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Chapter

Location Analysis and Application of GIS in Site Suitability Study for Biogas Plant

Emmanuel C. Chukwuma, Chinenye F. Okey-Onyesolu, Daniel C. Anizoba and Joseph I. Ubah

Abstract

Proper livestock waste management and development of robust system for the treatment of the bio-waste has been emphasized and investigated by several searchers. Utilization of bio-waste for bio-energy production is advantageous for sustainable environment and socio-economic viewpoints. This study therefore is essential in providing critical strategy needed in situating bio-energy plants, consideration was made in the application of geospatial technology owing to it wide adoption and numerous advantages. Data for site analysis of biogas plant was obtained from GIS organizations and agency, the biomass generation and sites data was obtained from field survey. The biomass potential was based on paunch content generated in the various 43 abattoirs in the study area. The ArcGIS 10 software was used for all GIS operations and subsequent map production. The final suitability index map was obtained by overlaying the land use suitability map with the biomass spatial density layer. The suitable areas were divided into 4 classes: the Most Suitable, Highly Suitable, Moderate Suitable and Not Suitable. The study indicates that suitable sites are predominant in the East and central region of the study area, this study is essential in developing framework for siting biogas plant.

Keywords: biomass utilization, geospatial technology, location analysis, bio-energy plant, waste management

1. Introduction

Biogas technology is a renewable energy technique from which biogas is obtained from biomass by anaerobic digestion of substrates obtained from Industrial, agricultural and municipal wastes [1]. It is has been acclaimed as an appropriate technology and has received global massive attention recently, and has equally been recommended as a strategy to ease global energy and environmental problems [2]. The potential of biomass as energy source have been estimated by different experts and scientists, using various assumptions and scenarios. For instance, the European Biomass Association (AEBIOM) asserted that the European production of biomass based energy can be increased from the 72 million tones in 2004 to 220 Mtoe in 2020 [3]. As the global trend is advocating for a transition from fossil energy waste to Renewable Energy (RE) based on several socio-economic and

environmental justification, the necessity to embark on a process that ensures that biogas plants are properly sited for energy production is inevitable [4–6].

Siting of biogas plants in strategic locations is a major means of combating some of the environmental challenges of bio-waste generation; that would also be convenient and economically advantageous [7]. One of the biggest barriers in utilizing bio-waste in several countries is the dispersion of livestock farms across a given geographical location. This often leads to generation of relatively small or inadequate bio-waste; also most farms lack the technical capability of operating a farm scale biogas plant. Therefore, based on technical feasibility and economic viability, centralized large scale biogas production has been advocated, however suitable location for the plant requires geospatial consideration and location modeling. Implementation of spatial information technologies such as remote sensing and GIS in addressing this issue have been receiving enormous attention recently, and has been described as appropriate methodology to be utilized in site selection and analysis for biogas plant [8, 9]. The application of GIS as an appropriate tool for site suitability analysis by several researchers is a strong indicator of its capability to resolve location issues [10–12]. This study therefore attempted to present logical framework that would serve as a guide in the process of identifying suitable sites for biogas plant using the power of geospatial technology.

2. Biogas plants for processing agricultural wastes

The biogas plants for processing agricultural wastes are considered as those plants which are utilized in processing feedstock that have agricultural origin. Common or notable feedstock types for this kind of plants are vegetable residues and vegetable, animal manure and slurries, dedicated energy crops, sewage sludge, various residues from food industries etc. [1]. The design and technology of biogas plants differ from one country to another, it depends on the climatic conditions and national frameworks, energy or biomass availability and affordability. Based on sizes, functions and locations, agricultural AD plants can be classified as [3]:

a. Family scale biogas plants (very small scale)

b. Farm scale biogas plants (small or medium to large scale)

c. Centralized/ joint co-digestion plants (medium to large scale)

3. The major driving factors in adoption of biogas technology

The benefits of biogas have increased the adoption rate amongst many countries. Biogas for instance can be utilized after treatment in numerous applications such as provision of electricity and heat generation, connection to the natural gas grid, or as biofuel in vehicles [13]. Several studies on biogas technology potentials and their adoption in various developing countries have shown that biogas technology has high potential in developing countries as an alternative energy source [15–17]. Further discussion on the benefits based on energy production, and environmental concern is discussed below:

3.1 Energy interest

After water, energy is a vital resource required for development globally, the demand is high especially in developing countries. To prevent further growth on

the impact of climate change in most developing countries, it is argued that the energy market in such regions should be based on renewable sources [14]. Biogas as a renewable energy source, have received widespread adoption in Europe, they produce clean energy from organic waste and have framework for increase production [6]. The adoption of biogas technology based on energy interest in developing countries though faced with several barriers, critical information on viability of adoption of biogas technology is receiving attention currently by various researchers in these countries [7, 15–17].

