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Suitability Mapping for Optimum Soybeans (Glycine Max (L.) Merr.) Production in Konshisha LGA, Benue State, Nigeria using Satellite Remote Sensing Data

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ABSTRACT: *Land suitability mapping is a pre-requisite for optimum and sustainable crop production which ensures food security. However, in Konshisha Local Government Area, Benue State, Nigeria, little efforts have been made in this direction to provide land suitability information required for optimum soybeans production resulting to low productivity which threaten efforts to achieve the Sustainable Development Goal (SDG) 2 of eradicating hunger by 2030. Thus, the aim of this study was to map land suitable for optimum and sustainable soybeans production in the area. Remote sensed data from Climate Research Unit (CRU), University of East Anglia, National Aeronautical Space Agency's (NASA) Shuttle Radar Topographic Mission (SRTM), Environmental Systems Research Institute's (ESRI) land use land cover data and African Soil Information Service's (AFSIS) digital soil data acquired using remote sensing and geographic information system (GIS) techniques were collected as well as field observation with hand held Global Positioning System (GPS) device for multi-criteria evaluation (MCE). GIS reclassification and, analytical hierarchical process (AHP) were applied. Result of the multi-criteria analysis shows that rainfall, temperature, slope, land use land cover and phosphorus have suitable conditions, while soil organic carbon, pH and drainage have limiting conditions for optimum soybeans production. Result of the overall suitability mapping shows that 30.3% of the land is highly suitable (S1) with greater proportion of it in Ikyurave, Mbavaa and Mbatsen districts; 69.5% moderately suitable (S2) and 0.2% marginally suitable (S3) for soybeans production. Based on the findings, the study concluded that low soil organic carbon, pH and soil drainage are major land limiting factors for optimum soybeans production. Therefore, the study recommends application of mixed organic and inorganic fertilizers, lime, composite manure, agro-forestry, crop rotation and creation of open deep drains as supplement of the limiting factors for optimum soybeans production in the study area.*

KEY WORDS: crop production; climate; land suitability, MCE and SRTM

INTRODUCTION

The number of people in urgent need of food is on the increase in the world. About 820 million people in the world do not get enough food to eat yet the population is growing at an alarming rate [1]. To meet the increasing demand for food, the farming community must produce optimally [2]. Without added efforts, the world will fall far short of actualizing the Sustainable Development Goal (SDG) number two (2) of eradicating hunger by 2030 [3]. To increase food production and guarantee food security, land suitability mapping becomes imperative in order to identify suitable lands for optimum and sustainable crop production [4].

Land suitability mapping is a measure of land fitness for a defined use on a sustained basis [5]. Land comprises biophysical and cultural elements. The biophysical aspect includes vegetation, climate, topography, soils, geology and hydrology while the cultural aspect comprises past and present human activities that influence potentials for land use like soybeans [5]. Suitability means the fitness of a defined use on sustained basis. Suitability mapping according to FAO framework for land evaluation involves identification of the land use type (soybeans), land use requirements, matching of the requirements with the land characteristics and definition of suitability classes [6]. This according to [7] enables agricultural decision makers, planners and farmers to develop sustainable agricultural management systems for optimum crop production.

Crop production is the major sub sector and driver of agriculture which is the mainstay of the people in Nigeria [8]. It plays a vital role in Nigerian economy by providing food, employment and income to the people, raw materials for industries and has accounted for 87.6% of the nominal agricultural contribution (23%) to the Gross Domestic Product (GDP) in the year 2020 (Nigeria Bureau of Statistics [NBS] [9]. However, soybeans as one of the vital foods and cash crops produced in Nigeria with high nutritional, economic and environmental benefits is constrained by low yield [10].

Soybeans (*Glycine max (L.) Merr*) is a leguminous crop grown in tropical, subtropical and temperate climates either as food or cash crop. It provides inexpensive and high-quality source of protein comparable to fish, meat, poultry and egg [10, 11]. It is also a vital and preferred source of animal feeds. Soybeans has potentials to arrests malnutrition, particularly protein deficiency prevalent in many parts of Africa as animal protein is too expensive for most populations [10]. It has potentials to improve declining soil fertility, enhance household nutrition security, and raise rural incomes [12]. The benefits of soybeans have made it gained popularity worldwide [13].

World soybeans production has increased from 223.4 million metric tons in 2009 to 333.7 million metric tons in 2019 due to demand and consumption [14]. Nigeria ranked second in Africa with a production output of 630,000 tons in 2019 behind South Africa, despite cultivating higher land area thus indicating low yield per hectares [14]. Soybeans in Nigeria is largely produced in the northern and southern guinea savannah ecological zone with Benue State as the major producer

[15]. Other major producing states include Adamawa, Kaduna, Kano, Katsina, Kwara, Niger and Taraba states with the poor households accounting to produce over 80% of soybeans [10].

Benue State produced about 30% of the total production in Nigeria [16]. However, soybeans production in Benue is based on the vastness of cultivated land and not high yield per hectare [17]. Major soybeans producing centres in Benue include Gboko, Konshisha, Tarka, Gwer East and Buruku Local Government Areas (LGAs) [18]. Konshisha LGA however recorded the lowest yield per hectare among the major soybeans producing centres in Benue State with a total cultivated farm size of 217 hectares with an output of 62.8 tonnes [17].

Soybeans yield is strongly influenced by climate, soil and topographic characteristics [19]. Production limits are set by the land characteristics thus need to be analysed and mapped first for optimum and sustainable production as recommended by [20] agronomic practice for optimum soybeans production. However, little effort has been made in this direction for soybeans production in Konshisha LGA. This has contributed to the low soybeans productivity in the area which impedes effort to actualise the SDG number two (2) of eradicating hunger by 2030. It was against this background that this study was carried out to provide land suitability information necessary for optimum soybeans production in the study area.

Land suitability data is a basic requirement to increase crop yield on a sustainable basis. In Konshisha LGA of Benue State, Nigeria however, there is no evidence of land suitability data available for soybeans production which contributes to low productivity. Low yield is a major problem to optimum soybeans production in Konshisha LGA [18]. The area has recorded the lowest yield per hectare among major soybeans producing centres in Benue State with a total farm size of 217 hectare an output of 62.8 tonnes [17]. This has resulted to soybeans shortages, economic losses and unsustainable production practices which impede efforts to achieve the Sustainable Development Goal (SDG) 2 of eradicating hunger by 2030.

