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Land suitability evaluation for rainfed maize production using geospatial technologies in Nzara and Yambio counties, South Sudan

Isaac Aziz Justin Bazugba[1,2]*, Boniface Hussein Massawe[1], Mawazo Jamson Shitindi[1] and Pio Kur Deng[3]

[1]Department of Soil and Geological Sciences, Sokoine University of Agriculture, P. O. Box 3008, Morogoro, Tanzania.
[2]National Ministry of Agriculture and Food Security, Juba, The Republic of South Sudan.
[3]Department of Soil Sciences, Faculty of Agriculture, Upper Nile University, Malakal, The Republic of South Sudan.

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Classifying land based on its suitability for agriculture is crucial for agricultural development and future planning for food production. In this context, a land suitability assessment for rainfed maize varieties was conducted in Sakure and Nginda Payams of Nzara and Yambio counties, covering an area of 47,500 ha. The purpose of this assessment was to create a semi-detailed land suitability map (scale 1:100,000) using georeferenced soil survey data and spatial environmental data to assist agricultural development planners and decision-makers. The analytical hierarchy process was employed in ArcGIS to generate the land suitability map using the co-kriging method. The results indicated that 56% of the land was highly suitable, while 44% was moderately suitable for maize production. The most critical limiting factors for maize production included poor road conditions, distance from the main road, very low CEC (cation exchange capacity), and a decline in soil fertility, which has led to the practice of shifting cultivation. Based on these findings, it is recommended to conduct a detailed land suitability assessment at a scale of 1:25,000. Additionally, a study on farming systems should be carried out since mixed cropping is practiced in the area.

Key words: Land suitability map, socio-economic, ArcGIS, analytical hierarchy process.

INTRODUCTION

Selecting suitable land is vital in building sustainable agriculture and improving food production (Chivasa et al., 2019; Ramamurthy et al., 2020, Maulana and Kanai, 2021). The scarcity of land resources is growing more pronounced, driven by factors such as population growth, land degradation, and the impacts of climate change (Massawe et al., 2019; Tashayo et al., 2020, Ramamurthy et al., 2020). Ramamurthy et al. (2020), has reported significant growth of agricultural production in India but at the cost of declining soil quality with about 57% of soils under different kinds of degradation jeopardizing food production in India.

Land evaluation is the assessment of land performance when used for specified purposes (Tashayo et al., 2020). It encompasses the conduct and analysis of fundamental surveys related to climate, soil, vegetation, and various

*Corresponding author. E-mail: bazugbai@gmail.com.

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land attributes, assessing their suitability for diverse land use options (Tashayo et al., 2020, Moisa et al., 2022). Evaluation takes into consideration the economics of the proposed enterprises, the social consequences for the people of the area, and the consequences for the environment (FAO, 1976; Massawe et al., 2019; Moloudi and Mahabadi, 2019; Tashayo et al., 2020). According to Chivasa et al. (2019), land suitability analysis for producing maize is largely based on environmental factors because they are stable over time while socio-economic conditions are time dependent and easily altered by humans.

Decisions about the allocation of suitable land use type, entail assessing various criteria based on multiple objectives, often with conflicting priorities (Massawe et al., 2019, Chivasa et al., 2019; Tashayo et al., 2020) using the analytical hierarchy process (AHP). However, AHP has been criticized for its rank reversal phenomenon (Ishizaka and Siraj, 2020) but López et al. (2020) affirms it is the most used multicriteria evaluation technique. Rank reversal means the order of alternatives belonging to a certain set is changed when a new alternative is added to that set or one of the current ones is removed (Kizielewicz et al., 2021). According to Kizielewicz et al. (2021) there is a new approach to eliminate reversal in MCDM, but the debate is ongoing (Kazibudzki, 2022). With the advent of Geographic Information System (GIS), the potential for a more explicitly rationalized environmental decision-making process has been strengthened (Eastman et al., 1995). In the realm of land suitability mapping, GIS-based land suitability assessments have showcased their efficacy as a resilient tool for seamlessly integrating a wide range of physical environmental factors and expert knowledge, irrespective of their relative significance (Chivasa et al., 2019). GIS is the powerful tool for input, storage and retrieval, manipulation and analysis, and output of spatial and attribute data (Eastman et al., 1995). GIS is one type of geospatial technology; and Geospatial Technology is used to collect and analyse geospatial data (Schade et al., 2020). It is a collective term for the various modern tools and systems that help people to map the earth's surface understand societies and interpret spatial patterns (Schade et al., 2020).

The goal of this study was to conduct a land suitability analysis for maize production in Nzara and Yambio Counties, South Sudan, employing the Analytical Hierarchy Process. Maize (*Zea mays*) is second important cereal crop after sorghum grown on an estimated 21% of the total area under cereal in South Sudan (FAO, 2020). Despite its importance, production has, not kept pace with the demand in the country. Besides catastrophic episodes such as war and floods (FAO, 2022), many areas of the arable land in the country are naturally low in available nutrient and organic matter (MAFS, 2011).

According to Abdelrahman et al. (2016) and Tashayo et al. (2020), quantitative land evaluation analysis identifies the main limiting factors and opportunities for the agricultural production and enables decision makers such as land users, land use planners and agricultural support services to develop a crop management to overcome identified physical and chemical constraints and increasing the productivity. Therefore, the objective of the study was to conduct land suitability assessment for rainfed maize variety in Sakure and Nginda Payams of Nzara and Yambio Counties.

