Agriculture Land suitability analysis evaluation based multi criteria and GIS approach

Goma Bedawi Ahmed[1, 2*], Abdul Rashid M. Shariff [1], Siva Kumar Balasundram [3], Ahmad Fikri bin Abdullah[4]

1- Geospatial Information Science Research Centre (GISRC), University Putra Malaysia
2- Arab Center for Desert Research and Development of Desert Communities Morzok- Libya
3- Department of Agriculture Technology, University Putra Malaysia
4- Department of Biological and Agricultural Engineering, University Putra Malaysia
E-mail: joma762001@gmail.com

Abstract. Land suitability evaluation (LSE) is a valuable tool for land use planning in major countries of the world as well as in Malaysia. However, previous LSE studies have been conducted with the use of biophysical and ecological datasets for the design of equally important socio–economic variables. Therefore, this research has been conducted at the sub national level to estimate suitable agricultural land for Oil palm and Rubber crops in Seremban, Malaysia by application of physical variables in combination with widely employed biophysical and ecological variables. The objective of this study has been to provide an up–to date GIS-based agricultural land suitability evaluation (ALSE) for determining suitable agricultural land for Oil palm and Rubber crops in Malaysia. Biophysical and ecological factors were assumed to influence agricultural land use were assembled and the weights of their respective contributions to land suitability for agricultural uses were assessed using an analytic hierarchical process. The result of this study found, Lenggeng, Setul, and part of Pantai Setul, and Rantau as the most suitable areas for cultivating Oil palm; whereas, Rasah, Ampangan, are moderately suitable for growing Oil palm., Labu, Rantau and Seremban are not suitable for growing Oil palm as the study foresaw potential environmental degradation of these locations from agricultural intensification. For Rubber Lenggeng, Pantai, Setul as the most suitable areas for cultivating Rubber; whereas, are Ampangan, Seremban, Rasah, and Rantau are moderately suitable for growing rubber. Since Seremban, Labu, and Pantai are not suitable for growing rubber while this study could be useful in assessing the potential agricultural yields and potential environmental degradation in the study area, it could also help to estimate the potential conversion of agricultural land to non–agricultural uses.

1. Introduction

The growing population numbers, acutely in developing countries, has intensified the pressure on both natural and agricultural resources. To meet the economic demands of the growing world population, an increased economic return is required. Both population increases and the process of urbanization have increased the pressure on agricultural resources [1]. This increased pressure on the available land resources may result in land degradation [2]. Dependable and accurate land evaluation is, therefore, indispensable to the decision-making processes involved in developing land use policies that will support sustainable rural development. If self-sufficiency in agricultural production is to be achieved in developing and transitional countries, land evaluation techniques will be required to develop models for predicting the land's suitability for different types of agriculture [3].

Multi-criteria evaluation processes are already used in some regional planning processes since they aim at ‘‘estimating the potential of land for alternative land uses; among which, the agricultural land use may be the most important area where it is applied’’ [4]. This method could play a key role in future land-use planning [4, 5]. Agricultural land suitability classification based on indigenous knowledge is vital to land use planning. The systematic assessment of land and water potential aims to identify and put into practice future alternative land uses that will best meet the needs of the people while at the same time safeguarding resources for the future [6].

The land evaluation method is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crop. Theoretically, the potential of land suitability for agricultural use is determined by an evaluation process of the climate, soil, water resources and topographical, as well as the environmental components under the criteria given and the understanding of the local biophysical restraints [7]. The use of GIS Multi-Criteria Decision Making (MCDM) methods allows the user to derive knowledge from different sources in order to support land use planning and management [7, 8]. One multi-attribute technique that has been incorporated into the GIS-based land use suitability procedure is the Analytical Hierarchy Process (AHP) [9, 10]. MCDM methods, such as the AHP method, have been successfully applied to land evaluation techniques [11]. These methods, which aim to allow for a transparent decision-making base, are, however, only rarely used in developing and transitional countries such as Malaysia. We have used a GIS-based MCDM land suitability analysis method to classify the study area (Seremban District) with respect to the potential for Oil palm and Rubber cultivation. We assumed that this goal could effectively help agricultural insurance through the identification and separation of land-based capabilities with regards to environmental, Biophysical and Socio-economical potential.

