Geospatial Assessment of Land Suitability for Oil Palm (*Elaeis guineensis Jacq.*) Growing in Northern Uganda.

Anjo Abraham[1], Ivan Bamweyana[1]
[1] Department of Geomatics and Land Management, Makerere University P.O Box 7062, Kampala, Uganda,
Corresponding email: ivanson5@gmail.com

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Abstract

Under the second phase of the National Oil Palm Project, the Government of Uganda plans to extend the oil palm project to Northern Uganda. According to the Final Project Design Report (2017) of the National Oil Palm Project, and based on the rainfall, soil and temperature of the region, areas in Northern Uganda have already been mapped for the project. However, no detailed information on the degree of suitability of the areas has been provided. In this research, other parameters such as land cover, elevation and slope were identified through the literature review. Furthermore, on the basis of the reclassify tool in ArcMap 10.8, the data were then reclassified into four classes, namely, highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N.) With the aid of the Analytical Hierarchical Process (AHP), pairwise comparison matrices were constructed and the weight of each parameter was computed. The suitability map obtained from a weighted linear combination identified 38.18%, 35.54%, 21.41% and 4.87% of the land area as highly suitable, moderately suitable, marginally suitable and unsuitable, respectively. A geospatial assessment of the suitability of the land for oil palm growing was carried out. It was based on only the soil types, but excluded the chemical properties of the soil. Therefore, further research on the chemical properties of the soils at suitable sites should be carried out. In-depth research should be carried out While considering social and economic factors among the criteria to determine the willingness and financial capability of the people to venture into oil palm growing as a source of income, Oil Palm Uganda Limited should conduct in-depth research into this issue.

Keywords: Geographical Information System, Remote Sensing, Land Suitability, Oil Palm

1. Introduction

Both globally and locally, oil palm production has increased significantly in recent decades. This has been due to the increased demand for the use of palm oil as an ingredient in processed foods, frying oil, as a raw material in detergents, cosmetics, and pharmaceuticals, and in biodiesel production. It is mainly grown for palm oil production, and most researchers and observers anticipate that the demand for palm oil will continue to rise in the coming years (Pirker *et al*., 2015). It is a highly favoured vegetable oil crop because it is cheap and its yields are more than four and seven times those of rapeseed and soy, respectively (Product Board MVO, 2010). Oil palm growing is mainly carried out in Malaysia, Indonesia, Brazil, Peru, and Central and Western Africa, since these countries and regions fall into the tropical and sub-tropical zones where favourable growth factors prevail.

Owing to the increasing demand for *Elaeis guineensis Jacq*., its growth on a global scale has increased between 2000 and 2012 from an area of ten to seventeen million hectares, to the extent that it now accounts for a tenth of the world's permanent cropland (Pirker *et al*., 2015). A suitability analysis for growing oil palm on a global scale has been carried out using remote sensing and GIS. However, global datasets were used, thus leaving a gap for more accurate results at a local scale that would be influenced mainly by soil properties (Pirker *et al*., 2015).

There has been a continuous and ever-increasing reliance on oil palm growing by many African countries (e.g., Ghana, Nigeria, Angola, Tanzania, Uganda, Gabon, Liberia, Togo and Cameroon), mainly to eradicate poverty. Africa believes that through the Comprehensive African Agriculture Development Programme (CAADP), agriculture can be an engine of economic growth, job creation, food security, nutrition, and the empowerment of women. An oil palm suitability analysis was initially carried out by the Government of Uganda under the Ministry of Agriculture, Animal Industry and Fisheries on the islands of Kalangala, Bugala and Buvuma. Oil palm is currently grown on a large scale in these areas, while limited attention has been devoted to other areas in the country that, if researched, could also favour its growth.

The continuous advancement in Remote Sensing (RS) and Geographic Information Systems (GIS) has enabled the assessment of suitable areas for oil palm growth on a global, regional and local scale. RS and GIS offer quick, cheap, accurate and effective techniques for determining how suitable an area is for oil palm growing.

Area suitability assessments are very important in the planning process before the oil palm is actually cultivated because they provide a viable basis for making effective decisions as to where to plant in order to obtain optimum growth and promote sustainable agricultural land use.

In this study, the main objective was to assess the sites suitable for oil palm growing in Northern Uganda by integrating the tools of remote sensing and GIS. The term "suitability" usually refers to the socio-economic, environmental and climatic potential of a piece of land, and it refers to the mechanisms that are used to evaluate the land's ability to sustain primary production (Qiu 2014; McDowell *et al.* 2018). Furthermore, the suitability of the land needs to be considered before cultivating oil palm to allow farmers to select suitable areas for this purpose and to subsequently attain optimal growth.

