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Assessing and Mapping Land Suitability Units for Maize (*Zea mays* L) Production Using Integrated DEMATEL-ANP Model and GIS in the Foumbot Agricultural Basin (Cameroon Western Highlands)

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Abstract

Land suitability assessment (LSA) is an essential step in the process of determining environmental limits for sustainable crop production. Up to date, studies on LSA for crop production in Cameroon have been based on empirical methods which are limited as they consider similar singnificance levels for all evaluation criteria and do not consider the interrelationships of criteria in the best-fit models. In the present study a qualitative land suitability evaluation by an integrated multi-criteria decision-making (MCDM) approach and geographic information system (GIS) was tested to assess and map suitable land units for maize (*Zea mays* L) production in Cameroon Western highland. Eight environmental criteria identified as the most relevant for maize production in the area of interest (AOI) saw their thematic maps prepared using ArcGIS 10.8. The relationship between criteria was considered by the DEMATEL method. The criteria were weighted using the ANP method. Thereafter, the land suitability map was obtained using the weighted overlay analysis (WOA) in ArcGIS. The results obtained indicated that slope has the highest specific weight and consequently the greatest influence on land suitability for maize production in the locality. The land suitability map generated showed that Foumbot's agricultural land suitability for maize production varies from very high to marginally suitable (99% of the surface area). Specifically, 11% (8056 ha) is very highly suitable, 29% (21,119 ha) is highly suitable, 38% (27,405 ha) are moderately suitable and 20% (14,422 ha) are marginally suitable. The remaining 1% that falls under non suitable class represents 606 ha and is located on the steep slopes around the Mount Mbappit. The kappa analysis reveals a total overall accuracy of 78.67% and a kappa value of 0.7256 with an asymptotic error of 0.058 which is good. Then the model used in this research is highly recommended for future land evaluation works in Cameroon and similar ecosystems around the world.

Keywords

Decision Making Trial Evaluation Laboratory, Analytical Network Process, Geographic Information System, Land Evaluation, Maize, Weighted Overlay Analysis, Foumbot, Western Cameroon

1. Introduction

Maize is the leading cereal consumed in Cameroon (2/3 of production, i.e., approximately 1.3 million tons in 2020), far ahead of sorghum, rice, and wheat. Maize production is also used to supply local agro-industries (2% for breweries and 16% for animal feed mills) and countries in the sub-region (Mbodiam, 2021). However, the sector still suffers from uncontrolled use of land resources, low productivity and under-exploitation of available natural resources. The growth of agribusinesses and the increasing demand from neighboring countries are contributing to the widening gap between domestic demand and supply (Epule & Bryant, 2015). The growing demand for maize could be met either through an increase in cultivated areas or through appropriate technological intervention. In a context where the pressure on land resources for different uses is increasing, it is hardly feasible to bring more land under cultivation. However, the market demand for maize could be met through maize cultivation in appropriate areas with high-yielding hybrid varieties and adopting a set of improved practices. Thus, there is a need to accurately identify suitable land for maize cultivation in Cameroon in general and in its main agricultural basins in particular. Land evaluation is the first step in the process of sustainable land use planning or management (Baroudy, 2016; Tashayo et al., 2020). This process guides towards optimal land use by providing information on opportunities and constraints in the use of the AOI (Bandyopadhyay et al., 2009; Mokarram & Aminzadeh, 2010; Akıncı et al., 2013). Land suitability is a multi-criteria problem as it involves the use of several criteria that are either socio-economic or environmental, in addition to properties inherent to the land units (Duc, 2006; Bandyopadhyay et al., 2009). In Cameroon, some works have been conducted on land evaluation for crop production (Ngandeu, 2008; Tsozué et al., 2015; Enang et al., 2016; Azinwi Tamfuh et al., 2018; Kome et al., 2020). These studies are inadequate to decide on the optimum exploitaion of land resources as they were based only on empirical methods considering the same level of singnificance for all evaluation criteria. It is therefore necessary to use modern methods that can better express the real potential of land for crop production.

Previously, several studies have applied the MCDM methods for land suitability assessment (LSA) (Sarmadian et al., 2010; Mustafa et al., 2011; Zabihi et al., 2015; Seyedmohammadia et al., 2018; Herzberg et al., 2019; Orhan, 2021; Mugiyo et al., 2021) considering that the criteria do not have the same level of significance as is the case with empirical methods. However, many advances have been observed during the last 20 years in the implementation of MCDM methods for LSA, especially by combining GIS with MCDM methods (Malczewski, 2006; Mendas & Delali, 2012; Nguyen et al., 2015; Ngandam et al., 2019; Ramamurthy et al., 2020; Schulze-González et al., 2021). The most commonly used MCDM methods for LSA are Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW) and Decision Making Trial and Evaluation Laboratory (DEMATEL) (Sipahi & Timor, 2010; Yohannes & Soromessa, 2018). Nevertheless, each MCDM method has its advantages and disadvantages for solving problems. Most MCDM methods assume that the criteria do not interact with each other, which is not the case with many real-life situations; several forms of interactions between criteria do occur, thus requiring more sophisticated/intelligent MCDM techniques to meet particular needs of problems (Gölcük & Baykasoğlu, 2015).

The DEMATEL method was developed by the Science and Human Affairs Program of the Battelle Memorial Institute in Geneva (Gabus & Fotala, 1972), and is well known for its ability to deal with the degree of importance of the evaluation criteria, and more importantly, to establish cause and effect relationships between the evaluation criteria (Si et al., 2018; Awang et al., 2019). The ANP method was developed by Saaty (1996) to overcome the hierarchical shortcomings in the AHP (Yang & Tzeng, 2011). In addition, the ANP method is used to determine the composite weights of the criteria through the development of a "supermatrix" (Schulze-González et al., 2021). However, the ANP method, when used alone, has some flaws which can lead to incoherent judgment, and then to poor results (Kheybari et al., 2020). Therefore, the combination of the DEMATEL and ANP methods has been extensively explored (Tseng, 2009; Tsai & Chou, 2009; Büyüközkan & Güleryüz, 2016; Dehdasht et al., 2017; Kadoic et al., 2018; Wu & Tsai, 2018; Zhu et al., 2020) and has been adopted to address the imperfections of the ANP method. But, so far, only a few studies have used this integrated method for LSA (Pourkhabbaz et al., 2013; Azizi et al., 2014; Pourahmad et al., 2015; Gigović et al., 2017; Ghobadia et al., 2021). None of these studies have been conducted in Africa, let alone in Cameroon. The aim of this study is to assess suitable land for sustainable maize production using DEMATEL-ANP integrated approach and GIS in the Cameroon Western Highland ecosystem. The results obtained will provide data to farmers on the best land management strategies to adopt for uptimum maize production.

2. Materials

2.1. Description of the Study Area

The study area is located in the Foumbot Sub-division in the Cameroon Western Highlands between 5˚12'00"N and 5˚40'00"N and 10˚30'00"E and 10˚50'00"E (Figure 1). It has a surface area of about 84,488 ha. The area shows three major physiographic units namely mountains, plateaus and valleys. The highest and lowest altitudes are 1967 and 876 m, respectively. This area is characterized by a long rainy season of 8 months (March to October) and a short dry season of five months (November to February). The average annual rainfall is 3000 mm and the mean annual temperature is 21˚C. The major soil types are Andosols and Red Ferralsol meanwhile Gleysols cover the swampy lowlands (Ngandeu et al., 2016). The area is drained mainly by small streams in addition to the Nkoup River which longitudinally crosses a major part of the study area. The bedrock is essentially made up of gneiss and migmatites intruded by various granitoids. This geological substratum is covered by a thick layer of pyroclastic material (Wandji, 1985). The main activity of population in the area is subsistence agriculture. Dominant crops of the area are maize, tomato, beans soybeans and Irish potato.

