Suitability Analysis for Ginger Production in Song Local Government Area, Adamawa State, Nigeria

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Abstract

Identification of land with high productivity and net profit, while minimizing input requirements, is crucial for enhancing agricultural production and promoting sustainable development in Nigeria. This study aimed to assess the suitability of land for ginger cultivation in Song LGA, utilizing geographic information system (GIS), remote sensing, and the analytic hierarchy process (AHP). Key criteria considered for the suitability analysis included slope, land use land cover, nitrogen, phosphorus, potassium, and soil texture. Standardization of all criteria was performed, and AHP facilitated the determination of weightage for each criterion through pairwise comparison. The suitability map for ginger production was generated using weighted overlay techniques. The findings revealed that approximately 75% of the study area is marginally suitable, while 25% is moderately suitable for ginger cultivation. However, it is important to note that future research should focus on acquiring more precise and accurate spatial data related to soil properties, topography, and climate. By incorporating such data, it is anticipated that a more refined and reliable land suitability map for ginger production can be developed. This study highlights the potential for using GIS, remote sensing, and AHP as valuable tools for assessing land suitability for ginger cultivation. The generated suitability map can serve as a valuable resource for policymakers, land managers, and farmers seeking to make informed decisions regarding ginger production. Further investigations should aim to refine the methodology and expand the data sources to enhance the accuracy and applicability of land suitability assessments for ginger cultivation.

Keywords: Land Suitability, GIS, Remote Sensing, Ginger, AHP

INTRODUCTION

Ginger is a plant with high medicinal and commercial values (Park and Pizzuto, 2012). Nigeria produces 50,000 metric tonnes of fresh weight ginger per year on average. Approximately 10% of the produce is consumed locally as fresh ginger, while the remaining 90% is dried for both local consumption and export (Ezeagu, 2006). The major producing areas include Kaduna, Nassarawa, Sokoto, Zamfara, Akwa Ibom, Oyo, Abia, and Lagos states (KADP, 2004; Bernard, 2008). Nigeria ranked first in terms of total hectares under cultivation of ginger, but her contribution to global output is too small in comparison to other countries (Ibrahim *et al.*, 2019). This may be due to the fact that agricultural land use is frequently done without a proper pre-assessment of its potential and underlying challenges. Identification of suitable land with the highest productivity and highest net profit on lower inputs is required for improving agricultural production and sustainable development in Nigeria.

Agricultural land suitability study for crop production is one of the most effective instruments for guaranteeing sustainable agriculture and meeting the present global food security target set by the United Nations Sustainable Development Goals (SDGs) (Akpoti *et al.*, 2019). Cropland suitability identification activities address issues such as "where" a given crop is grown in a specific location (Kazemi and Akinci, 2018). The primary components in determining site suitability for diverse crops are the prevailing soil, climate, available water resources, structural landscape, environmental factors, and native biophysical conditions (Zabel *et al.*, 2014). GIS and remote sensing are essential in appraising specific locations, both globally and locally (Singha and Swain, 2016).

Land suitability Assessment (LSA) is an agricultural planning tool that identifies suitable areas where crops can be grown for the least amount of money and with the least amount of environmental impact with high productivity (Olaniyi *et al.*, 2015). Land suitability management's main goal is to promote sustainable agricultural development and scientific land use planning (Baroudy, 2016). Because there are so many variables taken into account during LSA, the procedure is frequently referred to as "multi-criteria evaluation" (MCE) (Akpoti *et al.*, 2019).

The introduction of geographic information system and remote sensing (GIS and RS) technologies paved way for more quantitative and qualitative land evaluation methods to be used (Ashraf, 2010). The availability of GIS and multi-criteria decision analysis (MCDM) methods allow combining knowledge derived from different sources to support land-use planning and management (Malczewski, 2000). There are many different land suitability analysis (LSA) methods used nowadays (Malczewski, 2006). The most commonly used MCDM are analytic hierarchy process (AHP), weighted linear combination, ordered weighted averaging, ELECTRE and so on (Rikalovic *et al.*, 2014).

