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Suitability of Large Scale Jatropha *Curcus* Cultivation in Edo State: A Preliminary Assessment Using the Analytical Hierarchy Process (AHP) Method

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Abstract

The aim of this study is to assess the suitability of agro-ecological regions for *Jatropha Curcas* cultivation using GIS and Analytical Hierarchy Process (AHP) tools. Rainfall amount and temperature data were collected from the Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation, Oshodi, Lagos and Climate Prediction Centre of the United States Agency for International Development (USAID) for a period of 3 years (2010 - 2012). Rainfall amounts in Edo state ranges between 1400mm-1500mm in the south most part of the state and decreases to 1200mm-1350mm at the centre of the State and 1000mm-1200mm in the north. These values fall within the optimal range for *Jatropha* cultivation. There are six (6) to seven (7) months of moisture adequacy in Edo state usually from April/May – September/October. Within this period, there is adequate moisture supply to satisfy the consumptive needs of Jatropha cultivation during its vegetative and flowering/fruiting stages. There are two rainfall peaks in Edo state namely May/June and September/October which guarantees two-times planting seasons, namely April planting season prior to the first rainfall peak in May/June and July/August planting season before the last rainfall peak (September/October). Runoff peaks in Edo state occur between September and October. Within this period soils are at field capacity and not suitable for onset of Jatropha cultivation. Analysis of slope conditions in Edo state showed that vast expanse of land in the state may be categorized as highly suitable with small patches of moderately suitable locations in the north. Soil condition in Edo state showed marginally suitable for soils in the mangrove region, southernmost part of the state and moderately suitable for hydromorphic soils of the Owena Basin west of the State. Finally, the result of multi-criteria analysis showed that Edo state can be grouped into two main classes of suitability namely; moderately and highly.

Key Words: Jatropha Curcas, Energy production, Climatic factors, moisture storage, Soil condition

Introduction

In many countries, the use of energy crops, including the use of Jatropha as feedstock for biodiesel has increased significantly (Rowe *et al*., 2007). *Jatropha curcas* is highly adaptable to different ecological conditions. It is well adapted to most tropical conditions at annual rainfall range between 250 and 3000 mm and optimal range of 1000mm – 2000m (Foidl *et al*., 1996). Average temperature of 20-28°C has been considered suitable in the seed provenance. In addition, Jatropha can grow in different soil types particularly sandy soil which facilitates the root formation (Heller, 1996). These conditions put Nigeria in a better position for large scale biodiesel production using *Jatropha* as feekstock. However, for the purpose of planning and decision making regarding a large-scale cultivation of *Jatropha curcas* for fuel, detailed assessment of ecological and economic information for identifying the strength and limitation of the land for energy crops are fundamental. Studies have shown that all crops have specific growth requirements and a first step towards evaluating the potential of any energy crop is to match its particular requirements with the soil and climate characteristics of the area under consideration among others (FAO, 1976; Sys *et al*., 1990).

Furthermore, it has been shown that the suitability of energy crop production and their associated social, economic and environmental impacts are site-specific. Broad generalizations about the energy crop's situation across regions, or even within the same country, have often resulted in misleading conclusions, poor planning and ineffective implementation (Dovorin *et al*., 2010). The suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use (FAO 1976). Land suitability analysis therefore answers the question what is to grow where?

In spite of the relevance of *Jatropha curcas* as energy crop, study has shown that there are few studies in developing countries on the extent of its production potentials (GEXSI, 2008a). In 2008, the organization on Global Exchange for Social Investment (GEXSI) found that approximately 900,000 ha of *Jatropha curcas* was cultivated globally. The major parts of these cultivation areas were found in Asia (85%) and 13% found in Africa. For the year 2015, the study projected a global dissemination of *Jatropha curcas* on 13 million ha. For Africa, the study projects an expansion of cultivation area from 119,000 ha in 2008 to 2’000’000 ha in 2015 (GEXSI 2008b). In order to attain this goal, it is therefore necessary that more objective and accurate information on the suitability of land resources over time and space for energy crops be initiated to guide biodiesel development in developing countries including Nigeria. In recent time, many GIS-based land suitability analytical approaches have been developed to enhance the assessment of suitability factors (Baniya, 2008). Unfortunately, in Nigeria, studies with the aim of mapping the potentials land for large scale bioenergy crop cultivation has been scanty and far in between. In southern Nigeria, no such study has been conducted. This has informed the need for the present study.