2. Study Area

As shown in Figure 1, the study area for this research project is limited to Northern Uganda. Northern Uganda is one of Uganda's four regions, and is located between latitudes 1.5^0N and 3.9^0N, and longitudes 30.75^0E and 35^0E. It is 284 kilometres from Kampala, Uganda’s Capital City. Northern Uganda is bordered by the Democratic Republic of Congo to the west, South Sudan to the north, Kenya to the east, and Central, Western and Eastern Uganda to the south. Northern Uganda covers an area of 85,146.79km^2. According to the 2014 Census, Northern Uganda has a population of 7,188,139. Its annual climate is characterized by temperatures ranging from 20 to 25 degrees Celsius and rainfall ranging from 1,000 to 1,500 millimetres. Northern Uganda has an average elevation of 1,078 metres above sea level, with the highest point at Moroto Mountain, 3,083 metres above mean sea level. Amongst other types of soils, Northern Uganda has alluvial sandy soils, of low productivity, that occur mainly in the Acholi and Lango sub-regions The main economic activities in Northern Uganda are farming, commercial trading and beer-brewing.

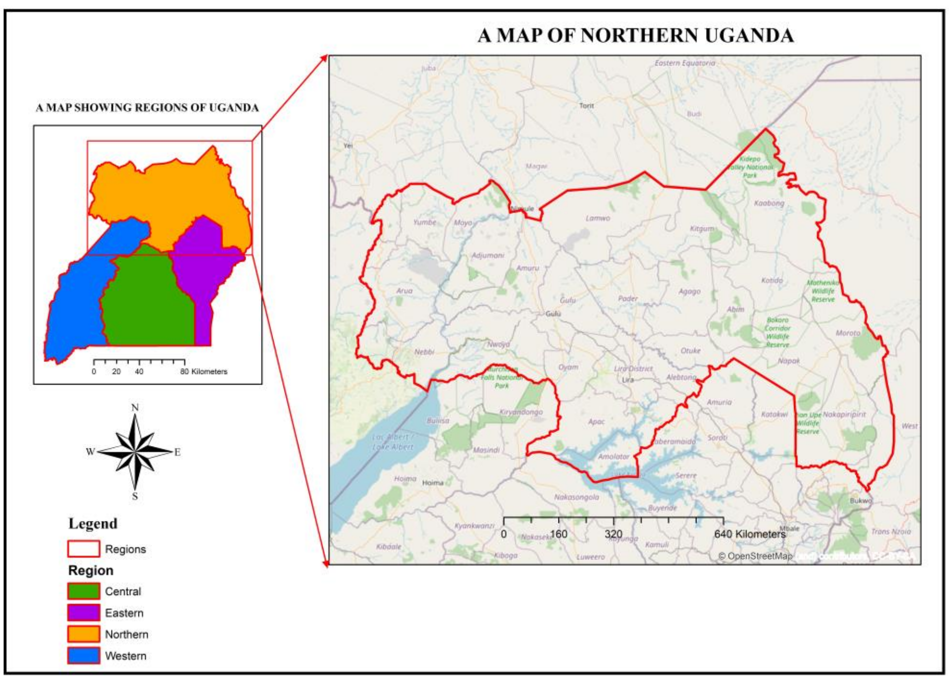
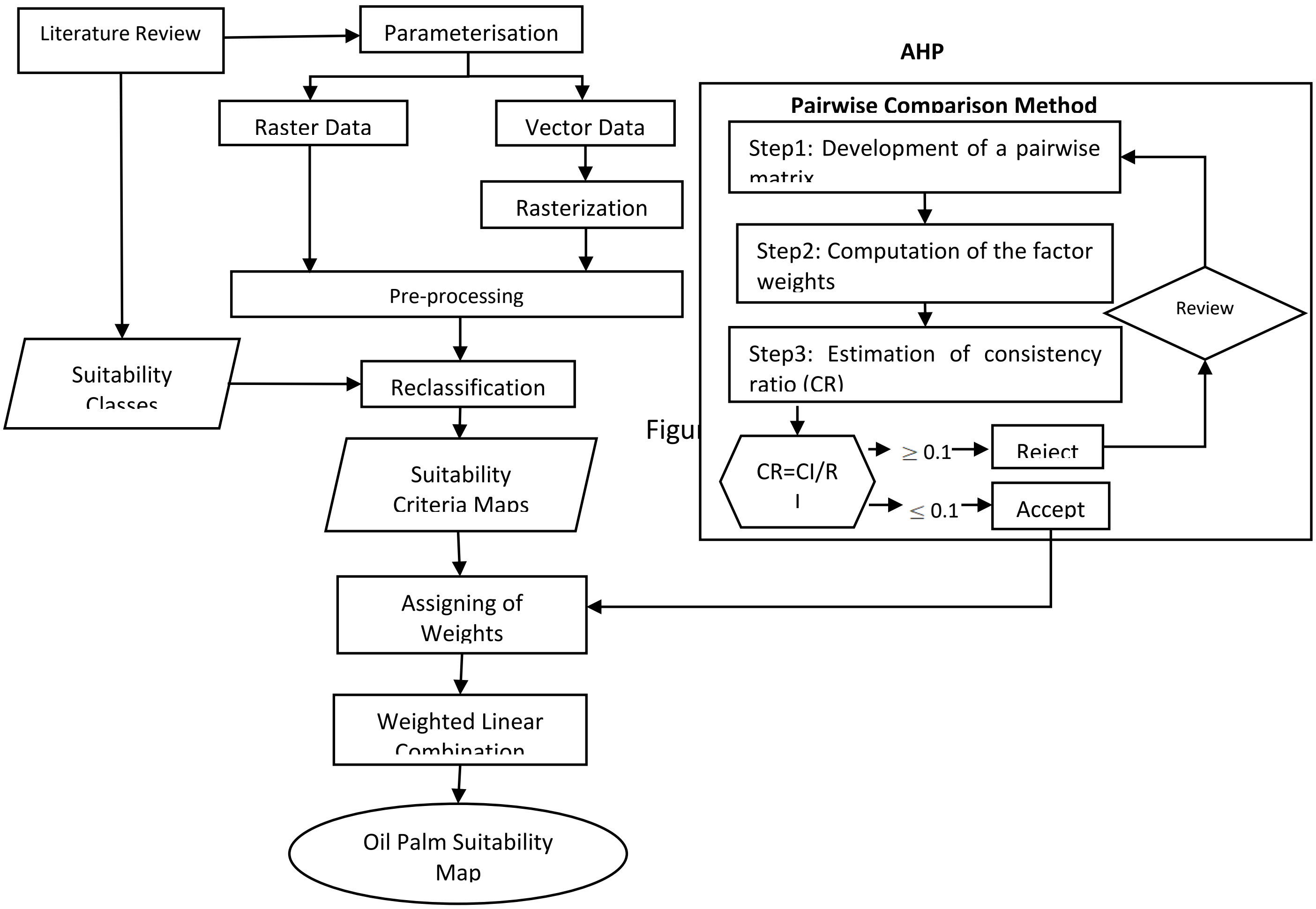


