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GEOSPATIAL MAPPING OF AGRICULTURAL LAND SUITABILITY IN ZARIA, NIGERIA

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ABSTRACT

This study mapped out the agricultural land suitability in Zaria using Geospatial Techniques (GT) with a view to highlight areas of improvement in production to enhance food security. The Agricultural Land Suitability (ALS) is the fitness of a land to a specific crop. ALS selects the land that best suits and supports a crop optimal yield, by matching the land qualities with the crop's requirements; hence increasing productivity per unit land at minimum inputs and cost. The agricultural lands in the study area were identified and mapped as well as the biophysical land qualities that influence rice cropping. The prevalent biophysical land qualities were matched with the rice requirements; and evaluation of the agricultural land suitability was done using GT and Multi Criteria Decision Making (MCDM) modelling approach. Food and Agricultural Organization (FAO) method to land suitability evaluation was adopted via GT; which entails delineating the study area into highly suitable (S1), moderately suitable (S2), marginally suitable (S3), temporarily not suitable (N1), and permanently not suitable (N2). The study findings were that about 5% of the area is highly suitable, 9% very suitable, 18% moderately suitable, 55% is marginally suitable, and 13% not suitable. The results of this study can be used by individuals, private organizations, and government to increase agricultural productivity in the study area for sustainable rice farming in order to optimize yield as well as mitigate degradation and erosion.

Keywords: Geospatial techniques**,** Agricultural land suitability, Multi-criteria evaluation, Weighted overlay, Food security, GIS and Remote sensing

INTRODUCTION

Agricultural Land Suitability (ALS) is a measure of fitness of a land to function for a specified cultivation at minimum cost and degradation (Olaniyi *et al*, 2007; FAO 2007; Otgonbayar *et al*, 2017). Land is a limited, non-renewable, and indispensable natural resource base for most human activities especially agricultural uses (FAO, 2007). Improper use of land brings unproductive utilization of natural resources, land degradation, cultivation failures, hunger and poverty (Rossiter, 1996). These are exacerbated in Nigeria, because of the intensification of farming activities as a result of high demand for more food triggered by high rate of population growth, which in turn has surpassed the rate of agricultural production (Economic Recovery and Growth Plan (ERGP), 2017)). Consequently, this directly create challenges on food security and indirectly exerts stress on other socio-economic activities (Orji-Okoro, 2008). Thus Nigeria imports food including sugar costing about 20% of the Gross Domestic Product (GDP) (ERGP, 2017; Trading Economics, 2019).

However, ALS evaluation boosts agricultural productivity by selecting the best land to grow a crop thru delineating the area of land into highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) (Al-Mashreki *et al.,* 2011; Widiatmaka *et al.,* 2015). In essence, ALS provides the interface between land resources survey and land use planning and management (Rahman and Saha, 2008; Wani *et al.,* 2009). Modern methods of evaluating ALS include the use of Geospatial Techniques (GT). GT refers to combination of Remote Sensing (RS), Geographic Information System (GIS), Global Positioning System (GPS), and Web Based Mapping Technologies (WBMT) (American Association of Advanced Science (AAAS), 2017)).

About 80% of the total land mass of Nigeria is fertile (World Bank, 2011); but is declining due to degradation, erosion, and conversion to other more competitive land uses like built-up areas (Oni, 2013). Hence, the need to increase agricultural production, by raising productivity per unit land area through ALS evaluation, which also mitigates degradation and erosion as well (FAO, 2007). This ensures that the best crop is planted on the best land which will support its optimum growth at minimum cost of inputs (fertilizer, irrigation, implements), for maximizing output and yield (Olaniyi *et al.,* 2007; FAO 2007; Keshavarzi, 2011).

According to Crop Production Manual (CPM (2015)) most farmers are harvesting far less than the potential yield. Amongst the reasons is the selection of unsuitable crop(s) for their farms: as they rely on local, traditional, and sometimes trial-and-error methods. Hence, there is need for accurate crop selection and evaluation of agricultural land suitability thru scientific approach using the geospatial mapping. Hence, many studies used conventional methods in evaluating ALS including Aondoakaa and Agbakwuru (2012), Chukwu *ett al.,* (2014), Abah and Petja (2016), Agber *et al.,* (2017), Jimoh *et al.,* (2018).

However, in the study of Jimoh *et al*., (2018) conventional method was used titled land suitability evaluation of Kubanni Floodplain for rice production in Zaria, Kaduna State, Nigeria. Three soil mapping units (KBI, KBII, KBIII) were delineated by soil survey, and soil samples collected using auger for laboratory analyses. The results showed that KBI and KBII were suitable for rice production, while KBIII was marginally suitable. The study used traditional soil survey which is slow, tedious, expensive and takes long time even year(s) to complete (McKenzie *et al*., 2008); which can leave out highly suitable land units (Alegbe, 2008). Moreover, suitability evaluation was done through maximum limitation procedure, which maps a land based on its limiting factor

(FAO, 2007). Hence, the need for faster and holistic methods like the digital techniques (Al-Mashreki *et al.*, 2011).