MATERIALS AND METHODS

Study area

The study area is located between 28.10 E and 28.42 E and between 04.32 N and 04.64 N covering an area of 47 500 ha (Figure 1). The altitude ranges from 606 to 744 masl (Bazugba et al., 2023) obtained from the digital elevation model (DEM) (USGS, 2014). According to the International Resource Group (IRG) (2007), the area falls within the high rainfall woodland savannah that stretches diagonally from northwest of South Sudan along the Central African Republic (CAR), the Democratic Republic of Congo (DRC) and Uganda boarders. The study area is about 500 km west of the capital Juba. The vegetation is made up of a variety of plant species with riparian forest along the riverbanks. The study area experiences two seasons (FAO, 2020), rainy season that commences late March to late November with dry spell in July and dry season for about four months starting in November/ December. The annual rainfall varies between 1000 mm to 1200 mm, with the peak between August, September and October; the average temperature is about 30ºC (CHIRPS, 2015).

Identifying attributes for land evaluation in Sakure and Nginda Payams.

The multi-criteria attributes presented in Table 1 and the flow chart shown in Figure 2 were identified for this study through a combination of literature search and expert knowledge. Table 1 also serves as the basis for making decisions regarding the levels of suitability classes. ArcGIS version 10.5 was used to conduct all the analyses.

Environmental criteria

Climate: Temperature and rainfall data were downloaded from Climate Hazards Group InfraRed Precipitation with Station *data* (*CHIRPS*, 2015), and 12 surface observation points in the study area were used to generate the rainfall and temperature patterns for the study area and the original resolution was 4.6 km.

Topography: The topography of a field greatly determines how susceptible the soil i*s to erosion by water and* is considered as a dominant factor contributing to the occurrence of flooding (Ogunwumi et al., 2021). The most important elements in topography are slope and elevation (Table 1). The slope is related to land management and erosion hazard (Habibie et al., 2019; Lopes et al., 2020). The degree of slope directly influences soil depth, susceptibility to erosion, agricultural machinery usage, irrigation, plant adaptability, and nutrient levels (Selassie et al., 2015).

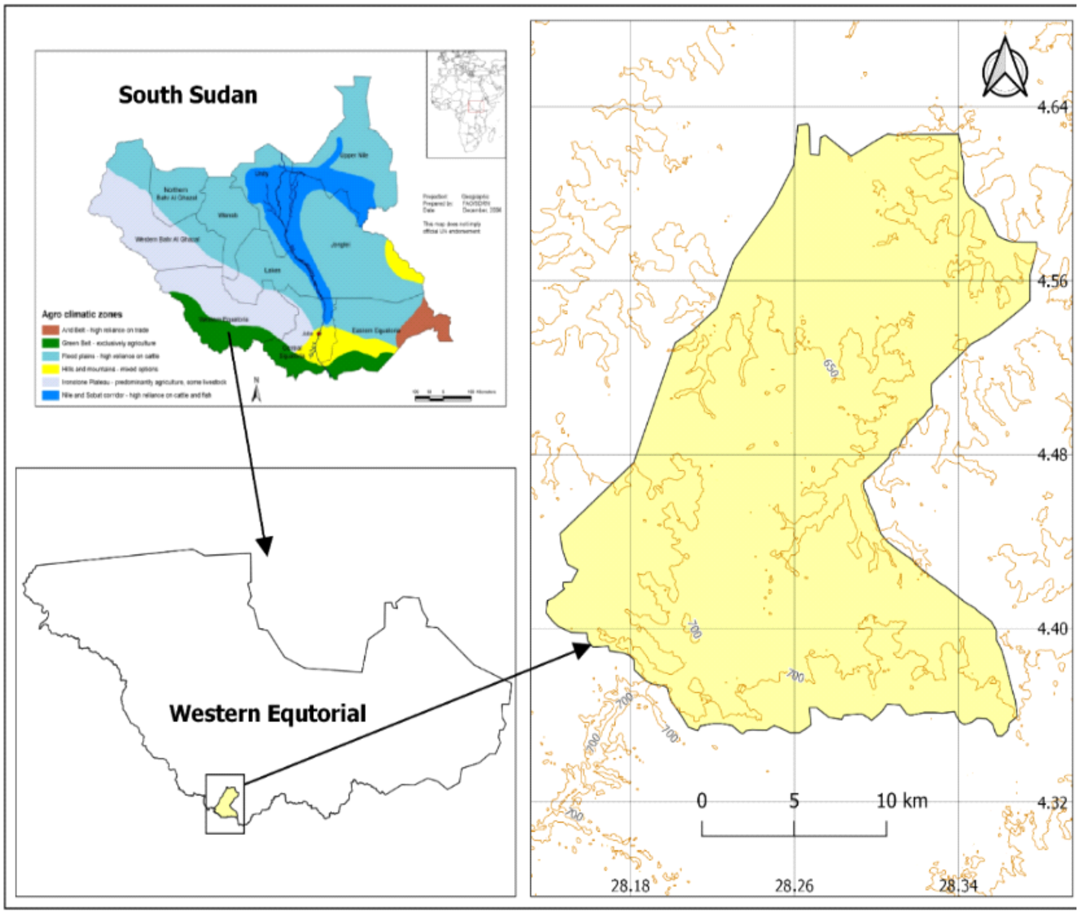

Figure 1. Study area location.
Source: Bazugba et al. 2023

Table 1. Climatic, topographic, socioeconomic and soil attributes used for land evaluation in South Sudan.