2. Multi-criteria decision making MCDM approaches

Multi-criteria decision making MCDM approaches were developed in the 1960s in order to assist decision makers in incorporating numerous options, reflecting the opinions of concerned parties into a potential or retrospective framework. This framework is ‘‘primarily concerned with how to combine the information from several criteria to form a single index of evaluation’’ [10]. They were designed to define the relationship between data input and data output. The integration of the GIS and MCDM methods provides powerful spatial analysis functions[12, 13]. In the MCDM approach, GIS is best suited for handling a wide range of data criteria at multi-spatial, multi-temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating the GIS capability with MCDM processes[14].

The Analytical Hierarchy Process is a well-known multi-criteria technique that has been incorporated into GIS-based suitability procedures [10]. For the classification of land suitability within our case study area in Seremban, we utilized the AHP’s ability to incorporate different types of input data, and the pairwise comparison method for comparing two parameters, simultaneously. The application of the AHP process involves several steps in order to rank Criteria or factors to the set of suitable criteria. This is usually achieved by domain and experts’ opinions: The consistency of the overall set of pairwise comparisons is assessed using its Consistency Ratio CR).

One of the most important factors affecting the land suitability classification for cultivation is soil properties. The soil properties’ criteria consist of soil texture, surface stoniness, soil depth, pH, EC, soil phosphorus, Potassium and organic matter.

3. Materials and Methods

3.1. Study area

Seremban city is the largest district and the capital of the Negeri Sembilan State. The study area is located between longitudes (101o 45' 0'' E and 102o 6' 0'' E) and latitudes (3o 0' 0'' N and 2o 30' 0'' N). The city occupies a total land area of approximately 935.78 sq. km. Seremban City includes the districts of Seremban, Setul, Labu, Rasah, Ampangan, Rantau, Pantai and Lenggeng (Fig. 1). Seremban is located at about 20 kilometers from Putrajaya, which is considered the national capital of Malaysia, and at about 67 kilometers from Kuala Lumpur, the economic center of Malaysia.

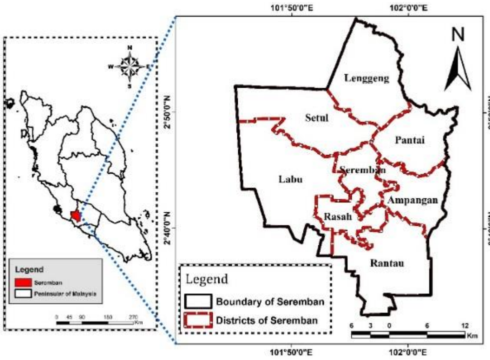
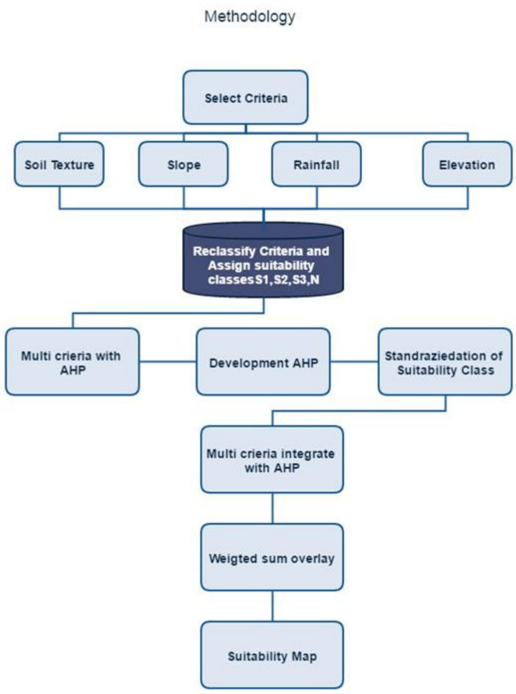


Figure 1. Location of the study area, Seremban district.



3.2 Methodology

Figure 2. Flowchart of methodology.

3.3 Data collection and preparation using GIS

For the Data Preparation for the Spatial Analysis, geographical, climatic, proximity and socioeconomic factors that influence land suitability for agricultural uses were aggregated in this study [15]. All these factors constitute the criterion maps; and, the maps were projected to the same scale, boundary extent, resolution and spatial reference before they were standardized to a cell size of 300 m and UTM Zone 47N projection.