3.2 Environmental interests

Biogas technology is suitable for recycling various types of biomass waste, however the operational conditions and parameters are of interest since this can inhibit the microbial operations necessary for the digestion and may restrict the end use of digested biomass as a bio-fertilizer [18]. It is of major environmental interest that nutrient losses from residue of anaerobic digestion process is minimized when applied to the soil. Additionally, anaerobic treatment in a biogas plant reduces odor nuisances during slurry application, this is a welcome issue by many farmers [19]. Furthermore, biogas technology tend to reduce the potency of greenhouse gases (GHG), by capturing and combusting methane during anaerobic digestion and utilization as cook gas or energy source, GHG has been reported to be 21 times as much atmospheric warming potential as CO_2 [20, 21]. Therefore, global attraction and adoption of biogas technology is hinged on the numerous environmental benefits associated with the technology.

4. Application of GIS in land/location suitability analysis

GIS is a computer system that enhances capturing, checking, storing, integrating, analyzing, and displaying data about the earth in a spatially referenced way. The application of GIS is cross-disciplinary and has been adopted and applied in several fields of science and engineering. Land suitability analysis involves the search for the best location of one or more facilities to support some desired function, it involves the process to ascertain whether the land resource is appropriate for some desired uses and to determine its suitability level. Land suitability refers to the inherent suitability of the land for some specific, persistent uses. Examples range from retail site location to the location of multiple ambulance dispatch points. Land suitability analysis or assessment is achieved by considering certain land features such as hydrology, geography, topography, geology etc. in an enabled environment using GIS technologies [22].

GIS technology has been applied by various researchers in biogas plant location suitability assessment. Few instances are stated here: To develop potential for collective biogas plants in France, GIS was used to geo-reference the bio-resources potential and also to locate the optimal sites at both national and regional scales for the country [23], the final suitability map from the study provided constraint map and the energy potential grid, synthesized in the form of a raster GIS file. The study provided successfully a suitability map using precise geo-location of farms obtained through the analysis of aerial photographs and Landsat imagery used in the identification of crop residues. Similarly, a study was done to determine the optimal locations, sizes and number of biogas plants in Southern Finland, this study analyzed the spatial distribution and amount of potential biomass feedstock for bio-methane production for the study area [24]. In addition to numerous studies on site suitability analysis for biogas plant, a GIS based spatial data mining approach was adopted

to model the optimal location for distributed biomass power generation facilities in Tumkur district, India [25], these studies asserted that GIS is an appropriate and recognized spatial tool for location analysis [23–25].

5. Location and site suitability considerations

Suitable areas for biogas plants are evaluated to avoid close proximity to land features and uses that may be sensitive to the characteristics of utility-scale power production and waste streams. Sensitive land features to be avoided include surface water, wetlands, forests, public lands, highly sloped lands, and developed residential areas, with acceptable slopes of 14° or fewer [26]. Location and site suitability consideration for biogas plant includes:

Slope: Slope is usually derived from the Digital Elevation Model (DEM) of the study area. The lower the slope value, the flatter the terrain; similarly, the higher the slope value, the steeper the terrain, higher slopes is associated with higher cost of land preparation and grading, while an acceptable slope of 14% and below has been suggested [26]. The slope derived from the DEM is used to produce the slope layer.

Biomass availability within the region: Biomass availability is critical for the sustenance of biogas production plants, it is characterized with year to year variability and is subject to non-homogeneity [27]. Several studies have therefore embarked on assessment of biomass availability as preliminary study for biogas plant siting. The biomass resource potential is usually estimated using geospatial technology, the amount of agricultural biomass in the form of crop residues, wood and forestry products, animal waste production etc. are usually estimated.

Density of biomass production: clustering of biomass waste source are usually of economic advantage, it offers several benefits such as ability to maximize labor skills and professionals, reduction in transportation costs, easy access to common infrastructure for production and biomass resource. Areas with high clustering or density of biomass resource are usually considered potential areas for centralized biogas plants.