Parameter	S1		S2	S3
	0	**1**	**2**	**3**
	100 - 95	**95 - 85**	**85 - 60**	**60 - 40**
Climate				
Precipitation in the growing cycle (mm)	750 - 900	900 - 1200	1200 - 1600	>1600
Temperature (^{0}C)	24 - 26	26 - 32	32 - 35	35 - 40
Topography				
Elevation (M)	<1100	1100 - 1150	1150 - 1200	12
Slope (%)	0 - 2	2 - 4	4 - 8	8 - 16
Socio-economic				
Distance from road (km)	0 - 2	2 - 5	5 - 10	10<
Soil attributes				
Texture	C<60s, SiC, SiCL, SiL, CL	SC C>60s SCL, L	C>60v, SL, LS	S,
CEC (cmol (+)/ kg)	>24	24 - 16	16 - 8	8 - 5
SOC (%)	>1.2	1.2 - 0.8	0.8 - 0.5	<0.5
pH	6.6 - 6.2	6.2 - 5.8	5.8 - 5.5	5.5 - 5.2

S1= Highly suitable, S2= Moderately suitable and S3= Marginally suitable, C=clay, SiC=silt clay, SiCL=silt clay loam, SiL=silt loam, CL=clay loam, SC=sandy clay, SCL=sandy clay loam, L=loam, LS=loam sand, SL=sandy loam, S=Sand.
Source: Sys et al. (1993), Chivasa et al. (2019), Tashayo et al. (2020) and Kenzong et al. (2022).

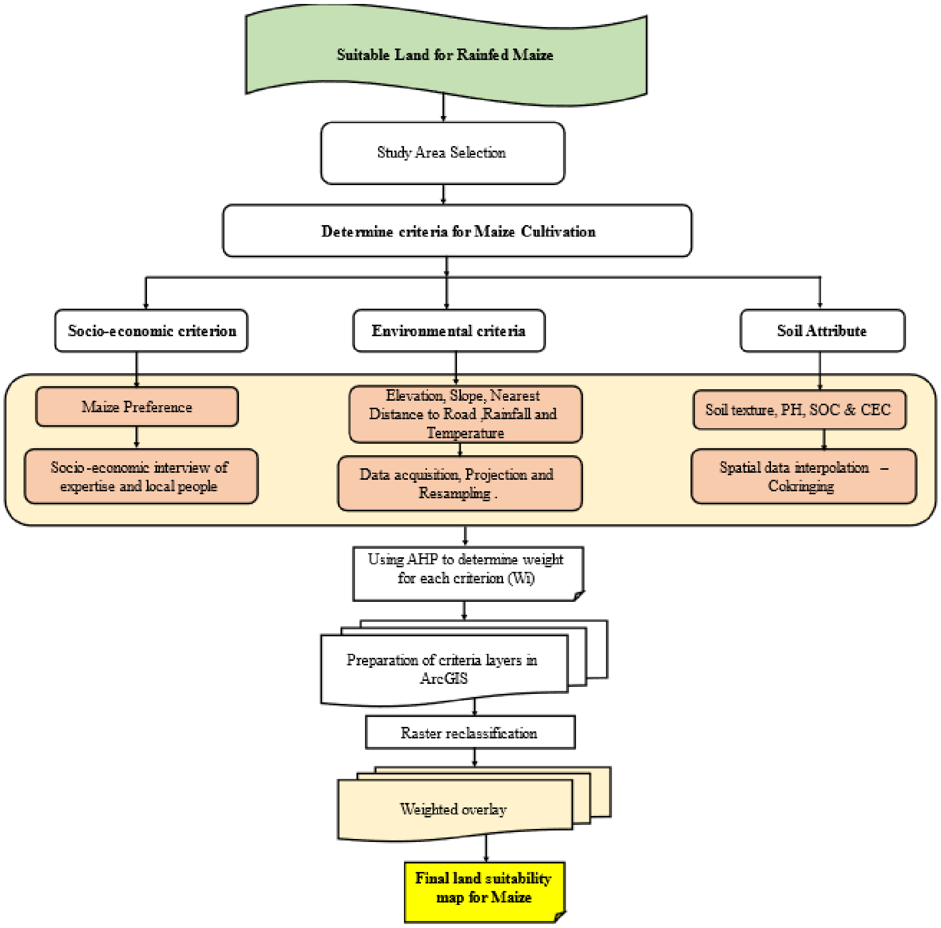

Figure 2. Flow chart for generating land suitability map.
Source: Aggregated and constructed by the author.

According to Everest et al. (2021), elevation is one of the fundamental elements for agricultural production and diversity. Elevation is related to temperature and solar radiation and thus closely linked to plant requirements (Ritung et al., 2007). Physiological and morphological variances may emerge within a single plant species in response to shifting climatic conditions, primarily temperature, corresponding to changes in elevation. This phenomenon can result in one of the plants from the same species maturing in a shorter timeframe than the other (Major, 1980; Sys et al., 1993).

Nearest distance to road

Three road types were considered: the major roads, local roads, and footpaths. A major road is running all the way from Juba to Wau that can be used for large transportation across the two counties. Road distance was considered important because Habibie et al. (2019) states shorter distance between fields and roads indicates the convenience of reaching the market. Following Habibie et al. (2019), the distances were decided as follows 0 to 5 km highly suitable, 5 to 10 km moderately suitable and more than 10 km marginally suitable (Table 1). The obtained polyline data were subsequently transformed into raster data. Following this conversion to raster format, spatial analysis was conducted using the Euclidean distance method to compute road distances. The resulting distances were then extracted through masking to delineate the study area, as detailed by Habibie et al. (2019).

Soil attributes

The soil attributes were obtained from a soil field survey that the researchers conducted in the study area (Bazugba et al., 2023). Soil textural class was used to assess the land based on the information in Table 1. Landon (1991), emphasizes that soil texture is an important characteristic that influences agricultural production, affecting crop selection, crop growth, soil moisture availability, erodibility, root penetration, and the movement of nutrients and water.

According to Sys et al. (1993), maize thrives in a variety of soils, including well-drained, well-aerated, deep loam, and silt loam soils with sufficient organic matter.