3.3.1Soil

Landform data for the study area were derived from the 1:50 000 topographic map of Peninsular Malaysia (JUPEM, 2010). The soil characteristic was acquired from the data supplied by the Malaysian department of Agriculture (2010). The original landform and soil data were obtained in vector format and were converted into 300m raster data after they were clipped to the boundary of the study area.

3.3.2 Slope

The slope data were derived from the 1:50 000 contour data using the method described by (Deng, 2011). The slope dataset was re-classified based on the NPP classification sequence to represent different suitability situations.

3.3.3 Climatic factor

Climate variables were aggregated based on the annual averages. Kriging interpolation was used to determine the spatial approximations and to calculate the value of the variables for each grid.

4. Suitability Classification

This study used the four levels of (Table 2) [highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N)] suitability classes commonly used by the Food and Agricultural Organization (FAO, 1976)[16]. A complex decision problem was decomposed into its constituent criteria. The criteria were, therefore, prioritized according to their relative importance within each level.

Table 1. Classes of suitability *Source[16]*.

Code	Class	Description
S1	Highly suitable	land having no significant limitation for agricultural productivity
S2	Moderately suitable	land having some limitations that are severe for sustained productivity
S3	Marginally suitable	land with major limitations for sustained agricultural productivity
N	Unsuitable	land with extreme limitations for sustained agricultural productivity

4.1. Generation of the Criterion Maps

The criterion maps were classified into four classes (Table 1). Raster layers have numerical values 4, 3, 2 or 1, which represent S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).

4.2. Standardization of the criteria

The process of setting the relative importance of each criterion is known as the standardization of the criteria [10]. In this process, scales of 0 to 1, 0 to 10 or 0 to 100 (etc.) are normally used for the criteria standardization. A pairwise comparison technique is typically used for rating and standardizing the ordinal values. In order to compare the criteria with each other, all values needed to be transformed to the same unit of measurement scale (from 0 to 1).

Table 2. Scales for the pairwise AHP comparisons[10] .

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

4.3. Selection of the Criteria

Four criteria were selected for evaluating the agricultural land suitability in the study area (Table 3). These criteria were selected based on an extensive literature review of potential factors affecting agricultural land use and a review of the recommendations of the Malaysian National Physical Plan[15] .

Table 3. Weighting matrix for the main criteria and sub criteria for oil palm and Rubber.

No.	Criteria	Oil palm Weight	Rubber Weight
1	Elevation	0. 584	0.059
2	Soil series	0.061	0.42
3	Slope	0.215	0.048
4	Soil texture	0.061	0.42
5	Rainfall index	0.079	0.049
Total	-	1	1

4.4. Weighing of the criteria

Criterion weights are the weights assigned to the objective and attribute maps. Deriving weights for the selected map criteria (land characteristic map layers) is a fundamental requirement for applying the AHP method. For determining the relative importance of the criteria, the pairwise comparison matrix using Saaty's nine-point weighing scale was applied (Table 2).

Table 4 Land suitability requirements for oil palm based on land qualities..

			Suitability class and rating scale		
Land qualities	S1		S2	S3	N
	100	95	85	60	40
Workability	Very good	Good	Moderate	Poor	Very poor
Availability of foothold for roots coarse fragment volume (%)	0-5	6-15	16-35	36-75	> 75
Water availability (%)	85	85-70	70-60	60-50	< 50
Oxygen availability drainage class	Well drained	Moderately well drained	Imperfectly drained	Poor (easily drained)	Poorly (difficult to very poor to drained)
Nutrient availability					
Ca (cmol (p +) kg^{-1} soil)	> 2.6	2.5-1.5	< 1.5		
Mg (cmo (p +) kg^{-1} soil)	> 0.6	0.5-0.4	< 0.4		

K (cmol (p +) kg^{-1} soil)	> 0.2	0.2-0.1	< 0.1		
CEC (cmol (p +) kg^{-1} soil)	> 10	10-8	8-6	< 6	
Organic carbon (%)	> 2	1.9-1.0	< 1.0		
pH (H_2O)	> 5.5	5.5-4.2	4.1-4.0	3.9-3.5	< 3.5

Table 5 Land suitability requirements for oil palm based on land qualities.