6. Application of GIS in siting biogas plant for abattoir biomass

An application of GIS in determination of suitable sites is applied here using a typical biomass data collected in Anambra state of Nigeria for demonstration purposes.

6.1 The study area and data collection

The study area for the application of GIS in biogas plant location analysis is Anambra State in South-east of Nigeria. The area is located between Latitudes $05^{0}42^{1}56^{11}$N and $06^{0}45^{1}34^{11}$N and Longitude $06^{0}37^{1}30^{11}$E and $07^{0}25^{1}30^{11}$E, it is surrounded by several states such as Delta State in the West, Imo State and Rivers State in the South, Enugu State in the East and Kogi State in the North. Data used in the study include primary and secondary data collected from various organizations, literatures and individuals. The flow chart of the research method is shown in **Figure 1**.

Figure 1 present the research procedure which usually involves data collection and analysis. Data for site analysis of biogas plant was obtained from GIS organizations and agency, the biomass generation and sites data was obtained from field survey. The figure also shows the major layers used for the study. The primary data was collected from field survey through visit to slaughter houses in the study area,

the biomass potentials was determined using Global Positioning System (GPS) receiver (Handheld GARMIN 76S), the biomass potential was based on paunch content generated in the various 43 abattoirs in the state. The data on the biomass generation capacity of all the abattoirs is shown in the appendix. GPS was used to obtain the geographical co-ordinate of the biomass source for geo-coding in data analysis. ArcGIS 10 software was used for all GIS operations and subsequent map production. The GIS-based thematic maps used for the production of the suitability map include political boundary map layer, Land Use and Land Cover (LULC) map obtained from the Landsat imagery, slope layer and the biomass layer. The land use map for the study area, was generated from the Landsat-7 ETM+ image and then classified to extract the different land uses of the study area using maximum likelihood classification algorithm. The residential and reserved areas in the study area were termed constrained areas and were exempted in the suitability map, the constrain map was made considering several environmental and socio-economical factors. The data types, format, scale and sources is shown in **Table 1**.

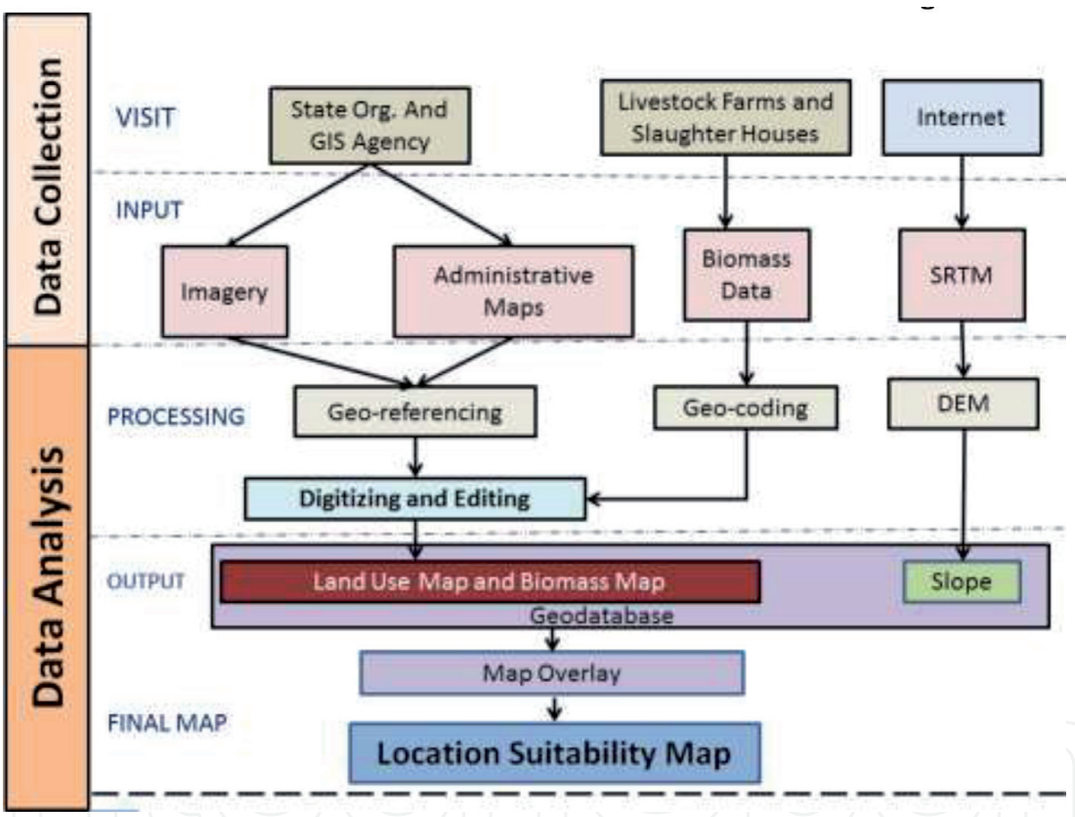


Figure 1.
Flowchart of geospatial modeling for biogas plant.

