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Original scientific paper

LAND SUITABILITY FOR RICE CROP FARMING IN KWARA STATE USING GIS-BASED MULTI-CRITERIA DECISION ANALYSIS

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ABSTRACT
This study employs GIS-based multi-criteria decision approach to identify suitable areas for cultivating rice crop in Kwara State, Nigeria, using essential climatic, soil, terrain and environmental variables selected based on FAO framework for land evaluation. Weights indicating the relative importance of each variable was determined using Analytical Hierarchical Process (AHP). The criteria, their weights and constraints were integrated in GIS environment to produce suitability map, classified into five levels of suitability (Very highly suitable, highly suitable, moderately suitable, low suitable and not suitable) using weighted overlay operation. The result indicates that 9.7% (343803.75 ha) of the total land area is unsuitable for cultivating rice while 14.6% (516169.46 ha) is classified as low suitable area. The moderately suitable, highly suitable and very highly suitable classes occupy 30.8% (1091145.20 ha), 40.56% (1436504.55 ha) and 4.4% (154408.94 ha), respectively. Quantitative assessment of the work yields overall accuracy (area under the ROC curve) of 0.97 (97%). Based on the findings of this study, we recommend that the state land use planning agency review zoning mechanism, incorporates grassroots participatory land use planning policy and evaluate suitable land for other essential crops by incorporating GIS in order to sufficiently allocate lands for optimal utilization.

Key words: Remote sensing, food security, agriculture, AHP, Nigeria, land use planning.

INTRODUCTION
All crops require water, suitable topography and geomorphology, fertile soil, and favorable climate. As many of the underlying processes influence the suitability of crop cultivation, spatially heterogeneous soil chemistry and land features can be easily identified using remote sensing and GIS technologies (Hao et al., 2019). The problem of selecting appropriate land for cultivation of a particular crop has long been an empirical issue with many researchers and institutions developing framework for optimal agriculture land use. This notwithstanding, many agricultural land uses are currently below optimal capacity in most part of the world. The classification of land into different suitability classes is dependent on particular set of soil characteristics, climatic condition, topographic and other attributes of land specific to a crop type or a family of crops (Kihoro et al., 2013; Sinha et al., 2014). This has made precision in land utilization planning a necessity.

As the world population continue to grow geometrically, with many living in urban areas, agricultural productivity and food security are issues of discuss across the globe. The impact of unsustainable use of land resources and absence of utilization of land according to potential suitability portends serious danger to food production and supply in developing countries, particularly rice crop.

Rice (*Oryza sativa*) is a staple food for nearly half of the world's population, and also a key source of employment and income for rural populace (Khattak & Shabbir, 2012; Oriola & Olabode, 2014). It is rapidly becoming a major food crop in most of sub-Saharan Africa. Rice can be grown as a dry land crop, but it is by origin and by preference of most farmers a wetland crop. Demand for rice is driven by population growth; however, it is produced in much smaller quantities far below local demand.

Nigeria is the most populous black nation in the world whose citizens largely depend on agriculture at the household level (Merem et al., 2017). Nonetheless, more than 90% of the rice consumed is imported. The demand for rice in recent time has motivated massive investment in its cultivation to keep pace with the rising local and international market needs. However, potentially rich (sub humid and sub arid) rainfed farm land is experiencing high rate of nutrient depletion caused by climate change (Kumar & Patel, 2020; Oriola & Olabode, 2014). Other factors limiting rice production and yield is lack of sufficient information on soil characteristics as well as poor agricultural practices (Ceballos-Silva & López-Blanco, 2003).

Kwara State, located in the Nigeria North-Central zone, is one of the hubs of rice production in the country. In recent years, the state has consistently record low rice production, resulting to increase in rice importations to meet local consumption (Babatunde et al., 2019; Falola et al., 2014). The State has abundant unexploited land resources that can be utilized to increase rice production. However, no land evaluation studies have been done to determine how well the qualities of land units in the region match rice crop growing and yield requirements. One of the efforts of the state to reposition agriculture is the development of Agricultural Master Plan for efficient management and optimum utilization of land resources (http://www.kwarappp.gov.ng/kamp.html). Utilization of agriculture land in past decades regardless of land suitability has impacted negatively on food production capacity (Abah & Petja, 2016; Merem et al., 2017). This study utilizes multi-criteria decision evaluation (MDE) technique to map suitable land for rice cultivation in Kwara State using topographical, soil and climatic factors.

MATERIALS AND METHODS

Study Area and Dataset

Kwara, located in the North-central zone, is one of the States in Nigeria. Geographically, the State lies between longitude 08^o 30'N to 10^o 08'N and latitude of 05^o 00'E to 06^o 12'E covering approximate area of 36,835 Km^2 and altitude that range between 13 m and 657 m above msl. Kwara state is bordered in the North by Niger state, in the East by Kogi and Ekiti States, Osun and Oyo states in the South while in the West by Republic of Benin (Figure 1). The population of Kwara state is reported to be about 2,365,353, based on the 2006 census (NPC, 2006). The state is situated in the transitional zone within the forest and the guinea savannah regions of Nigeria. The vegetation is typically of tropical savannah species with riparian forest along the river bank. In terms of climate, the state is classified as tropical savannah under the influence of the two trade winds prevailing over the country. The state experiences two seasons, rainy season and dry season. The rainy season occurs between March and November with annual rainfall that varies between 800 mm to 1200 mm, with the peak between August and September while dry season is experienced from November and March. Also, the mean monthly temperature is generally high throughout the year with daily average temperatures vary from 22.5 ºC and 27.5 ºC (Babatunde et al., 2019; Falola et al., 2014; Sadiq et al., 2017).

