The Application of GIS Model as a Location Selector for Biomass Gasification Plant in Bogoro Local Government Area, Bauchi, Nigeria.

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Abstract

The demand for energy especially in small-scale applications is increasing day-by-day worldwide. While energy demand is met through fossil fuels, the associated greenhouse gas (GHG) emission from fossil fuel combustion has been a global environmental concern. Thus, significant demand for future energy has to come from renewable energy sources to meet the projected demand and to halt GHGs emissions to an acceptable level. Globally, crop residue biomass has been acknowledged as a positive alternative source of energy because it is renewable, cheap, readily available, and carbon neutral. The methodology employed in this study is to assess the renewable energy potential of biomass derived from agricultural residues and suitable sites to locate the plant. The analysis gave a total residue estimate in the study area to be 215,725.8 tons for groundnut shells. This information is important to the successful utilization of these residues. The study estimated the number of crop residues and their energy potential in Bogoro local government area of Bauchi state, Nigeria utilizing a GIS-based approach. The optimal locations of crop residue gasification plants were also identified in the study area. Similarly, a GIS model that automates the process of crop residue estimation and identifies potential sites for biomass plants was created using ArcGIS extension Model Builder.

Keywords. Bioenergy, Biomass. GIS, Gasification, Groundnut shell, syngas, bioenergy.

1. Introduction.

Globally, biomass has been acknowledged as a positive alternative source of energy because it is renewable, cheap, readily available and carbon neutral. Likewise the global demands for small-scale energy production have continued to increase. The projected per capita energy demand (toe) globally would increase from 1.8 in 2007 to 2.0 in 2030, (IEA, 2012). The situation is further worsened due to the persistent energy crisis in Nigeria which has also weakened industrialization and significantly undermined efforts to achieve sustained economic growth. (Iwayemi, 2018). The associated greenhouse gas (GHG) emission from the burning of fossil fuel which is the major source of fuel has been the top global environmental concern. Thus, a significant share of future energy has to come from renewable energy sources to meet the projected demand and to reduce GHGs emissions to an acceptable level. (USDE, 2008).

1.1. Bioenergy Potentials in Nigeria

Nigeria is blessed with an abundant mix of renewable energy sources such as biomass, solar, wind, and hydro-power. Among these options, biomass stands higher in the Nigerian context as the biomass is uniformly spread in the country and biomass-based energy has a vital role in the rural life where agriculture is the principal activity (Ramachandra *et al* 2000). Biomass is currently the principal global contributor of renewable energy and has considerable potential to expand in the production of electricity and biofuels for transport (IREna, 2012). Biomass resources are said to account for 76.9% of energy in Nigeria (IEA, 2010) and amongst these resources, fuelwood has been the main source of energy for 60% of the rural population, however, the recent decline in fuelwood resources has also led to a shift towards the utilization of crop residues for energy generation. Several biomass technologies have been mentioned as being viable for energy generation through direct combustion, gasification and many more (Nzila *et al.* 2010). In Nigeria, the larger population is involved in agricultural production with more than 70% of the farming population being smallholder farmers (< 5 ha). This high percentage of arable land is a potential for high crop residue generation.

A key challenge for Biomass energy production is to ensure that the right kind, the right quality, the right amount and the right channels of procurement of biomass are available within a certain distance from the plant. Each of the above is essential for the effective and economic operation of the biomass energy plants. It is paramount to note that different types of biomass plants (gasifiers) require different kinds of biomass. Consequently, the location of gasifiers has to be in line with the kind of biomass available in that location. (FAO, 2008). The channels of procurement of biomass are the ones that reduce the cost of running of biomass energy power plants. For instance, the cost of transporting biomass is key to whether the biomass-based plant runs economically or not. A megawatt-scale power plant can economically draw biomass from within 25 – 50 km whereas a kilowatt (kW) scale power plant has to draw biomass from within few kilometers. From the above, it becomes clear that the first step in setting up any biomass plant is to identify and estimate relevant biomass resources available in specific areas and regions.

