

Land Suitability Analysis for Maize Production in Egbeda Local Government Area of Oyo State Using GIS Techniques

Abegunde Linda, Adedeji Oluwatola, Tope-Ajayi Opeyemi

Abstract—Maize constitutes a major agrarian production for use by the vast population but despite its economic importance; it has not been produced to meet the economic needs of the country. Achieving optimum yield in maize can meaningfully be supported by land suitability analysis in order to guarantee self-sufficiency for future production optimization. This study examines land suitability for maize production through the analysis of the physicochemical variations in soil properties and other land attributes over space using a Geographic Information System (GIS) framework. Physicochemical parameters of importance selected include slope, landuse, physical and chemical properties of the soil, and climatic variables. Landsat imagery was used to categorize the landuse, Shuttle Radar Topographic Mapping (SRTM) generated the slope and soil samples were analyzed for its physical and chemical components. Suitability was categorized into highly, moderately and marginally suitable based on Food and Agricultural Organisation (FAO) classification, using the Analytical Hierarchy Process (AHP) technique of GIS. This result can be used by small scale farmers for efficient decision making in the allocation of land for maize production.

Keywords—AHP, GIS, MCE, Suitability, *Zea mays*.

I. INTRODUCTION

THE economic fortune of most developing countries, including Nigeria, revolves around the exploitation and use of its land base resources [13]. Agriculture is one of the age-long human occupations which have undergone radical transformation with diverse technological advancement. Consequently, the type of tools, techniques and management practices has changed considerably overtime as a result of technological dynamics. In addition, the rampant poverty, food scarcity, malnutrition and increasing food distance have combined to changing the mode and type of agricultural production. Pressure on agriculture has often times resulted in overexploitation of land resources through excessive use of fertilizers with consequence on land degradation [9]. Excessive use of fertilizers and land degradation are two major problems inhibiting food and fibre production to meet the needs of the rapidly growing population and thus endangers

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food security [11]. In Nigeria, there is noticeable evidence of land degradation which varies by type, duration, severity and socio-economic impact from one place to another [1], [11].

Research into combination of land attributes and cropping pattern or system that will give crops highest productivity is required. This is important because of the acute shortage of food and over increasing population [9]. Maximizing benefits derivable from land requires its proper utilization. Consequently, a landuse plan which incorporates different land characteristics is important. Land evaluation and crop suitability analysis using GIS and remote sensing would provide better landuse options to the farmers. GIS and remote sensing offer a convenient and powerful platform to integrate spatially complex and different land attributes for performing land suitability analysis and allocations. This involves the use of multi-criteria decision analysis using analytical hierarchy process (AHP) due to wide range of factors which has to be put into consideration. AHP provides a structured approach to measuring suitability by decomposing the suitability analysis problem into hierarchical units and levels. This allows a systemic and more in-depth analysis of the factors which may be better understood when deconstructed into their lower and more specific forms or indicators. The development of Multi-Criteria Decision Analysis (MCDA) or Multi-Criteria Evaluation (MCE) is to improve spatial decision making when a set of criteria is to be evaluated. Results obtained from the integration of MCDA into the crop suitability assessment would most likely be more accurate since the methodology permits the incorporation of experts' opinion into decision making. Therefore, land suitability analysis is needed in developing countries like Nigeria for self sufficiency in agricultural production.

Maize is one of the important grains in Nigeria on the basis of the number of farmers engaging in its cultivation and in its economic value. It is a multipurpose crop in which every part of it has great economic value. The grain, leaves, stalk, tassel and cob can all be used to produce a large variety of food and non-food products. Demand for maize is increasing at a faster rate because it is a major staple food for human and animals. Studies in maize production in different parts of Nigeria have shown an increasing importance of the crop amidst growing utilization by food processing industries and livestock feed mills. In Nigeria, the demand for maize is increasing at a faster rate daily, but despite the economic importance of maize, it has not been produced to meet food and industrial needs of the country, and this could be attributed to low productivity due to

lack of improved technologies for maize production [7]. One of the major limitations to maize production in Nigeria is the declining soil fertility which is exacerbated by the high cost and sometimes unavailability of fertilizer [3].