In this study, the process of assessing site suitability for rice cultivation in Kwara state involves a number of datasets categorized under four subgroups: topographical factors, soil characteristics, climate and environmental factors. The topographical factors which include altitude, slope and slope aspect were derived from 30 m resolution SRTM digital elevation model (DEM) downloaded from the United States Geological Survey (USGS) data archive (http://srtm.csi.cgiar.org/). Soil data was also utilized in this study. Soil characteristics, texture, soil drainage, depth, nitrogen, potassium, and phosphorus were obtained from the Harmonized World Soil Database (http://www.isricl.com) while 250 m grid carbon and soil PH data were downloaded from SOILGRID data depository (https://soilgrids.org). Also, the climatic data, temperature and precipitation, were gotten from the World Climate data depository (http://www.worldclim.org) whereas the environmental factors, administrative boundary, road network and river, and land use and land cover were acquired from DIVA-GIS (http://www.diva-gis.org/) and Landsat-8 imagery downloaded from the USGS data depository (http://earthexplorer.usgs.gov).

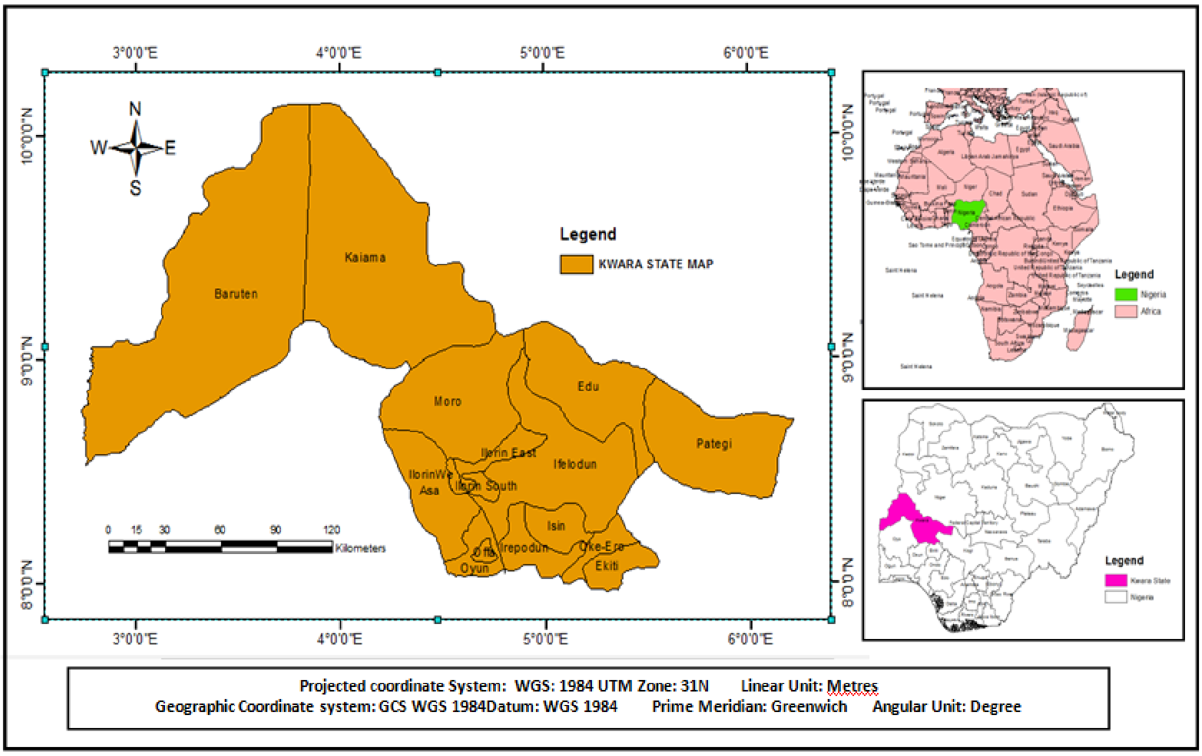
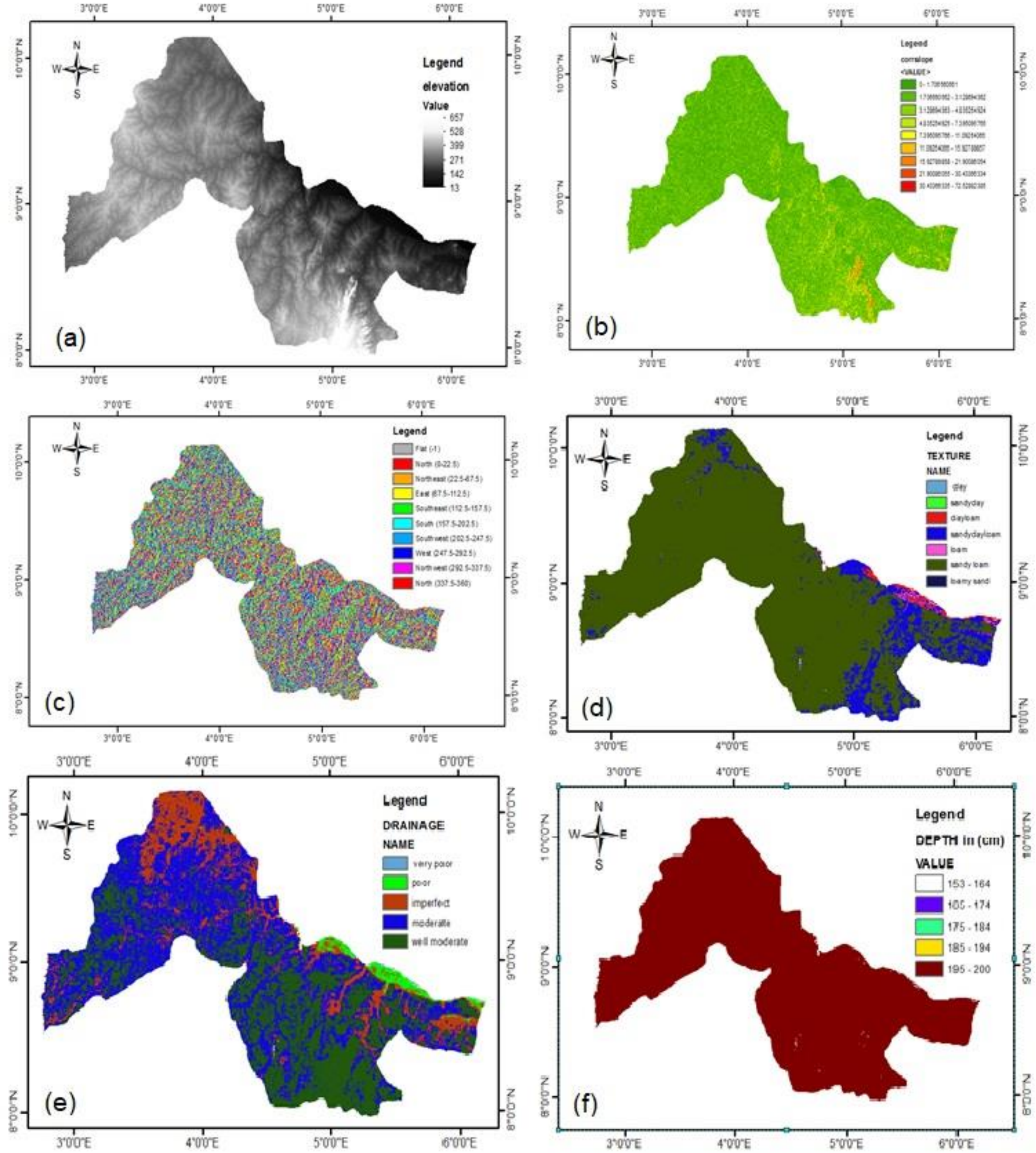
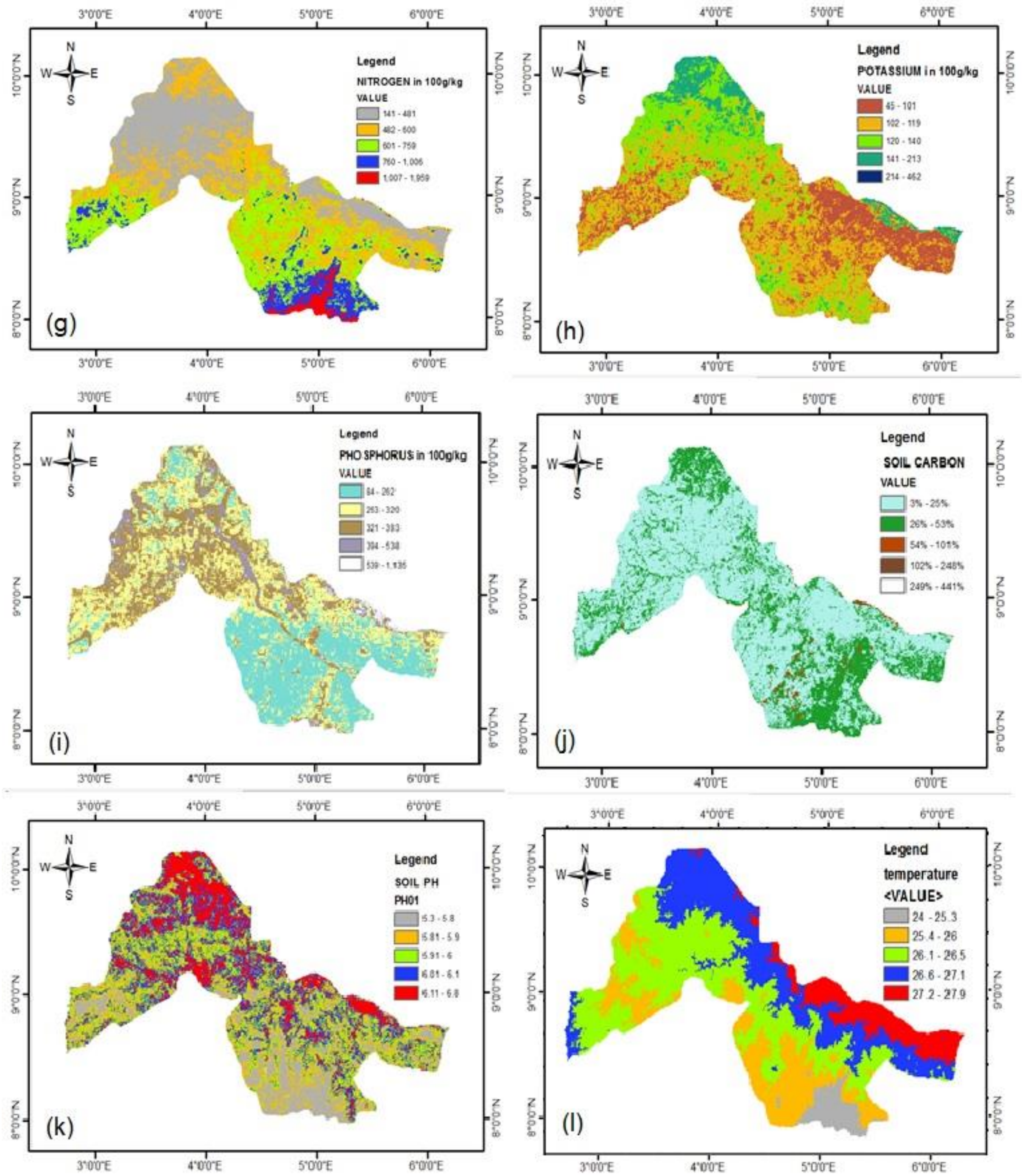