The soil chemical attributes used in this study are soil CEC, SOC, and pH and based on information in Table 1, the land was assessed. Brown and Lemon (2021) states, CEC is one of the very important inherent soil characteristics that is difficult to alter significantly in short time. The Cation Exchange Capacity serves as an indicator of a soil's capacity to retain positively charged ions and holds significant importance in comprehensive evaluations of soil fertility, as noted by Hazelton and Murphy (2019). The decline of SOC can affect important soil processes, such as regulating water

Table 2. AHP evaluation scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation.

Source: Saaty, 1980

Table 3. Random Index values**.**

N	1	2	3	4	5	6	7	8	#9	10
values	0.00	0.00	0.58	0.90	1.12	1.00	1.32	1.41	1.45	1.49

 # The RI value for 9 criteria is 1.45.
Source: Saaty and Tran, 2007.

dynamics, stabilizing the soil structure, releasing, and holding nutrients for plants, carbon sequestration and the activity of soil microorganisms (Casci, 2008; Gomes et al., 2023). Soil pH determines the availability of nutrients in the soil (Adegbite et al., 2019).

Resampling, projection, and standardization

The identified attributes for land evaluation all exist in different units, differ in terms of spatial resolution and spatial coordinate system; hence projections were performed to make sure all criteria were converted/ projected into the same coordinate system (Massawe et al., 2019), in UTM zone 35 N covering the study area. Also, all raster images criteria were resampled and converted to a spatial resolution 30 M for further analysis in AHP Model.

The multi-criteria approach is used to generate land suitability map

The AHP method was used as described by Saaty (1980). The definitions used in the comparison were made based on the criteria given in Table 2.

1) A matrix was developed where: slope, elevation, road distance, rainfall, temperature, soil texture, CEC and SOC were listed horizontally in rows and vertically in column in the table. A pairwise comparison was made between each pair starting with the first factor and comparing it with all those in the column, making judgements for the dominant criterion. The second factor was compared the same way until all the comparisons were made. The lower triangular matrix was filled using the reciprocal values of the upper diagonal.
2) The sum of each column was calculated. Then, each binary comparison matrix element was divided by the total value of the column in which it was located. With this calculation, the normalized pairwise comparison matrix values were obtained.
3) The arithmetic mean values were calculated for each row that belonged to the normalized pairwise comparison matrix values. The obtained mean values present an estimate of relative priorities for the compared elements.
4) Finally, the consistency ratio was checked. For this, eigenvectors and the maximum eigenvalue of each matrix were calculated. Then, the consistency index was tested with the formula given in Equation (1). CR was calculated by the formula given below (Equation 2).
To be valid, its consistency rate should be 0.10 (10%) or less. If the obtained rate is greater than 0.10, it was necessary to generate the pairwise comparison matrix again (Saaty, 1980).

Experts can estimate the dominance of a criterion over the other in pairwise comparison individually and final judgement is obtained by averaging their opinions or just by consensus (Saaty, 2008, Masswe et al., 2019; Chivasa et al., 2019; Everest et al., 2021). Hence, seven relevant stakeholders from Ministry of agriculture, University of Juba and including a representative of South Sudan Farmers' Union were invited to the Ministry of Agriculture and requested them to give the judgement about the factors by consensus under the guidance of the researcher.

$$CI = \frac{(\lambda max \ - n)}{(n-1)} \tag{1}$$

Whereby:
CI = consistence index, λ_{max} = represents the maximum eigenvalue of the matrix, n = is the number of criteria being compared.

Consistency Ratio (CR) was calculated using formular (2); once the CR was compliant to the rule not more than 0.1, then the derived weights were used. The formular used:

$$CR = \frac{CI}{RI} \tag{2}$$

RI = random consistency index (Table 3) determined by Saaty and Tran (2007), CR = consistency ratio, a measure of the decision maker's consistency when rating the factors used in the pairwise comparisons. The ideal CR is ≤ 10% as discussed above in the introduction.

Table 4. Pairwise comparison matrix.

Rain-fed maize	Slope	Elevation	Dist. to road	Rainfall	Temp	Soil pH	Soil texture	Soil CEC	Soil OC
Slope	1	5	0.33	1	0.2	1.00	0.01	0.02	0.05
Elevation	0.20	1.00	0.50	0.03	0.25	0.25	0.04	0.03	0.04
Road distance	3.00	2.00	1.00	0.50	2.53	0.33	0.30	0.29	0.48
Rainfall	1.00	1.00	2.00	1.00	9.00	0.09	0.50	0.10	0.11
Temp	5.00	4.00	1.00	0.11	1.00	0.20	0.50	0.14	0.30
Soil pH	1.00	4.00	1.00	1.00	5.00	1.00	3.00	0.50	5.00
Soil Texture	1.00	3.00	1.00	2.00	2.00	0.33	1.00	0.33	3.00
Soil CEC	1.00	1.00	1.00	5.00	9.00	2.00	3.00	1.00	3.00
Soil OC	3.00	2.00	2.00	3.00	3.00	0.20	0.30	0.33	1.00
Total	16.20	23.00	9.83	13.64	31.98	5.40	8.64	2.75	12.98

Lambda max = 9.8, CI = 0.10, and CR = 0.07.
Source: Author.

Table 5. Criteria weights.

Criteria	Soil CEC	Soil pH	Soil OC	Soil texture	Temp	Rainfall	Dist. to road	Slope	Elevation
Weight	24%	19%	12%	11%	9%	8%	8%	7%	2%
Ranking	1	2	3	4	5	6	7	8	9

Source: Author

Predicting overall maize suitability map

The thematic maps were integrated into the GIS environment according to the already established suitability conditions for maize production as presented by FAO (1976) and Sys et al. (1993). Each thematic map is generated in a class of S1, S2, or S3 and values ranging from 1 to 3, where 1 represents S1 (highly suitable) and S3 represents marginally suitable (Sys et al., 1993). The various weights of the thematic maps were combined using the weighted overlay (MCE) tool in the ArcGIS spatial analyst tool to produce the final maize suitability map using Equation (3) (Chivasa et al., 2019).