Efforts have been made by agricultural research institutes and development donors such as the International Institute for Tropical Agriculture (IITA), the National Cereal Research Institute (NCRI) to improve soybeans yield through development of several improved varieties of soybeans seeds (TGX 1448-2E and TGX 1895-35) and the United State Agency for International Development (USAID) intervention project (USAID MARKETS II Soybeans Production Project). However, high yielding varieties and other interventions cannot give the desired optimal yields without land suitability information. Hence, the urgent need for land suitability mapping to provide suitability information as recommended by [20] for optimum soybeans production.

Even though a number of studies have been carried out on land suitability analysis, the reviewed literature available to the researcher has shown that there is a knowledge gap in land suitability information for soybeans production in Konshisha LGA despite the fact that it is a vital cash and food crop produced in the area. It was against this backdrop that the following research questions were answered

1. What are the land characteristics for soybeans production in the study area?
2. What is the extent of the land suitability for soybeans production in the study area?
3. What is the quality of the suitability map for soybeans production in the study area?

Aim and Objectives

The aim of the study is to map land suitable for optimum soybeans production in the study area. The aim was achieved through the following objectives. Which are to;

i. analyse land characteristics for soybeans production in the study area;
ii. map the extent of land suitability for soybeans production in the study area and
iii. validate the quality of the suitability map produced for optimum soybeans production in the study area.

THE STUDY AREA AND METHODOLOGY

Konshisha LGA is one of the LGAs in Benue State, Nigeria with a total land mass of about 1,829 km^2 located between Latitude 6^0 05' to 7^0 02' North of the Equator and Longitude 8^0 04' to 8^0 09' East of the Greenwich meridian. It shares boundaries with Gboko and Gwer East LGAs to the North, Oju LGA in the West, Ushongo and Vandekya LGAs to the East and Cross River State to the south. The LGA has eleven (11) council wards. These are Mbatsen, Mbanor, Mbatem Mbatser, Mbawar, Ikyurav, Iwarnyam, Mbaikyaise, Mbayegh and Mbaake with the administrative headquartres called Tse-Agberaggba. See Figure 1.

The study area is located within the tropical savannah climate zone with a tropical wet and dry season ideal for grains production. The wet season onsets from April and ends in October with a total rainfall of about 1500mm per annum suitable for soybeans growth and yield [21]. The area has rainfall period of seven months with a peak period in August/September. The dry season, however, starts at the cessation of the wet season in early November and ends in March. It usually has a period of high temperature with the average maximum and minimum temperatures of 28^0 and 21^{0}C respectively [22]. This dry season also features harmattan period that characterized dust, haze, and dry conditions for easy drying, thrashing and winnowing of soybeans and other grains. Climate is considered necessary in land suitability for soybeans production because it affects the planting period, growth, yields and harvesting thus have positive or negative impacts on the crop production [23].

Konshisha Local Government has a population of about 225, 672 persons [24]. It comprises of Tiv ethnic group. The people are predominantly farmers and produce different varieties of crops such as yam, cassava, rice, soybeans, guinea corn, ground nuts, pepper and oranges. Orange (Citrus) dominate fruit cropping in the area closely followed by mango and cashew. Farming is the main occupation of the people and they depend majorly on the cultivation of land as a means of livelihood. However, due to the reduction in the fallow period as the population density increases, the yield per area cultivated is reducing drastically. Hence, the need for land suitability information to select suitable areas for optimum crops production and sustainable management of the land.

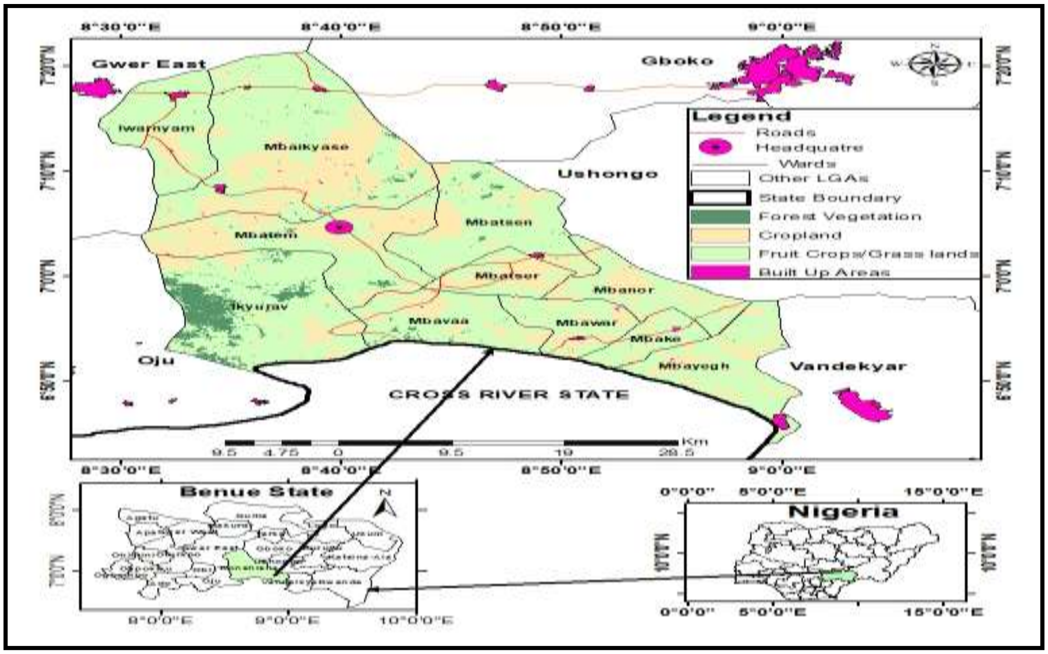

Figure 1: The Study Area.
Source: Modified from Benue Geographic Information Services [BENGIS], (2021).

Types and sources of data

According [5] the ultimate success of a land suitability mapping depends on the data availability, measurement techniques and knowledge of climate, topography and soils. Accurate data of these land characteristics has greatly improved at low cost with the aid of earth observation satellites [26]. Thus, satellite remote sensed data was used in this study. The data types, sources and purpose used are presented in Table 1.

