Fuzzy set method in GIS raster to analyze the characteristics of agricultural lands

Nurmiaty¹, S Ari⁴, S Baja², A Ridwan¹, Rahmad D.¹, Sukmawati³, M S Lalu⁴ and Ida Suryani⁵

¹Pangkep State Polytechnic of Agriculture, Pangkep, South Sulawesi, Indonesia.
²Universitas Hasanuddin, Makassar, South Sulawesi, Indonesia.
³Universitas Muhammadiyah Parepare, Parepare, South Sulawesi, Indonesia.
⁴Indonesian Cereals Research Institute (ICERI), Maros, South Sulawesi, Indonesia.
⁵Cokroaminoto University, Makassar, South Sulawesi, Indonesia.

E-mail: nurmiatyamin@yahoo.co.id

Abstract. The increasingly growing and detailed spatial data onto land resources required a precise method for the data management can be more effective. Generally, spatial data onto land resources is categorized by sharp boundary and role of every land attribute to the land suitability is equated. On the other hand, the reality of land attribute in the field varied greatly and did not have sharp boundaries also the role of each attribute towards land suitability was varying. It caused the detailed data could not be presented properly so it did not reflect the actual condition at the field. The continued approach from fuzzy set in GIS is a method that can handle such problems. This study examined land characteristics in Pangkep District using a continuous fuzzy set approach from GIS raster. The research was conducted by using exploratory method (field survey and laboratory analysis) for the review scale. The results were then analyzed using the Semantic Import Model (SIM) fuzzy set method of GIS raster. The considered value of the attribute was converted into a general membership value (0 to 1.0), according to class limits that were determined by the Agricultural Research and Development Agency criteria (2011) adapted from the FAO criteria (1976) for planned land use. The results of land characteristic analysis by continuous fuzzy set approach were divided into three groups i.e. 1) climate characteristics: rainfall, temperature, and dry month, 2) physical characteristics of soil: slope, texture, surface rock, soil depth, soil drainage, erosion hazard, and flood hazard, and 3) soil fertility characteristics: Cation Exchange Capacity (CEC), soil acidity, organic C, and salinity. The index value of each land characteristic varied from 0 (minimum) to 1.0 (maximum), according to the prospective of each land characteristics for planned land use. The results are presented in a detailed raster GIS form so it is very effective to inform and represent the actual field conditions.

1. Introduction
There are two types of commonly used land evaluation. First is the categorical system (CS), and the second is based to the continuous function (CF). According to its name, CS techniques use categorical classes to identify the characteristics of the land and display the obtained results. This system is also characterized by the initial determination of 'land mapping units' covering all land properties used as evaluation criteria, the units then the basis of the outcome picture of the overall analysis [1-6]. In the
category method, used criteria and spatial clustering. For example, land suitability classes S1, S2, and S3 are representative methods of category methods [6, 7].

While the CF method, consider the spatial continuity of the land characteristics, and the analysis results are then expressed as the continuous value (or index) of land suitability. Criteria and space are represented in the form of continuous values. For example, conformity is expressed continuously from number 0 (very bad) to number 1.0 (very good), and Digital Elevation Model (DEM) illustrates the height of the earth's surface continuously. It is showed DEM that does not use a soft boundary.

The increasingly growing and detailed spatial data onto land resources required a precise method so that the data management can be more effective. Generally, spatial data onto land resources is categorized by sharp boundary and role of every land attribute to the land suitability is equated [6]. On the other hand, the reality of land attribute in the field varied greatly and did not have sharp boundaries also the role of each attribute towards land suitability was varying. It caused the detailed data could not be presented properly so it did not reflect the actual condition at the field. The continued approach from fuzzy set in GIS is a method that can handle such problems. This study examined land characteristics in Pangkep District using a continuous fuzzy set approach from GIS raster.