Improving yield and efficiency in resource use is vital to ensuring adequate food security and environmental sustainability. The slight increase in maize production in Nigeria has been attributed to increase in hectares devoted to its cultivation and not optimum yield of each farmland. However, recent report of [2] have shown that the productive cultivation of areas used for maize production have declined by about 20 % from the periods of 1991 to 2000 and 2001 to 2010. Also, the potential yield of maize crop using the improved seedling in Southwest of Nigeria is small compared to that of the developed countries [8]. Improper land use results to land degradation and decline in agricultural productivity. However, in practice, particularly in Southwestern Nigeria, the use to which land is put is not often related to the land potential capacity for its use type [11]. Land have been utilized intensively for all purposes at the expense of its suitability capacity thereby resulting in land degradation and altering of the natural ecological conservatory balances in the landscape [5]. The starting point towards sustainable management is adequate information on the land resources. Hence, in order to get the optimum benefit out of the land, proper utilization of its resources is inevitable.

Prior studies relating to this research work includes: Land suitability system for rice cultivation in the Tana delta based on the method described in the FAO Guideline for Land Evaluation for Rainfed Agriculture using GIS program studied by [16]. Suitability rating of land for rice cultivation in the Tana delta area is distributed as follows: 67% is highly to moderately suitable, 14% is moderately suitable and 10% is marginally suitable. About 9% of the study area classified as Eutric Fluvisol was found to be currently unsuitable for rice cultivation due to some limitation factors such as partly sandy clay texture, saline, low water retention and high hydraulic conductivity. Reference [14] assessed the land suitability for rice cultivation based on GIS modeling of Central Anatolian region of Turkey. Nutrient availability index (N, P, K, Zn), soil quality index (physical and chemical properties – drainage, texture, soil depth, topography, pH, soil salinity) were the land quality parameters which were overlaid to generate four suitability classes. Reference [15] conducted a research on the use of GIS and AHP technique for land use suitability analysis for coffee in Lam Ha District, Lam Dong Province of Viet Nam based on local farming practices, opinions of farmers, scientists, and local district and province leaders. Using economic, social and environmental criteria, three classes of very high, high and not suitable areas were generated. These studies recognize the relevance of land suitability evaluation for planning purposes and in ensuring that land resources are put to maximum use.

This study thus attempts to contribute to knowledge by applying multi-criteria evaluation (MCE) integrated with GIS to delineate the suitable areas for maize production using the relevant variables of the physical and chemical properties of

soil, topographic factors and land use, to improve productivity and allocate the land to the most suitable use type for maize production.

II. STUDY AREA

This study was carried out in Egbeda LGA, which is one of the 33 LGAs in Oyo State, a suburban located in the rainforest agro-ecological zone. It lies between latitudes $7^{\circ} 21'$ and $8^{\circ} N$ of the equator and longitudes $4^{\circ} 02'$ and $4^{\circ} 28' E$ of the meridians, and bounded in the North by Lagelu LGA, in the West by Ibadan North East, in the East by Osun State and in the South by Ona-Ara LGA. The annual mean temperature and rainfall in the area is to be about $28^{\circ}C$ and 2650 mm respectively.

The pedological characteristics of soils in the area shows that it is highly weathered and as a result has more nutrients leached and therefore, substantial nutrients must be added to complement the in-situ nutrients available for crops such as maize, cowpea, soybean, tomato, vegetables and the host of others. It has been pointed out that land-man ratio is reducing progressively and the lands are over-cropped [6]. Oyo State according to [4] is the highest producer of maize among the South-western states of Nigeria.

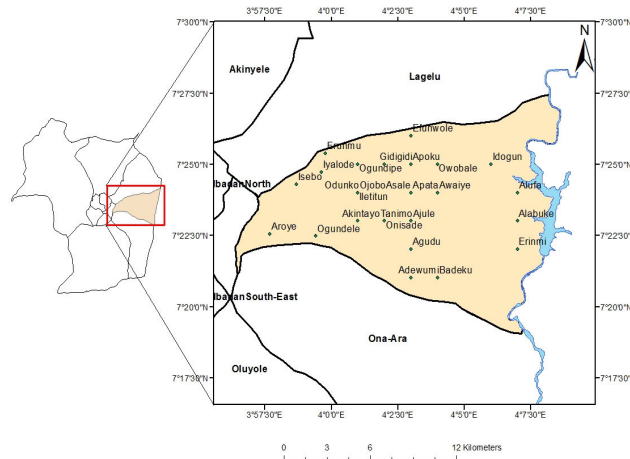


Fig. 1 Study Area Map

III. METHODOLOGY

Both primary and secondary data were utilized for this research. Primary data includes the horizon wise collection of representative soil samples from 20 point locations randomly selected using grid method from agricultural lands of the study area at 0 – 25cm depth, while secondary data includes satellite imagery which consists of Landsat imagery and Shuttle Radar Topographic Mapping (SRTM) data. Landsat imagery was used to generate the Land use/Landcover (LULC) map, with vegetation, waterbody and settlement as the major type of uses of the land. Slope angle was developed using Shuttle Radar Topographical Mapping (SRTM) data.

