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An Application of GIS-Based Multi-Criteria Decision Making Approach for Land Evaluation and Suitability Mapping for Rice Cultivation in Oye-Ekiti, Nigeria

Otokiti Kolade Victor[1] & Adesina Olufemi Samson[2]

Abstract

This study adopted a GIS-based multi-criteria decision approach in mapping the inherent qualities and potentials of land peculiar to rice cultivation in Oye-Ekiti. FAO framework was used as a guide in selecting variables for the land evaluation. An Analytical Hierarchical Process was used to assign weights to the selected factors with respect to their relative importance, while pairwise comparison was used to rank the factors. The priority generated was used to assign weights in ArcGIS 10.5 weighted overlay toolset in spatial analyst tool. The resulting weights are based on the principal eigenvector of the decision matrix. From the priority value derived from the pairwise comparison result, the criteria were reclassified according to their suitability level and weighted overlay toolset was used to merge the criteria from which the results were obtained. The study area was classified into three categories based on rice cultivation suitability, namely: Highly suitable-S1, moderately suitable-S2, marginally suitable- S3. The result indicates that that 18% (79.925 sq.km) of the total land area is highly suitable for cultivating rice, 70% (326.019 sq.km) is moderately suitable while 12% (57.725 sq.km) is marginally suitable. The study is a GIS-based multi-criteria decision-making approach in selecting the best rice cultivation site.

Keywords: Land suitability analysis, Geographic Information Systems, Analytical hierarchy process, Multi-criteria decision making, Rice, Oye-Ekiti

1. Introduction

The economic benefits attached to rice are significant in many nations. It is a dependable source of revenue in the United States and Southern Europe, it is also the most widely consumed staple food for a large part of the world's human population, especially in Asia where it upholds the economies of China, Indonesia, Thailand and Vietnam [1].

In 2018, Nigeria recorded an increase in rice consumption at 6,900,000 metric tonnes, which was an increase of 200,000 metric tonnes over the previous year [2]. However, efforts from public and private investors in rice production in Nigeria have yielded positive results as production received a boost [3]. Nonetheless, the country's production capacity is still low to sustain her consumption needs as the Nigeria population is projected to surpass 300million by 2050 [4].

The Federal Government of Nigeria has been effective in discouraging importation of rice by imposing various measures, from high tariffs to restrictions on the use of foreign exchange to limitations on transport across land borders. These have drastically reduced the quantity of rice imported into Nigeria. However, importation growth is still much anticipated as consumption increases in the year 2019 [2]. A major contributing factor to the forecasted importation growth in 2019 is due to flooding, as rice-producing states like Edo, Jigawa, Kebbi, Anambra, and Kogi were severely affected by flood in 2018 [5]. Like the Federal Government, the State Governments are part of the efforts to promote the concept of food security and greater self-sufficiency in rice production. This was evident in the activities of many state governments with the aim of boosting local production of rice in Nigeria.

[1] Department of Urban and Regional Planning, Federal University of Technology, Akure, Nigeria. otokitikolade@gmail.com
[2] Department of Food Security, University of Warwick, Coventry, United Kingdom. femi.wumi007@gmail.com

One of those measures was the partnership deal that was signed between Ekiti and Kebbi states with Lagos state to further boost rice production and revenue drive. Urban planning has been described as a means to protect and redistribute public goods (e.g., land) and their benefits equitably and efficiently [6]. GIS in a planning environment can be used to identify the inherent qualities of land, information, characteristics, and resources peculiar to the crop understudied. Therefore, land could be significantly put into sustainable use, these can be easily determined with respect to land use planning. The GIS evaluation process uses criteria such as rainfall, soil, drainage pattern, topography, etc. in identifying land potentials and understanding the local environment [7]. A single criterion is not adequate to determine the permissibility of land for the cultivation of crops.

Therefore, a GIS-based multi-criteria analysis was used to assess land suitability for rice cultivation; so as to ensure that rice cultivation corresponds with environmental sustainability with the aim of achieving maximum economic outputs [8]. The analytic hierarchy process (AHP) is one of the most frequently used methods in solving multi-criteria decision-making (MCDM) issues [9].

