Siting a Waste to Energy Power Plant in Ibadan, Oyo State, Nigeria

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Abstract—Ibadan being the third largest city in Nigeria generates over 7600 tonnes of wastes daily and currently, there is no efficient method backed up with known policy for effective management of the wastes. Nigeria has been battling with epileptic power generation and supply since her independence in 1960 even though there is abundant waste generation in the country. Exactly 10 criteria were considered for the selection of the waste to energy power plant in Ibadan. The criteria were dumpsites, transport networks, power transmission lines, power substations, settlement, rivers, slope, markets, institutions, and industries. The datasets were sourced from world-pop and shuttle radar topographic mission (SRTM) for the raster layers, and Ibadan Master Plan and Grid 3 for the vector data. The data were processed as Euclidean distance and reclassification into either two or three depending on which layer was considered. Reclassification into suitable or unsuitable, and or most suitable, less suitable and unsuitable was done before the analytic hierarchy process was carried out for the weighted overlay analysis. The multi-criteria decision analysis was done in order to select the suitable site for waste to energy plant in Ibadan. Two sites A and B are proposed as the most suitable site to establish the waste to energy plant to be in Akinyele and Ido Local Government Areas in Ibadan City, Oyo State of Nigeria.

Key Words: Waste-To-Energy, GIS, SDGs, Ibadan, Nigeria

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1 INTRODUCTION

THE World Bank projected municipal waste generation will rise worldwide from 1.3 billion tons annually in 2012 to 2.2 billion tons annually by the year 2025 (Hoornweg, and Bhada-Tata, 2012). Along with population explosion, rapid urbanization, economic development and improvement of people's living standards, the quantity of Municipal Solid Waste (MSW) has been on the increase rapidly and its composition has become more varied (World Bank, 2019). It is anticipated to expand rapidly in the future; thus, waste disposal and management pose serious challenges to cities around the world. In developing countries, municipal waste threatens both the environmental and social qualities (Costi, *et al.*, 2004). These recent projections have attracted more attention to the challenges waste disposal and waste management posed as an integral topic to be considered by present and future policy makers to attain sustainability of cities. Troschinetz and Mihelcic, (2009) reported that MSW is regarded as a major environmental problem that affect urban sustainability in many developing countries. Ayodele *et al* (2018) saw the economic gained municipal waste can provide to the city of Ibadan and encourage various stakeholders to adopt biogas from MSW for energy generation in Nigeria. Waste-To-Energy (WTE) continues to remain the best solution because of its ability to convert heat energy to electrical energy thereby producing sustainable energy for many cities (Ryu, 2013). Among the sustainable means of waste management and energy generation being adopted around the world, Waste-To-Energy remains a best practice to properly manage waste and reduce the depleting of natural resources, and other environmental challenges associated to waste generation (Cucchiella *et al.*, 2017). Nigeria has an installed electricity generation capacity of 7000 MW, but capacity utilization currently ranges between 3500-4500 MW and in June 2013 was as low as 2200 MW. Waste managers and policymakers in developed and emerging economies must respond to the challenges of urbanization and energy demand (Dar, 2017). In recent times, WTE has gradually been regarded as a way out to the problems derived from growing waste quantities in expanding cities as well as fast increasing energy consumption. Again, limited solid waste management capabilities mostly in developing nations are aggravating the problems as well as its socioeconomic and environmental consequences (Rodriguez, 2011). It is worthy to mention that a well-organized municipal solid waste management system is concerned not only with efficient collection of generated municipal solid wastes but also with appropriate use of the solid waste in recycling, treatment and/or energy generation (Costi *et al.*, 2004). Electricity generation from municipal solid waste through Waste-To-Energy will produce economic and environmental gains for a city like Ibadan, Oyo State, Nigeria facing constant electricity shortage. Taking the importance of a waste to energy plant as the best option of strategic plan for waste management in any city must be focused on finest economic model for the sustainability of the city with high economic consideration on resource management and high environmental performance standards (O'Leary and Walsh, 1995). Strategies to improve the profitability of a waste to energy design must include charges from waste collection, dumpsite charges, penalties and liability from violation against the law, power bills and continue venture supports to operate all the facilities (Garcia, 2008). The UNEP (2019a) set reasonable approach to tackle bad perception waste incineration energy facility has on both human and environment. According to the World Bank publication in the year 2000 by Rand *et al* (2000), even though nearly all modern thermal waste to energy facilities comply with EU standards, WtE location frequently generates community criticism because of apprehensions about irremediable impact on human wellbeing and ecological damages. Therefore, in order not to face undesirable opposition by residents to such facility, complying with important criteria guiding European Union standards of waste to energy plants site allocation must be well considered. This study considers site allocation conditions that guide thermal waste to energy location as stated below by UNEP (2019a);

- Moderately near to a regulated and well-functional dumpsite for residue disposal
- In small or large industry estate areas
- In industrial areas near to electricity facility.
- In nearness to power transmission grids
- In area where transportation cost from the waste collection zones to the facility is lessened. This study carried out a suitability analysis for siting a waste to energy power plant in Ibadan, Oyo State, Nigeria using GIS and remote sensing techniques with compliance with above stated standards.