Soil samples were analyzed for its physical and chemical properties using the routine soil analytical technique at the soil laboratory in the Agronomy Department, University of Ibadan.

Results of the soil laboratory analyses were imported into the GIS software. The GPS coordinates of each point with its corresponding nutrients values were interpolated using the Inverse Distance Weighting (IDW) technique, and a raster image was generated for each attribute. The decision support wizard in the Idrisi software was used to carry out the Analytical Hierarchy Process (AHP) for the suitability classes based on the raster images generated. This started with the fuzzy classification technique which standardized the criteria from a scale of 0 (not suitable) to 1 (highly suitable) in order to give the criteria uniform rating. Pairwise comparison matrix evaluated the importance of one criterion over another based on experts' opinion and generated weight values which were used for the final suitability process.

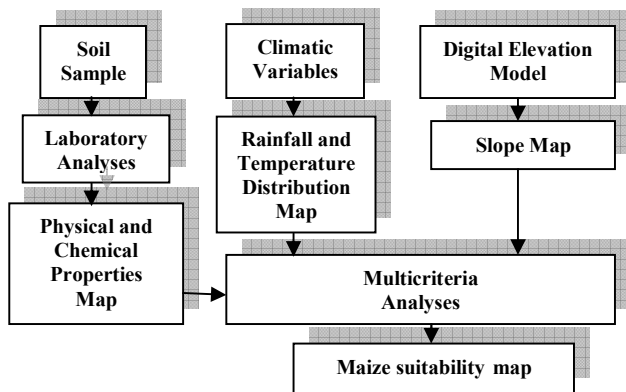


Fig. 2 Flowchart for the Research Work

IV. RESULT

A. Landuse/Landcover

Out of the total study area which is approximately 264 km², vegetation covers a greater landcover compared to settlements and waterbody. The settlement area is mostly dominated westward and waterbody is to the east.

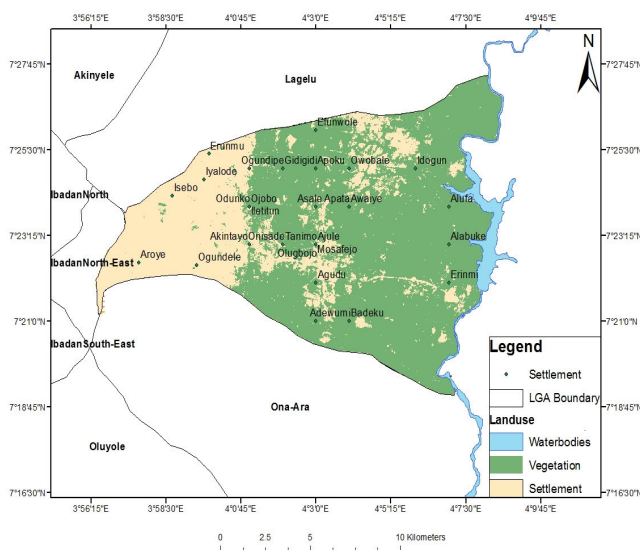


Fig. 3 Landuse/Landcover Map

B. Spatial Variation of Soil Physical and Chemical Properties

Based on the routine soil test analysis, the soil samples were found to contain the following components:

TABLE I
STATISTICAL VARIATION OF SOIL PROPERTIES

Properties	Low Value	High Value	Mean
Nitrogen (%)	0.0801939	0.859767	0.325
Phosphorus(Me/100g)	4.99581	23.0091	14.5215
Potassium (Me/100g)	0.200046	1.4391	0.4095
Organic carbon (%)	0.370811	3.34614	1.369
Cation Exchange Capacity (Me/100g)	10.15	18.62	13.255
Magnesium (Me/100g)	1.15	3.08	1.503
Calcium (Me/100g)	5.86	12.75	8.378
pH	6.50005	6.79996	6.625

Thematic maps in Fig. 4 were created for each soil property based on the statistics shown in Table II and in accordance with the range values in Table III.