Materials and Methods

Study Area

The State is located between longitudes 5° E and 6° 42" and latitudes 5° 45" N and 35" N. It is bounded by Kogi State to the North; to the South by Delta State and by Ondo State to the West (Fig. 1). Edo State has a total land area of 19,281.93 square kilometers with eighteen (18) Local Government Areas. Edo State experiences the humid tropical climate according to the Köppen climatic classification scheme. Rainfall in the area depends on the interaction of the tropical maritime (mT) and tropical continental (cT) air masses which meet along the Inter-Tropical Divergence (ITD). The annual rainfall in the north occasionally exceeds 2000mm, with a bimodal distribution. The first peak occurs in July with monthly precipitation of 344.7mm and the second in September with 457.2mm. The highest mean monthly temperature of 29.1°C is recorded in March and the lowest of 24.4°C in June. In the southern part of the state, rainy season begins in March/April and ends in October/November. Rainfalls are usually of high intensity with double maxima and a dry little spell in August usually referred to as ‘August Break’ (Atedhor *et al.*, 2010). Annual rainfall amount in the southern part of Edo State ranges from 1800 to 2780mm.

The soil of Edo north can be classified as ferallitic, being highly weathered, leached and having high proportion of kaolinite and free iron oxide, but generally without a lateritic iron pan layer (Areola, 1978). The original vegetation of most part of Edo north may be classified as equatorial rain forest. However due to urban expansion this natural vegetation cover is transcending to derived savannah forest. In the southern part, the soil is of dark reddish brown with a top cover of 0.0-50 cm.