Some scholars (Chivasa et al., 2019; Kenzong et al., 2022) have used these techniques successfully for land suitability as well as identifying risk areas to flood and mass movement (Lopes et al., 2020; Ogunwumi et al., 2021).

Where SI = Suitability value, Wi is the weight of the factor i, Xi is the criteria score of factor i, Ci is Boolean value (the constraints), and is product.

SI lies between 0 and 1 because values of both W*i* and X*i* are between 0 and 1. In this case values near zero represent unsuitable areas, while those near one indicate highly suitable areas. Since C*i* is the land use constraint, it only takes a value of either 0 or 1 (Boolean logic), where zero was assigned to protected land (forests) and non-agricultural land (built-up areas) and 1 represents current and potential cropland (Chivasa et al., 2019).

RESULTS AND DISCUSSION

Multi - criteria decision-making method

Thematic suitability maps

Table 4 presents the pairwise comparison matrix and the generated weights are indicated in Table 5. The thematic maps for rainfall, temperature, slope, elevation, and distance from road is presented in Figure 3. while the four soil properties (pH, CEC, SOC, and texture classes used are presented in Figure 4. The Suitability area and their distribution for each thematic layer is shown in Table 6.

Environmental criteria for maize production at Sakure and Nginda Payams

Climate and topography

Rainfall and temperature thematic maps are presented in Figure 3a and b. The temperature and rainfall data were resampled using the spatial analyst tool, increasing from 4.6 km to 30 m resolution. Rainfall classes range was: 750 to 1 200mm, highly suitable, 1 200 to 1 600 mm, moderately suitable, and more than 1 600 mm, marginally suitable. While temperature in degrees Celsius was categorized into three classes as follows: 24 to 32, highly suitable, 32 to 35 moderately suitable and 35 to 40 marginally suitable (Table 1). Both rainfall and temperature are adequate and cover the study area by 99.8 and 100% respectively. This implies that rainfall and temperature in the study area are both at optimum for the growth of maize but what is not clear here is whether the rainfall is uniformly distributed monthly or not. Maize is a tropical crop and can survive with a short exposure to high temperatures (>40°C), about 1°C rise but not for the

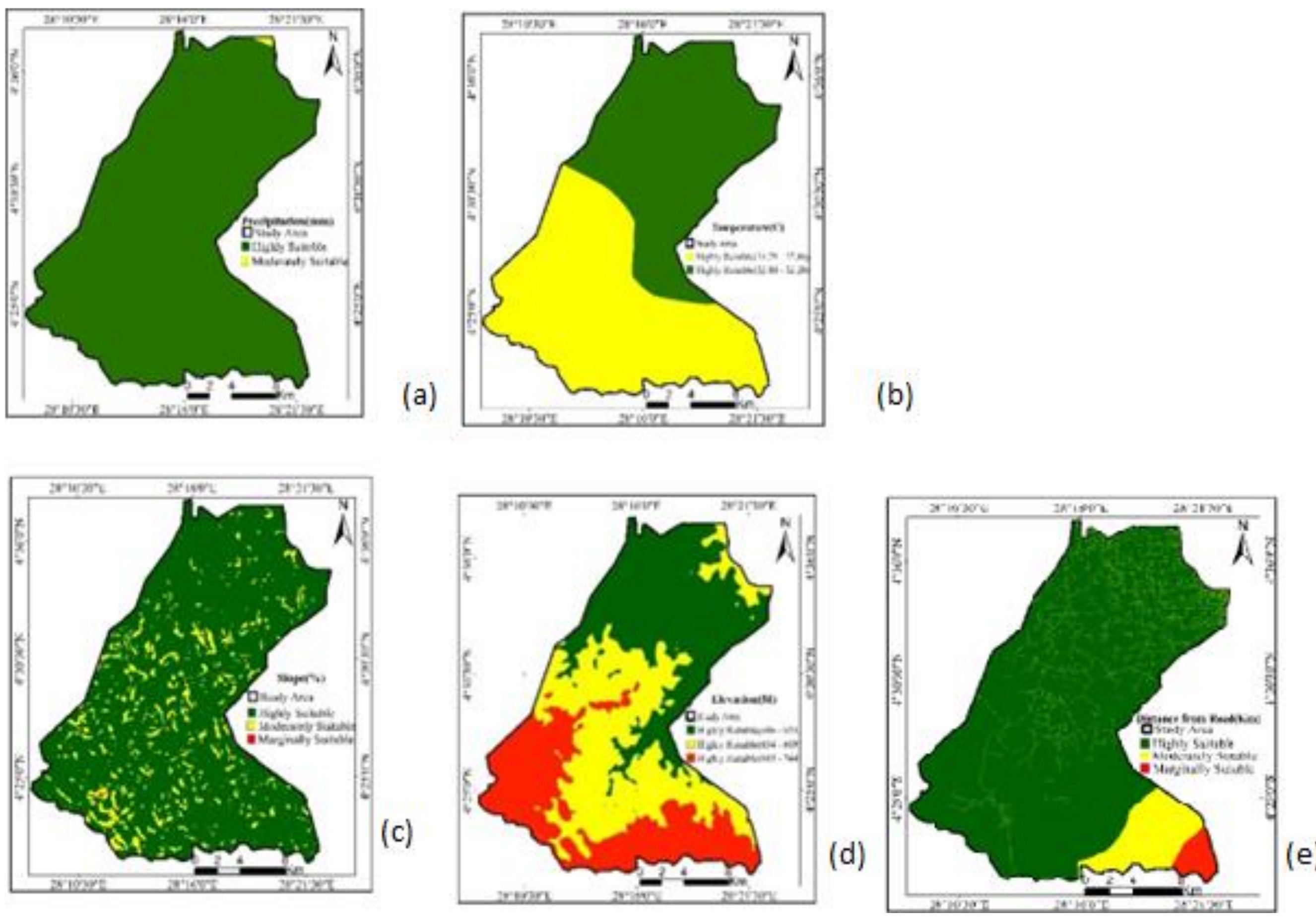

Figure 3. Maps of environmental and socioeconomic criteria used to generate the maize suitability map.
Source: Maps prepared by the author

crop growth period (Chandra et al., 2022). According to Sys at al. (1993), Chivasa et al. (2019) the optimum temperature range for maize is from 18 to 32ºC, but maize has a wide range of growing temperature from 18 to 40ºC.