Table 1: Data Type, Sources and Purpose

S/N	Data type	Data source	Spatial Resolution	Purpose
1	SRTM (DEM)	United States Geological Survey (USGS).	30m	Slope map
2	ESRI Land Use land Cover 2020	Environmental System Research Institute (ESRI).	10m	Land use map
3	Climate data (1991-2021)	Climate Research Unit (CRU) University of Anglia (UEA).	0.04*0.04	Rainfall and Temperature map
4	Soil data	African Soil Information Service (AFSIS).	250m	Soil property maps
5	Sentinel-2 data	Sentinel data hub	10m	NDVI for Validation
6	Soybeans data	Field Observation with GPS	-	Validation

Source: [27, 28, 29, and 30]

Data processing
All the acquired datasets were extracted by mask to the boundary of the study area and projected to Universal Transverse Mercator (UTM) Zone 32N coordinate system to enable area calculation as it is impossible in Geographic Coordinate System (GCS).

The Environmental Systems Research Institute (ESRI) 10m spatial resolution land use land cover 2020 data developed from Sentinel-2 Multi Spectral Instrument (MSI) was extracted with the following classes in the study area. These are cropland, forest, shrubs/grassland, built up areas and water bodies. The classes and their definitions are presented in Table 2.

Table 2: Land Use Land Cover Classes and Definitions

S/N	Land Use Land Cover Types	Definitions
1	Cropland	Human planted/plotted cereals and crops like corn, wheat, soybeans and fallow plots of structured land.
2	Forest (Trees)	Significant clustering of tall dense vegetation typically with a closed or dense canopy.
3	Shrubs	Moderate to sparse cover of bushes, shrubs and tufts of grass, savannahs with very sparse grasses, trees or others.
4	Built Up Areas	Human made structures; paved road and large homogenous impervious surfaces including parking structures, office buildings and residential housing; dense villages / towns / cities
5	Water bodies	Areas where water is throughout the year.

Source: ESRI, (2021)

Slope mapping
Slope map was generated from the National Aeronautical Space Agency's (NASA) Shuttle Radar Topographic Mission (SRTM) 1 arc second (30m resolution) Digital Elevation Model (DEM) using slope tool in the Spatial Analyst tools in ArcGIS 10.7 software preparatory for reclassification operation. Sentinel-2 imagery was atmospherically corrected to enhance the spectral quality using SEN2COR of the Sentinel-2 Application Platform (SNAP) by converting Top of Atmosphere (TOA) digital numbers (DN) in to Bottom of Atmosphere (BOA) reflectance

Data analysis
The data obtained were analysed using MCE-GIS method. This method was used because of the multiple criteria involved and the analytical capabilities of GIS to integrate data from multiple sources with high precision, flexibility and display the information in map format. This method has long been incorporated into spatial based decision-making procedure [31, 32] and used by [33] and [30] for a variety of spatial decision making in land suitability assessments.

Land characteristics constitute both favourable and limiting factors to crop production thus are employed in suitability analysis by matching them with the crop requirements [5]. Based on soybeans production guideline, expert opinion and reviews, data on relevant land characteristics known to influence soybeans production were acquired and analysed in GIS (reclassification analysis) according to FAO suitability classes using soybeans production requirement criteria presented in Table 3.

Table 3: Criteria/ Factor Rating of Land use Requirement for Soybeans Production

Criteria	**Unit**		**S1**	**S2**	**S3**	**N1**	**N2**
Available P	**(ppm)**		>30	30-12	12-10	<10	
SOC	(%)		>2	1.99-0.68	0.67– 0.14	<0.14	
Ph			7-6.0	6.0 – 5.6	5.5 – 5.2	<5.2	
Texture			SCL, SiL	SL, SiC,	CL,C	Sandy	Gravel
Slope	(%)		0-3	4 - 8	8-12	>12	
Rainfall	(mm)		>800	800	700	<700	
Temp.	(0^0)		21-33	20	19	>34 <18	
Land Use			Croplands	Shrubs/Grasses	Forest	Built Up	Waters
Drainage			Well drained	Moderately	Imperfectly	Poorly drained	

Key: S1: Highly Suitable, S2: Moderately Suitable, S3: Marginally Suitable, N1: Currently Unsuitable, N2: Permanently Unsuitable, SCL: Sand Clay Loam, SiL: Silt Loam, SiC: Silt Clay, C: Clay.

Source: [6, 34, and 20].

FAO suitability classes S1, S2, S3 and N were assigned score 9, 7, 5 and 3 respectively on a linear scale of 1 to 9 by 1 as used by [35]. Classes with higher scores are considered most suitable for soybeans. Reclassification is a spatial analysis in GIS that recode raster data in order to extract the desired information [36]. It takes input cell values and replaced them with new cell values. Thus, reclassification was carried out using ArcGIS 10.7 Software to produce thematic map for each land factor (criterion).

This was achieved using AHP technique developed by [34] and weighted map overlay operation in GIS environment. AHP was preferred because it has been proven as a superior and powerful MCE analytical tool to solve complex spatial decision-making process which involved multiple criteria in suitability mapping. Thus, the factors were ranked on the scale for pair-wise comparison developed by [34] according to their importance to optimum soybeans production as used by [37]. The scale for PWC is presented in Table 4.

Table 4: The scale for pair-wise comparison

Intensity of importance	Description
1	Equally importance
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6, 8	Intermediate values

Source: [34]

Using the AHP scale, all the criteria were ranked based on their importance to soya bean production and compared with one another using pair-wise comparison matrix and normalized to derive weights by dividing each value by the sum total of value in each column as was used by [34] and [33]. The weights were obtained by calculating the average of each row.
Consistency Ratio (CR) of the pair-wise comparison was computed following the procedure by [34] given as

Consistency ratio (CR) = $\frac{CI}{RI}$ -- Equation 2

Where:
CI= Consistency Index
Consistency Index = $\frac{max-n}{n-1}$
RI = Random Index derived from random index values n ≤ 10 presented in Table 3.5

Table 5: Random Index Values

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Source: Saaty (1980)

The derived weights were used to generate the final land suitability map of the study area in ArcGIS Software using Weighted Overlay tool in spatial analyst tools.