Figure 1. Location of the study area

Preparation of Data Layers

From the four data subgroups, 16 conditioning factors that influence rice cultivation were generated. The conditioning factors are chosen based on thorough examination of the variables reported in literatures (e.g. Abah & Petja, 2016; Ceballos-Silva & López-Blanco, 2003; Hao et al., 2019; Kihoro et al., 2013, 2013; Victor & Samson, 2019). Most of the data layers come in geographic coordinate system and in different spatial resolution. Therefore, the various dataset collected were preprocessed prior to generating input map layers. Upon clipping to the study area, all the data acquired were reprojected to the Universal Transverse Mercator (UTM), WGS84 coordinate system using nearest neighbor resampling method. From the 1 arc second (30 m resolution) SRTM global DEM, three topographical factors, altitude, slope and aspect, were derived. The resolution of the soil data is coarse (250 m). All the eight soil characteristics (texture, drainage, soil depth, nitrogen, potassium, phosphorus, carbon and soil P^H) were also resampled to 30 m resolution raster map layers. Similarly, 1 km resolution climatic factors, temperature and precipitation were reprojected and resampled to match the other dataset. The land use/cover map was generated from the Landsat-8 satellite imagery using the supervised classification method (Ceballos-Silva & López-Blanco, 2003; Jeevalakshmi et al., 2016) while the distance road and distance from river map layers were produced using the Euclidean distance tool in ArcGIS 10.4.




(g)
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NITROGEN in 100g/kg
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482 - 600
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45 - 101
102 - 119
120 - 140
141 - 213
214 - 462
(i)
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PHOSPHORUS in 100g/kg
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84 - 262
263 - 320
321 - 393
394 - 538
539 - 1,135
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SOIL CARBON
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3% - 25%
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SOIL PH
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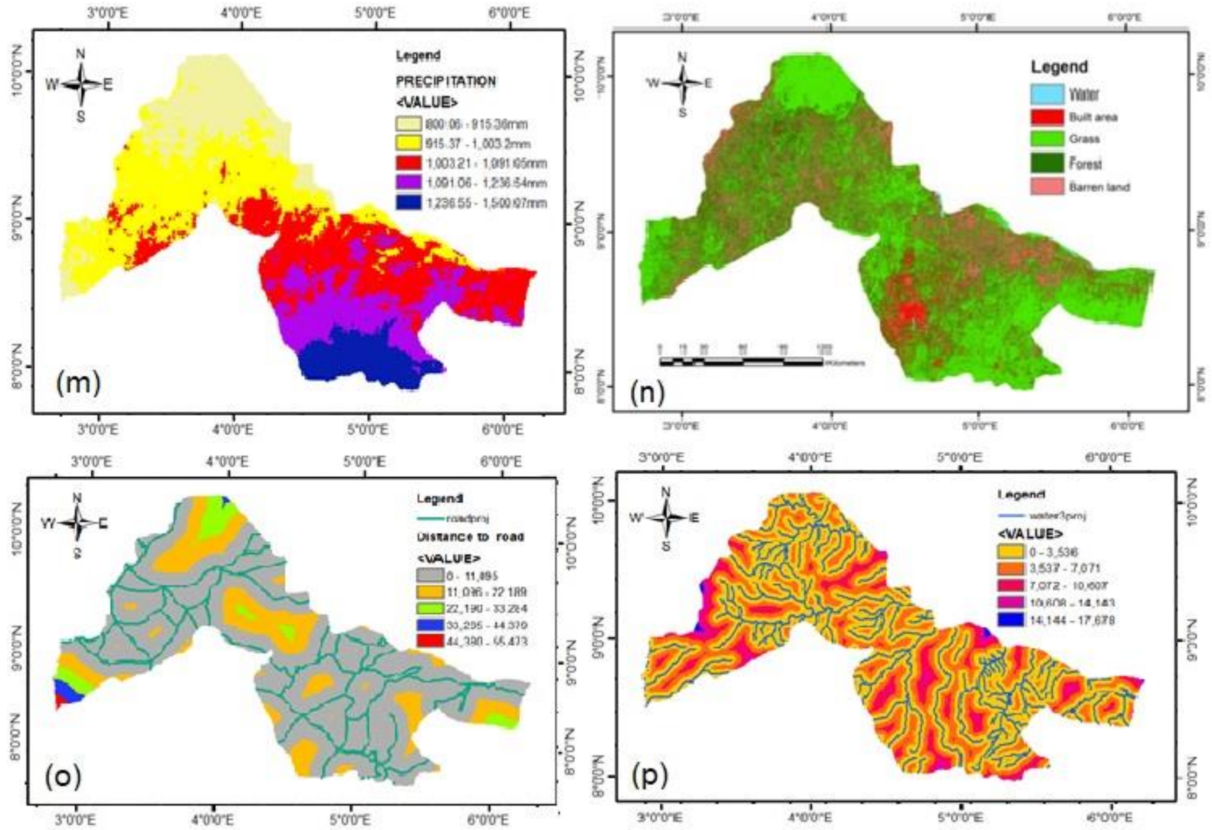

Figure 2. Topographical, soil, climatic and environmental variables influencing rice growth; (a) elevation, (b) slope, (c) slope aspect, (d) soil texture, (e) soil drainage, (f) soil depth, (g) soil nitrogen, (h) potassium (i) phosphorus, (j) soil carbon (k) soil PH, (l) temperature, (m) precipitation, (n) LULC, (o) distance from road, and (p) distance from river.

Topographical Factors. Elevation, Slope and Slope aspects (Figure 2a, 2b and 2c) are topographical factors that determine the position of points relative to reference datum, the rate of change of the vertical distance between two points and their distance (gradient) and direction the slope faces. Rice crop is generally said to thrive well in low altitude, slope less than 15^o and flat north facing slope (Kihoro et al., 2013). Flatter terrain corresponds with lower slope value, while steeper terrain corresponds with higher slope value. Flat fields having smooth surface are reported to be better for rice cultivation because it facilitates proportionate distribution of water (Kaaya et al., 2019; Victor & Samson, 2019). In addition, high slope and elevation increase the cost of operation and maintenance of machinery where mechanized farming is practiced.