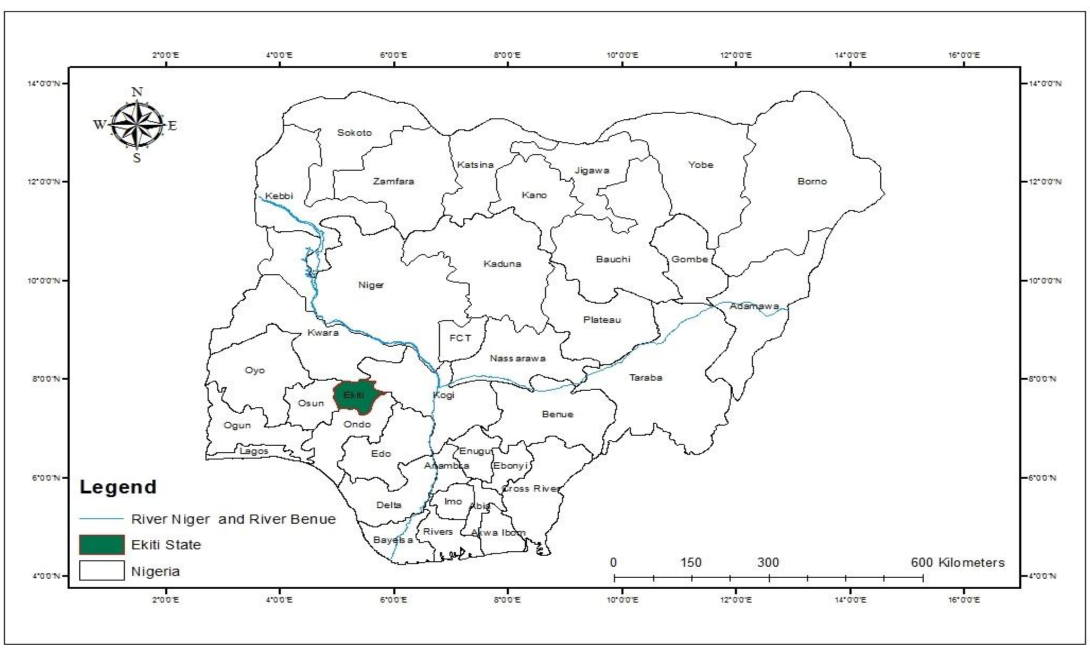
The aim of this paper is to harness GIS-based MCDM land suitability analysis and the Food and Agricultural Organization (FAO) framework as a guide to determine fit and unfit land for cultivating rice in the study area. The results obtained from this process would help in formulating potent and far-reaching policies to promote sustainable development of agriculture in the study area and serve as a means of readily identifying opportunities for farmers and investors to access and put the land into suitable use.

2. Materials and Methods

2.1 Research Locale

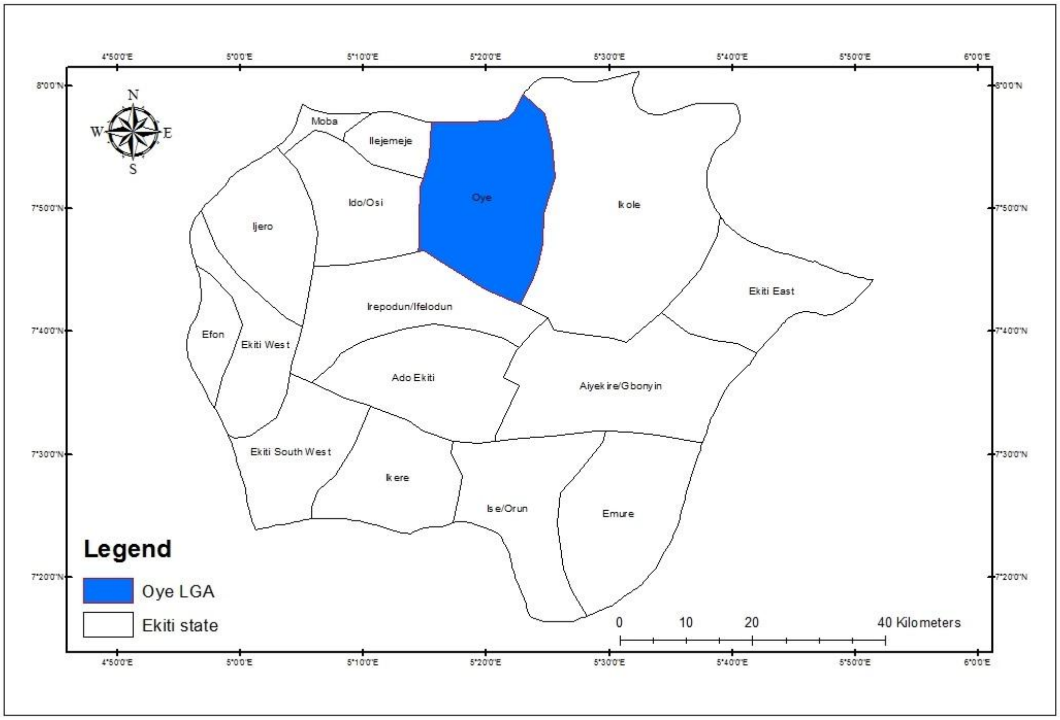
The study area is the Oye Local Government Area in Ekiti State, Nigeria. The study area is located in the north-eastern part of the state where it shares boundaries with Kwara State in the North; Ikole LGA in the East; Illejemeje LGA in the West; and Ifelodun/Irepodun LGA in the South. The population Oye Local Government Area was 168,251 [10]. It is located on altitude 457.2 m, Latitude 7.7979^{o} N and Longitude 5.3286^{o} E. The study area covers an area of 463.669sq.km with hills and granite outcrops rising above 60.96 m. Figure 1and 2 shows the study area in its national and regional settings. The study area like other areas in Ekiti attached much importance to farming due to its location amidst the dense evergreen forest. Agriculture provides income and employment for more than 75% of the population [11]. It is surrounded by hills and covered by thick forest with very small patches of high forest [12]. Igbemo rice is one of the major agricultural products in the state [13].

