Land Suitability Assessment for Cocoa Cultivation in Ife Central Local Government Area, Osun State

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Abstract: ***Cocoa is a major cash crop in Nigeria making the country the leading exporter and second largest producer of cocoa in the world in the 1960's. However, cocoa production has dropped significantly due to inadequate land information resulting to poor utilization of land and marginal crop yield. Thus, land suitability assessment based on the FAO Land Framework was carried out for cocoa in Ife Central Local Government Area using Geospatial techniques, soil diagnostics survey, and Multi-Criteria Evaluation (MCE). Soil samples were collected and analysed using standard methods; while other ancillary data with spatial attributes were prepared and analysed using appropriate geospatial techniques. All the data was integrated into a work geo-database from which spatial queries and multi-criteria analysis were carried out. The result of the analysis revealed that 19.44% (28.26 km^2) and 25.67% (36.45 km^2) are moderately and marginally suitable respectively while 54.38% (77.29 km^2) of the study area is not suitable. Some of the constraints affecting the crop suitability are unsuitable soil textures, low organic matter, nitrogen, phosphorus and cation exchange capacity (C.E.C). Therefore, this study recommends effective soil management and nutrient enrichment to increase yield and promote sustainable cocoa production.***

Keywords: Cocoa, Land Suitability, Geospatial Techniques, MCE, Soil Management

1. Introduction

Land suitability assessment provides information on constraints and opportunities for land use and hence serves as guide for decisions on optimal utilizations of the land resources, whose knowledge is an essential prerequisite for land use planning and development. This kind of assessment identifies the main limiting factors for the agricultural production and enables decisions makers such as land users, land use planners, and agricultural support services to develop crop management that can overcome such constraints, thereby increasing crop yield[19]. Geospatial technologies like Remote sensing and Geographical Information System (GIS),which incorporate database systems for spatial data, can be designed and developed to enable the acquisition, compilations, analyzing and displaying topological interrelations of different spatial information for land suitability assessment**[**20]. The conventional method for land suitability analysis rely more on field data and soil analysis but this can be very costly, time consuming and not feasible for very large and tortuous terrain [3]. Since land suitability analysis requires both spatial and attributes data of land in many layers, GIS can be used to combine the biophysical and socio-economic characteristics for land evaluation and multi-criteria evaluation tool can be developed for its suitability for crop production. Hence, the integration of GIS and AHP into a multi-criteria land suitability assessment for cocoa cultivation in Nigeria can greatly improve the crop yield. Nigeria was a leading exporter of cocoa and also the second largest producer of cocoa in the world earning over 20 million dollars annually as foreign exchange from the export of cocoa beans alone, besides revenue from cocoa by-products [1]. However, the country has lost its former status as major exporter of cocoa to Cote de voir and Ghana [14]. This decline in production has been attributed to the discovery of oil and consequent neglect of the sector by government [2]. Some research also identified inadequate agriculture practices such lack of fertilizers, poor cropping system and poor site selection as factors that has contributed to decreased production of cocoa [11,18]. Hence, information on land capability and suitability and input requirement for the cultivation of cocoa is necessary to increase the current yield of the crop and restore the country back to its former status. This research focuses on utilizing the integration of geospatial technologies with multi-criteria evaluation in identifying areas suitable for cocoa cultivation in Ife Central Local Government Area (L.G.A). This is aimed at providing agriculture policy makers, cocoa investors; stakeholders and farmers in particular with necessary information to ensure optimal and sustainable cocoa production in the Ife Central L.G.A.

2. Study Area

Ife Central Local Government Area is bounded in the south by Ife East Local Government Area, in the west by Ife North Local Government, in the east by Ondo State and in the north by Ilesha. It is located between latitudes 7°28' 43.5"N and 7°34' 51.41"N and longitudes 4°27' 22.5"E and 4°35' 40.61"E and an altitude of 256m above sea level (Fig 1). The rainy season starts from mid-March to late October with mean annual rainfall of about 1400mm, relative humidity is about 75.8% and 86% while the dry season runs from November to March with temperature ranging between 280C to 340C. The population of the area is about 167,254 persons consisting of 88,403 males and 78,801 females based on the National Population Commission 2006 census result. The study area is characterized by two types of soil: deep clay soil formed on the lower smooth hill crests and upper slopes; and sandy (hill wash) soil on the lower slopes. The mixture of clay and sandy soil forms loamy soil and this helps water retention from seepage. The natural vegetation of the area is under tropical rainforest belt characterized with multiple canopies and lianas which can sustain cocoa production. The people are mostly farmers producing such food crops as yam, maize, cassava, cocoyam and cash crops which include cocoa, tobacco and oil palm produce.