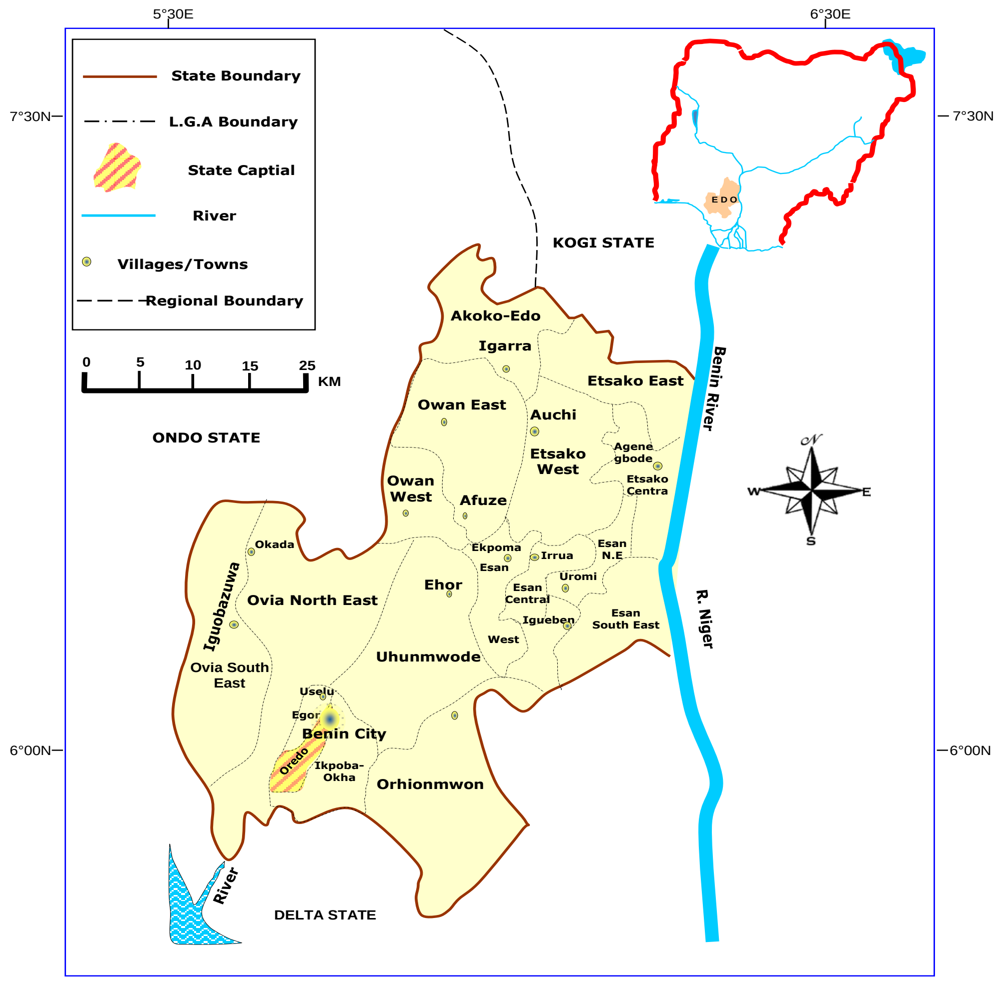

FIG. 1 MAP OF EDO STATE SHOWING THE STUDY AREA

Source: Ministry of Lands and Survey, Benin City 2009

Data collection

To model the suitability of *Jatropha curcas* in Edo State, data on precipitation, water balance components, slope and soil characteristics are needed. Furthermore, a Digital Elevation Model (DEM) was used in the study, which is the basis for the determination slope factor.

Climate data

Rainfall amount and temperature data were collected from the Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation, Oshodi, Lagos and global Climatic Research Unit CRU TS 3.0 dataset, which covers the entire globe for the period 1901-2012 on a 0.5 x 0.5-degree grid (Mitchell *et al.,* 2003). The climatic data collected was for a period of 3 years (2010 - 2012) for Abudu, Igogbo, Benin City, Uselu, Igbuobazuwa and Okada stations in Edo south, Ehor, Ekpoma, Igueben, Irrua, Uromi, Ubiaja, Sabogidda-Ora and Afuze stations in Edo Central and Igarra, Auchi, Fuga and Agenegbode stations in Edo North. Quality control of CRU datasets is discussed in detail by New *et al* (2000) and Mitchel and Jones (2005). In addition, the suitability of CRU data sets was verified by correlating data from this source with measured data from the Nigerian Meteorological Agency.

Soil data

In the absence of soil database for Edo state, the Harmonized World Soil Database (HWSD) was used. For the purpose of this study, only "soil texture attribute was used. Over 16000 different soil mapping units are recognized in the Harmonized World Soil Database (HWSD) which is linked to harmonized attribute data. Reliability of the information presented in the Harmonized World Soil Database has been confirmed in studies in North America, Australia, West Africa (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009).

Ground Check for Soil Textural Characteristics

Ground check involves taking soil samples at various locations and subjecting them to laboratory tests to determine their textural characteristics against the Harmonized World Soil Database which is available in the FAO/UNESCO, 1970-1980. Soil samples were collected randomly from boreholes using a shovel. At each borehole, samples were collected at different depths (0-15 cm and 15-30cm). Collection was done by Technical Team of the National Centre for Energy and Environment, University of Benin. Samples were carefully stored in bags and transported to Laboratory, for analysis. The study found 0.52 degree of association between the FAO/UNESCO, 1970-1980 Harmonized World Soil Database and soils from study area.

