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Developing Agricultural Land Geospatial Information in Supporting Regional Food Resilience

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Abstract. One of the major obstacles in increasing the agricultural production yields is the inappropriate management of land use due to the differences in land biophysical characteristics in each region. Therefore, it is necessary to have spatial-based land use management that is appropriate for handling agricultural land. This research aims at structuring geospatial information of agricultural land biophysical characteristics and agricultural land appropriateness (potential and limiter) for food plants development in Pangkep Regency. This research uses the up-to-date approach of multi-scale observation, so the problems becoming the restricting factors of productivity can immediately be overcome. The method used consists of 2 stages, namely stage 1, analysis of agricultural land (biophysical) climate and land characteristics through land survey, laboratory analysis, and land characteristic spatialization; stage 2, analysis of agricultural land appropriateness (potential and limiter) using land appropriateness method of *fuzzy set*/FAO, satellite image information extraction, *ground truth,* and *ground sampling*. The results of the research are in the form of geospatial information on agricultural land biophysical characteristics and agricultural land appropriateness (potential and limiter) for food plants development in Pangkep Regency. With the information, decision makers will have more ease and they integrate into making policies for agricultural land use management in Pangkep Regency that will end up aiming to increase food production.

1. Introduction

The amount of food production from rice commodities in Pangkep Regency is quite large, which is 189,022 tons. Nevertheless, the average productivity is still relatively low, which is 6.3 tons/ha from the potential production of 7-9 tons/ha. The same goes for the amount of corn production, which is 4,711 tons with an average productivity of 6.4/ha from the production potential which can reach 13 tons/ha. The same thing happens to plants in the plantation sector, cocoa production in Pangkep Regency 55.36 tons with productivity averaging 0.17 tons/ha from production potential of 1.5 tons/ha and coffee production 126.24 tons with an average productivity of 0.16.ton/ha of potential production of 1.5-2 tons/ha. This indicates that in general agricultural production in Pangkep Regency is mainly food crops and plantations, far lower than the production potential that can be achieved (Pangkep Regency Agricultural Service, 2017).

The low production and average productivity of agricultural commodity land, especially food crops, which are far below the production potential that can be achieved are triggered by the inaccuracy of land use management in the form of inaccurate space (location), time, and management of agricultural land in Pangkep Regency. The inaccuracy of this space, among others, agricultural commodities are cultivated in areas that are not suitable, for example, food crops are cultivated on sloping areas, which in addition to reducing production, also affect the damage to the environment and spur the occurrence of flooding. Inaccuracies can be inaccuracies in determining planting time. Whereas inaccurate management relates to fertilizer input. Possibly, the input of the fertilizer that is used too generically, using commonly used doses. Meanwhile, each region has different land agro-ecological characteristics (land and climate), so the recommended general dosage is not always suitable for the land.

The accuracy of the management of space, time and management is influenced by the characteristics of land agroecology, socio-economic, and government policies. On the other hand, this information is minimally available and generally is not spatially based (space) and is not integrated between the existing aspects. For this reason, careful research is needed on the land in Pangkep Regency so that land use is in the right space, the right time, and appropriately managed, with effective spatial, time and land design on land with a spatial and integrated approach. The approach with a user-friendly Spatial Decision Support System (SDSS) was built to facilitate policymakers in making decisions for agricultural land management. This study aims to compile geospatial information on the biophysical characteristics of agricultural land and the suitability of agricultural land (potential and limitation) for the development of food crops in Pangkep Regency.

2. Research Method

2.1. Area of Study

This research was conducted in Pangkep Regency, South Sulawesi Province. Pangkep Regency is geographically located between 40 33 ‘20.0 "to 40 57’ 5.6" South Latitude and 1190 22 ‘54.8 "to 1190 48’ 35.8" East Longitude. The area is 145,266 ha which consists of 9 sub-districts, namely: Balocci, Bungoro, Labakkang, Mandalle, Ma’rang, Minasatene, Pangkajene, Segeri, Tondong Tallasa. Pangkep Regency is one of the largest rice producers in South Sulawesi (Figure 1). Variability is quite complex, consisting of beaches, lowlands, and highlands. Bordering Maros and Makassar, the capital of South Sulawesi Province, population pressure has led to greater land use change.

2.2. Analysis Method

This research employed a cutting-edge approach to multi-scale observation so that problems that can be a barrier to productivity can be solved immediately. The method used consists of two stages, namely stage 1, analysis of land and climate (biophysical) characteristics of agricultural land, through land surveys, laboratory analysis, and spatial characteristics of land; stage 2, analysis of agricultural land suitability (potential and limiting), using fuzzy set/FAO land suitability methods, extraction of satellite image information, ground truth, and ground sampling.