1.1 Waste-To-Energy in Africa

Like every other dumpsite in Africa, the Koshe dumpsite in Addis Ababa has posed serious environmental challenges to the residents living at the outskirts of the Ethiopian capital. However, by September 2014, the Reppie Waste-to-Energy facility started the construction of their WtE plant on Koshe site and was commissioned on August 2018 to generate 50MW of electricity thereby providing electric energy for 20% of the Addis Ababa's residents. The Ethiopian government provided $96 million for the construction of the first major WtE plant in Africa (AA, 2019). A major consortium of Cambridge Industries Limited based in Singapore, China National Electrical Engineering Company and Ramboll Engineering of Denmark carried out the project over a period of four years to generate first output of 25MW of electricity using about 1400 tonnes of waste generated daily from the city. The facility not only provides energy for the city but also create over 1500 direct and indirect jobs. It significantly reduces the environmental impact of the dumpsite through international best practices targeted at waste reduction, recycling and energy generation. The project adopted European emission standards where countries like France have 126 WtE plants, Germany 121 and Italy 40. This WtE facility surely should stimulate other major African cities to adopt the model to meet up with Sustainable Development Goals (UNEP, 2019b).

2 LITERATURE REVIEW

There are large and growing interest of published studies demonstrating the important roles GIS and Remote Sensing can contribute to effective siting of solid waste management and electricity generating facilities. Hassaan (2015) provides in-depth analysis using GIS-based multi-criteria analysis to locate a municipal solid waste incineration power facility in the city of Alexandria, Egypt. The work considered 5 factors that are: Lowest operation price, Nearness to the electrical power line, Least conflicts with delicate land use and Vacant Land and a Composite index. It was recommended to incorporate these factors in numbers to replicate the suitability values of various criteria guiding regulatory standards for best location to site solid waste to energy facility. In another work by Idris and Latif (2012), the strength of geospatial techniques to aid decision for locating electricity generating facility in Raud town in Pahang, Malaysia was recorded. The study adopted the use of Analytical Hierarchy Process (AHP) and GIS in identifying the finest site for locating a nuclear power facility was successfully demonstrated. Factors thought to influence location of nuclear power facility were stated and geospatial data used in the investigation are nearness to river, topography, land use, electrical facility and landowners. The authors produced each geospatial data criterion to meet specific values according to importance of each layer to successfully perform weighted overlay analysis. Their result was presented in maps, the most suitable site was found in around Ulu Dong as the best site for nuclear power station with area covering about 10064 acres. Numerous researchers attempting to make best decisions affected by several factors that may influence the outcome of the spatial decision employ a combination of Geographic information systems (GIS) and various systems and technique like decision making (DSS), multi-criteria decision making (MCDM. These systems are recognized to be integrated to form the multi-criteria analysis, sometimes referred to as Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Aid methods (MCDA) by different researchers in the field of Operation Research model. MCDA which is a GIS-based tool provide solutions to geospatial difficulties associated with site selection by factoring various values assigned to each criterion using mathematical or weighted overlay methods to make best spatial decision (Rikalovic *et al.,* 2014). Saaty (2008) indicated that Analytic Hierarchy Process (AHP) is the most widely used techniques of Multi-Criteria Decision Making (MCDM) and it was introduced by Saaty in 1980 using pairwise comparisons of criteria to establish a relationship matrix (proportion). Analytic Hierarchy Process (AHP) is a method which aid decision makers to come out with unsurpassed explanation and facts that fits their objective and their considerations of the difficulties, prompted by a planned likelihood solution guided by baseline knowledge of the challenge. AHP try to mimic the impression of the natural ways we humans view and make reasonable conclusions about strategic planning. GIS combined with other systems has shown a suitable and dominant base for investigating the most suitable location for siting of waste to energy plant which is the major aim of this study.

3 MATERIALS AND METHOD

3.1 Study Area

The capital of Oyo State Ibadan is the third biggest city in Nigeria in terms of demography coming after Lagos and

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Kano in that order. The city is located at a distance of 145 km Northeast of Lagos and approximately on longitude 3° 55' 00'' East and latitude 7° 23' 47'' North. Ibadan city comprises of 11 local government areas. There are 5 major urban local government areas at the centre of the city with dense urban development and the remaining 6 are located at the outer surrounding suburban areas of Ibadan city, see figure 2.1. In Ibadan, 42% of households dumped their wastes in official waste dumpsites whereas 28% household residents put their wastes on unofficial dumpsites including water ways while 20% adopt burning method and the rest use other methods. Like other major cities around the world, Ibadan generates large amount of waste about 7600 tonnes of waste daily and collection of waste services in Ibadan metropolis are provided by Oyo State Waste Management Authority (OYOWMA), Local Governments and the Private Sectors (Dar, 2017).