Figure 1: Oye LGA in its National Settings



Source: Ministry of Surveys, Abuja (Digitized in ArcMap, 2018 by Authors)

Figure 2: Oye LGA in its National and Regional Settings



Source: Ministry of Surveys, Abuja (Digitized in ArcMap, 2018 by Authors)

2.2. Material

2.2.1 Topographic Factor

The topography factors adopted for this study were slope and drainage pattern. Slope as a topographic element for cropland suitability mapping is a major variable when used with other variables, a slope is vital in site analysis and predicting suitability [14]. In this study, the 30m spatial resolution DEM data of SRTM was acquired from USGS [15]. Then, the Slope function of the Spatial Analyst Toolbox of ArcGIS 10.5 was used to generate the slope layer. The cell output was used to calculate the percentage of slopes. Every cell in the output raster has a slope value.

Flatter terrain corresponds with lower slope value, while steeper terrain corresponds with higher slope value. Flat fields having smooth surface are better for rice cultivation as it facilitates even and equal distribution of water [16].

Just like the slope, The DEM data of SRTM was also used to generate the drainage pattern using ArcGIS 10.5 hydrology toolset in spatial analyst tool, it was digitized to get the line feature. Then the drainage density was gotten from the use of a line density tool in ArcGIS 10.5.

2.2.2 Soil Factor

Soil properties vary from place to place. Hence, the knowledge of soil chemical and physical characteristics is a vital criterion for cropland suitability analysis and mapping [16]. Soil allows for the growth of any agricultural crops including rice.

The soil textures and soil pH were the selected parameters in this study. The United State Department of Agriculture (USDA) classified soil texture into twelve categories; namely sand, loamy sand, sandy loam, silt loam, loam, sandy clay loam, silty clay loam, clay loam, clay, sandy clay, silty clay, and silt. Clay, silty clay, silty clay loam, textures of the soil allows rice crop to flourish [17].

Soil information was obtained from the digital soil data produced by the Harmonized World Soil Database [18]. It provides vector polygon layers of soil physical and chemical properties. The thematic layer for each of the parameters has been extracted from this polygon attribute table and rasterized based on their value fields in the ArcGIS 10.5 platform. The pH of the soil is defined as “the negative logarithm of the hydrogen-ion concentration of the soil solution”. Rice grows optimally in slightly acid soils having a pH value of 6 to 7 [17].

2.2.3 Climate Factor

Climate has a significant influence growth of crops, developments and yields of agricultural crops including rice, favorably or unfavorably [16]. Temperature and rainfall are the two most important climatic elements considered in this study. Rice is a tropical and sub-tropical crop which is normally grown at a fairly high temperature – high rainfall regime, ranging from20 to 40°C and 1250mm to 2000mm of annual rainfall [17]. Temperature and Rainfall of the area are favorable. Hence, they were not included in the criteria.

2.2.4 Land Use/Cover

Land use/cover map was used in this study to distinguish different feature on the land surface that is recorded by the Landsat 8 sensor. The land use/cover thematic map was generated by stacking band 5, 4, 3. Composite banding toolset in the data management tool of ArcGIS 10.5 software was used to show false color composite, it was classified using a supervised classification method.

2.3 Method Used

Spatial multi-criteria decision-making approach is a process where geospatial data are combined and transformed into a decision. It involves input data, the decision maker's preference and manipulation of both information using specified decision rules [17]. In this study, the following environmental data were combined using a multi-criteria decision approach to select suitable sites for rice plantation: topography, land use/cover, physical and chemical properties of soil, and geology.