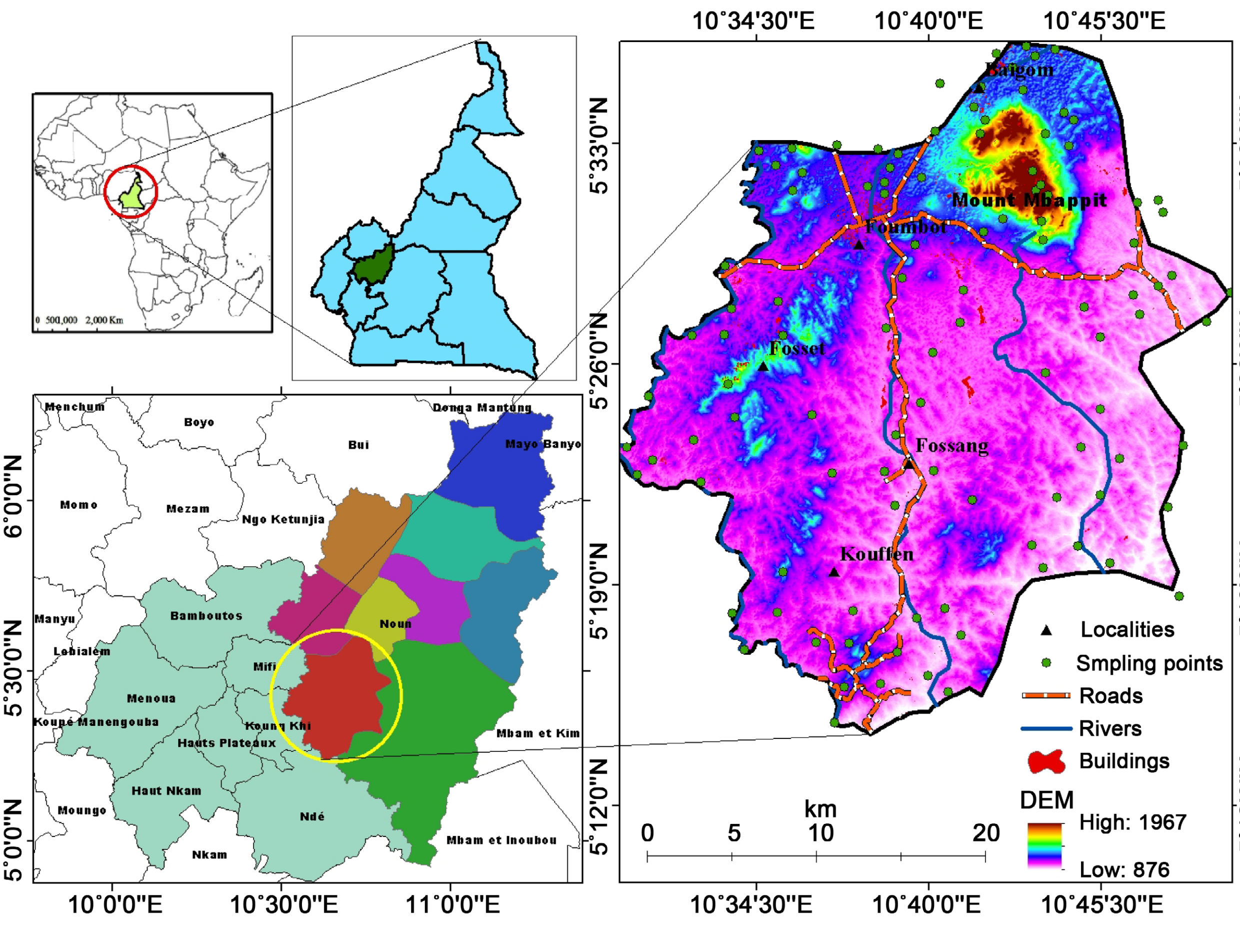

Figure 1. Location of the study area and sampling points.

2.2. Input Data and Softwares Used

The input data used was selected according to the criteria used for land evaluation for maize production in the AOI. These include topographic data (Topographic map and Digital Elevation Model), soil data (Soil sample collected in the field), sofwares (SuperDecision, ArcGIS and Excel 2013) and maize yield data (over a periode of 03 years from 2018-2020).

2.3. Choice of Land Use Type

The choice of land use type (crops) for LSA was made on the basis of economic and food importance following the results of the census carried out by the Foumbot Council in 2018 over 14,752 household in the area and field observations (Commune de Foumbot, 2019). Maize was identified as the most important crop in the locality.

2.4. Evaluation Criteria Selection.

Five experts (Researchers) working at the Agricultural Research Institute for Development (IRAD) of Foumbot participated in the criteria selection process, identification of the suitable ranges of each criterion and evaluation of criteria weights. These experts have worked for at least 15 years at the IRAD centre and have been working in Foumbot for more than 10 years. After discussion with the experts during the field survey period and analysis of the existing literature (Abagyeh et al., 2016; Pilevar et al., 2020; Muhammed et al., 2019; Tashayo et al., 2020), eight criteria were identified to be the most relevant for assessing suitable sites and establishing suitability map for maize production: soil factors (soil reaction, soil depth, soil texture, coarse fragment, soil drainage and cataion exchange capacity/CEC), and topography factors (slope, elevation). The requirements of maize against these criteria are presented in (**Table 1**) bellow.

3. Methodology

The process of Land Suitability Assessment for maize production in Foumbot is shown if **Figure 2**. First (in step 1) all evaluation criteria were selected following the procedure describe in section 2.4. In step 2, non agricultural land was identified and an exclusionary land map was prepared. In step 3, DEMATEL was used to determine the relationships between criteria and in step 4; ANP was used to weight evaluation criteria. Thematic maps of criteria were prepared in step 5 then, the overlaying was done using ArcGIS in step 6. The land suitability map was reclassified into five suitability classes from least suitable to most suitable in step 7. In step 8, the exclusionary areas (non-agricultural land) were removed using the exclusionary map and final land suitability map was extracted in step 9. Finally, in step 10, a model accuracy analysis was carried out.

3.1. Field Work and Laboratory Analysis

Field work involved the identification and collection of soil samples. Thus, surface

Table 1. Maize requirements in relation to selected criteria.

Criteria	Suitability classes					
	Very highly suitable	Highly suitable	Moderately suitable	Marginaly Suitable	Temporaly unsuitable	Permenently unsuitable
	100 95	95 85	85 60	60 40	40 25	25 1
Topography criteria						
Slope (%)	0 - 2	2 - 5	5 - 8	8 - 16	16 - 25	>25
Elevation (m)	<1100	1100 - 1150	1150 - 1200	1200 - 1250	1250 - 1300	>1300
Coarse fragments (%)	0- 3	3 - 15	15 - 35	35 - 55	-	>55
Soil criteria						
Soil depth (cm)	>100	100 - 75	75 - 50	50 - 20	-	<20
Soil texture (classes)	C < 60s, Co, SiC, SiCL, Si, SiL, CL	C < 60v, SC, C > 60s, L, SCL	C > 60v, SL, LfS, LS	Fs, S, LcS	-	Cm, SiCm, CS
Soil reaction (pH)	6.6 - 7	6.6 - 5.8	5.8 - 5.6	5.6 - 5.2	<5.2	-
CEC Clay (Cmol(+)/Kg)	>24	24 - 16	16 - 8	8 - 5	-	<5
Drainge (classes)	Good	Moderate	Marginal	Imperfect	Poor	Water bodies

Adapted from: Muhammed et al., 2019; Pilevar et al., 2020; Tashayo et al., 2020; Seyedmohammadia et al., 2018; Abagyeh et al., 2016 and Sys et al., 1993.

(0 - 30 cm depth) soil samples were randomly collected in the studied site. At each sampling point, five samples were collected and then mixed to obtain a composite soil sample. A total of 109 composite samples were collected (**Figure 1**). These samples were preserved in plastic sachets and take to the laboratory for further processing and analysis.