3.2 Materials

To successfully select the best location for waste to energy plant in Ibadan, Oyo State, Nigeria, the following geospatial data were processed. They include waste dump sites, transportation network, power substations, power lines, that were vectorized and Euclidean distance was carried to convert them to raster and were reclassified accordingly with other raster layers settlement and slope with their properties shown in Table 2.1.

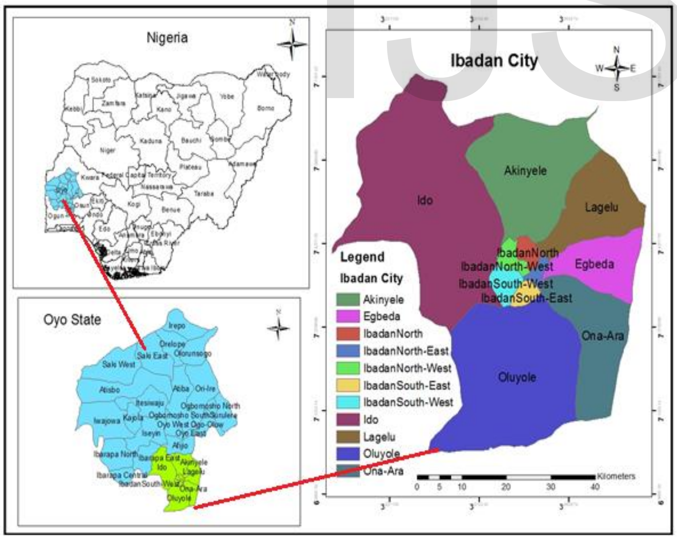

Figure 2.1 Map showing the study area – Ibadan City

Table 2.1 Dataset and sources used in this study

S/N	Data	Source/Link	File format	Date
1	Settlement	https://www.worldpop.org/geodata/summary?id=17208	Raster	2019
2	Elevation	http://srtm.csi.cgiar.org/	Raster	2018
3	Transportation network	Ibadan Master Plan	Vector	2017
4	Sub station	Ibadan Master Plan	Vector	2017
5	Power lines	Ibadan Master Plan	Vector	2017
6	River	Ibadan Master Plan	Vector	2017
7	Markets	Grid 3		
8	Institution	Grid 3	Vector	2017
9	Industries	Grid 3		
10	Waste dump sites	Grid 3	Vector	2019

3.3 Methodology

The various criteria used for the study were then standardized according to the expert knowledge and the pairwise comparison was assigned using the percentage influence and the scale value of 1 to 9 (with least suitable being 1, and most suitable being 9).

All the required data were processed according to Saaty's (1980) Analytic Hierarchy Process (AHP) by assigning scale values to fit percentage influence. In this technique, the relative ranking of each specific class within the same geospatial data considered were weighted among one another using pair-wise. The AHP was used to determine the areas of high, moderate and low influence**.** According to Lüscher (2019) weighted overlay uses comparative scale of importance to process all the raster geospatial datasets input together to produce a final site suitability map. In order to achieve a successful weighted overlay operation for selecting waste-to-energy plant in Ibadan, procedures set by ArcGIS Online were considered which is in accordance with Saaty's pair-wise comparison method, see table 2.2 below.

Table 2.2 Scales of pair wise comparison Source: (Satty, 1980)

Variables	Preferences expressed in linguistic variables
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values between adjacent scale values

All the criteria for siting a Waste-to-Energy plant were prepared using remote sensing and GIS techniques in order to identify the suitable areas. The layers considered for the suitability analysis were as follows: the settlement, dumpsites, transportation networks, industries, river, market, power substations, power transmission lines and slope. Each criterion was assigned a weight and rank for its fields according to their importance. The relative ranking of each criterion was assigned an AHP using Spatial Analyst tool of ArcGIS.