Figure 1: A map showing the regions of Uganda and Northern Uganda in particular

3. Methodology

3.1. Methodology Flow Chart



3.2. Data Collection

As shown in Table 1, the necessary data for the project were identified through a literature review of the previous related research (Pirker *et al*., 2015).

Table 1: Collected Data

Factor	Unit	Format	Projection	Spatial Resolution	Date	Source
Rainfall	mm/year	Raster	WGS84	1km x 1km	2018	http://worldclim.org
Temperature	Degrees Celsius	Raster	WGS84	1km x 1km	2018	http://worldclim.org
Elevation	Meters a.s.l	Raster	WGS84	90 m x 90 m	2018	http://srtm.csi.cgiar.org
Soils	Soil Type	Vector	UTM Arc1960		2015	NARO
Slope	Degrees	Raster	WGS84	90 m x 90 m		Derived from elevation using the 'slope tool' in ArcMap
Landcover(use)	Cover type	Raster	WGS84	20m x 20m	2016	http://2016africalandcover20m.esrin.esa.int/download.php

3.3. Pre-Processing

This involved preparing the collected data before carrying out the actual processing in order to obtain acceptable results. The following pre-processing techniques were carried out on the data:

3.3.1. Coordinate system transformation

The data (Table 1) were projected onto the same coordinate system (WGS__1984_Arc 1960/UTM_ Zone 36N) using ArcGIS 10.8 software. This led to the successful overlaying of the data layers.

3.3.2. Clipping

In order to specify the area of study, and by using the clip tool in ArcMap 10.8, the data were clipped.

3.3.3. Rasterization

By using the polygon-to-raster tool, the data obtained in vector format were converted into the raster format in ArcGIS 10.8. This process provided a uniform data format for the overlaying of the final criteria maps. By using the resample tool, the raster data was then given a uniform spatial resolution of 30m by 30m. The data downloaded in raster format were resampled to a spatial resolution of 30m by 30m.

