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LAND SUITABILITY ASSESSMENT IN AGRICULTURE, USING GIS MODEL BASED ON FUZZY APPROACH: A CASE STUDY FOR COCOA CULTIVATION IN ENREKANG, INDONESIA

J.S Nurfadila[1], S Baja[1*], R Neswati[1], and D Rukmana[2]
[1]Department of Soil Science, Faculty of Agricltural sciences, Hasanuddin University, Indonesia
[2], Department of Agriculture Socio-Economics, Hasanuddin University, Indonesia
*Corresponding author: S Baja Email id:sbja02@yahoo.com.au (Whatsapp no. +62 812 4262 988)

Abstract

One useful tool in agricultural management is geographic information systems (GIS). There have been many approaches used in GIS, one of which was the fuzzy method which provides assessment based on continuous data values. The weights of the important variables were calculated using a mathematical formula to determine their relative priorities. This research used two sets of indicator selectors: total data set (TDS) and minimum data set (MDS). With these methods, the land suitability index were obtained, which include 13 soil TDS and 6 climate MDS indicators used in 15 land units. The multivariate test was conducted to assess the effectiveness of the methods used, and their abilities to distinguish between soil and climate indicators in regions with suitability classes S1 and S2. When the corresponding P is 0.01 or less than 0.05, it indicates significant difference in the quality of indicators in both regions. Therefore, the approaches and methods used in this study properly distinguish land suitability classes, and this concept can also be applied to the assessment of other plant species.
***Keywords*:** Fuzzy approach, Geographic Information System (GIS), Land suitability assessment, Land management, Sustainable agriculture.

Abbreviations: GIS, geographic information systems; TDS, total data set; MDS, minimum data set; CEC, cation-exchange capacity; SOM, soil organic matter; PCA, principal component analysis; MF, membership function; JMF, join membership function; SQI, soil quality index; CQI, climate quality index; LSI, land suitability index.

Introduction

The intensification of various commodities cannot be separated from the efforts to find new land opened for agricultural expansion. In the process of opening new areas, it is necessary to examine the land resources for sustainable production, since some characteristics influenced crop growth. Suitability analysis is a requirement for persistence agriculture, which consists of several evaluation criteria (Prakash, 2003). The conditions analyzed should be based on the plant growth standards being evaluated. The land appropriation evaluation is a tool to plan and regulate activities to yield good farming results (Hills, 2015) and also requires fitting methods to provide better management plans (Rabia & Terrible, 2013). In sustainable agriculture, assessing soil's characteristics and crop requirements is the most important step (Vasu et al., 2018).

Geographic information system (GIS) has been widely used in decision-making process to find a potential land for specific use (Akıncı, Özalp, & Turgut, 2013; Boonyanuphap, Wattanachaiyingcharoen, & Sakurai, 2004). GIS is an important tool to store, retrieve, and manipulate large data needed to map and calculate the various quality index for land suitability (Baroudy, 2016). One of the GIS methods that has been widely used is the fuzzy approach (Hall & Wang, 1992). Land maps produced by this procedure is more informative and better in prediction accuracy than conventional maps (Qiu, Chastain, & Zhou, 2014). In the last decade, several quantitative methods in decision making have been widely used, especially the AHP and the fuzzy approach which is used for transforming data intervals continuously (approximately one indicates better while close to 0 signifies inappropriate). This method was developed from the approach, which was considered too rigid and standard (almost the same but with different land suitability classes). Fuzzy method used the important indicator at the hierarchical level, for decision making objectives to be fulfilled. The membership values in fuzzy sets present valuable information for identifying the main constraints on a land (Elaalem, 2013). These sets are suitable for converting numerical data of various magnitudes into membership functions values and representing land suitability (Zhang, Su, Wu, & Liang, 2015).

Materials and Methods

A. Study site

The study area was located in Enrekang Regency, one of the districts in Indonesia, sited between 3°14'36" - 3°50'0" S Latitude and 119°40'53" - 120°6'33" E Longitude with an area of 1,786.01 km^2 (Fig. 1). The topography consists of high and lowlands with Hydromorphic, Mediterranean, and Podzolic soil types, tropical climate, and significant precipitation. The mean annual precipitation was 1553 mm/year, while the temperature was 23^{o}C. In general, Enrekang's morphology consists of karst stretching from the north to the middle, valleys, and rivers.

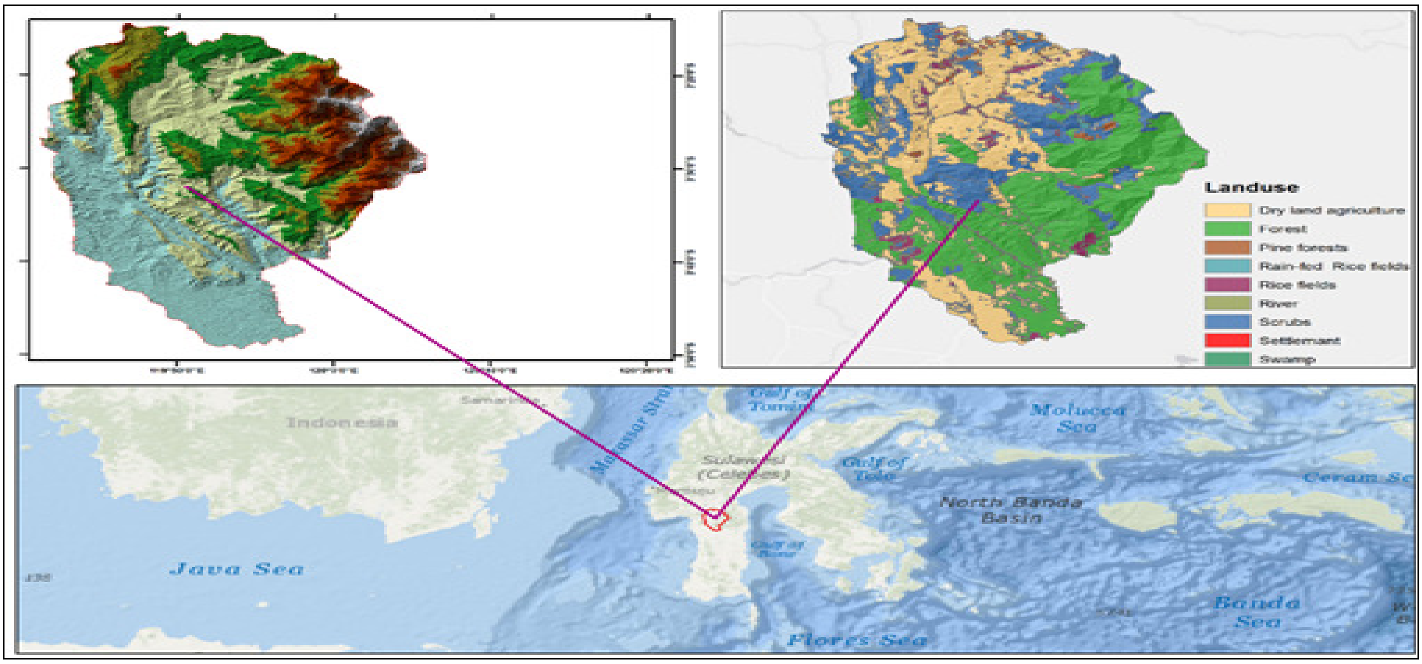


Fig. 1. : Location map of Enrekang regency.