Accuracy assessment of the land suitability map in the study area.
This was to ascertain the accuracy of the suitability map generated with an independent data set. No official data or reliable information on soybeans production at the field level exist in the study area, thus field observation with GPS and Normalized Difference Vegetation Index (NDVI) derived from satellite data were used to obtain data about soybeans health (greenness) in the field as used by [27]. NDVI was considered because it correlated with land biophysical properties [38] thus offers a potential solution in the validation of crop suitability map due to its accessibility from global multispectral satellite missions (Sentinel-2, Land-Sat 8) and being a reliable predictor of crop properties. NDVI is computed from satellite reflectance measurements in the Red (R) and Near Infrared (NIR) portion of the spectrum [39] given as

NDVI= (NIR-R)/ (NIR+R) --- Equation 3

By calculating the NDVI, information on the crop vigour was obtained. The crop vigour information of the study area was very crucial in order to compare the suitability map with the crop greenness in the field in order to see the agreement or relationship between the suitability map and soya bean vigour.

Geographic coordinate of soybeans farms was collected during the growing period and overlaid on both the derived NDVI from Sentinel-2 satellite data in the month of September 2020 and the produced suitability map. 'Extract values to points' tool in spatial analyst extension in ArcGIS was used to extract the suitability index and NDVI value on each farmland and analysed using Confusion Matrix (error matrix). The confusion matrix provides a variety of measures for accuracy. The most accepted among all measures are the percentage of correctly matched classes, the percentage of misclassified (omitted) and the overall accuracy [30]. The overall accuracy is calculated thus,

Overall Accuracy = (Sum of matched pixels)/(Total number of pixels) ×100 ------------Equation 4
The methodology adopted in this study is shown in Figure 3.4.

RESULTS AND DISCUSSION

In order to map land suitable for soybean production in the study area, characteristics of the land were analysed (reclassified) for soybeans production. The factors selected are land use land cover, slope, rainfall and temperature. Others are soil drainage, pH, organic carbon, texture and available phosphorus). Thematic maps for each of the factor was produced in ArcGIS 10.7. Results of the analysis are presented and discussed in Table 5 to 9 and Figure 4 to 8 respectively.

Land use/cover (LULC)

Human activity on the land (land use) and the biophysical characteristics of the landscape (land cover) information is important in determining, planning and sustainable management of land resources for crop production. LULC of the area was extracted from ESRI Sentinel-2 10m resolution LULC imagery 2020 and reclassified. The result of LULC analysis for soybeans production suitability is presented in Figure 2 and Table 5.

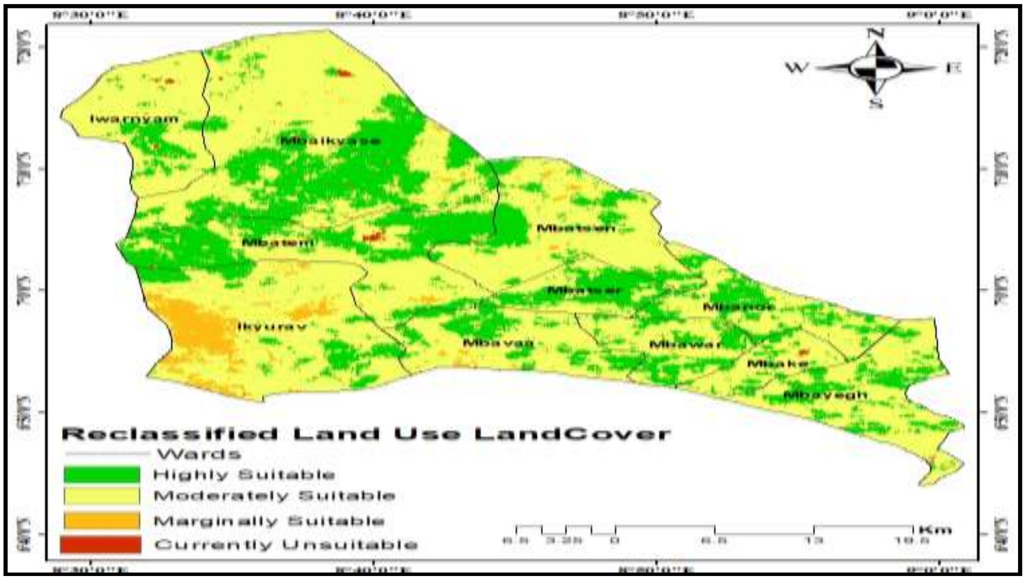

Figure 2: Reclassified land use land cover
Source: Authors Analysis (2021**)**

Table 6: Result of LULC Analysis for Soybeans Production

Land use Land cover	Rank	Suitability	Area (ha)	%
Cropland	9	Highly Suitable	52,724.72	28.8
Shrubs and Grasses	7	Marginally Suitable	6,397.70	67.4
Forest	5	Moderately Suitable	123,230.51	3.5
Built up area/waters	3	Currently Unsuitable	540.82	0.3
Total			182,893.75	100

Source: Author's Analysis (2021)

Data on LULC analysis indicates that 28.8% of the land is highly suitable covered with human planted vegetation like corn yam, rice and soybeans on plots of structured land (cropland). 67.4% moderately suitable covered with cluster or single perennial fruit crops such as cashew, mango and oranges mixed with naturally grown shrubs and grasses. 3.5 % marginally suitable occupied by significant clustering of tall dense vegetation typically with a closed or dense canopy (forest vegetation) and 0.3 % currently unsuitable for soybean production covered with man -made structures of large impervious surfaces (built up areas) and water bodies. The result reflects the fact that the study area is more of villages with disperse settlement pattern whose major occupation is farming of cereals and perennial fruit crops like orange and mango. This corroborates the findings of [29] which showed that land use land cover is not a limiting factor in Benue state for crop production. This also agrees with the findings of [21] that natural vegetation (forest) has almost been replaced by economic trees such as citrus, mangos and cashew.