Soil Factors. Soil physical (texture, drainage and depth) and Chemical (nitrogen, potassium, phosphorus, carbon and Ph) properties vary from place to place. Thus, the knowledge of soil chemical and physical characteristics is vital to crop growth and yield. Soil texture (Figure 2d) is described by the relative amount of sand, silt, and clay contents, which affect the workability, aeration, drainage, root penetrability and water-releasing capacity of soil (Ahmed et al., 2017). The United State Department of Agriculture (USDA) categorizes soil texture into twelve classes; 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 loam. Of these classes, clay and clay loam are the most suitable for rice growth (Ahmed et al., 2017). Soil drainage (Figure 2e) is also a characteristic of texture.

According to the United State Department of Agriculture (USDA), soil drainage could be well drained, moderately well drained, imperfect, poor, and very poor. For optimum growth and productivity, the very poor and poor drainage soil is better for rice farming to guarantee steady availability of water in the soil. Soil depth (Figure 2f) describes the thickness of topsoil above the subsoil such as consolidated rock or cemented materials like gravel restricting root soil penetration (Ahmed et al., 2017). Most annual crops have a rooting depth of about 50cm, unlike tree crops that can reach beyond 150cm. Studies have shown that effective soil depth of about 100cm is considered best for most annual crops because they produce good yields at this soil depth (Ahmed et al., 2017).

Rice absorbs large quantities of nitrogen, phosphorus and potassium (N.P.K) to enhance growth, yield and grain quality (see Figures 2g, 2h and 2i). Nitrogen is present in the soil, but often in insufficient quantities. Rice needs Nitrogen almost throughout the vegetative cycle, particularly at tillering and panicle initiation stages (Samanta et al., 2011). The higher the percentages of Nitrogen available in soil, the higher the yield of the rice. Deficiency in nitrogen content in soil manifest in the rice leave as uniform yellowish appearance. Phosphorus is an important soil chemical element that controls the physiological development of rice plant. It is vital to healthy root development, tillering, early flowering, pollination and ripening. Phosphorus in sufficient quantity accelerates rice development, reduces the period of maturity and accelerates plant recovery after stress resulting from rodent attack, cold, water shortage, etc. Potassium is a coordinating element regulates the biochemical activity of nitrogen and phosphorus in plant. It regulates photosynthetic activities and its transformation into carbohydrates (Daniel, 2011; Khattak & Shabbir, 2012).

Other parameters of importance to rice growth and yield are soil PH and organic carbon matter (Figure 2j and 2k), both of which affect soil fertility. Soil pH expresses the concentration of hydrogen ions ($H+$) measured in terms of the soil solution's (soil water and its dissolved substances) acidity and alkalinity usually determined on a scale from 0 to 14. Acidic solutions have a pH less than 7, while basic or alkaline solutions have a pH greater than 7 (McCauley et al., 2009). Rice grows optimally in slightly acid soils of Ph value between 6 to 7 (Samanta et al., 2011). Soil organic matter is the combination of plant and animal residues at various stages of decomposition and cells and tissues of soil organisms. Soil organic matter controls soil nutrient and organic carbon management. Soil carbon determines nutrient availability and the capacity of the soil to improve plant development and also to deliver ecosystem services such as reduction in greenhouse gas emissions and pollutant (Daniel, 2011; Kaaya et al., 2019; McCauley et al., 2009). Specifically, soil carbon improves rice yield and crop adaptation to environmental changes.

Climatic Factor. Precipitation and temperature (Figure 2l and 2m) are the two most important climatic elements considered in this study. Rice is a tropical and sub-tropical crop normally grown at a fairly high temperature and high rainfall regime between 20ºC to 40°C and 1250 mm to 2000 mm of annual rainfall. Both climatic factors are favorable for rice cultivation in most parts of the study area (Khattak & Shabbir, 2012; Kihoro et al., 2013).

Environmental factors. Human settlement and activities are largely controlled by natural phenomena such as the physical landscape, water availability, vegetation/forest distribution, and fertile soil for crop production (Ceballos-Silva & López-Blanco, 2003; Maddahi et al., 2017). Here, the land use map of the study area was classified into five classes: water body, forest, grassland, bare earth and built-up area (Figure 2n). The land use map allows assessment of the distribution of land use/cover to determine available land for inclusion or exclusion in the decision-making process.

Water availability is essential for rice cultivation to support growth and irrigation (Samanta et al., 2011; Sinha et al., 2014). Thus, distance from river is included as a variable for assessment of suitable land to farm rice. The closer the land is to the river, the more likely the soil water content particularly at lower elevation and slope. Similarly, movement of farm machinery, seedlings and produce in and out of the farm requires accessibility. Using the Euclidean Distance tool, distance from road, distance from river were generated (Figure 2o and 2p). Euclidean Distance analysis allows quantifying the spatial relationship between the factors and the suitable location in linear distance (Anees et al., 2020; Mukti et al., 2016).

Multi Criteria Evaluation (MCE)

Determination of rice crop requirements and definition of sub criteria is based on expert opinion and the knowledge gained from previous studies (as cited in Table 1). Since it is unscientific to assume that all the criteria contribute to rice growth and yield equally, the weight of each criterion was determined using analytical hierarchical process (AHP). The AHP introduced by Saaty (Saaty, 2004) is multi-criteria decision analysis (MCDA) that has been widely utilized to objectively determine the relative importance decision elements in many studies (Abach & Ngigi, 2016; Ahmed et al., 2017; Hao et al., 2019; Kihoro et al., 2013, 2013; Kumar & Patel, 2020; Park et al., 2019; Tien et al., 2018). In AHP, a measure of how significant the input parameters are is examined through the process of pairwise comparison in which the degree of importance of each pair of criteria is valued on a scale of 1 – 9, where 1 indicates "equal importance", 3 represents "Moderate importance", 5 denotes "Strong importance", while 7 and 9 signify "Very strong- and Extremely importance" respectively (Taherdoost, 2018). One of the advantages of AHP is that it provides mechanism for verifying the reliability of the final decision of the pairwise comparison process through assessment of the consistency ratio - CR (Equation 1) which indicates whether the matrix ratings were randomly generated or not (Saaty, 2013). In principle, CR less than or equal to 0.1 (10%) indicates that the decision is acceptable but where CR >10%, the pairwise matrix need to be revised.

$$CR = \frac{CI}{RI} \tag{1}$$

Where CI= (λ_{max} - n)/(n-1), RI = Random Index, n = number of criteria, λ = average of consistency vector and λmax = priority vector multiplied by each column total.