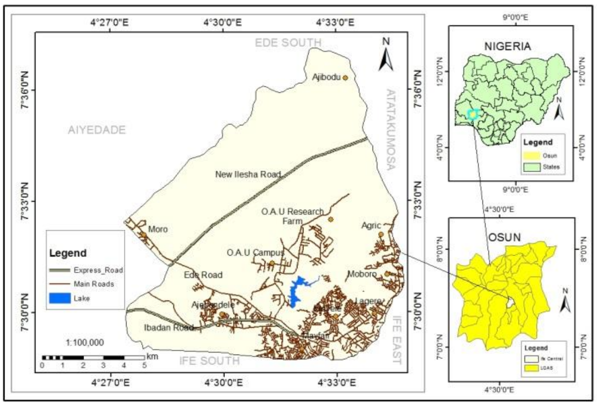

Figure 1: Study Area

3. Methodology

The methodology followed in the study can be classified into five steps namely: extraction of study area, soil sample collection and analysis, generation of thematic maps, image processing and multi-criteria evaluation. The workflow diagram is shown in Figure 2 below and Table 1 summarizes the data sets used in the study.

Table 1: Secondary Data and their Sources

Sr. No.	Data	Year	Source
1.	Mean Annual Temperature, Rainfall and Relative Humidity of Ife Central Local Government Area	2009 to 2012	Nigerian Mesoscale Experiment (NIMEX), Ile – Ife
2.	Existing Shapefile of Ife Central Local Government Area	2012	Office of the Surveyor General of the Federation (OSGOF), Nigeria
3.	SRTM Image covering Ife Central Local Government Area.	2008	Global Land Cover Facility (GLCF)
4	NigeriaSat 1 Image covering Ife Central Local Government Area.	2007	National Space Research and Development Agency, Abuja.

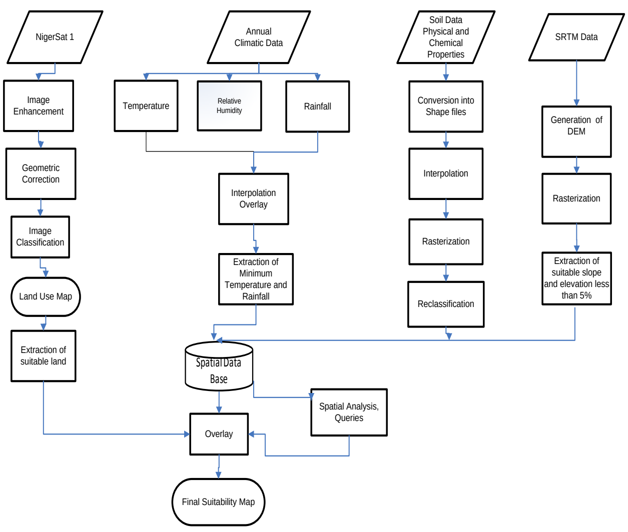

Figure 2: Flow Chart

3.1: Extraction of Study Area: The existing shapefile of the Ife Central Local Government Area was used to carve out the study area from the satellite image using the clip extract function in ArcGIS 10.1 version.

3.2: Soil Samples Collection and Analysis: Based on the soil types identified in the area, the study area was divided into twenty homogenous land units using a 3km by 3km grid system that ensured adequate coverage of all the soil types in the area. This conformed [7] recommendation for a large scale intensive in forested area such as the tropical rain forest zone where the study area is located. The grid was used as guide in the field survey, soil sampling and also used to develop a more detailed soil map using interpolation of soil analysis. Soil classification was made based on FAO [8]. Twenty composite soil samples were obtained using soil auger from the demarcated horizons of the four profile pits and their coordinates recorded using a GPS hand receiver. The soil samples were taken for physico-chemical analysis of the following parameters: Soil texture, Organic Matter, pH, Cation Exchange Capacity (C.E.C), Base Saturation, Nitrogen and Phosphorus. These soil parameters were determined using methods described by [4-5,23, 27].