Table 7: Result of Climate (Rainfall and Temperature) Analysis

Climate	Suitability	Area (ha)	Area (%)
Rainfall (1537-1411 mm)	Highly Suitable	182,893.75	100
Temperature (25.7-26.3 ^{0}C)	Highly Suitable	182,893.75	100

Source: Author's Analysis (2021)

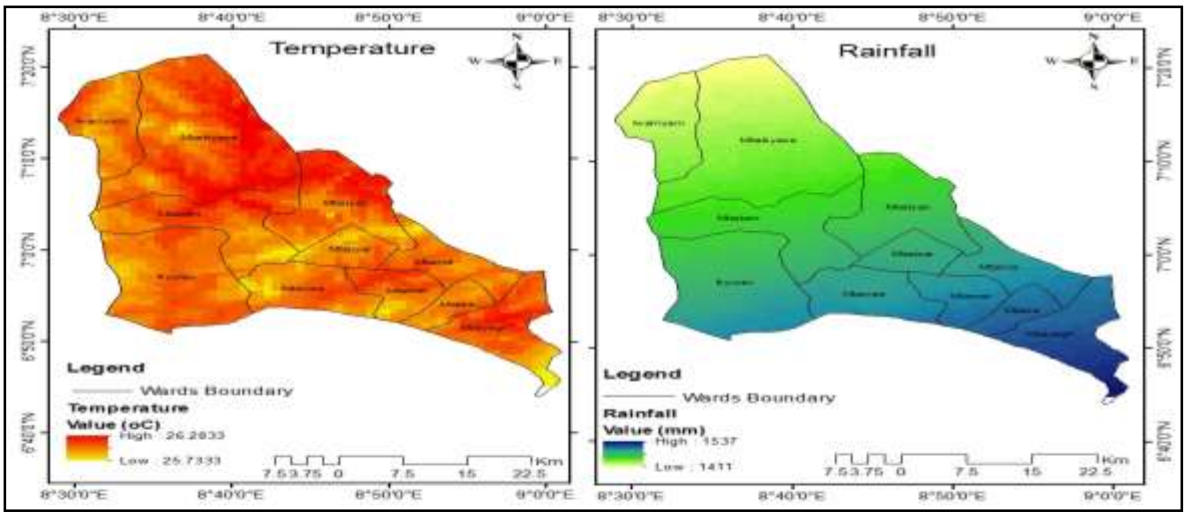

Figure 3: **Rainfall and Temperature**
Source: Author's Analysis (2021)

Result shows that climate is not a limiting factor for soybeans production in the study area as also found by [22]. Precipitation and temperature amount in the study area varies between 1411 and 1537 mm and 25.7^{0}C and 26.3^{0}C respectively which is highly suitable for soybeans production as revealed by [20]. This is because the study area is location within the tropical savannah climatic zone which characterized by seven months of rainfall averaging about 1500mm [21]. Rainfall variation shows that higher rainfall is experienced at the southern part of the study area while it reduces towards the northern part. This variability in rainfall aligns with the change in the amount of rainfall observed from the tropical rainforest to savannah region in Nigeria as also observed by [28]. Climate data of the Climate Research Unit, University of East Anglia used in this study has been widely used across West Africa for climatic modelling and validated by [29] with the in-situ Nigerian Meteorological Agency (NiMET) data which showed a high level of accuracy.

Soil drainage

Soil drainage is a hydro-topographic variable giving an indication of moisture content in the soil and the ability of the soil to remove excess water. It determines oxygen available to plant roots for optimum growth. Result of soil drainage shown in Table 8 and Figure 4 reveals that 1.6 % of the area is highly suitable, 38.7, moderately suitable and 57.0 marginally suitable (S3) for soybeans production. Result reveals that 2.7 % of the soil has poor internal drainage which may lead to waterlogging thus rated currently unsuitable for soybeans.

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Table 8: Result of Soil drainage Analysis for Soybeans Production

Soil drainage	Suitability Index	Suitability	Area (ha)	%
Well drained	9	Highly Suitable	593.75	1.6
Moderately	7	Moderately Suitable	72,662.50	38.7
Imperfectly	5	Marginally Suitable	106,937.50	57.0
Poorly drained	3	Currently Unsuitable	2,700.00	2.7
Total			**182,893.75**	**100**

Source: Author’s Analysis (2021)

The result disagrees with [40] which stated that the soil has excessive internal drainage. According to [15] soybeans requires well drained soil for optimum production. The nature of the soil drainage in the study area could be attributed to low elevations and clay content which may become waterlogged when it rains due to its high-water holding capacity.

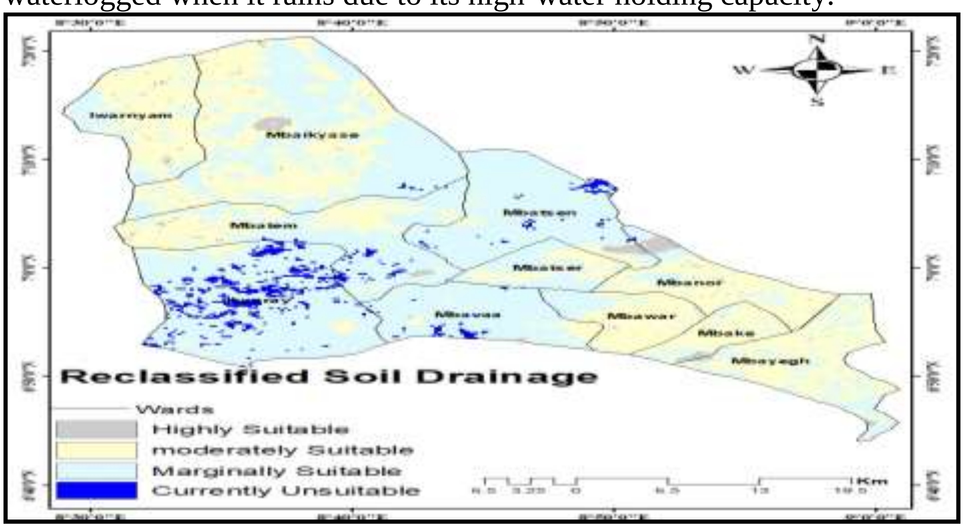

Figure 5: Reclassified soil drainage
Source: Author’s Analysis (2021

Soil pH

Soil reaction (pH) is an excellent determinant of land suitability for crop production as it affects crop development, yield, nutrient availability and soil microorganism activity. Result of soil analysis indicates that soil pH values in the study area range from 5.2 - 6.1. (Strongly acidic to slightly acidic). See Table 8; Figure 5. Results shows that 4.7% of the total area is highly suitable to soybeans production having pH from 6.0-61 (slightly acidic) while 51.7. % of the area is characterized by moderately acidic soils with pH values ranging from 5.6 to 6.0 rated as moderately suitable for soybeans production while 43.4% were rated marginally suitable to soybeans production with strongly acidic values from 5.2 -5.59.