AHP is a decision-making method for assessing and analysing land use suitability that uses multiple criteria. Within a hierarchical system, AHP entails multiple selections based on the relative importance and weight of the parameters (Saaty, 1980). AHP is a system that uses a hierarchical approach to evaluate a variety of criteria. To determine a factor's relative importance to other factors on a level, the system uses scoring and a pairwise comparison matrix (Akbulak, 2010). GIS-based AHP has earned a lot of attention and a solid reputation for solving spatial problems because it can incorporate a sizable amount of heterogeneous data and is relatively simple to acquire the necessary weights, even for a sizable number of criteria (Rahaman and Aruchamy, 2022).

Several studies (Sunarto *et al.*, 2011; Sati and Wei, 2018; Ingle *et al.*, 2019; Abdullahi *et al.*, 2021; Mugiyo *et al.*, 2021; Badamasi *et al.*, 2022; Rahaman and Aruchamy, 2022) in Nigeria and around the globe employed AHP for land suitability analysis for maize, millet, Tea, soya beans and so on but there is limited information about GIS-based AHP for a land suitability analysis for ginger production. As a result, this study used GIS and multicriteria techniques to assess land suitability for ginger farming in Song LGA. This research can help agricultural planners and policy makers make more precise decisions about how to develop agriculturally appropriate measures in Song LGA of Adamawa State Nigeria.

Study Area

Song Local Government Area (LGA) is located between Longitudes 12°10' and 13°05' and, between Latitudes 9°30' to 10°10' (see Figure 1). It has area extent of about 4,206 km^2. The climate in the study area is typical of a West African savannah climate. The temperature in this climatic region is high due to the relatively even distribution of radiation income. The temperature, on the other hand, tends to fluctuate with the seasons. Most of the soils in the area, like most of northern Nigeria, have sub-surface horizons with high content of iron concretions and fissile iron stone; the soils are drained from basement complexes, while a few other locations are on sandstone, shales, and alluvium. Weatherable minerals are generally more abundant in the soils (Helen, 1999). The study area is shown in Figure 1.

