Assessment of Biomass Energy Potentials and Appropriate Sites in Nigeria using GIS Computing Strategy

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Abstract— **The geographical variability of biomass energy is an issue that requires the optima location of biomass energy facility. This paper presents a multicriteria GIS-based assessment of biomass energy potentials and appropriate siting of biomass plant in Nigeria. The study applies the weighted overlay multicriteria decision analysis method. Crop, and forest areas; settlement (energy supply areas); shrub/grass lands; barren land; waterbodies; distance from water sources; road accessibility; topography; and aspect are the criteria that were considered for locating the biomass facility in this study. The results suggest that the theoretical, technical and economical energy potentials of crop residues are highest in the north-east region of Nigeria and estimated at 1163.32, 399.73 and 110.56 PJ/yr, respectively, and least in the south-east at 52.36, 17.99 and 4.98 PJ/yr, respectively. The theoretical, technical and economical energy potentials of forest residues are highest in the north-west, estimated at 260.18, 156.11 and 43.18 PJ/yr, respectively, and least in the south-east at 1.79, 1.08 and 0.30 PJ/yr, respectively. The GIS computing was able to identify the most suitable areas for siting biomass plants across Nigeria, in the Northern part of the country, and include; Niger, Zamfara, the Federal Capital Territory, Nassarawa, Kano, Kebbi, Kaduna and Borno state.**

Keywords— Biomass resources, residues, GIS technology, clean energy, optimal biomass plant location, carbon neutrality.

I. INTRODUCTION

Biomass resources from crop and forest residue have great potentials and are very good sources of cleaner energy, especially in Nigeria, where sustainable and clean energy has been a major challenge. Biomass is not only a cheap source of energy; it is readily available and considered to be carbon-neutral. Energy generation from biomass can be made possible by utilizing biomass to energy conversion processes such as gasification, briquetting, biogas digestion, direct combustion etc. Nevertheless, biomass application has been limited to heating, cooking and lighting not only in Nigeria, but in most developing economies. The continuous release of atmosphere contaminating gases such as methane (CH4), carbon monoxide (CO), and Carbon dioxide (CO_2) from the uncontrolled burning of biomass residues which otherwise could have served the purpose of energy generation in Nigeria, is a - - great concern. Also, there has been a continuous increase in energy demand which the conventional form of energy generation is not able to meet, not to mention the adverse environmental implications of the conventional energy sources. Thus, it becomes important to harness renewable energy sources; biomass energy, in this case, which is not only sustainable but can also provide affordable and clean energy.

To assess and analyze biomass energy, the Geographic Information System (GIS), Remotely Sensing and Global Position System (GPS) data [1] are critical tools. The GIS is a very good data collection and survey tool that is capable of working with georeferenced database and handling volumes of data, performing arithmetic and mapping out results obtained by distributed maps of different variables. The remote sensing tool can be used to capture Landsat imagery and other relevant data.

Studies of GIS assessment of biomass energy source has been ongoing. Voivontas et al. [2] developed a GIS support system to identify the distribution of biomass for the purpose of electricity generation. Key parameters that were considered include; the biomass plant facilities, locations, plant capacities and usable spatial biomass potential distribution. Papadopoulos and Katsigiannis [3] performed a GIS-based analysis and developed a computer program that identify optima biomass plant site locations based on the available biomass resources and other energy-related parameters. Ranta [4] carried out a GIS based studies on biomass potential assessment and determination of appropriate locations for biomass power plant construction. Bennui et al. [5] conducted an integrated GIS-based multi-criteria decision-making study on suitable site selection research of wind turbines installation in Thailand. In the study, the Analytical Hierarchy Program (AHP) method was utilized for weighting important criteria based on their level of importance. Shi et al. [6] employed remote sensing (RS) and GIS to evaluate feasible areas to set-up new biomass plants for energy generation in Guangdong, China. The model utilized information from field survey, statistical data (from government), ecological and economic modelling, to determine the biomass quantity and its distribution. Fernandes et al. [7] utilized the GIS tool to assess biomass energy potential and uses of crop and forest residues in Marvão, Portugal. In the study, it was proposed that Marvão can produce an approximately 10.6 ktonnes of residue annually, which is equivalent to about 106 TJ, annually. Based on the biomass energy potential assessment and energy demand in Marvão village, Portugal, the biomass to energy-based system was more beneficial both economically and environmentally to investors, when compared against the fossil-fuel heating system.