The laboratory analyses were carried out at the Research Unit of Soil and Environmental Chemistry of the University of Dschang (Cameroon), according to the procedures reported in Pauwels et al. (1992). Thus, soil organic Carbon (SOC) content was determined by the Walkley and Black method (Walkley & Black, 1934). Total nitrogen (N) and available phosphorous were determined by the Kjeldahl wet digestion and the Bray II methods (Bray & Kurtz, 1945), respectively. Exchangeable bases were determined following the Schollenberger method using a 1 M ammonium acetate solution buffered at pH 7 (Soil Survey Staff, 1996). The concentrations of exchangeable sodium and potassium, ions in the extract were determined by flame photometry, and those of exchangeable calcium and magnesium by complexometry using a 0.002 M disodium ethylenediaminetetraacetate dihydrate (Na_2-EDTA) solution. The CEC was determined by direct continuation of the Schollenberger's method using a 1 N KCl saturation solution. The hydrometer method was used for particle size analysis following procedures described by Bouyoucos (1962). The pH-H_2O and pH-KCl were determined in a soil-to-water ratio of 1:2.5 and a soil-to-1 N KCl solution

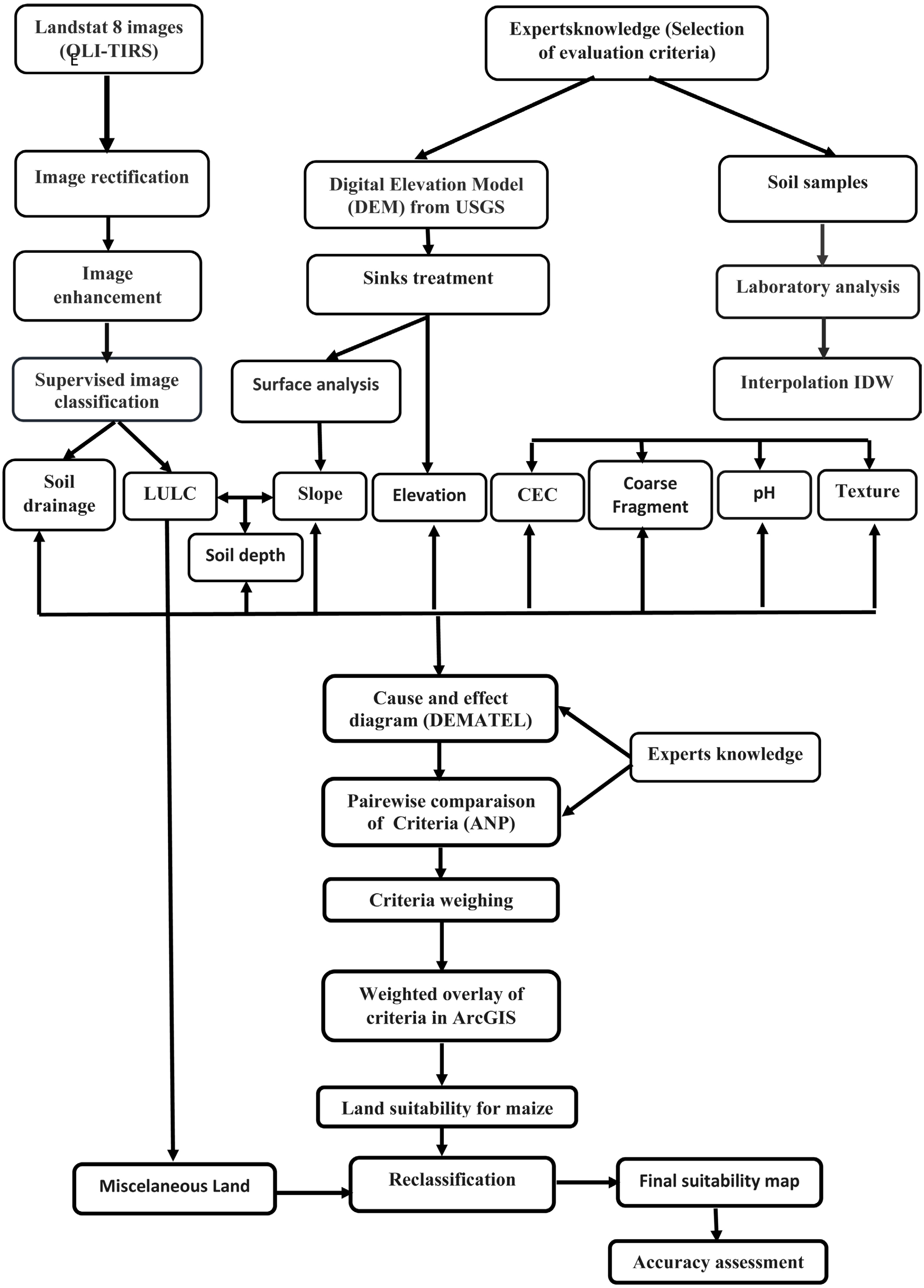

Figure 2. Schematic diagram of the modelling procedure for land suitability assessment for maize production in Foumbot.

of 1:2.5, respectively.

3.2. Standardization and Spatial Variability of the Evaluation Criteria

Evaluation criteria have different units. For instance, slope is measured in percentage and soil depth in centimeters, etc… It is therefore necessary to standardize those units by bringing them to a common scale before their superposition during LSA (Voogd, 1983). According to Malczewski (2004), linear scale transformation is the most common method used to standardize criteria during land suitability map establishment. In this study, criteria thematic maps prepared using ArcGIS 10.8 were standardized using reclassify spatial analyst tool, to make sure that each criterion has an equivalent measurement basis. Simultaneously during reclassification, factor ratings were also assigned for suitability analysis as it was done by Sarkar et al. (2014).

3.3. Criteria Weight Determination

This study uses an intergrated DEMATEL-ANP method to determine criteria weights. Since in real life there are different levels of influence and different types of relationship between the evaluation criteria, it would be irrational to consider equal levels of influence and the same type of relationship between them.

3.3.1. DEMATEL Analysis

The DEMATEL method was used to deal with the importance and causal relationships among the criteria, and to recognize the influential criteria of the LSA for Maize. In this study, the onlineoutput software (Available at: https://onlineoutput.com/dematel-software/) was used to compute the six major steps involved in the DEMATEL technique as describe by Schulze-González et al. (2021).

Step 1: *Establishment of measurement scales, direction and degree of influence between factors.*

This step entails identifying and defining criteria that influence maize production in the study area by using data obtained from literature review, brainstorming or expert opinions (see Section 2.4). Then five experts were asked to assess the direct influence between criteria. A measurement scale of 0, 1, 2, 3 and 4 was used to respectively illustrate no influence, very weak influence, weak influence, moderate influence and very strong influence in reference to Jayasinghe et al. (2019).

Step 2: *Establishment of a direct relation matrix* ***Z***.

The direct relationship matrix was constructed from the arithmetic mean of the pairwise comparison matrices generated by each expert and is determined as shown in Equation (1) below. In this equation, z_{ij} corresponds to the degree of influence of criteria *i* on criteria *j*.

$$Z = \begin{bmatrix} 0 & Z_{12} & \cdots & Z_{1n} \\ Z_{21} & 0 & \cdots & Z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{n1} & Z_{n2} & \cdots & 0 \end{bmatrix} \quad (1)$$

Step 3: *Establishment of the normalized matrix* ***N***.

The normalized matrix is obtained from Equations (2) and (3) by dividing each element of the initial direct influence matrix by the maximum value of the sum of the row. All diagonals in the matrix are zero, and the sum of each row and column does not exceed 1.

$$\lambda = \frac{1}{\max_{1 \le i \le n} \left(\sum_{j=1}^{n} z_{ij} \right)} \quad (2)$$

$$N = \lambda Z \quad (3)$$

Step 4: *Establishment of the total relation matrix T*.

The total relationship matrix (T) was then calculated from the normalized direct influence matrix using Equation (4) where I denotes the identity matrix.

$$T = \lim_{k \to \infty} \left(N + N^2 + \cdots + N^k \right) = N \left(I - N \right)^{-1} \quad (4)$$

Step 5: *Calculating the sum of the values in each column and each row*.

This step entails summing the values of each column and row in the total relation matrix, where D_i is the sum of the i^{th} row and R_j is the sum of the j^{th} column. The D_i and R_j values represent both the direct and indirect influences between factors.

$$D_i = \sum_{j=1}^{n} t_{ij} \quad \left(i = 1, 2, \cdots, n \right) \quad (5)$$

$$R_j = \sum_{i=1}^{n} t_{ij} \quad \left(j = 1, 2, \cdots, n \right) \quad (6)$$

Step 6: *Illustrate the DEMATEL cause and effect diagram*.

In this step, $(D_i + R_j)$ is defined as Prominence and $k = i = j = 1, 2, \cdots, n$, illustrating the overall influential directions of a service attribute. The parameter $(D_i - R_j)$ is defined as relationship factor, indicating the level of influence of each criterion. A positive value suggests that criteria are a cause and a negative value suggests that the attribute is an effect.