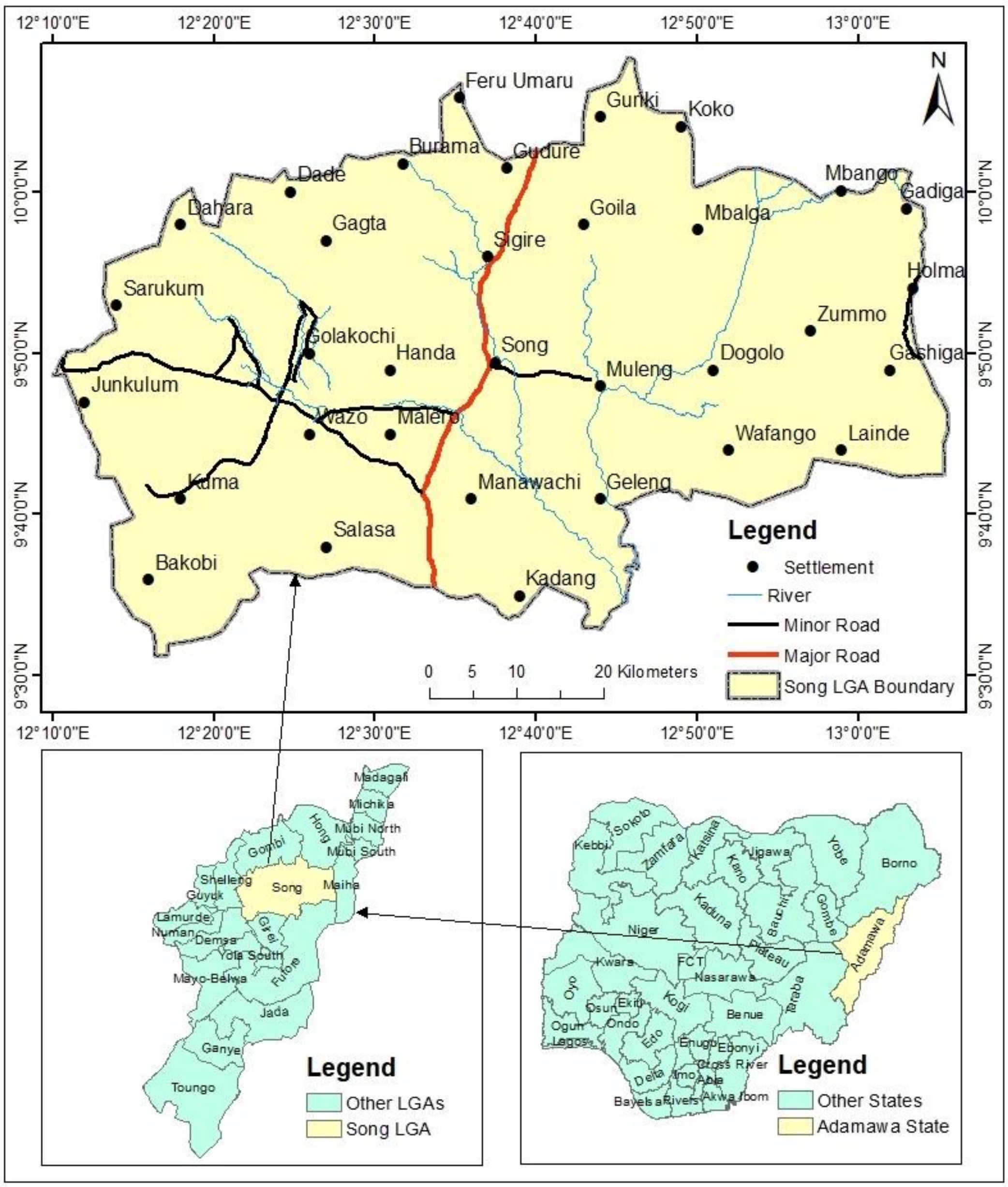


Figure 1: Song Local Government Area, Adamawa State, Nigeria.

MATERIALS AND METHODS

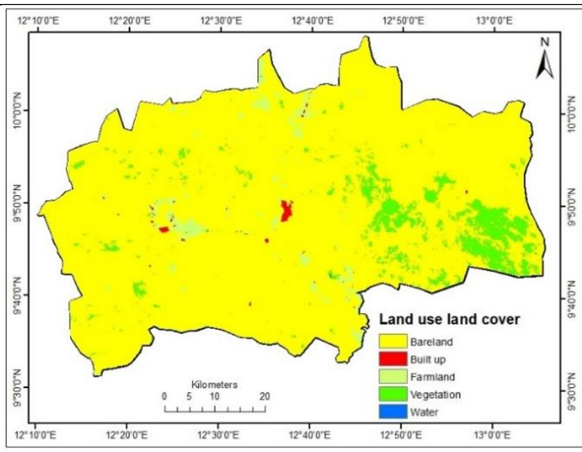
Types and Sources of Data

Table 1: Types and Sources of Data

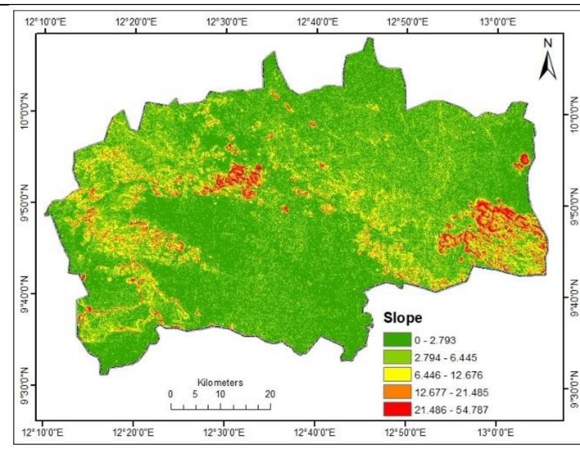
S/N	Data	Resolution	Source
1	Sentinel-2 LULC of 2020	10m	Downloaded from Sentinel-2 Land Use/ Land Cover Downloader
2	Shuttle Radar Topographic Mission, (SRTM)	30m	USGS
3	Soil data (Nitrogen, Phosphorus and Potassium and soil texture)	250m	Downloaded from www.isric.org

Production of Criterion Maps

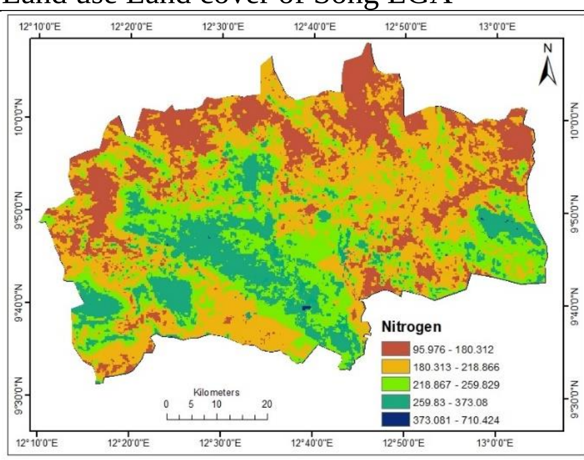
This step deals with GIS process and working with spatial data input that represents the criteria to assess the fulfilment of a specific objective. After establishing a set of criteria, every criterion was represented as a map layer as shown in Figure 2.