2. Methods

2.1. Study region
The research was conducted in Pangkep Regency, South Sulawesi Province. Pangkep is geographically located on 4° 33' 20.0" to 4° 57' 5.6" Southern Latitude and 119° 22' 54.8" to 119° 48' 35.8" Eastern Longitude. Its region area is 145,266 ha consisting of 9 sub-districts, namely: Balocci, Bungoro, Labakkang, Mandalle, Ma’rang, Minasatene, Pangkajene, Segeri, Tondong Tallasa. Pangkep regency is one of the biggest producers of rice in South Sulawesi (figure 1). Its variability is complex, consisting of coast, low land, and high land. Having a border with Makassar, the capital of South Sulawesi province, the population pressure has caused greater land function change.

![Sulawesi Island and Location of the Study Region](image)

Figure 1. Sulawesi Island and Location of the Study Region

2.2. Soil and climate databases
This study employed data bases source including: (i) digital topography map; (ii) land map and soil characteristics; (ii) climate data; and (iii) satellite data (SPOT image 6). A digital topography map of the study area of 1: 50,000 scale from the Geospatial Information Agency is used as a reference for
mapping. Digital topographic maps in GIS vector format make it easier to build databases in standard GIS vectors, then it was converted to raster format. All data layers are stored using Universal Transverse Mercator (UTM) coordinate system.

The main reference of this study for the soil data layer was the result of the soil survey. Soil mapping units (based on topography, land use, and geology) were derived from land system maps to provide the base for field surveys (figure 2). Soil sampling is stratified random sampling by calculating the number of samples using the equation [9]:

$$N = \frac{(Z^2 \times p \times q)}{E^2}$$

N = Number of samples  
Z = the default value for certain confidence  
p = expected accuracy  
q = 1 - p  
E = confidence interval

![Figure 2. Land units (a) and sampling points (b)](image)

37 homogeneous mapping was obtained, and soil sampling was conducted in 55 locations (figure 3). The characteristics of surveyed and analyzed soil and climate are as follows (see table 1).

**Table 1.** Land quality and land characteristics used in the analysis [10].

| Land Qualities          | Land Characteristics                                                                 |
|-------------------------|--------------------------------------------------------------------------------------|
| Temperature (t)         | Average temperature (°C)                                                            |
| Water availability (w)  | Rainfall (mm), Number of dry months                                                 |
| Rooting condition (r)   | Texture, drainage, Soil depth (cm)                                                  |
| Nutrient retention (f)  | Clay CEC (cmol/kg), Base saturation (%), pH (H₂O), Organic C (%)                   |
| Toxicity (x)            | Salinity (dS/m)                                                                     |
| Nutrient availability (n)| N, P₂O₅, K₂O                                                                   |
| Terrain (s)             | Slope (%), Surface stoniness (%), Surface outcrops (%)                              |
2.3. *Analysis methods*

The study was conducted using exploratory methods (field survey and laboratory analysis) for the review scale. The results were then analyzed using the Semantic Import Model (SIM) fuzzy set method in GIS raster. The value of the considered attributes was converted into a general membership value (0 to 1.0), according to class limits determined under by the Agricultural Research and Development Agency criteria [10] adapted from the FAO (1976) criteria for planned land use.

Each soil characteristics was converted to the continuous value (from 0 to 1,0) [11], based on the class boundary that was determined according to field experiment, experimental result, or define conventional standart [7,12,13,14,15,16].

Each attribute of land characteristics in every component that is valued from 0 (minimum) to 1,0 (maximum) based on the criteria of Agricultural Research and Development Agency [10] that is adapted from FAO criteria (1976) for maize land use (see [7,16,17,18,19,20,21].

Values are represented as membership values ranging from 0 to 1.0. Analytical procedures are carried out through the following steps: (i) selecting and designing evaluation criteria; (ii) standardizing the data set; (iii) determining the field / climate attribute values; (iv) selecting the appropriate scoring function and parameters[21] (v) converting the data format between software programs (raster to vector or vice versa [6].