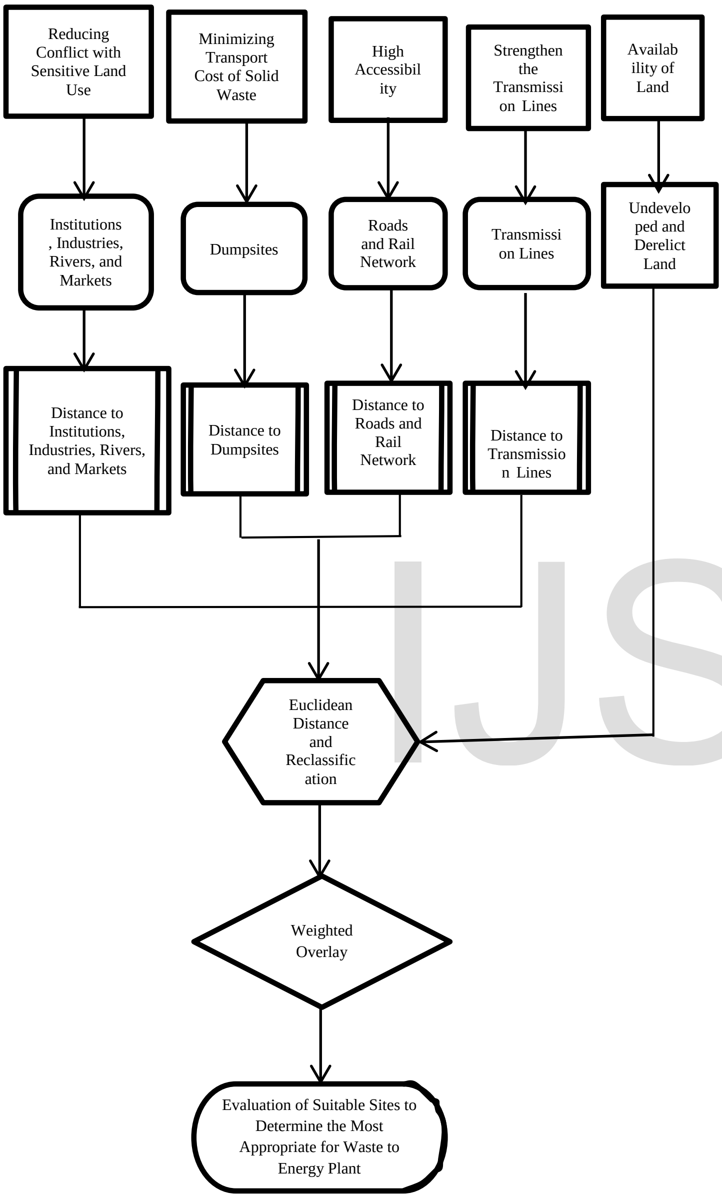

Figure 2.2 Methodology Flow Chat.

3.3.1. Dumpsites and Transportation Network

The dumpsite layer was classified into 3 categories with unsuitable, less suitable and most suitable as shown in figure 4.6. Most of the operational costs of WtE facilities are related to waste transportation, nearness to transmission lines that otherwise may affect the financial viability of the project (Shi *et al.*, 2008; Tavares *et al.*, 2011). In order to reduce cost of transportation, WtE are preferably located within or relatively close to dumpsite (World Bank, 1999; Hu *et al.*, 2015 and UNEP 2019a). Also, minimizing transportation cost can be attained by highly accessible sites that ensure uninterrupted supply of solid waste (Tavares *et al.*, 2011). Logically, the site of solid waste WtE is best located close to major transportation network. The dumpsite was considered as a major criterion and a determining factor for the feasibility of WtE plant as shown in table 2.3 and the influence of the dumpsite was assigned 18% with proximity of the WtE to the Dumpsite less than 15 kilometers. Roads and railway network access play an important role in WtE facility and considering the accessibility to these networks are essential in siting the plant thereby reducing the operational cost. As indicated in Table 2.3, the railway network and roads were assigned an influence of 16% and the reclassification was analyzed based on the distance from the major roads. Areas nearer to the networks at approximately 1km were classified as highly suitable, those at approximately 2km were considered Suitable and those approximately 7km were considered least suitable. This is shown in figure 4.5. The construction of new access roads for transportation of waste from the dumpsites to the power plant is very expensive and is one of the factors that might affect the lifespan of the power plant.

Table 2.3 Dumpsite and Transportation network Suitability Influence.

Raster Layer	% Influence	Distance (km)	Level of Suitability	Scale Value
Dumpsite	18	0 - 15 15.1 - 25 25.1 - 35.6	Most suitable Less suitable Unsuitable	9 2 1
Transportation network	10	0 - 0.9 1 - 2 2.1 - 7	Most Suitable Less suitable Unsuitable	3 2 1