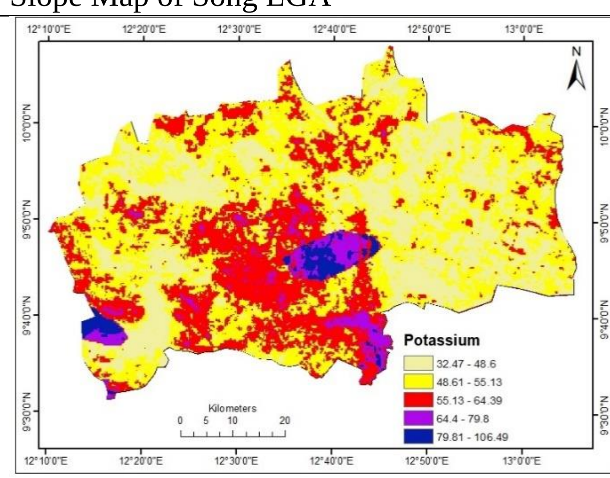
Land use Land cover of Song LGA



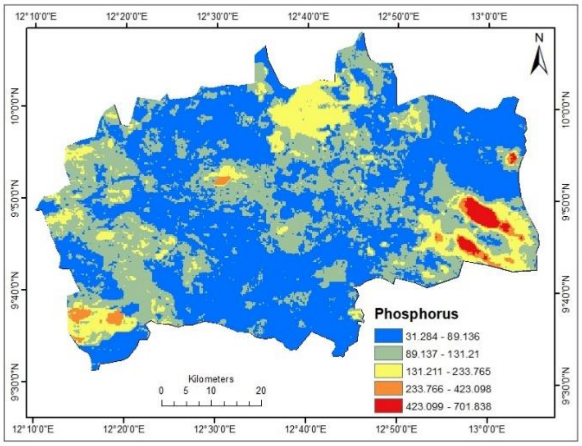
Slope Map of Song LGA



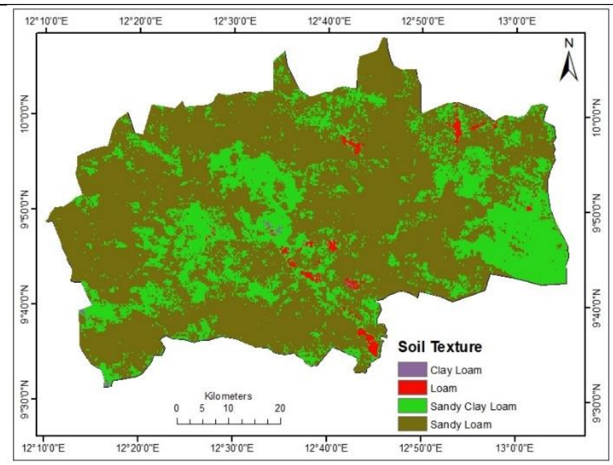
Nitrogen Map of Song LGA



Potassium Map of Song LGA



Phosphorus Map of Song LGA



Soil Texture Map of Song LGA

Figure 2: Criterion Maps

Standardization of Criterion Maps

A number of factors influence and affect the selection of an appropriate site for any land use. Tables 2 shows the criteria and their suitability classes that were chosen after a careful review of relevant literature. Multiple criteria gathered from different sources and scales need to be standardized to a common scale. On a scale of 1 to 9, each criterion was categorized into not more than five land suitability classes using the reclassify tool in ArcGIS 10.8 as shown in Table 5 and illustrated in Figure 3.