List of data	Format/Map scale	Source
Land use map	Landsat-7 ETM + imagery	National Remote Sensing Centre, Jos.
Administrative layer map	Arcinfo shapefile/digitalized from 1:50,000 scale map	Survey deparment, Ministry of Lands, Survey and Town Planning, Awka
Biomass source Location map	Arcinfo shapefile	Field trip to farms, Use of GPS
DEM	SRTM imagery at 30 m resolution of 2000	(http://www.landcover.org)

Table 1.
List of data sources and format.

The site suitability was assessed using Eq. 1 below:

$$S_i = \sum W_i X_i \quad (1)$$

Where Wi is the weighted score of the factor, Xi is the suitability rank of the factor, S is the suitability value for each factor and i is factor i.

7. Result and discussion

Data collection is critical in geospatial analysis, typical data used for this study include Land Use map classified from Remote sensing data source; geo-coded data of the biomass sources, this is usually in the form of point data, obtained using GPS device. The acquired data points and the value was transferred into Arcmap environment of ArcGIS and processed into vector map for the site suitability analysis. The result of the various data analysis and modeling of suitable sites for the biogas plant by excluding unwanted areas identified in the constrain map and overlaying the thematic maps is fully discussed below.

7.1 Land Use classification map

Based on prior knowledge of land use of some geographical co-ordinates points, six classes were categorized. They are agriculture areas, barren/open land, dense forest, sand, urban land, and water body. The classified land use map is shown in **Figure 2**.

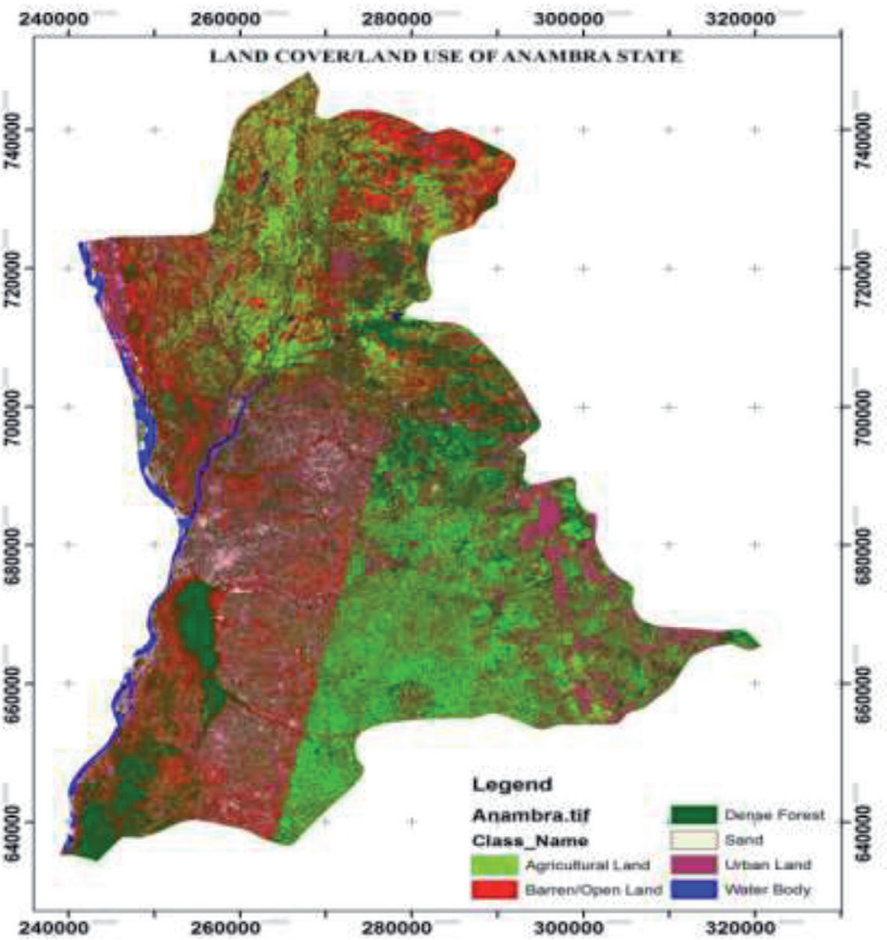


Figure 2.
Land cover and land use suitability map.