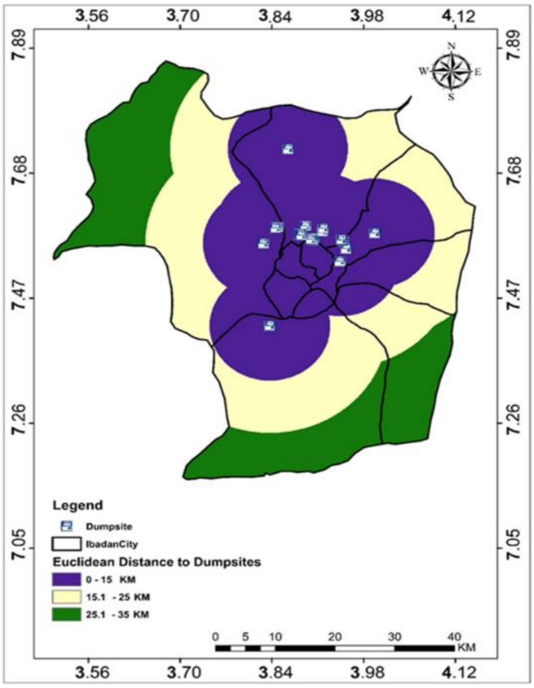

Figure 2.3 Euclidean distance of dumpsites

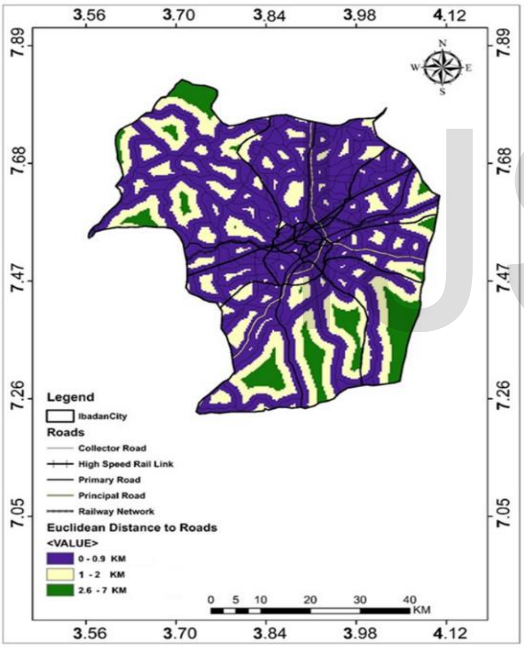

Figure 2.4 Euclidean distance of Transport

3.3.2 Transmission Lines and Substations

Transmission lines and substations are economically considered as significant criteria for electricity generation because they can increase or decrease the cost of production. Thus, they should be considered in selecting the suitable locations for waste to energy power plant (Bartnicki and Willamson, 2012 and UNEP 2019a). With regard to this, the transmission lines and substations were assigned 9% influence respectively as shown in table 2.4. To guarantee optimum use of the generated electricity, the solid waste to energy facility must be located near to the power transmission lines and substations that pre-existed in the location to make connections easy to end-users (World Bank, 1999; Tavares *et al*., 2011). The local electricity distribution company can easily allow direct power injections from the waste to energy power plant into the electricity distribution across the study area that was presently facing electricity shortage. The transmission lines and substations were classified to 3 categories as highly suitable when the distance is less than 5km, less suitable when the distance is more than 5.1 to 10km and unsuitable when the distance is more than 11km. Having a good waste to energy resource will only be beneficial if the energy generated by the power station can be delivered to the purchaser in a cost-effective manner. It is usually physically possible to connect a site closer to a transmission system. As a result, areas which are near to the transmission line and substations were classified as highly suitable, areas far were classified as suitable and areas very far as unsuitable as shown in Table 2.4.

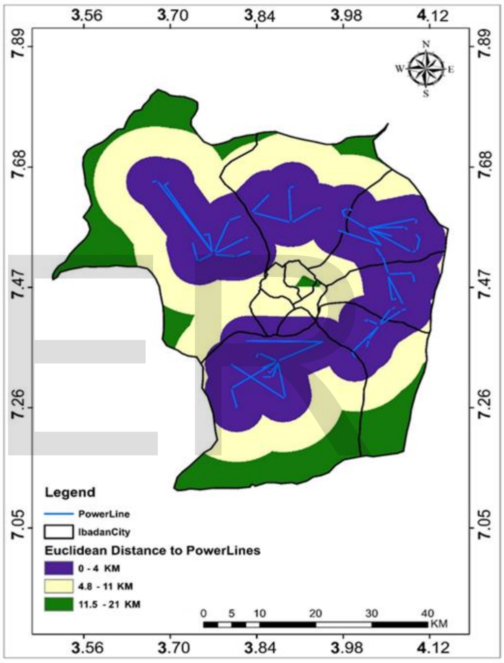

Figure 2.5 Euclidean distance of transmission lines

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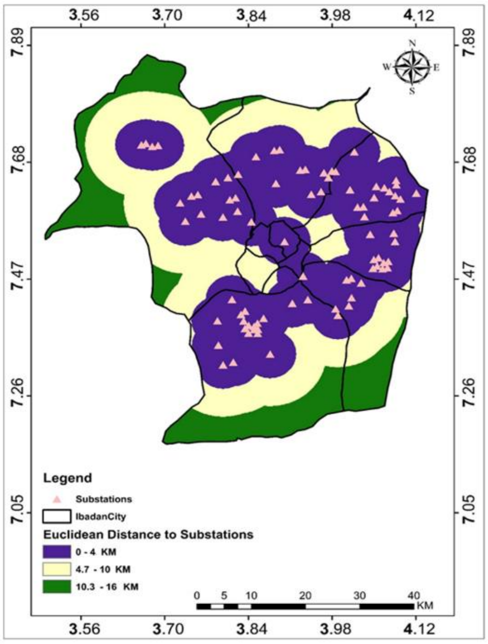