In this study, causal diagram was attained by depicting all dataset of the $(D_i + R_i, D_i - R_i)$, where the vertical axis is $D_i - R_i$ and the horizontal axis is $D_i + R_i$. The Network Relation Map (NRM) is a proper diagram, which presents a valuable insight for decision-making. The NRM was obtained by defining a threshold value based on the opinions of experts. It illustrates a structural relationship between the different evaluation criteria to visualize complex correlation. However, only relationships that are greater than the defined value should be shown in the graph.

3.3.2. Analytic Network Process (ANP) Analysis

In this section, after determining the interdependency among criteria using

DEMATEL, the ANP technique is applied to obtain the final weight of the evaluation criteria. The first step in the analysis was that the ANP model was constructed based on the relationship structure that was developed using DEMATEL. The network connections between group of critria and criteria express dependencies that can be inner or outer. The second step was the comparison of criteria in the whole network in order to form an unweighted supermatrix by pairwise comparisons. In this phase, decision makers compare two elements. Pairwise comparisons were made with the grades ranging from 1 - 9. In the survey, they were asked questions such as: in a maize production activity in Foumbot, how important is the "CEC" in relation to the "soil reaction"?

In order to build this decision model and obtain the weight of the criteria, the Super Decisions software was used (available on: http://www.superdecisions.com/) (Adams & Saaty, 2003). This is an easy-to-use professional software for building decision models. This software made it possible to build pairwise comparison matrices, calculate the results to define the supermatrix and find the limited supermatrix and the weight of each criterion. In addition, throughout the calculation process, consistency was tested by the software. The consistency ratio (R.C.) is a measure of consistency that confirms that the original expert assessments have been maintained. It is recommended that the consistency ratio be less than or equal to 0.10.

3.4. Establishment of Maize Suitability Map

The land suitability map for maize production in the Foumbot agricultural basin was created using WOA in ArcGIS 10.8 by assigning weight to each criterion. Each raster was assigned a percentage influence depending on its importance as defined by the average weights obtained at the end of the DEMATEL-ANP analysis. Each criterion was multiplied by its percentage influence and then added to create the output raster. The Equation (7) below was used to calculate land suitability index (*LSI*).

$$LSI_i = \sum_{i=1}^{8} X_i \times W_i \tag{7}$$

where, X_i = Raster map of each criterion, W_i = weight values of each criterion, and LSI_i = Land Suitability Index of cell *i*.

The final suitability map of the study area for maize production was generated after removing non agricultural lands from the suitability map obtained above using Equation (8) below.

$$SM_f = LSI \times ML_m \tag{8}$$

where SM_f is the final suitability map, *LSI* is the initial suitability map obtained using Equation (7) and ML_m is the miscellaneaous (non agricultural) land map.

This study used six levels of suitability classes commonly used by the Food and Agricultural Organization (FAO, 1976): very highly suitable (S1-0), highly suitable (S1-1), moderately suitable (S2), marginally suitable (S3), temporally unsuitable (N1) and permanently unsuitable (N2).

3.5. Validation of the Land Suitability Map

The accuracy of a suitability map consists of comparing the data obtained from the LSA model with reference data existing in the field (Zolekar & Bhagat, 2015). For this, maize yield data obtained from the MINADER over a period of three years (2018-2020) was used. Then, land suitability indexes were compared to maize yield values.

Cohen's kappa coefficient was used to validate the land suitability map for maize as it accurately measures the agreement between the verified data (maize yield) and those predicted on the suitability map (Bergeri et al., 2014). Cohen's Kappa coefficient (K) was calculated from the error matrix using the formula below:

$$K = \frac{Co - Ca}{1 - Ca}$$

where Co is the observed agreement, Ca the expected agreement, $Co - Ca$ is the actual agreement and $1 - Ca$ is the perfect agreement. The observed agreement Co is the proportion of individuals classified in the matching diagonal cells of the contingency matrix.

4. Results

4.1. Descriptive Statistics of Land Characteristics

The parameters for descriptive statistics (minimum, maximum, mean, standard deviation (SD), coefficient of variation (CV), skewness and Kurtosis) of soil physical and chemical properties are presented in **Table 2**. The pH value ranged from 4.8 to 6.20 in surface soils of the study area. Soil acidity is an important indicator of land degradation and has been proved to restrict fertility in agricultural land, resulting in reduced plant biomass and lower crop yields (Behera & Shukla, 2015; Andrew & Gazey, 2010). The pH values indicate the existence of very strongly acidic areas in the study area. Therefore, spatial distribution of pH values in a farmland should be taken into account for land use planning. The

Table 2. Descriptive statistics of soil related evaluation criteria.

	Min	Max	Mean	Median	Std.dev	CV	Skweness	Kurtosis
CEC	8.4	38.4	19.95	18.8	6.98	34.99	0.19	−0.73
Soil reaction	4.8	6.2	5.55	5.5	0.24	4.32	0.01	0.33
Coarse fragment	7.9	19	12.58	12.4	2.3	18.28	0.53	0.29
Soil depth	45	260	123.9	110	54.52	44.00	0.59	−0.86
Clay	20	55	32.66	32	7.65	23.42	0.7	0.09
Silt	20	52	33.2	32	6.04	18.02	0.73	0.49
Sand	7	50	33.98	36	10.52	30.96	−1.03	0.51

average Cation Exchange Capacity (CEC) content (19.93 meq/100g) of surface soils were moderate that was ranged from low (8.46 meq/100g) to high (38.4 meq/100g) levels. The soils had adequate coarse fragment concentrations. The coarse fragment concentration ranged from 7.9% to 19% with a mean value of 12.58%. Soil depth of the study area varies from Shallow (25 - 50 cm) to very deep (>150 cm). This is very good for maize cultivation since it require minimum soil depth of 50 cm. Sand is the only criterion which shows a slightly negative skeweness coefficient. This indicates that values distribution shifted to the right of the median and therefore a distribution tail spread to the left. The other parameters have a slightly positive coefficient varying from 0 to 0.73 indicating normally distributed data. An application of the Kolmogorov-Smirnov test confirmed the previous claim that all soil properties involved in this study are normally distributed for $P < 0.05$. The variability of attributes within study area was interpreted using the coefficient of variation (CV). The soil attribute was classified into the most (CV ≥ 35%), moderate (CV 15% - 35%) and least (CV ≤ 15%) variable classes according to the criteria proposed by Wilding (1985). CEC and soil depth are most variable with coefficient of variation CV) above 35%. The coarse fragments, clay, silt and sand vary moderately (15% < CV< 35%). Finally, pH varies very little as it's is CV < 15%.

4.2. Criteria Weighing

4.2.1. DEMATEL Analysis

Table 3 shows the set of interaction relationships between evaluation criteria. It can be seen that elevation and coarse fragments are not influenced by any criterion, but they influenced at least five of the eight criteria each. Slope and texture are affected by one criterion each, but they affect 4 and 3 criteria respectively. Soil reaction and CEC are the most influenced criteria as they are influenced by all other criteria and are followed by drainage and soil depth.

Table 3. Total relation matrix based on DEMATEL survey of experts in maize production.

	Slope	Elevation	pH	Soil drainage	Soil depth	CEC	Coarse fragment	Soil Texture
Slope	0.014	0.068	**0.237**	**0.172**	**0.172**	**0.237**	0.012	0.014
Elevation	**0.203**	0.014	**0.280**	**0.205**	**0.258**	**0.280**	0.019	0.021
pH	0.000	0.000	0.018	0.000	0.000	**0.136**	0.000	0.000
Soil drainage	0.000	0.000	**0.260**	0.022	**0.137**	**0.260**	0.010	0.011
Soil depth	0.000	0.000	**0.221**	**0.168**	0.027	**0.221**	0.074	0.083
CEC	0.000	0.000	**0.136**	0.000	0.000	0.018	0.000	0.000
Coarse fragment	0.000	0.000	**0.265**	**0.260**	**0.103**	**0.265**	0.021	**0.211**
Soil texture	0.000	0.000	**0.224**	**0.222**	0.034	**0.224**	0.070	0.016
Threshold value = 0.093								

According to Figure 3 and Table 4, each criterion can be evaluated according to the following aspects:

- The horizontal vector ($D_i + R_i$) represents the degree of importance that each criterion plays in the entire model. In other words, ($D_i + R_i$) indicates both the impact of criterion i on the entire model and the impact of other criteria of the model on the criterion. The ($D_i + R_i$) values of all criteria are positive, indicating the importance of these criteria use in the land suitability assessment for maize production. In terms of the degree of importance, the soil reaction and CEC are ranked in the first position follow by the soil drainage and soil depth because they have the highest ($D_i + R_i$) values. The lowest position indicator values are attained by texture and slope. CEC and soil reaction interact the most with the other factors because they have the highest $D_i + R_i$ values and the slope has the least interaction with the other criteria.