Assessment of classification accuracy was carried out using the scatter plot analysis in statistical toolbar in ArcGIS 10. All the training data were highlighted to compare the scatter plot of the six classes to each other. The classes were examined to detect any form of overlap (these are classes having different pixel value). This shown in **Figure 3**, the statistics for the training data was also used to assess the accuracy of the classification. The statistic are usually organized for each training area. The covariance statistics evaluates the correlation between the values of different bands and were adequate for the study.

The areas covered by each class of the LULC shows that urban land occupies 36.52% which represent 506896km^2 of landmass of the overall LULC while the least class is the sand class followed by water body, these feature classes occupies landmass of 13080km^2 and 14000km^2 respectively. The overall classification accuracy determined is 83%. The Table of LULC classification of Anambra State, area occupied in km^2 and percentage occupies by the various classes is shown in Table 4.1 (**Table 2**).

7.2 Biomass data of abattoir waste generating centers and map

One of the basics for site analysis of biogas plant is the biomass potential density; **Figure 4** shows the abattoir biomass data indicating areas where the bio-wastes are generated across the study area. **Figure 4** shows the towns and villages in the State that has abattoir centers. From the Figure, there are no abattoir centres in the



Figure 3.
Scatter plot of image classification in ArcGIS.

Class	Area(km)	Percentage (%)
WATER BODY	14000	1.00
SAND	13080	0.94
DENSE FOREST	257999	18.59
URBAN LAND	506896	36.52
AGRICULTURAL LAND	356430	25.68
BARREN/OPEN LAND	239400	17.25
TOTAL	1387805	100

Table 2.
Area occupation of various LULC classes.

Northern parts of the state. There are highest number of abattoir biomass within the central region of the state, and scarce generating centers towards the extreme of the Southern parts of the state.

Though the energy source from biomass in the study area could be utilized for biogas production and clean energy, this would be better to the current practices of burning wood in most homes and even in the abattoirs during meat processing operations. Biomass wastes generated during the slaughter of these animals includes blood, wastewater, ruminal content etc. The concentration of abattoirs in some of the areas in the study area is probably connected to the high population density of these areas. Since meat demand logically increases with increase in population. Areas with high concentration of biomass generation and clustering are best sites when considering proximity of waste sources as major criteria for bio-energy plant location. **Figure 4** was used to produce a vector map of biomass spatial density layer, used in the final suitability analysis.

7.3 Land use suitability map

The slope was derived from the digital elevation model of the study area. The slope of the study area was obtained through the slope function in spatial analyst tool in

