Evaluation of land suitability for coffee plants based on fuzzy logic in Enrekang district

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Abstract. Ecological perspective is important in agriculture, because sustainable agriculture is based on cultivation practices that do not deviate from natural systems. In an ecological perspective, agriculture is based on differences in climate, soil properties, soil morphology that requires different management and processing of agriculture between regions. Research was conducted in Enrekang district with reference to 18 Land systems. This study aimed to assess the land suitability for coffee plants based on geographic information systems using a fuzzy logic approach. Primary data as evaluation criteria were divided into three main components; for potential land erosion, potential flooding and soil profile. Land cover was considered as well. In fuzzy analysis, the value of land attributes was converted to sustainable values (ranging from 0 to 1.0) according the class limits determined based on experience and standard conventional. There was distribution of land suitability for coffee plants in Enrekang district. 65% of the area had the potential to develop coffee plants. The main limiting factor in the development of coffee plants in the study area was the erosion potential, especially the slope.

I. Introduction

Land degradation and decline in agricultural productivity are a serious threat to agriculture. Along with increasing population, environmental sustainability becomes a very important issue in order to maintain environmental and social balance. The prerequisite for land use planning is land suitability assessment [1]. Land suitability evaluation is the key and the first step in designing a sustainable land use and management system. Evaluation of land suitability can play a role in a better land management, mitigating land quality reduction and designing land use patterns which optimize the prevention of environmental catastrophe. Land suitability evaluation is carried out to reverse the negative nature of the environment on arable land. The characteristics of a land with other land are not the same, so that the compatibility between one and another land should be different. At present, land under pressure from the use of various sectors, a lot of land use is forced to change from its nature to critical land [2–4]. 41.3% of the world's land is critical land status while 34.7% of the world's population occupies it and the only about 11% have quality for environmental development and food production [5,6]. According to FAO (1990) that it is very important to cultivate a land unit in accordance with its environmental characteristics. Land evaluation is the process of estimating land potential for alternative uses. For efficiency, plan agricultural areas require the variety of spatial
information [7]. Spatial analysis can be interpreted as techniques used to examine and explore data from a spatial perspective. All mathematical calculation techniques or approaches related to spatial data are performed with the spatial analysis function. In GIS data processing, spatial analysis can be used to provide solutions to spatial problems. Geographic Information Systems (GIS) are useful for analyzing some geo-spatial data with higher flexibility and precision. The use of graphical information systems (GIS) and the Multi criteria decision making approach can help in understanding the key elements and in developing and improving resource management strategies which is very important to ensure the sustainability of an area [8].

In agriculture, land suitability assessments make it possible to identify the main limiting factors production and enable decision making to develop crop management which can be improved land productivity [9]. In this study, an analysis was conducted to assess the suitability of coffee plantations. Coffee (Coffea) is one of the leading plantation commodities in Enrekang district but data needed to evaluate estimation of land suitability and productivity for plants is not always available, impacting to some difficulties of some planners in mapping potential areas for coffee development purpose.

To date, some researchers, research institutes, organizations and governments have tried to provide comprehensive procedures for evaluating optimal agricultural land use, but it is difficult to balance competing problems systematically [10]. There are many methods in assessing land suitability using a spatial analysis approach such as logika bolean, logika fuzzy, markovian theory, rule-based modelling, and others. Fuzzy logic is a continuous membership function. In contrast to evaluations using conventional methods, the fuzzy approach organizes criteria in the membership function continuously to adjust the suitability factor into decision making, also a fuzzy approach can increase the accuracy of the evaluation system [11]. To date there have been many studies on land suitability assessments using fuzzy approaches such as; Using Fuzzy-AHP and order weight average (OWA) methods for land suitability determination for citrus cultivation in ArcGIS [12], Fuzzy inference system for site suitability evaluation of water harvesting structures in rainfed regions [13], and others, which is the core of their research results that the Fuzzy Interface System produces land suitability maps that can be used in appropriate decision making for environmental management. The use of fuzzy set theory is based on the thought of the need for a solution to the value of member numbers or membership values (MF) which are not only oriented to true or false [14]. Fuzzy functions can analyze the characteristics of sustainable soils without categorizing them into different classes. Fuzzy subsets are defined by MF which defines the membership value of fuzzy objects or phenomena in sequential pairs, consisting of objects and their membership values. The MF of the fuzzy subset determines the level of membership x in a [15]. The fuzzy inference system mainly includes four important parts: the basic rules, the fuzzifier, the inference engine, and the defuzzifier [6].

In this study, the use of a fuzzy approach to assess land suitability and assist in the decision making related to coffee land planning in the study area was conducted. Several soil, climate and topographic parameters were input material for decision making.