B. Soil and climate quality for cocoa growth

Soil quality had an impact on productivity and could only be assessed by measuring its characteristics. Each soil layer had 28 features which include: texture, permeability, depth, available water capacity, bulk density, organic matter content, and others (Mulla, 2012). One important consideration in cocoa growth was the chemical substances, such as soil organic matter (SOM), pH, base saturation, sum of basic cations, and cation-exchange capacity (CEC). All soil attributes used in this study could be seen in Fig. 2.

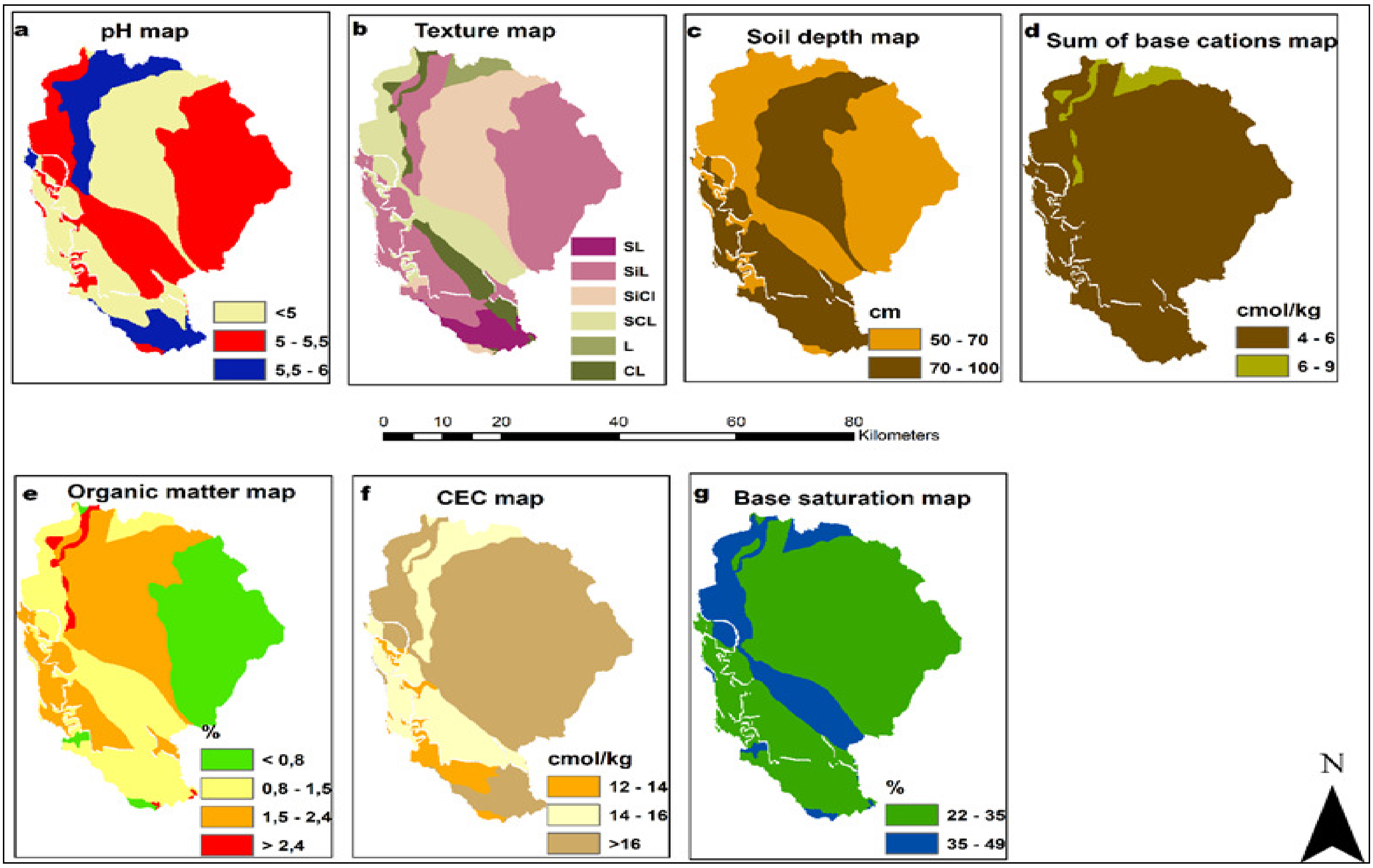


Fig. 2 : Distribution spatial map of soil attributes in Enrekang.

The chemical elements that were also important for the growth, were base saturation and the soil pH which affected the dissolution of nutrients and caused plant mineral uptake to be varied (McCauley, Jones, & Olson-rutz, 2017). Base saturation was one of the factors that influenced the soil pH (Arshad & Coen, 1992), and its optimal value for cocoa growth is 6.4. CEC's role was to store and release nutrients for plant growth, and was affected by the soil texture and SOM (Arshad & Coen, 1992). In addition, the optimum CEC for cocoa production was >24 cmol/kg. The basic cations needed in the nutrients included calcium, magnesium, and potassium. Their individuals' roles were cell permeability, chlorophyll formation, and physiological processes, respectively.

The other physical conditions needed to be considered for cocoa growth were texture, and the soil depth which had a significant influence on the indicators such as bulk density, porosity, field capacity, and wilting point. The cocoa had thick and long roots, which amounted to 150 cm in length, therefore required deep soil (Jiska et al. 2015). They grew well in depth of more than 100 cm, and those in Enrekang ranged relatively from 50-100 cm (Fig. 2c). The texture which was related to porosity and bulk density influenced the soil ability to store water and nutrients, and also affected the root growth (Ayorinde, Lawal, & Muibi, 2015). In general, clay soil type contains more minerals and had better water storage capacity for root systems, compared to sandy with drainages. Therefore, clay soil type was considered to give the best results.

Variations in precipitation and temperature had impacts on cocoa production (Sadiq, 2010). These two factors were the dominant climatic elements that affected cocoa growth. The formation of young shoots and flowers on this crop was influenced by temperatures with an ideal range from 15^{o} to 30^{o}C.

C. Fieldwork and laboratory analysis

Field sampling was an essential stage for assessing the physical and chemical properties of samples to determine their quality through laboratory analysis. This analysis should describe the actual state of the soil (Table 1).

Table 1 : Soil quality in Enrekang based on cocoa growth requirements

Land unit	Texture	Soil depth	CEC	Base saturation	Sum basic cations	pH H20	SOM
Bukit Balang	S1	S3	S1	S2	S1	S3	S1
Bukit Ayun	S1	S3	S2	S2	S1	N1	S3
Pendreh	S2	S3	S1	S1	S1	S3	S2
BatangAnai	S1	S3	S2	S1	S1	S2	S2
Bukit Pandan	S1	S3	S1	S2	S1	S3	S3
Okki	S1	S3	S2	S2	S1	S2	S1
Kalung	S1	S3	S1	S1	S1	S2	S1
Maput	S1	S3	S2	S2	S1	N1	S1
Bakunan	S2	S3	S2	S2	S1	S3	S2
Hiliboru	S1	S3	S2	S2	S1	S3	S2
Teweh	S1	S3	S2	S2	S1	N1	S2
Watampone	S1	S3	S2	S1	S1	S3	S3
Sungai Aur	S2	S3	S1	S2	S1	S2	S2
DanauLindu	S1	S3	S1	S1	S1	S2	S1
Mantalat	S1	S3	S1	S2	S1	N1	S2
	S1	S2	S3	N1			