Using the analytical hierarchy process (AHP) as a supporting tool for decision making will help to gain a better insight in complex decision problems. Structuring the problem as a hierarchy, makes researchers consider possible decision criteria and select the most significant criteria with respect to the decision objective. Using pairwise comparisons helps to discover and correct logical inconsistencies. The method also allows to "translate" subjective opinions, such as preferences or feelings, into measurable numeric relations. AHP helps to make rational, transparent and understandable decisions [19].

The suitability levels for each factor were ranked as highly suitable-S1, moderately suitable-S2, marginally suitable- S3, based on the structure of land [20] suitability classification. Parameters were assigned to variable weights depending on the relative importance of a parameter. Using pairwise comparison to rank the criteria, the priority generated will be used to assign a weight in ArcGIS 10.5 weighted overlay toolset in spatial analyst tool. The resulting weights are based on the principal eigenvector of the decision matrix. Table 1 shows the resulting weights for the criteria based on the Authors' pairwise comparisons.

Table 1: Weight Values

	Landcover	Texture	Drainage density	Slope	Priority
Landcover	1	2	3	4	34.5%
Texture	0.5	1	2	1	24.8%
Drainage Density	1	0.5	1	1	20.9%
Slope	0.5	1	1	1	19.8%

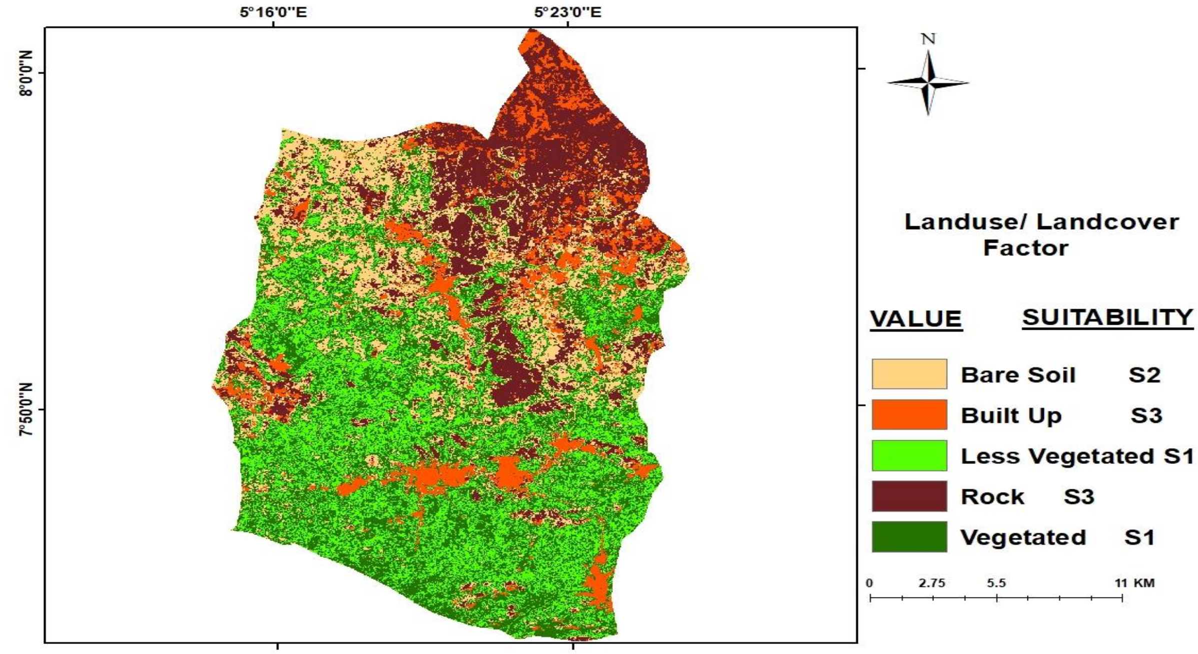
3.0. Result and Discussion

3.1. Thematic Layer Generated and Their Description

3.1.1 Landuse/ Landcover

According to Natural Resource Canada [21], although the terms land cover and use are often used interchangeably, their actual meaning is quite distinct. Land cover refers to the surface on the ground, while land use refers to the purpose which the land serves. The land use/cover a map of the area was derived from layer stack of band 5, 4, and 3 in ArcGIS 10.5 composite banding toolset in Data Management tool, which was reclassified using maximum Likelihood Classification Method in the same software. The result of the landcover/landuse analysis is presented in Figure 3.