3.4. Reclassification

Based on the suitability classes, reclassification was conducted on the raster data to assign the cells new values. Four classes from FAO, i.e., highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N) were used to standardise the datasets to a common scale. The reclassify tool in the spatial analyst tools in ArcMap 10.8 was used to reclassify the data. The results of the reclassification were the suitability criteria maps, classified into the four above mentioned classes according to FAO (1976).

3.5. Determining of Weights

The pairwise comparison matrix using Saaty's nine-point weighing scale, as shown in Table 2, was generated.

Table 2: Scale for Pairwise Comparison

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

(Source: Saaty, 1980)

The weights per criteria were generated using the pairwise comparison method with guidance from the literature review. The derived values were applied in the AHP method.

The maximum eigen values were also calculated for purposes of computing the consistency ratio using Equation (1).

$$\text{Consistency Ratio} = \frac{\text{Consistency Index}}{\text{Random Consistency Index}} \qquad [1]$$

The Random Index was obtained from Table 3.

Table 3: Random consistency index values in a pair-wise comparison matrix

Number of items being compared(n)	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.9	1.12	1.24	1.3	1.4

Source: Adopted from Saaty and Vargas (1991)

$$\text{Consistency Index} = \frac{\lambda\text{max} - \text{n}}{\text{n}-1} \qquad [2]$$

Where;

λ_{max} is the sum of the criteria weights

n is the number of the criteria

3.6. Overlaying map layers

The weighted linear combination method was used to overlay the criteria maps in order to generate the suitability map. The weighted linear combination was used because it is regarded as the best for physical land suitability assessments (Dansagoonpon and Tripathi, 2006). It is also a simple and time-efficient method for aggregating the criteria.

The weighted overlay tool in ArcGIS 10.8 was used to generate the final suitability map based on Equation (3).

$$S = \sum wiXi \times C \qquad [3]$$

Where;

w_i denotes the weight of criterion i

X_i denotes the standardised value of criterion i

C denotes a Boolean layer of constraints

4. Results and discussions

4.1. Determining the factor suitability classes

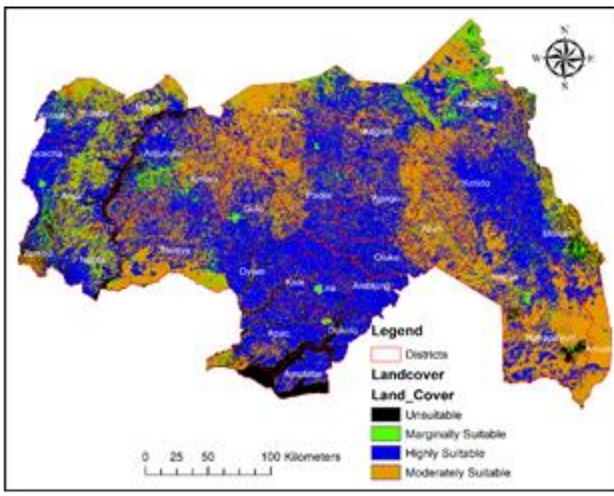
Table 4: Factor Suitability Classes

Criteria	Range	Class	Score	Literature
Temperature	25-28	Highly suitable	4	Dansagoonpon and Tripathi, 2006
	20-25	Moderately suitable	3	
	15-20	Marginally suitable	2	
	Below 15 and above 28	Unsuitable	1	
Rainfall	2000-2500	Highly suitable	4	Dansagoonpon and Tripathi, 2006
	1500-2000	Moderately suitable	3	
	1000-1500	Marginally suitable	2	
	Below 1000 and above 2500	Unsuitable	1	
Elevation	0-500	Highly suitable	4	Dansagoonpon and Tripathi, 2006
	500-1000	Moderately suitable	3	
	1000-1500	Marginally suitable	2	
	Less than 1500	Unsuitable	1	
Slope	0-4	Highly suitable	4	Abd Aziz *et al.*, 2013
	4-15	Moderately suitable	3	
	15-25	Marginally suitable	2	
	>25	Unsuitable	1	
Soil	Clay loam, Sandy clay loam, Silty clay loam	Highly suitable	4	Pirker *et al.*, 2015
	Sandy loam, Silt loam, Silt	Moderately suitable	3	
	Loam	Marginally suitable	2	
	Clay (heavy), Loamy sand, Sand	Unsuitable	1	
Land cover	Open Grassland, Annual Commercial Cropland, Perennial Commercial Cropland	Highly suitable	4	Taddese, 2014
	Sparse Natural Forest, Sparse Woodland, Closed Grassland, Open Shrubland,	Moderately suitable	3	
	Moderate Natural Forest, Plantation Forest, Moderate Woodland, Closed Shrubland	Marginally suitable	2	
	Dense Natural Forest, Dense Woodland, Wetland, Waterbody, Urban Settlement	Unsuitable	1	