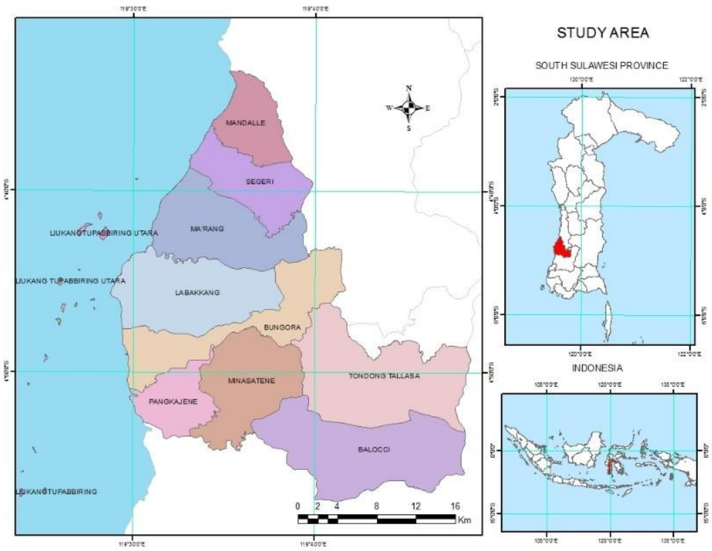

Figure 1. *The Location of Study and South Sulawesi Province*

Database sources consist of: (i) digital topographic maps; (ii) land maps and soil characteristics; (ii) climate data; and (iii) satellite data (SPOT 6 imagery). The digital topographic map of the study area with a scale of 1: 25,000 from the Geospatial Information Agency was used as a reference for mapping. Digital topographic maps in GIS vector format so that it is easier to build databases in the standard GIS vector, which is then converted to raster format.

Each land attribute in each component was assessed from 0 (minimum) to 1.0 (maximum) according to the suitability of corn [1, 2, 3, 4, 5]. Values 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 data sets, (iii) determining field/climate attribute values, (iv) selecting appropriate scoring functions and parameters [6], (v) converting data formats between software programs (raster to vector or vice versa). The analysis procedure is then followed by three main steps [7].

Step 1, determining individual ratings of land attributes, using equations [8]:

$MF (xi) = [1/(1 + \{(xi - b)/d\}\ 2)]$ if $0 < MF (xi) < 1$ (1)

For the optimum range (Model 2):

$MF (xi) = 1$ if $(b1 + d1) < xi < (b2 - d2)$ (2)

For the asymmetric left (Model 3):

$MF (xi) = [1/(1 + \{(xi - b1 - d1)/d1\}\ 2)]$ if $xi < (b1 + d1)$ (3)

For the asymmetric right (Model 4):

$MF (xi) = [1/(1 + \{(xi - b2 + d2)/d2\}\ 2)]$ if $xi > (b2 - d2)$ (4)

in which MF (xi) = individual membership value for land with attributes x, d = transition zone range (i.e., x at MF = 0.5 or mentioned as crossover point, CP), xi = land attribute i (x) value, and b = the value of the land attribute x at the ideal point [7].

Step 2, the derivation of the rank attribute class of land, through membership integration of land attributes values using the following convex combination:

$$JMF(X) = \sum_{i=1}^{n} \lambda i\ MF(xi) \quad (5)$$

in which $0 < JMF (X) < 1$; $0 < MFxi < 1$; $\lambda 1 + \lambda 2 + \lambda 3 + ... + \lambda n = 1$, and $0 < \lambda i < 1.0$. JMF (X) symbol is a plural membership function of all variables considered in class X, λi is a value factor for land attributes x which in i, MF (xi) are membership values for land attributes xi, and n is the number of land attributes considered.

Step 3, calculate the overall land suitability index (LSI), using a multiplication function based on cells with cells in the GIS raster, as follows:

LSIP (corn) = JMF (S (p)) x JMF (T (p) x JMF (C (p)) (6)

in which LSIP (corn) is LSI for corn in cell p, JMF (S (p)), JMF (T (p)), and JMF (C (p)) is the JMF value in cell p for soil profile, topography, and climate, respectively. The use of the multiplication function indicates that there is no compensation between land attributes. In other words, land with extreme limitations cannot be compensated, with other characteristics that are very good on land, or vice versa [6, 7]. The multiplication function then produces a land suitability index (LSI) which is represented in the form of a continuous value, ranging from 0 (not suitable) to 1.0 (very suitable) [7].