2. Materials and Methods

Land evaluation methods have been widely adopted by soil scientists in the prediction of land potential from various angles of interest. Land evaluation is a process to determine the suitability of a particular land use [16]. Land evaluation is an attempt to assess or interpret the performance of a land when it is used for a use to present a rational basis or framework in making appropriate land use decisions and is based on the relationship between land use requirements and the characteristics of the land itself and provides estimates of the necessary inputs and expected output projection.

This research utilized a spatial approach with sustainable methods to produce land suitability. Land evaluation in this study included soil quality, topography and climate. Soil quality was the physical and chemical nature of the soil in the form of soil depth, carbon organic, soil texture, CEC, base saturation, Sum of base cation, Ph H₂O, drainage and flooding. Material in this study can be seen in table 1.
Table 1. Variable and land quality for coffee used in the analysis

| Material          | Optimal (S1) | S1          | S2          | Marginal (S3) | N1          | N2          |
|-------------------|--------------|-------------|-------------|---------------|-------------|-------------|
| Ranking           | 1            | 2           | 3           | 4             | 5           | 6           |
| Precipitation     | 1500-1600    | 1600-1800   | 1800-2000   | >2000         |             |             |
| Topography        | 0-4          | 4-8         | 8-16        | 16-30         |             |             |
| Texture           | Silty clay Loam, Clay loam, Clay | Sandy Clay Loam | Sandy Clay Loam | Sandy loam, Loam | Fine sand | Massive silty clay, massive clay, loam sand |
| Soil Depth        | >200         | 200-150     | 150-100     | 100-50        |             |             |
| CEC               | >24          | 24-16       |             | <16           |             |             |
| Base saturation   | >80          | 80-50       | 50-35       | 35-20         | <20         |             |
| Sum of base cation| >6.5         | 6.5-5.4     | 4-2.8       | 2.8-1.6       | <1.6        |             |
| Ph H₂O            | 6.5-5.8      | 5.8-5.6     | 5.6-5.4     | 5.4-5.2       | <5.2        |             |
| C Organic         | 2.4          | 2.4-1.2     | 1.2-1.8     | <0.8          |             |             |
| Flooding          | Fo           | Fo          | Fo          |               |             |             |
| Drainage          | Good, Groundwa>150 | Good  | Groundwa<15 | Moderate | Imperf | Poor but drainage | Poor but not drainage |

Land Use

2.1. Area Study
Anggeraja is one of the sub-districts in Enrekang district. There are 3 land systems in this study area. rainfall in this region is relatively high ranging from 1750 to 2250 mm per year. Over 50% of land use in Anggeraja areas are fields and 20% of shrubs and the remainder as forests are also settlements. Most of the population are horticultural farmers like shallots. The research location can be seen in figure 1.

Figure 1. Area Study, Anggeraja Enrekang district South Sulawesi.
2.2. Data collection and selection variable
In land suitability analysis, soil sampling was based on a land system map which can be seen in figure 2. The land system becomes the basis for taking soil quality such as texture, effective depth of soil, organic carbon, CEC, basic saturation, Ph H2O, Sum of base cation, drainage and flood hazard.

The data used in this study consisted of biophysical data, both primary and secondary. For biophysical data, data collection was conducted by a field survey and soil sampling was used a land system reference. The Enrekang regency land system especially in the Anggeraja sub-district consists of 4 which can be seen in figure 2.

2.3. Land suitability assessment using fuzzy approach.
Slope, soil quality and climate are the main points in this study. Soil quality consists of several factors as explained above, while climate and slope are the sole factors in explaining climatology and topography in this study. the analysis phases in research were:

a. Calculate the membership of each parameter to be assessed.

\[ MF (x_i) = \frac{1}{1 + \left( \frac{(x_i - b)}{d} \right)^2} \] if \( 0 < MF (x_i) < 1 \) …………(1)

Where \( MF (x_i) \) = membership function of each soil characteristic \( x \) which is I, \( d \) = width of the transition zone (ie \( x \) in \( MF = 0.5 \)), \( x_i \) = value of \( x \) to I, and \( b \) = ideal value for soil characteristics \( x \).

In this study sampling based on land systems, and each land system consists of several layers of horizon, so as to calculate the MF quality of land for each land system, with the formula:

\[ \mu_i = \left( \sum_{j=1}^{m} MF (x_i) \right) / m \] ………………… (2)

Where, \( \mu_i \) is MF value of soil attribute \( i \) on the land system. \( MF (x_i) \) is the soil attribute value of each layer. \( m \) is the number of land horizons considered.

b. Calculate the Joined Membership Function on value.
For soil quality in each land system, the JMF value was calculated by:
\[ JMF (LS) = \sum_{i=1}^{n} \pi i(\mu i) \]  

(3)

\( JMF (LS) \) is a joint membership function for all land attributes in a land system. \( \Pi \) is weight factor, \( \mu \) is the average value of soil MF i on each land system. The combination of land attribute values (soil quality, topography and slope) is calculated by formula:

\[ JMF (X) = \sum_{i=1}^{n} \pi i \cdot MF (xi) \]  

(4)

\( JMF (LS) \) is a joint membership function for all suitability analysis. \( \Pi \) is weight factor, MF is Membership value of each land suitability analysis variable.

c. calculate the land suitability index with Formula:

\[ LSI = JMF (S) \times JMF (T) \times JMF (C) \]  

(5)

To calculating the MF value, refer to the fuzzy set model theory as in the following figure.