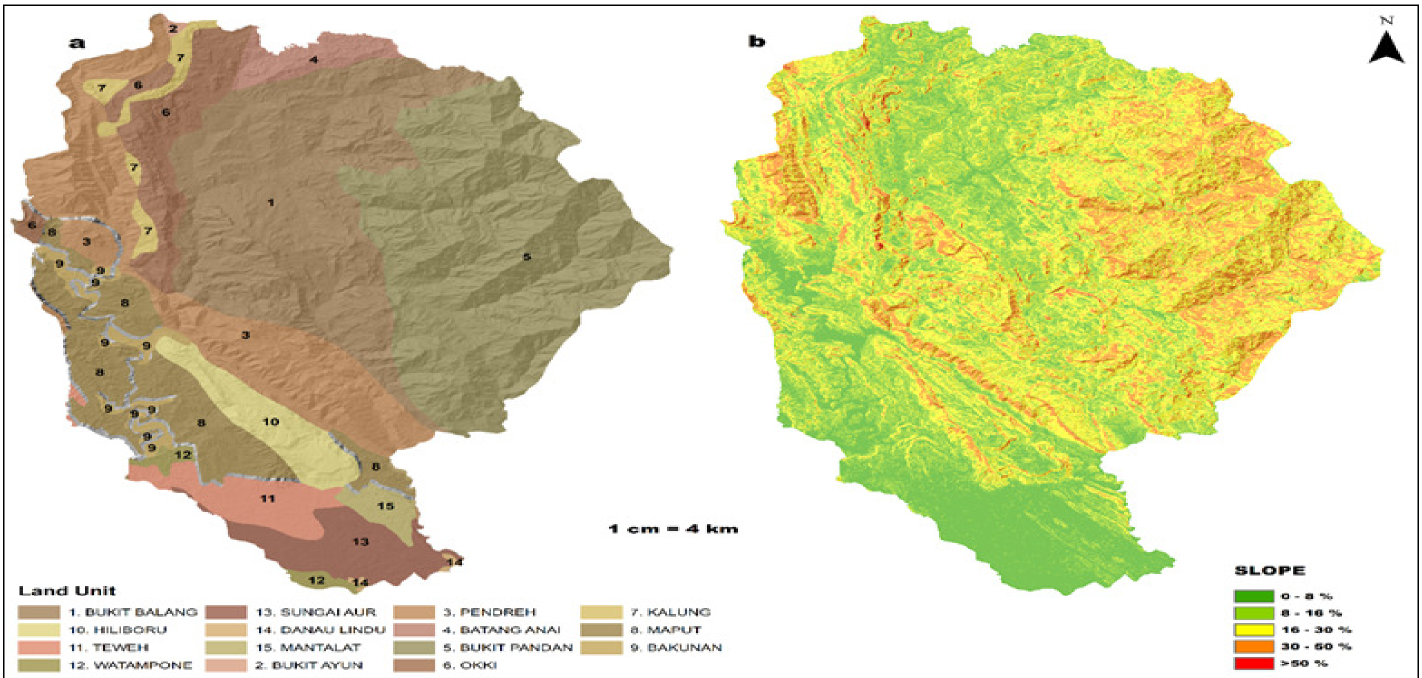


Fig. 2 : Land unit map (a) and slope map (b) of Enrekang

We used a land unit map as a references for soil sampling (Fig. 3a).The land unit map used was combined of the ecological principles relating to rock types, hydroclimate, landforms, soil, and organisms (Blasi, Zavattero, Marignani, Smiraglia, & Copiz, 2008). According to Zonneveld (1989), the survey results including the unit map, could be used as a basis for land evaluation. Based on these considerations, Enrekang land unit map was used as reference for soil sampling. The slope map was obtained from the 30 m digital elevation model (DEM) of SRTM image extraction. The Shuttle Radar Topography Mission (SRTM) provided information regarding the height of the place. The elevation recorded at the study site ranged from 25 to 3000 masl, and a slope of 4% to more than 50% (Figure 3b). Slope were essential factors to consider when preparing agricultural land, since they affected variability in the soil quality (Kravchenko & Bullock, 2000). Slopes were known to control the minerals and water movement that spatially contributed to the soil quality (Tsui, Chen, & Hsieh, 2004). They also aided in the diversity of soil requirements, intensity of erosion, and the drainage capacity (Seibert, Stendahl, &Sørensen, 2007). High-slopes resulted in nutrients been carried away by erosion (Ziadat & Taimeh, 2013).

D. Evaluation criteria

Evaluation criteria by Sys *et al*. (1993) were used as a basis for land suitability assessment and assisted in determining the specific use of a land. This assessment was based on the relationship between land-use requirements and land characteristics to provide maximum results. This study used a spatial approach with a fuzzy method. Materials and control points were summarized in Table 2.

Table 2 : Material and control point used in this study.

Variable	Material	LCP	B	UCP	d	Model Fuzzy	Weight**
Climate	Annual Precipitation	1200	1900		700	Model 4	**0.5**
	Length of dry season	-	0	4	4	Model 3	
	Annual temperature	21	26	-	5	Model 4	
	maximum temperature	-	28	31	3	Model 3	
Soil	Slope	-	0	30	30	Model 3	**0.5**
	Texture		1	4	3	Model 3	
	Soil Depth	50	200		150	Model 4	
	CEC	15	24		9	Model 4	
	Base saturation	20	50		30	Model 4	
	Sum of basic cations	1.6	8.8		7.2	Model 4	
	pH H2O	5	6.4		1.4	Model 4	
	Organic matter	0.7	2.5		1.7	Model 4	
Land Use						NoFuzzy	

LCP: Lower Cross point; b: optimal value; UCP: Upper cross point; model fuzzy 3: smaller is better; model fuzzy 4: bigger is better; weight**: weight of soil variable and climate variable

E. Variable selection

Minimum Data Set (MDS)

Variable selection with MDS used principal component analysis (PCA) to reduce data and chose the most appropriate indicators that could represent others in a component group (PC). Each PC had eigenvalue and the percentage variance, and each indicator had a factor loading value, which functions in explaining the data (Table 3).

Table 3 : Principal component analysis results

Variabel	Component	Eigen Value	Proportion (%)	Cumulative (%)
Soil	**1**	**2,707**	**33,120**	**33,120**
	2	**2,188**	**23,994**	**57,115**
	3	**1,568**	**23,654**	**80,769**
	4	0.745	9.312	90.081
	5	0.451	5.634	95.715
	6	0.256	3.200	98.915
	7	0.076	0.944	99.859
	8	0.011	0.141	100.000
Climate	**1**	**3.266**	**81.657**	**81.657**
	2	0.616	15.398	97.056
	3	0.097	2.429	99.485
	4	0.021	0.515	100.000

PCA was carried out on eight soil and four climate factors, for appropriate indicators to be selected. The bold values (Table 3) had eigenvalue larger than one and variance more than 10%. The components retained were components that have an eigenvalue more than one and have percentage variance of more than 10%. Based on these criteria, three components were selected from the soil variables and only one formed by climate variable (Table 3). PCA explained variables by grouping them into one group with the same characteristics, and MDS was elaborated more clearly in section 3.2.1.

Total Data Set (TDS)

In contrast to MDS, variable selection with TDS used all indicators that were considered essential to cocoa growth. Therefore, the eight soil and four climate variables used to evaluate the crop land suitability were as follows: soil depth, base saturation, sum of basic cations, pH H2O, slope, soil texture, rain, dry season, annual and maximum temperature, CEC, and organic matter. Land supervision was also included in this study to isolate areas that were not directly relevant.

F. *Indicator priority (Weight)*

Indicator priority (weight) was calculated after being selected, with a range of 0-1 and based on mathematical functions, and also considering the percentage variance of individual PC and the loading values of the indicators both TDS and MDS. The component variance explained how individual PC contributed to data interpretation, while the loading factor explained the correlation between indicators and their PC group (Armenise, Redmile-gordon, Stellacci, Ciccarese, & Rubino, 2013).

