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Crop Suitability Mapping for Rice, Cassava, and Yam in North Central Nigeria

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Abstract

Agricultural production has contributed over time to food security and rural economic development in developing countries particularly supporting the countryside. Evidence of crop yield decline exist in the Lower River Benue Basin. This was a crop suitability mapping for rice, cassava, and yam to guide policy makers in strategic planning for sustainable agricultural development. Data was collected on various themes including climate, drainage, soil, satellite imagery, and maps. Remote Sensing was used to analyse satellite imagery to produce a digital elevation model, land use and land cover map, and normalised difference vegetation index map. GIS was used to produce thematic maps, weighted percentages of attribute data, and to produce crop suitability maps through weighted overlay. Soils in the study area require fertility enhancement with inorganic fertilisers for better crop yield. Soils in the Lower River Benue Basin are suitable for yam, cassava, and rice cultivation on maps of suitable areas. Some areas were found to be highly suitable for the cultivation of rice (34.22%), cassava (17.08%) and yam (16.08%). Some other areas were found to be moderately suitable for the cultivation of cassava (48.18%), rice (45.46%), and yam (48.85%). Areas with low suitability were 14.99% (rice), 33.68% (cassava), and 29.57% (yam). This study has demonstrated the importance of crop suitability mapping and recommends that farmers' cooperative societies and policy makers utilise the information presented to improve decision making methods and policies for agricultural development.

Keywords: GIS, remote sensing, precision agriculture, crop suitability mapping, sustainable agriculture

1. Introduction

Nigerian cassava production is by far the largest in the world, and Benue and Kogi state in the North Central zone are the largest producers of cassava (IITA, 2004). The country produces about 50 million metric tons a year within a cultivated area of about 3.7 million hectares. Nigeria accounts for 20% of world produce, 34% of Africa's produce, and 46% of West Africa's produce (FAO, 2016). Nigeria accounts for 71% (over 37 million tons) of the 94% of world production of yams which comes from West Africa (IITA, 2009). Nigeria is Africa's largest consumer of rice. Rice production in Nigeria is mainly for market value as rice generates more income than most agricultural produce. Nigeria is one of the leading importers of rice in the world. Most agricultural produce in Nigeria including cassava, yam and rice is by small-scale farmers (FAO, 2016).

Suitable parameters for the cultivation of cassava, yam and rice exist in many areas of Nigeria. Conditions for cassava cultivation in savannah regions are documented in Titus et al. (2011) and Ande (2011). Cassava can grow on a wide variety of soils within a temperature of between 25 °C and 29 °C, and with a rainfall range of 500 to 1500 mm. Cassava can grow on level to moderate slope and does not require much water for growth. The conditions for rice cultivation in southern guinea savannah is presented in Aondoakaa and Agbakwuru (2012), and rice requires a temperature range of 20 °C to 27 °C and a rainfall range of 1150mm to 3000mm. The main ecologies for rice cultivation in West Africa include rain-fed upland, rain-fed lowland, and irrigated lowland with water control. Conditions for yam cultivation as discussed in Kutugi (2002) and Eruola et al. (2012) are similar to that of cassava but yam has less tolerance for water stress.

These conditions are prevalent in Benue state which is predominantly made of small-scale farmers heavily involved in the cultivation of cassava, yam, and rice. Through an integrated scientific planning approach which is aimed at enhancing small-scale farm activities, the aim of development which is centred on enriching quality of life in all segments of the population particularly the rural population can be achieved (M. Ghosh & S. K. Ghosh, 2013).

As part of efforts towards enhancing the production of cassava, yam and rice, it is beneficial to accurately match agricultural practice with appropriate spatial information on adequate conditions. Geographic Information System (GIS) and remote sensing has been extensively used in other sectors of national development but the use of such technology to support decisions for sustainable agricultural development in rural settings is still evolving. The use of these technologies is therefore encouraged towards improvements in the standards and quality of rural life (Petja et al., 2014).

Agricultural land use patterns are highly dynamic features of a cultural landscape and social and economic factors are the most prominent factors that influence land use change in rural areas (Ortserga, 2012). The Food and Agricultural Organisation framework for land evaluation (FAO, 1976) has provided guidance for land suitability assessment in developing countries where data scarcity often constrains modelling. Riveira and Maseda (2006) revealed that there is a shortage of models focused on rural land use and that designing a rural land use planning model should involve the integration of different computer tools. According to Kumara (2008), the principal application of GIS in rural development are land and resource mapping, integration of local and scientific spatial knowledge, community-based natural resource management, area planning, environmental management, and management of pests and natural hazards. The integration of local knowledge into GIS makes analysis more participatory and enhances ownership and utilisation of information.

The utilitarian value of GIS and remote sensing provides robust analytical and manipulative capabilities which can enable modelling for rural agricultural enhancement (Enete & Amusa 2010). Various studies (Nuga, 2001; Rilwani & Ikuoria, 2006; Rilwani & Gbakeji, 2009; Uchua et al., 2012) have revealed the need to adopt geo-informatics methods to improve agricultural productivity to meet the nutritional need of the teeming Nigerian masses as well as for export income.