Climate elements such as temperature and precipitation have a direct impact on the growth of maize plants and, consequently, influence the ultimate grain yield, as highlighted by Zhang et al. (2020). Climate factors, such as temperature, and precipitation directly affect the development of maize plants and hence the final grain yield (Zhang et al., 2020). Chandra et al. (2022) has reported a decrease in maize yield by 7.4% compared to wheat and rice respectively due to temperature rise. Implying maize is very sensitive to temperature rise compared to the other two crops. Rainfall of the study area on average is about 1 096 mm per annum, aggregated from data (CHIRPS, 2015) and generally decreases from the boarder with DR Congo in the south to the north. Though maize can grow between 500 – 5000 mm/ annum rainfall but the optimum is between 1000 to 1 500 mm/ annum Ritung et al. (2007).

The slope and elevation thematic maps are shown in Figure 3 c and d. Griffel et al. *(*2022) states, there are varying suitable slope ranges for producing each crop; normal slope is between 5 and 15 degrees. From the DEM, slope was calculated using the slope tool in ArcGIS. The class categories and percentage coverage are indicated in Table 6. The slope categories were: 0 to 4 highly suitable, 4 to 8 moderately suitable and 8 to 16 marginally suitable. The slope is 90% high, 9% moderately and 1% marginally suitable for maize production. The maximum slope is 11%.

Climate and topography

The elevation classes are presented in Table 6, and they are: 1 700 to 2 000 highly suitable, 2 000 to 2 300 moderately suitable and above 2 300 m was considered marginally suitable. The maximum elevation is approximately 744 m above sea level (Bazugba et al., 2023). In this scenario, both the elevation and slope are within acceptable range for maize production and

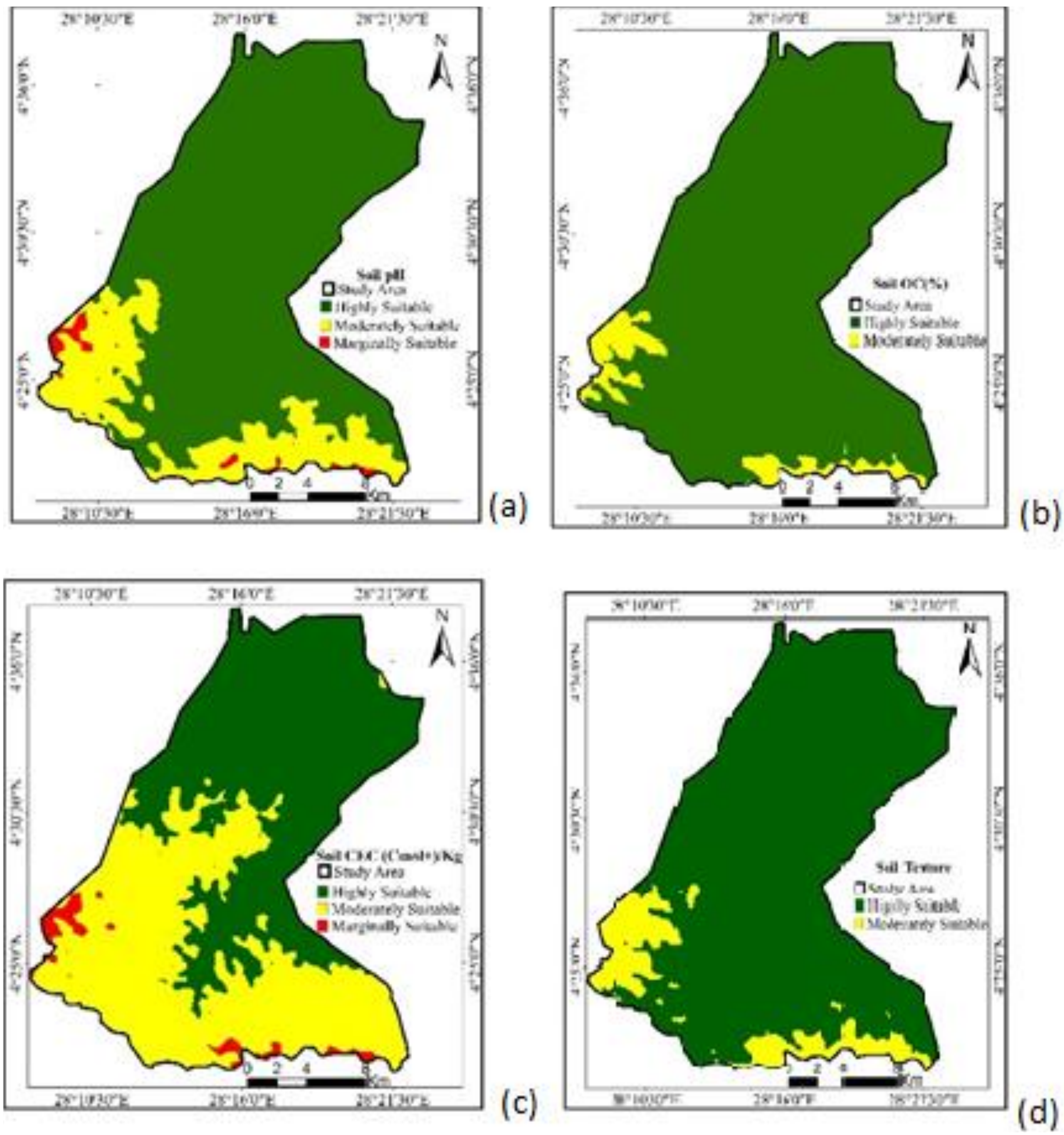

Figure 4. Selected soil properties used to generate land suitability.
Source: Author