Diyoke *et al* 2014 recommended that an accurate estimate of the potential biomass resource base in Nigeria should be undertaken for the implementation of a decentralized biomass gasification power plant. Biomass gasification technology possessed a huge potential as a decentralized power generation system in meeting the energy needs of the Nigerian rural dwellers like domestic lighting, running of irrigation pumps, and small-scale commercial activities such as floor mill and other rural micro-enterprises.

2.2. Geographical Information System (GIS).

Geographical information System GIS) is a computer-based tool designed for capturing, storing, verifying, incorporating, manipulating, scrutinizing, displaying information associated with locations on the earth's surface. It facilitates the exploration of spatial data and successfully creates multiple layers of information (Dagnall & Pegg, 2000). The key feature of a GIS is that it links the spatial location of an object (a country for example) with data and information that are associated with the object (different types of biomass). Several authors have reported a global increase in the utilization of agricultural residues for energy generation in both developed and developing countries, numerous reasons have been suggested for the increase. However, in Africa, more focus is on the estimation of only the total amount of crop residues that can be generated and their energy potential (Valdez-Vazquez *et al.,* 2010). But a more thorough and detailed assessment of the geographical distribution of crop residues is required for the development of local bioenergy systems (Gan & Yu, 2008). By utilizing Geographical Information System (GIS), the availability and spatial distribution of biomass resources can be identified and it is essential for their successful exploitation because it provides information on the best sites for locating bioenergy plants (Chanthunyagarn *et al.*, 2004; Voivontas *et al*., 2001).

Globally, various studies have also utilized GIS to estimate the theoretical amount of agricultural residues and their energy potential (Ćosić *et al*., 2011; Fernandes & Costa, 2010; Hiloidhari & Boruah, 2011). According to Nagendra *et a*l., 2013 most GIS techniques used can be easily replicated on larger scales for more comprehensive studies, but the capabilities of LIDAR (Light Detection and Ranging) remote sensing and advanced GIS information extraction methods can be explored further for more accurate mapping results of urban aerial information, so that better estimates can be obtained. The spatial coverage of large area biomass estimates that are constrained by the limited spatial extent of forest inventories may be expanded through the use of remotely sensed data. Biomass and carbon stock estimates derived from forest inventory data usually have some spatial, attributional, and temporal gaps. Remotely sensed data can be used to fill these gaps, thereby leading to estimates closer to the actual value.

Remote sensing data are available at different scales, from local to global and various sources including optical or microwave, and hence are expected to provide information that relate directly or otherwise to biomass information

Studies in the past have shown that the fusion of optical (multi and PAN) and also SAR data resulted in an improved performance for biomass estimation. However, more research is needed to explore the improvement of biomass estimation through multisensory data fusion. The results presented comprised the number of agricultural residues that can be generated and their energy potential and their spatial distribution. One of the Characteristics of the GIS is its ability to automates processes, but that have not been considered in most of these studies (Jiang *et al,* 2012).Voivontas *et al* 2001, proposed a GIS decision support system to identify the geographic distribution of the economically exploited biomass potential based in four-level analysis to determine the theoretical, available, technological and economically exploitable potential. Lack of information on the geographical distribution of biomass resources in Sub-Saharan Africa (SSA) has been mentioned as one of the key barriers to the introduction of one of the modern biomass conversion technologies. (Dasappa, 2011). More research needs to be conducted in the African continent to determine the potential of crop residues for energy generated especially the geographical distribution. A study by (Asiyanbola, 2014) revealed that the use of RS and GIS in Nigeria is higher in the South West. The study also suggested the need to encourage and promote indigenous technology, industries, and firms particularly on remote sensing and GIS method development. The results on the application of RS and GIS revealed that the percentage usage in energy analysis is 1.3%.

