Suitability Analysis for Siting a Waste To Energy Power Plant in Kaduna, Nigeria

Agbaje, G.I. *, Adegbite, A. A.*, Oladosu, R. O.*, Ivian, A.I.**, Nkem, F.N.**. Bianka, A.C.* *, Chikodili, E.E**, Hosea, J.A**, Umar, M.T.**, and Elugoke, N.O.*.

*(African Regional Centre for Space Science and Technology Education in English (ARCSSTE-E) Obafemi Awolowo University, Ile-Ife, Osun State, NIGERIA Email: rahhmannn1@yahoo.com)
** (Strategic Space Applications, National Space Research and Development Agency Headquarters, Abuja, NIGERIA Email: neriako@yahoo.com)

Abstract:

Municipal solid trash is regarded as one of the major threats to environmental quality in developing countries' metropolitan areas. Our cities' inappropriate solid waste management poses a severe health risk in terms of solid waste appropriateness. They reduce pollution emissions, conserve resources, and save energy. This study conducted a site suitability analysis in Kaduna with the goal of finding a suitable location for waste-to-energy generating plants. The slop map of the study area was created using the Shuttle Radar Topographic Mission (SRTM). In the ArcGIS environment, Euclidean distance analysis was performed on institutions, rivers, dumpsites, roads, markets, transmission lines, and electricity substations. The waste to energy power plant suitability map was created using a multi-criteria technique by overlaying the datasets. The waste-to-energy-power-plant suitability map was made by combining the criteria. Dogon Dawa, Sabon Birinin Jaji, Ganga, Buruku, chikun, Dokwa, ikara, and Kuban are the best sites. This research demonstrates how geospatial technologies can help with solid waste management decision-making. It is also suggested that decision-makers in the study region use it as a guide before authorizing a waste-to-energy power plant location.

Keywords — **Waste-To-Energy, GIS, AHP, Kaduna, Nigeria.**

I. INTRODUCTION

Waste is defined as any unwanted material that must be discarded (Abdullahi, 2011). However, garbage is officially classified as a resource in the incorrect location. Anything we do not need and desire to get rid of is considered waste. Unusable residues in raw materials, leftovers, rejections, and trash from industrial activities, used or scrap packaging materials, and even the saleable product all contribute to solid waste. Waste collection, disposal, and dumpsite management are critical issues, particularly when rapid urbanization is present (Butu et al, 2013). A third and half of the solid waste produced in most Nigerian cities are not collected, resulting in illegal dumping on streets, open spaces, and wasteland. According to Ajibuah (2013), indiscriminate waste disposal along the Kaduna Metropolis is the primary factor influencing residents' yearly vulnerability to floods. The Kaduna State Government established the Kaduna Environmental Protection Agency (KEPA) and the Kaduna State Urban Development Authority to supervise city planning and development (KASUDA) but they are bedeviled by sharp practices, professional inadequacy, and technical inefficiency by all standards. Furthermore, waste management has been identified as a challenge in many countries around the world, especially in developing countries, and a link has been found between rapid urbanization, population explosion, industrial development, and the rate of waste generation in such cities. Waste management has become a major problem in most Nigerian cities. The amount of waste that people generated daily in the country has increased dramatically in recent years. This is owing to the massive amount of waste generated daily in cities, which necessitates efficient management to safeguard the environment and the inhabitants. World Bank projected municipal waste generation emerging economies must respond to the challenges of will rise worldwide from 1.3 billion tons annually in urbanization and energy demand (Dar, 2017). In the recent improvement of people living standards, the quantity of consumption against limited solid waste management 2012 to 2.2 billion tons annually by the year 2025 times, Waste-to-Energy (WTE) has gradually been regarded as a way out to the (UNEP, 2019). Along with population problems derived from growing waste quantities in the explosion, rapid urbanization, economic development and expanding cities as well as fast increasing energy.