The weight of each indicator was calculated by:

$$W = \frac{|y_i|}{\sum |y|} \times m_i \qquad \text{... (1)}$$

yi was the loading factor of indicator *i*, $\sum y$ was the sum of the loading factors in the PCi group, *mi* was the percentage of component variance in PCi.

G. *Land suitability analyze*

Soil and climate variables were the regional characteristics assessed in this study, and consisted of several indicators, as described in Table 2. There were five suitability classes used as shown in Table 4.

Table 4 : Index and classes of land suitability used in this study.

Suitable classes	Index Suitable
S1 (highly suitable)	75.01 – 100.0
S2 (moderately suitable)	50.01 – 75.00
S3 (marginally suitable)	25.01 – 50.00
N1 (currently unsuitable)	12.51 – 25.00
N2 (permanently unsuitable)	0.00 – 12.50

Fig. 4 was a summary of the research framework. The stages of analysis were as follows:

1. Determining research indicators. The TDS and MDS selection method was used.
2. Preparing the digital maps to be processed in geographic information systems (GIS).
3. Standardizing the data and calculating the membership values for each indicator (Burrough, 1989):
$$MF(x_i) = [1 / (1 + \{(x_i - b) / d\}^2)] \qquad \text{...(2)}$$
Where MF (xi) was the membership function of each indicator, xi was the indicator's value i, b was the ideal point value, d was the width of transition zone / crossover point.
4. Calculating the weight of each indicator by considering the percentage component variance of their PC, and the factor loading value of all the variables, as explained in section 2.6
5. Calculating the Joint Membership Function (JMF) valueusing the combination function as follows:
$$JMF(X) = \sum_{i=1}^{n} \pi i \, MF(x_i) \qquad \text{... (3)}$$
JMF (X) was a joint membership function of the variables X, which consisted of the climate and soil variable.*Пi* was the indicator's weight i. MF (xi) was the membership value of indicator i.
JMF value indicated the soil quality index (SQI) and the climate quality index (CQI). It was the combined value of several indicators assessed in cocoa suitability analysis, and consisting of the climate and soil JMF (Baja et al., 2002)
6. Calculating land suitability index by multiplication function using the GIS. This resulted to spatial index with sustainable values.
$$LSI = JMF(S) \times JMF(C) \qquad \text{... (4)}$$

LSI was the land suitability index, JMF (S) was the joint membership value of the soil variable, and JMF (C) was the joint membership value of the climate variable.

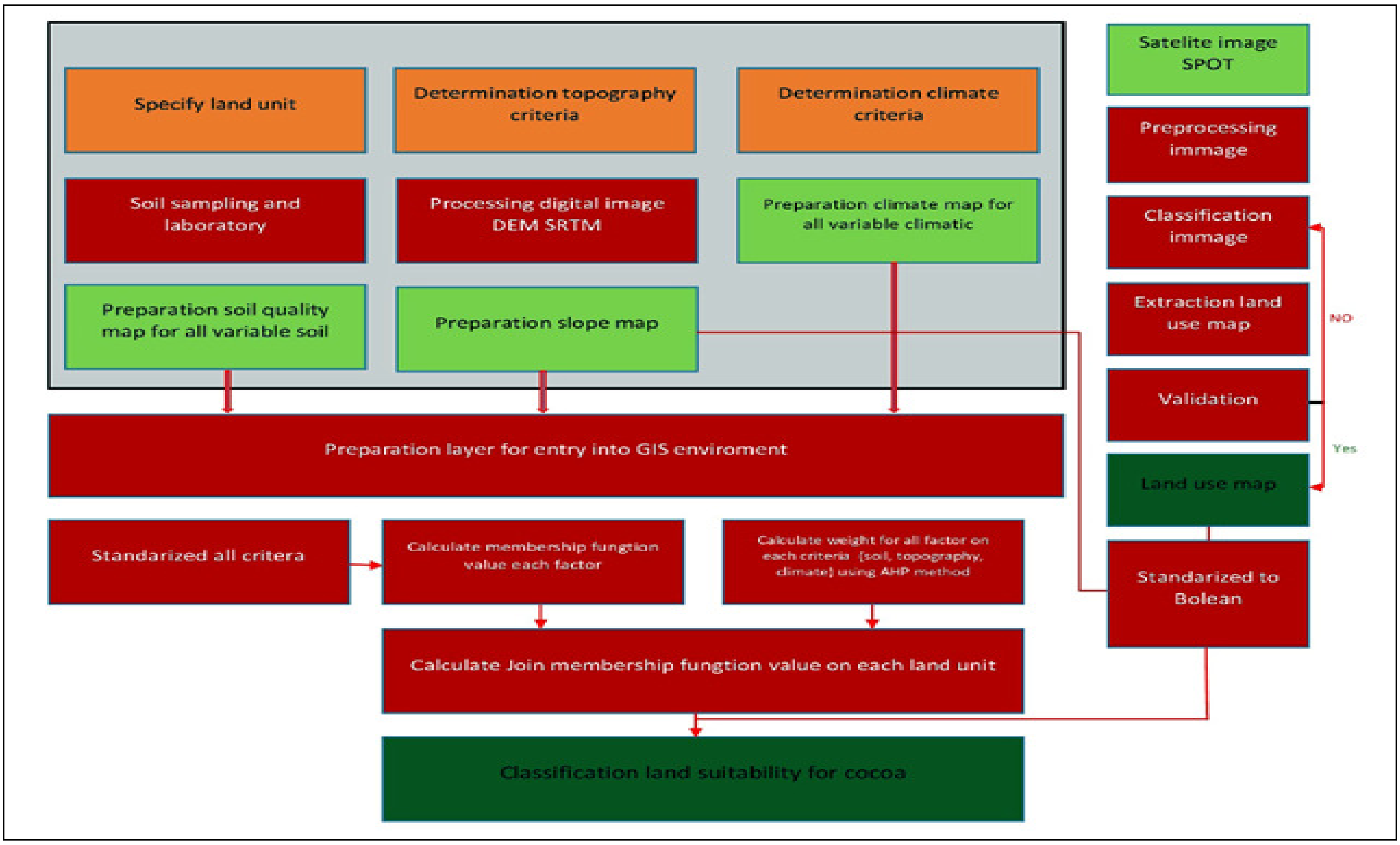


Fig 3. Land suitability mapping procedures

Results and Discussion

A. *Exploratory data analysis*

15 land units were surveyed, and 30 soil samples were taken for laboratory analysis which included: texture, pH, CEC, the sum of basic cations, base saturation, and SOM. The soil depth and slope information were analyzed directly during the survey. Descriptive statistics of all indicators used were summarized in Table 5.

Table 5 : The statistical description of land properties in Enrekang.