2.3. Potential Sites for Biomass Power Plant.

Biomass and biofuels are two important resources available to many of the PICs. However, before these forms of renewable energy can be used, a necessary first step is the assessment of the availability of these resources, and the land area required to produce them. Remote sensing and GIS are two important techniques that can be employed for this purpose. In the technique of remote sensing, satellite imagery is used to quantitatively assess the biomass cover and available land area over large areas of a country. The information thus collected is conveniently stored in GIS systems which can be used for decision-making. The spatial distribution of the biomass resource and the collection distance are key factors affecting the selection of potential sites of the biomass plants (Voivontas *et al*., 2001). In the non-GIS based study, potential sites for a biomass gasifier can be identified based on the amount of biomass generated and the proximity of the biomass resource. No information was found regarding the potential site for a gasification plant using GIS in the Study area. According to (Hiloidhari and Boruah, 2011), many authors have reported the use of GIS in biomass resource assessment and planning. However, most of the studies are aimed at regional or country scale planning for MW size power plants, with lack of prominence for smaller geographical and administrative units. The first step in setting up any biomass-based plant is to identify and estimate relevant biomasses available in specific areas and regions. Hence, the identification of spatial distribution and economically exploitable crop residue location is the backbone and ultimately instrumental in the designing of agro-waste bioenergy power plants. In other words, the bulky nature or low energy density of agricultural residues possesses some challenges in handling, storage, transportation, and conversion processes. Therefore, it becomes necessary to ensure the availability of adequate crop residue in the vicinity of the gasification plant location. To fill this gap remote sensing was used to investigate the crop residue availability and GIS to assess the siting of power plant locations to minimize the overall cost of biomass feedstock.

To efficiently and effectively use biomass as a renewable energy source, it is important to have a detailed knowledge of its distribution, abundance, and quality. Remote sensing offers the technology to enable rapid assessment of biomass over large areas relatively quickly and at a low cost. It is a technology that can be used to ensure that biomass as a renewable energy source is used in a sustainable manner. Remote sensing techniques have many potential benefits in biomass estimation over traditional field measurement methods at different scales ranging from local to regional, including cost, labor, and time. However, the selection of suitable remote sensing data based on information on the scale of the study area, the data analysis procedure and costs is an important factor to be considered for the most appropriate aboveground biomass estimation procedure

. High-spatial resolution data from both airborne and satellite platforms can provide accurate biomass estimates at local scales; however, for regional scales, a large volume of data is required, which is not only expensive but also difficult to process; this limits its application for larger areas.

Biomass estimation from remote sensing data is a complex analysis process which involves many factors such as mixed pixels, data saturation, and complex biophysical environments. The selection of suitable algorithms for information extraction is also difficult and needs higher analytical skills. The most commonly used methods for biomass estimation are linear or nonlinear regression models, neural network, and k-nearest neighbor, and also biomass is estimated indirectly from remotely sensed canopy parameters.

3. Methodology.

The methodological aspect of this research is grouped into three; first is the field work and ground data collection, the second aspect is the data preparation and other remote sensing analysis, and lastly GIS modeling for the potential energy estimations and site suitability for crop residue gasification plant.

3.1. Study area.

Bogoro is one of the 20 local government areas in the southern part of Bauchi State in Nigeria. It is located in the southern part of Bauchi state on Latitude 9^{o} 40' 0" N and Longitude 9^{o} 36' 0" E. (9.65 and 9.61667 in decimal). Bogoro local government area consisting of three village areas occupies a total area of 894km^2 with a population of 84,215 (2006 Census). It is bounded by Plateau state in the south and Tafawa Balewa local government area in the north. The economy of the local government revolves around agriculture, as crop farming is the main agricultural activity in the area. Hence crop residue generation potential is high. The study was based on the 10 wards in the local government area. Figure 1. Is a map showing the geographical location of Bogoro local government area in Bauchi state, Nigeria.