Municipal Solid Waste (MSW) has been on the increase mostly in developing nations caused by rapid urbanization and resulting in socio-economic and environmental challenges (World Bank, 2019). It is anticipated to witness rapidly increase in urban waste generation in the future and more environmental consequences (Rodriguez, 2011). It is worthy to note, waste disposal and management pose serious challenges to most cities around the world thus serious management systems to adopted by city planners. In developing countries, municipal waste threatens both the environmental and social qualities of life (UNEP, 2019). These projections have drawn increased attention to the issues that garbage disposal and waste management face as an important topic for current and future policymakers to consider achieving city sustainability. Troschinetz and Mihelcic, (2009) reported that MSW is regarded as a major environmental problem that affects urban sustainability in many developing countries. Ayodele et al (2018) saw the economic gain municipal waste can provide to the city of Kaduna and encourage various stakeholders to adopt biogas from MSW for energy generation in Nigeria. Waste-to-Energy (WTE) remains the greatest solution because of its ability to convert thermal energy into electrical energy, resulting in the production of sustainable energy for many communities (Ryu, 2013). Waste-to-Energy remains a best practice for effectively managing garbage and reducing the depletion of natural resources, as well as other environmental concerns linked with waste generation, among the sustainable means of waste management and energy generation being embraced around the world (Cucchiella et al., 2017). In order to manage waste generation sustainable the Ethiopia's government invested $96 million in the construction of Africa's first WTE facility at the Koshe dumpsite in Addis Ababa, like every other dumpsite in Africa, has created major environmental threats to communities living on the fringes of Ethiopia's capital. (AA, 2019). The primary difficulty in managing solid waste in affluent countries has switched from ensuring minimal harm to public health and the environment to determining how discarded materials should be managed so that future generations do not lose out on their value (Chandak, 2010).

Study Area

On May 27th, 1967, Kaduna State was created. It is located in the sub-humid agro-ecological zone of north-central Nigeria and has borders with Zamfara, Katsina, and Kano in the north, Bauchi and Plateau in the east, Nassarawa and the Federal Capital Territory (F.C.T) in the south, and Niger State in the west. The State is between longitudes 7^0 and 9^0 East of the Greenwich Meridian and between latitudes 9^0 and 11^0 north of the equator. The state covers a total size of about 48,473.2 square kilometers. The capital of the state is Kaduna metropolis. The metropolis is made up of two main local government areas, Kaduna North, and Kaduna South, as well as neighboring local government districts Igabi and Chikun.

II. MATERIALS AND METHOD

Ndu (2013), published studies illustrating the essential roles GIS and Remote Sensing may play in the optimum location of solid waste management and energy generating facilities have sparked a lot of attention. Residential (household waste), industrial, institutional, street sweeping, construction, sanitation, and business solid waste are the different types of municipal waste. Furthermore, municipal strong or solid trash refers to solid garbage generated by households, streets and public areas, stores, offices, and hospitals, which are typically the responsibility of municipal or other governmental bodies. Commercial solid trash is usually no longer considered municipal. However, because this garbage eventually becomes part of the municipal garbage stream, it must be considered when managing solid trash. Hassaan (2015) conducts an in-depth examination of a municipal solid waste incineration power facility in Alexandria, Egypt, utilizing GIS-based multi-criteria analysis. To create the optimum spatial option, the work analyzed five factors: Lowest operation price, Nearness to the electricity, and each criterion was assigned to each criterion using mathematical or weighted overlay methods (Rikalovic et al., 2014. Several studies have been conducted on the site suitability of waste-to-energy generating plants, with GIS analysis being used to locate the most ideal places. These experiments demonstrated the relevance of locating the waste-to-energy generating facility using GIS techniques.

Mahmoud (2015) developed a GIS-based model for siting a municipal solid waste incineration power plant in Alexandria governorate, Egypt, using multi-criteria analysis. four factors such as identifying setting criteria, Data preparation, developing suitability index and Identifying the suitable site are studied for this purpose, and the data used are land use pattern, Roads, electricity grids were digitized from topographic map scale for Alexandria composite index was proposed to integrate these criteria into a numerical term that reflects the feasibility of different sections of the governorate for locating solid waste incineration power.

Rosniza and Zulkiflee (2012) proposed a GIS multi-criteria site selection method for power plants. The function of AHP and GIS in choosing the best location for a nuclear power plant is detailed in the paper, along with site selection criteria and outcomes. The Raub District in Pahang was chosen as a research location because its geography met the majority of the criteria. Low population density, residential area, river access, geography, land use, power infrastructure, and land ownership were among the seven characteristics considered in the analysis. In addition, the following stages were completed: represent the criterion in GIS layers, conduct GIS analysis to obtain numerous proposed sites, and classify the criteria based on their weight value. A GIS-based site suitability analysis for developing a solar power park in Namakkal District, Tamil Nadu was presented by (Kalaiselvan and Purushothaman, 2016). The major parameters that were evaluated in identifying a suitable location were topography, distance to infrastructure, and area for organizing a park. The efficiency of the incoming solar energy for tapping was determined. Power consumption by industry in the analysis, peak demand and cost considerations were taken into account. Two interconnected steps were used in this research. To begin, the research area's land use/land cover map was created using remote sensing and LANDSAT 8 satellite data. Second, the aspect angles map and slope map for the research area was created using a Digital Elevation Model (DEM). This research reveals a potential site for a Solar Power Park.