Though, many studies used digital techniques for ALS evaluation including Rossiter (1996), De la Roasa *et al.*, (2002), Belal *et al.*, (2014), Ayine *et al.*, (2015), and Widiatmaka *et al*., (2015). While in the study of Widiatmaka *et al*., (2015) Automated Land Evaluation System (ALES) was used to carry out land suitability analysis to establish local specific inputs for paddy fields (rice) in Subang, West Java, Indonesia. However, ALES software handles only the matching process that requires programming dexterity which is difficult for non-computer programmers, and has no mapping functions to map the suitability. Therefore, the study mapped the land mapping units and the existing paddy fields using remote sensing (SPOT 6), in Erdas Imagine and ArcGIS 10.2 software. Hence, in order to have a holistic and simple ALS evaluation a GT based ALS evaluation is required, where the matching and mapping are all carried out in a single system. Hence, this is identified as a gap which is envisaged to be addressed by the GT.

There are some studies that incorporated GT in matching and mapping ALS. Studies within this category include Bandyopadhyay *et al*., (2009), Al-Mashreki*et al*., (2011), Mustafa *et al.*, (2011), Lupia (2012), Halder (2013), Otgonbayar *et al*., (2017).

However, in the study of Halder (2013), land suitability assessment for rice and wheat cultivation by remote sensing and GIS. Topographic map and remote sensing (IR P6 LISS-III image) were used for extracting the study area and agricultural land in GIS. The study used six soil characteristics of Nitrogen (N), Phosphorous (P), Potassium (K), pH, Organic Carbon (OC), and texture to assess ALS. These factors were rated by Sys, Van Ranst, Debaveye, and Beernaert (1993) rating, while ArcGIS 9.3 was used to map the ALS based on qualitative maximum limitation approach to classifying the land into S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (temporary not suitable), and N2 (permanently not suitable). Also, the maximum limitation rule used designates suitability to a land based on the least favourable characteristic despite having many favourable ones. Hence, there is need for refinement of this approach through the use of GIS-MCDM modelling which would designate hierarchical weight values (coefficient) to the land qualities/characteristics in the model based on their relative influence or importance with one another with respect to the crop growth and yield. Additionally, only Land Characteristics (LC) of soil texture and fertility (nutrients) were used in that study; as such other important Land Qualities (LQ) like water availability, temperature regime, rooting conditions, oxygen availability, and others were not included. The aim of this study, therefore, is to map the agricultural land suitability in Zaria using geospatial techniques with a view to highlight areas of improvement in production for enhancing food security.

MATERIALS AND METHOD

The study area is located in Zaria within Latitude (11° 06′ 45’’ to 11° 07′ 30) N and Longitude (7° 40’ 15’’ to 7° 41′) E on the high plains of Northern Nigeria. It is 652.6 metres above sea level and 950 kilometres from the coast. The study area covers 100 Km², and has two distinct seasons the wet and dry, the mean minimum and maximum temperatures can reach 13° and 42° in January and April respectively. Mean annual rainfall is about 1000 mm (Sawa and Buhari, 2011; Badamasi et al., 2016). The area’s geology is composed of granites, gneisses, and schists belonging to the Precambrian age. River Galma is the only perennial river in Zaria. All other streams and rivers discharges into the Galma. The main Galma-tributaries are river Saye, Basawa, Shika, and Kubanni. Zaria possesses guinea savannah vegetation with a good savannah woodland cover, a variety of grasses, woody shrubs, and short trees (Figure 1).

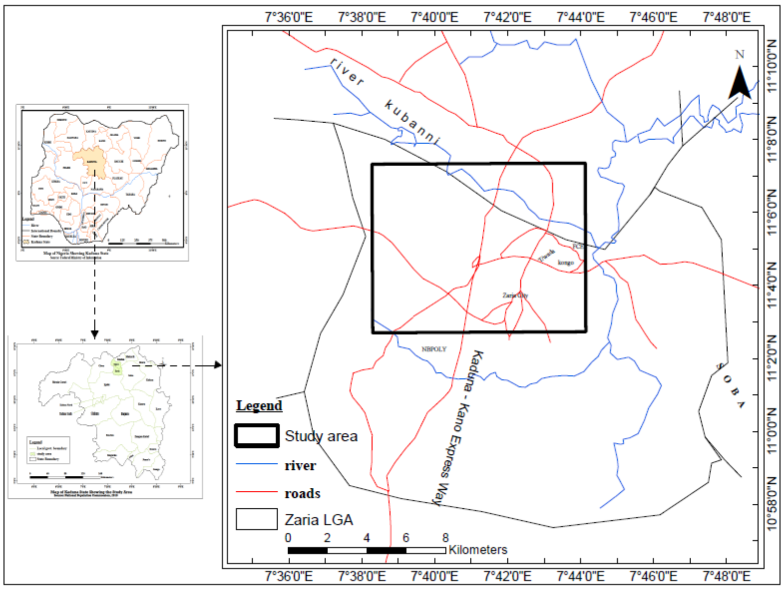

Figure 1: Study area
Source**:** GIS analysis 2022

Preliminary work entails the review of related studies based on the subject matter to grasp the components, the framework, materials and methods (Figure 2). A short visit was taken to the study site to identify features of interest (LQs) that are important to the ALS according to FAO (2007). Hence, 7 factors were identified (Table 1).