A study was conducted by Ashraf (2010) which involved land suitability analysis for wheat using multi-criteria evaluation and GIS. The study by Ashraf (2010) used GIS to provide information at local level for farmers to select their cropping patterns. In a large study by Stickler et al. (2007), the biophysical potential for three major crops (soybean, sugar cane, oil palm) in the tropics were mapped globally. Stickler et al. (2007) identified growth requirements for these crops and used the data to develop spatially-explicit variables and identified regions where these crops can be profitably grown. Heumann et al. (2013) embarked on land suitability modelling using a geographic socio-environmental niche-based approach in north-eastern Thailand. The study by Heumann et al. (2013) tried to understand the land suitability for crops and utilised data on the built environment, natural abiotic conditions, and household social factors which were responsible or externally influenced the human modification of the niche.

This study aimed to produce crop suitability maps for cassava, rice, and yam by utilising a broad range of quantified data on physical aspects of the local community for the improvement of agriculture in Benue state. Cassava, rice and yam are widely cultivated crops in Benue state but produce have not appreciably increased over the years with indications of low productivity, low yields, and high post-harvest losses owing a subsistence culture of farming. This study explores the most suitable areas for the cultivation of cassava, rice, and yam which can lead to sustainable increase in yield.

2. Method

2.1 Study Area

The area of study falls within Benue State, north central Nigeria, between Latitudes 7°13′N and 8°00′N and Longitudes 8°00′E and 9°00′E (Figure 1). There are thirteen Local Government Areas (Makurdi, Gboko, Tarka, Gwer west, Gwer east, Guma, Buruku, Otukpo, Agatu, Ushongo, Ohimini, Obi, and Konshisha) covered either in whole or in part by the study area.

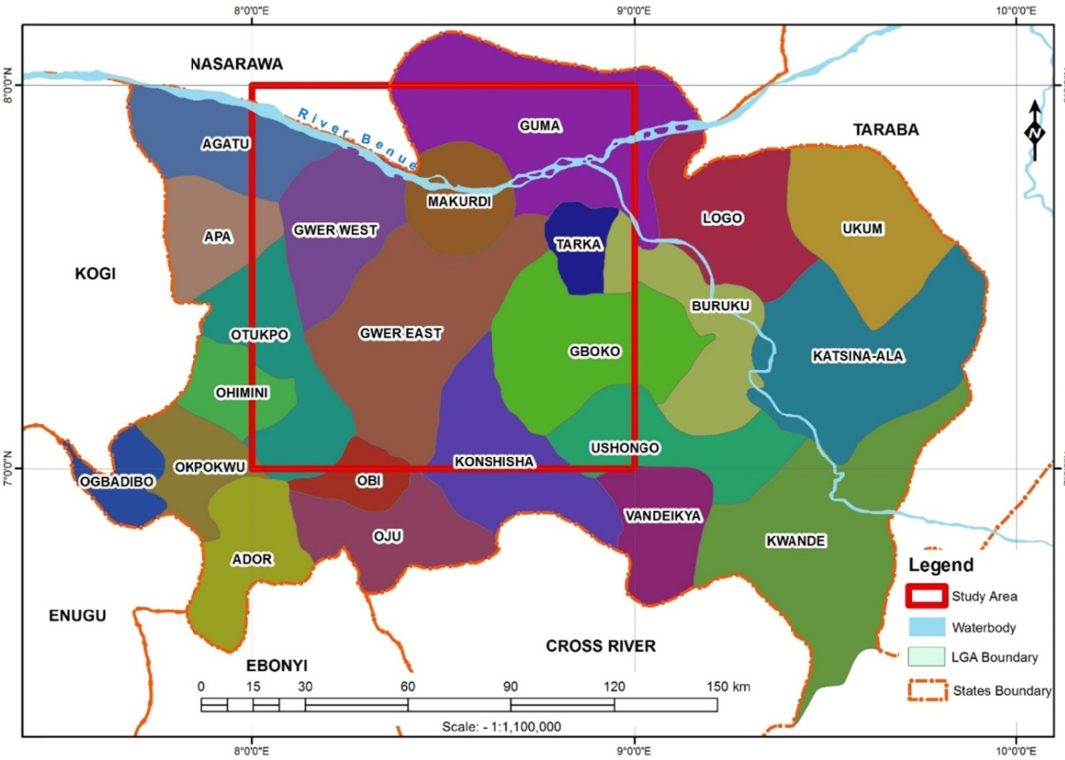

Figure 1. Map of Benue state showing study area

2.2 Data Collection

The methodology utilised for the study involved primary and secondary data for physical, remote sensing and GIS analysis. Data on climatic parameters (1973-2014) were collected from the Nigerian Meteorological Agency. Drainage data (1955-2012) on the River Benue from Makurdi and Umaisha hydrological stations and on River Katsina Ala from the Nigerian Hydrological Service Agency. Physical and chemical analysis of 36 top and subsurface soil samples collected from Makurdi, Tarka, and Gboko Local Government Areas located in Benue State and supported by secondary soil data from other studies to cover the study area.