Prior to obtaining the suitability map for oil palm growing in Northern Uganda, the ranges of the classes, as shown in Table 4, were derived from literature reviews. The reclassification process enabled the standardisation of all factors into four classes, thereby giving them a uniform scale.

4.2. Suitability Criteria

The datasets were reclassified using the classes in Table 4, resulting in suitability criteria maps. as shown from Figure 3 to Figure 8. The area coverage of each suitability class was calculated and expressed as a percentage of the total area, as shown from Table 5 to Table 10.



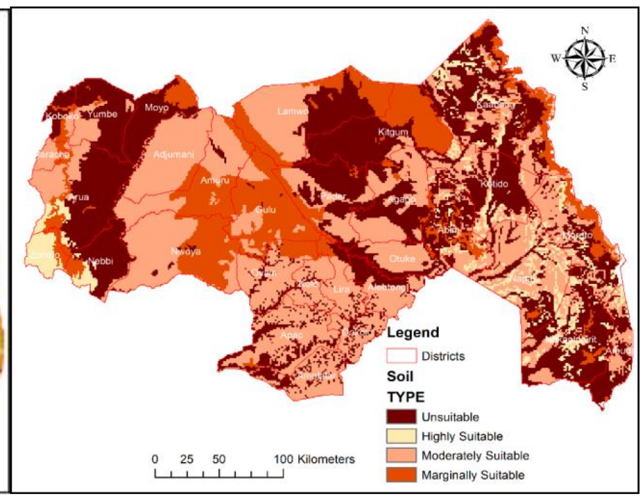
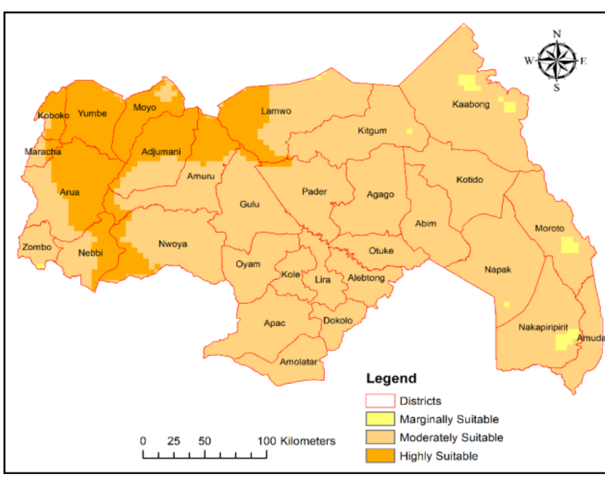