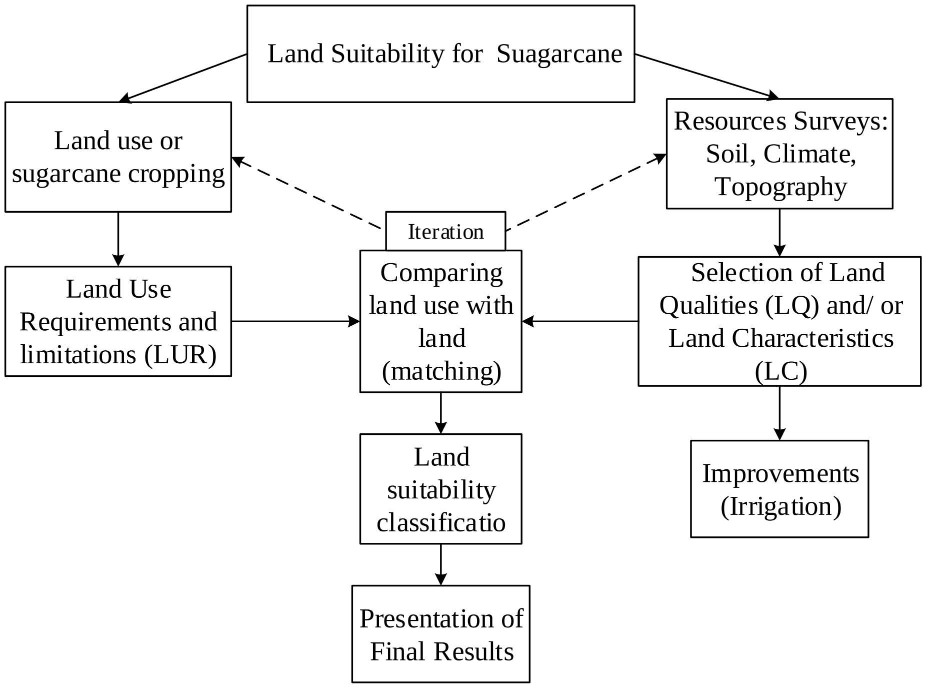

Figure 2: Workflow diagram of agricultural land suitability evaluation
Source: CSR/FAO, 1983

Table 1: Land Qualities (LQ) with their Land Characteristics (LCs)

S/n	Land Quality	Land Characteristics
1	Temperature regime	Annual average emperature (°C)
2	Water availability	Dry months (< 75 mm rainfall) Average annual rainfall (mm)
3	Oxygen availability	Soil drainage class Soil texture (surface) Rooting depth (cm)
4	Nutrient retention	CEC; me per 100 g soil (subsoil) pH (surface soil)
5	Nutrient availability	Total nitrogen Available P_20_5 Available K_20
6	Toxicity	Salinity mm hos cm^{-1} (subsurface)
7	Terrain	Slope (%)

Source: CSR/FAO (1983), Hall et al. (2016)

Primary data used include:

i. Global Digital Elevation Model (GDEM 2022) version 2 with 70m resolution (a product of Advanced Spaceborne Thermal used Emission and Reflection Radiometer (ASTER)): used to identify the slope in the study area (Table 2).

ii. Coordinates of soil samples sites or points was collected by GPS for the purpose of interpolation using geostatistics.

Table 2: Data Types and Sources

S/n	Data types	Sources	Resolution/Scale
1.	Landsat 8 (OLI) Image and TIRS (2021)	Glovis (http://glovis.usgs.gov) (2021)	30m
2.	GDEM (ASTER) (2021)	Glovis (http://glovis.usgs.gov) (2021)	15m
3.	Admin. map of Zaria LGA	Admin. Shapefiles of Nigeria	-
4.	Meteorological data (Rainfall, Temperature)	Nimet , IAR, FCE	-
5.	Soil Edaphic Factors Maps	Field work & Lab analysis	-
6.	Infrastructure Map	Google Earth, Google Map	-

Source: Badamasi et al. (2016)

The tools, instrument, data collection, processing and analyses instruments:

a. Handheld Garmin 76S GPS to collect coordinates of samples points/sites
b. Prismatic Compass for giving direction of grid points

c. ArcGIS Software10.5 for spatial analyses, mapping and modelling; it was used because it has modelling modules, could manage large data, and has simple interface
d. Erdas Imagine (2015) Software for satellite image processing including radiometric corrections, and classification
e. AHP Software for weighting land qualities and sub criteria

Soil samples were collected by field survey, using GPS to identify locations for sample collection. A pit was excavated to collect samples, for soil laboratory test and analyses and results recorded. The lab analyses determined the soil's physio-chemical properties and characteristics in terms of nutrient/NPK (Nitrogen, Phosphorous, Potassium), CEC, pH, texture, drainage, salinity, stoniness, and depth (CSR/FAO, 1983). These were compared with the rice crop requirements (Table3)