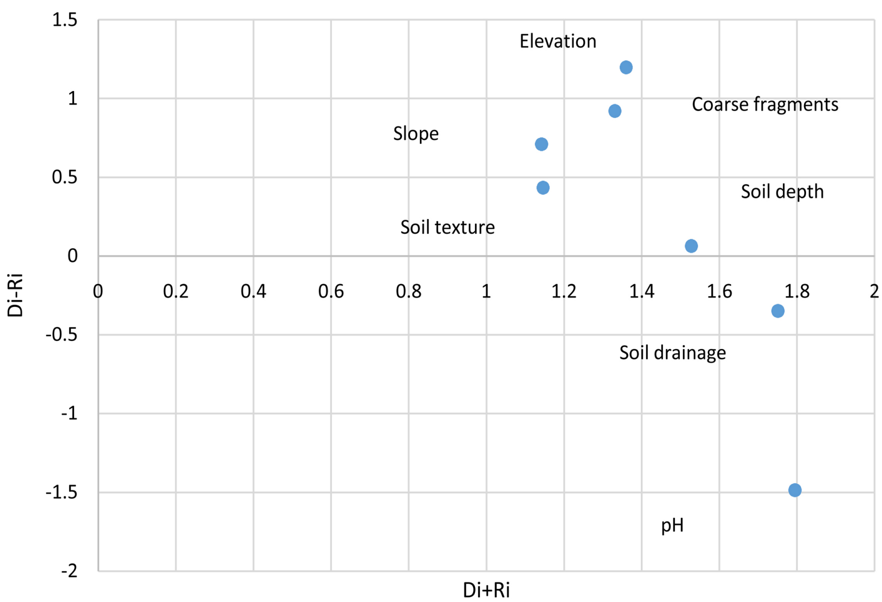

Figure 3. Causal diagram of criteria used for the land suitability assessment for maize.

Table 4. Relationship and influence vectors values for each criterion.

Criteria	D_i	R_i	$D_i + R_i$	$D_i - R_i$
Slope	0.926	0.216	1.142	0.710
Elevation	1.279	0.081	1.360	1.198
pH	0.154	1.641	1.795	−1.487
Soil drainage	0.701	1.050	1.751	−0.349
Soil depth	0.795	0.732	1.528	0.063
CEC	0.154	1.641	1.795	−1.487
Coarse fragment	1.125	0.206	1.331	0.920
Soil texture	0.790	0.357	1.146	0.433

- The vertical vector ($D_i - R_i$) represents the degree of influence of a factor on the model. In general, the positive value of $D_i - R_i$ represents a causal variable, and the negative value of $D_i - R_i$ represents an effect. In this study, Altitude, slope, soil depth, soil texture and coarse fragments have a positive value of $D_i - R_i$ and are therefore considered to be effect criteria and thus affect the other criteria, while CEC, soil drainage and soil reaction are the most influential criteria.

4.2.2. ANP Analysis

The first step in the analysis was that the ANP model was constructed based on the relationship structure that was developed using DEMATEL as shown in Figure 4. As it can be seen, each group of criteria has a direct relationship with its corresponding subset. In addition, the loops indicate the internal relationship of each group, which means that the criteria affect itself indirectly through other criteria groups.

Figure 5 illustrates a sample questionnaires administered to experts in orther to compare evaluation criteria two by two based on the network relation matrix obtained from DEMATEL analysis. It appears from the first line that CEC is equally to moderately more important than coarse fragments as regard of maize production in Foumbot.

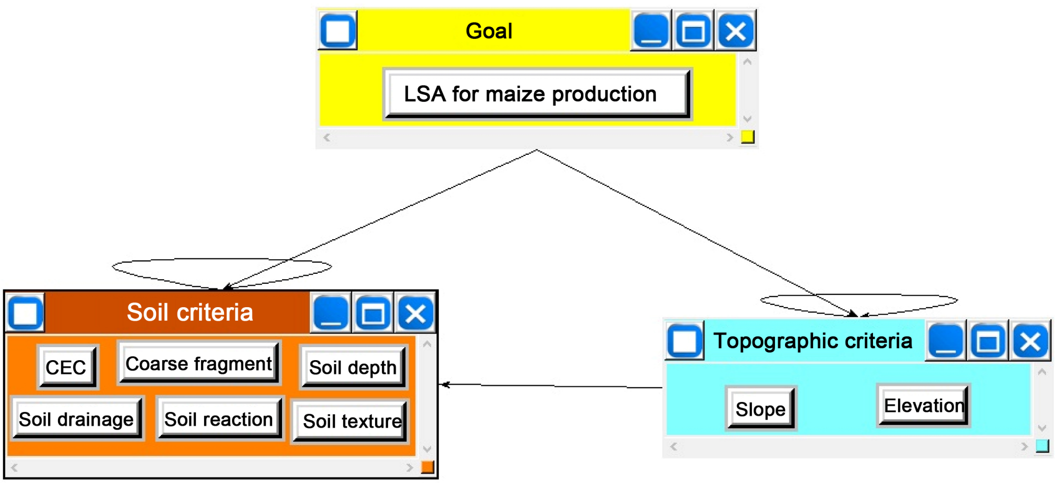

Figure 4. Decision network model of the ANP analysis.

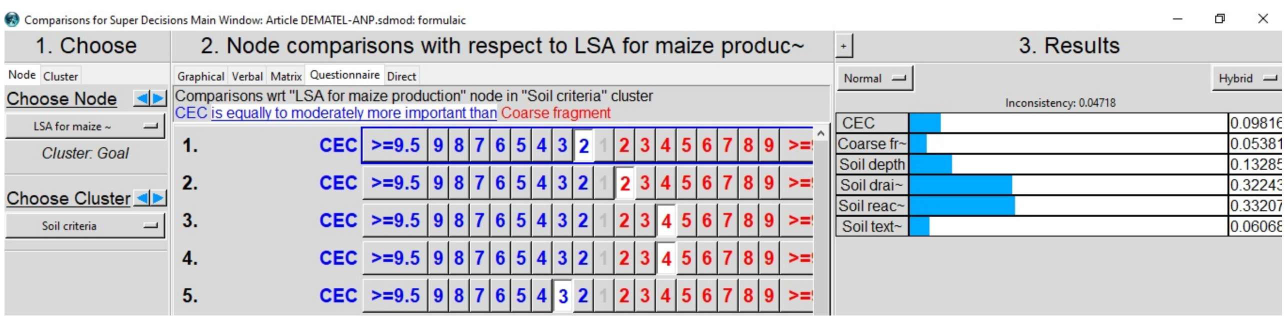

Figure 5. Sample questionnaire for pairwise criteria comparison in super decision.

The limited supermatrix presented in Table 5 is the final result of ANP analysis and was calculated from the weighted supermatrices. This table shows criterion weights calculated based on interactions between criteria as presented in the total relation matrix. For criteria such as CEC and soil restion that doesn't affect any other criterion no weight was calculated. The final weight of each criterion for the corresponding group is calculated in the limited matrix and is presented in Table 6.

The results of the ANP analysis demonstrate that topographic criteria influenced the suitability of Foumbot agricultural land for maize production more than criteria related to soil physico-chemical properties (Table 6). Indeed, the highest weight was assigned to the slope (0.300) followed by pH (0.234), elevation (0.200) and soil drainage (0.114) see Table 6. Slope is thus is the most limiting factor for maize production in Foumbot since more than 30% of the total surface area has a slope degree greater than 16%.

Table 5. Limited supermatrix with criteria weight.