Table 2: Criteria for Land Suitability Map for Ginger Production

Criteria	Category	Rank	Level of Suitability	Source
Phosphorus	30-50	7	Moderately Suitable	Adapted from
	>50	9	Highly Suitable	Vikaspedia
			Total	(2022)
Nitrogen	<150	3	Less Suitable	Adapted from
	150-250	5	Marginally Suitable	Vikaspedia
	250-400	7	Moderately Suitable	(2022)
	>400	9	Highly Suitable	
			Total	
Potassium	>90	3	Less Suitable	Adapted
	50-90	5	Marginally Suitable	fromAkhter *et*
	<30-50	7	Moderately Suitable	*al.* (2013)
			Total	
Soil Texture	Clay Loam	5	Marginally Suitable	Adapted from
	Loam	9	Highly Suitable	Sys *et al*
	Sandy Loam	9	Highly Suitable	(1991)
	Sandy Clay Loam	9	Highly Suitable	
			Total	
Slope	>50	1	Not Suitable	Adapted from
	30-50	3	Less Suitable	Sys *et al*
	16-30	5	Marginally Suitable	(1991)

	8-16	7	Moderately Suitable	
	0-8	9	Highly Suitable	
			Total	
LULC	Bult up	1	Not Suitable	Adapted from Abebe (2020)
	Water	1	Not Suitable	
	Bareland	3	Less Suitable	
	Vegetation	7	Moderately Suitable	
	Farmland	9	Highly Suitable	
			Total	

Criteria weight estimation using Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision-making method invented by Saaty (1980). AHP allows for a systematic and logical evaluation of group decisions. It enables the decision maker to identify the relationship between the aims, criteria, sub-criteria and alternatives of a complex problem by modeling in a hierarchy. It further leads to correct and logical results (Ozdemir and Saaty, 2006; Dezert *et al.*, 2010).

i. The first step in the AHP method is structuring the hierarchical model. The hierarchical process involves defining the problem from top to bottom, determining criteria and sub-criteria and creating alternatives (Saaty, 1980).
ii. The second step is generating the decision matrix and performing pairwise comparisons. Here, a factor in a level is compared relatively to another factor at a higher level in the hierarchy. The values of the mapping units which will be used for land suitability are calculated by using weights that are assigned to criteria. The process of calculating the weights for the criteria is as follows (Mohammadizadeh *et al.*, 2016):
    (a) To form a (n × n) pairwise comparison matrix for multiple factors. It is proposed that a_{ij} = the selected factor (factor i to factor j). Then, it assumed that $a_{ij} = 1/a_{ij}$ (Table 5).
    (b) Then, the matrix values are normalized for this calculation; the sum of each column is calculated. Then, each binary comparison matrix element is divided by the total value of the column in which it is located. With this calculation, the normalized pairwise comparison matrix values are obtained (Table 6).
    (c) The arithmetic mean values are calculated for each row that belongs to the normalized pairwise comparison matrix values (Table 6). The obtained mean values present an estimate of relative priorities for the compared elements.
iii. In the final step, the consistency ratio (CR) is checked. For this, eigenvectors and the maximum eigenvalue of each matrix are calculated. Then, the consistency index is tested with the formula given below.

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (1)$$

where λ_{max} indicates the eigenvalue of the pairwise comparison matrix. Finally, the consistency of the pairwise comparison matrix is tested. For this, the random index (RI) value in Table 3 is used. CR is calculated by the following formula;

$$CR = \frac{CR}{RI} \quad (2)$$

To be valid, its consistency ratio should be 0.10 (10%) or less. If the obtained rate is greater than 0.10, it is necessary to generate the pairwise comparison matrix again.

Table 3: AHP evaluation scale (Saaty, 1980)

Intensity of Importance	Verbal Judgement of Preference of the Criteria
1	Two Criterion are equally important
3	One Criterion is moderately important than the other
5	One Criterion is strongly important than the other
7	One Criterion is extremely important than the other
9	One Criterion is extremely more important than the other
2, 4, 6, 8	Intermediate values between adjacent scales values

Table 4: Random Index Values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Aggregation of the weight and standardized Criterion Maps

Weighted Linear Combination (WLC) method was used for aggregating the criterion maps to produce composite map of suitability. The WLC method operates by multiplying each standardized factor map by its factor weight and then sums the results. The Raster calculator tool in ArcGIS 10.8 was used to compute the composite map of suitability using the following mathematical formula;