Figure 2.6 Euclidean distance of substations

Table 2.4 Table for transmission lines and substations suitability influence

Raster Layer	% Influence	Distance (Km)	Level of Suitability	Scale Value
Transmission lines	9	0 - 4 4.1 - 11 11.1 - 25	Most suitable Less suitable Unsuitable	5 2 1
Substations	9	0 - 4 4.1 - 10 10.1 - 16	Most Suitable Less suitable Unsuitable	5 2 1

3.3.3 Settlement and River

Several experts including Mbuligwe (2004); Pavlas *et al* (2010) and UNEP (2019a) have commented on the general impacts of municipal solid waste to energy plants on humans and the environment worldwide. However, due to the impact on built-up areas and water body, this study considered best way to militate against and avoid such impacts associated with location of the waste to energy power plant. In order to reduce the various impacts of pollutants that are associated with waste to energy operations which includes water, air, noise, and visual pollutants may have on the built-up urban areas and natural environment, certain distance were set away from the WtE plant. This means that selected sites should be located away from sensitive land uses e.g. residential areas, educational, health services and water body. As a result, places with rivers and built-up were restricted so as not to be close to the power plant. Therefore, distance from the settlement and rivers is classified into two based on the impacts of the power plant to the town residents and water body. Consequently, the settlement area and rivers were classified as unsuitable and suitable and assigned 9% influence respectively as shown in figure 2.7, 2.8 and table 2.5.

Table 2.5: Table for settlement and rivers suitability influence

Raster Layer	Influence (%)	Field Value	Level of Suitability	Scale Value
Settlement	9	Others Built-up	Suitable Unsuitable	2 Restricted
Rivers	9	2 Km above 0 - 2 Km	Suitable Unsuitable	2 Restricted

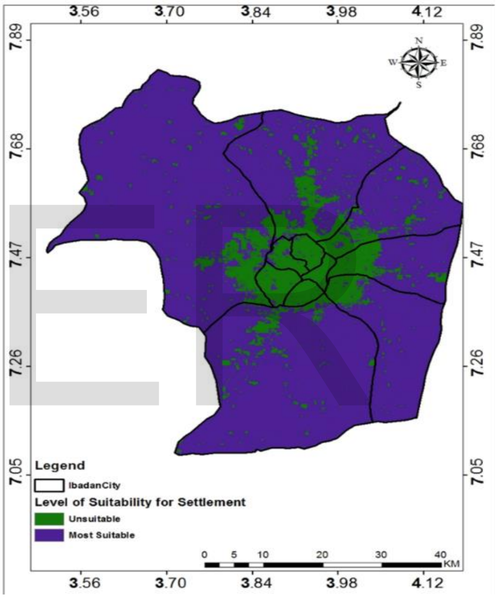

Figure 2.7 Settlement map of the study area

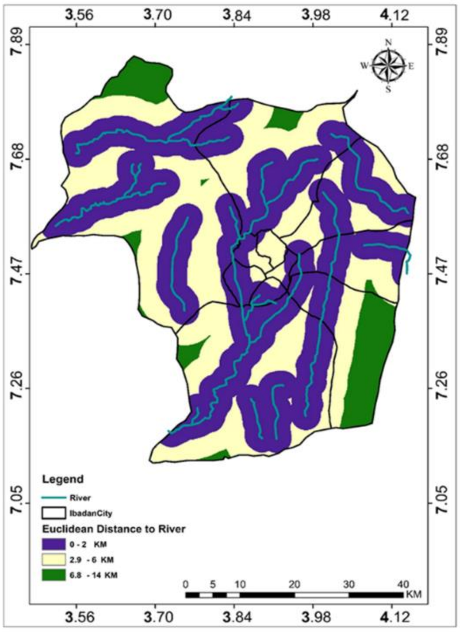

Figure 2.8 Euclidean distance of rivers

Table 2.6 Table for markets, institutions and industries suitability influence

Raster Layer	Influence (%)	Distance (Km)	Level of Suitability	Scale Value
Markets	9	0 - 16	Most suitable	3
		16.1 - 27	Less suitable	2
		27.1 - 35	Unsuitable	1
Institution	9	0 - 7	Most Suitable	3
		7.1 - 19	Less suitable	2
		19.1 - 40	Unsuitable	1
Industries	9	0 - 4	Most Suitable	3
		4.1 - 10	Less suitable	2
		10.1 - 15	Unsuitable	1

3.3.4 Markets, Institutions and Industries

As mentioned by Rand *et al* (2000); Mbuligwe, (2004) and UNEP (2019a) commercial activities from markets, institutions and industries have huge influence on geographic distribution of waste generation and important factors such as good transportation network, electric transmission lines and other facilities are required to successfully operate a waste to energy plants. Principally, UNEP (2019) stated that siting location of WtE plant close to industrial land use areas are very suitable and because of market, institution and industries provide large amount of waste that are needed to operate the WtE. Due to the potential benefits of these factors 9% influence was assigned to market, institution and industries respectively as shown in the table 2.6. Most importantly, as shown in figure 2.10 any area below 4 kilometers are most suitable in the industrial layer map.