For each of the input factors, suitability levels were defined on a scale of 1 to 5 (Table 1); 5 (very high suitability), 4 (high suitability), 3 (medium suitability), 2 (low suitability), and 1 (very low suitability). Apart from defining criteria levels of importance, the process also satisfies the requirements for all input raster to be integer which was done using the Reclassification Tools in ArcGIS environment.

Suitability Evaluation and Validation

The final suitability map was produced using weighted overlay analysis. Weighted overlay analysis combines the input raster layers and their assigned weights indicating relative importance or percent influence. Overlaying two or more datasets is much easier with raster data than vector data since the former does not require any topological operation (Bagheri et al., 2012). The weights of all the input variables must integer and sums up to 100; where decimal value is obtained; it must be rounded up to the appropriate whole number. For areas required to be excluded in the analysis, such as water body and urbanized or developed areas, restricted value was used in the land use and land cover map. The process compares the different criteria in each layer and their respective degree of relevance to arrive at an objective suitability decision for the entire area. The resulting suitability map was validated using the receiver operating characteristic's (ROC) area under the curve (AUC) measure. This was done by analyzing sampled points of rice farms obtained from the Kwara State Ministry of Agriculture combined with field data collected using handheld GPS and negative points randomly selected based on the knowledge of the authors of the study area.

Table 1. Rice crop requirements and sub-criteria

Parameters	Level of suitability					Reference
	NS (1)	LS (2)	MS (3)	HS (4)	VHS (5)	
Elevation (m)	528 – 657	399-528	271 – 399	142 – 271	13 – 142	Ujoh et al., 2019
Slope (%)	30-72%	25-30%	20-25%	15-20%	0-15%	Ujoh et al., 2019
Aspect	West, South	South West	East, South East	North East, North West	Flat, North	Ujoh et al., 2019
Soil Texture	Loamy sandy	Loam	Sandy/clay/loam	Clayloam, loam	Clay	Suhairi et al., 2018
Soil Drainage	Well drain	Moderate	Imperfect	Poor	Very poor	Suhairi et al., 2018
Soil Depth (cm)	153-164	165-174	175-184	185-194	195-200	Suhairi et al., 2018
Nitrogen (100g/kg)	141-481	482-600	601-759	760-1006	1007-1959	Suhairi et al., 2018
Potassium (100g/kg)	45-101	102-119	120-140	141-213	214-462	Suhairi et al., 2018
Phosphorus (100g/kg)	84-262	263-320	321-393	394-538	539-1135	Suhairi et al,. 2018
Carbon (%)	3-25%	26-53%	54-101%	102-248%	249-441%	Olaleye et al., 2008
Soil PH	-	<5.0	5.3-5.8	5.8-5.9	6.0-6.8	Olaleye et al., 2008
Temperature ^{0}C	-	-	-	-	20^{0}C – 30^{0}C	
Precipitation (mm)	-	-	-	800-1000	1000-1500	
Distance to water (m)	14144-17678	10608-14143	7072-10607	3537-7071	0-3536	Abah & Petja, 2016; Sinha et al., 2014
Distance to Road (m)	44380-55473	33284-44379	22190-33284	11096-22189	0-11095	Merem et al., 2017
LULC	Built-up area and Water	Barren Land	Forest	Grass land	Wet land	Victor & Samson, 2019

NS – Not suitable, LS – low suitable, MS – moderately suitable, HS – highly suitable, VHS – very highly suitable

RESULTS AND DISCUSSION

Relaibility of the outcome of any multicriteria decision process with AHP depends on the suitability of the pairwise comparison (Table 2) and consequently the reliability measured through the consistency ratio (Table 3).

Table 2. Pairwise comparisons matrix of the input variables

	Precipitation	Temperature	Soil Texture	Soil Drainage	Soil Depth	Nitrogen	Phosphorus	Potassium	Carbon	Soil PH	Elevation	Slope	Aspect	Distance to Rivers	Distance to Roads
Precipitation	1	2	3	1	2	3	3	3	3	3	2	2	2	1	5
Temperature	1/2	1	3	2	2	2	2	2	2	2	3	3	3	2	5
Soil Texture	1/3	1/3	1	2	2	2	2	2	2	2	2	2	2	2	5
Soil Drainage	1.0	1/2	1/2	1	2	2	2	2	2	2	3	3	3	1	5
Soil Depth	1/2	1/2	1/2	1/2	1	2	2	2	2	2	3	3	3	2	4
Nitrogen	1/3	1/2	1/2	1/2	1/2	1	1	1	1	1	3	3	3	2	5
Phosphorus	1/3	1/2	1/2	1/2	1/2	1	1	1	1	1	2	2	2	2	5
Potassium	1/3	1/2	1/2	1/2	1/2	1	1	1	1	1	2	2	2	2	5
Carbon	1/3	1/2	1/2	1/2	1/2	1	1	1	1	1	2	2	2	2	5
Soil PH	1/3	1/2	1/2	1/2	1/2	1	1	1	1	1	2	2	2	2	5
Elevation	1/2	1/3	1/2	1/3	1/3	1/3	1/2	1/2	1/2	1/2	1	1	1	2	3
Slope	1/2	1/3	1/2	1/3	1/3	1/3	1/2	1/2	1/2	1/2	1	1	1	2	5
Aspecct	1/2	1/3	1/2	1/3	1/3	1/3	1/2	1/2	1/2	1/2	1	1	1	3	2
Distance to Rivers	1	1/2	1/2	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/3	1	4
Distance to Roads	1/5	1/5	1/5	1/5	1/4	1/5	1/5	1/5	1/5	1/5	1/3	1/5	1/5	1/4	1
Weight	0.134	0.120	0.095	0.097	0.086	0.065	0.058	0.058	0.058	0.058	0.037	0.039	0.039	0.042	0.015
	16.077	0.048													