Agro–suit classes	S1	S2	S3	N
Annual Rainfall (mm/yr)	2500 - 4000	>4000	2000 – 5000	<1500
Dry month	<1	<1	2	>2
Land drainage	Well	Somewhat excessive Moderately well	Somewhat excessive	Very poor, poor Excess drain
Texture	SaL., L, SaCL, SiL, CL, Si, SicL	Lsa, SaC	C, SiC	Gravel, sand, massive clay, peat
Soil depth	>200	130 – 120	80 – 130	<80
Slope %	< 10	10 – 37	37 – 47	>47

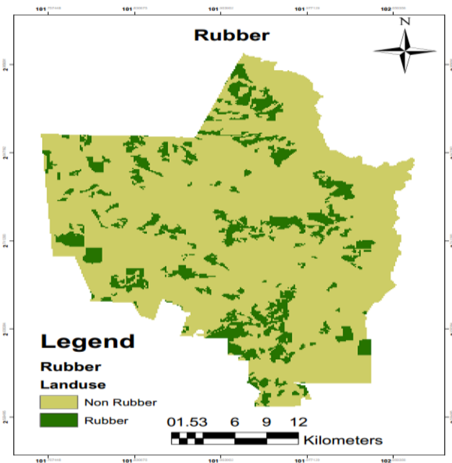


Figure (3) rubber plant

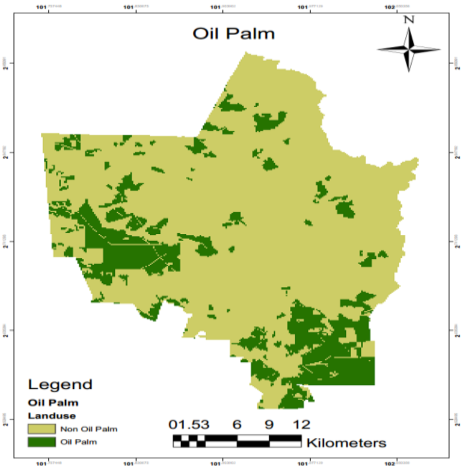


Figure (4) oil palm plant

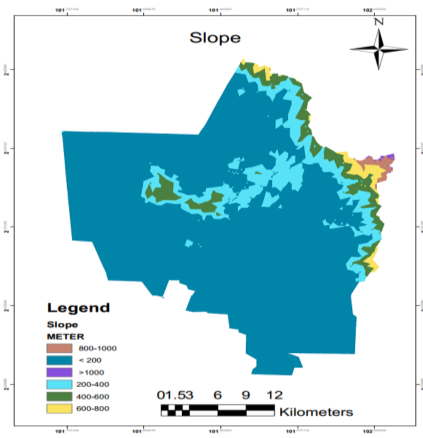


Figure (5) slope

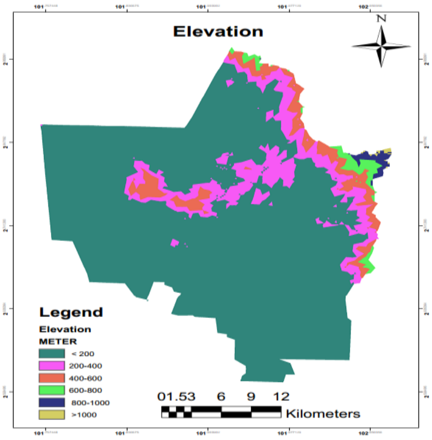


Figure (5) Elevation

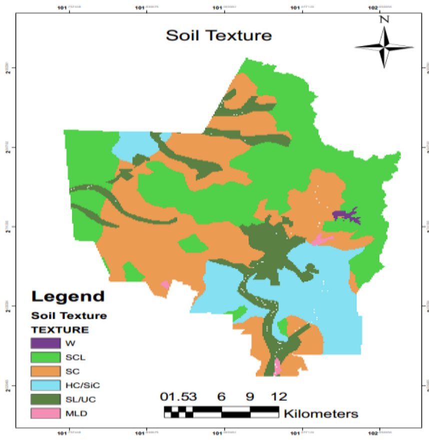


Figure (6) Soil Texture

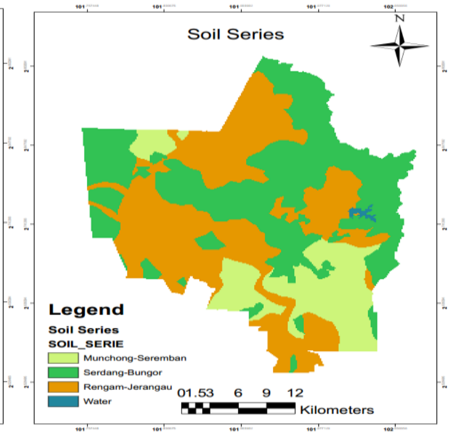


Figure (7) Soil Series

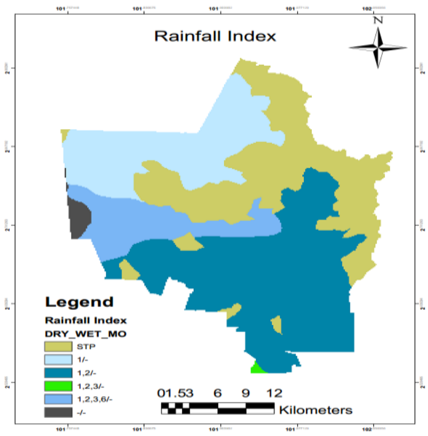


Figure (8) Rainfall Index

4.5. Overlaying map layers

The weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis. After weighing of the criteria, regarding their importance for the land suitability analysis, all the criteria maps were overlaid using a suitability index.

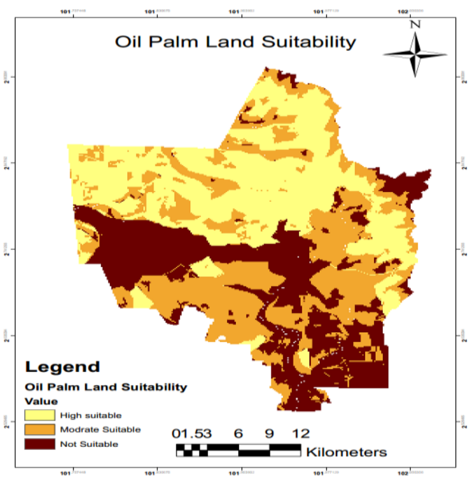


Figure (9) Oil palm land suitability

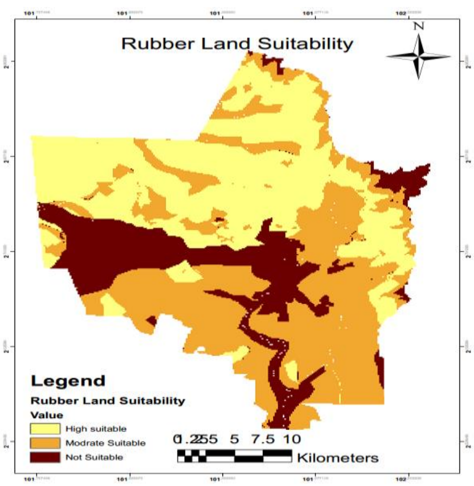


Figure (10) Rubber land suitability

5. Results & Discussion

The weight was derived for each of the independent variables as obtained from the analytical hierarchical process (AHP) for both rubber and oil palm presented in Table 3. For the Rubber, Elevation was the most important factor affecting Rubber land suitability; whereas, Soil series had less weight, and slope and rainfall had an equal effect on rubber in the study area.

The area of (Lenggeng, Setul, and Pantai) parts of the district are the most suitable locations for cultivating Rubber; whereas, the (Ampangan, Seremban, and some part of rash and Rantau) have been found to be moderate suitable for Rubber. The North- eastern parts (Ampangan, Lenggeng) of the district are not suitable for rubber cultivation (Figure 10).

Elevation and slope weigh most important factor for oil palm whereas soil series, soil texture and rainfall index less important for oil palm. The area of (Lenggeng, Setul, and some part of Pantai) of the district are the most suitable locations for cultivating Oil palm; whereas, the (Ampangan, Rash, and some part Labu) have been found to be moderate suitable for oil palm. The North- south parts (Labu, Seremban rash) of the district are not suitable for oil palm cultivation (Figure 9).