![Figure 3. Curves in fuzzy theory: upper left corner (optimum model), lower left corner (bigger is better), lower right angle (smaller is better), adopted by [17].](image)

3. Results and discussion

3.1. Soil quality of the study area

Description of the quality of the soil in the study area is shown in figure 4. The quality of the soil found was in the form of texture, CEC, effective depth of soil, \( Ph \) \( H_2O \), basic saturation, Sum of base cation. In the lowest Organic C, there were land quality at S2 level, soil depth, texture, CEC and sum of base cation. In organic carbon, \( Ph \) \( H_2O \) and base saturation were the lowest quality land at S3 level. In a glance, the best quality land was shown in Kalung land system. Selection variable commenced with literature review to identify agroecological variables that influence coffee cultivation. In the literature review, crop requirement land evaluation was followed to Sys et al. (1993). Climate and soil characteristic consist of mean annual temperature, annual mean precipitation, dry season length, \( pH \) in \( H_2O \), soil organic carbon, bulk density, sum of base cation, soil texture and slope. Research on the geological-geography conditions for coffee plants was conducted [18,19], [20]. From these variables, we will further develop land suitability levels from optimal land to unsuitable land. Soil organic matter
is indirect effect for coffee plants [7]. Texture and depth of the soil affect to soil properties and plant fertility and productivity [7]. Unlike texture, the chemical properties of soils such as CEC, Ph H₂O and sum of base cation can be modified in the adoption of agricultural practices. However, the slope is not always linear with the level of erosion in an area [22].

| Parameter                  | Unit | Value     | Value |
|----------------------------|------|-----------|-------|
| Soil pH                    |      | >6.5      | <15   |
| Soil depth                 | cm   | >200      | <50   |
| Sum of B C U               |      | >6.5-5.4  | <1.6  |
| Base Saturation U          |      | >200-150  | 150-100|
| CL, SC, L, S               |      | >0.8      | <0.8  |
| CEC U                     |      | >24       | <20   |
| CEC B                     |      | >24       | <20   |
| C organic U               |      | >80       | <20   |
| C organic B               |      | >24       | <20   |
| Soils depth               | cm   | >200      | <50   |
| Sum of B C U              |      | >6.5-5.4  | <1.6  |
| Base Saturation B         |      | >200-150  | 150-100|
| CL, SC, L, S              |      | >0.8      | <0.8  |
| CEC U                    |      | >24       | <20   |
| CEC B                    |      | >24       | <20   |

Figure 4. Soil quality in area study.

3.2. Parameter used in this research

An important step in evaluating land suitability using the fuzzy approach is to determine the optimum value (d), as well as the marginal limits (UCP and LCP) of plant growth conditions. The b value of each parameter used is determined based on the optimal level (limiting degree = 0), while the UCP and LCP values are the marginal class values of each parameter based on plant growth requirements. The difference between the optimum and marginal values refers to as the transition zone (d). Optimum value (b), marginal values (UCP and LCP) and transition values (d) in Table 2 based on the evaluation criteria in Table 1.

The weight was used to assess the quality of land in each unit of land. Soil depth and texture were given the highest weight, then drainage and flooding conditions. The lowest weights were given for CEC, Ph H₂O, basic saturation, C organic and the number of bases. The weight indicated to each land suitability variable, where soil was the most important factor, then climate and topography. The structure and permeability of the soil affect the ability of the soil to collect or escape water [10]. Soil depth is important factor in this research. According to [23, 24], Soil depth was the most important characteristic of soil and was one of the main considerations in evaluating soil quality. Depth of land was important for activities such as irrigation planning hydrological modeling, estimating soil also estimation carbon stock. C organic, CEC, Base saturation, Sum of base cation, and Ph H₂O was a chemical property of soil that can be modified. Soil pH played a role in the availability of nutrients,
growth and productivity of plants. pH provides nutritional information and phyto-toxicity and land suitability for specific plants.