Figure 3: Landuse/Landcover Map of the Study Area



3.1.2 Soil pH

Soil pH is a measurement of the acidity or alkalinity of a soil. On the pH scale, 7.0 is neutral. Below 7.0 is acidic, and above 7.0 is basic or alkaline. A pH range of 6.8 to 7.2 is termed ***near neutral*** [22]. The soil pH map of the study area is presented in Figure 4. The study area soil pH was derived from the Harmonised World Soil Database and was rasterized for use. The pH value permissible for rice cultivation is 5.4 to 6.3 [17]. However, the Soil pH value of the whole area falls within the range of 6 and 6.3. Thus, the study area is suitable for rice cultivation. It was then considered constant and not used in the AHP criteria.

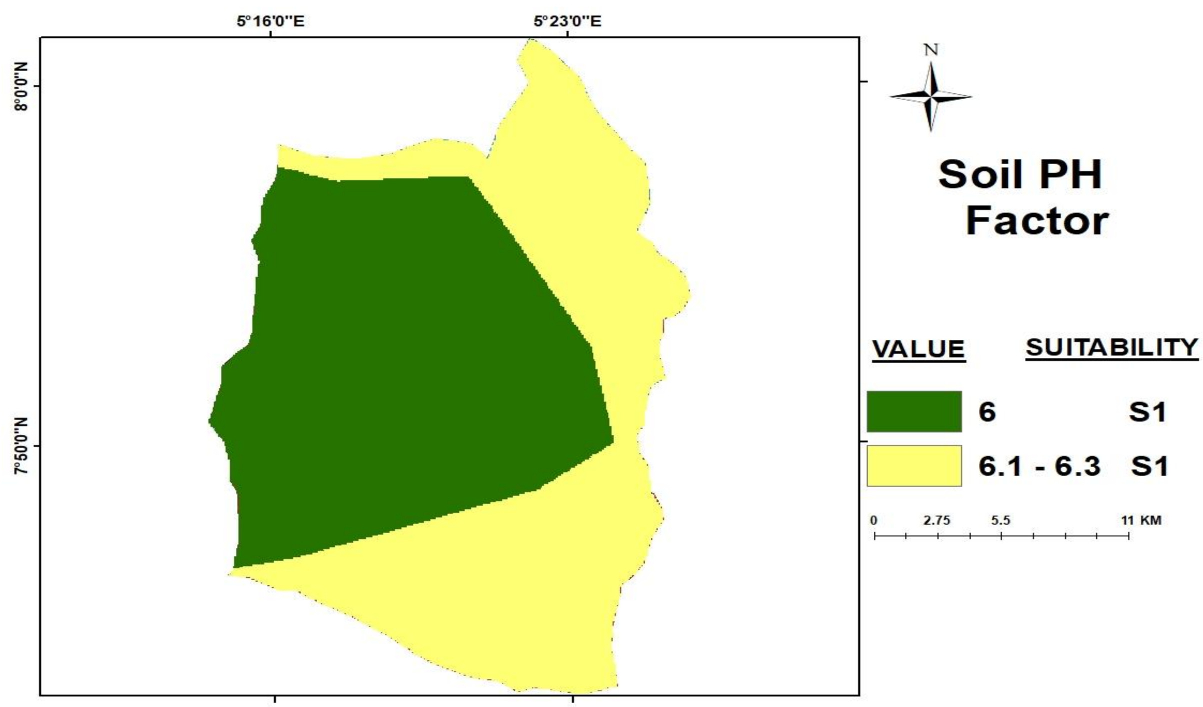


Figure 4: Soil pH Map of the Study Area

3.1.3 Soil Texture

Figure 5 shows the result of the study area soil texture. Soil Texture is the level of coarseness of the soil, and rice being a Tropical crop, requires a soil texture that can retain water for a longer period, according to the classification of soil suitability for rice by Al-Mashreki, [23]. The Study area has 2 soil classification which is clay (heavy) and clay loam. These soil textures are better for rice cultivation.