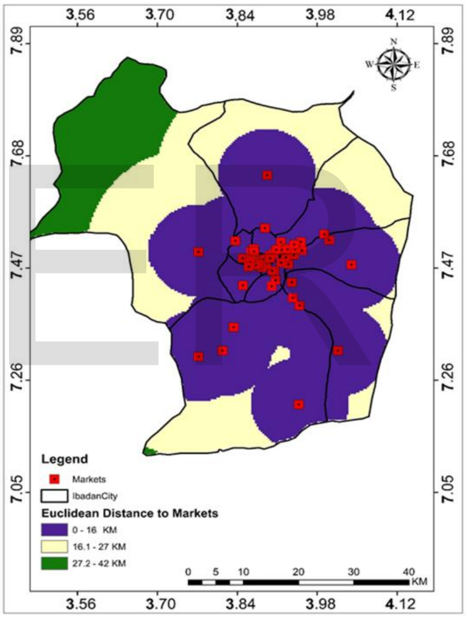

Figure 2.11: Euclidean distance of markets

3.3.5 Slope

The slope suitability layer of figure 2.12 was derived from SRTM image elevation data. With regards to the elevation data, many of the most suitable location are gentle slope with elevation ranging from 171 to 283 meters, see table 2.7. Most of the less suitable locations are found in flat slope with the elevation below 170 meters and areas with steep slope range between 284 to 399 meters which are unsuitable for siting waste to energy facility.

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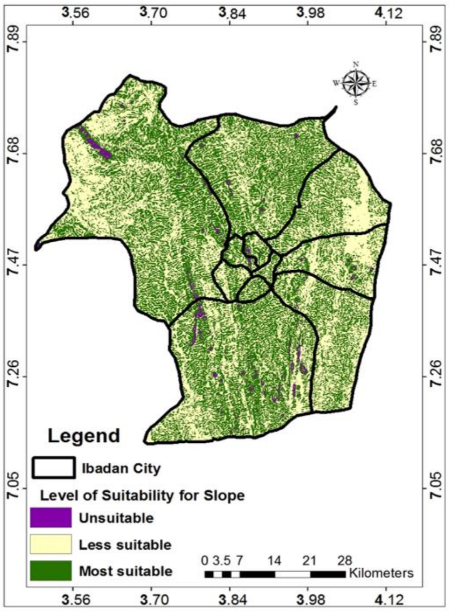

Figure 2.12: Slope map of the study area

4 RESULTS

At this stage, all the 10 aggregated reclassified raster layers that include the settlements, transportation network, transmission lines, substations, market, institutions, dumpsites and slope were combined in order to identify suitable site for a waste to energy power plant in the study area. The spatial analyst tools in the ArcToolbox integrated the weighted analysis that provided the ability to combine all the sub-layers in various scale values to produce a single most favorable layer with best preference value in the final model map. Therefore, the final suitability map for the waste to energy plant was identified by aggregating all raster layers based on their weights.

According to the results of the waste to energy power plant suitability criteria, four suitability classes were identified with varying degree of suitability. For each factor, a weight value was given from 1 (Unsuitable) to 4 (Most Suitable), see table 3.1. Each parameter was given a value based on its suitability for waste to energy power plant site selection. The result for the waste to energy power plant suitability analysis reveals that approximately 83991 hectares of the study area is most suitable, and this was represented by 26% of the study area. The area moderately suitable was 18% represented by 59474 hectares and about 34221 hectares representing 11% of the area is less suitable. Also, approximately 45% of the study area is unsuitable and was represented by 142900 hectares which were areas occupied by mostly settlements and river areas that were restricted for this type of development. This is shown in figure 3.1

Table 3.1 Waste to energy power plant suitability index

Suitability Level	Value Scores	Hectares	Percentage (%)
Unsuitable	1	142900	45
Less suitable	2	59474	18
Moderate suitable	3	34221	11
Most suitable	4	83991	26

4.1 The Final Suitability Site

The final suitability map of a waste to energy power plant site is based on the characteristics of the site. Figure 3.2 shows the composite suitability of the criteria layers. The areas are labelled as Unsuitable, Less suitable, Moderately Suitable and Most Suitable. The areas that are near the dumpsites, transmission line and substations are more suitable than those far away. The most suitable area appeared at the Northern part of the town in Akinyele and Ido Local Government Area in which two sites **A** and **B** are proposed as the most suitable site to establish a waste to energy plant. These sites satisfy different site selection criteria and are close to the landfill site, power line and substations which then means no additional cost for disposing residues from incineration power plant and making connections of the electricity generated from the power plant easy to supply to end-users.

This study conforms with all the site allocation standards by UNEP (2019a) for considering locating the waste to energy power plant within this site, many factors have been considered in order to ensure minimizing the impact of the waste to energy power plant on the environment.