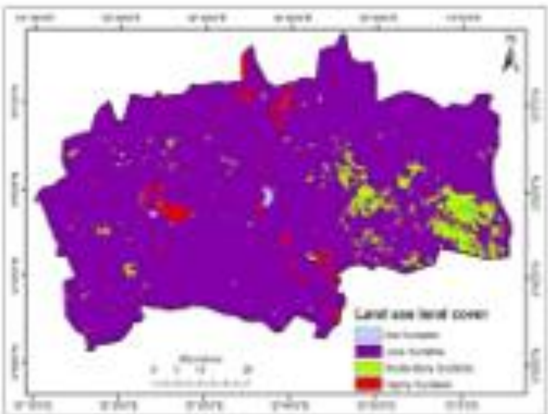
$$S = \sum_{i=1}^{n} W_i S_I \qquad (3)$$

where S is suitability; W_i is weight of land suitability criteria; S_i is the score of criteria i; and n is the number of criteria.

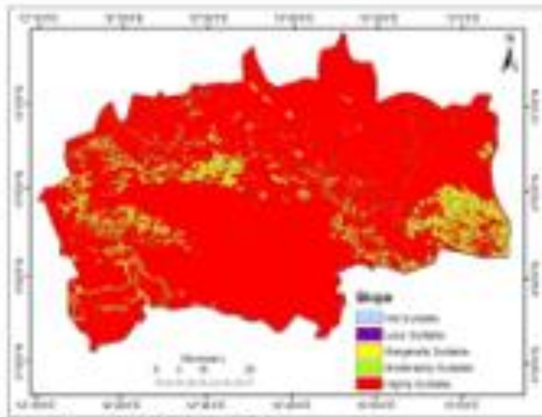
RESULTS AND DISCUSSION

Suitability Classification of Criteria

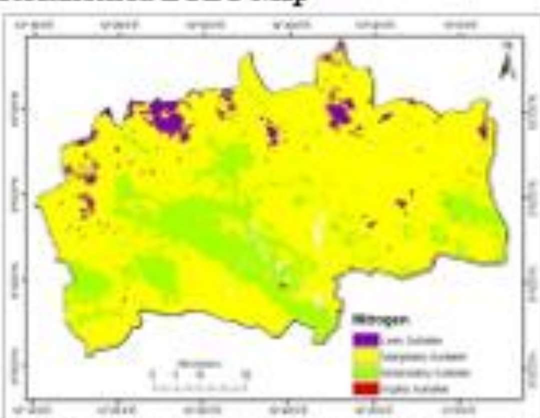
The land use land cover map of the study area for the year 2020 revealed that more than 91% of the LGA is covered by bare land while 5.6% and 2.3% of the total land area are vegetation and farmland respectively. Farmland and vegetation are highly and moderately suitable for ginger production, respectively. A phosphorus suitability classification was performed, and nearly all of the study area was deemed highly suitable for ginger cultivation. Many fundamental plant processes, such as rooting and seed formation, are aided by phosphorus. Nitrogen was divided into four categories, with areas with more than 400kg/Ha classified as highly suitable for ginger farming and those with 250 to 400kg/Ha classified as moderately suitable. Nitrogen is important for leaf development because it affects the colour and production of chlorophyll in plants. More than 75% of the study area has nitrogen value that is considered marginally suitable for the cultivation of ginger. Areas with a potassium (K) content of 50 to 90 kg/Ha covered more than 61% of the total land area and were classified as marginally suitable for ginger production, while areas with 30 to 50 kg/Ha of K were considered moderately suitable. Potassium is known to help plants resist disease, aid in the movement of water and nutrients within the plant, and can be especially beneficial in areas where the weather is cold or dry. The predominant soil texture in the study area was sandy loam (71%), which was classified as highly suitable for ginger cultivation alongside loam and sandy loam soils. Clay loam soils were considered marginally suitable. The slope of the study area was divided into five categories, with more than 88% of the study area having slope values ranging from 0 to 8 degrees considered highly suitable for ginger production. Lower sloped areas are better suited for agricultural production. The rate at which runoff flows on the soil surface and erodes the soil is influenced by the slope.