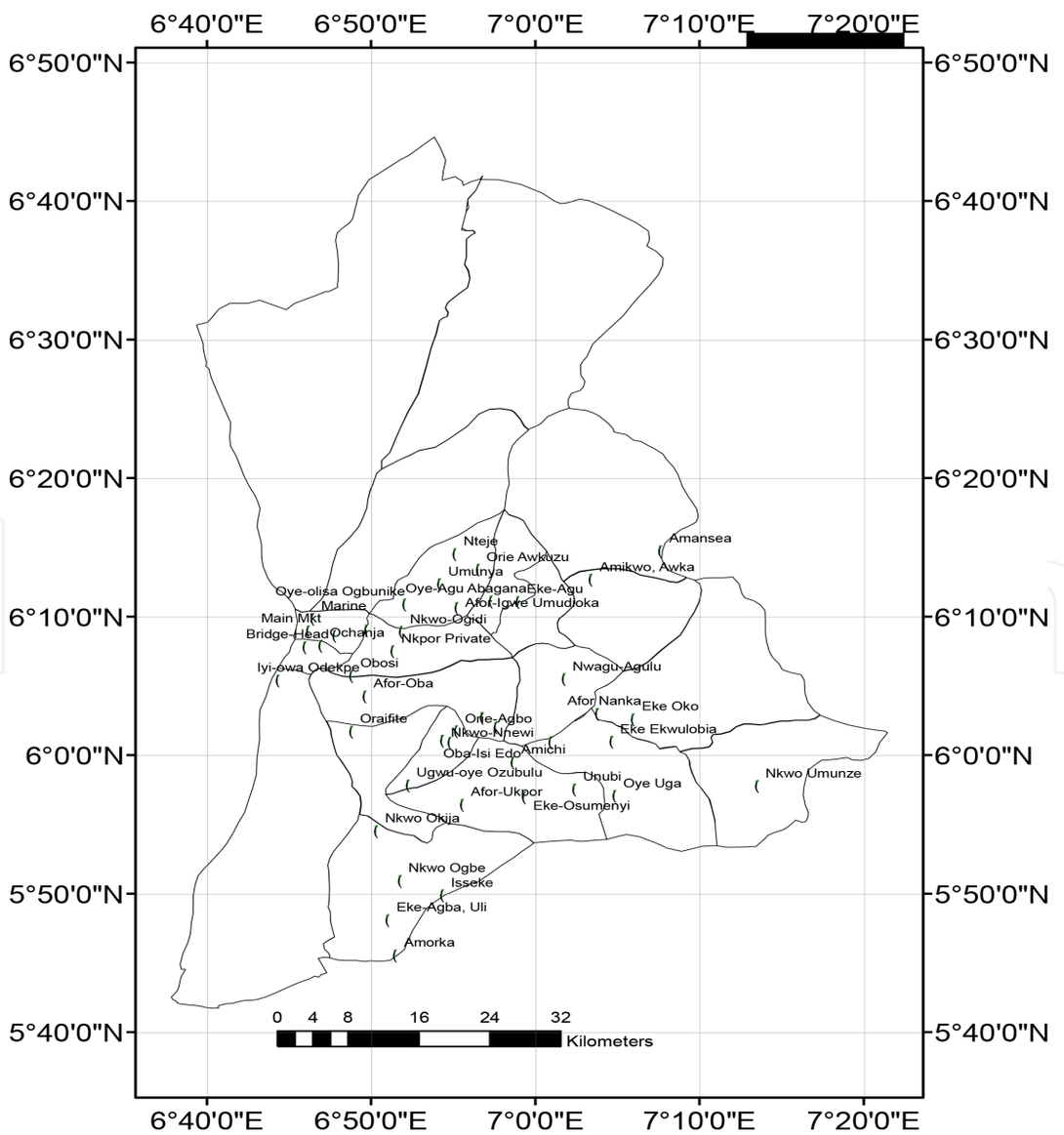


Figure 4.
Biomass potential density of the study area.

ArcGIS 10. The Slope command takes an input surface raster and calculates an output raster containing the slope at each cell, **Figure 5** shows the slope of the study area.

The output slope raster is in percent (percent rise) as shown in the figure.

The red color in the map represents areas in the study area that are less than 8%, thus they represent suitable locations to site biogas plant. Areas shown in the map within the range of 62–89% signifies high sloped areas, and should be avoided, this is of economic importance in siting and building of structures. Other land features such as hill-shade view for maximizing sunlight effect for increase in temperature for the biogas plant was created. Elevation layer was created from DEM to avoiding flood occurrence, all the layers was classified into 5 classes. The most suitable were sites with higher elevation, lower slope, and higher hill-view values. All the layers and land use layer obtained from Satellite imagery were overlaid using in ArcGIS using Weighted Overlay Tool. The result of such geospatial operation is the land use suitability map (not shown).

7.4 Final suitability map

The final suitability index map was obtained by overlaying the land use suitability map with the biomass spatial density layer. The output is shown in **Figure 6** below. The suitable areas were divided into 4 classes- the Most Suitable, Highly Suitable, Moderate Suitable and Not Suitable. **Figure 6** shows that the suitable sites are