agricultural farm mechanization (Sys et al., 1993; Kenzong et al., 2022). From field observations the dominant soil erosion in the study area is rill and mass flow; with good vegetation cover it can be managed. Although the land scape has a gentle slope still the use of cover crops and best practices of soil management need to be applied, because Bazugba (2001), cultivated maize inter cropped with cowpeas as cover crop, on less than 4% slope recorded severe nutrient loss in runoff and soil loss on bare plots.

Socioeconomic criteria

Distance to the road: Distance to road is presented in Figure 3 (e) and the shorter the distance the better. The reason for this classification was based on the poor road conditions in the counties. According to the analysis, 90% was highly suitable, 8% moderately and 2% marginally suitable (Table 6). The highly suitable means it is within 5 km from the main road that enables farmers reach market easily. However, the moderately and marginally suitable

Table 6. Suitability area and their distribution for each thematic layer.

Main criteria	Sub criteria	Class	Suitability	Area (ha)	Area (%)
Precipitation (mm)	750 - 1200	S1	Highly suitable	47403	99.8
	1200 - 1600	S2	Moderately suitable	97	0.2
			Total	47500	100
Temperature (^{0}C)	24 - 32	S1	Highly suitable	47500	100
			Total	47500	100
Elevation (m)	< 1000	S1	Highly suitable	47500	100
			Total	47500	100
Slope (%)	0 - 4	S1	Highly Suitable	42954	90
	4 - 8	S2	Moderately Suitable	4526	9
	8 - 16	S3	Marginally suitable	20	1
			Total	47500	100
Distance to the road (km)	0 - 5	S1	Highly Suitable	42831	90
	5 - 10	S2	Moderately Suitable	3661	8
	10 <	S3	Marginally Suitable	1008	2
			Total	47500	100
Soil Texture	SCL	S1	Highly Suitable	42800	90
	LS, SL	S2	Moderately Suitable	4700	10
			Total	47500	100
Soil CEC (Cmol/kg)	24 - 16	S1	Highly Suitable	997	52
	16 - 8	S2	Moderately Suitable	21125	46
	8 - 5	S3	Marginally Suitable	24579	2
			Total	47700.63	100
Soil OC (%)	1.2 - 0.8	S1	Highly suitable	44921	95
	0.8 - 0.5	S2	Moderately suitable	2579	5
			Total	47500	100
pH	6.6 - 5.8	S1	Highly suitable	37831.23	80
	5.8 - 5.5	S2	Moderately suitable	9071.80	19
	5.5 - 5.2	S3	Marginally suitable	596.97	1
			Total	47500	100
Overall suitability map		S1	Highly suitable	26463	55.7
		S2	Moderately suitable	21463	44.3
			Total	47500	100

Source: Author

are still good land for planting maize but it was limited for the purpose of conserving forest biodiversity.

Soil attributes used in the final land suitability map

The thematic maps for soil pH, CEC, SOC, and texture are indicated in Figure 4a to d. Where pH 6.6 to 5.8 is highly suitable, 5.8 to 5.5 moderately suitable and 5.5 to 5.2 marginally suitable. The study area pH is 80% highly suitable, 19% moderately and 1% marginally suitable. CEC classes: 24 to 16 highly suitable, 16 to 8 moderately suitable, and 8 to 5 marginally suitable. Soil CEC in the study area is about 52% highly suitable, 46% is moderately and 2% is marginally suitable for maize production. SOC classes:1.2 to 0.8 highly suitable, 0.8 to

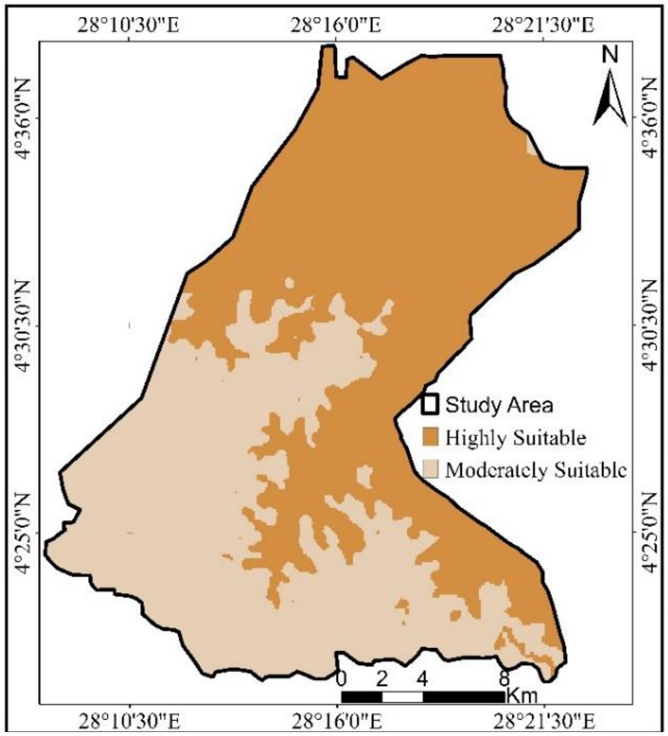

Figure 5. Final Land suitability map for rainfed maize in Sakure and Nginda Payams.
Source: Author

0.5 moderately suitable, and < 0.5 marginally suitable. SOC is 95% highly suitable and 5 % moderately suitable for maize growth. Sandy clay loam was categorized as highly suitable, Sandy loam and loam sand were moderately suitable and sandy soil was marginally suitable. The texture is 90% highly suitable and 10% moderately suitable for growing maize.

