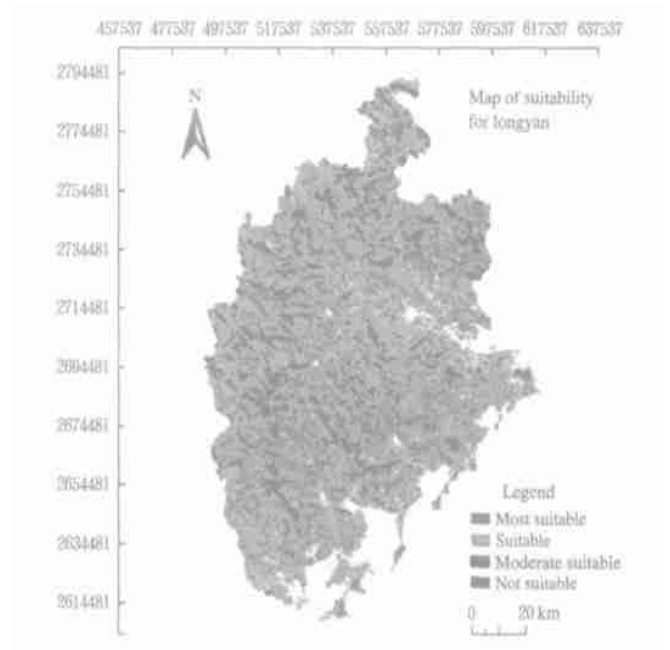


Fig 5 Map of suitability for longan

Analyzing the crossed suitability of banana and land use/cover maps indicated that suitable area was principally located in forestland and paddy field (Table 1). The suitable area was mostly located in the current forest, paddy field and meadow. Mostly very suitable, suitable areas have not been cultivated with banana when compared with the distribution map of fruits.

Table 4 Result of crossed land use/cover map and the suitability map for the banana

Land use type	Not suitable /%	Moderate Suitable/%	Suitable /%	Very suitable /%
Paddy field	0.00	0.96	11.19	2.97
Dry land	0.00	0.92	6.44	1.56
Forest	0.01	14.23	36.51	5.74
Meadow	0.01	3.26	13.38	2.71
Unused land	0.00	0	0.07	0.02

4 Conclusion

1) MCE method was adequate to integrate databases required for different kinds of fruit trees in a GIS context and useful to determine where was suitable to develop.

2) On the basis of DEM and the meteorological statistics data, the yearly average temperature and minimum temperature were simulated through spline interpolation method. It is important for suitability evaluation of mountainous land resources.

3) Remotely sensed data were crucial to obtain land use/cover map. Crossing of land use/cover map and suitability map can identify differences and similarities between the present land use and the suitable areas for specific fruit trees.

4) Suitability evaluation results show that most areas of Zhangzhou are very suitable or suitable for banana, lichee and longan. The current plantations of these fruit trees are mostly located in most suitable, or suitable areas. But there are still many areas that are most suitable, or suitable for these fruits have not been cultivated with these fruit trees.

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基于 GIS 和多目标评价方法的果树适宜性评价

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摘要: 漳州地区是福建省乃至全国有名的水果之乡, 地貌复杂, 自然资源与生态环境差异显著。为了科学合理地利用自然资源, 对该地区进行果树适宜性综合评价, 分析其种植现状与利用潜力, 提供科学决策依据。首先建立研究区域内土壤、气候与地形等数据库, 并利用地形对气候分布状况进行校正, 同时通过 Landsat TM 遥感影像的分析解译得到研究区域内的土地利用现状分布图和主要果树种植分布图, 在此基础上采用 GIS 和多目标评价 (MCE) 方法对漳州地区三种主要果树 (香蕉、荔枝和龙眼) 进行适宜性评价, 最后综合分析这些果树适宜分布现状与利用潜力。研究结果表明, 漳州地区大部分区域都非常适宜种植这三种水果, 发展水果生产潜力较大。
关键词: 果树适宜性评价; 多目标评价; 数字高程模型; 地理信息系统 (GIS)