3. Findings and Discussion

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

*3.1. **Climate***

The climate type of Pangkep Regency based on Oldeman climate classification is climate types B2 and C, while according to the Schmidt-Ferguson classification are climate types A and B (very wet). The average amount of rainfall is 3,346 mm/year with the dry season rainfall distribution pattern falling in June - October every year. The average number of dry months ranges from 3-4 months. The pattern of rainfall distribution is shown in Figure 2.

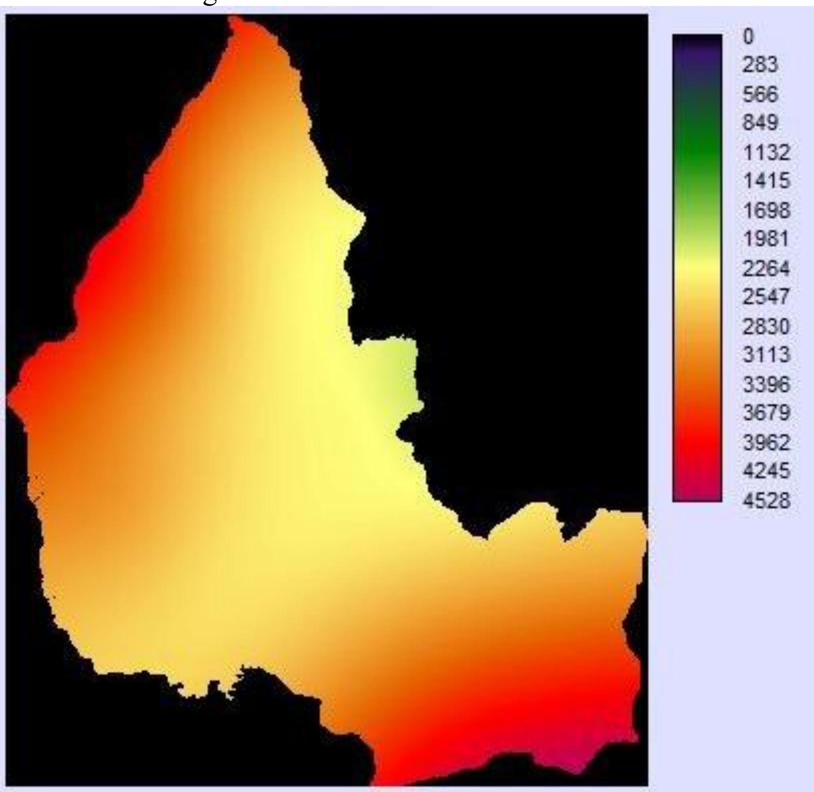

Figure 2. The pattern of rainfall distribution in Pangkep Regency

3.2. Soil

Based on the soil type map (RePPProT, 1988), land in Pangkep Regency consists of 8 types of soil, namely Alluvial Hydromorph (1201.10 ha), Alluvial Gray (4,474.64 ha), Comprehensive Mediterranean brown (2,117.89 ha), Yellowish red lithosol (1,475.12 ha), Lithosol (42,494.23 ha), dark brown Mediterranean (8,539.77 ha), red Podsolic (12,448.69 ha), brownish brown Regosol (6,062.67 ha). The type of land that dominates the area of Pangkep Regency is the type of Lithosol soil which covers a wider area compared to other types of soil. However, the characteristics of lithosol soil is a soil with a low fertility level, because it has a very little nutrient in the soil, which only reaches 45 cm

3.3. Characteristics of Slope Land Based on the FAO Boolean Method and the Continuous Fuzzy Set Method

Figure 3a shows the distribution of regions and the extent of each category of slope land characteristics based on the FAO Boolean method. Each polygon category is bounded with a strict and homogeneous attribute. This does not describe the condition of the land in the field, because of the facts on the ground, the slope has no firm boundaries, but rather continuous. While image 3b shows the distribution of the area and the area of each category of slope characteristics based on the continuous fuzzy set method after the reclass. The values of land attributes are converted to continuous values (starting from 0 to 1.0) [9], according to class boundaries determined based on field experience, the results of conventional trial results [10, 11, 12, 13, 14]. Each coordinate has a different slope value, this condition is more representative of the condition of the land slope in a continuous field and has no firm boundaries.