The Landsat Satellite imagery was obtained from Global Land Cover Facility (GLCF) through the earth explorer platform. Landsat 7 ETM+ data was obtained for the study area for the year 2015, which had ortho-rectified the systematic radiometric, atmospheric and geometrical distortions of the imagery to a quality level of 1G before delivery (USGS, 2015). The Landsat scenes covered a region of approximately 182 km × 185 km and had a spatial resolution of 30 metres. The Landsat scenes covering the study area were Path 187 and 188 of Row 055. The Topographic maps of the study area were obtained from the Office of the Surveyor General of the Federation, Nigeria in Abuja. The topographic map sheets were at a scale of 1:50,000 for more details to be captured. The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data was downloaded from the National Map Seamless Data Distribution System, or the USGS ftp site. The elevation details was obtained from the SRTM using the Global Mapper 15 software and compared with the contour extracted from the topographic map using the ArcMap 10.3 software, to have a full understanding of the topography. Maps were derived for themes such as climate, drainage, and soil.

2.3 Data Processing

The remote sensing analyses for the research included Land use land cover analysis and NDVI. These two (2) analyses were achieved using a combination of software (Idrisi 17.0 Selva edition and ArcMap 10.3) and geoprocessing operations. The spatial analyses were done in Idrisi while the cartographic finishing was achieved using the ArcMap 10.3 software. Classification involved labelling the pixels belonging to particular spectral classes using the spectral data available. The supervised method of classification was used which gave rise to the training sets. The Landsat imagery was first mosaicked using the geo-reference properties of both imagery and a feathering of two (2) was applied to reduce the edging. The various bands from 1-4 was independently mosaicked.

After which, a subset of the study area was made from the two (2) scenes of Landsat imagery downloaded. This subset was done using the Idrisi 17 Selva edition software. From empirical analysis and Principal Component Analysis, it has been proven that the bands that carry the greatest information about natural environment are the visible (Red, Blue and Green) wavelength bands. Using the Idrisi Selva software a true colour composite was made in Red, Green and Blue (RGB) representing Bands 3, 2 and 1 respectively. The tool considered both the variance and covariance of the class signatures as it assigned each cell to one of the classes represented in the signature file. With the assumption that the distribution of a class sample was normal, classes were characterised by the mean vector and the covariance matrix. Given these two characteristics for each cell value, the statistical probability was computed for each class to determine the membership of the cells to the class. The NDVI is expressed as the difference between the near infrared and red bands normalised by the sum of those bands. This is the most commonly used vegetation index as it retains the ability to minimise topographic effects while producing a linear measurement. The NDVI was calculated using the empirical format by Rouse et al. (1973).

Operations such as vector to raster conversion, reclassification, weighted overlay etc. were performed at this stage using the ArcMap 10.3 software and its geoprocessing tools in ArcToolbox. A "Weighted Overlay Operation" was adopted using GIS techniques for identification of areas of the various crop suitability depending on a number of thematic layers and based on the principle of Multi-Criteria Evaluation. The ArcMap 10.3 software was used to create the various thematic maps from available data. The maps (rainfall, drainage, temperature, DEM, Land use land cover and soil) were converted from vector format to raster format using the conversion tools in ArcToolbox for use in the GIS weighted overlay operation. Using the spatial analyst tools in ArcToolbox, the various raster maps were reclassified. A scale of 1 to 5 was adopted to indicate the level of importance. Value 5 represented extreme importance while value 1 represented not important. The scaling of the criteria was done in line with the level of contribution of the factors to the growth of rice, yam, and cassava from literature and conditions obtainable in the study area. Given the requirements for the growth of rice, yam and cassava from literature, the range requirements of extreme importance for each crop was ranked within the biophysical results obtained in this study. All the parameters were compared against each other in a pair-wise comparison matrix which was a measure of the relationship between the parameters in order to rule out bias. Subsequently, a numerical value expressing the level of importance of one parameter against another was assigned. After the preparation of all the thematic layers, reclassification as well as preparation of the table of weights, the weighted overlay operation was performed on the ArcMap 10.3 software. The crop requirements used and assigned weights are presented in Table 1 and 2. The crop suitability maps were created through the weighted overlay geoprocessing tool in ArcMap 10.3 ArcToolbox by using the weights assigned to each of the parameters (climate, soil, land cover, and DEM). Using five classes, the various layers were classified from very high suitability to very low suitability. Suitability maps were created for rice, yam, and cassava. Each raster was assigned a percentage of influence according to its importance derived for each crop. Similar GIS and remote sensing models have been used elsewhere (Stickler et al., 2007; Ashraf, 2010; Petja et al., 2014).

3. Results

3.1 Physical Conditions

The annual average rainfall amount recorded for the period 1973-2013 was 1194.1 mm, and the median was 1207.9 mm. The year with the highest amount of rainfall was 1999 (1617.1 mm). Other years with high amounts of rainfall were 1984 (1572 mm), 1998 (1537.6 mm), 1975 (1508.6 mm), 2012 (1466.7 mm), 1980 (1425.5 mm), and 2009 (1407.5 mm). The year with the lowest amount of rainfall was 2003 (761.5 mm). The average annual temperature calculated for the period January 1973 to December 2014 was 27.84 ^{o}C. The highest annual temperature averages were recorded in 2005 (28.6 ^{o}C), 1998 (28.55 ^{o}C), 2010 (28.5 ^{o}C), and 2003 (28.43 ^{o}C). The lowest temperature values were recorded in 2012 (26.8 ^{o}C) and 1974 (27.2 ^{o}C). Relative humidity in Makurdi was quite high annually with an annual average of 67.8% calculated for the period 1974-2008. The most extreme value (99.5%) was recorded on August 13 in 1997.