	Sd	Cec	Bs	Sum	pH	SOM	Prept	Ds	Antmp	Slope	Max
Sd		.323	-.386	-.177	.013	.469	.757**	-.392	.752**	-.660**	.676**
Cec	.323		-.267	.380	.142	.488	-.129	-.261	-.044	.271	-.111
Bs	-.386	-.267		.774**	.562*	.091	-.195	.045	-.151	.091	-.004
Sum	-.177	.380	.774**		.647**	.403	-.247	-.215	-.159	.276	-.086
pH	.013	.142	.562*	.647**		.561*	.042	-.328	-.010	.033	.037
SOM	.469	.488	.091	.403	.561*		.047	-.211	.051	-.006	-.017
Prept	.757**	-.129	-.195	-.247	.042	.047		-.512	.944**	-.730**	.906**
Ds	-.392	-.261	.045	-.215	-.328	-.211	-.512		-.579*	.084	-.529*
Ann tmp	.752**	-.044	-.151	-.159	-.010	.051	.944**	-.579*		-.658**	.970**
Slope	-.660**	.271	.091	.276	.033	-.006	-.730**	.084	-.658**		-.641*
Max tmp	.676**	-.111	-.004	-.086	.037	-.017	.906**	-.529*	.970**	-.641*	

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)
Sd: Soil Depth; Bs: Base Saturation; Sum: Sum of Basic Cations; SOM: Soil Organic Matter; Prept: Precipitation; Ds: Dry Season; Ann tmp: Annual Temperature;
Max tmp: Maximum Temperature

Low variance values on all soil and climate indicators (except the soil depth and precipitation) indicated insignificant spatial variability in the area studied. Based on laboratory analysis, the soil at the research site was acidic, with a pH ranging from 4.5 to 6 caused by the widespread use of inorganic fertilizers by farmers. Based on cocoa growth requirements, the pH had a marginal suitability level (S3).

SOM ranged from 0.68 - 2.46% and the mean average was 1.45%. The SOM less than 2% was relatively low (Grossman, 1996). In Enrekang, farmers continuously carry out agricultural activities, causing SOM decrement for plant growth. Furthermore, the drastic drop of SOM was as a result of the increase in cultivation activities: however, returning to native vegetation or planting permanent crops minimized this loss (West & Post, 2002).

Sum of basic cations (Ca, Mg, K, Na) had values that ranged from 4.1 - 8.88 cmol/kg with a mean average of 5.05 cmol/kg. Moderate precipitation (1300-2000 mm/year) made the basic cations to stick on the topsoil, preventing it from water percolation and resisting it from going down the horizon layer below.

Cation exchange capacity (CEC) values ranged from 12.14 - 21.25 cmol/kg with an average of 15.97 cmol/kg. Deforestation and Cultivation were the major problems in reducing CEC (Saikh, Varadachari, & Ghosh, 1998). Base saturation was the ratio between the sum of basic cations (Ca, Mg, Na, and K) and the number of CEC by colloidal soils, and inversely proportional to the CEC.

The texture and dry season used interval values of 1-5 where a value of 1 signified highly suitable, and 5 indicated permanently unsuitable. In general, the fuzzy parameter for texture values of the entire studied area were optimum (1.0).

Annual precipitation ranged from 1300 to 2000 mm/year, and the average of the dry season was 2 or 3 months per year. The annual temperature ranged from 22^o to 26^{o}C with maximum of 26^o - 30^{o}C.

The correlation of variables used shown in Table 6.

Table 6 : The correlation test of all individual land properties in Enrekang.

	Sd	Cec	Bs	Sum	pH	SOM	Prept	Ds	Antmp	Slope	Max
Sd		.323	-.386	-.177	.013	.469	.757**	-.392	.752**	-.660**	.676**
Cec	.323		-.267	.380	.142	.488	-.129	-.261	-.044	.271	-.111
Bs	-.386	-.267		.774**	.562*	.091	-.195	.045	-.151	.091	-.004
Sum	-.177	.380	.774**		.647**	.403	-.247	-.215	-.159	.276	-.086
pH	.013	.142	.562*	.647**		.561*	.042	-.328	-.010	.033	.037
SOM	.469	.488	.091	.403	.561*		.047	-.211	.051	-.006	-.017
Prept	.757**	-.129	-.195	-.247	.042	.047		-.512	.944**	-.730**	.906**
Ds	-.392	-.261	.045	-.215	-.328	-.211	-.512		-.579*	.084	-.529*
Ann tmp	.752**	-.044	-.151	-.159	-.010	.051	.944**	-.579*		-.658**	.970**
Slope	-.660**	.271	.091	.276	.033	-.006	-.730**	.084	-.658**		-.641*
Max tmp	.676**	-.111	-.004	-.086	.037	-.017	.906**	-.529*	.970**	-.641*	

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); Sd: Soil Depth; Bs: Base Saturation; Sum: Sum of Basic Cations; SOM: Soil Organic Matter; Prept: Precipitation; Ds: Dry Season; Ann tmp: Annual Temperature; Max tmp: Maximum Temperature

The soil depth had a strong positive correlation with precipitation and temperature, but had a negative correlation with slope. In chemical properties, pH had a moderate positive correlation with base saturation, COM, and the sum of basic cations.

B. Land suitability assessment

Minimum data set (MDS)

In MDS method, indicators were analyzed using factor analysis (FA) with the varimax rotation technique. Based on PCA results in Table 3, three soil and one climatic factor were used to explain most of the information obtained from the 12 original indicators for cocoa growth. When a "factor" had more than one indicator selected, correlation tests should be performed to choose indicators that were considered essential to be maintained as MDS indicators. Table 7 presented the rotated structures. The labelled factors which described the major indicator were as follows:

1. "Soil fertility" (PC1) was the most important factor, explaining 33% of the total cumulative variances and included four indicators: base saturation, the sum of basic cations, pH, and soil organic matter. After the correlation test, pH was chosen to represent soil fertility factors caused by high relationship among the 4 indicators.
2. "Water and nutrients storage" (PC2) explained 24% of the total cumulative variances and captured two indicators: soil texture and CEC. Based on the correlation tests, the two indicators did not correlate so both were included in the MDS indicators.
3. "Root growth" (PC3) explained 24% of the total cumulative variances and included two indicators: soil depth and slope. After the correlation test, the soil depth was chosen to represent "root growth".
4. For climate variables, only one factor explained 82% of the total variance, labelled "climate factor", and the annual temperature was included in the MDS indicators.

Table 7 : Rotated factor structure of land properties in Enrekang.

Soil variables				Climate variables	
Indicators	**Soil Fertility**	**Water And Nutrients Storage**	**Root Growth**	**Indicators**	**Climate Factor**
Base saturation	0,772	-0,430	-0,275	Precipitation	0,949
Sum of basic cations	0,888	0,164	-0,250	Dry season	-0,690
pH H_2O	0,883	-0,032	0,114	Annual temperature	0,983
Organic matter	0,608	0,481	0,417	Max temperature	0,961
Texture	0,219	-0,685	0,051		
CEC	0,228	0,867	0,047		
Soil depth	-0,050	0,349	0,907		
Slope	0,109	0,364	-0,86		

Note: Values in underline indicate the largest loading of each indicator among the factor labelled and values in bold are selected indicators to be included in the assessment based on TDS after correlation test.

Indicators were selected to the MDS method had the highest correlation among the indicators and considered to represent others in their respective PC groups. In some previous land suitability assessments, pH and CEC were chosen as MDS indicators of soil quality (Rahmanipour *et al.*, 2014; Seyedmohammadi, Sarmadian, Asghar, & Mcdowell, 2019). pH was the main influencer of soil systems, plants, and micro-organisms (Husson, 2013), and CEC was an excellent mineral for soil fertility (Fageria, Baligar, Clark, & Virginia, 2002). Depth as a physical indicator had an impact on root growth, porosity, bulk density, wilting point, and field capacity (Arévalo-gardini *et al.*, 2015). MF values of each indicator in MDS needed to be evaluated using equation (2). Four soil and one climate indicators were identified by their membership values as shown in Fig. 5.