		Soil criteria						Topographic criteria	
		CEC	Coarse	Soil depth	Soil drainage	Soil reaction	Soil texture	Elevation	Slope
Soil criteria	CEC	0.000	**0.135**	**0.250**	**0.152**	0.000	**0.135**	**0.077**	0.000
	Coarse	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.130**
	Soil depth	0.000	**0.118**	0.000	**0.172**	0.000	**0.058**	**0.071**	0.000
	Soil drainage	0.000	**0.229**	0.000	0.000	0.000	**0.277**	**0.155**	**0.116**
	Soil reaction	0.000	**0.478**	**0.750**	**0.676**	0.000	**0.531**	**0.310**	**0.202**
	Soil texture	0.000	**0.040**	0.000	0.000	0.000	0.000	0.000	**0.552**
Topographic criteria	Elevation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Slope	0.000	0.000	0.000	0.000	0.000	0.000	**0.387**	0.000
CR = 0.039									

Table 6. Criteria weight obtained from DEMATEL-ANP analysis.

Criteria	Weight	Rank
Topographic criteria		
Elevation	0.200	3
Slope	0.300	1
Soil Criteria		
Coarse frag	0.011	8
Soil depth	0.061	6
Soil texture	0.013	7
Soil reaction	0.238	2
CEC clay	0.063	5
Soil drainage	0.114	4

4.3. Land Suitability with Respect to Selected Criteria

Figure 6 shows the standardized criteria maps for maize suitability. Each of the criteria was separately analysed for their suitability for supporting maize production based on its requirements (Table 7). Most of Foumbot's north central parts do not have suitable slope and elevation requirements for maize cultivation. Table 7 shows that, 95% of the total Foumbot's area has a coarse fragment concentration highly suitable for maize production. Also, 60% of the total surface area of Foumbot's district has pH varying from 5.2 to 5.5 which is marginally suitable for maize production. The thematic maps of slope, drainage and elevation illustrate varying degrees of suitability to produce maize. Overall, soil properties in many parts of Foumbot are suitable for maize cultivation. The eastern north of the study area has an imperfect to poor drainage classes and represents almost 55% of the total surface area of the district.

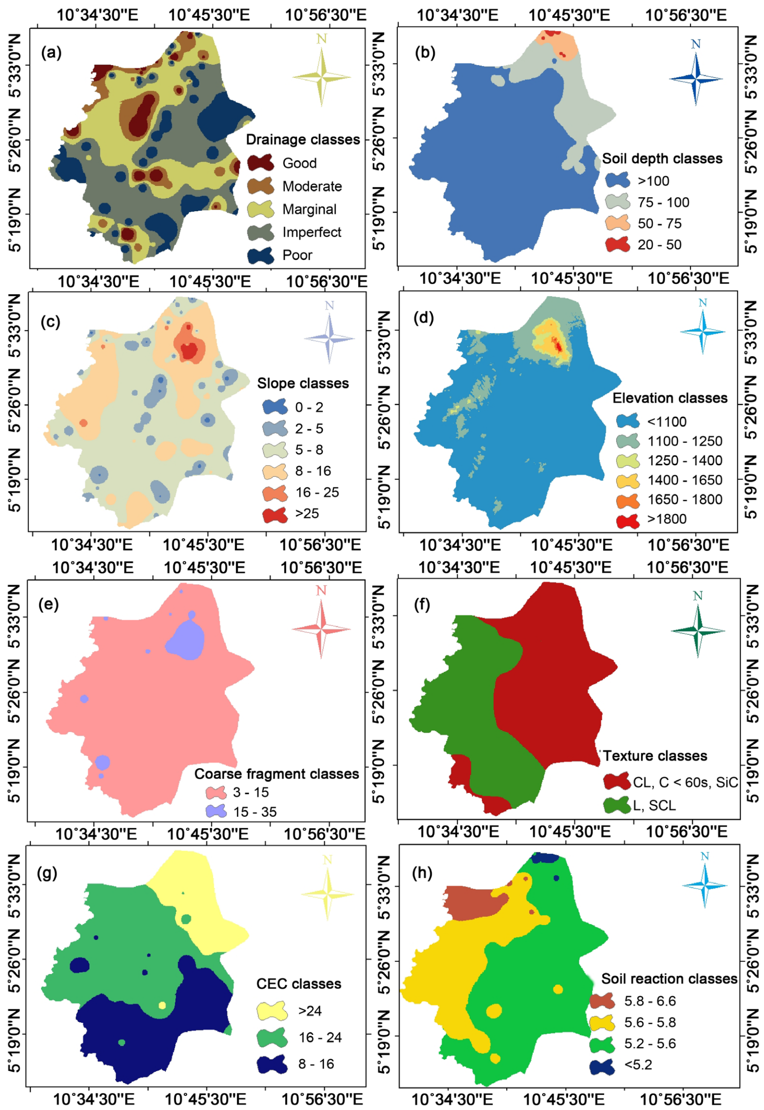

Figure 6. Spatial distribution of criteria in the study area (a) soil drainage, (b) soil depth, (c) slope, (d) elevation, (e) soil coarse fragment, (f) soil texture, (g) CEC, (h) soil reaction.

Table 7. Areal and percentile distributions of criteria and sub-criteria parameter in the study area.

Main criteria	Sub-criteria	Suitability classes	Area (ha)	Area (%)
Slope	0 - 2	Very highly suitable	2191	3
	2 - 5	Highly suitable	10,427	12
	5 - 8	Moderately suitable	14,107	17
	8 - 16	Marginally suitable	32,696	39
	16 - 25	Temporally unsuitable	15,353	18
	>25	Permenently unsuitable	9291	11
Altitude	<1100	Very highly suitable	70,089	83
	1100 - 1250	Highly suitable	10,882	12.9
	1250 - 1400	Moderately suitable	1538	1.8
	1400 - 1650	Marginally suitable	1699	2.0
	1650 - 1800	Temporally unsuitable	198	0.2
	>1800	Permenently unsuitable	76	0,1
Coarse fragment	3 - 15	Highly suitable	80,180	94.9
	15 - 35	Moderately suitable	4308	5.1
Soil depth	>100	Very highly suitable	67,935	80.4
	75 - 100	Highly suitable	14,151	16.7
	50 - 75	Moderately suitable	2120	2.5
	20 - 50	Marginally suitable	280	0.3
Soil texture	SiCL, SiL, CL, C < 60s	Very highly suitable	47,592	56.3
	L, SCL	Highly suitable	36,892	43.7
Soil reaction	5.8 - 6.2	Highly suitable	5000	5.9
	5.5 - 5.8	Moderately suitable	28,021	33.2
	5.2 - 5.5	Marginally suitable	50,698	60.0
	<5.2	Temporally unsuitable	769	0.9
CEC clay	>24	Very highly suitable	15,544	18.4
	16 - 24	Highly suitable	40,680	48.1
	8 - 16	Moderately suitable	28,264	33.5
Drainage	Good	Very highly suitable	4371	5.2
	Moderate	Highly suitable	8314	9.8
	Marginal	Moderately suitable	25,301	29.9
	Imperfect	Marginally suitable	31,699	37.5
	Poor	Temporally unsuitable	14,803	17.5

4.4. Overall Land Suitability Assessment

Figure 7 shows the global Land suitability classes for maize cultivation in Foumbot including non-agricultural lands (Figure 8) while Figure 9 represents the final suitability map of Foumbot agricultural land for maize production. It can be seen that the suitability classes vary from very highly suitable to temporarily unsuitable in the region.