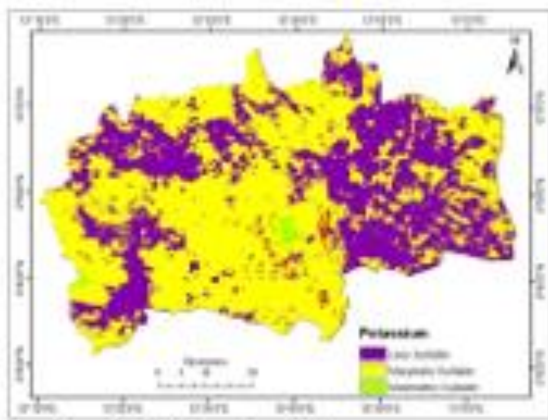
Reclassified LULC Map



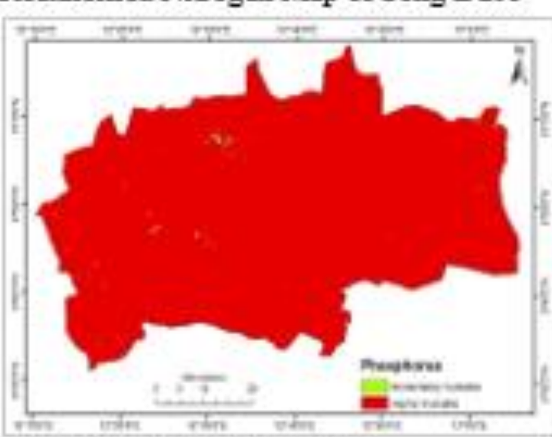
Reclassified Slope Map



Reclassified Nitrogen Map of Song LGA



Reclassified Potassium Map



Reclassified Phosphorus Map

Reclassified Soil Texture Map

Figure 3: Classified Maps of Criteria

Table 5: Suitability Analysis of Criteria for Ginger Production

Criteria	Category	Rank	Level of Suitability	Area (Ha)	%
Phosphorus	30-50	7	Moderately Suitable	1071.7	0.25
	>50	9	Highly Suitable	419487.4	99.75
			Total	420559.1	100
Nitrogen	<150	3	Less Suitable	15703.1	3.73
	150-250	5	Marginally Suitable	319846.1	76.05
	250-400	7	Moderately Suitable	84819.0	20.17
	>400	9	Highly Suitable	191.0	0.05
			Total	420559.1	100
Potassium	>90	3	Less Suitable	158765.8	37.75
	50-90	5	Marginally Suitable	258344.9	61.43
	<30-50	7	Moderately Suitable	3448.4	0.82
			Total	420559.1	100
Soil Texture	Clay Loam	5	Marginally Suitable	493.7	0.12
	Loam	9	Highly Suitable	4889.3	1.16
	Sandy Loam	9	Highly Suitable	298721.9	71.03
	Sandy Clay Loam	9	Highly Suitable	116454.3	27.69
			Total	420559.1	100
Slope	>50	1	Not Suitable	1.1	0.00
	30-50	3	Less Suitable	1506.4	0.36
	16-30	5	Marginally Suitable	14516.8	3.45
	8-16	7	Moderately Suitable	30645.3	7.29
	0-8	9	Highly Suitable	373889.5	88.90
			Total	420559.1	100
LULC	Bult up	1	Not Suitable	1199.2	0.29
	Water	1	Not Suitable	70.3	0.02
	Bareland	3	Less Suitable	385727.6	91.72
	Vegetation	7	Moderately Suitable	23736.1	5.64
	Farmland	9	Highly Suitable	9826.0	2.34
			Total	420559.1	100

Table 6: Pairwise Comparison Matrix

	LULC	Slope	Texture	Nitrogen	Phosphorus	Potassium
LULC	1	3	2	6/5	3/2	3/2
Slope	1/3	1	2/3	2/5	1/2	1/2
Texture	1/2	3/2	1	3/5	3/4	3/4
Nitrogen	5/6	5/2	5/3	5/4	5/4	5/4
Phosphorus	2/3	2	4/3	4/5	1	1
Potassium	2/3	2	4/3	4/5	1	1

Weighting of Criteria

The weight of all the criteria were calculated using AHP pairwise comparison matrix, and the results are presented in Tables 6 and 7. The results show that land use land cover has the highest weight of 0.25 (25%), followed by nitrogen with about 0.208 (20.8%) Slope had the smallest weight of 0.083 (8.3 %). Because the consistency ratio was calculated to be less than zero, it was accepted.