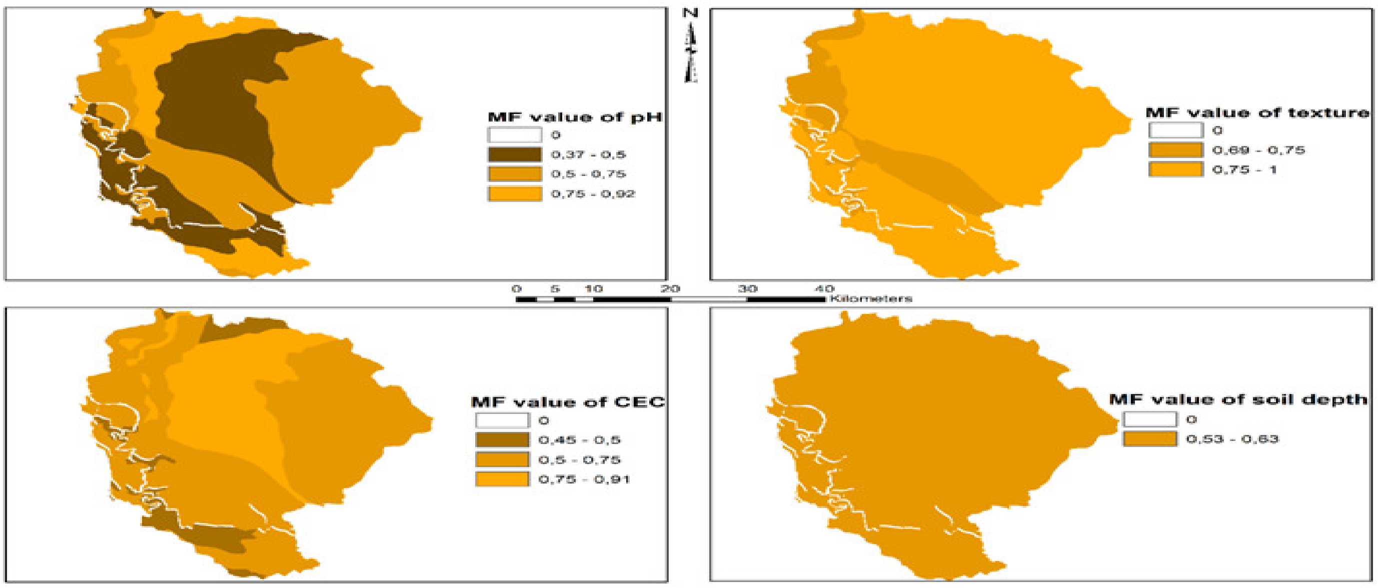


Fig. 5 : Spatial pattern of soil MF values used in MDS method

MF value indicated the quality of individual land attribute. Based on the results of the analysis, soil indicators were dominated by MF value of 0.5 to 0.75 and climate indicator was dominated by moderate and optimum quality for cocoa land suitability with MF values of 0.61 to 1. After assessing the quality of individual land attributes, the next step was to calculate the JMF value. Among the MDS factors used as input include pH, texture, CEC, soil depth and annual temperature. It was necessary to evaluate the weight (Table 8) of each factor before obtaining the JMF value.

Table 8 : Derived weights for each factor used in MDS selection indicators

Indicator selection	Index	Land unit														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
MDS	SQ	0.67	0.50	0.63	0.66	0.63	0.68	0.80	0.59	0.54	0.65	0.57	0.59	0.71	0.79	0.60
	CQ	0.61	0.61	0.61	0.74	0.61	0.61	0.61	0.74	0.61	1.00	1.00	0.74	1.00	1.00	1.00
TDS	SQ	0.74	0.62	0.68	0.73	0.69	0.68	0.83	0.70	0.65	0.70	0.69	0.68	0.75	0.84	0.73
	CQ	0.62	0.62	0.62	0.73	0.65	0.65	0.65	0.70	0.66	0.85	0.85	0.80	0.85	0.85	0.85

The weight was calculated based on equation (1) considering factor loading and percentage component variance. For soil factor, the highest weight was given for pH while texture was the lowest weight. Annual temperature was given an optimum weight of 1.

Land quality index denoted as JMF shown on Table 9. JMF value on each land unit was calculated by integrating MF values of each indicator using equation (3).

Table 9 : Land quality index in each land unit.

	Soil variable				Climate Variable
	Factor 1	Factor 2		Factor 3	Factor 4
	pH	Texture	CEC	Soil depth	Annual temperature
Component variance	33.120	23.994		23.654	81.657
Factor loading	0.883	-0.685	0.867	0.907	0.983
Weight	0.400	0.130	0.170	0.300	1.000

Research area had JMFs (soil quality index) of 0.5 - 0.79 and JMFc (climate quality index) of 0.61 – 1 (see Table 9). JMF values in each land unit indicated the land quality for cocoa growth. Based on the results, soil factor was dominated by moderate quality, while climate factor was influenced by moderate and optimum requirement for cocoa land appropriation.

Total data set (TDS)

In TDS, all the important indicators were used for the research. 13 indicators were utilized as shown in Table 2. MF values of the 13 variables were calculated based on equation (2) using indicator attribute value (xi), the ideal point value for plant growth (b), and the transition zone value of each indicator (d). MF values described the quality of individual indicators shown in Fig. 6. MF soil attribute was dominated with moderate requirements, while its climate values were majorly influenced by the average optimum quality (ranging from 0.58 to 1) for cocoa land suitability. Table 10 showed the weight used in TDS which were derived from equation (1), while the JMF values were calculated using equation (3).

Table 2 : Derived weights for each indicator used in TDS selection indicators.

Variable	Indicators	Component variance	Factor loading	Weight
Soil	Base saturation	33.120	0.772	0.10
	Sum of basic cations		0.888	0.11
	pH H_2O		0.883	0.11
	Organic matter		0.608	0.08
	Texture	23.994	-0.685	0.13
	CEC		0.867	0.17
	Soil depth	23.654	0.907	0.15
	Slope		-0.860	0.15
Climate	Precipitation	81.657	0.949	0.25
	Dry season		-0.690	0.19
	Annual temperature		0.983	0.27
	Max temperature		0.961	0.27