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Table 8: Soil pH Analysis in the Study area

pH	Description	Suitability	Area (ha)	%
>6.0	Slightly acidic	Highly Suitable	6,712.50	4.7
5.6-6.0	Moderately acidic	Moderately Suitable	98,262.50	51.7
5.2-5.59	Strongly acidic	Marginally Suitable	77,556.25	43.4
>5.2	Strongly acidic	Currently Unsuitable	362.50	0.2
Total			182,893.75	100

Source: Author's Analysis (2021)

The study area is classified moderately suitable for soybeans production and might require improved management practice for optimum soybeans yields. Because according to [20] optimum soybeans production requires a pH range of 6 to 7, and results shows that only 4.7 % of the study area is characterized by soils in this pH range indicating slightly acidic. Soil pH levels that are too high or too low lead to deficiency of many nutrients, decline in microbial activity, decrease in crop yield, and deterioration of soil health. According to [30] soil pH values below 5.5 limit availability of phosphate to most crops including soybeans. Thus, understanding of spatial variation of soil reaction within an area is important in site specific management for soybeans. The spatial variation of soil reaction in Konshisha indicates that soil pH is major limiting factor to soybeans production. This may be caused by low soil organic matter contents therefore need specific management practices. This agrees with the findings of [30]

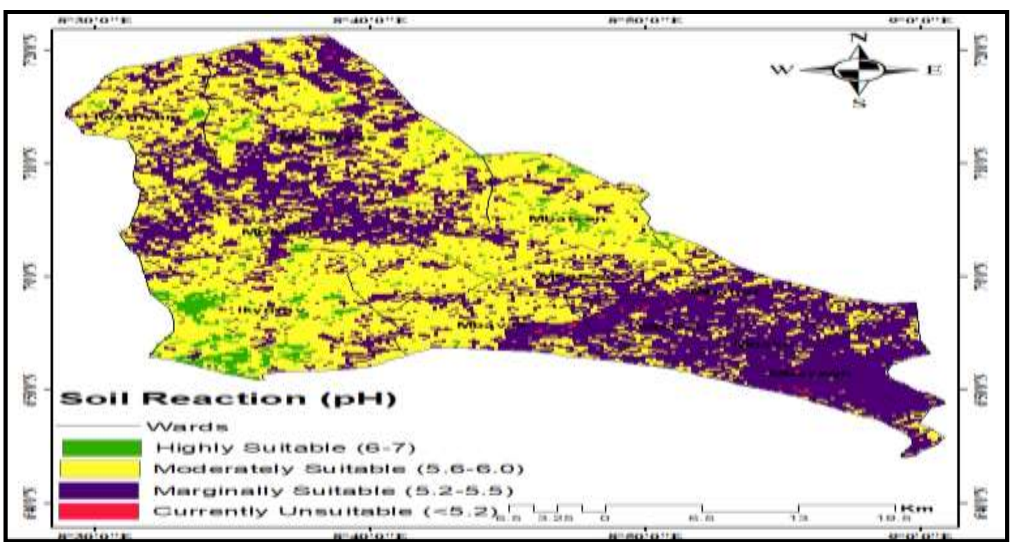

Figure 5: Reclassified soil Reaction (pH)
Source: Author's Analysis (2021)

Soil texture

Soil texture determines effective germination, growth of soybeans, nutrient and water retention. Result of soil texture presented in Table 8 and Figure 5 shows that 27.6 % of the area is highly suitable, 72.4% was moderately suitable and 0.1 marginally suitable for soybeans production. The soil comprises of sand (S), loam (L), sandy Clay loam (SCL), clay (C) and clay loam (CL). It is known that the best soil for optimum soybeans production is a loose, well-drained loam with less clay fractions [15].

Table 9: Soil Texture

Texture	Suitability Index	Suitability	Area (ha)	%
SCL	9	Highly Suitable (S1)	50,956.25	27.6
SL	7	Moderately Suitable (S2)	131,749.75	72.3
CL	5	Marginally Suitable (S3)	187.75	0.1
Total			**182,893.75**	**100**

Source: Author's Analysis (2021)

The soils with high clay content are not suitable for soybeans production as they become waterlogged when it rains and they usually form a hard crust surface on drying which becomes a barrier to emerging seedlings [20]. The spatial distribution of the soil texture on the map shows that the soil has low clay contents with sandy loams (SL) dominating in the study areas. Probably, it may be from the underlying sandstones, cretaceous sandstones and the shale rocks. This result corroborates the findings of [22, 40].

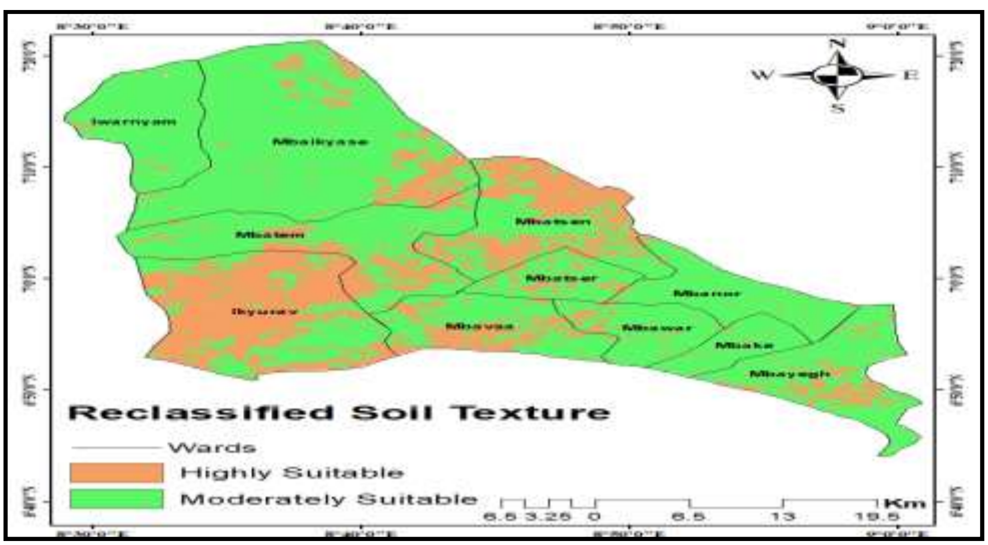

Figure 6: Reclassified soil texture
Source: Author's Analysis (2021)

Land Suitability Map for Soybeans Production

In order to generate the final land suitability map for soybeans production in the study area, all the reclassified thematic maps of the various factors influencing land suitability in the study area were ranked using AHP pairwise comparison matrix and normalized to derived weights of the criteria. The weights were added to produce the final suitability using weighed overlay in ArcGIS environment. The result of AHP pairwise comparison matrix is presented in Table 9, 10 and weighted map overlay in Figure 7.