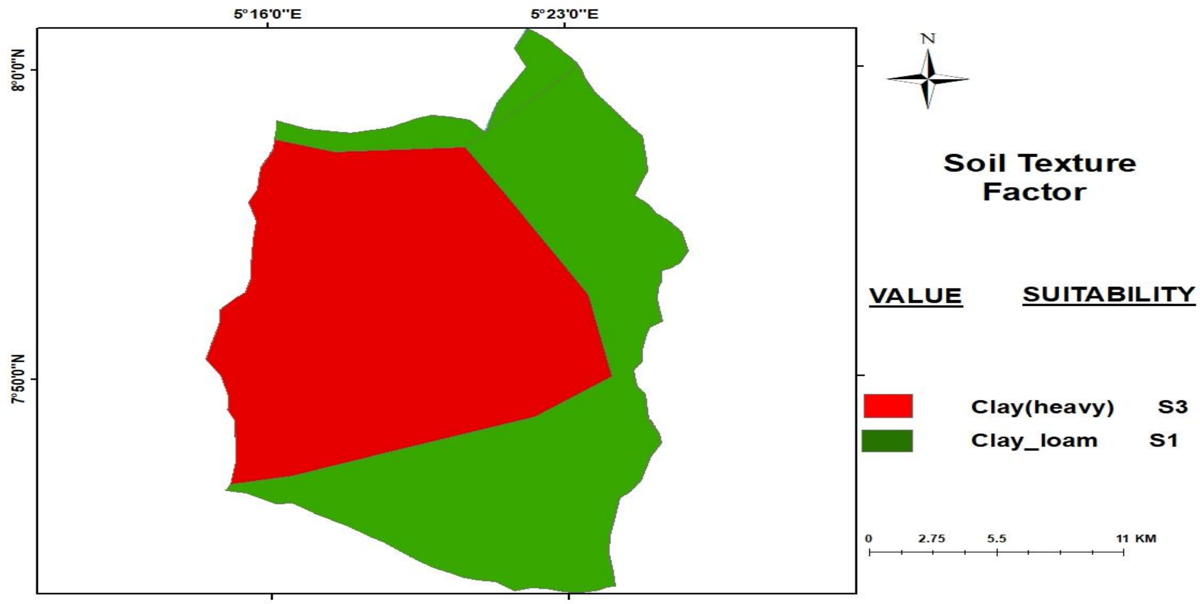


Figure 5: Soil Texture Map of the Study Area

3.1.4 Slope

The **s**lope or gradient of a line is a number that describes both the direction and the steepness of the line. The slope of the area was generated using the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model, it was reclassified, and the result was shown in Figure 6. Rice cultivation is best planted where the land is flat because it ensures even water distribution [24].

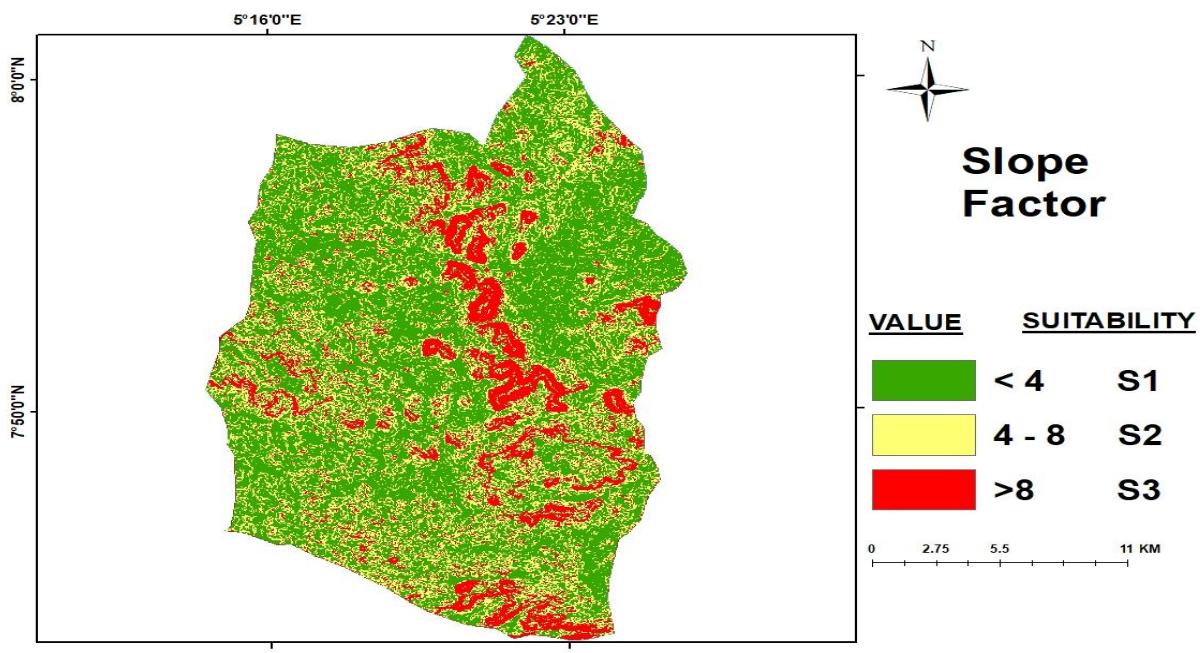


Figure 6: Slope Map of the Study Area

3.1.5 Drainage Density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. The Drainage density map of the area was constructed from the digitized stream map of the study area from the SRTM elevation map and was shown in Figure 7.