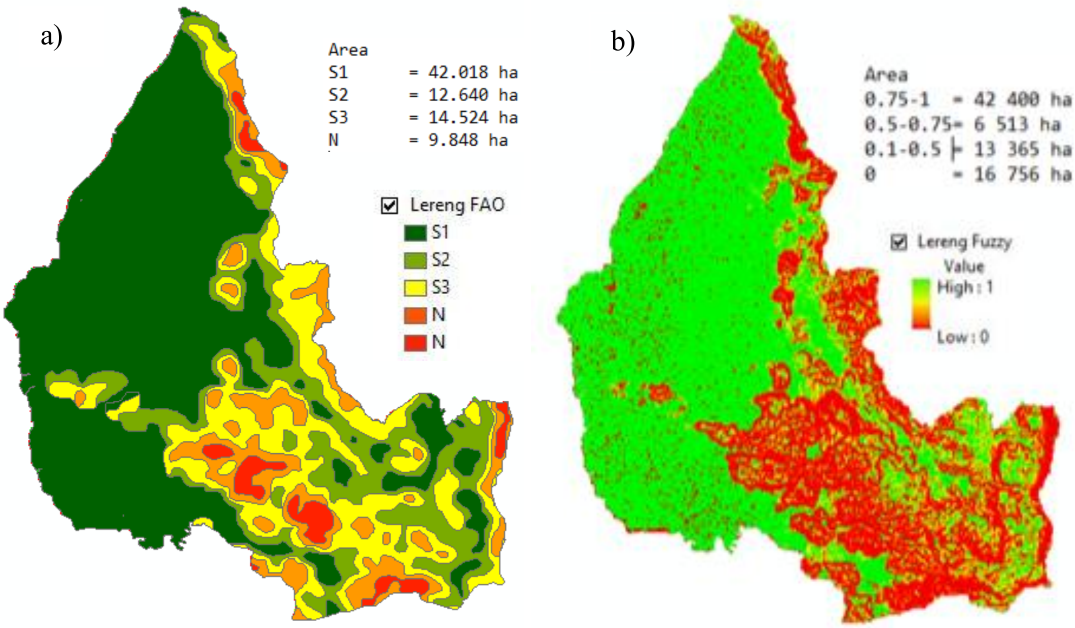

Figure 3. Results of slope category analysis based on FAO Boolean method (a) and continuous fuzzy set method (b)

The land area of each slope category based on the results of the analysis with the FAO Boolean method approach (Figure 3a) differs from the extent of each slope category based on the analysis of the fuzzy set continuous method approach. This is due to the fact that regions considered homogeneous in the FAO category still have other categories based on the fuzzy set method. In the N category, the Boolean FAO method (equivalent to the category 0 in the fuzzy method category) has an area of 9.848 ha (see Figure 3a) and enhancement in the 0 fuzzy set method, 16.756 ha (see figure 3b). Figure 4 shows the results of the slope category analysis on the same land area using the Boolean FAO method (black box) and continuous fuzzy set (inset) method. The facts in the field also indicate heterogeneous conditions, so that categorization with continuous fuzzy set methods is more effective in representing conditions in the field.

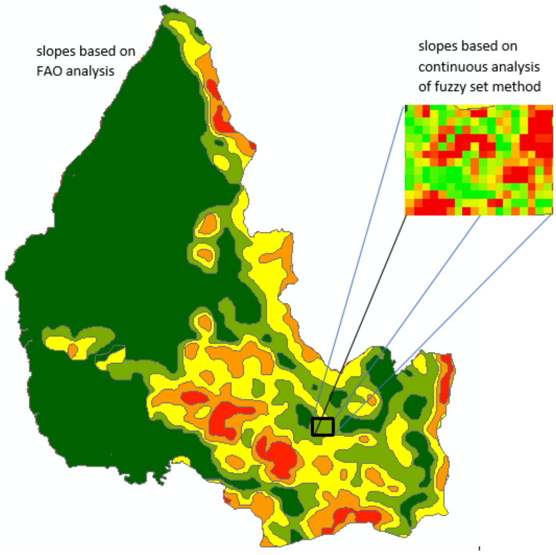

Figure 4. Results of analysis of slope categories in the same land area

3.4. Spatial Distribution of Land Suitability and Land Suitability Index

Land suitability classes for food crops (rice, corn, and soybeans) using the FAO method are shown in Figure 5. While figure 6 displays the Land Suitability Index (LSI) for corn plants. In general, the appearance of the corn crop LSI image indicates that the dominant low LSI value is found in the southeastern part of Pangkep Regency. This area is dominated by limiting factors where there are Bantimurung-Bulusaraung National Parks, karst areas and other ancient sites. Nevertheless, in the region, there are still areas that have high LSI values, which can be identified by the appearance of green in the image. As for the western central region, it is dominated by a higher LSI value; this is because the western region has a relatively sloping topography and is flat. It's just that, getting to the west, getting closer to the coastal area so that it is limited by the limiting factor of salinity.