Figure 3: Landcover Suitability Map

Figure 4: Soil Suitability Map



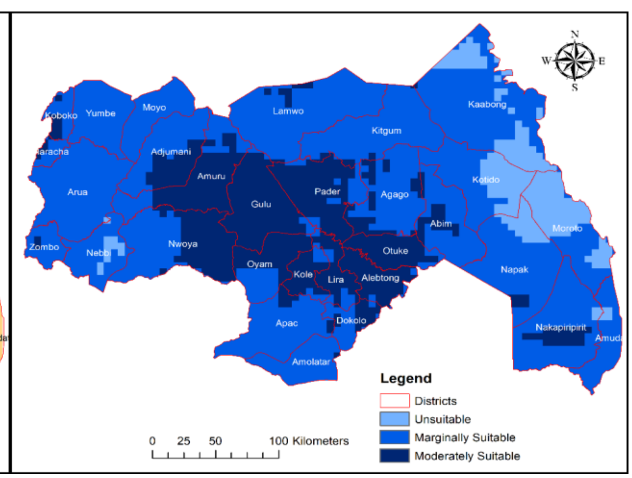


Figure 5: Temperature Suitability Map

Figure 6: Rainfall Suitability Map

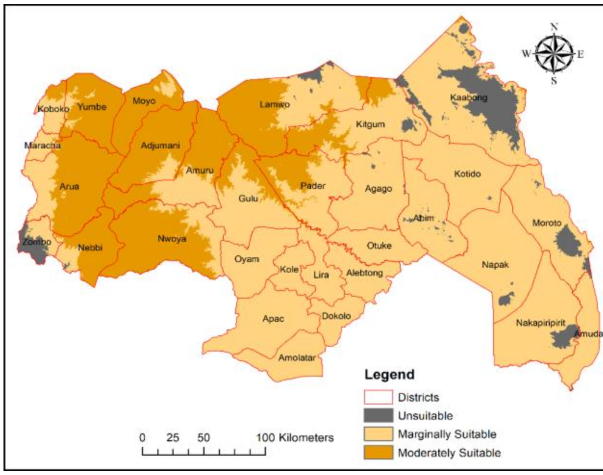


Figure 7: Elevation Suitability Map

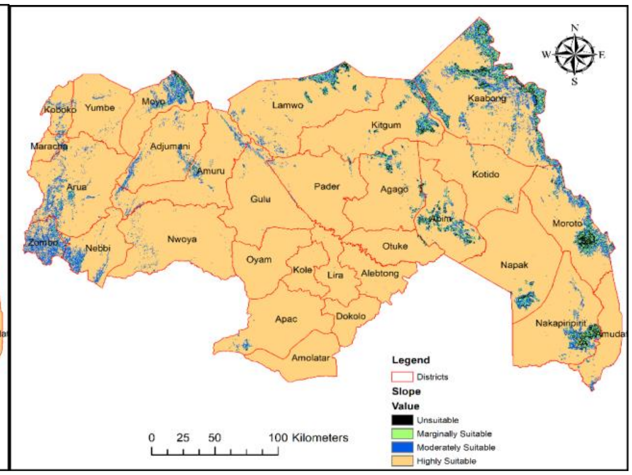


Figure 8: Slope Suitability Map

Table 5: Areas for Landcover Suitability

Score	Area (sq.km)	Percentage (%)	Suitability Class
4	4,711.48	5.53	Highly suitable
3	34,715.09	40.77	Moderately suitable
2	14,432.65	16.95	Marginally suitable
1	31,287.57	36.75	Unsuitable
Total	**85,146.79**	**100**	

Table 6: Areas for Soil Suitability Classes

Score	Area (sq.km)	Percentage (%)	Suitability Class
4	77,445.32	90.96	Highly suitable
3	5,811.11	6.82	Moderately suitable
2	1,075.36	1.26	Marginally suitable
1	815.00	0.96	Unsuitable
Total	**85,146.79**	**100**	

Table 7: Areas for Temperature Suitability Classes

Score	**Area (sq.km)**	**Percentage (%)**	**Suitability Class**
4	14,720.90	17.29	Highly suitable
3	69,620.40	81.76	Moderately suitable
2	805.49	0.95	Marginally suitable
1	0	0	Unsuitable
Total	**85,146.79**	**100**	

Table 8:Areas for Rainfall Suitability Classes

Score	**Area (sq.km)**	**Percentage (%)**	**Suitability Class**
4	0	0	Highly suitable
3	21,757.90	25.55	Moderately suitable
2	56,616.59	66.49	Marginally suitable
1	6,772.30	7.96	Unsuitable
Total	**85,146.79**	**100**	

Table 9: Areas for Elevation Suitability Classes

Score	Area (sq.km)	Percentage (%)	Suitability Class
4	0	0	Highly suitable
3	24,426.70	28.69	Moderately suitable
2	56,839.20	66.75	Marginally suitable
1	3,880.89	4.56	Unsuitable
Total	**85,146.79**	**100**	

Table 10: Areas for Slope Suitability Classes

Score	Area (sq.km)	Percentage (%)	Suitability Class
4	77,895.10	91.48	Highly suitable
3	4,491.36	5.28	Moderately suitable
2	1,851.68	2.17	Marginally suitable
1	908.65	1.07	Unsuitable
Total	**85,146.79**	**100**	

From Table 5, it was observed that 63.25% of the total area of 85,146.79km^2 had suitable land cover for oil palm growing. Suitable landcover is characterised by small-scale farming, woodland, grassland, bushland, and shrubland that can be easily converted to oil palm growing. Only 36.75% of the total area was found to be unsuitable. Unsuitable areas were characterised by open water, dense natural forests, wetlands, and built up areas, all of which were considered as constraints on account of environmental and urban and rural policies. The unsuitable areas were dominant in districts with waterbodies such as Amolatar and Apac, and areas covered by the River Nile.