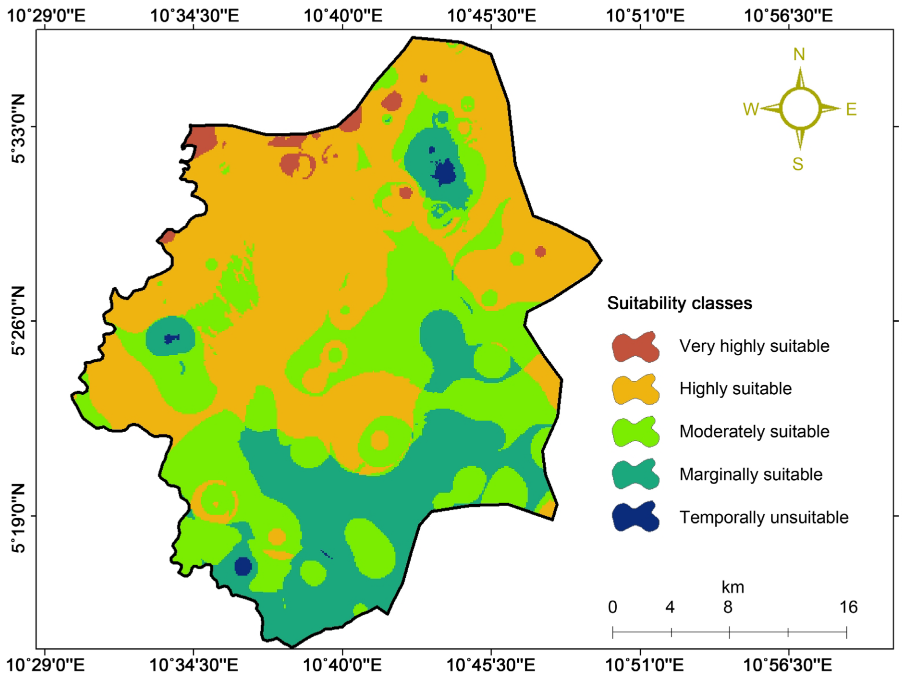

Figure 7. The global land suitability map of Foumbot for maize production.

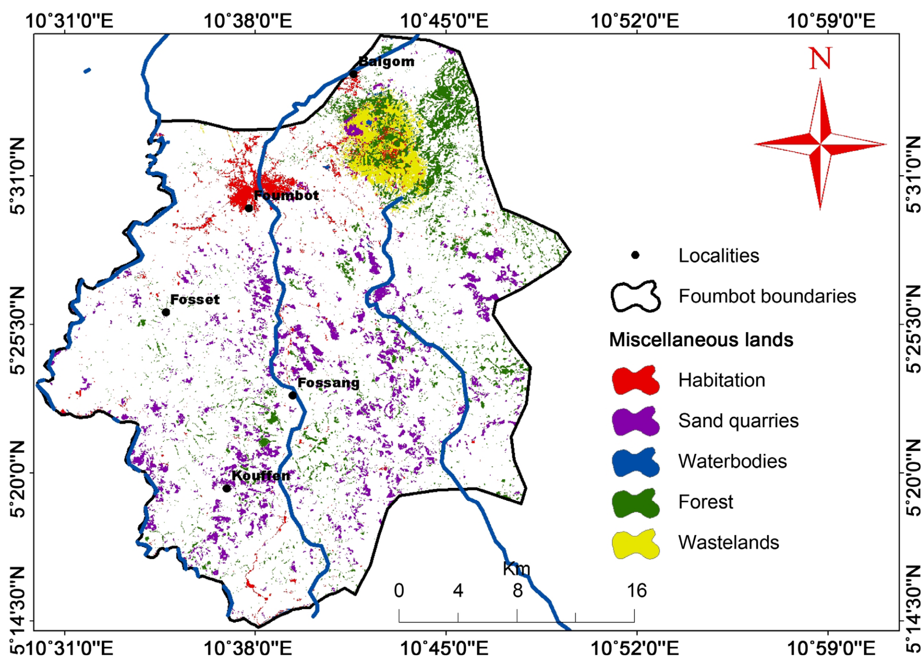

Figure 8. Miscellaneous land (non-agricultural land) of Foumbot.

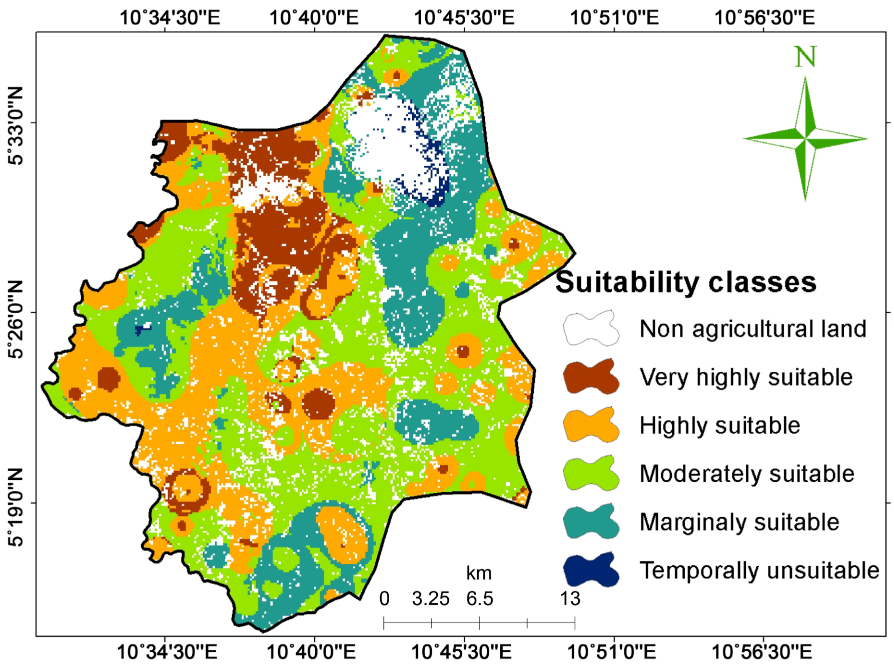

Figure 9. The final suitability map of Foumbot agricultural lands for maize production.

4.4.1. Very Highly Suitable Class (S1-0)

The very highly suitable class S1-0 involves all the northeastern part of the Foumbot district (Figure 9). This unit has suitable properties such as low elevation <1100 m, flat slope <2% which is very good for maize cultivation and a very good drainage. Soils of these areas have an effective depth >100 m, no coarse fragments and a silty or sandy-clayey texture. From the point of view of chemical properties, the CEC in this unit varies from 16 to 24 cmolc + kg^{-1} soil and the pH is between 5.6 and 5.8. These areas covered 11% of the total area of agricultural land in the district which represent 8056 ha (Table 8).

4.4.2. Highly Suitable Class (S1-1)

The lands of this unit are considered to be highly suitable for sustenaible maize production (Figure 9). This area is located around the previous class and extends to the southern part of the study area. It is more than twice as large as the previous unit as it covers 29% of the total area of agricultural land in the district which represent 21119 ha (Table 8). It has an almost flat topography with slope ranging from 2% to 5%, and an altitude from 1100 to 1250 m. identically as the previous unit; it has a low concentration of coarse fragments (3% - 15%) and a good drainage. The soil texture is loamy or sandy clay loam and the soil depths vary from 75 to 100 m.

4.4.3. Moderately Suitable Class (S2)

The land unit with moderate suitability class S2 covers an area of 27,405 ha. It represents 38% of the total area of agricultural land in the Foumbot district or 31,212 ha (Table 8). In this unit, the slope varies from 5 to 8% and the elevation is less than 1400 m. The soils in this unit are more than 75 m deep and have a

Table 8. Potential land area per suitability classes.

	Suitability area before deducting miscellaneous land*		Suitabilty area after deducting miscellaneous land			Miscellaneous land per suitability classes		
	Ha	% per total land	Ha	% per agricultural land	% per total land	Ha	% per non agricultural land	% per total land
Very highly suitable	9454	11	8056	11	85	1398	11	15
Highly suitable	23,699	28	21,119	29	89	2580	20	11
Moderately suitable	31,212	37	27,405	38	88	3807	30	12
Marginally suitable	17,483	21	14,422	20	82	3061	24	18
Temporally unsuitable	2553	3	606	1	24	1947	15	76

*Miscellaneous lands = non agricultural lands.

clayey silty, silty, sandy silty, silty clayey and clayey texture. The chemical properties such as CEC vary between 8 and 24 cmolc + kg^{-1} and pH between 5.2 - 5.6.

4.4.4. Marginally Suitable Class (S3)

This unit represents the boundary between the suitable and unsuitable zones (Figure 9). It covers 14,422 ha which represents 20% or 17,483 ha of the total agricultural land area in the Foumbot (Table 8) and surrounds the S2 class. It is characterized by a slope raging from 8% to16% and an elevation of less than 1650 m. The soils of this unit are very shallow in general with a depth ranging from 20 to 50 m and their drainage is marginal or even imperfect. They generally have a silty clayey, clayey and clay loamy texture. The CEC of this unit varies between 8 and 16 meq/100g and its pH between 5.2 and 5.5.