Determination of the individual rank from the land attributes, using equations [22]:

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

For optimum range (Model 2):

\[
MF (x_i) = 1 \quad \text{if } (b_1 + d_1) < x_i < (b_2 - d_2)
\]

For asymmetric left (Model 3):

\[
MF (x_i) = \frac{1}{1 + \left\{ (x_i - b_1 - d_1) / d_1 \right\}} ^ 2 \quad \text{if } x_i < (b_1 + d_1)
\]

For asymmetric right (Model 4):

\[
MF (x_i) = \frac{1}{1 + \left\{ (x_i - b_2 + d_2) / d_2 \right\}} ^ 2 \quad \text{if } x_i > (b_2 - d_2)
\]

where MF (x_i) the individual membership value for the i^{th} soil attribute x, d the range of transitional zone (that is, x in MF = 0.5 or otherwise mentioned as a crossover point, x_i = = the i^{th} soil attribute (x) value, and b = the value of soil attribute x in the ideal point.

3. *Results and discussion*

The results of land characteristic analysis with Boolean FAO method and continuous fuzzy set approach were divided into three groups i.e. 1) climate characteristics: rainfall, temperature, and dry moon, 2) physical characteristics of soil: slope, texture, surface rock, soil depth, drainage land, erosion hazard, and flood hazard, and 3) soil fertility characteristics: Cation Exchange Capacity (CEC), soil acidity, organic C, and salinity.

3.1. *Land characteristics of the FAO Boolean method*

Figure 3 shows the spatial distribution of slope land characteristic based on Boolean FAO method and table 2 shows the extent of each category. Each category polygon is bounded by a sharp boundary and it has homogeneous attributes.
3.2. Land characteristics continuous Fuzzy Set method

Figure 4 shows the distribution of slopes characteristic categorization based on the method of continuous fuzzy set, while table 2 shows the extents of each category after reclassing. The value of the soil attributes is converted to a continuous value (ranging from 0 to 1.0) [11], according to class boundaries that determined by field experience, experimental result, define conventional standard [12-15].

3.3. Comparison of land characteristics of FAO and Fuzzy Set Methods

The land area of each slope category based on the analysis result with the FAO Boolean method approach (figure 3) was different from the width of each slope category based on the analysis result of the method of continuous fuzzy set approach. It was due to the areas that considered homogeneous in the FAO category was not the only categories based on the fuzzy set method. In the S2 category of the Boolean FAO method (equivalent to category 0.5-0.75 in the fuzzy method category) was 12,640 ha (see figure 3) and dramatically decreased in the category of 0.5-0.75 of fuzzy set method (see figure 4).
4. Figure 5 shows the results of slope category analysis on the same land area using the Boolean FAO method (black box) and the continuous method of fuzzy set (inset). The facts on the ground also show heterogeneous conditions, therefore categorizing with continuous fuzzy set methods more effectively represents the conditions in the field.

![Figure 5](image.png)

**Figure 5.** The result of land category in the same land area

4. **Conclusion**

The index value of each land characteristic varied from 0 (minimum) to 1.0 (maximum), according to the prospective of each land characteristics for planned land use. The results are presented in a detailed raster GIS form so it is very effective to inform and represent the actual field conditions.

**Acknowledgements**

The authors are deeply thankful to the DRPM DIKTI and Pangkep State Polytechnic of Agriculture (through the PSNI research grand) for providing data, fund, and other supporting facilities in this study.