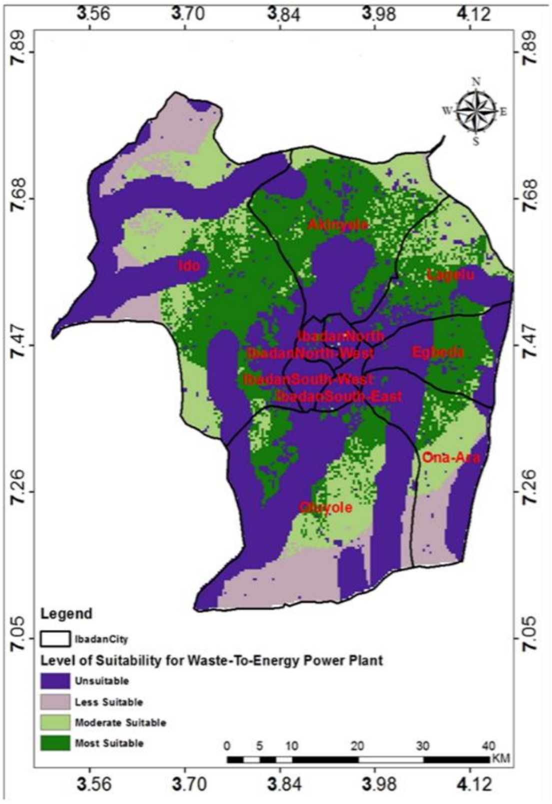

Figure 3.1: Waste to energy power plant suitability map

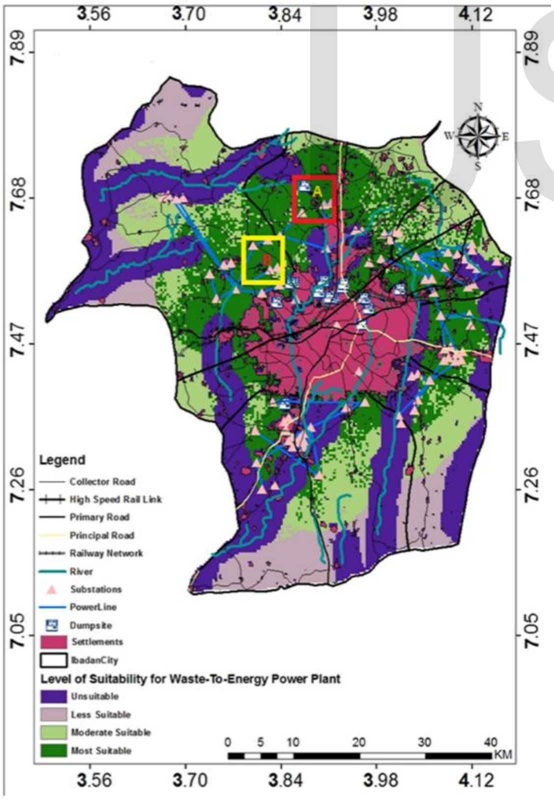

Figure 3.2: Final propose sites A and B

5 CONCLUSION

This work has demonstrated that the GIS weighted overlay analysis is effective for assessing and revealing the rates of suitability for the waste to energy plant in Ibadan. We succeeded in using a combination of ten aggregated geospatial datasets to identify potential suitable sites for a waste to energy power plant in the study area. The findings from the final suitability map showed that the most suitable areas can be find in the Northern part of the town in Akinyele and Ido Local Government Areas with two sites A and B that fit the standard set by UNEP (2019a) to establish a waste to energy plant. These locations conform with the various wastes to energy allocation criteria and are close to the landfill site, power line and substations which meant no additional cost for disposing residues from incineration power plant and making connections of the electricity generated from the power plant easy to supply to end-users. Furthermore, the study provides the foundation for decision makers to develop the waste to energy power plant location in Ibadan City, Oyo State, Nigeria. The use of urban solid waste for electrical energy production in Ibadan will help in achieving the Sustainable Development Goals through provision of needed energy for economic growth of Ibadan city, which will surely create direct and indirect jobs. Also, it will significantly reduce the environmental impact of dumpsites in the Ibadan City through international best practices in waste management targeted at waste reduction, recycling and energy generation. Moreover, this would increase the amount of electricity supply to Nigeria national grid. Yet, improving efficiency of municipal solid waste management system can boost the feasibility of the power plant, as this would mean ensuring regular flow of solid waste for the power plant.

5.1 Recommendations

Having identified most suitable sites for waste to energy power plant in the study area, it is recommended that decision makers in Ibadan and Nigeria should have a useful knowledge about the locations where waste to energy power plant can be sited in Ibadan. Government should endeavor to adopt the result of this study in constructing a waste to energy power plant all over major cities in Nigeria to help prevent waste from being dumped indiscriminately and eventually help solve the problem of power generation and distribution since this study has taken care of all the criteria as regards suitable locations of waste to energy power plant.

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