Going by the studies in the open domain, GIS-based analysis is capable of analyzing both spatial and non-spatial data, and capable of carrying out a multicriteria decision process. However, optima mapping of biomass energy facility has not been considered in Nigeria. Yet, biomass residues are abundant in the country, and capable of clean energy generation to support the Nigerian bio-energy policy. This research therefore presents a multicriteria GIS-based assessment of biomass energy potentials and appropriate siting of decentralized biomass plant in Nigeria. Ten criteria were considered and include crop areas, forest areas, settlement (energy supply areas), shrub/grass lands, barren land, waterbodies, distance from water source, road accessibility, topography (slope) and aspect to verify the appropriate biomass-plant location considering the spatial distribution of biomass-resources. It applies the weighted overlay multicriteria decision analysis to obtain the feasible region for siting biomass facility in the context of providing sustainable, affordable and clean energy to support the UN SDGs, Paris agreement and other climate mitigation pledges.

II. MATERIALS AND METHODS

The GIS tool was used to assist in the resource assessment. The ArcGIS was used to conduct the GIS analysis. Remotely sensed data like the Land Used Land Cover (LULC), Digital Elevation Model (DEM), Global Positioning System (GPS) and other primary and secondary data were gathered, integrated into the ArcGIS platform and analyzed to produce GIS maps showing the biomass potential, and further analyzed to display suitable areas for siting biomass plants in Nigeria based on specific criteria. Ten criteria were considered in this analysis; crop areas, forest areas, settlement (energy supply areas), shrub/grass lands, barren land, water bodies, distance from water source, road accessibility, topography (slope) and aspect.

NDVI which stands for 'Normalized Difference Vegetation Index' was employed to analyze the Land Use Land Cover data which include the crop areas, forest areas, settlement (energy supply areas), shrub/grass lands, barren land, water bodies data. The NDVI quantified the vegetation data that are strongly reflected (near-infrared) and those that are absorbed (RED). The estimation was done by dividing the difference between the near-infrared (NIR) and RED channels, with the sum of the near-infrared (NIR) and RED channels (NDVI=((NIR-RED))⁄((NIR+RED))). This value ranges from -1 to +1; the negative values show tentatively high-water regions, while values close to +1 indicates high dense green leaves.

The remotely sensed data (raster data) collected (in pixel form) were analyzed separately in spatial analysis and visualization due to their unique structure and format. GPS data which are generally saved in '.GPX' format was imported into GIS platform and converted into shapefile formats. Primary data with specified location, X, Y coordinate (longitude and latitude) data was also imported into the GIS. All these data were integrated into the GIS domain to form a geodata base system, which were queried and analyzed to create good business and smart decision that are databased driven.

Geoprocessing, statistical analysis, symbolizations and other forms of analysis was then performed on the various data collected and synchronized. The results obtained were presented in form of maps showing the suitable areas to locate biomass plant systems across the country.

2.1 Geographic Location and Demographic Data

Nigeria is situated between longitude 2.9833 – 15.0000 [E] and latitude 3.2500 and 13.5000 [N] in the West Africa region. It shares boundary with Chad and Cameroon to the east, Benin Republic to the west, Gulf of Guinea to the south and Niger to the north. It falls in the tropical region with seasonally humid climate. Nigeria has the largest population in Africa and 7th largest in the world with about 200 million people [30] and land mass of about 920,000 km^2. Nigeria has a total number of 775 Local Government Areas (LGA), contained thirty-six (36) states, including the FCT which are section into six (6) geopolitical zones. Figure 1 shows the map of Nigeria, including the various states and the geopolitical zones, with the North Central (NC), North East (NE), North West (NW), South East (SE), South South (SS) and South West (SW) symbolized with Olivine yellow, Rhodolite rose, Electron gold, Topaz sand, Autunite yellow and Sugilite sky colorations, respectively.