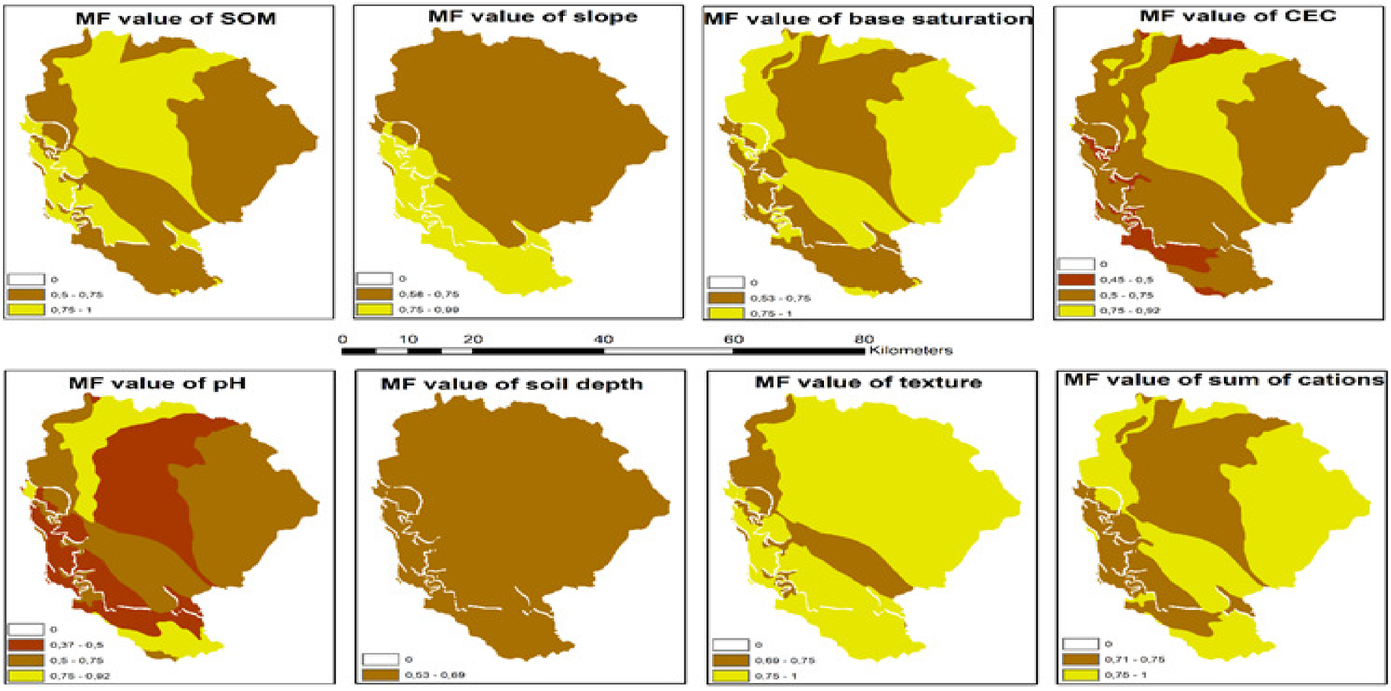


Fig. 6 : Spatial pattern of soil MF values used in TDS method

The highest weights for soil variables were found in CEC (0.17), depth (0.15), and slope (0.15), while the lowest was observed in SOM (0.08). In climate variables, the highest weight was the annual and maximum temperature (0.27), while the lowest was the dry season (0.19). JMF values for soil variables ranged from 0.62 to 0.84, and the climate variables ranged from 0.62 to 0.85 (see Table 9). Integrated JMF values of soil and climate using equation (4) produced LSI by assigning equal weights (0.5) to the two variables. LSI and two land suitability classes using TDS were shown in Fig. 7.

Discussion

SQI and CQI represented by JMF values ranged from 0 to 1, the same as in LSI. In assessing LSI, its weight was the critical issue. The weight accuracy depends on the ratio consistency. Research showed the consistency ratio of 0.06 should be lower than the threshold value of 0.1 for it to be accepted. The index units moving closer to 1 indicated high suitable value. Final map land suitability of cocoa in Enrekang shown on Figure 8.

Based on the analysis, 12.18% (21770 ha) signified highly suitable while 87.82% (156912 ha) denoted moderately suitable, which influenced the land for cocoa production. In the final suitability assessment (Fig. 8), land that covered the areas in the forest, rice fields, settlement, dryland farming, and river became the limiting factors. They were assessed by Boolean logic with a value of 0. 80% (144888 ha) of the studied area were found to be dominated by these factors, while 95% (20675 ha) of the highly suitable parts were also influenced, and 78% (121694 ha) of the marginally suitable areas were dominated by limiting factors. The results (Table 11) showed that only two classes; highly and marginally suitable. Suitability classes in MDS were similar in TDS, though with different index value. These values decreased with ten land units (1,2,3,4,5,6,7,8,9 and 12) using MDS, which signified that the fewer the indicators used, the lower the index value. With the five land units (10,11,13,14, and 15), the points increased due to the high climate index on the land, which denoted that LSI was also influenced by indicators' quality.

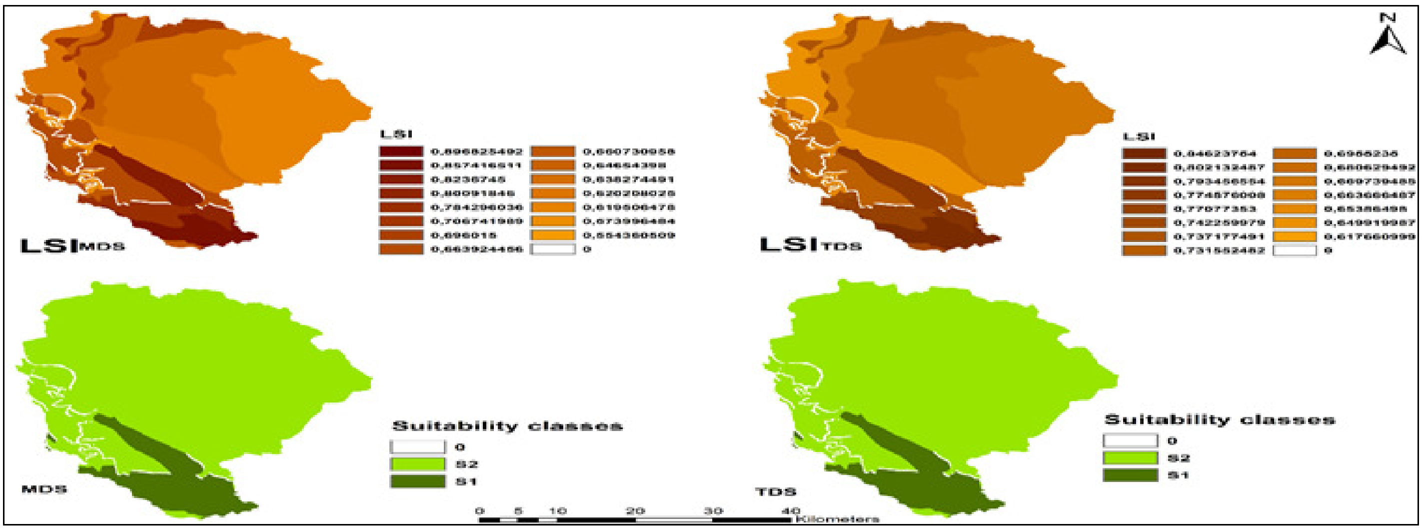


Fig. 7 : Cocoa land suitability map before removing the LULC.

Table 11 : Index and classes land suitability of cocoa in Enrekang.

		Land unit														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Index	MDS	0,64	0,55	0,62	0,70	0,62	0,65	0,71	0,66	0,57	0,82	0,78	0,66	0,86	0,90	0,80
	TDS	0,68	0,62	0,65	0,73	0,67	0,66	0,74	0,70	0,65	0,77	0,77	0,74	0,80	0,85	0,79
Class	MDS	S2	S2	S2	S2	S2	S2	S2	S2	S2	S1	S1	S2	S1	S1	S1
	TDS	S2	S2	S2	S2	S2	S2	S2	S2	S2	S1	S1	S2	S1	S1	S1

Table 12 indicates whether the MDS or TDS is a good fit, and compare means using a multivariate test conducted to assess the effectiveness of the method used for its ability to distinguish the quality indicators in S1 and S2 regions. For investigation of mapping unit's segregation accuracy, the Hotelling test was conducted, and the corresponding P indicated that the regions were significantly different both with MDS and TDS method. The fuzzy models used were all statistically accurate and the indicators in the S1 and S2 regions were separated.

Table 12 : Comparison mean of all indicators used in TDS and MDS.