Table 4.9: Pairwise Comparison Matrix of the Parameters

Criteria	AP	pH	OC	TX	TE	RF	SD	LU	SL	Weight
AP	1	9/7	9/3	9/3	9/5	9/5	9/3	9/2	9/4	22.0
pH	7/9	1	7/3	7/3	7/5	7/5	7/3	7/2	7/4	17.1
SL	3/9	3/7	1	3/3	3/5	3/5	3/3	3/2	3/4	7.3
TX	3/9	3/7	3/3	1	3/5	3/5	3/3	3/2	3/4	7.3
TE	5/9	5/7	5/3	5/3	1	5/5	5/3	5/2	5/4	12.2
RF	5/9	5/7	5/3	5/3	5/5	1	5/3	5/2	5/4	12.2
SD	3/9	3/7	3/3	3/3	3/5	3/5	1	3/2	3/4	7.3
LU	2/9	2/7	2/3	2/3	2/5	2/5	2/3	1	2/4	4.9
OC	4/9	4/7	4/3	4/3	4/5	4/5	4/3	4/2	1	9.8

Consistency Ratio=0.03
Source: Author's Analysis (2021)

Key: AP: Available phosphorus, PH: pH, OC: Soil Organic Carbon, TX: Texture, TE: Temperature, RF: Rainfall, SD: Soil Drainage, LU: Land use Land cover, SL: Slope
Result from the AHP analysis presented in Table 9 reveals that Available Phosphorus has the highest weight of 22.0 followed by soil pH 17.1 while land use land cover has the lowest rank of 4.9.

Table 10: Land suitability Class for Soybeans Production

Suitability	Suitability Index	Area (ha)	%
Highly Suitable	9	55,637.00	30.3
Moderately Suitable	7	126,380.75	69.5
Marginally Suitable	5	876,.00	0.2
Total		**182,893.75**	**100**

Source: Author's Analysis (2021)

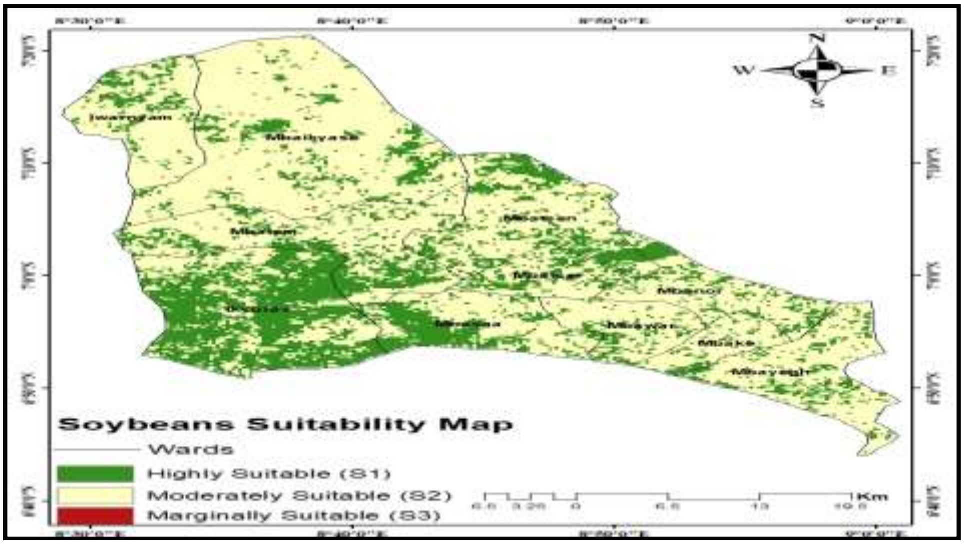

Figure 9: **Land Suitability Map for Soybeans Production in Konshisha LGA**
Source: Author's Analysis (2021)

Result of the suitability mapping (combined land characteristics) using weighed overlay shows that 30.3 % of the area is highly suitable (S1) having land with optimum conditions for soybeans growth and yield with minor limitations. Large proportion of the land was found within Ikyurave, Mbavaa, Mbatsen and part of Mbatem and Iwarnyam wards with Ikyurave as the most suitable ward in the study area. Land classed as S1 according FAO frame work for land evaluation possess attributes for sustainable usage, without any significant disruption to the ecosystem. They are identified with minor limitations, that does not significantly decrease efficiency or produce, and which do not require the increase of input above a reasonable level as also observed by [28].

While 69.5% of the land is moderately suitable (S2) with average conditions for soybeans production. This class has limitations (soil drainage, texture, SOC and pH) which are moderately severe for sustained production of soybeans. These limitations make soybean production lesser in efficiency than being highly suitable.

Furthermore, 0.2 % is marginally suitable for soybeans production with severe limitations (soil drainage, SOC and pH) for sustained production, therefore, reduces yield or benefits which increase inputs. See Table 8; and Figure 9. Soybeans production in areas rated moderately and marginally suitable can however be improved by taking into consideration the main limiting factors associated with each of these classes such poor soil drainage, soil pH and low availability of SOC for optimum production. Thus, variation in the suitability level probably is due to the limiting factors.

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Validation of Land Suitability Map for Soybeans Production

The objective of the assessment is to provide a statistically sound estimate of the accuracy of the map output. The accuracy of the map was assessed by measuring the degree of agreement between the output map and validation data using confusion (error) matrix. Thus, the shape-file containing the locations of twenty one soybeans farms was superimposed on the suitability and NDVI maps of the study area and 'Extract values to points' tool in spatial analyst extension in ArcGIS 10.7 was used to extract the suitability index (9, 7 and 5 for S1, S2 and S3 respectively) and NDVI values on each farmland as presented in Figures 10, 11 and Table 11.