Table 1. Requirements of extreme importance for cultivation of rice, yam, and cassava

Parameters	Rice	Yam	Cassava
Rainfall (mm)	> 1500	1000-1250	750-1000
Temperature (^oC)	23-26	26-29	26-29
Soil classes	Clay loam	loamy sand	loamy sand
Soil pH	5.0-5.5	6.0-6.5	5.5-6.0
Soil organic carbon	1.5 < 2.0	2.0 >	2.0 >
Soil Phosphorus (mg kg^{-1})	5-10	10-15	10-15
Soil Potassium (cmol kg^{-1})	0.8-1.0	0.5-0.7	0.5-0.7
Land Cover classes	Wetland	Scattered vegetation	Scattered vegetation
DEM (metres)	0-100	100-200	100-200

Note. Kutugi (2002), Titus et al. (2011), Ande (2011), Aondoakaa and Agbakwuru (2012), Eruola et al. (2012).

Table 2. Weighted index of parameters

Parameters	Weights (%)		
	Rice	Yam	Cassava
Rainfall	23.08	33.33	23.08
Temperature	10.25	15.00	10.38
Humidity	5.14	10.00	5.00
Soil class	12.82	4.45	7.69
pH	10.26	1.11	1.54
Organic carbon	5.13	5.56	4.62
Phosphorus	7.69	3.33	6.15
Potassium	2.56	2.22	3.08
Land cover	7.69	8.33	7.69
DEM (slope)	15.38	16.67	30.77
Total	**100%**	**100%**	**100%**

The average discharge of River Benue at Umaisha hydrological station for the period was 4,919.47 cubic metres per second (m^3/s). The maximum discharge for the period was 19,120 m^3/s which was recorded on the 15th October 2012. Average discharge of River Benue at Makurdi hydrological station was 3,468.24 m^3/s. The peak flow discharge of 16,400 m^3/s was recorded in three days 19th, 29th, and 30th in the month of September 2012 while the peak flow of 2011 was 9,436 m^3/s. At River Katsina Ala hydrological station, the average discharge from January 1955 to May 2014 was 933.12 m^3/s. The maximum discharge for the period was 4,401 m^3/s which was recorded on the 20th October 1977.

Soils in Makurdi were mostly loamy sand. Loamy sand soils have low water holding capacity, good drainage and aeration. Soils from Tarka, and Gboko were mostly sandy loam. Loamy sand and sandy loam soils appear moderately suitable for irrigation, but may be drought prone (Utsev et al., 2014). A summary of the chemical composition of analysed soil samples from Makurdi, Tarka, and Gboko is presented in Table 3.

Table 3. Descriptive summary of chemical properties of soils in the study area

Parameters	Makurdi		Tarka		Gboko	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
pH	5.9083	.28110	5.6500	.30896	5.3083	.18809
C (%)	.5200	.06769	1.1275	.57089	1.2725	.49393
N (%)	.0342	.00515	.0817	.04324	.0983	.03810
P (mg kg^{-1})	5.01	11.79	4.56	7.45	13.73	11.05
Ca (cmol kg^{-1})	2.7283	.62098	2.8517	.91714	3.9967	.77787
Mg (cmol kg^{-1})	2.2408	.45821	1.4733	.27988	2.2742	.72055
K (cmol kg^{-1})	.0892	.02353	.0708	.01379	.0967	.02425
Na (cmol kg^{-1})	.0592	.01084	.0550	.01168	.0675	.01055
Al3+ (cmol kg^{-1})	.2033	.08083	.3758	.59220	.1242	.09811
H+ (cmol kg^{-1})	.6092	.11389	.8542	.33288	.7425	.20877
ECEC (cmol kg^{-1})	5.9025	.80093	5.6808	.93675	7.3025	1.44385
Base saturation (%)	86.0833	2.71221	78.5000	14.78021	88.0000	2.79610

3.2 Land Use and Land Cover of Study Area

The study area had a predominance of scattered cultivation which supported the finding that the study area has a preponderance of agrarian peasants. Scattered cultivation covered a total area of 4,691.18 km^2 which made up 38.28% of the total study area which affirmed the field findings. The Built-up area accounted for 2,343.14 km^2 (19.12%) of the total area under study. Wetland and Waterbody (including rivers) covered a total area of 1,645.84 km^2 (13.43%) and 1,523.29 km^2 (12.43%) respectively. Bareland surfaces covered an area of 1,388.48 km^2 (11.33%) while Rock outcrops accounted for the least area occupying 662.99 km^2 representing 5.41% of the total area under investigation. The generated land use and land cover map is presented in Figure 2.

3.3 Normalised Difference Vegetation Index

The NDVI results showed that the study area is appreciably vegetated which buttressed the finding from the Land Use Land Cover. The NDVI analysis showed values ranging from -1 to +1 (Figure 3). After the reclassification operation, areas without vegetation were found to occupy a total area of 601.72 km^2 which represented 4.91% of the study area. Sparsely vegetated areas covered 8,312.51 km^2 (67.83%) which was the highest vegetal cover class. This was followed by 27.26% (3,340.69 km^2) which was covered by high vegetation. The result of the NDVI showed the general vegetation condition of the study area (Figures 4). These results further attest to the general suitability and potential of the study area for crop cultivation.