Once the matrix pairwise comparison has been obtained, factor weights were calculated and the computed weight were (Table 3): precipitation (0.134), temperature (0.120), soil texture (0.095), soil drainage (0.097), soil depth (0.086), nitrogen (0.065). Others are phosphorus, potassium, carbon, soil PH (0.058, each), elevation (0.037), slope and aspect (0.039 each), distance to rivers (0.042), and distance to roads (0.015). The consistency ratio obtain was 4.8% (0.048), which is considered acceptable (Abach & Ngigi, 2016; Saaty, 2004). Also, the computed consistency ratio for each of the factors varies between 0.5% and 6.5%, all of which are within the acceptable limit of <=10%. Parameter ranking identified precipitation, temperature, soil drainage, soil texture and soil depth as the first, second, third and fifth best variables, respectively. Next to these variables are nitrogen in the sixth position while phosphorous, potassium, carbon and soil PH occupied the seventh position. At the base of the rating are Distance to river, slope, aspect, elevation and distance to roads from 11th to 15th position.

Table 3. Variable weight, rank and consistency check

	Variable	**Priority**	**Rank**	**Consistency check**
1	Precipitation	13.4%	1	6.5%
2	Temperature	12.0%	2	5.0%
3	Soil Texture	9.5%	4	4.0%
4	Soil Drainage	9.7%	3	3.3%
5	Soil Depth	8.6%	5	2.7%
6	Nitrogen	6.5%	6	2.4%
7	Phosphorus	5.8%	7	1.2%
8	Potassium	5.8%	7	1.2%
9	Carbon	5.8%	7	1.2%
10	Soil PH	5.8%	7	1.2%
11	Elevation	3.7%	14	1.5%
12	Slope	3.9%	12	1.7%
13	Aspect	3.9%	13	2.4%
14	Dist. to Rivers	4.2%	11	3.0%
15	Dist. to Roads	1.5%	15	0.5%
Consistency Ratio CR = 4.8%; Principal eigen value = 16.08 and Eigenvector solution: 6 iterations				

Figure 3 presents the suitability map categorized into five classes: restricted area, low suitable, moderately suitable, highly suitable and very highly suitable, utilizing the natural break classification method (Ouri et al., 2020; Shabani et al., 2020). Kwara state has a total landmass of 3542031.89 hectares classified into five landcover classes; grassland/shrubs, forest, built-up areas, bare earth/cultivated land, and water body. The grassland/shrubs and forest cover types occupy about 77% of the land (42.68% and 34.41%, respectively) while built-up areas, bare earth/cultivated land, and water body occupy 7.57% (268128.29 ha), 14.86% (526481.40 ha) and 0.47% (16762.69 ha). According to Figure 3, the number of hectares available to each suitability class are: very highly suitable 154408.94 ha (4.36%), highly suitable 1436504.55 ha (40.56%), moderately suitable 1091145.20 ha (30.81%), and low suitable 516169.46 ha (14.57%), while the remaining 10% comprised of water body and developed areas are excepted from the analysis. The validation result yields area under the ROC curve value of 0.98 (98%).