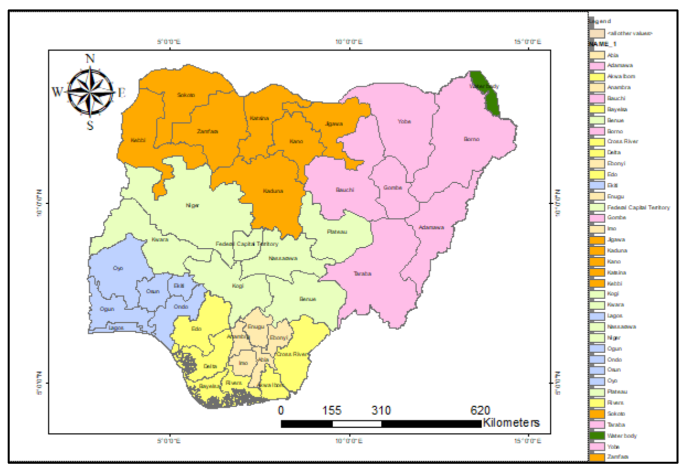

Fig. 1 Map of Nigeria Showing the various States across the country.

2.2 Remote Sensing using Normalized Difference Vegetation Index (NDVI)

NDVI is used to quantify vegetations by estimating the vegetation which are strongly reflected (near-infrared) and vegetations that are absorbed (RED). Its value ranges between -1 to +1. Negative values indicate high possibility of water, while values close to +1 indicates high possibility of dense green leaves, which are high temperature and tropic rain-forest areas. Values from; -0.28 to 0.015 indicates area characterized by water, 0.015 to 0.14 indicates built-up areas, 0.14 to 0.18 stipulates barren lands, 0.18 to 0.27 stipulate shrub and grass lands, 0.27 to 0.36 specifies areas with sparse vegetations, while ≥ 0.36 specifies areas with dense vegetation.

NDVI Calculation

NDVI makes use of near-infrared (NIR) and RED channels to estimate the feature of a given area, and it is given as;

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

2.3 Simulation and Optimization software

Simulation tool is utilized for evaluating the best location in siting the biomass plant. The optimal site location may be obtained by using GIS simulation software for the analysis based on stipulated criteria with assigned weighted values based on their level of importance.

2.3.1 Criteria for site selection of the biomass plant site

A total of ten criteria were used for the selection of the optimal biomass plant locations, they include : – *Crop and forest areas*: these are the most pertinent criteria that shows the availability of the biomass residue feed which will serves as fuel for the running of the biomass plant; *settlement:* this is another important criteria that entails areas where the energy generated will be supplied/utilized; *shrub/grass lands, barren land and waterbodies:* these criteria feature the grass land, barren land and waterbodies in the study area; *distance from road*: accessibility of the site is vital for the supply of feed, transportation of biomass plant facilities and carrying-out of maintenance of the biomass plant by professionals when require; *availability of water*: this is needed for the cooling of the plant system and heat exchange. Moreso, the waterline can also serve as a means of transportation of biomass plant facilities, supply of feeds and other forms of site accessibility; the *slope*: a stable or flat landscape is critical for the siting of the CHP plant. This will reduce the cost of sand-filling or levelling of the land at the initial stage of preparing the biomass plant site; the *aspect*: sunlight is required to fall on the plant at a good temperature value (about 15 ^{0}C) which is vital for the pre-treatment of biomass residue and drying before been feed as fuel into the biomass plant.