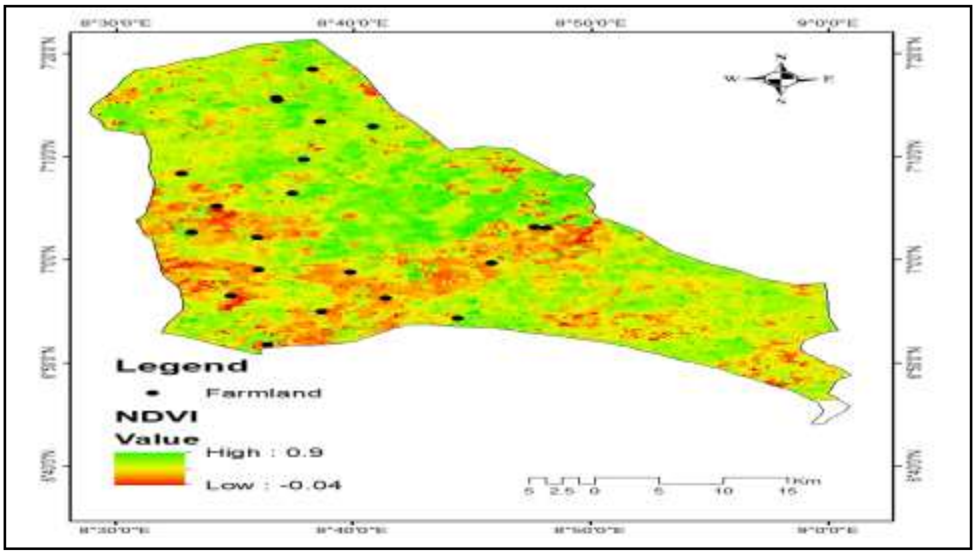

Figure 10: Overlaid Soybeans Farms on NDVI
Source: Author's Analysis (2021).

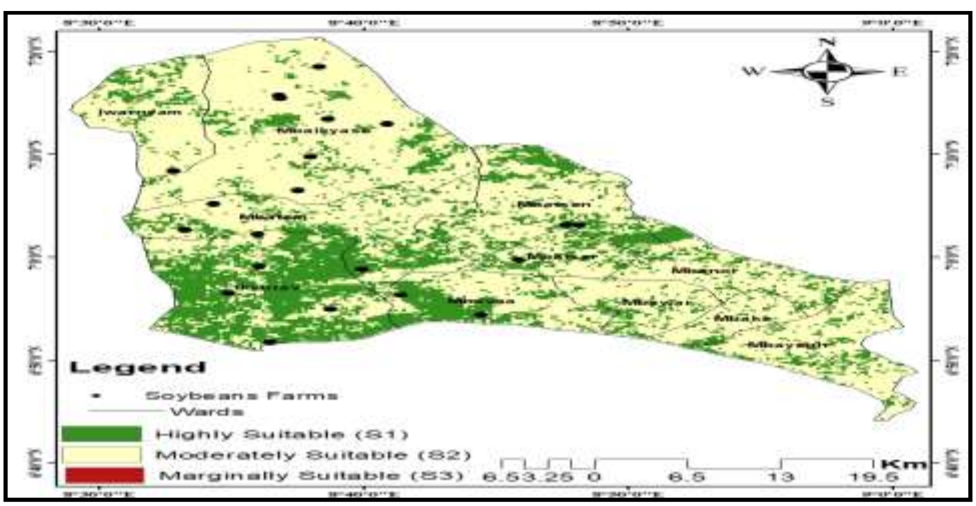

Figure 9: Superimposed Soybeans Farms and Suitability Map
Source: Author's Analysis (2021)

Table 11: Soybeans Farms Coordinates, the Extracted NDVI and Suitability Index

SN	Latitude	Longitude	NDVI	Suitability Index
1	6.939	8.693	0.62	7
2	7.111	8.731	0.62	9
3	6.974	8.909	0.58	7
4	6.892	8.626	0.62	9
5	7.023	8.784	0.56	7
6	7.03	8.84	0.29	7
7	7.056	8.723	0.34	7
8	7.037	8.666	0.38	7
9	7.121	8.604	0.28	7
10	7.293	8.622	0.32	7
11	7.29	8.543	0.61	7
12	7.045	8.468	0.44	7
13	7.007	8.595	0.13	7
14	7.124	8.814	0.38	9
15	7.252	8.622	0.71	9
16	6.907	8.843	0.53	7
17	6.808	8.971	0.68	9
18	7.143	8.573	0.54	9
19	6.99	8.7828	0.11	7
20	7.034	8.501	0.74	9
21	6.915	8.923	0.24	7

Source: Author's Field work (2021**)**

Result of the extracted suitability index and NDVI shows that soybeans farms located in highly suitable (S1) areas with suitability index nine (9) have higher NDVI values than those in moderately suitable (S2) area with a suitability index seven (7). Therefore, could produce higher yield respectively. The extracted NDVI and suitability index were analysed by comparison using confusion matrix. The result is presented in Table 12.

Table 12: Confusion (Error) Matrix

Suitability Classes	Validation Data	Matched Points	Result	%
Highly Suitable (S1)	7	5	0.71	71.4
Moderately Suitable (S2)	14	10	0.71	71.4
Marginally suitable (S3)	0	0	0.00	00.0
Total	**21**	**15**	**1.42**	**71.4**

Source: Author's Analysis (2021)

Result from the confusion matrix shows that 15 points out of 21 validation data correctly matched the suitability map produced accounting for the overall accuracy of 71.4%. Therefore, the map can rightly be used by farmers and agricultural decision makers in selecting site locations for soybeans in the study area. [29, 27] also used this method to compare the models generated in their respective studies and concluded that the maps were good enough to be used in decision making for agriculture. According to [26, 30] once the suitability map has been validated or the models used have been validated it serves as guide in decision making. The validation results in this study revealed that the suitability map has close agreement with what is expected of the land in the area and soybeans is strongly influenced by land characteristics. This corroborates the views of [38] that NDVI values are thought to reflect the land characteristics influencing crop growth and yield leading to a more comprehensive expression of the crop health than an index based on single element. Therefore, the map can be used as a guide in decision-making on-site selection for optimum soybeans production in Konshisha LGA.

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