From Table 6, it was observed that 99.04% of the total area of 85,146.79km^2 had suitable soils for oil palm growing. On the other hand, 0.96% of the total area was found to be unsuitable because of the dominance of clay, loamy sand and sandy soils, as shown in Table 4, which are unfavourable for the effective growth of oil palm.

From Table 7, it was observed that 100% of the 85,146.79km^2 had temperature ranges suitable for oil palm growing, with a moderately suitable class of 69,620.40km^2. On the other hand, 0% of the total area was found to have unsuitable temperature ranges for oil palm growing because the region has temperatures lying in the ranges required for the effective growth of oil palm. Generally, the greater portion of the study area had moderately suitable temperature ranges for oil palm growing.

From Table 8, it was observed that 0% of the 85,146.79km^2 is not highly suitable for oil palm growing because of the lower rainfall received in the area. On the other hand, 7.96% of the total area was found to have unsuitable ranges in terms of its rainfall, predominantly in the Kotido, Napak, Moroto, and Kaabong districts, because the area is semi-desert. The rest of the study area was moderately and marginally suitable, with the marginally suitable occupying the largest area of 56,616.59km^2 (66.49%). Generally, the study area has varying rainfall patterns with the preferred areas for oil palm growing in the districts of Adjumani, Amuru, Nwoya, Gulu, Oyam, Kole, Lira, Pader, Otuke, Alebtong and Dokolo.

From Table 9, it was observed that 66.75% of the total area of 85,146.79km^2 had marginally suitable elevations for oil palm growing. This area is dominant because the average elevation of Northern Uganda is 1,078m and also lies in the range of marginally suitable rainfall, as shown in Table 8. The 4.56% area which is unsuitable is insignificant and characterised by raised hills and mountains such as Mt. Moroto in the Moroto district.

From Table 10, it was observed that 91.48% of the total area of 85,146.79km^2 had highly suitable slopes for oil palm growing because Northern Uganda is generally flat with few scattered hills. The 1.07% area which is unsuitable for oil palm growing is insignificant. As such the whole study area was considered to have suitable slopes for oil palm growing.

4.3. Computing of weights

As shown in Table 1, the pairwise comparison matrix using Saaty's nine-point weighing scale, was generated in order to determine the weights of each criterion. With guidance from the literature review, the weights per criterion were generated using the pairwise comparison method, and the consistency ratio was subsequently calculated.

Factor	Slope	Elevation	Landcover	Rainfall	Temperature	Soil	Weights
Slope	0.031	0.045	0.036	0.162	0.023	0.048	0.058
Elevation	0.045	0.073	0.070	0.027	0.070	0.143	0.071
Landcover	0.428	0.140	0.214	0.115	0.235	0.333	0.244
Rainfall	0.071	0.136	0.112	0.324	0.071	0.143	0.143
Temperature	0.220	0.136	0.214	0.095	0.279	0.143	0.181
Soil	0.214	0.273	0.325	0.324	0.349	0.333	0.303
Total	1.009	0.803	0.971	1.047	1.027	1.143	1.000

λ_{max} = 6.23573, n=6, CI=0.05, RI=1.124, CR=0.04

4.4. Final Suitability Map

The standardised factor criteria maps were combined with their corresponding weights using the Weighted Overlay tool in ArcMap 10.8 in order to generate the final suitability map, as shown in Figure 9.