2.3.2 Reclassification of criteria

To identify locations with high prospect, the LULC was classified into various categories. The reclassification of all the criteria used to determine the best location for siting the biomass CHP plant is done in different level, depicting regions with the very-high, high, moderately-high, low and very-low potentials. Based on the potential level of the criteria, a reclassification ranges of 1–10 is assigned, to indicate the potential level from the least to the highest.

2.3.3 Weighted Overlay Analysis

The weighted overlay analysis is used to display low – high potential regions using a scale of 1 – 9. The weighted overlap of the crop and forest areas is carried-out base on the reclassified criteria using the weighted overlay tool in the ArcGIS platform. The reclassified criteria are then uploaded into the weighted overlay domain in the ArcGIS platform and assigned a weighted percentage summing 100% based on the influence level of each criterion. The reclassified values are then used to match the scale range value of 1–9 in the weighted overlay domain.

The weighted overall score is computed as;

$$W_{score} = \sum_m^n C_i * W_i \; ; \quad (2)$$

$$i = \begin{Bmatrix} LULC\ resource, \text{distance from road, distance} \\ \text{from water, slope, aspect} \end{Bmatrix};$$

where, W_{score} is overall weighted overlay score; C_i is criteria score of i; W_i is weight value of criteria i.

2.3.4 Suitability Analysis

The weighted overlay result is subjected to further analysis in the Map Analyst tool in Raster calculator section in the ArcGIS domain to get the most suitable area in siting the plant. The suitability area (SA) calculation based on the criteria is performed by using;

$$SA_i = W_i \times LULC \; ; \; i = (crop, forest) \quad (3)$$

where, SA_i represents suitability area, W_i represent weighted vegetation and $LULC$ represents land use and land cover.

Figure 2 Shows the suitability analysis model used to identify the suitable areas for siting the biomass plant

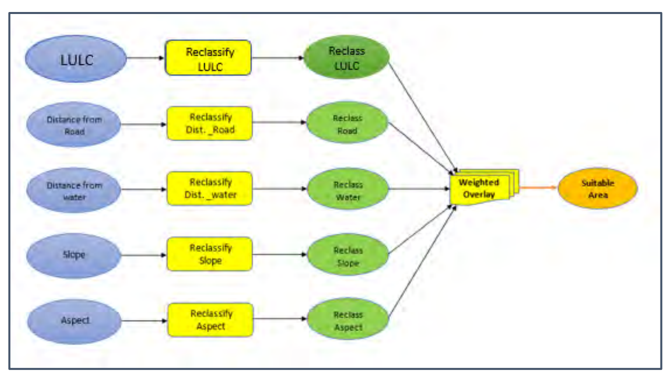

Fig. 2 Suitability Analysis Model.

2.4 Crop/Forest Residue

2.4.1 Theoretical assessment

Theoretical assessment is the maximum amount of biomass resources available for energy generation, aside from those to be used for food or industrial purposes. It considers the specific region, cultivation area, and total biomass yield (estimated utilizing parameters like climatic condition, soil and biomass characteristics) and identifies the annual biomass energy availability from crop and forest residues. The biomass properties are production rate, low heating value (LHV), residue-to-product ratio (RPR) and estimated residue, which is the product of the crop production rate and the mean residue-to-product ratio (RPR). The theoretical energy potential is obtainable from the product of the residue potential (obtainable residue) and the mean energy content of the residue. Hence theoretical energy potential is given as;

$$E_{theoretical} = \sum_i^n F_j * LHV; j = \{crop, forest\} \quad (4)$$

where; $E_{theoretical}$ is theoretical energy potential; LHV is low heating value or mean energy content ($\bar{E}_c$)[kJ/kg]; F_j is residue potential or obtainable residue [k-tonnes] given as

$$F_{crop} = \sum_i^n P * \overline{RPR} \quad (5)$$

where P is crop production [k-tonnes]; $\overline{RPR}$ is mean residue-to-product ratio [-]

For the forest residue, the mass of the various forest products having a volume (m^3) value can be obtained from Equation (6).

$$m_F = \rho \times V \quad (6)$$

where m_F is mass of forest product; ρ is density of forest product and V is the volume of the forest product.