Table 7: Normalized Pairwise Comparison Matrix

	LULC	Slope	Texture	Nitrogen	Phosphorus	Potassium	Average
LULC	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.250
Slope	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.083
Texture	0.1250	0.1250	0.1250	0.1250	0.1250	0.1250	0.125
Nitrogen	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.208
Phosphorus	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.167
Potassium	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667	0.167
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.000

Suitability Map for Ginger Production

The suitability map for ginger production was computed in ArcGIS 10.8 and the result is presented in Table 7 and illustrated in Figure 4. The result reveals that about 75% and 25% of the study area are marginally suitable and moderately suitable for ginger cultivation respectively. A very small proportion (0.04%) of the study area is highly suitable for ginger cultivation. Because the majority of Song LGA is marginally suitable for ginger production, management measures are needed to improve the suitability of the land for maximum yield. This is contrary to the findings of Sunarto (2011) who conducted land suitability analysis for ginger cultivation in Bogor regency, Indonesia and discovered that 50.8% of the study area was not suitable for ginger production.

Table 8: Suitability Analysis for Ginger Cultivation

Level of Suitability	Area (Ha)	%
Less Suitable	9.63	0.00
Marginally Suitable	345647.6	82.19
Moderately Suitable	74901.91	17.81
Total	420559.1	100

CONCLUSION

This study demonstrated the capability of GIS, remote sensing, and multicriteria analysis tools in the creation of land suitability maps. From the results of land suitability evaluation it can be concluded that the study area is marginal suitable for growing ginger with nitrogen and potassium having marginal limitation. Therefore, management measures are needed to improve the suitability of the land for maximum yield. It is suggested that future research be conducted with more precise and accurate spatial data on soil properties, topography, and climate to produce a better land

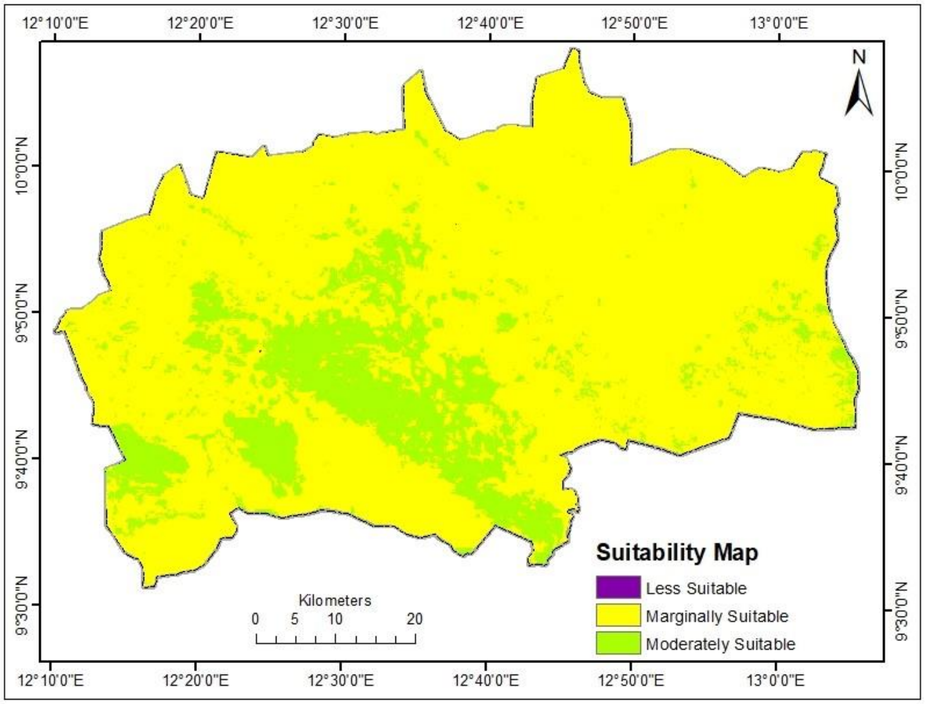


Figure 4: Suitability Map for Ginger production in Song Local Government Area.

suitability map for ginger production. The findings of this study have implications for achieving the United Nations' Sustainable Development Goal (SDG) of ensuring a sustainable food production system and implementing resilient agricultural practices (target 2.4), as well as increasing agricultural productivity and income (target 2.3).

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