The soil pH in the study area ranged from 5.5 to 7.3. Numerous studies, including the work of Adegbite et al. (2019), have indicated that this pH range is conducive to the availability of both micro and macro nutrients, with particular emphasis on phosphorus, nitrogen, potassium, calcium, and magnesium, making these nutrients readily accessible to plants. Conversely, in soils with a pH below 5.2, maize crop roots may experience hindrances due to aluminum toxicity, which restricts nutrient uptake, as discussed by Wafula (2021). The soil properties fall within acceptable ranges categorized as S1, S2, and S3 in the suitability class according to the FAO framework. Approximately half of the study area exhibits poor nutrient retention capacity. Conversely, there is a high probability of losing Soil Organic Carbon (SOC) due to forest degradation (Akinde et al., 2020) and unnecessary wildfires (ASPF, 2012), unless deliberate efforts are made to maintain SOC. The addition of organic matter can contribute to an increased Cation Exchange Capacity (CEC) of the soil, although it may take several years to yield noticeable effects, as discussed by Brown and Lemon (2021).

Overall land suitability

The flow chart for generating land suitability map is presented in Figure 2. and the weighted criteria in Table 5 were overlaid using the Boolean approach to produce detailed maize suitability map (Figure 5). The map delineates two levels of suitability: high suitability and moderate suitability. The highly suitable land means the conditions are favourable for the growth of maize (Chivasa et al., 2019) and it covers 56% (26 463 ha) of the land. The meaning is the slope ranges from 0 to 4%, SOC is 1.2 to 0.8%, the pH is optimal (5.5 to 7.3), rainfall is good (1 000 to 1 500 mm/ annum), and closer to main and the local roads within 5 km. About 44% (21 037 ha) is moderately suitable for growing maize implying that the slope ranges from 4 to 8%, SOC is decreasing as well as pH range from 5.8 to 5.5 and the distance from the main and local roads is increasing up to 10 km. However, in general the land is suitable for rain-fed maize growing and with good land management and agronomic practices high yield of maize would be obtained.

Multicriteria approach in conducting land suitability analysis using AHP combined with GIS is handy;

therefore, it is a powerful tool in the analysis and resolving complex issues in multi disciplines. Saaty (2008), reports that the AHP has been used in several disciplines including the military, education, agriculture and many more. Decomposing complex problems to finer details goal, criteria, and sub criteria, also makes decision process easier (Chivasa et al., 2019). The AHP excels in assessing and addressing inconsistencies, enhancing the reliability and precision of the analysis (Mendoza et al., 1999, Saaty, 2008, Chivasa et al., 2019; Ishizaka and Siraj, 2020). The consistency ratio obtained in this study in the beginning was 35% and was greater than the threshold of 10% (Saaty, 1980). The consistence check process was repeated, and we obtained 10% and the weights were used.

Nevertheless, the methodology does have certain limitations. Subjectivity plays a role in factor weighting, and different individuals may prioritize certain indicators differently. This, in turn, can influence the ranking process, which relies on land characteristics as the foundation for decision-making. Secondly, this study only considered a limited number of variables; other significant factors such as macro nutrients and micro-nutrients like zinc, along with additional factors, could be incorporated in future research, potentially yielding different outcomes. Bazugba et al. (2023) discovered deficiencies in phosphorus and nitrogen in the study area.

Thirdly, the integration of GIS and AHP proved to be a valuable approach for generating land suitability maps. However, it's worth noting that there was no available yield data for validation purposes, as reported by Chivasa et al. (2019)."

CONCLUSION AND RECOMMENDATIONS

This study conducted a thorough land suitability analysis for rainfed maize cultivation in Sakure and Nginda Payams of Nzara and Yambio Counties in Western Equatoria State. By employing a multicriteria approach, which incorporated nine distinct parameters (rainfall, temperature, slope, elevation, distance to roads, soil texture, soil CEC, soil OC, and pH) through the Analytical Hierarchy Process (AHP) integrated into a Geographic Information System (GIS). The research aimed to assess the appropriateness of land for maize cultivation.

The findings underscore that both Sakure and Nginda Payams offer favorable conditions for growing maize. The study provides valuable insights for decision-makers such as policy makers and stakeholders involved in land management and agricultural planning, aiding in the formulation of judicious approaches for crop cultivation and soil enrichment. These approaches are designed to address identified limitations such as CEC, pH, and SOC, thereby enhancing overall productivity. It highlights the greenbelt zone's favorable climate and topography, which contribute to highly suitable conditions for maize cultivation.

Approximately 56% of the land is classified as highly suitable (S1) for maize cultivation, while 44% exhibits moderate suitability (S2). This suggests that the study area demonstrates a potential for maize production, though certain soil-related challenges need to be addressed. From a socio-economic perspective, infrastructure development, including bridges and roads, is crucial to support agricultural activities.

Given the prevalent mixed cropping practices, a detailed analysis of existing farming systems is recommended. The comprehensive analysis of the current farming practices would offer valuable insights for optimizing agricultural productivity in the region. To further enhance the accuracy and applicability of the findings, the study proposes an in-depth soil survey at a scale of 1:25,000. This survey would provide a comprehensive understanding of the area's potential and constraints regarding maize cultivation. In conclusion, this research contributes valuable insights to inform land management strategies, paving the way for sustainable maize cultivation in the studied area and serving as a model for similar agro-ecological regions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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