The forest residue can be obtained from Equation (7)

$$F_{forest} = m_F \times RPR \quad (7)$$

where F_{forest} is forest residue, and RPR is the residue-to-product ratio, which can be assumed as 0.72.

The estimated energy content or low heating value (LHV) of wood fuel and wood charcoal can be assumed as 19.5 MJ/kg and 28.0 MJ/kg, respectively.

2.4.2 Technical assessment

The technical assessment has to do with the fraction of the theoretical energy potential which can be converted for energy use. The technical potential is a function of the theoretical residue potential that can be gathered annually. Hence, the availability factor is introduced to account for the residue potential that can be gathered yearly. This availability factor (η) ranges from 0 – 1 and varies from place to place and from the crop residue in the view given as:

$$E_{technical} = \sum_i^n E_{theoretical} * A_F \quad (8)$$

where; $E_{technical}$ is technical potential; A_F is availability factor [–] (ranging from 0 – 1)

The availability factor (A_F) of 0.4, 0.5 – 0.75, and 0.8 were assumed for rice residue, wood residue and oil-palm residues respectively, whereas 0.30 was assumed for the other crop, since the range of values is not available for all agro-crops, which matches with that of Jekayinfa *et al*., [8] and Deng *et al*., [9], at the time of this review. In addition, the availability factor (A_F) of 0.6 was assumed for all the forest residues in Nigeria, in consonance with Jekayinfa *et al*. [8].

2.4.3 Economic assessment

The economic assessment shows the fraction of the technical potential that meets the economic profitability criteria at a given condition. From the literature, the biomass residue collection area has a vital role on the overall cost of electricity generation. When the residue collection area is large, it provides the room for installing a biomass plant with high power capacity, which is cost advantageous. The residue transportation cost to the plant site is an operational cost that forms a significant part of the overall power generation cost. Thus, factors about biomass residue collection, processing and transportation pose constraints on the viability of the biomass residue.

Meanwhile, all available biomass residues cannot be totally used for useful energy; an assumption on the economic radius to identify optimal economic transportation distance becomes pertinent. A good tool that has proven to handle the optimal distance of the biomass residue is the Geographical Information Systems (GIS). The optimal feasible distance varies from place to place and ranges from 30 - 100 km and gives an economic radius of 24 – 59 % of the technical potential. The economic potential can thus be calculated from Equation (9).

$$E_{economic} = \sum_i^n E_{technical} * r \quad (9)$$

where; $E_{economic}$ is economic potential; r is economic radius [%].

In this research, the feasible distance or economic radius is assumed to be 27.66% of the collection area as a first approximation, which is in line with Souza et al. [10] work in Brazil.

III. Results and Discussions

3.1 Land Cover Classification and Analysis

Based on the described methodology, Nigeria NDVI classification range for six LULC derived from Landsat-8 OLI data is displayed in Table 1. The classification range corresponds with those in the literature, aside the initial (water body) and final (dense vegetation) classification range, which variation varies from based on geographical location. The LULC map of Nigeria based on the NDVI classification ranges is presented in Figure 3.