This shows the potential of such areas being over exploited for agricultural purposes and the impending environmental implications of this practice. This study showed the potentially sustainable agricultural land use in the study area after the exclusion of locations that are prone to topsoil erosion. The analysis of the current agricultural land use in Seremban, Malaysia indicated that land is mostly being not used for what it is exactly suited for. However, there exists some challenges in the future agricultural land use in the district. For instance, the land that has been shown as less suitable and not suitable for oil palm cultivation might be suitable for different crops, such as Rubber in the Seremban district.

6. Conclusion

This study has revealed the potential agricultural land in Seremban, Malaysia. Unfortunately, available evidence showed that some of these agricultural lands are being taken up by non – agricultural uses and this has a potential of negatively affecting the country's economics. On the other hand, the scenario could create a situation where the country may be achieving its food security at greater economical and environmental costs. For crops to be matched with the biophysical conditions, the biophysical variables (climatic, geomorphological, and number of rainy days, average temperature, and relative humidity) of the study area were collected to enable the interpretation of the climatic variables with reference to their suitability for specific crop production. The climatic adaptability of crops forms the basis of defining the crop-climatic requirements.

References

[1] S. A. Abdullah and A. A. Hezri, "From forest landscape to agricultural landscape in the developing tropical country of Malaysia: pattern, process, and their significance on policy," *Environmental Management*, vol. 42, pp. 907-917, 2008.

[2] A. P. D. Aguiar, G. Câmara, and M. I. S. Escada, "Spatial statistical analysis of land-use determinants in the Brazilian Amazonia: Exploring intra-regional heterogeneity," *Ecological modelling,* vol. 209, pp. 169-188, 2007.

[3] E. Attual and J. Fisher, "Land Suitability Assessment for Pineapple Production in the Akwapim South District, Ghana:. A GIS-MultiCriteria Approach," *Ghana Journal of Geography,* vol. 2, pp. 47-84, 2014.

[4] J. Malczewski, *GIS and multicriteria decision analysis*: John Wiley & Sons, 1999.

[5] J. Malczewski, "GIS-based land-use suitability analysis: a critical overview," *Progress in planning,* vol. 62, pp. 3-65, 2004.

[6] O. Marinoni, "Implementation of the analytical hierarchy process with VBA in ArcGIS," *Computers & Geosciences*, vol. 30, pp. 637-646, 2004.

[7] A. MashayekhanA and A. S. MahinyB, "A Multi-Criteria Evaluation approach to Delineation of Suitable Areas for Planting Trees (Case Study: Juglans regia in Gharnaveh Watershed of Golestan Province)," *Journal of Rangeland Science*, vol. 1, 2011.

[8] V. Meyer, D. Haase, and S. Scheuer, "A multicriteria flood risk assessment and mapping approach," 2009.

[9] H. Pourkhabbaz, S. Javanmardi, and H. Faraji Sabokbar, "Suitability Analysis for Determining Potential Agricultural Land Use by the Multi-Criteria Decision Making Models SAW and VIKOR-AHP (Case study: Takestan-Qazvin Plain)," *Journal of Agricultural Science and Technology*, vol. 16, pp. 1005-1016, 2014.

[10] T. L. Saaty, "The Analytic (Hierarchy) Process, New York, St," *Louis ua*, 1980.

[11] C. HUYNH VAN, "MULTI-CRITERIA LAND SUITABILITY EVALUATION FOR SELECTED CROPS USING GIS AT COMMUNITY LEVEL IN CENTRAL VIETNAM," 2008.

[12] H. Van Chuong, "MULTICRITERIA LAND SUITABILITY EVALUATION FOR CROPS USING GIS AT COMMUNITY LEVEL IN CENTRAL VIETNAM."

[13] H. Voogd, *Multicriteria evaluation for urban and regional planning*: Taylor & Francis, 1983.

[14] F. SarmadianA, A. KeshavarziA, B. RajabpourA, and S. AskariA, "Application of MCDM method in fuzzy modeling of land suitability evaluation," in *19th World Congress of Soil Science*, 2010.

[15] M. M. S. MALAYSIA, "Department of Statistics, Malaysia," 2014.

[16] A. FAO., *A framework for land evaluation*: Food and agriculture organization of the United Nations, 1976.