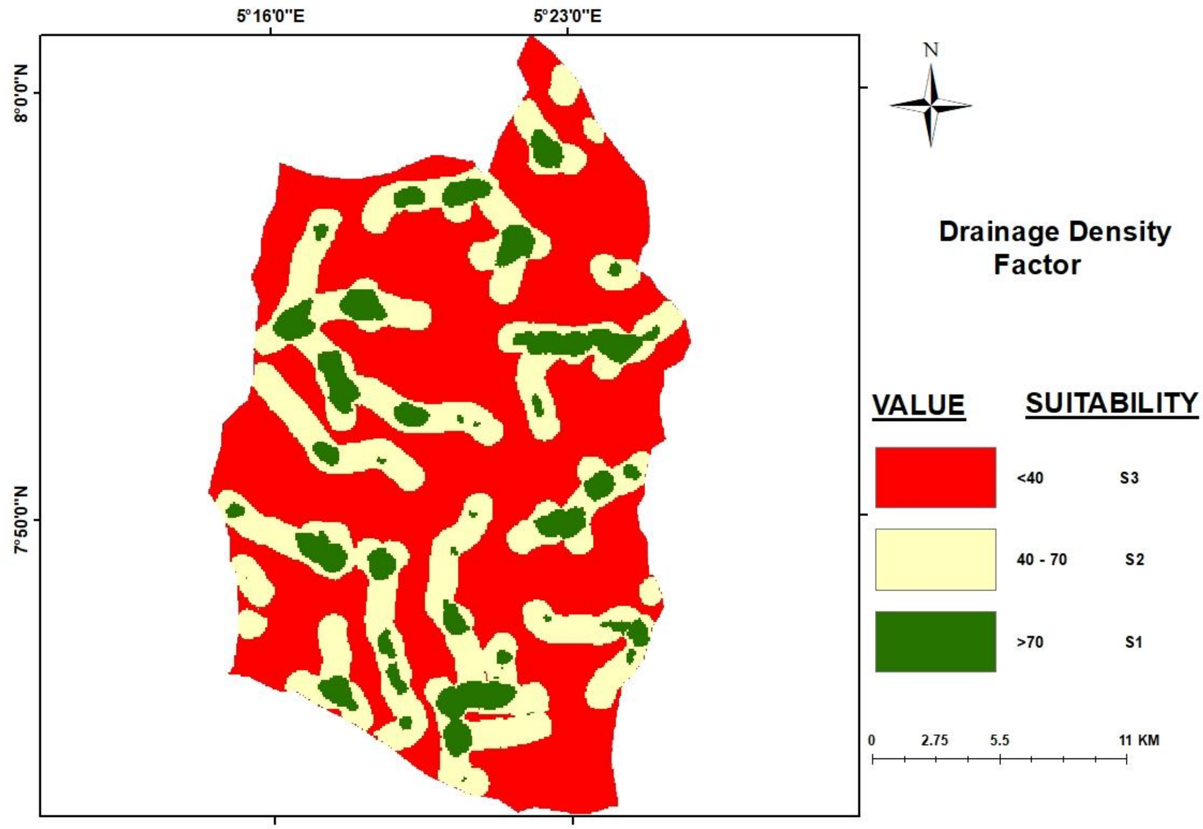


Figure 7: Drainage Density Map of the Study Area

3.2 Land Suitability Result

From the priority value derived from pairwise comparison result, the criteria were reclassified according to their suitability level and weighted overlay toolset was used to merge the criteria and the result was gotten. The Area of each factor was calculated and shown in Table 2. It shows that 18% of the total land area is highly suitable for cultivating rice, 70% is moderately suitable while 12% is marginally suitable. Since 88% of land in the study area is either suitable or moderately suitable. This implies that rice cultivation potential is high in the study area.

Figure 8 shows the result of land suitability for rice cultivation in the study area. The figure shows that the most suitable land is found dominantly in the southern part of the study area. The suitability index ranges from highly suitable to moderately suitable and marginally suitable as shown in green, yellow and red colors respectively. The output is useful at developing land use plans and promoting sustainable agriculture.