3.3: Generation of Thematic Maps: The thematic map of each of the soil properties and climatic data was generated using inverse direct weighted (IDW) method of interpolation in the ArcGIS 10.1 software. The weight is a function of inverse distance and IDW lets the user control the significance of known points on the interpolated values, based on their distance from the output point. The thematic maps were rasterized and reclassified into five suitability classes based on the crop requirement using the spatial analyst tool in ArcGIS 10.1. The topography and slope information were obtained from Digital Elevation Model (DEM) using GIS software package Arc GIS 10.1. The source of DEM was SRTM (Shuttle Radar Topographic Mission) which was 30m spatial resolution. The DEM and slope was rasterized and reclassified into five suitability classes based on the crop requirement.

3.4 Image Processing: The land use land cover information was generated using the NigerSat 1 image acquired in 2007 with a spatial resolution of 32m pixel size and processed using ERDAS Imagine version 9.2. The image was checked to conform to UTM Zone 31N of WGS 1984 and geometric correction carried out to enhance the image. Supervised classification was done using the maximum likelihood algorithm for 3 spectral bands corresponding to 432 combination green, red and near infrared (G, R, NIR). The kappa statistics indicating the accuracy of the land use/cover classification was determined in ERDAS Imagine 9.2 by using the samples points collected from the field survey. The land use /cover classes identified in the image was classified into six (6) basic features such as forest, vegetation, riparian forest, settlement, water bodies and rockout crop using the land classification scheme described by [3].

3.5: Multi Criteria Evaluation: The objective of weighting is to express the importance of each factor relative to other factor effects on crop yield and growth rate [15]. The factors were established based on the expert opinions of local agronomists and researchers who have identified the following variables as relevant to suitable growing areas for cocoa: soil texture, organic matter, pH, organic matter, C.E.C, base saturation, nitrogen, phosphorus, slope, rainfall, temperature and relative humidity as the relevant criterion set. Suitability levels for each factors was defined and these levels were used as basis for constructing the criteria maps for each factor. The suitability levels were: Highly suitable-S1, Moderately suitable-S2, Marginally suitable-S3, Not suitable-N based on the FAO 1976 framework for land suitability classification. Specific suitability level of each facto was defined with respect to the crop requirement as shown in table 2. The Analytic Hierarchical Process (A.H.P) was used to generate weights and criteria as described by [21]. The weight and criteria of each factor was used to produce the standardized thematic layer (Table 3) and the weighted overlay function in ArcGIS 10.1 was used to produce the soil and topography suitability maps. These maps were then overlaid on the land use land cover to generate the final suitability map for cocoa in the study area.

Table 2: Climatic, Soil and Land Requirement for Cocoa

Land use / Land characteristics	*S1*	*S2*	*S3*	*N1*	*N2*
Average annual temperature (^{0}C)	25 – 28	22 – 25 28 – 32	20 – 22 32 – 35	16 – 20 35 – 37	<20 >37
Average annual rainfall (mm)	1600 – 2500	1400 – 1600	1200 – 1400 3000 – 4000	1000 – 1200	<1000
Average annual relative humidity	40 – 65	65 – 75 35 – 40	75 – 85 30 – 35	85 – 95 25 – 30	>95
Soil texture	Fine, Slightly fine, medium	-	Slightly coarse	Coarse	
Coarse materials %	<15	15 – 35	35 - 55	>55	
Nitrogen	>1.8	1.5	1.0	0.5	<0.5
Phosphorus				<0.02	
C.E.C-clay (cmol/kg)	>24	20 – 24	16 – 20	12 – 16	<12
Base saturation %	>50	45 – 50	40 – 45	35 – 40	<35
Ph	6.0 – 7.0	5.5 – 6.0	<5.5		
Organic matter %	2.5 – 3.5	2.0 – 2.5	1.5 – 2.0	1.0 – 1.5	<1.0
Slope %	<4	4 – 8	8 - 16	16 – 20	>20

Table 3: Factors and Weights for Cocoa

	COCOA	
Factor	*Weight*	*Weight (%)*
Soil		
Physical Property		
Texture	0.2572	25.72
Chemical Properties		
pH	0.0514	5.14
Organic matter	0.0171	1.72
Cation Exchange Capacity	0.0342	3.43
Base Saturation	0.0342	3.43
Nitrogen	0.0172	1.72
Sulphur	0.0172	1.72
Climate		
Rainfall	0.1143	11.43
Temperature	0.0857	8.57
Relative humidity	0.0857	8.57
Topography		
Slope	0.0857	8.57
Elevation	0.0571	5.71
Land use		
Vegetation	0.0999	10.00
Forest	00428	4.28
Total	**1**	**100**