3.4 Rice Suitability Classes

The total area of 4,193.65 km^2 representing 34.22% of area under investigation was found to be highly suitable for rice cultivation (Table 4). Most of the other parts of the study area are moderately suitable for rice cultivation 45.46% (5,570.51 km^2). Very high suitable areas covered only 500.00 km^2 (4.08%). The suitability map is presented as Figure 5.

3.5 Cassava Suitability Classes

Cassava suitability classes showed that moderate suitability covered the largest part of the study area occupying 5,904.52 km^2 (48.18%). It was closely followed by areas of low suitability covering an area of 4,127.49 km^2 representing 33.68% of the total area (Table 5). Highly suitable areas occupied 2,093.13km^2 (17.08%) of the total area under investigation. The least area was occupied by the very low suitability class covering 96.90km^2 (0.79%) of the study area. Cassava is a crop that can survive on many soil types and usually copes with adverse weather conditions. It is therefore not surprising that given these fringe suitability classes (moderate and low), cassava seems to be a thriving crop in Benue state (Figure 6).

3.6 Yam Suitability Classes

Moderately suitable areas for yam cultivation made up 48.85% (5,986.41 km^2) of the study area and spread across the entire area under investigation (Table 6). The closest to moderate suitability was low suitability covering 29.57% (3,623.86 km^2) of the study area. The areas marked with very low suitability for yam cultivation was 598.54 km^2 representing 4.88% of the total study area (Figure 7).

Table 4. Suitability classes for rice

Suitability classes	Area (km^2)	Percentages %
Very low suitability	153.25	1.25
Low suitability	1,837.52	14.99
Moderate suitability	5,570.51	45.46
High suitability	4,193.65	34.22
Very high suitability	500.00	4.08
Total	12254.92	100%

Table 5. Suitability classes for cassava

Suitability classes	Area (km^2)	Percentages %
Very low suitability	96.90	0.79
Low suitability	4,127.49	33.68
Moderate suitability	5,904.52	48.18
High suitability	2,093.13	17.08
Very high suitability	32.89	0.27
Total	12254.92	100%

Table 6. Suitability classes for yam

Suitability classes	Area (km^2)	Percentages %
Very low suitability	598.54	4.88
Low suitability	3,623.86	29.57
Moderate suitability	5,986.41	48.85
High suitability	1,994.80	16.28
Very high suitability	51.31	0.42
Total	12254.92	100%

4. Discussion

In this paper, the use of remote sensing and GIS techniques allowed for the inclusion of various attributes specific to the study area which enhanced the accuracy and presentation of suitability maps for rice, cassava, and yam. These maps have revealed most suitable areas where cultivation of these crops should be focused. These results are in line with the assertion by Lingjun et al. (2008) that GIS and remote sensing has allowed for a transition from qualitative to quantitative assessment of land suitability based on relevant natural, economic, social and technical data. Similar modelling techniques have been documented in literature (Joss et al., 2008; Twumasi et al., 2012) which attest to the utilitarian value of this approach to suitability mapping for improved crop cultivation. The Lower River Benue Basin is known for high amounts of agricultural produce especially cereals, roots and tubers, and legumes. It is therefore not surprising that most parts of study area was found to be moderately suitable for the cultivation of rice, yam, and cassava. Notwithstanding, the suitability maps indicated that areas highly suitable and very highly suitable for these crops are not as predominant except for rice which had an appreciable percentage marked as highly suitable. The suitability map for rice (Figure 5) showed a high variation.