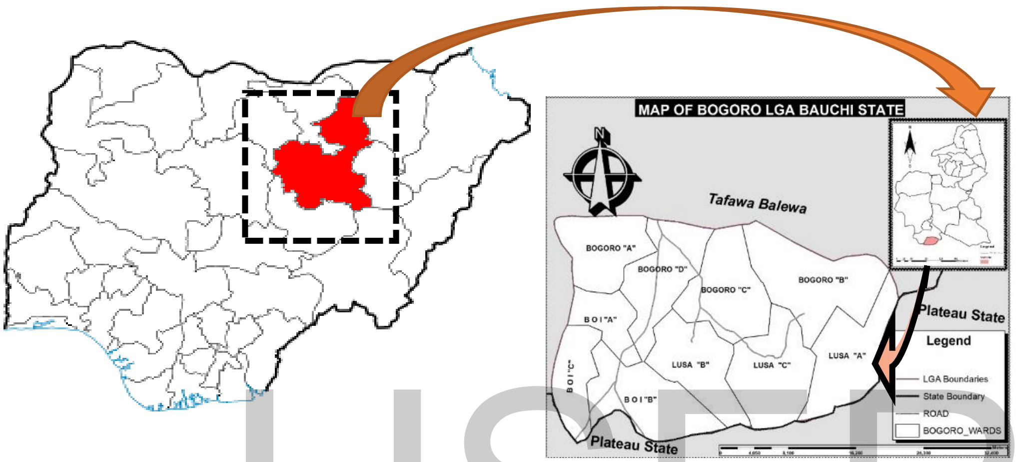

Figure. 1. Map of study area

3.2. Field Work

For the determination of the actual amount of crop residues in the study area, field samplings as done and for the purpose of mapping of groundnut fields a hand handheld GPS was used to collect ground control points (GCPs) of randomly selected locations of the study area. During the field survey a total of 215 farms were visited, of which 162 points were groundnuts farms. These points were collected with the purpose of training and validation of the remote sensing analysis, especially image classification and crop type identification and mapping. Plate I and II illustrate the field survey of the study area and the GPS instruments used respectively.

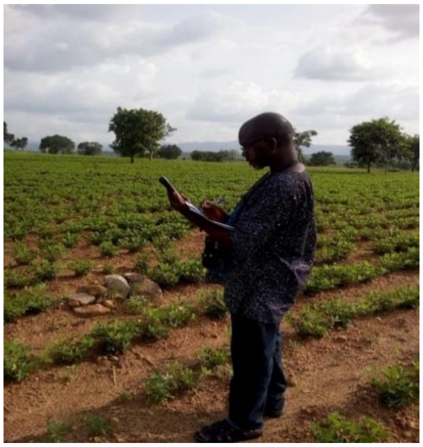

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Plate 1. Field Data Collection

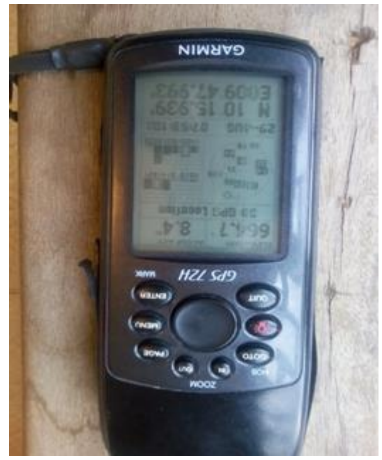

Plate 11. Handheld GPS

3.3. Land cover and cropland masking

A total of 18 scenes of Landsat-8 data covering the cropping window was used to first generate a cloud free mask of Bogoro LGA. Then we produced a Landcover map of five classes using the cloud free composite, then the Landcover classes were collapsed into two binary classes of cropland and non-cropland areas. All data was unified to the same projected zone (Projected - Northern Hemisphere - Universal Transverse Mercator (UTM) - Zone 32). This is to enable all layers to overlay in a GIS environment. The second analysis was to subset all layers to the spatial extent of the study area (Bogoro LGA). This was achieved by using the LGA boundary shapefile of the study area in the Analyst tools function of ArcGIS 10.3. The last analysis here was layer stacking as three optimal bands were selected from the 11 downloaded Landsat bands. Bands 5, 4 and 3 were selected and stacked as “green”, “Red”, and “Blue” bands. This was stacked to form one ‘false color composite” image which is appropriate for LULC, based on the desired LULC classes.

A supervised image classification was used for generating the LULC map of the study area. The remote sensing tool used here was “supervised classification” tool of the Erdas Imagine 9, 2 Package. Training sites or training pixels were created on the satellite images for each land cover type and the grouped pixels were coded accordingly to represent a LULC class. To test the accuracy and validate the classification procedure, the farmlands were selected separately and cross-checked with the farm points collected on the field. A total of 205 points out of 215 farm points falls within the farm class indicating an accuracy of 95.3% and the remaining 10 points fell within wetland and water. The LULC table was exported to Excel to calculate the total coverage of each class in Ha and percentage. Figure 3.