4. Results and Discussion

4.1 Soil Properties Variability: Land suitability assessment, on the basis of soil properties requires criterion from the soil attributes and the result of the various physio-chemical properties of the soil analyzed are presented below. Soil texture is most useful in land suitability assessment and management as it provides information about the porosity of the soil and bulk density thus indicating possible limitation to root growth and penetration. Sandy loamy was most dominant soil while clay loamy had the smallest coverage in the study area. The result of the analysis shows that just 1.5% of the study area was highly suitable for cocoa production; 32.4% is moderately suitable while 25.1% is marginally suitable. The remaining 22.29% are not suitable for cocoa production. The suitable soil texture identified for the crop was clay loamy, sandy clay loamy, sandy loamy and silt loamy. The result of the soil texture obtained is in tandem the findings of [22] and [17] who also identified similar soil texture in the study area.. The Soil pH is useful in soil suitability evaluation as it provides information about the solubility and phyto-toxicity of elements for specific crops. The soil pH of the study area ranged from 5.5 to 7.2 representing different level of suitability for crop indicating that the soils are slightly acidic. The result of the analysis shows that 26.7% of the study area is highly suitable; 46.8% is moderately suitable; 23.4% marginally suitable while just 1.3% is not suitable. The pH range is in agreement with [17] who observed pH values of 6.5 and below tend to be found in regions such as rain forest with abundant rainfall and moderate to high temperature like the study area.. Soil organic matter exert major influence on the soil properties such water-holding capacity, retention, infiltration, pH, exchangeable capacity of the soil and source of nitrogen. Generally the organic matter of soil ranges from 0.13 to 3.3 with 12.5% of the study area highly suitable; 24.27% moderately suitable; 9.1% marginally suitable while the remaining 54.2% is not suitable. The area with high organic matter confirms the result of [26] who observed that soil with high pH have corresponding high organic matter. The areas with suitable organic matter may be due to the high clay content and it is in tandem with the findings of [10] that organic matter increases corresponding with clay content. The cation exchangeable capacity ranges from ranges from 0.31 to 3.3 and just 31.2% of the whole study area is marginally suitable for cocoa production while the remaining 68.8% is unsuitable for cocoa production. Studies by [11] obtained low CEC in cocoa soils and attributed this to low clay and organic matter of the soil. The base saturation ranges from 45.6 to 99% showing that most the study area (94.7%) is highly suitable for cocoa production while the remaining 5.3% is moderately suitable. The nitrogen content of soil ranges from 0.04 to 1.5 indicating that over half of the study area (74.5%) is highly suitable for cocoa production; 10.4% is moderately suitable; 8.8% is marginally suitable and just 4.3% unsuitable. The phosphorus content of soil ranges from 1.7 to 8.8 in the study area showing that 18.3% of the study area is highly suitable for cocoa production; 2.4% is moderately suitable; 7.5% is marginally suitable and over half of the study area (71.8%) unsuitable. Thus, less than one third of the study area is suitable for cocoa production. The soil suitability map of the study area for cocoa was produced (Figure 3) showing that 21.4% of the soil is moderately suitable, 56% marginally suitable while 23.6% is unsuitable. None of the soils in the study area is rated as highly suitable thus confirming the [10] findings that over 48 % of the Nigerian soils fall into class 4 and 5.