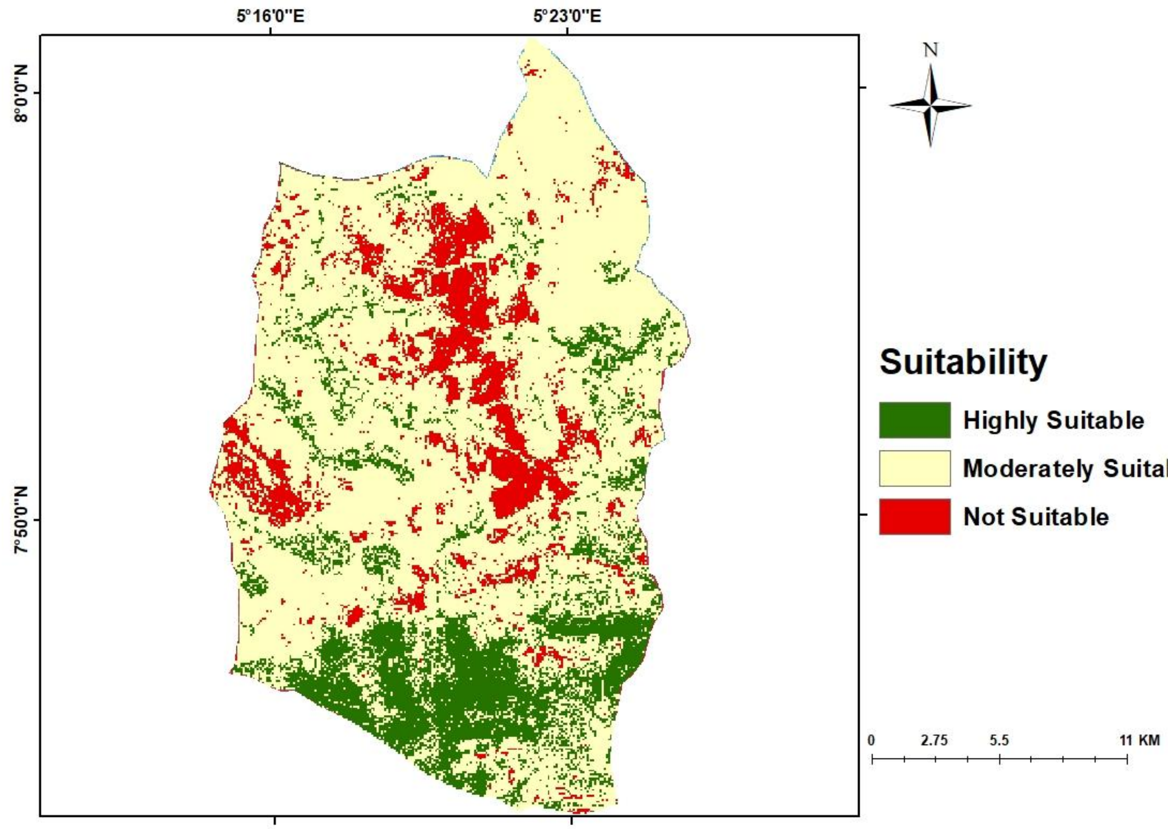


Figure 7: Land Suitability Map of the Study Area

Table 2: Land percentage suitable for Rice cultivation

Suitability	Area (sq. km)	Percentage
Highly Suitable	79.925	18%
Moderately Suitable	326.019	70%
Marginally Suitable	57.725	12%

4.0 Conclusion

GIS-based multi-criteria decision making analysis was used to generate land suitability map for rice cultivation in Oye Local Government Area. Land suitability map would help in developing land use plans and formulating environmental planning policies that are capable of enhancing the sustainable development of agriculture and help in improving the existing rice production in the state while combating the lingering issue of food insecurity in Nigeria.

The result revealed that the largest percentage of land area (70%) in the study area is moderately suitable for rice cultivation. This implies that with techniques such as the installation of irrigation systems in areas that lack water to facilitate water supply all year round, coupled with sustainable application of fertilizers etc. can guarantee optimum rice output in those areas. Highly suitable area (18%), where rice cultivation has the best potential should be given high preference by both public and private investors.

The Nigerian government and concerned investors should incorporate GIS-based multi-criteria decision making analysis in selecting (but not limited to) the best rice cultivation site. Thereby, helping to generate maximum returns from agricultural land and sustainable production. With this, Nigeria is on its course to transform from a rice importing nation to a rice exporting nation thereby reducing the challenge of food insecurity in the Nation.

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