***Digital Elevation Model (DEM Data*)**

A DEM with a resolution of 90m at the equator is available free of charge on the homepage of the CGIAR Consortium for Spatial Information (CGIAR-CSI). This data was acquired during the *Shuttle Radar Topography Mission* (SRTM) (Jarvis *et al.,* 2008). The needed tiles of the *SRTM 90m DEM version 4* product were downloaded in imagine Image format. The data is projected in a Geographic (Lat/Long) projection, with the WGS84 horizontal datum and the EGM96 vertical datum (Jarvis *et al.,* 2008). For the slope computations to be in linear units of meters, the DEM was projected with the *Project Raster tool (Data Management toolbox)* in *ArcGIS* into UTM 32N. Then, slope classes were generated using the *Slope tool* out of the *Spatial Analyst toolbox.* The slope is represented in degree.

Multi-Criteria Function

Multicriteria decision making (MCDM) method exposes and integrates multiple choices in order to solve “real-world” GIS-based planning and management problems. In this study, the Analytical Hierarchy Process (AHP) which is based on pairwise comparisons on a ratio scale was used (Saaty, 1980). The AHP uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Saaty, 1980).

Determination of Weight and Score for Each Factor

Weight and score for each factor chosen within the study were determined based on the AHP (Saaty, 1980). This method evaluates the relative significance of all factors involved by assigning a weight for each of them in a hierarchical order. For the last level of the hierarchy, a suitability score (or rating) for each class of factors is given. The method is usually implemented using the pairwise comparison technique that simplifies preference ratings among decision criteria. In this study, experts’ opinions were used to calculate the relative importance of the involved factors (or criteria). The relative importance of each factor was compared to one another. Results of the comparison (for each pair of factors) were described in term of integer values from 1 to 9 based on Satty’s scale where a higher number means the chosen factor is considered more important than the other (Table 3). The overall results were kept (and managed) in the form of a pairwise comparison matrix where the relative weight (and score) for each critical factor could be derived (Table 4).

Table 2: Pairwise Scale (After Satty 1977)

Numerical values	Verbal judgement of preferences
1	equally important
3	slightly more important
5	strongly more important
7	very strongly more important
9	absolutely more important

2, 4, 6, 8 => Intermediate values

In Multi-Criteria Evaluation using a weighted linear combination, the assigned weights need to be summed up to 1 for each category/subcategory defined. However, each factor in the final layer had their suitability scores presented in the standardized format ranging from 1 (least suitable) to 3 (most suitable). The overall result of the weights and scores for each factor involved in each hierarchical layer is shown in Table 3.

Table 3: Reciprocal Matrix for Determining Weights

FACTOR	RAINFALL	SLOPE	SOIL
Rainfall	1	5	1/3
Slope	1/5	1	1/7
Soil	3	7	1

To verify the credibility of the relative significance used, the consistency ratio (CR) was also calculated. This value indicates the probability that the ratings were randomly assigned (Saaty, 1980). Consistency Ratio is the ratio of the consistency index to the corresponding random index:

$CR = CI / RI(n)$,

Where CI denotes the consistency index

RI the random index

n is the number of criteria or sub-criteria in each pairwise comparison matrix. According to Hossian et al (2007) if the CR is smaller than 0.10 then the degree of consistency is acceptable. The value of the CR was found to be 0.07 which is acceptable.

Table 4: Standardized Factors and weights assigned

S/N	FACTOR	WEIGHT	VALUE	SUITABILITY	SCALE
1	Rainfall	28% (0.28)	3	Highly suitable	1000 – 2000mm
			2	Moderately Suitable	700 – 999mm
			1	Marginally Suitable	300– 699mm
2	Slope	7% (0.07)	3	Highly suitable	$0^o – 15^o$
			2	Moderately Suitable	$15.1^o – 30^o$
			1	Marginally Suitable	30.1^o – above.
3	Soil	65% (0.65)	3	Highly suitable	Sandy Loamy
			2	Moderately Suitable	Sandy-clay-loamy
			1	Marginally Suitable	Clay-loamy
		100% (1)			

Results and Discussion

Suitability maps for the different suitability criteria for *Jatropha curcas* cultivation in Edo state are presented below. Rainfall distributions within a year in Edo State during the period under study are shown in Figures 2 to 5. Annual rainfall in Edo state showed marked variability in terms of spatial and temporal patterns.