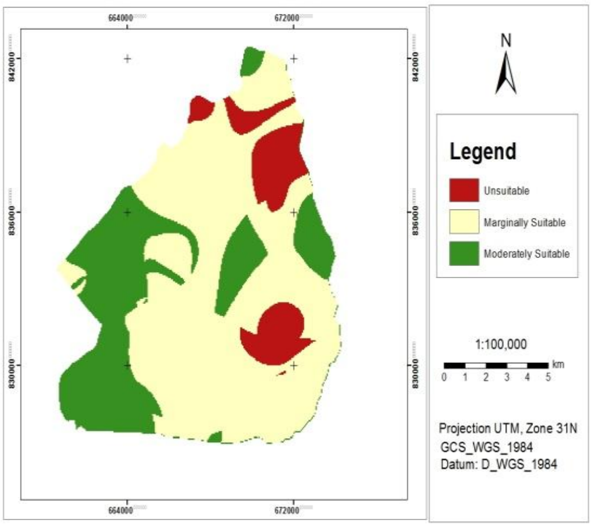

Figure 3: Soil Suitability for Cocoa

4.2: Climatic Data and Topography

The annual temperature ranged from 24 – 28.320C with a mean value of 26.150C; the annual rainfall ranged from 1250 -1300mm with a mean value of 1300mm while annual relative humidity ranged from 64.86 to 85.60% with mean value of 77.82%. The mean annual temperature and relative humidity of the study area are suitable for cocoa cultivation; however the mean annual rainfall of 1,300m is insufficient when compared to the rainfall requirement of the crop as described by [25]. In terms of elevation, the Digital Elevation Model (DEM) varies from 216m to 440m above mean sea level with an average of 283m above mean sea level. The analysis of the slope, indicate that the area has a slope range of 10 to 16% which is marginally suitable for the crop. The reclassified DEM analysis shows that reveals that the majority of the study area is flat with 137.7km2 (96.34%) of its total area under 300m, which is characterized mainly by flat and gently sloping lowlands and suitable for cocoa production (Fig 4). The remaining 5.2km2 (3.66%) is above 300m is characterized by mountains and hills

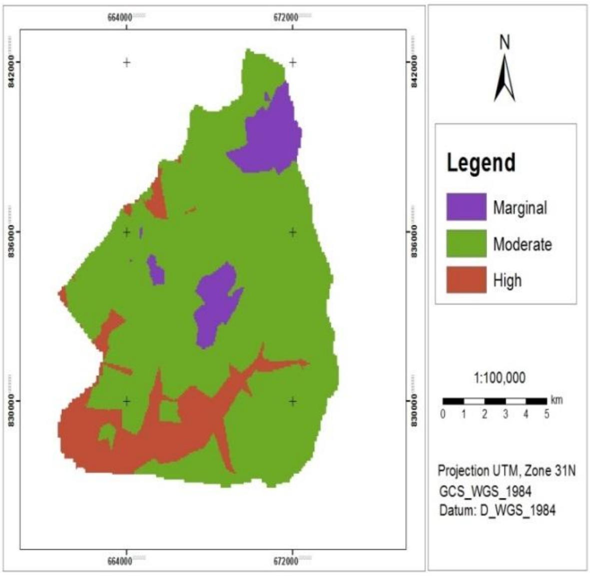

Figure 4: Reclassified Elevation

4.3: Land Use/ Land Cover Map

The result of the supervised classification performed on the Land Use/ Land Cover Map (Figure 5) showed forest as constituting 46.83km^2 which represent the highest share of 33.0% followed by vegetation which had 39.15km^2 (27.59%). Riparian forest constitutes 32.17km^2 (22.68%) and settlement 17.58km^2 (12.39%) of the study area. Water body constitutes0.78km^2 (0.26%) representing the least while rockout crop was 5.79km^2 (4.08%). The result of the Kappa statistics indicates 81.1% accuracy showing that the classification is a fair representation of the features in the study area.