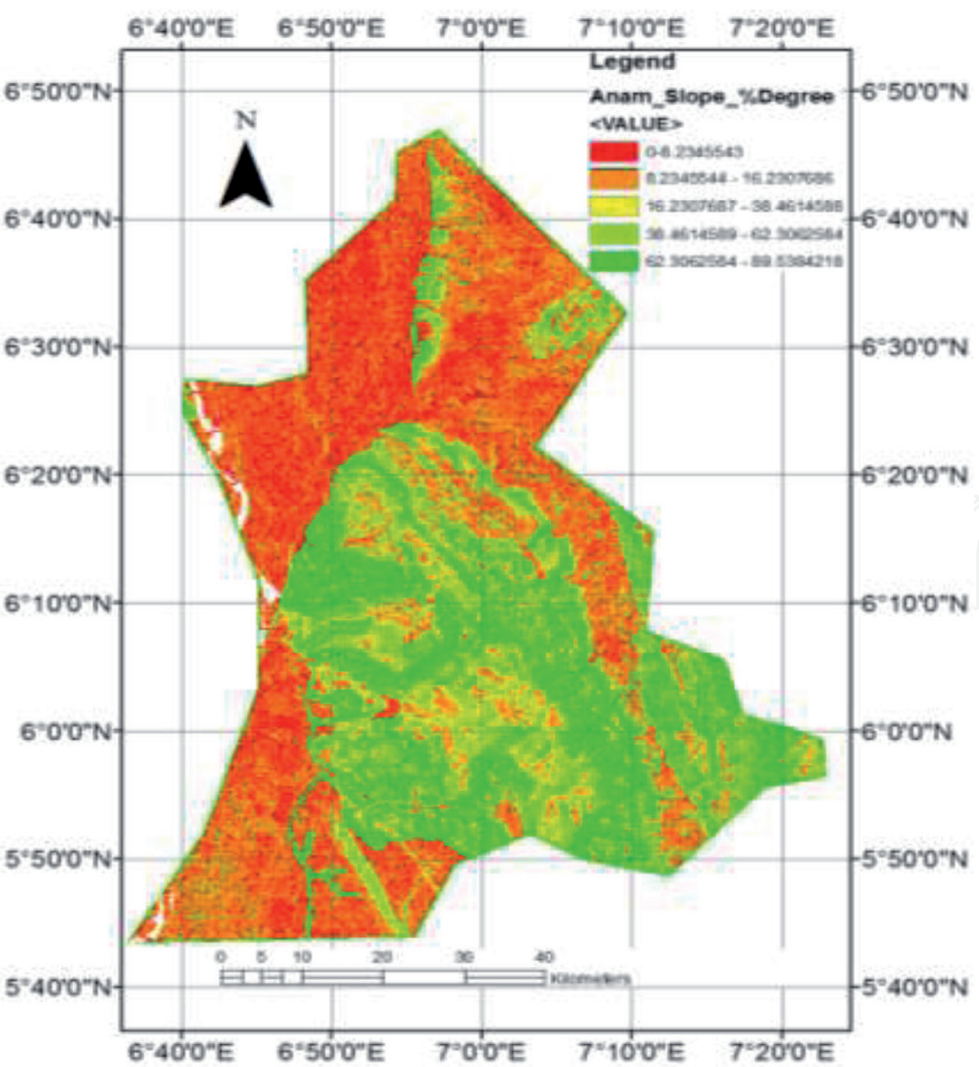


Figure 5.
Slope map of the study area.