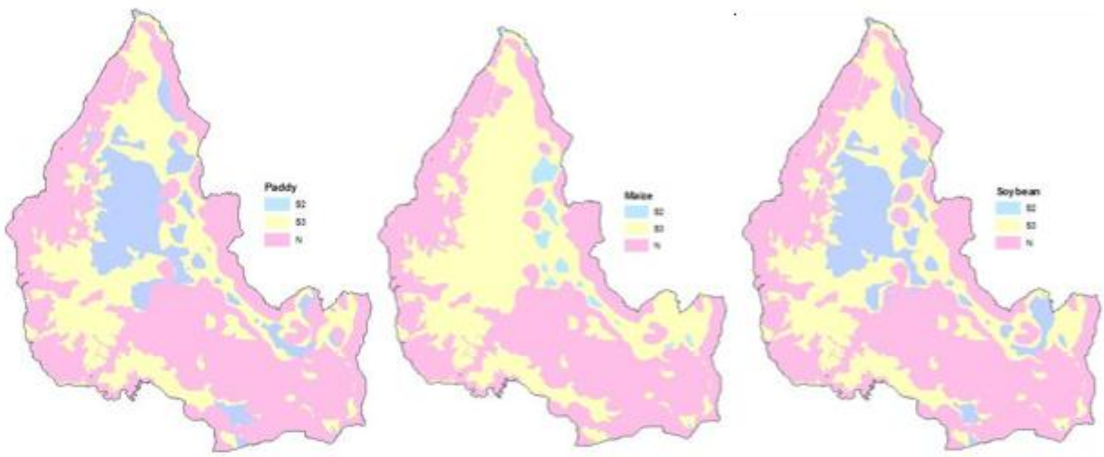

Figure 5. Class of land suitability of food crops (rice, corn, and soybeans) based on the FAO method

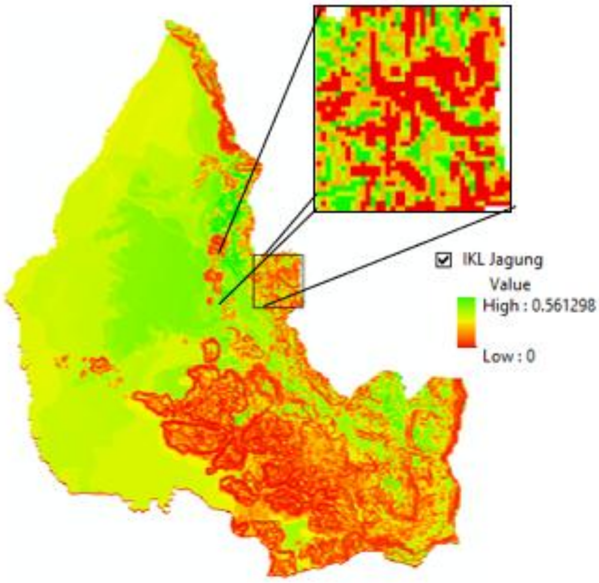

Figure 6. Land suitability index for corn plants based on a continuous fuzzy set method

Land suitability evaluation using the fuzzy set method approach has a range of index values from 0 (very poor) to 1 (very good). The maize land suitability index value which reached 0.561 indicates suitability and production for maize accordingly, although it is limited to regions that have a range of these index values. This value is equivalent to the S2 land suitability class on FAO land suitability evaluation criteria (1976).

3.5. Food Resilience
Detailed spatial information on LSI characteristics and land that better represents land conditions in the field will support efforts to increase agricultural production. The land that has been considered homogeneous is not suitable for the allocation of food crops, with the use of a continuous fuzzy set method, in which land is found to be suitable for the allocation of food crops. With more detailed data and more represent conditions in the field, decision making on agricultural land development will be more effective and efficient, so that higher productivity leads to regional food resilience.

4. Conclusion
The conclusions that can be drawn in this study are as in the following:
1. The characteristics of the land and its potential for land suitability for food crops are spatially distributed based on the magnitude and extent of the land boundaries both physically and chemically. In general, the characteristics of the central part of the land favor the use of agricultural land compared to other parts of the land.
2. The height of the Land Suitability Index (LSI) is dominantly found in the middle segment area. The index value reached 0.561 in corn plants, which is equivalent to the S2 land suitability class on FAO land suitability evaluation criteria (1976). Validating with the FAO category system, in certain regions (especially in high slope areas with low FAO land suitability classes), the standard deviation (SD) value of LSI is relatively high, indicating a high variation in LSI in this area, which means there are regions which actually has high potential (high LSI) even in narrow areas.

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