TDS				MDS		
Indicators	**S1**	**S2**		**Indicators**	**S1**	**S2**
Soil depth	90.00	67.00		Soil depth	90.00	67.00
Texture	1.00	2.00		Texture	1.00	2.00
CEC	16.06	15.93		CEC	16.06	15.93
Base saturation	31.60	34.50		pH	5.24	5.24
Sum of basic cations	5.40	5.00		Annual temperature	26.00	22.00
pH	5.24	5.24				
Organic matter	1.52	1.41				
Precipitation	1920.00	1370.00				
Dry season	2.00	3.00				
Annual temperature	26.00	22.00				
Slope	10.00	19.00				
Maximum temperature	30.00	26.00				
Hotelling's trace value = 154.29. F = 25. dfH = 12. dfE = 2. P = 0.01				Hotelling's trace value = 26.82. F =48. dfH = 5. dfE = 9. P = < 0.001		

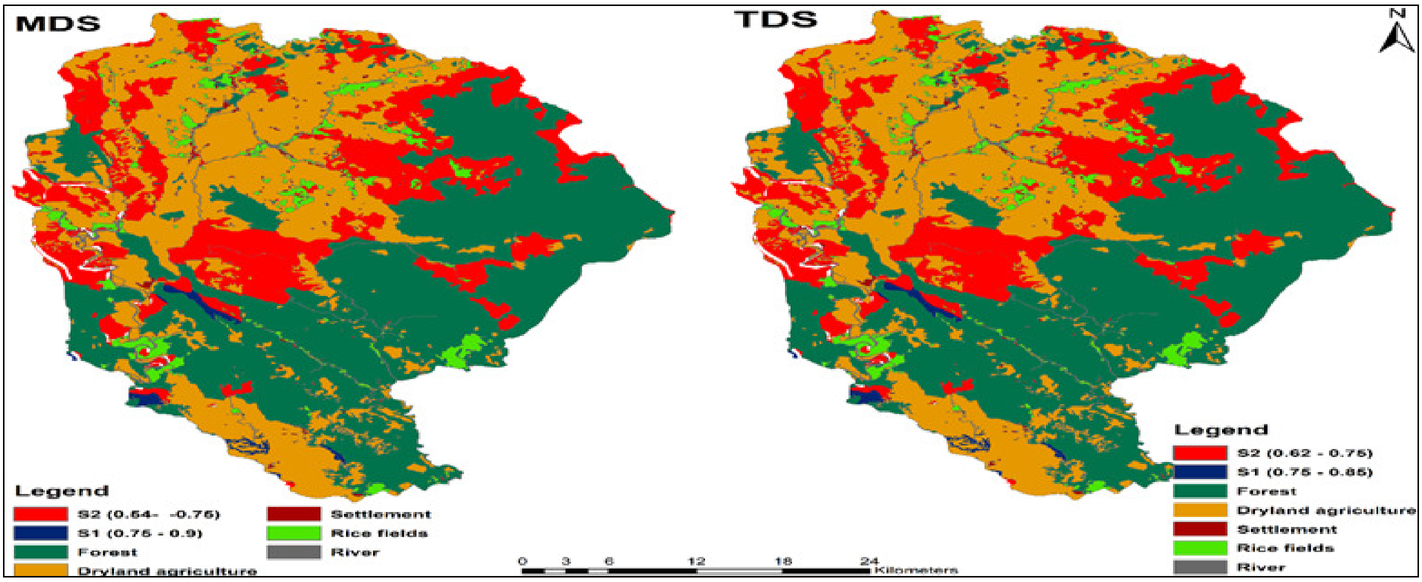
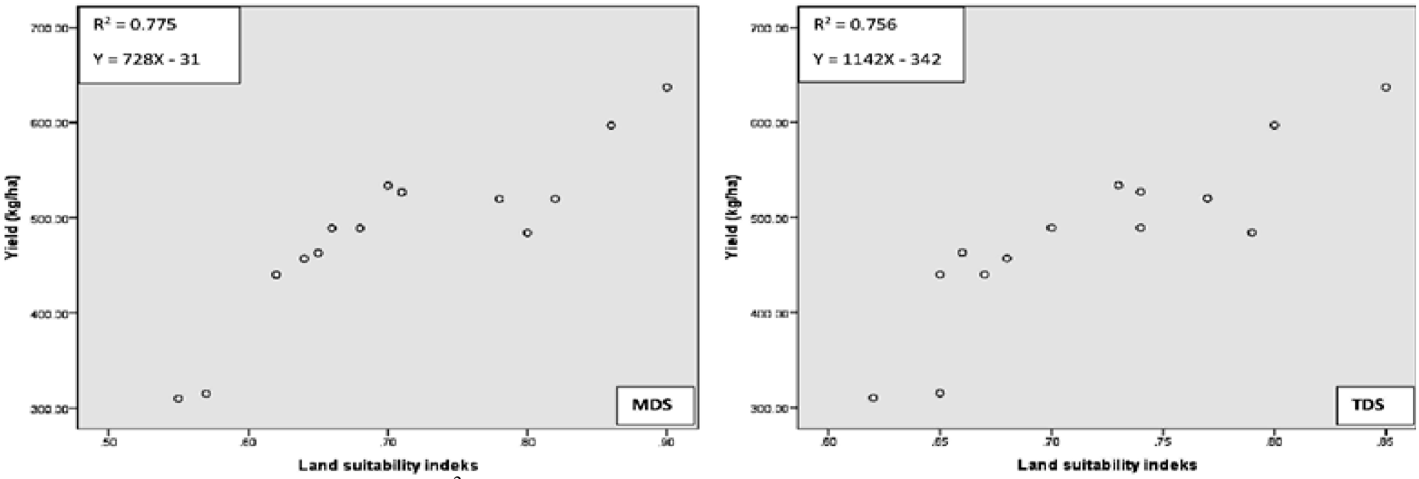


Fig. 8 : Final map of cocoa land suitability in Enrekang.

The relationship between land suitability index and the cocoa produced was calculated by the coefficient of determination (R^2). Plots on MDS and TDS showed positive linear curves with $R^2 > 0.75$ (see Fig. 9). The curve indicated that an increase in the value of the land index increases the land production. However, the R^2 of 0.75 on TDS and MDS means that there were still other factors that affected the land production. To assess the fuzzy model performance using MDS compared with TDS, the coefficient of determination (R^2) of the land suitability index was calculated. The results showed R^2 of 0.95 using TDS and R^2 0.94 using MDS, and indicated no big difference between them in explaining data. Therefore, MDS became a recommendation for selecting indicators for cost and time efficiency in land suitability assessment, reducing the number of research indicators, and providing adequate land suitability assessment.



TDS, the coefficient of determination (R^2) of the land

Fig. 9 : Linear regression between LSI and cocoa yield

Conclusion

This study aims to assess land suitability with two methods for selecting indicators: TDS and MDS. The results from a cultivated land show that 1096 ha and 35218 ha signifies highly and moderately suitable land for cocoa production The fuzzy set shows the similarity between the suitability classes of TDS and MDS. The weights of the important indicators were calculated using a simple mathematical formula to determine their relative priorities. The following features such as reducing the number of research indicators and providing adequate land suitability assessment, makes MDS a recommendation for selecting indicators for cost and time efficiency. The multivariate test was conducted to assess the effectiveness of the methods used, and their abilities to distinguish between soil and climate indicators in regions with suitability classes S1 and S2. When the corresponding P is > 0.01 or below the threshold value of 0.05. This indicates significant difference in quality of indicators in both regions. The approaches used in this study adequately distinguish the land suitability classes and can be applied to the assessment of other plant species.

Future Scope

This study compares the results of land suitability analysis using the fuzzy method with two indicators selected; TDS and MDS. The final result of land suitability is calculated using only the classical method by applying raster multiplication between soil and climate variables. Therefore to improve research accuracy, in the future it is necessary to compare several methods of calculating land suitability index.

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