TABLE II
CLASSIFICATION OF SOIL PROPERTIES [12]

Properties	Low	Medium	High		
Organic Carbon (%)	< 1.5	1.5-2.5	>2.5		
Nitrogen (%)	<0.1	0.1-0.2	>0.2		
Phosphorus (Me/100g)	<10	10-20	>20		
Potassium (Me/100g)	<0.15	0.15-0.30	>0.30		
CEC (Me/100g)	<15	15-25	>25		
	Very Low	Low	Medium	High	Very High
Calcium (Me/100g)	0-2	2-5	5-10	10-20	>20
Magnesium (Me/100g)	0-0.2	0.2-0.5	0.5-1.0	1.0-2.0	>2.0

Nitrogen is the most critical element obtained by plants from the soil and is a bottleneck in plant growth. The study area is dominated with high values greater than 0.2%. Lack of phosphorus in crops may prevent other nutrients from being acquired because it has a stimulating effect on root growth since it is usually concentrated in the root tips of most plants. It is dominated with values ranging between 10-20Me/100g. Potassium is essential for the general vigor of the plants, encourages the development of a strong root system and increases resistance to certain diseases. It ranges between low and high values. Organic carbon falls within the range of very low values, followed by medium and low concentration of high values. CEC, a basic single index of potential fertility, is the capacity of the soil to hold and exchange cations. It affects the soil capacity to supply nutrients cations for plant growth. It ranges between low and medium values. Magnesium, an important constituents of chlorophyll and therefore essential for photosynthesis is dominated by high values ranging between 1.0-2.0Me/100g. The presence of adequate amounts of calcium in the soil is very important in order to obtain satisfactory crop yield. This has low values within the high range of 10-20Me/100g. Nutrient availability in the soil is strongly dependent on pH. Values ranges between 6.5-6.8. Soil texture in the area consists of sandy, loamy sand and sandy loam, with high concentration of sand, followed by

loamy sand and sandy loam. Steep slopes allow rapid runoff, erosion of top soil profiles and mineral deposition in lower profiles.

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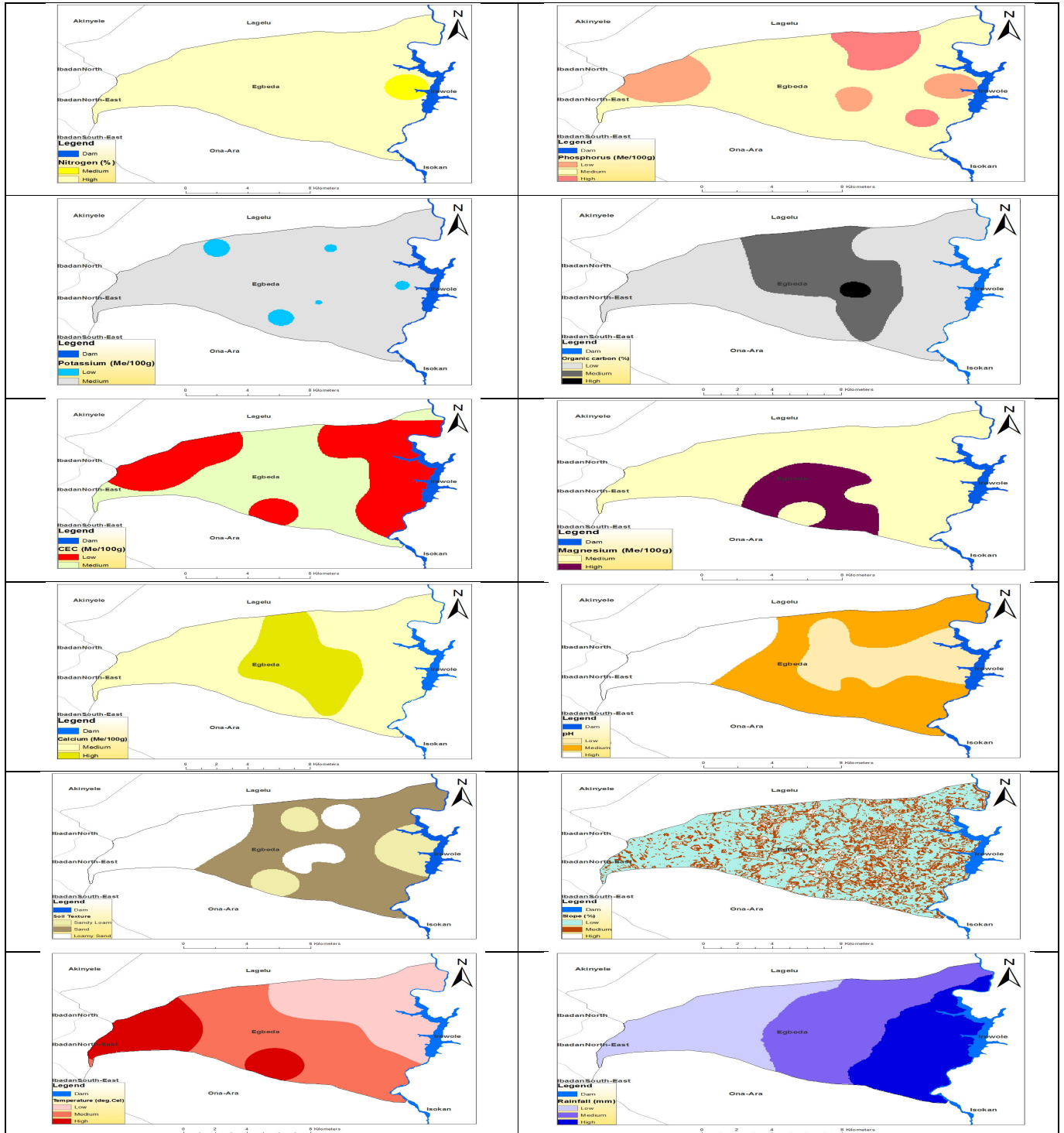