Table 3: Rice Requirements for Corresponding Land Qualities

Land Qualities (LQs)	**Land Characteristics (LCs)**	**Land Suitability Ratings**				
		S_1	**S_2**	**S_3**	**N_1**	**N_2**
Temperature regime, t	Growing cycle avg temp.(°C)	25 – 29	29-32 25-22	32-35 22-18	>35 <18	-
Water availability, w	Average annual rainfall (mm)	800- 1600 800 – 500	1600-2200 500 – 300	2200-2600 300 – 150	- -	>2600 <150
Oxygen availability, x	Soil drainage class	WD	MWD	ID	PD	VPD
	Soil texture /structure (surface)	SiCe, Co, SiCL. CL, Si, SiL, C-60s, C-60v, SC, L	C_60v, SCL, SL, Lfs	LS, LcS, fS	-	S, cS
	Rooting depth (cm)	>120-90	90-50	50-20	-	<20
Nutrient retention, *f*	CEC me per 100g soil (subsoil)	>24, ≥M	24-16, L	<16(-),VL	<16(+)	
	pH (surface soil)	5.5-7.5	7.5-7.9 5.5-5.0	7.9-8.2 5.0-4.5	<4.5 -	>8.2
Nutrient availability, *n*	Total nitrogen (%) Available P_2O_5 (mg/kg) Available K_2O (cmol/kg)	≥M(0.2-0.4) VH(-) ≥M(0.5-0.8)	L(<0.2) H(>35) L(<0.5)	VL (-) ML(10-25) VL(-)	- VL(<10) -	- - -
Toxicity, *x*	Salinity (dsm) (subsoil)	<3.0	3.1-5.0	5.1-8	>8	-
Terrain, *s*	Slope (%)	<1	1-2	2-6	>6	-

Source: (Langdon, 1991; Hall *et al.,* 1992; Sys *et al*., 1993; Rossiter, 1994)

RESULT, DISCUSSION, AND ANALYSIS

Identifying and mapping the land qualities influencing ALS

The land qualities influencing rice production were identified thru literature review and ground truthing (Table 2). Develop the land qualities' maps for the ALSE involved remotely sensed data from which the slope map was derived from the ASTER GDEM in the slope tool of the spatial analyst tool of ArcGIS 10.5 (Badamasi et al., 2016asrject). The Land qualities' maps like soil drainage, available nutrients, nutrients retention, toxicity, terrain were developed in ArcGIS 10.5 from results of lab analysis as seen in Table 4**.** Spatial autocorrelation was performed for each soil property to derive its variation over space in the study area (map) (Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, 12).

Table 4: Physico-chemical soil properties

	PARTICLE SIZE DISTRIBUTION CORRECTED				pH Ratio 1:2.50		(dsm)		(mg/kg)	(cmol/kg)	
SAMPLE II	(%)Clay	(%)Silt	(%)Sand	Text,Class	H20	0.01m CaC	Ece	TN	AP	K	CEC
1	20	44	36	LOAM	6.71	6.39	0.220	0.0280	20.09	0.18	4.21
2	10	24	66	ANDY LOAI	5.91	4.79	0.110	0.0336	21.56	7.16	13.87
3	12	22	66	ANDY LOAI	5.86	5.49	0.200	0.0560	12.74	5.32	10.54
4	14	28	58	ANDY LOAI	6.73	5.74	0.100	0.0140	21.56	1.53	6.28
5	10	30	60	ANDY LOAI	6.82	6.23	0.290	0.0364	12.25	1.64	7.00
6	20	22	58	ANDY LOAI	6.93	6.,51	0.150	0.0280	28.42	3.17	8.51
7	24	20	56	DY CLAY LC	6.72	6.14	0.100	0.0168	11.76	6.14	13.99
8	10	22	68	ANDY LOAI	6.55	6.13	0.300	0.0420	23.03	0.20	3.76
9	18	36	46	LOAM	6.26	5.8	0.250	0.0420	16.17	0.18	5.69
10	24	26	50	DY CLAY LC	6.41	5.98	0.180	0.0616	11.27	0.10	4.56
11	22	34	44	LOAM	6.49	6.11	0.190	0.0224	16.17	1.18	6.88
12	30	34	36	CLAY LOAN	6.6	6.22	0.300	0.0224	14.21	0.16	3.25
13	14	30	56	ANDY LOAI	6.15	5.97	0.110	0.0028	11.27	0.20	4.44
14	24	28	48	DY CLAY LC	6.54	5.91	0.050	0.0252	9.80	0.10	5.36
15	42	36	22	CLAY	6.3	5.58	0.020	0.1204	8.82	0.19	5.54
16	28	24	48	DY CLAY LC	6.42	5.96	0.150	0.0476	10.29	1.64	4.99
17	30	50	20	CLAY LOAN	7.04	6.42	0.280	0.0224	19.11	1.64	8.81
18	24	32	44	LOAM	6.53	5.36	0.100	0.0308	28.91	2.56	9.61
19	16	46	38	LOAM	6.65	5.45	0.090	0.0308	10.29	1.64	4.84

Matching LQs with crop requirements

Table 5 shows factor ratings LQ and LC according to the FAO suitability classification, by considering the suitability or else of the actual LQs regarding the crop requirement for it. Hence, Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 were reclassified based on Sys et al (1993) parametres.