**References**

1. Albaji M, Naseri AA, Papan P, Nasab SB 2009 Qualitative evaluation of land suitability for principal crops in the west shoush plain, Southwest Iran *Bulg J Agric Sci.* 15 135–45.
2. Al-Mashreki M, Akhir J, Rahim S, Desa K, Lihan T, Haider A 2011 GIS-based sensitivity analysis of multi-criteria weights for land suitability evaluation of sorghum crop in the Ibb Governorate Republic of Yemen *J Basic Appl Sci.* 1 1102–11.
3. Chinene VRN 1992 Land evaluation using the FAO Framework: an example from Zambia *Soil Use Manag.* 8 130–8.
4. Jafarzadeh AA, Alamdari P, Neyshabouri MR, Saedi S 2008 Land suitability evaluation of bilverdy research station for wheat, barley, alfalfa, maize and safflower *Soil Water Res.* 3 81–8.
5. Chandio IA, Matori AN, Lawal DU, Sabri S 2011 GIS-based land suitability analysis using AHP for public parks planning in Larkana City *Mod Appl Sci.* 5 177–89.
6. Nurmiaty and Baja S 2013 Spatial based assessment of land suitability and availability for maize (*Zea mays* L.) development in Maros Region, South Sulawesi, Indonesia *Open J Soil Sci.* 3 244–51.
7. Nurmiaty and Baja S 2014 Using fuzzy set approaches in a raster GIS for land suitability
assessment at a regional scale: Case study in Maros region, Indonesia Mod Appl Sci. 8 115–25.

[8] Nurmiaty and Baja S 2013 Land suitability assessment for maize cultivation using a Fuzzy Set approach in Geographic Information System (GIS) Proc. of the 11th International Conference the East and Southeast Asia Federation of Soil Science Societies p. 282.

[9] Eastman L J 1993 Retirement revisited: Extending the work-life of older americans Hum Resour Dev Q. 4 409–14.

[10] Agricultural Research and Development Agency criteria 2016 Petunjuk Teknis Pedoman Penilaian Kesesuaian Lahan untuk Komoditas Pertanian Strategis Tingkat Semi Detail Skala 1 : 50 . 000 37 p.

[11] Zadeh L. 1965 Fuzzy sets. Inf Control 1 137.

[12] Galindo J 2005 Fuzzy Databases: Modeling, Design and Implementation: Modeling, Design and Implementation. IGI Global.

[13] Sánchez-Moreno JF 2007 Applicability of knowledge-based and fuzzy theory-oriented approaches to land suitability for upland rice and rubber, as compared to the farmers’ perception: a case study of Lao PDR. A case study Lao PDR Master Thesis133. Available from: http://www.mtnforum.org/sites/default/files/publication/files/861.pdf

[14] Sediyono E, Setiawan A, Kaparang DR 2013 Fuzzy simple additive weighting algorithm to determine land suitability for crop in Minahasa Tenggara Int J Comput Appl. 84 26–9.

[15] Sui D 1992 A fuzzy GIS modeling approach for urban land evaluation Comput Environ Urban Syst 16 101–15.

[16] Keshavarzi A, Sarmadian F, Heidari A, Omid M 2010 land suitability evaluation using fuzzy continuous classification (A case study: Ziaran region) Mod Appl Sci 4 72–81.

[17] Kurtener D, Torbert H A, and Krueger E 2008 Evaluation of agricultural land suitability: application of fuzzy indicators In International Conference on Computational Science and Its Applications pp. 475-490 (Heidelberg Berlin: Springer).

[18] Mohammadrezaei N, Pazira E, Sokoti R, Ahmadi A. 2013 Comparing the performance of fuzzy AHP and parametric method to evaluate of land suitability of wheat production in the Southern Plain of Urmia Int J Agron Plant Prod. 4 3438–43.

[19] Reshmidevi T V., Eldho T I, Jana R 2009 A GIS-integrated fuzzy rule-based inference system for land suitability evaluation in agricultural watersheds Agric Syst 101 101–9.

[20] Sarmadian F, Keshavarzi A, Rajabpour B, and Askari S 2010 Application of MCDM method in fuzzy modeling of land suitability evaluation In 19th World Congress of Soil Science 25-8.

[21] Baja S, Chapman D M, and Dragovich D 2001 Fuzzy modeling of environmental suitability index for rural land use systems: An assessment using GIS In Proceedings of the Sixth International Conference on GeoComputation 24-26.

[22] Burrough P A 1989 Fuzzy mathematical methods for soil survey and land evaluation J Soil Sci. 40 477–92.