Fig. 4 Spatial Variation of Land Characteristics

C. Pairwise Comparison Matrix (PWCM)

The pairwise comparison matrix (PWCM) was carried out for rating and weighing of the different criteria. The fundamental scales given by Satty for comparing the two criteria was used. The quantitative value from 1-9 scales was given by [10] considering the comparative importance of two criteria. Based on experts' opinion, the overall rating for the comparison was generated on Table IV, which derived the weights with an acceptable consistency ratio. This was used to generate a soil suitability map which was then used in combination with other land attributes to generate the suitable map for maize production.

TABLE III
 PAIRWISE COMPARISON FOR THE CRITERIA

	N	P	K	Oc	CEC	Mg	Ca	pH	ST	Weights
N	1									0.1590
P	1	1								0.1590
K	1	1	1							0.1590
Oc	1/3	1/3	1/3	1						0.1061
CEC	1/3	1/3	1/3	1/3	1					0.0825
Mg	1/3	1/3	1/3	1/3	1/3	1				0.0642
Ca	1/3	1/3	1/3	1/3	1/3	1/3	1			0.0500
pH	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1		0.0389
ST	2	2	2	2	2	2	2	2	1	0.1815

TABLE IV
 WEIGHTS FOR LAND CHARACTERISTICS

Criteria	Weights
Temperature	0.3076
Rainfall	0.4789
Slope	0.1160
Soil	0.1019

D. Suitability Evaluation for Maize

Based on the weights generated in Table V, the suitability map for maize production was generated. Suitability evaluation for the study area revealed that 26.8% was highly suitable, 64.8% of the area was moderately suitable and 8.4% was marginally suitable for maize production.

V. CONCLUSION AND RECOMMENDATION

Current information on nutrient status of soils is needed to develop appropriate integrated nutrient management packages for sustainable maize production within the area. This research integrated the MCE and GIS techniques to predict the suitable areas for maize production in Egbeda LGAs of Oyo State. It also provides a good database and information for planners considering crop substitution to get better agricultural production. Most of the nutrients in the soils falls within the low and medium values, therefore fertilizer should be applied to increase its fertility rating. Good soil conservation practices are suggested to conserve soil nutrients in the highly suitable areas, and soil management recommendation includes use of organic fertilizer, mulching and leguminous cover crops to enhance soil quality. It is urgently recommended to disseminate the result of the present research to farmers in the LGA to make them understand the capacity and limitation in

range of suitability of their farmlands. Land parcel use potential, limitations and management measure should clearly be conveyed to land users so that the real use of the research will be seen.

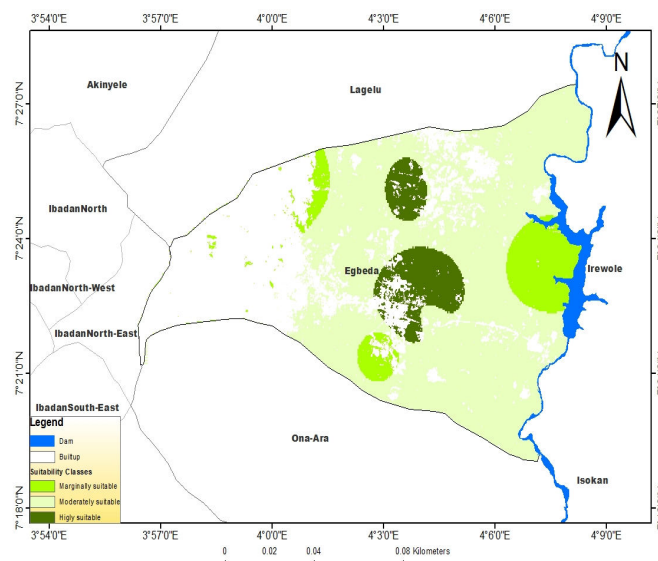


Fig. 5 Land Suitability Map for Maize Production

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