Table 5: The Land Suitability Rating Scale

Soil Characteristics	**Class, Degree of Limitation and Rating Scale**					
FAO Framework	S0	S1	S2	S3	N1	N2
Restriction Levels of Sys *et al*, 1993	0	1	2	3		4
Parametric Evaluation of Restrictions	100-95	95-85	85-60	60-40	40-25	25-0

Source: FAO (1976); Sys *et al* (1993)

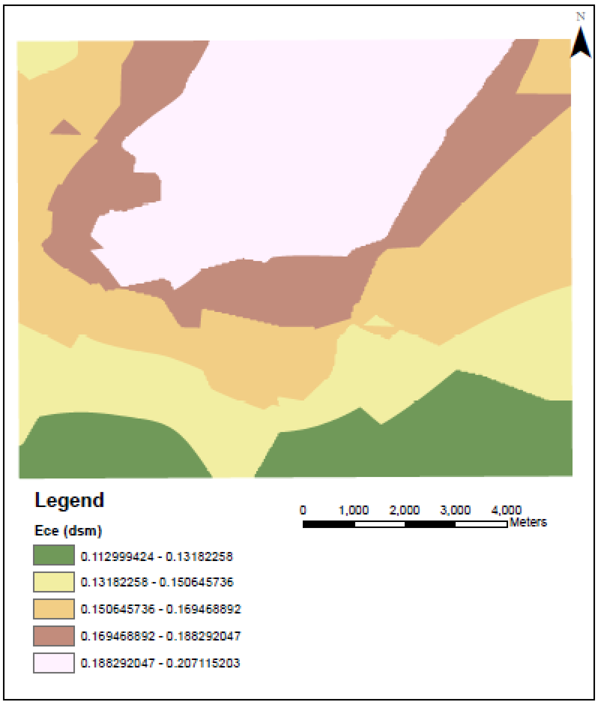

Figure 3: Soil toxicity

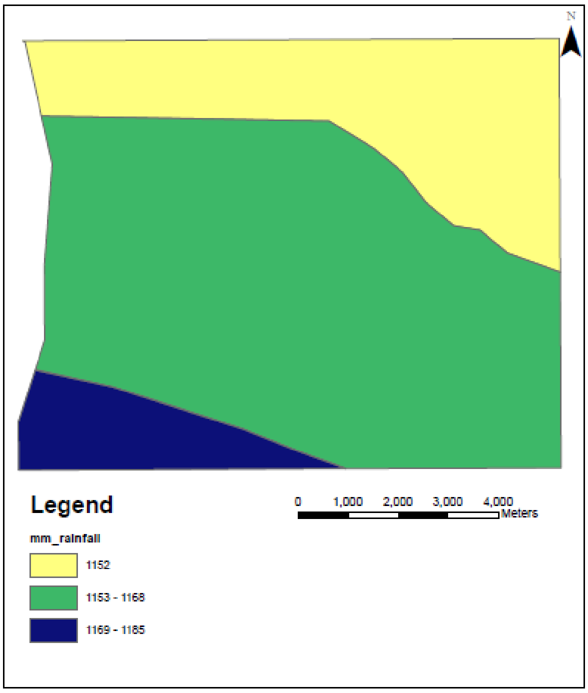

Figure 4: Rainfall of the Area

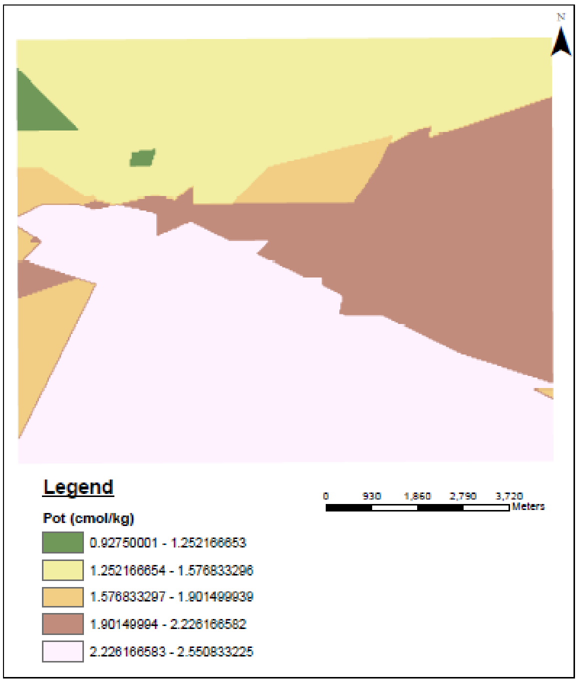

Figure 5: Soil Potassium

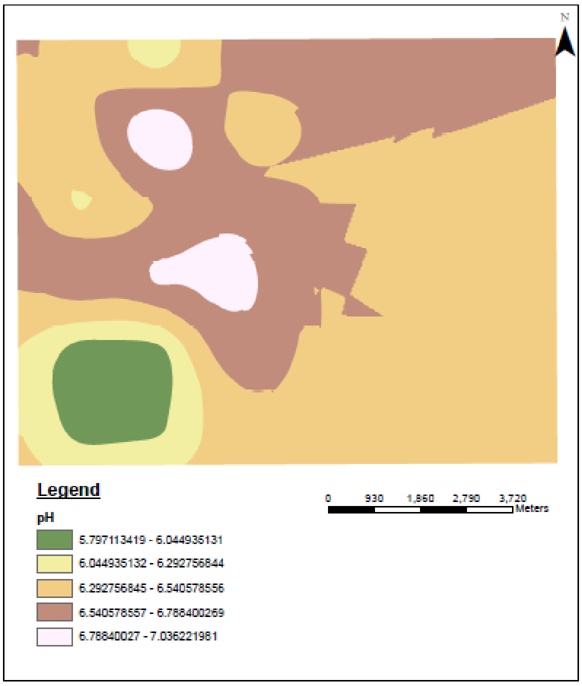

Figure 6: Soil pH

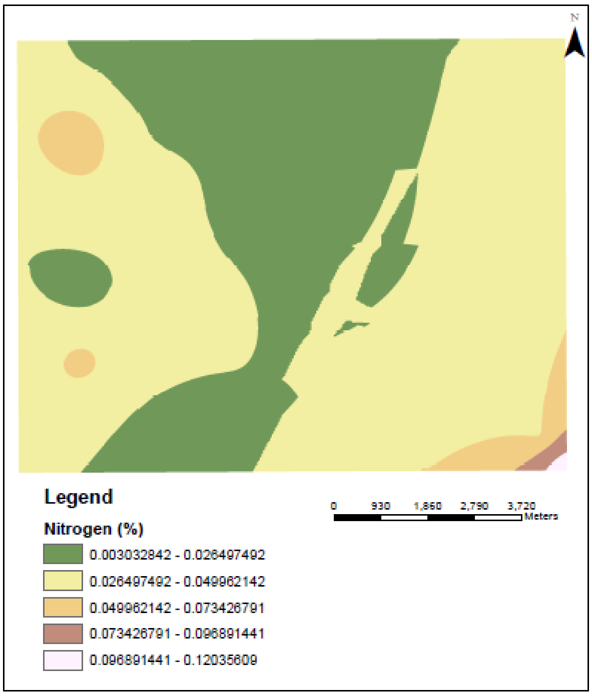

Figure 7: Soil Nitrogen

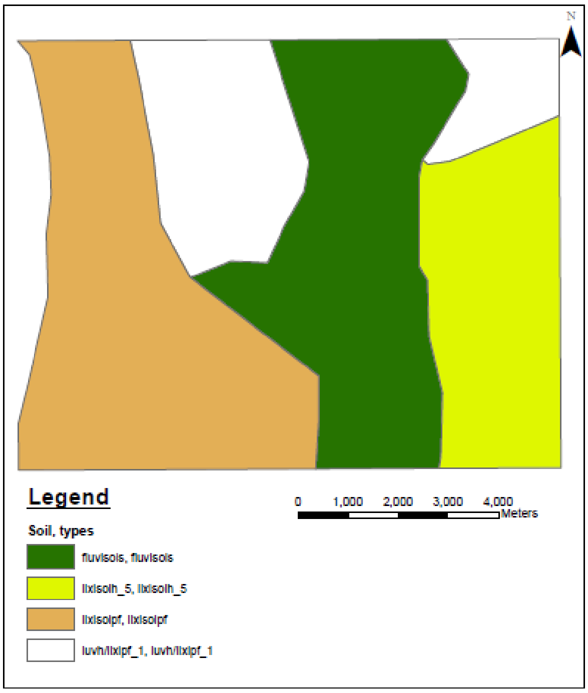