From the Landsat-8 data obtained from USGS, the crop and forest area counts were captured (See Figure 4), and analyzed with the total country's crop production in 2019 and forest production in 2020 based on the states counts to get the estimated crop and forest product respectively across the various states in Nigeria as presented in Figure 5-7. Figure 5 show the Crop and Forest production by state in North-East zone where Borno state features the highest crop and forest producing state (18456427.31 and 4123891.16 tonnes per year, respectively), followed by Taraba (15923044.46 and 3522180.17 tonnes per year, respectively) and then Yobe (14462983.83 and 1904296.22 tonnes per year, respectively). Figure 6 show the Crop and Forest production by state in North-West zone where Kaduna state features the highest crop-

TABLE I. NIGERIA NDVI CLASSIFICATION RANGE FOR LAND COVER

Classification	Label	NDVI Range	Colours
1	Water body	-0.65 – 0.015	Cretan Blue
2	Built up area	0.015 – 0.14	Mars red
3	Barren land	0.14 – 0.18	Topaz sand
4	Shrub and grass land	0.18 – 0.27	Autunite yellow
5	Sparse vegetation (Crop area)	0.27 – 0.36	Light (Quetzel) green
6	Dense vegetation (Forest area)	0.36 – 0.70	Dark (Fir) green

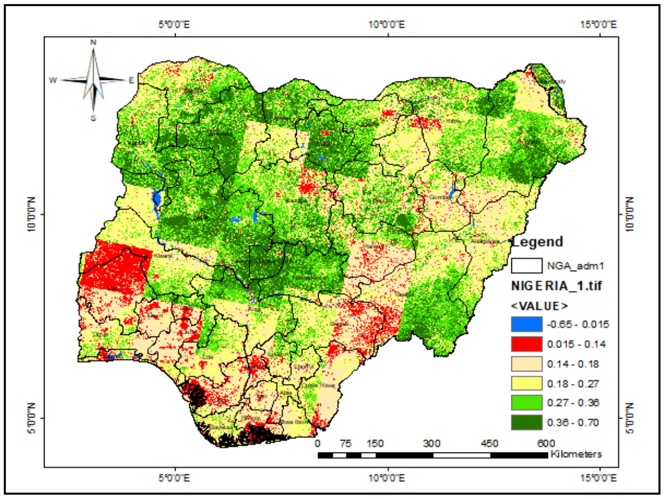

Fig. 3 Nigeria biomass distribution.

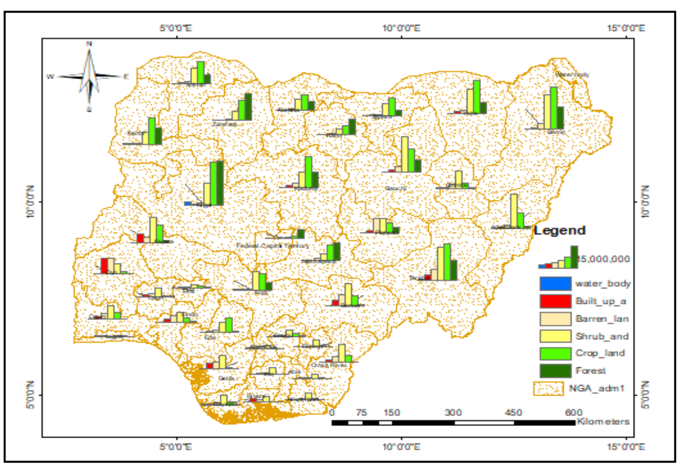

Fig. 4 GIS Bar Chart map of Nigeria LULC Count.

-producing state (13960218.20 tonnes per year), followed by Kebbi (11558167.74 tonnes per year) and then Sokoto (9718616.05 tonnes per year), that of forest production featured Zamfara as highest (4787048.96 tonnes per year), followed by Kebbi (2934235 tonnes per year) and then Kano (2818670.10 tonnes per year).

For North-Central (NC) zone as shown in Figure 7, Niger state features the highest crop and forest producing state (18955373.18 and 8018194.86 tonnes per year, respectively), followed by Kogi (7511411.46 tonnes per year) and then Kwara (7413940.86 tonnes per year) for crop production. For forest production, Nasarawa followed Niger state with 3275121.58 tonnes per year, followed by FCT which was group under NC (1464467.15 tonnes per year) and then Kogi (1464467.14 tonnes per year).