3.4. NDVI Crop mapping Validation

The Normalized Difference Vegetation Index (NDVI) was generated using the generated Landsat 8 data, band 4 and band 5 (Red Bands 4 and Near-infrared bands 5) This is a remote sensing measure of the greenness or vigor of vegetation. The generated NDVI maps were crossed with the groundnut field points, this is to ascertain the NDVI reflectance and spectral signature for groundnuts fields. This analysis was performed using the "Extract Values to Point" tool in ArcGIS using the NDVI and field points as inputs. The positive NDVI values were then sliced into 25 classes to assign a wide range of spectral signatures for the crops and other vegetation types across the landscape. This was again intersected to validate with the points where the crops were sampled on the ground.

3.5. Site Suitability Modeling.

The model was generated using ArcGIS 10.3 spatial model builder and was categorized into three parts. Section one is the identification and extraction of groundnut farms using the Normalized Differential Vegetation Index (NDVI) map. The second part is the residue estimations as well as the energy potential conversions with their geographical locations. While the third session is the site suitability modeling for choosing optimal sites to localize biomass Gasification plants.

In developing the site suitability model Spatial Multi-Criteria Evaluation (SMCE) was used to assess and overlay multiple factors. The factors considered here include; LULC (for availability), proximity to settlement (reduce labor cost), proximity to roads (reduces the cost of transportation) and in areas where a high amount of residue could be collected.

A Euclidian distance analysis was generated on both road and settlement layers, this analysis generates proximity intervals around the settlements and federal roads. The last analysis after the standardization of the factor maps is the overlay operation which was carried out using the "weighted overlay" tool of the ArcGIS toolbox. The total factor maps were rated 100% and this value was divided across all the factors depending on the most significant factor which is assigned a higher percentage.

The final step of the modeling was setting some model inputs as parameters to enable the user to change them based on their region and information required. This makes the model automatic and repeatable to other regions as long as the data is understood and assumptions considered are accepted. The parameters here include LULC, NDVI, field farm points, roads, ward maps, and settlement. The model was generated using ArcGIS 10.3 spatial model builder, the model is made of three parts. Crop land Identification and extraction. Residue estimation and energy potential Site suitability assessments. Figure 2.

4. RESULTS AND DISCUSSION.

4.1. Field Work.

The results of data collected shows that a total of 215 farms were visited and the results of validations of the field points show that a total of 205 points fall within the farm class of our Landover map and the remaining 10 points fell within wetland and water. The 205 points out of the 215 farms indicate an accuracy of 95 % which is very adequate for the analysis as compared with the 85% acceptable value.

4.2. Land cover and Cropland Mapping.

The classification of the land cover of the study area is as shown in Figure 3. The image classification revealed that farmland has the highest coverage with a value of 69,667.74 ha which is 78%. The results showed the total available residue estimate to be 215,725.8 tonnes for groundnut shells with a total energy potential of 676,181 MJ. The high distribution of farmland is an indication of high degree of crop residue generation. The low vegetation value can be attributed to the challenge of deforestation which also results in a limited supply of fuelwood for conventional bread baking. The result is higher than that of Ibrahim (2015) where it was reported that the estimate of groundnut shells generated for Bauchi state in 2014 was 144,352 tonnes. This high difference may be due to the assessment method or the difference in land use within the years. . The results confirms the fact that Remote Sensing and GIS assessment method is more effective than the conventional method

4.3. NDVI/Crop Mapping and Validation.

The results of the analysis indicates that about 127 farms out of the 162 groundnut farms fall within classes 14-16 as such these classes were selected as the groundnut farms. Therefore, the equivalent intersects were selected as the groundnut farms using the conditional statement in the ArcGIS toolbox

4.4. Site Location Modelling.

The potential sites for biomass power plants and the amount of crop residues that can be collected at different collection distances was determined**.** The location with the highest supply of groundnut production Bogoro C and D wards and Lusa B and C wards as shown in Figure 4. Four best possible locations of biomass plants were identified in areas where a high residue amount could be collected as shown in Figure 5. Figure 6 shows the generated factor maps showing proximity to roads and settlements while and Figure 7 shows the map of possible suitable areas. The optimal sites for plant location and best possible sites are represented in Figure 8 and Figure 9 respectively.