Figure 8: Soil drainage

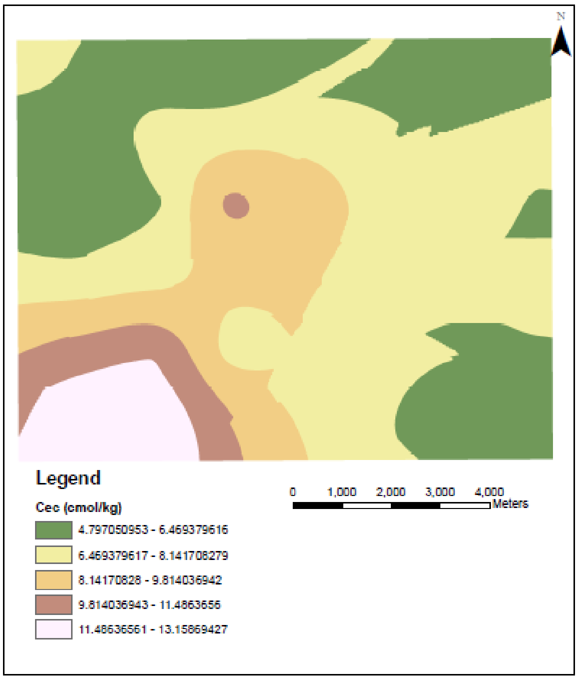

Figure 9: Soil CEC

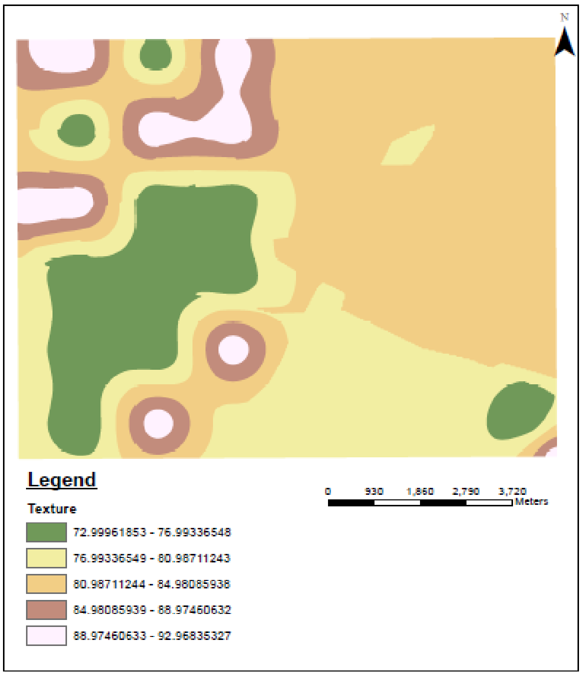

Figure 10: Soil texture

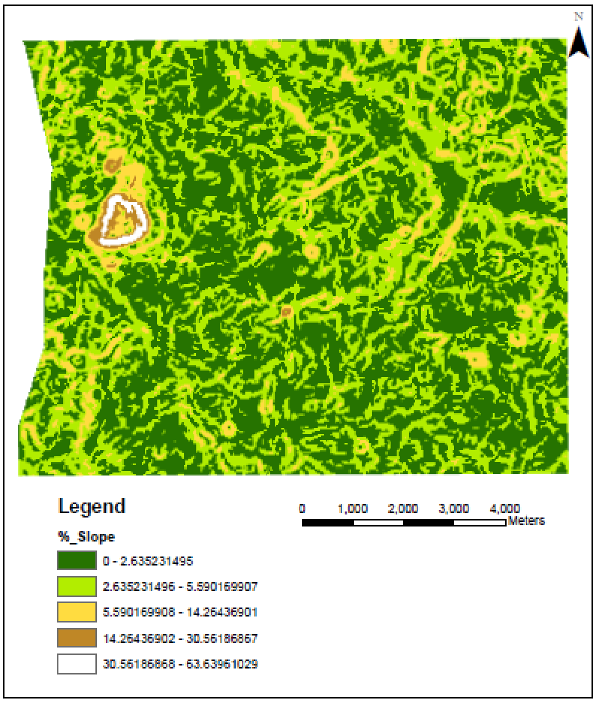

Figure 11: Slope

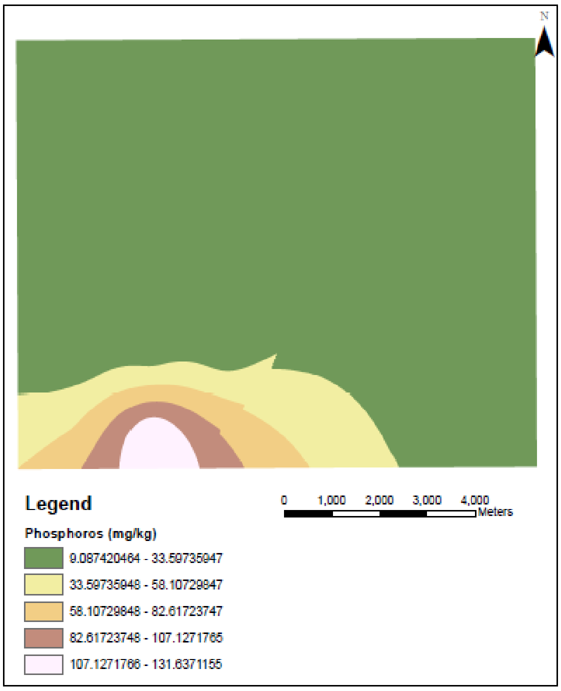

Figure 12: Soil Phosphorous

Evaluating ALS for rice using GIS-MCDM modelling

This involves the derivation of weights for each dataset by evaluating the relative importance of each criterion against the others known as the pair wise comparison matrix method; which were calculated using Analytical Hierarchical Process (AHP) in an MS Excel AHP template (Klaus, 2013). The criterion weights were automatically calculated once the pair wise comparison matrix is entered in Analytic Hierarchy Process (AHP) weight derivation template (Table 5) (Mulugeta and Alemu, 2022). According to Mendoza (1999) GIS-based integrated model permits both analytical planning and optimization of land use decisions at different levels including land or site suitability assessments based on different factors and specific land uses. Therefore, Land suitability model is expressed as follows:

$S = \sum_{j=1}^{n} Xj \,.\, Cj$ ………….(1)

where Xj = the criteria or factors affecting suitability; Cj = degree of effect on suitability associated with each factors (weights), and n is number of factors or criteria that influence the suitability in the study.