Fig. 2: Rainfall Distribution over Edo State (2010)

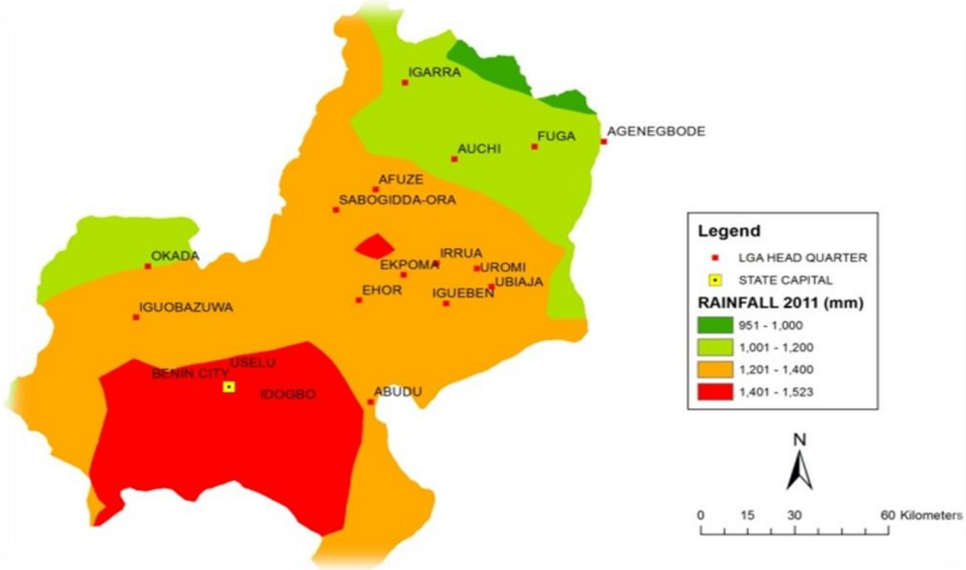

Fig. 3: Rainfall distribution over Edo State (2011)

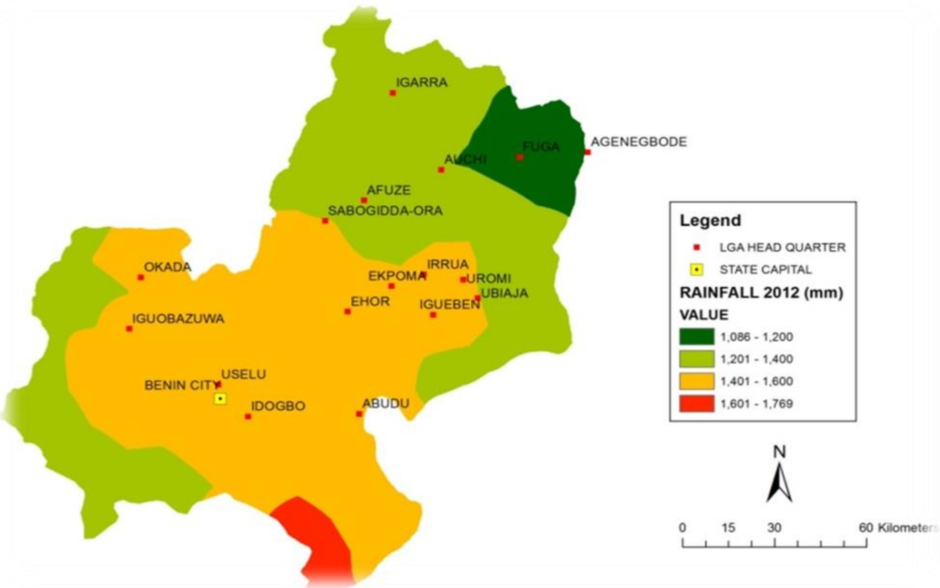

Fig. 3: Rainfall distribution over Edo State (2012)