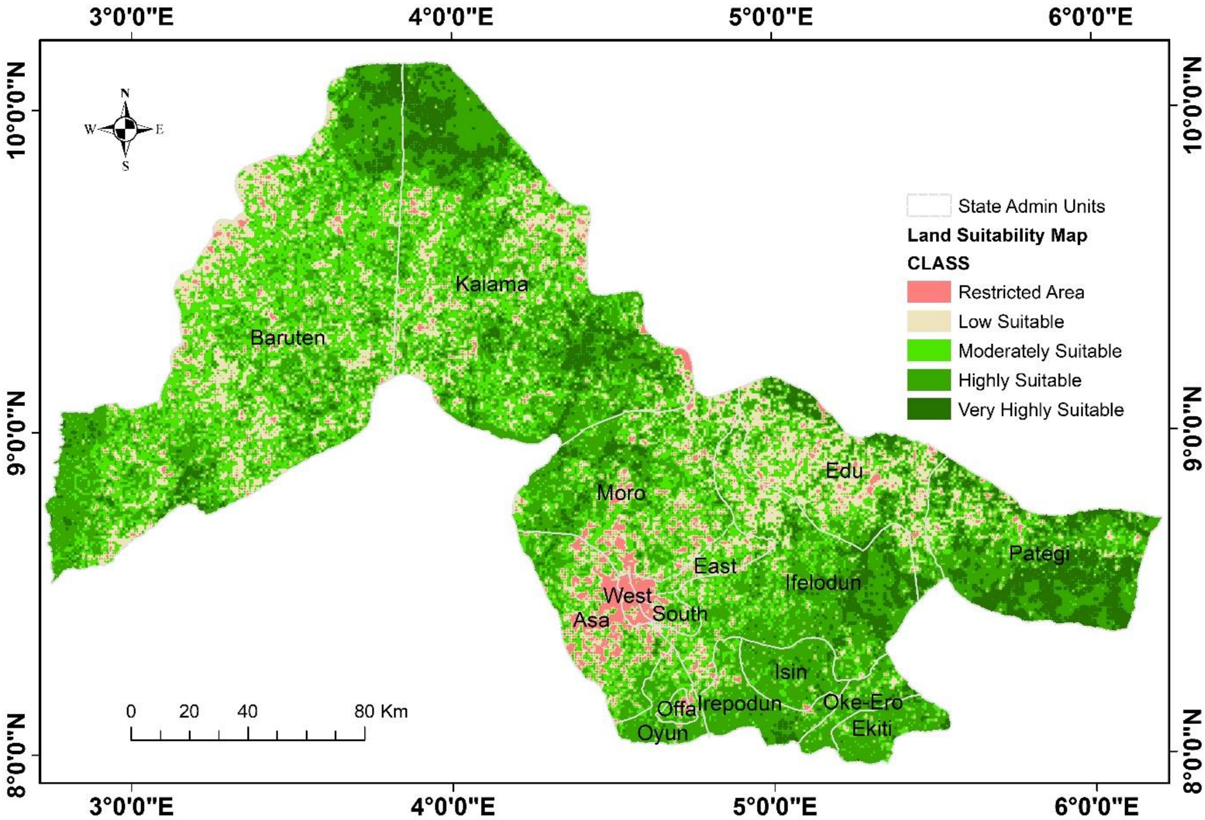

Figure 3. Map of suitable land for Rice crop farming in Kwara State

Generally, land suitability for crop production is dependent on a number of factors including climatic condition, soil physical and chemical properties, and the landscape of the area. In this study, through the combination of factors that favour rice crop cultivation (Figure 2), their respective weight produced using MCE technique (Table 3) and associated constraints (based on land use/cover types), areas suitable for the rice crop cultivation were delineated (Figure 3). Fundamentally, the mean annual temperature and precipitation receive in the study area favour rice crop growth and yield (Merem et al., 2017; Sadiq et al., 2017); so, both factors are not critical determinants of land suitability as the other variables, particularly the soil properties. Distance to river and road are environmental variables that are not directly linked to crop growth but support logistical requirement such as irrigation and ease of transportation of farm machinery and produce to the desire market (Babatunde et al., 2019; Kaaya et al., 2019).

Cross-sectional analysis between the map of suitable areas and the soil variables provides useful information on how each variable contributes to the final output. In terms of the soil physical property, the entire study area has high soil depth in the range of 195 cm – 200 cm. The very high and high suitability areas are located in areas with abundant clayloam, sandyclayloam and loaming soil associated with imperfect and well-moderately drained soil, whereas the moderate and low suitability classes are found on moderately drained sandyloam soil which dominates the study area. The distribution of the different suitability classes supports the finding of Daniel (2011), Kihoro et al. (2013) and Merem et al. (2017) that sorghum and rice are hydromorphic crops that grow well in silt and some combination of loamy soil, clayey and sand that develop within terraces.

In terms of the soil chemical properties, the study area possesses moderate to mild soil acidity with soil PH value between 5.3 – 6.8. High soil PH trends northwest – southeast in low land close to river channels and decreases southward (Figure 2k). The very high and high suitability classes fall within mildly acidic soil with PH value between 6 – 6.8 that is rich in nitrogen (500 – 1959 g/kg), potassium (120 – 462 g/kg), soil organic carbon (26% - 53%) but low in phosphorus (84 – 262 g/kg). These areas have moderately shallow soil depth relatively rich in plant nutrients to support productive rice cultivation with minimum tillage and careful erosion control (McCauley et al., 2009; Sadiq et al., 2017). Conversely, the moderate and low suitability classes are associated with moderate soil acidity (5.3 – 6.0), low nitrogen, potassium, and soil carbon in the range of 141 – 481 g/kg, 45 – 119 g/kg, and 3% - 25%, respectively, and high phosphorus between 263 and 534 g/kg. These fall in irrigated land largely affected by salinity, poor drainage and nutrients due to exposure to severe erosion influenced by topography. Our result has shown that Kwara state has very good climate and soil characteristics for rice production. Crossing the suiatbility map with the NDVI image depicts the present reality with respect to the land availability and vegetation amount and distribution. Based on the acreage currently been used for rice cultivation, the potential acreage available is underutilized. Our findings also indicated that majority of the area classed at very high and high suitable in the south-eastern area constitute forest while the north and central areas classed moderately suitable are fast becoming degraded lands perhaps due to nutrient depletion, urbanization and desertification.

CONCLUSION

This study demonstrates the application of remote sensing and spatial analysis by integrating various datasets of different spatial and temporal resolutions in a GIS environment. MCE of climatic factors, soil characteristics, relief and environmental variables useful to delineate suitable areas for rice crops production have been utilized. In this way, a thematic map that takes into account specific rice crop growth characteristics to indicate varying levels of suitability areas was generated. Absence of complete, reliable and up to date data from relevant local and national government agencies have negatively impacted on ability to provides information at a regional scale that could be used by local farmers to select their crop pattern. We found the freely available remote sensing data crucial to obtaining useful information in a precise and relatively fast way.

We applied the MCE technique to identify areas for rice crop farming within a GIS environment using the selected climate, soil, topographic and environmental variables that support rice farming. The soils are well drained and the topography relatively flat with few rock outcrops in the northern side of the state. Across the state, the soil have sufficient nutrients of high agricultural potentials in compliance with the USDA (1951) recommendation of soil with sand composition > 50% and clay of 15% to allow the soil cohere and mould fairly easily when mist without being sticky. This is evidenced with moderate, high and very high sutable classes occuping ~75% of the landmass.

This study has shown that combination of MCE–GIS provide rational and objective basis to making decisions in rice crop farming in Kwara state and the methodology can be replicated in other states of the Federation for future specific studies on rice crop. However, we know that decision-making process to select adequate land for rice crop could be based not only on the information provided in this study, but also on other issues such agricultural policies of the local and federal governments, crop production priority, and supports, in addition to local cultural farming traditions.

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