This is the first time this type of research has been carried out in the study area. The outcome of this model proves the suitability of areas to site plants for biomass conversion for energy generation. This model is an automated process of estimating the theoretical amount of crop residue biomass and energy potential. This model created for Bogoro can be transferable to other local governments. Crop residue availability and energy potentials have been identified for small scale application. The optimal location of gasification plant has been identified for the study area.

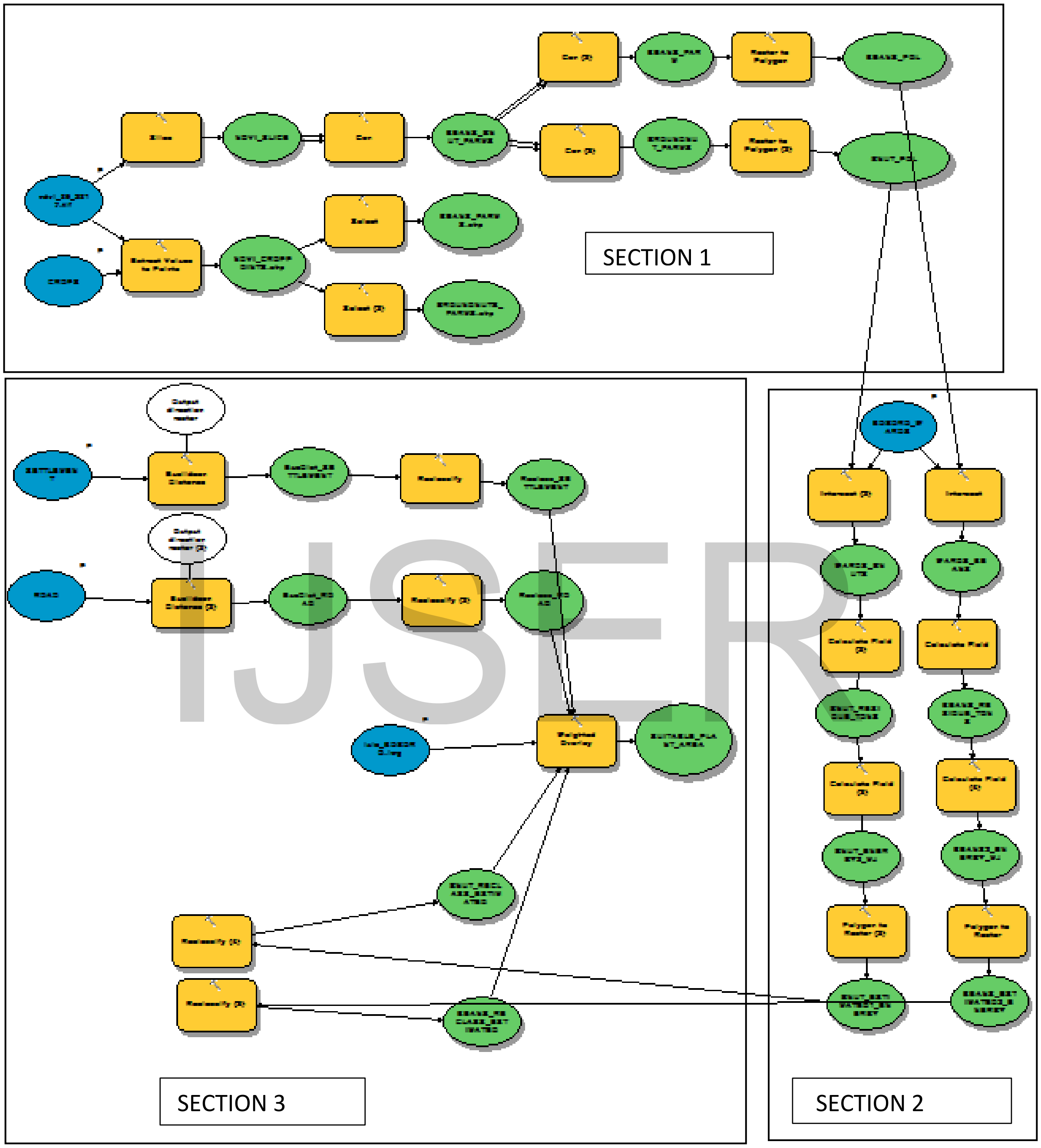

Figure 2. The GIS Model

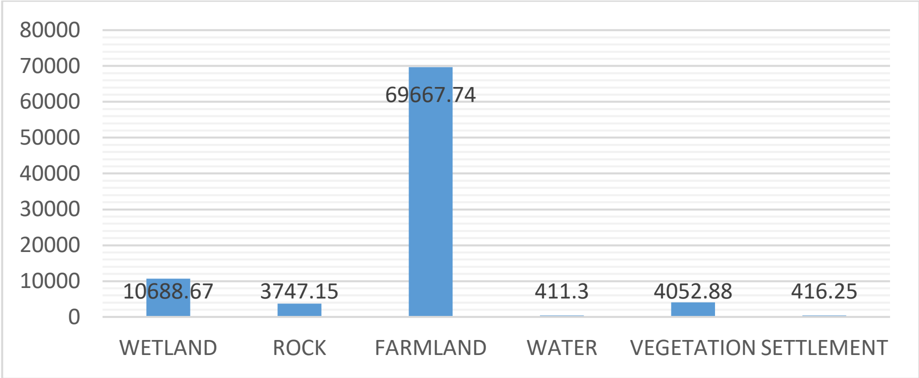

Figure 3. Histogram of Landuse/Landcover of study area.

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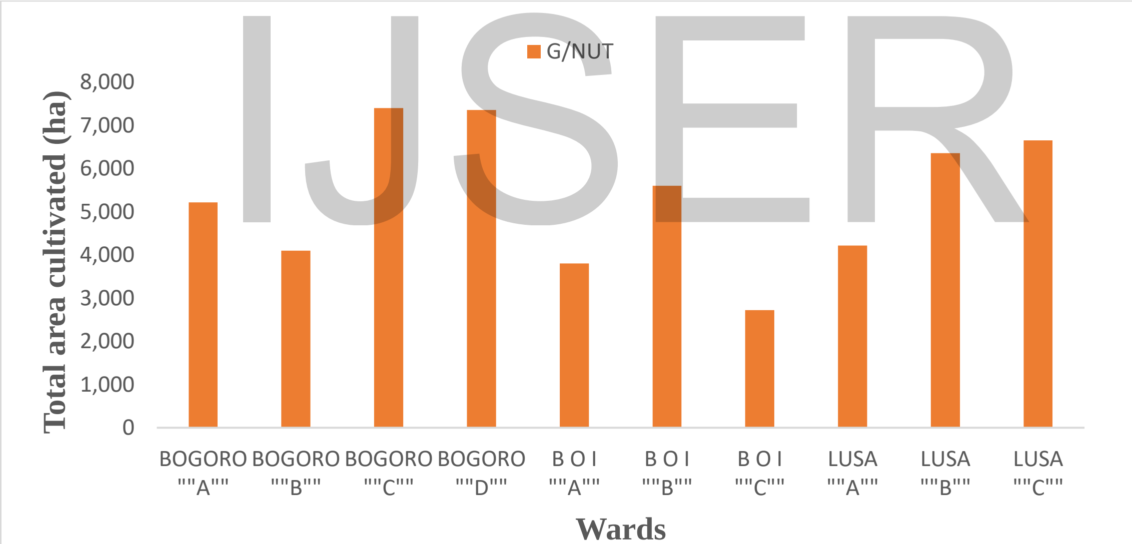

Figure 4. Groundnut area cultivated

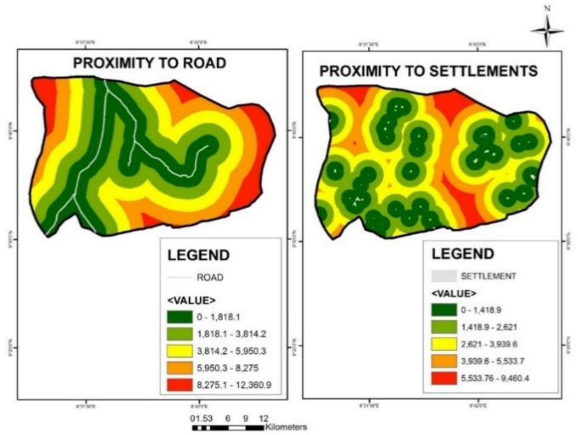

Figure 5. Generated factor maps.