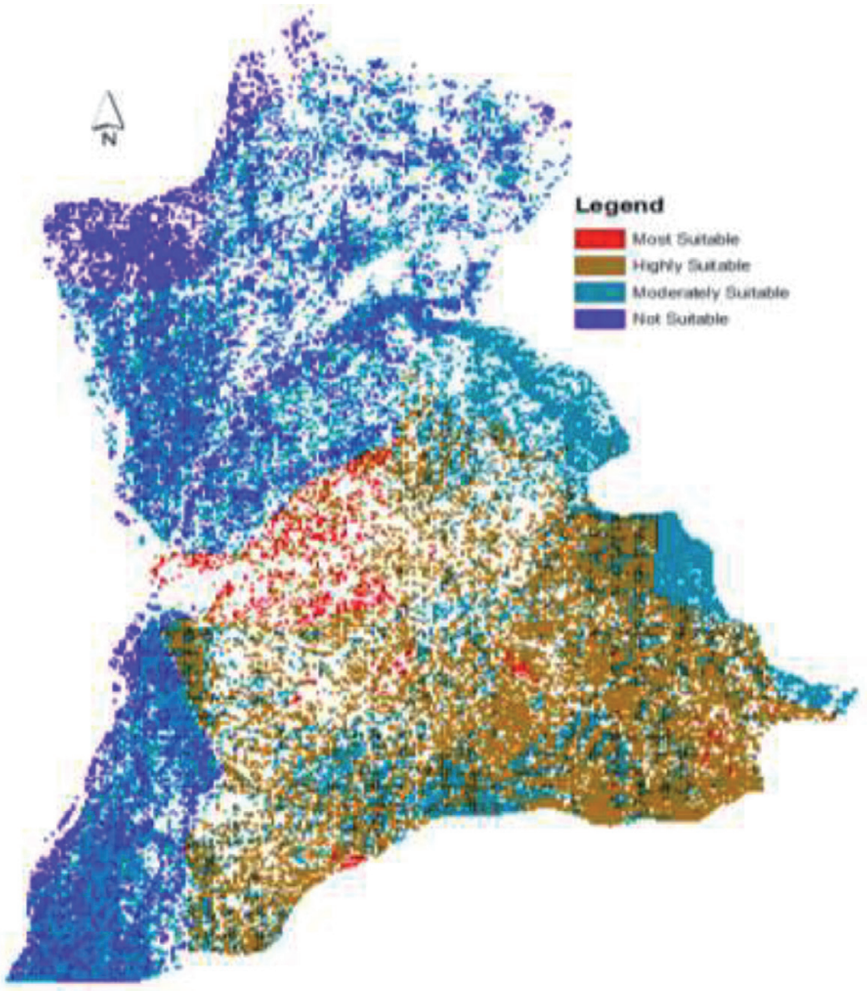


Figure 6.
Final suitability map. Source: [28].

predominant in the East and central region of the study area. Extraction of these areas based on the selected criteria indicates the power of GIS in extracting useful geospatial information for geographical data analysis.

8. Conclusion

This paper presents an application of GIS for site selection of bio-energy plant in Anambra State of Nigeria. Several environmental criteria and socio-economic factors were considered and used to obtain the land use suitability index map and biomass spatial density map. The final suitability index map was obtained by overlaying both maps. The suitable areas were divided into 4 classes- the Most Suitable, Highly Suitable, Moderate Suitable and Not Suitable and were predominant in the East and central region of the study area. This study therefore is a veritable framework tool in assessing and selecting suitable sites for siting of biogas treatment facilities.

Appendix

S/N	Locations	Aver. No. of cows Slaughtered daily	Amount Paunch (Kg/yr)
1	Nkwo Igboukwu	5	61137.5
2	Eke Ekwulobia	8.5	103933.75
3	Oye Uga	10	122275

S/N	Locations	Aver. No. of cows Slaughtered daily	Amount Paunch (Kg/yr)
4	Nwagu-Agulu	8	97820
5	Amikwo, Awka	18	220095
6	Amansea	23	281232.5
7	Afor-Igwe Umudioka	6.5	79478.75
8	Ugwu-oye Ozubulu	8	97820
9	Oraifite	3	36682.5
10	Nkwo-Ogidi	14.5	177298.75
11	Obosi	16	195640
12	Nkpor Private	5	61137.5
13	Nkpor	15	183412.5
14	Afor-Oba	7	85592.5
15	Afor-Nnobi	17	207867.5
16	Eke-Awka Etiti	35	427962.5
17	Eke-Agba, Uli	5	61137.5
18	Amorka	6	73365
19	Nkwo Ogbe	10	122275
20	Nkwo Okija	5	61137.5
21	Isseke	4	48910
22	Oye-Agu Abagana	6	73365
23	Eke-Agu	4	48910
24	Nkwo-Nnewi	10.5	128388.75
25	Orie-Agbo	3	36682.5
26	Oba-Isi Edo	14.5	177298.75
27	Amichi	4.5	55023.75
28	Afor-Ukpor	2	24455
29	Osumenyi Slaughter House	3	36682.5
30	Unubi Slaughter House	0.5	6113.75
31	Iyi-owa Odekpe	2	24455
32	Ochanja	70	855925
33	Bridge-Head	11.5	140616.25
34	Marine	26	317915
35	Ugwunabamkpa	1.5	18341.25
36	Main Mkt	20	244550
37	Afor Nanka	2	24455
38	Eke Oko	8	97820
39	Nkwo Umunze	4	48910
40	Nteje	13	158957.5
41	Oye-olisa Ogbunike	52.5	641943.75

S/N	Locations	Aver. No. of cows Slaughtered daily	Amount Paunch (Kg/yr)
42	Umunya	65	794787.5
43	Orie Awkuzu	12.5	152843.75
	Total	**565.5**	**6914651.25**

Source: [28].

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