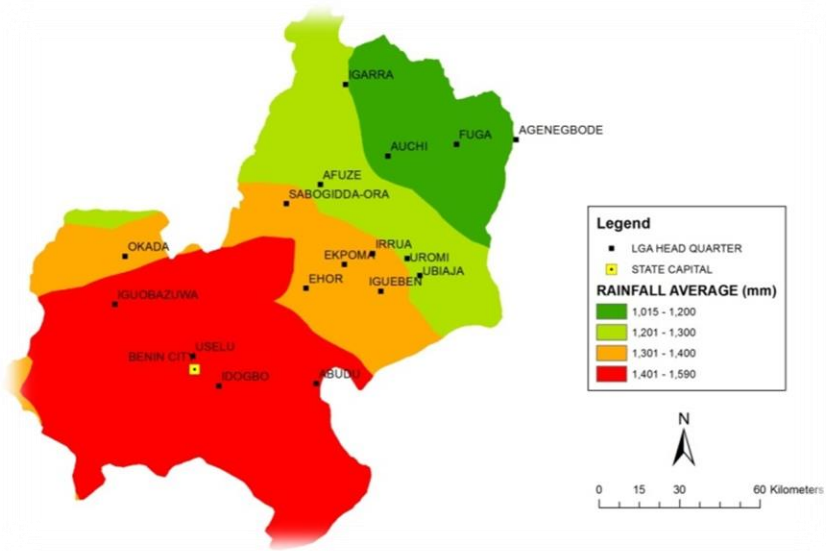

Fig.5: Rainfall distribution over Edo state (2010-2015)

In 2010, rainfall was highest in the southern part covering a large portion of the state which witnessed rainfall amounts between 1,401-1718mm stretching from the southernmost part of the state to Ehor, Ekpoma in the central and to the northern part where rainfall amount was recorded at 936-1000mm in Agenegbode (Fig.2). In 2011 there was a remarkable deviation from the rainfall trend (2010 rainfall year).

Unlike the 2010 rainfall pattern, few areas witnessed rainfall amount above 1400mm. however a considerable portion of the state received rainfall amount above 1200mm including locations that received very high rainfall amount of 1400mm and above in 2010 (Fig.3). In 2012, rainfall amount above 1500mm was confined to a very small portion of the state essentially the mangrove swamp area. Rainfall amount (1401-1600mm) spread through the south-eastern part of the state up to Sabongidda-Ora and Ubiaja towns before a discontinuity making way for rainfall amount, between 1200-1400mm stretching from Afuze town to Igarra town. At the southwestern portion of the state, there is a continuation of rainfall amount ranging between 1200-1400mm. Rainfall was highest in 2012 rainfall year when compared to other rainfall years in the study area (Fig.4).

In Fig. 5, there are more rains ranging from 1400mm and above in the southern portion of the State. This pattern is however terminated towards the centre by rainfall amounts between 1300 to 1400mm up to Irrua town. In the northern part of the state, rainfall amount was observed as 1000-1200mm. With a minimum rainfall of 936mm and maximum rainfall of 1770mm, it can be said that rainfall amount does not present restriction to *jatropha curcas* cultivation in the state, since the optimal range as adopted in this study range is 1000-2000mm (FAO, 1976; ICRAF 2009).

Analysis of suitability based on slope condition revealed that Edo state maybe categorize into two slope conditions namely areas of highly suitable for cultivation of *Jatropha curcas* and areas of moderate suitability for *Jatropha curcas.* There is an extensive area in Edo state which may be considered suitable for *Jatropha curcas* cultivation based on slope condition.