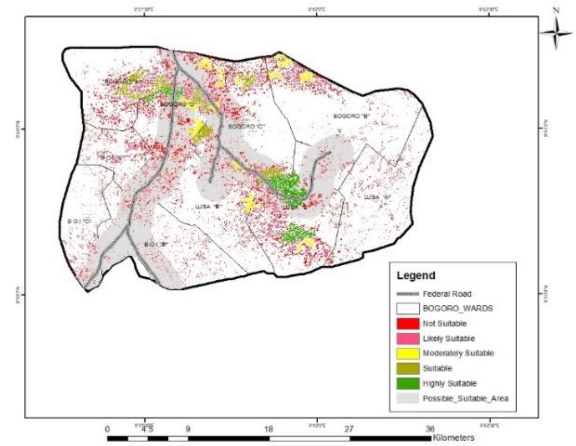

Figure. 6 Possible Suitable Areas

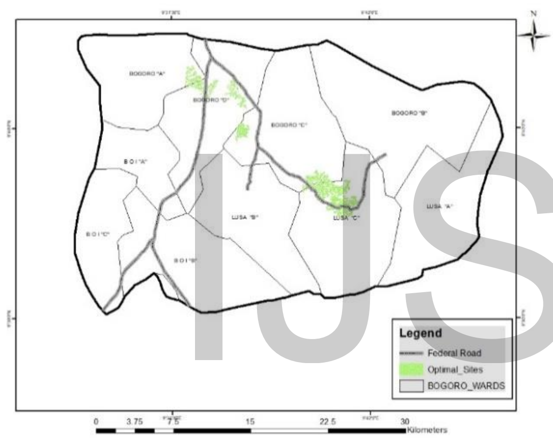

Fig. 7. Maps of optimal sites.

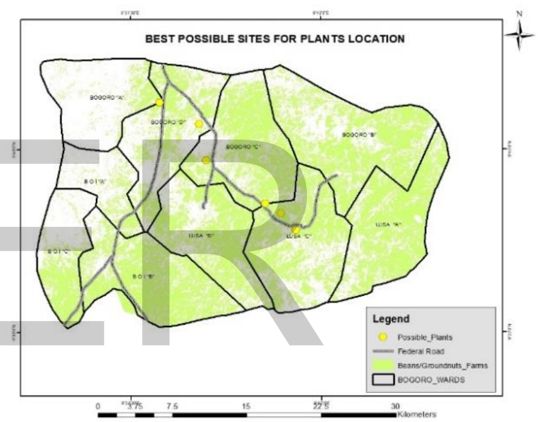

Figure 8. The best Possible Plant site

5. Conclusions and Recommendations.

Currently, crop residue make up a major part of biomass sources. Unfortunately, the utilization of biomass energy is very small as compared to the conventional ones. However, the use of gasification technology gives an opportunity to generate considerable amount of energy from crop residues. But studies and experimental data on gasification of groundnut shell biomass are limited.

This study shows that remote sensing and GIS tools are quite valuable for detailed identification, extraction and quantification of potential areas for biomass/bioenergy production in the study area. The conversion factors and assumptions used in the course of estimating the bioenergy potentials are quite promising for further use in other areas with similar parameters. Our findings are useful as guides for policy makers in decision making processes aimed at ensuring sustainable bioenergy production, meeting general energy demands and emissions reduction obligations locally, nationally and globally. The study presents a GIS model that automates the process of estimating the crop residues at village level in Bogoro and also identifies potential locations for biomass plants. The potential sites for gasification plants were identified to be in areas near or on the road network and where sufficient quantity of residue can be collected at a given distance to sustain their operation.

We do recommend that other crops from the study area can be considered for further analysis.

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