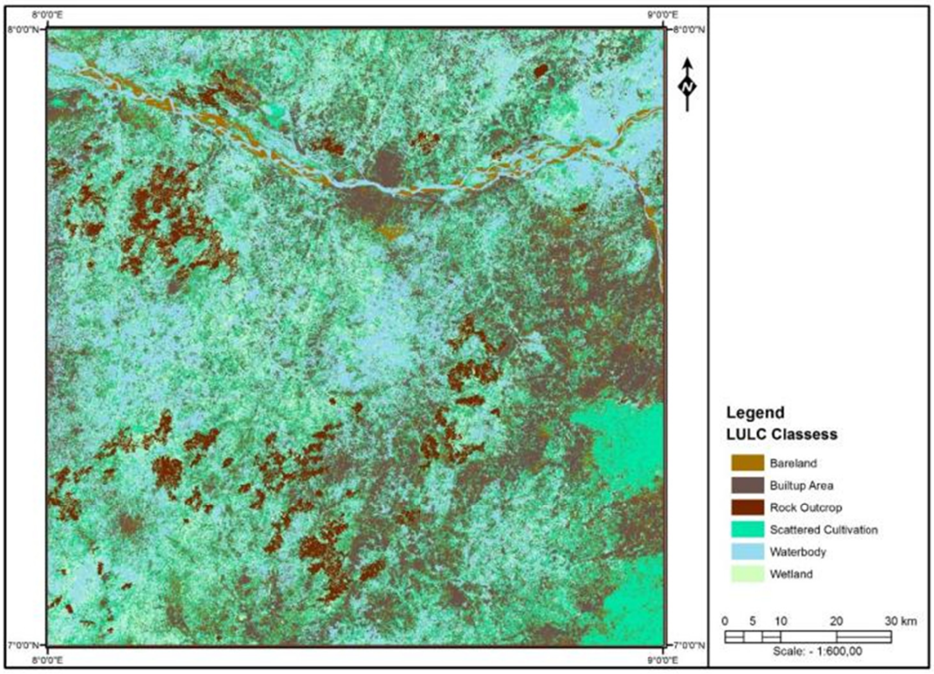

Figure 2. Land use land cover of the study area

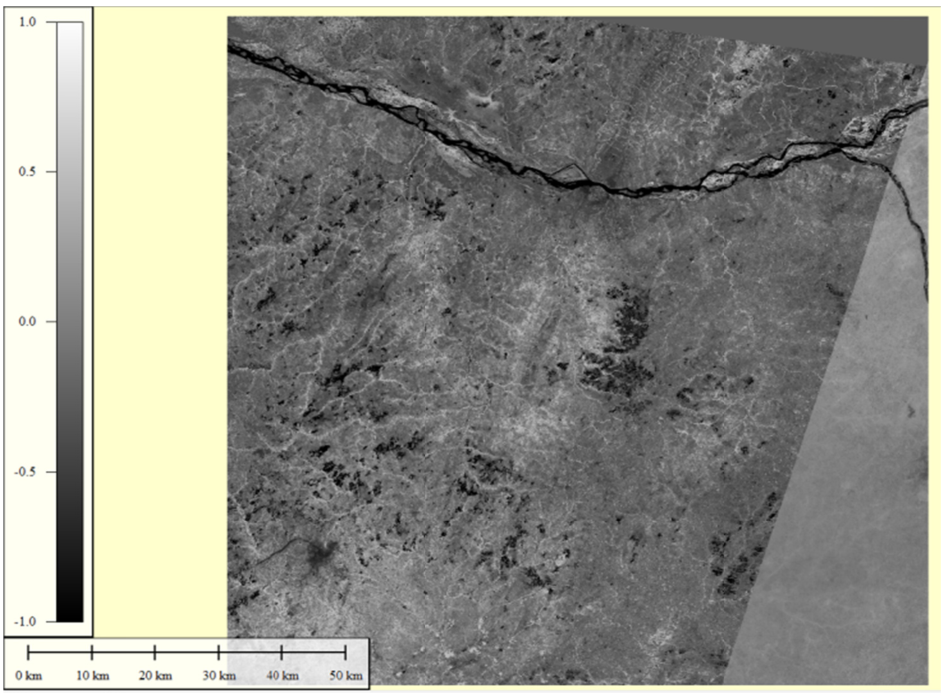

Figure 3. NDVI map of the study area

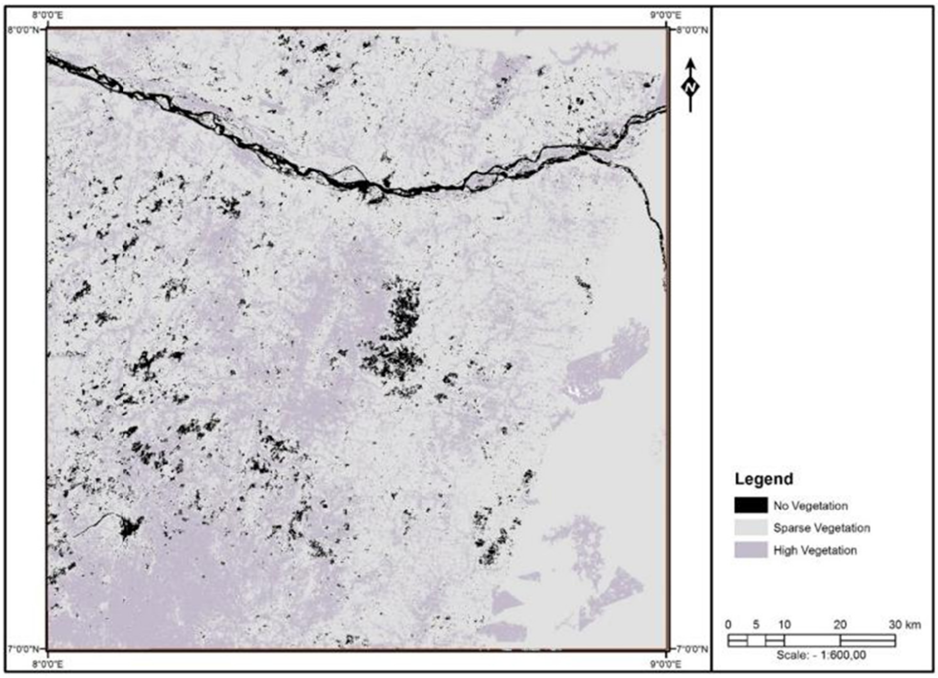

Figure 4. Reclassified NDVI map of the study area

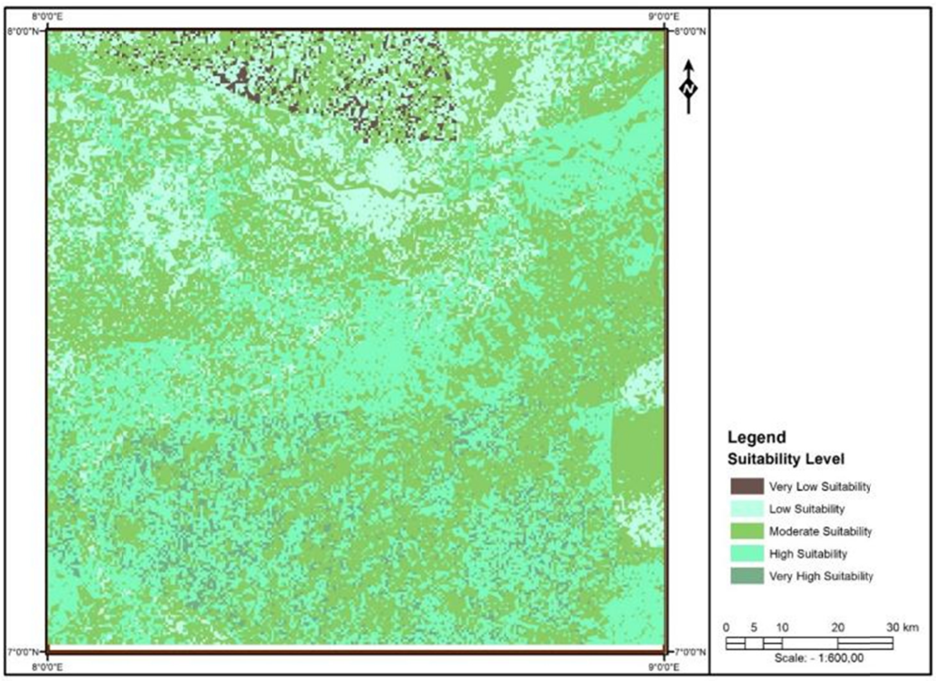

Figure 5. Rice suitability classes map

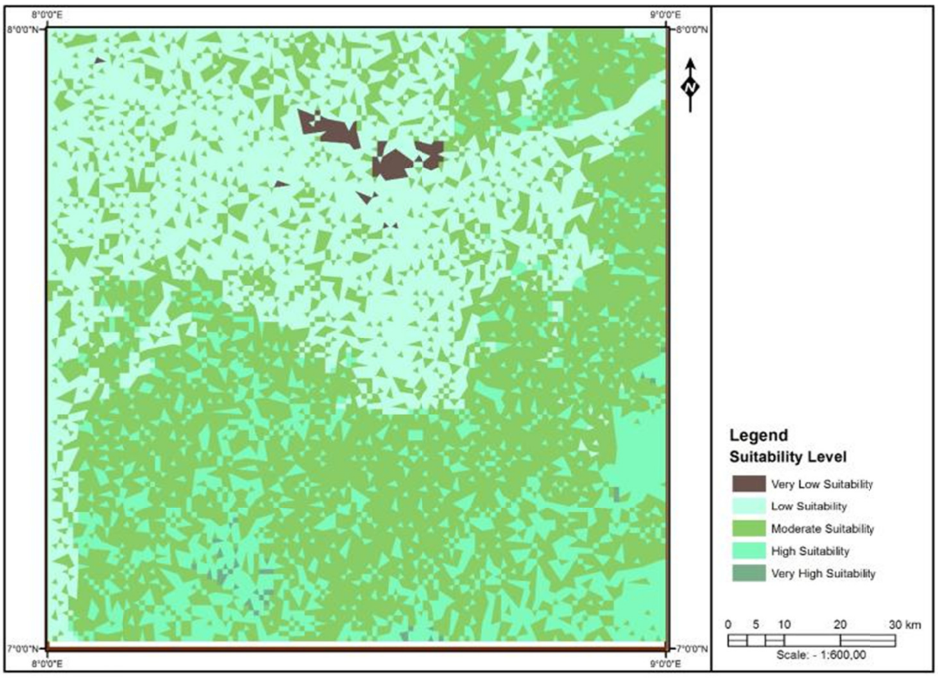

Figure 6. Cassava suitability classes map

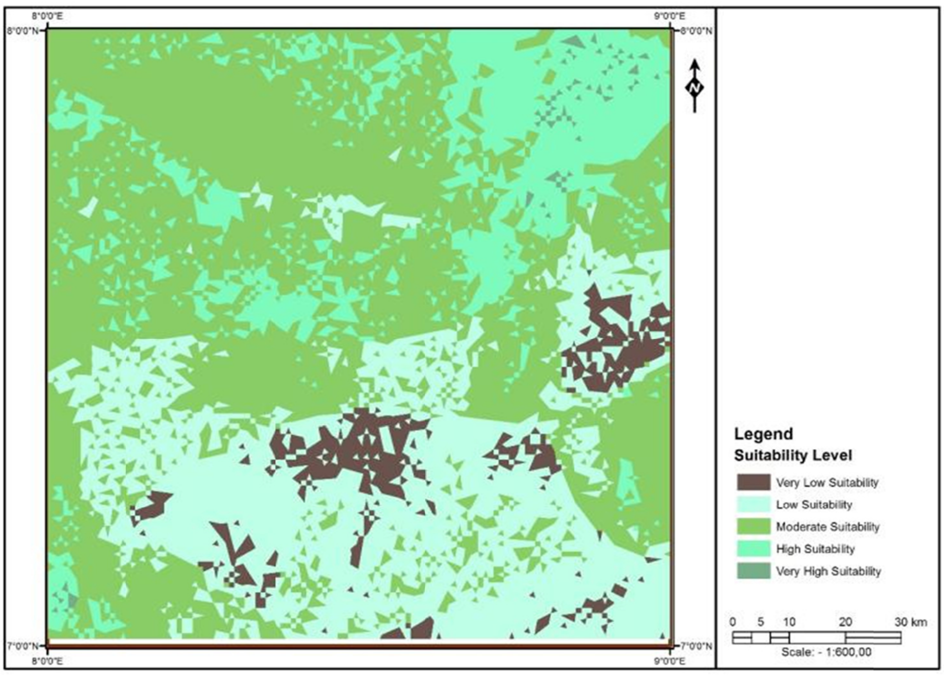

Figure 7. Yam suitability classes map

The areas found to be highly suitable and very highly suitable for rice cultivation fall under four Local Government Areas (L.G.As) including Gboko, Konshisha, Gwer east, and Otukpo (Figure 1). The streams in these areas are not tributaries of the River Benue but actually flow southwards from the River Benue. These areas experience the highest rainfall amounts and the least temperature. The areas marked as very highly suitable, highly suitable and moderately suitable for rice cultivation fall under the soil type Ferric Acrisol and Distric Notosol. One of the LGAs (Otukpo) used to have the largest rice mill in Nigeria but was neglected by

Government and succumbed to issues of illegal levies within the premises and obscure activities of middlemen. The areas marked high and very high suitability for rice cultivation have the highest concentration of built up areas.