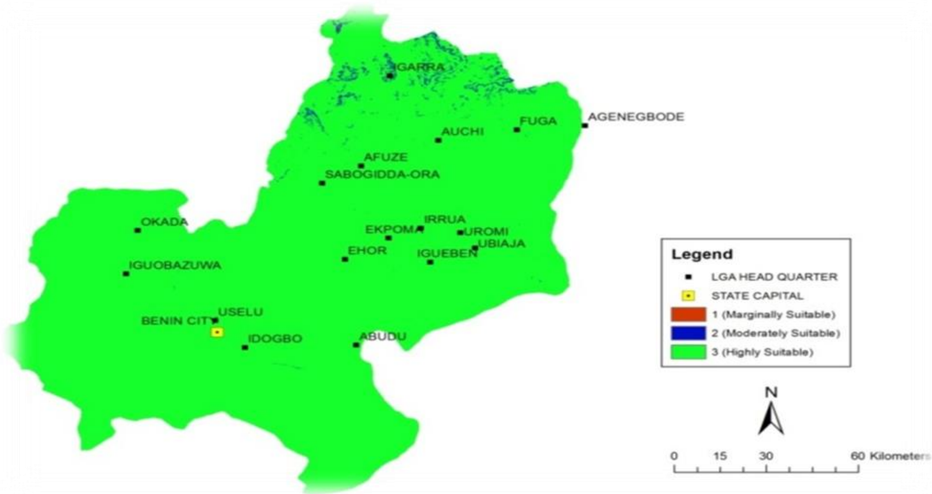

Fig. 6: Slope conditions over Edo State

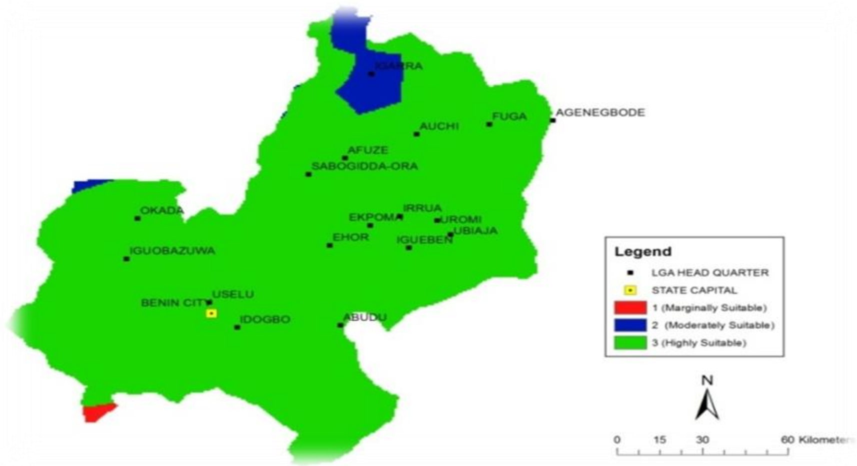

Fig. 7: Soil textural classes over Edo State

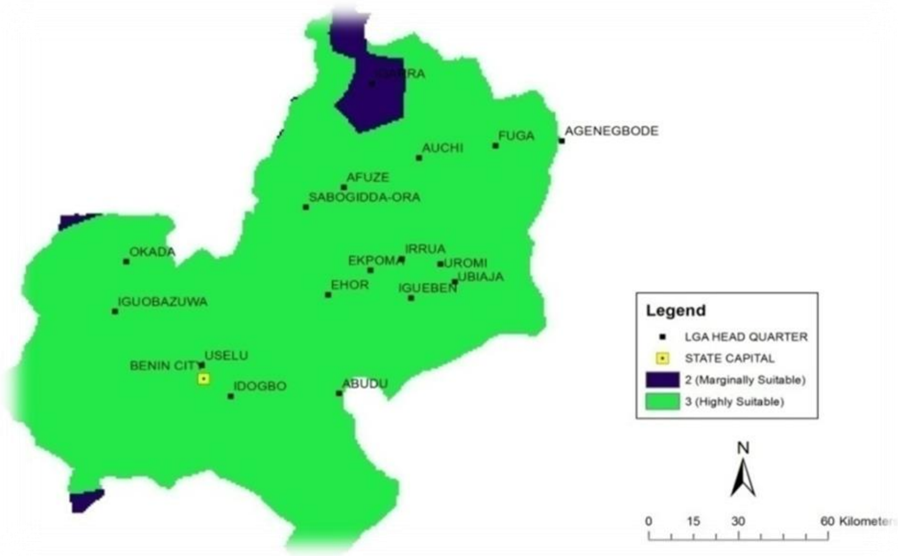

Fig. 8: Suitability conditions based on multi factors (rainfall, slope and soil) over Edo State

These include locations stretching from the southernmost part of the state up to the central part of the state. Slope condition of these locations was determined to range from 0-15º which is considered highly suitable according to slope classification adopted in this study. Two classes of slope condition were found in Edo north. In the northeast portion of the state, observed slope condition may be considered suitable for *Jatropha curcas* cultivation. However, in the extreme north of the state, there are small patches of areas in the class of moderate suitability (15.1-30º) with an interspace of highly suitable areas (Fig. 6). There are three classes of suitability based on soil characteristics (texture), namely marginally suitable, moderately suitable and highly suitable in Edo state. The marginally suitable areas of the state include the mangrove portion of the state due to poor infiltration rate of the dominant hydromorphic soils (Fig. 7). Study has shown that soils with high tendency for water logging are not suitable for *Jatropha curcas* cultivation unlike soils with good infiltration rate (Brittaine and Lutaludiu, 2010). In general, a large expanse of soil in Edo state was observed to be highly suitable for *Jatropha curcas* cultivation. There are however very small patches of moderately suitable areas for *Jatropha curcas* cultivation in the north and extreme west of the state. These areas (Highly suitable) are considered highly to moderately suitability because the dominant soils have good infiltration rates with less tendency for water logging unlike the hydromorphic soils in the mangrove areas of the state. The moderate nature of soils in parts of Edo north and west may be attributed to their high tendencies for waterlogging due to the natures of deltaic soils in the