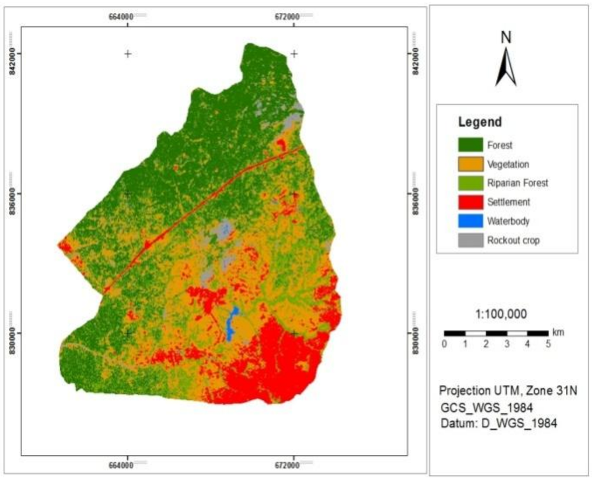

Figure 5: Classified Image of Ile-Ife Local Government Area

4.4: Final Land Suitability

The final weighted overlay land suitability analysis for cocoa production in the study area showed that the 16.32km^2 (11.51%) of the study area is moderately for cocoa production while 26.45km^2 (18.09%) is marginally suitable for cocoa production (Table 4). The study area was classified as having moderately climatic suitable. This finding is in agreement with other result obtained by [13]. The areas mapped as moderately suitable are having all the necessary requirements with minor limitations. The integration of land cover map with the crops suitability map was used to extract the suitable land cover and restrict the unsuitable ones as earlier described (Fig 5). The final suitability was overlaid on the Ikonos satellite image to validate it and the suitable areas identified were in conformity with existing cocoa plantations in the study area (Fig 6).Various studies have produced land suitability maps for agricultural crops using GIS to identify different suitability classes of land for the crops [6, 12] illustrating that GIS is power tool in land suitability analysis. This research has also demonstrated the effectiveness of geospatial technologies like GIS in land suitability assessment of agricultural crops like cocoa.

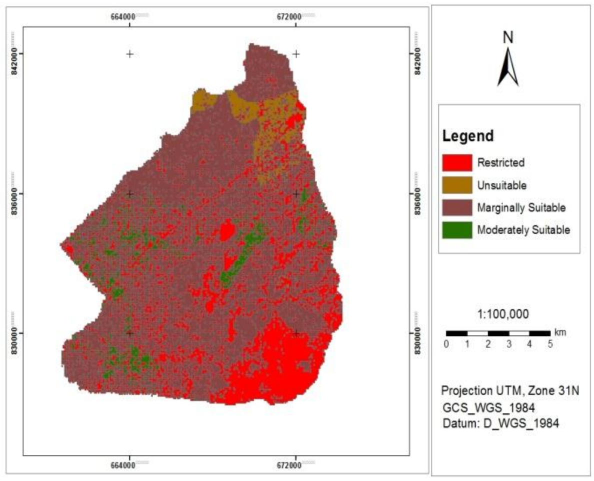

Figure 6: Final Land Suitability for Cocoa Production in the Study Area

Table 4: Land Suitability of Cocoa

Suitability Class	*Area (km^2)*	*Area (%)*
Moderately Suitable	28.26	19.44
Marginally Suitable	36.45	25.67
Unsuitable	77.29	54.38
Total	**142**	**100**

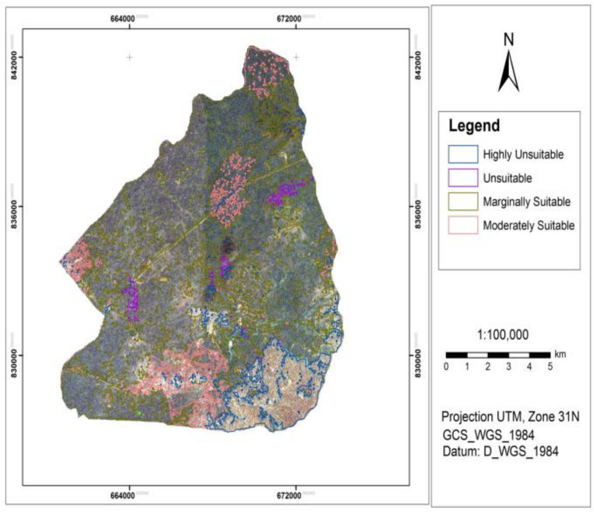

Figure 7: Validation of Land Suitability of Cocoa

5. Conclusion

This study identified sandy loamy, sandy clay loamy, silt loamy and loamy soil as the major types in the study area. Some of the physio-chemical properties of these soils and other land suitability parameters such as the climatic condition and topography affect the suitability of the land for cocoa cultivation. The major limiting land qualities for cocoa cultivation identified include soil texture, organic matter, nitrogen and phosphorus. The integration of the existing land use land cover map showed that over one third of the study area is moderate and marginally suitable for cocoa production. Consequently, this study recommends that: (I) sustainable cocoa cultivation be carried in areas categorized as suitable. (II) mitigating some of the limiting soil nutrients through application of nitrogen rich and phosphatic fertilizers; increasing the soil organic matter through effective crop residue management and increased use of leguminous crops. Further research should be carried out considering other parameters such as socio-economics factors in determining the land suitability. This study concludes that use of geospatial technologies is power tool in land suitability assessment for cocoa cultivation and ensuring sustainable land usage.

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