The suitability map for cassava (Figure 6) showed that cassava is more successfully cultivated in areas of moderate elevation. The areas of very high suitability fell under Gwer east LGA. Areas marked as moderately suitable which were predominant fell under Tarka, Gboko, Gwer east, Konshisha, and Otukpo (Figure 1). Most parts of Benue however are known to produce large amounts of cassava annually. The rainfall and temperature of these areas are similar to those of rice suitability. The areas of very low suitability were areas close to Makurdi.

The suitability map for yam (Figure 7) was quite different from that of rice and cassava. The areas marked with very low suitability and low suitability were in parts of Gboko, Konshisha, Ushongo and parts of Gwer east which were quite suitable for rice cultivation. This may be a function of the relief system in the area. The suitability map for yam showed the least variation. The preferred areas for yam suitability appeared more in areas of lesser rainfall, higher temperature and moderate relief in contrast to that of rice.

Overall, rice had the highest suitability percentages for both the very highly suitable and the highly suitable categories (Figure 8). This is an indication that more areas are quite suited for rice cultivation than for yam and cassava. However, Figure 8 showed that the study area was moderately suitable for either of the crops examined with an average of more than 40% for each crop. Cassava has the least suitability for the combined low suitability classes (34.47%), and was followed by yam (34.45%). Generally, the areas of suitability for these crops potentially provides a good population of farmers for these crops given that the major occupation in Benue State is crop farming. However, the predominant mode of farming is a mix of traditional and semi-traditional. The suitable areas presented have potential to provide adequate physical conditions necessary to optimise the produce of cassava, rice and yam. Associated benefits with cultivation of crop in most suitable areas include reduced cost of inputs, minimal labour efforts, and availability of close markets.

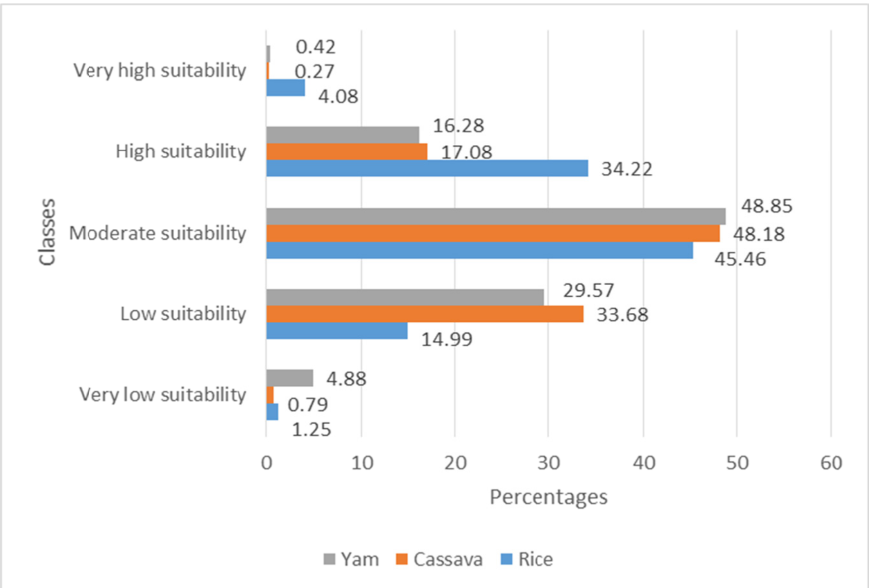

Figure 8. Suitability classes for rice, yam, and cassava in the study area

The study has dealt with crop suitability mapping for the promotion of rice, cassava, and yam cultivation in Benue State. The study utilised GIS and remote sensing methodology including an assessment of climate, soil, and crop cultivation variables. In order to draw focus to the improvement of crop cultivation in the study area, suitability maps have been produced to highlight areas most suitable for crop cultivation and especially the cultivation of rice, cassava, and yam. It is expected that farmers' cooperative societies and policy makers will utilise the information presented to improve decision making methods on choice of crop cultivation.

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