north and hydromorphic soils of the Owena river basin in the west. It was observed that 95% of areas investigated may be considered highly suitable for *Jatropha curcas* cultivation based on rainfall amount, soil and slope characteristics. These areas include a long extension from the southernmost part of the state to the north. There remaining 5% of the areas in Edo state may be considered marginally suitable for *Jatropha curcas* cultivation (Fig. 8).

Conclusion and Recommendations

The study investigated the suitability of geographical locations in Edo state for large scale cultivation of *Jatropha curcas* for biodiesel production in Edo State. The study however is confined to land resources appraisal, analysis of rainfall, temperature and soil moisture patterns of selected locations in Edo state. These include Abudu, Benin City, Idogbo, Iguobazuwa and Okada in Edo south, Ehor, Igueben, Ekpoma, Irrua and Uromi in Edo central and Afuze, Auchi, Agenegbode, Fuga, Igarra in Edo north. GIS-based land suitability analytical approach coupled with Analytical Hierarchy Process (AHP) was used in the study to enhance the assessment of suitability factors. Findings from this study will serve as guide to farmers, biofuel developers, policy makers on locating specific land areas obtain reasonable estimates of rainfall, moisture availability, slope, soil characteristics which influence cultivation of *Jatropha curcas.* Secondly, maps provided in this study will provide regional views of production potentials and will contribute to decision-making on support for handling and/or processing facilities. Notwithstanding, for comprehensive appraisal of locational potentials for *Jatropha curcas* cultivation in the state, it is recommended that environmental, social and economic surveys be undertaken to establish; willingness of the community to participate in Jatropha cultivation programmes; Economic viability of large scale cultivation of *Jatropha curcas* and environmental impacts of large scale cultivation of *Jatropha curcas* in Edo state.

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