4.4.5. Currently Unsuitable Class (N1)

This unit is located on the steep slopes around the Mount Mbappit and covers an area of 606 ha (1% of total AOI) of agricultural land in Foumbot or 2553 ha. It is characterized by very steep slopes greater than 16% and an altitudinal range from 1400 to 1800. Despite this very uneven topography, the unit has soils with a depth between 75 and 100 m with good to moderate drainage and a concentration of coarse elements greater than 15% (Table 3). The texture of the soils in this unit is identical to that of the previous unit. It has good chemical properties such as high CEC (CEC > 24 cmolc + kg^{-1}) and the pH is between 5.2 and 5.8.

4.5. Validation of Suitability Map

The error matrix presented in Table 9 was obtained by comparing the maize yields obtained in different land units over a period of three years and land suitability indixes obtained using the model.

The results of the kappa analysis (Table 10) give a total overall accuracy of 78.67% and a kappa value of 0.7256 with an asymptotic error of 0.058. This value shows that the accuracy of the suitability map established is good according to Landis and Koch (1977).

Table 9. Confusion/error matrix.

		Ground truth					Total
		S1-0	S1-1	S2	S3	N	
Predicted	S1-0	6	1	0	0	0	7
	S1-1	1	19	2	0	0	22
	S2	0	2	20	3	0	25
	S3	0	1	1	12	1	15
	N	0	0	0	1	5	6
	Total	7	23	23	16	6	75

Table 10. Results of kappa statistics analysis.

	S1-0	S1-1	S2	S3	N
User's accuracy	83.33	86.36	76	73.33	71.42
Producer's accuracy	71.42	82.61	82.61	68.75	83.33
Overall accuracy			78.67		
Degree of agreement Kappa			72.56		
Asymptotic standard error			0.058		

5. Discussion

The choice of the most pertinent algorithm for assessing land suitability is crucial for the current and future land use planning for maize production. A key step in assessing the suitability of land for agricultural production is to determine the weight of each criterion affecting the suitability of land (Duc, 2006). The presence of different and multiple criteria complicate the land suitability assessment because the criteria affecting land suitability are of unequal importance (Elsheikh et al., 2013). The ANP-DEMATEL method has been extensively explored (Tseng, 2009; Tsai & Chou, 2009; Büyüközkan & Güleryüz, 2016; Dehdasht et al., 2017; Kadoic et al., 2018; Wu & Tsai, 2018; Zhu et al., 2020) and has been adopted to remedy the imperfections of the ANP method. The application of the DEMATEL method not only makes it possible to describe the structure and interrelationships between the criteria, but also allowed us to identify the key criteria influencing maize in terms of land suitability (Si et al., 2018). The DEMATEL technique, on the other hand, evaluates both the importance of the criteria and shows the causal diagram that could help improve the long-term impacts of the choices. The integrated approach of GIS and the ANP-DEMATEL technique in this study has great potential to classify the land suitability for maize production. No previous studies have been conducted in Cameroon and the holistic approach of GIS and the ANP-DEMATEL technique are hence used for the first time to determine the land suitability for maize production. This study represents the efficacy of the ANP and weighted overlay model for the land suitability analysis of maize resulting in a CR value less than 0.1. The paired comparison matrix used in this study therefore appears to have sufficient internal consistency to be considered acceptable. Furthermore, the DEMATEL technique confirmed the importance of the criteria chosen to be use in the maize suitability assessment process.

Results obtained from this model were compared to maize yield of the last three years to evaluate the efficiency and accuracy of the hybrid model. Recognized experts were selected from one organization (IRAD) in the study region. Overall, 5 experts opinions were applied in this study. Opinions were collected from 5 specialist of maize production by questionnaire and by forums of experts. These results analysis demonstrate that topographic criteria influenced the suitability of Foumbot agricultural land for maize production more than factors related to soil physico-chemical properties. Indeed, the highest weight was assigned to the slope (0.3) followed by pH (0.238), elevation (0.200) and soil drainage (0.114). Thus the slope is the most limiting factor for maize production in Foumbot since more than 30% of the total surface area has a slope degree greater than 16%. These results reflect the reality and are confirmed by experts since Foumbot soils are developed on volcanic ash and are therefore potentially chemicaly fertile (Ngandeu et al., 2016). The good results of DEMATEL-ANP analysis emphasized the better performance of the hybrid model as it was the case with the results obtained by Azizi et al. (2014) who compared the ANP and DEMATEL-ANP methods in a study on site selection for the installation of a wind power plant. They observed that the weight and priorities of the criteria obtained by the two methods differ significantly. ANP established relationships regardless of strength, thus criteria with weak relations were paired with others in the comparison process. This means that the overall weight obtained from this method is not properly distributed among the criteria. Gigović et al. (2017) also recommend the use of this method after testing its effectiveness in a study that also focused on the selection of sites for the installation of a wind power plant in Serbia. DEMATEL-ANP method is a very useful in any field that needs considering many dimensions and criteria (Shao et al., 2018). Application of GIS-DANP combination techniques in environmental studies can prepare a simultaneous explanation of geographical data and environmental factors (Gigović et al., 2017). In current research, multidimensional data layers have been integrated into one-dimensional scales for priority assessment of suitable site for sustainable maize production. GIS and DANP applied in current research can improve Manager's and Planner's performance for spatial assessment procedures by preparing all dimensions on the basis of a collection of assessment criteria.

The GIS-DEMATEL-ANP algorithm helps decision-makers to select suitable lands based on a set of criteria related to the biophysical environment (Pourahmad et al., 2015). GIS-MCDM is a fast and cost-effective technique for LSA purposes, especially in the initial stages of land use planning (Ramadhini & Sihombing, 2018). In this stage, planners, stakeholders and experts partner to improve the process of identifying land suitable for agricultural production. Different ideas indicate the effectiveness of GIS-DEMATEL-ANP can rapidly aggregate this new opinion into the locating procedure (Kanani-Sadat et al., 2019).

Many types of research have indicated that integrating GIS and DEMATEL-ANP is an executive algorithm for ranking planning decisions in many felds. Azizi et al. (2014) used the GIS-DEMATEL-ANP approach in a spatial assessment to help locating suitable sites in Ardabil province, Iran. Pourahmad et al. (2015) assessed the effectiveness of the aggregation of GIS and DANP in Tehran city, Iran. Another study drawn by Gigović et al. (2017) investigated the integration of GIS and DEMATEL-ANP in an assessment on criteria for locating suitable site procedures in Vojvodina province, Serbia. Shao et al. (2018) indicated the combination of an executive procedure with GIS-based DEMATEL-ANP for suitable site selection in China. Ghobadia et al. (2021) assessed suitability of land (LSA) for aquaculture site selection via an integrated GIS-DEMATEL-ANP multi-criteria method. The current research prepares an executive method toward the integration of GIS and DEMATEL-ANP in agricultural field.

6. Conclusion

The main objective of this study was to assess and map suitable land units for sustainable maize (*Zea mays* L) production in the Foumbot Agricultural basin (Cameroon Western Highlands) using multi-criteria decision making (MCDM) approach and geographic information system (GIS). The DEMATEL-ANP was used to determine the weight and prioritization of each evaluation criterion. From this analysis, it appears that slope and soil reaction are the criteria that affect the most the suitability of agricultural land in Foumbot for maize cultivation. Also, 99% of the total land surface in Foumbot is suitable for maize production. However, this suitability varies from very high to marginally suitable: 8056 ha or 11% are very highly suitable, 21,119 ha or 29% are very highly suitable, 38% or 27,405 ha are moderately suitable and 20% or 14,422 ha are marginally suitable. The remaining 1% (606 ha) are unsuitable class for maize cultivation. The kappa analysis of the established suitability map gives an overall accuracy of 78.67% and a kappa value of 0.7256 with an asymptotic error of 0.058. The value of the kappa coefficient obtained shows that the accuracy of the suitability map generated was good and could be used for further decision making processes. The combination of ANP and DEMATEL provides compelling results in strategic decision making. It is thus recommended that this method should be tested in other studies related to land suitability assessment.

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Author Contributions

Original draft preparation, BK; DB and PAT; writing, review and editing, BK, DB, PAT, GSKK, JGV, RKE, ET and DBL; visualization, BK; DB and PAT; all authors have read and agreed to the published version of the manuscript.

Availability of Data and Material

All the data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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