Table 2. Control point and weight used in this research

| Variable          | Material | LCP | b   | UCP | d   | Model | Weight* | Weight** |
|-------------------|----------|-----|-----|-----|-----|-------|---------|----------|
| Climate           | Precipitation | 1500 | 2000 | 500 |     | Model 3 | 0.32    |          |
| Topography        | Slope    | 4   | 30  | 26  |     | Model 3 | 0.12    |          |
| Soil              | Texture  | 75  | 250 | 175 |     | Model 4 | 0.235   | 0.56     |
|                   | Soil depth | 27.5 | 80  | 52.5 |     | Model 4 | 0.059   |          |
|                   | CEC      | 16  | 24  | 8   |     | Model 4 | 0.059   |          |
|                   | Basic saturation | 2.2 | 6.5 | 4.3 |     | Model 4 | 0.059   |          |
|                   | Sum of base cation | 5.3 | 6   | 0.7 |     | Model 4 | 0.059   |          |
|                   | Ph H2O   | 0.8 | 2.4 | 1.6 |     | Model 4 | 0.059   |          |
|                   | C Organic | 4   | 1   | 3   |     | Model 3 | 0.117   |          |
|                   | Flooding | 4   | 1   | 3   |     | Model 3 | 0.117   |          |
|                   | Drainage | 4   | 1   | 3   |     | Model 3 | 0.117   |          |

Land Use

b) indicated optimal class,

LCP (lower crossover point) was lower margin on the fuzzy model 4 (bigger was better),

UPC (upper crossover point) was upper margin on the fuzzy model 3 (smaller was better) following figure 3.

3.3. Soil quality in each land system (soil factor)

The quality of the soil in each system of land was determined by the value of the JMF (soil). JMF (soil) obtained from the sum average membership function value (MF) of each land attribute in each land system multiplied by the weight factor. MF was only assessed by selecting the optimal value, the crossover point value (UCP, LCP), and also the range of CP values (LCP and UPC) with the optimal value (b). MF of each land system was obtained using formula 2. This MF value was used to calculate the JMF of land quality for each land system showing the land quality index. The quality of land was shown value from 0 (zero) to 1. The quality of land was better if approached value 1.

Table 3. MF and JMF (soil) on each land system

| Soil attributes | Pendreh | Okki | Bukit Balang | Kalung | JMF |
|-----------------|---------|------|--------------|--------|-----|
| Basic saturation| 1       | 1    | 1            | 1      | 0.69223 |
| C organic       | 1       | 1    | 1            | 1      | 0.884032 |
| Soil depth      | 1       | 1    | 1            | 1      | 0.792241 |
| CEC             | 1       | 1    | 1            | 1      | 0.890878 |
| Ph H2O          | 1       | 1    | 1            | 1      | 0.89233767 |
| Sum of base cation | 1 | 1  | 1            | 1      | 0.98386014 |
| Texture         | 1       | 1    | 1            | 1      | 0.98386014 |
| Drainage        | 1       | 1    | 1            | 1      | 0.98386014 |
| Flooding        | 1       | 1    | 1            | 1      | 0.98386014 |
3.4. Slope factor
The slope data were obtained from DEM data (figure 6). Slope data layers were available in raster structures and were calculated using formula 1. The optimal slope for coffee was set at 4% and the maximum threshold value was set at 30%. A graph depicting MF fuzzy slope was directed by figure 6. Slope is one of the erosion factors. Erosion is a big problem that occurs in areas with high slope. In areas with high slope, drainage occurred rapidly especially surface runoff and in contrast to sloping areas, drainage occurred slowly. It is known that the areas with low slope variations are better than high slope variations that requires much more effective soil treatment. The finding suggests that the slope weight factor for calculating land suitability was the smallest since a high slope area performed and people continued to cultivate various commodities for livelihoods. Sepúlveda and Carrillo [22] argues that the slope is not always linear with the level of erosion in an area. MF fuzzy for slope can be seen in figure 6. Slope quality index in figure 6 (left) shown value from 0-1, approaching value one means the quality is getting better.

Figure 5. Soil quality on each land system, (the quality of land was better if approached value 1)

Figure 6. Slope class (left) and membership function value (MF) of slope (right).
3.5. Land suitability index

In the land suitability analysis, the evaluation criteria structure used in the study is performed in table 1 and land suitability evaluation criteria for each plant analyzed can be seen in table 2 above. The degree of limitation in conformity evaluation in this study was 1. The land suitability analysis concepts and procedures were based on the fuzzy method. The map of land suitability with the fuzzy set method can be seen from figure 7. Land suitability assessment was resulted from JMF multiplication of soil quality, JMF topography and climate JMF. The finding suggests that the land suitability assessment was undertaken to determine the community (table 2, then determining the procedures and decision-making criteria used in the evaluation procedure, then the fuzzy set method was applied using the GIS method through several stages of the assessment process including setting parameters, determining the weight of criteria, determining the function of each membership, combining, and calculating the land suitability index.

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