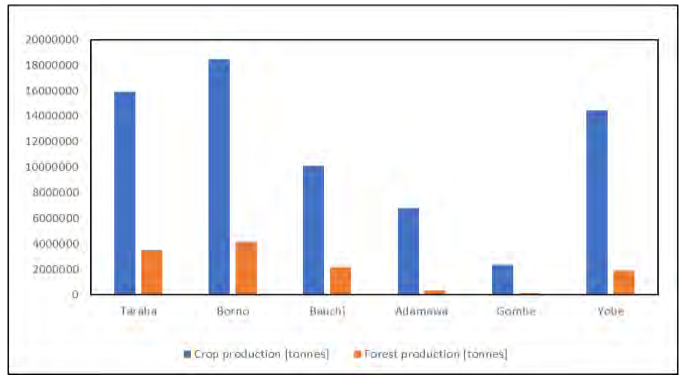

Fig. 5 North-East Crop and Forest production by State [tonnes].

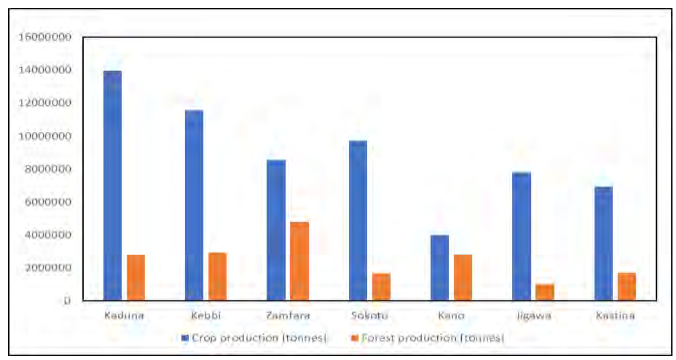

Fig. 6 North-West Crop and Forest production by State [tonnes].

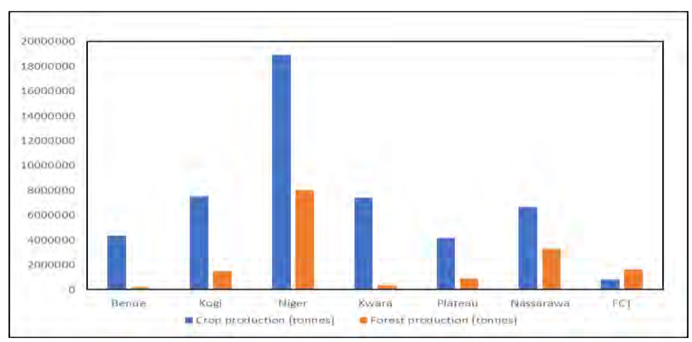

Fig. 7 North-Central Crop and Forest production by State [tonnes].

3.2 Suitability Analysis using Weighted Overlay in ArcGIS

To identify the optimal areas for siting biomass plants in Nigeria, the various criteria considered for the analysis; crop, forest, settlement, shrub/grass lands, barren land and waterbodies areas (embedded in LULC), distance from water source and road accessibility (GPS data) and, slope and aspect (DEM data) were classified into various categories. The reclassification was done so as to make all the parameters dimensionless for easy query and analysis. Figures 8–10 show the reclassification of the criteria used for the suitability analysis in the ArcGIS platform. The classification of was done in five (5) level. The legend with the thick green, light green, yellow, red and blue depicts region with the very-high, high, moderately-high, low and very-low potential respectively. Based on the potential level of the criteria, a reclassification ranges of 1 – 10 is assigned, to indicate the potential level from the least to the highest.