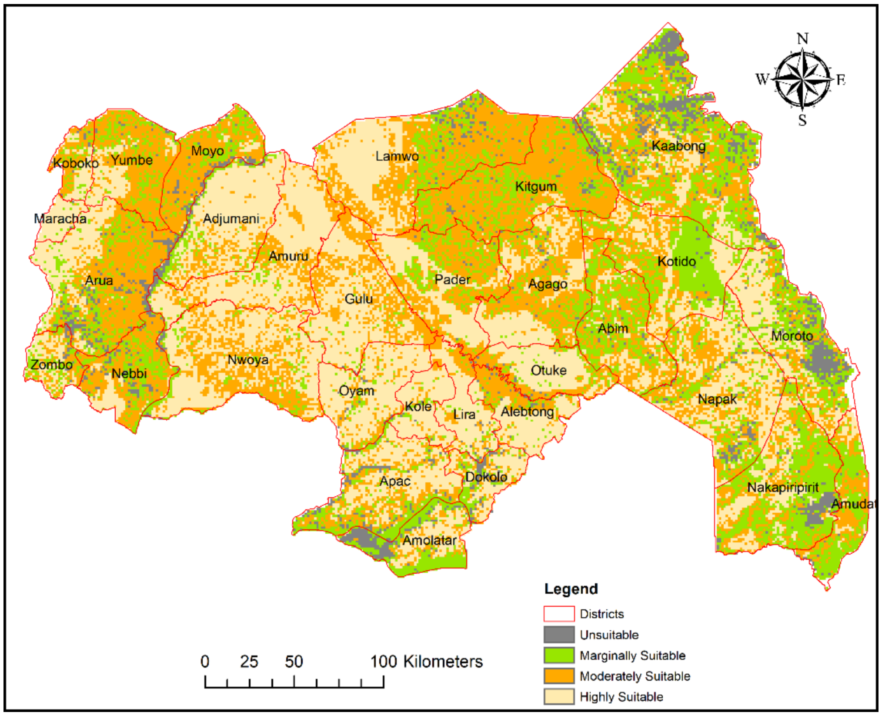


Figure 9: Oil Palm Suitability Map

As shown in Table 11, the area coverage of each suitability class was calculated.

Table 11: Areas for Suitability Classes

Score	Area (sq.km)	Percentage (%)	Suitability Class
4	32,498.25	38.18	Highly suitable
3	30,264.64	35.54	Moderately suitable
2	18,233.80	21.41	Marginally suitable
1	4,150.09	4.87	Unsuitable
Total	85,146.79	100	

From Table 11, it was observed that 95.13% of the total area of 85,146.79km^2 was suitable for oil palm growing. On the other hand, as shown in Table 11, 4.87% of the total area was found to be unsuitable. Unsuitable areas were predominant in the Karamoja region (Kaabong, Kotido, Moroto, Napak, and Nakapiripiriti). Generally, the study area was shown to have great potential for oil palm growing, with highly suitable and moderately suitable areas being the preferred areas because all of the suitability criteria maps were shown to have their most suitable areas in the same region. According to the Oil Palm Suitability Map (Figure 9), the following districts are highly preferred for oil palm growing: Adjumani, Amuru, Lamwo, Nwoya, Gulu, Oyam, Kole, Pader, Otuke, Alebtong, Lira, Dokolo, Amolatar, and Apac.

5. Conclusions and Recommendations

5.1. Conclusions

There are several factors, besides rainfall, temperature, and soil, that were found to influence the geospatial land suitability assessment for oil palm growing. Based on the literature review, factors such as land cover, elevation, and slope also influence the geospatial assessments for land suitability for oil palm growing. As opposed to those based on the three factors, namely, rainfall, temperature, and soil, the use of the six above mentioned factors provided more reliable results for geospatial land suitability assessments. It should be noted that socio-economic factors, which required interviews with the people in the study area, were not considered in this analysis because such an attempt to collect data would have proved to be too costly.

Soils weighed most in this study to assess geospatial land suitability for oil palm growing sites because, unlike chemical properties, physical properties such as porosity, depth, permeability and water retention are difficult to alter (Robert et al., 2002). Soil also determines the availability of soil nutrients and influences the distribution of diseases and pests. This means that soil requires more detailed analysis for it to be assessed more accurately for effective oil palm growing. Because of environmental and planning regulations, soils are followed by land cover. Oil palm cultivation is prohibited in certain types of land use/ land cover, such as swamps, water bodies and urban settlements. In this study, temperature weighed more than rainfall and slope because of man's inability to increase or reduce the temperature, whereas rainfall can be altered by irrigation. Elevation and slope were given the lowest weights because Northern Uganda is relatively flat, with only a few scattered raised landforms. After determining the weights, the results of the overlay in the geospatial assessment of land suitability in Northern Uganda determined that 38.18%, 35.54%, 21.41% and 4.87% of the land area were highly suitable, moderately suitable, marginally suitable and unsuitable, respectively for oil palm growing. The unsuitable areas predominated mainly in the Kaabong, Kotido, Moroto, Napak and Nakapiripirit districts because of the long dry weather spells prevailing in the area and the dominance of loamy sand soils.

5.2. Recommendations

Further research should be carried out by Oil Palm Uganda Limited in its process of considering the relevance of placing social and economic factors among the criteria in order to determine the willingness and financial capability of the people to venture into oil palm growing as a source of income.

A geospatial assessment of land suitability for oil palm growing was carried out. It was based on only soil types and excluded the chemical properties of the soil. Therefore, further research should be carried out by relevant institutions such as the National Agriculture Research Organization on evaluating the chemical properties of the soil (e.g., pH, soil nutrients, total carbon content, cation exchange capacity and salinity) by selecting soil samples from the suitable areas. In this way, more reliable results in terms of the soil could be attained.

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