Table 5: Computed Weights of Land Qualities by AHP Template

S/No	Land Qualities (LQ)	Weights (LQ)	Land Characteristics (L C)	Sub-Weights	Weights (LC)
1	Temperature regime	0.0900	Temperature (ºC) growing cycle average		0.0900
2	Water availability	0.1600	Rainfall (mm) annual average		0.1600
3	Oxygen availability	0.1900	Soil drainage class	0.3000	0.0570
			Soil texture/structure	0.5400	0.1026
			Soil depth	0.1600	0.0304
4	Nutrient availability	0.3700	Total Nitrogen	0.5000	0.1850
			Available P	0.2500	0.0925
			Exchangeable K	0.2500	0.0925
5	Nutrient retention	0.1000	CEC	0.6700	0.0670
			pH	0.3300	0.0330
6	Toxicity	0.0600	Salinity		0.0600
7	Terrain	0.0300	Slope		0.0300
	Sum	10.00			10.00

Source**:** Author(s) Analysis 2022

Finally, the criterion weights and the factor rated maps were combined/aggregated by means of weighted (Mulugeta and Alemu, 2022) overlay modelling technique in ArcGIS 10.5 to obtain the final Agricultural Land Suitability (ALS) for rice (Figure 13)**.**

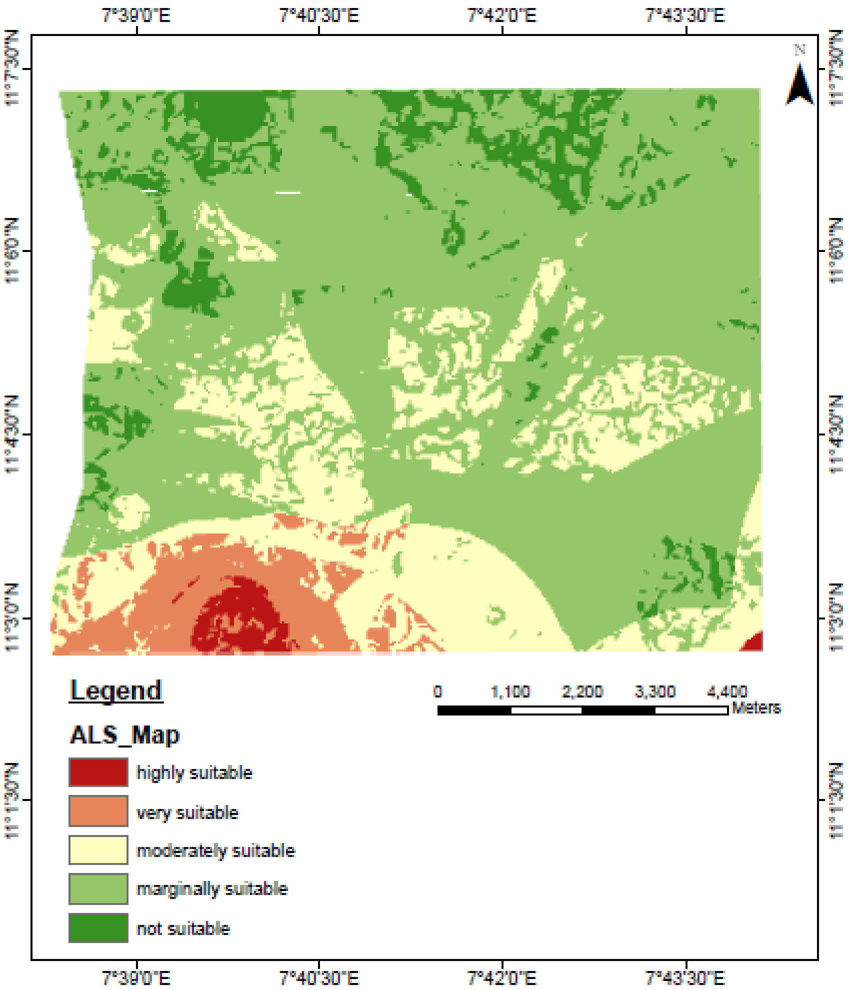

Figure 13: ALS for rice
Source: Authors' Analysis (2022)

CONCLUSION

The study findings were that about 5% of the area is highly suitable, 9% very suitable, 82% moderately suitable, 55% is marginally suitable, and 13% not suitable. It is believed that because of the lower levels of Nitrogen, Cation Exchange Capacity (CEC), and Phosphorous were the major limitations for rice cropping which lead to 55% marginally suitable. While, highly and very suitable making up just 14%. It is recommended that the results of this study can be used by individuals, private organizations, and government to increase agricultural productivity in the study area for sustainable rice farming in order to optimize yield, as well as to cushion economic meltdown.

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