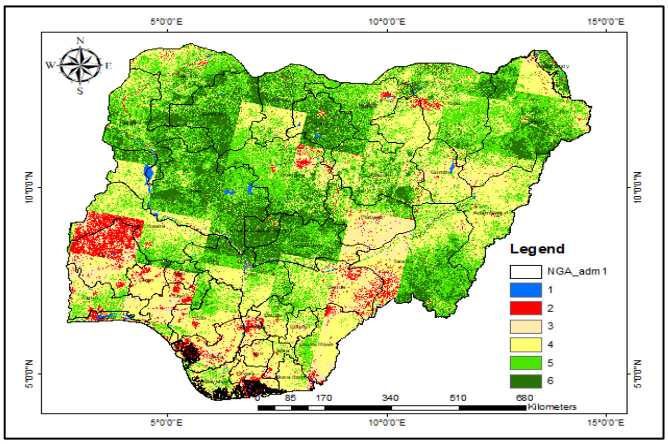

Fig. 8 Reclassified LULC.

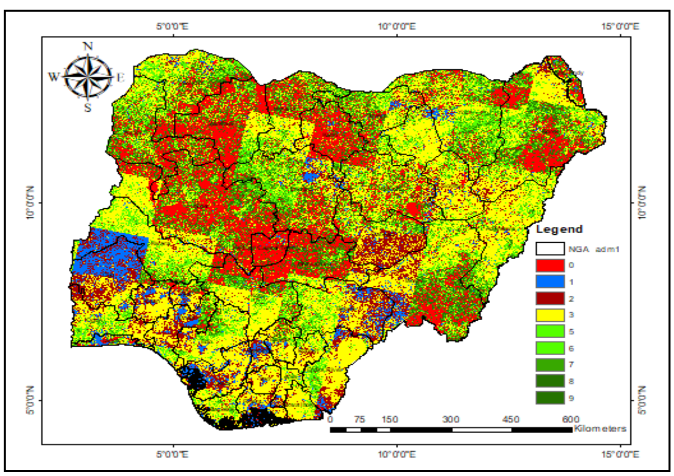

Fig. 9 Reclassified Crop lands.

IV. Conclusion

Biomass residues are attractive feedstock in biomass plant for the purpose of energy generation. Meanwhile, biomass resource estimation is a great task, especially where there is little-to-no data. Utilizing remote sensing application alongside GIS technique can provide high-resolution mapping of the biomass resource distribution across any region of interest. This paper presented a multicriteria GIS-based assessment of biomass energy potentials and appropriate siting of biomass plant in Nigeria. It applies the weighted overlay multicriteria

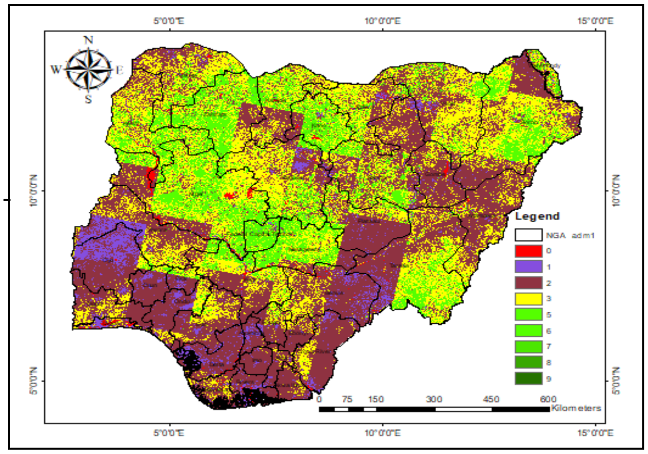

Fig. 10 Reclassified Forest lands.

- decision analysis with criteria which include crop areas, forest areas, settlement (energy supply areas), and shrub/grass lands, barren land, waterbodies, distance from water source, road accessibility, topography (slope) and aspect to optimized the best locations for siting biomass facility in Nigeria. ArcGIS was used to conduct the GIS analysis, while, Remote Sensing and other primary/secondary data were collected and integrated into the ArcGIS platform to form a geodata base system, which was queried and analyze to create reliable and smart decision that are database driven. Key findings reveal that the northern zones (North-East, North-West and North-Central) are the highest crop and forest production zones in Nigeria, and thus they have the highest residue generation in the country.

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