The selection of a good location for a Thermal Power Plant along the mining area in the Rajpardi district of Gujarat, India by (Kaliraj and Malar, 2012) is one of the examples of geospatial technology's contribution to humanity's development. The integrated thematic database on the GIS platform was generated using multi-spectral satellite data and geology data, geomorphology, topography, settlement and transport, forest cover, hydrology, and climate for identifying the suitable location for Thermal Power Station (TPS) construction. The TPS location was chosen using four key criteria: land, water, coal mine, and environment, as well as two additional criteria: settlement and site accessibility. According to the regulatory standards of MoEF (Ministry of Environment and Forestry) and CEA (Central Electricity Authority), the multi-spatial factors are processed into a Site-Suitability Index (SSI). Each class in the spatial layers is given a weighted value between 1 and 10 depending on its relative importance to appropriateness. The outcome was graded as high, medium, low, and not acceptable based on the sum of weightage of spatial layers utilizing weighted overlay analysis. In order to identify the right location for a waste-to-energy facility in Ibadan, Nigeria, a multi-criteria decision analysis was conducted by Adegbite et al., (2020). They came up with ten criteria for selecting a waste-to-energy power facility in Ibadan. Dumpsites, transportation networks, electricity transmission lines, power substations, settlements, rivers, slope, markets, institutions, and industries were all included in the requirements. Depending on which layer was considered, the data was processed as Euclidean distance and categorization into two or three layers.

Materials

The Kaduna Metropolis is the major focus for this study see figure 1. All the geospatial data were projected to WGS 1984 Zone 31N coordinate system this includes river, railway, high-speed rail connection, railway network, power substations, power lines, waste dump sites, settlement, and slope. All the data was resampled to fit the resolution of the SRTM data. Table 1 showing data and data source.

Table 1 data and data source.

Data	Source	File format
Settlement	worldpop.org	Raster
Elevation	srtm.csi.cgiar.org	Raster
Road	Grids3	Vector
Power lines	Grids3	Vector
Market	Grids3	Vector
River	Grids3	Vector
Waste dump	GPS Point	

This study employed a variety of geodata sets to conduct the analysis for locating a waste-to-energy power facility in Kaduna. The datasets utilized, as well as their format and resolution, are listed in table 1. This study adopted the method used by Adegbite *et al.*, (2020) to identify the most suitable site for waste-to-energy power plant in Ibadan. Figure 2 highlights the types of geospatial data used, the purpose for identifying set criteria, the data processing steps and analysis.

Prior to data integration, Satty's (1980) Analytic Hierarchy Process (AHP) was used to assess individual class weights and map scores; in this method, the relative importance of each individual class within the same map was compared pair-wise, and important matrices were prepared for assigning weight to each class. The zones were divided into three groups using the AHP: high, moderate, and low. The zones were classified using rubbish dumpsites in Kaduna, the river, the settlement, the rail, the transmission lines, the slope, the railway, the road, and the power substations. This stage assigns each theme layer a numerical weighting factor depending on its relative value.

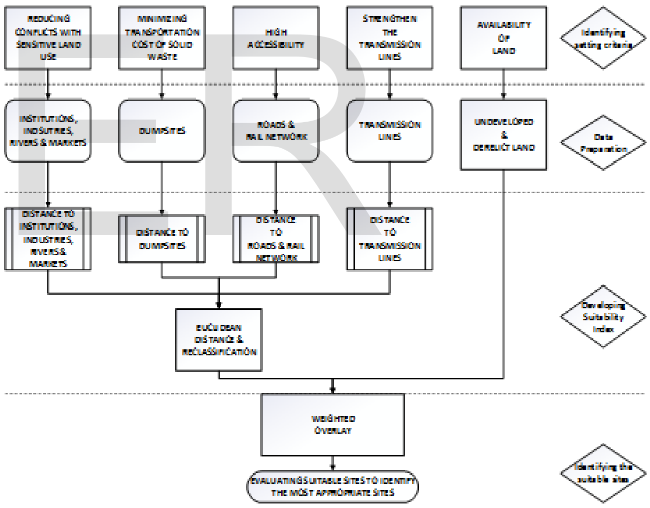

Figure 1 Methodology Flow Chat
(Adopted from Adegbite *et al.*, 2019)

III. RESULT AND DISCUSSION

Settlement and Rivers

In the case of a solid waste incineration power plant, some annoyance elements such as odor, noise, and emissions are unavoidable. This means that certain sites should be situated away from sensitive land uses such as residential neighborhoods, educational and health facilities, and so on. As a result, the greater the distance between the power plant site and sensitive land uses, the better the chances of avoiding and/or mitigating the negative effects of these bothersome elements. As a result, areas near rivers and densely populated areas were restricted in order to avoid being too close to the power plant. In the research area, settlements encompass 49960.954611 hectares, whereas other regions such as vegetation and bare land cover 276053.22122 hectares.

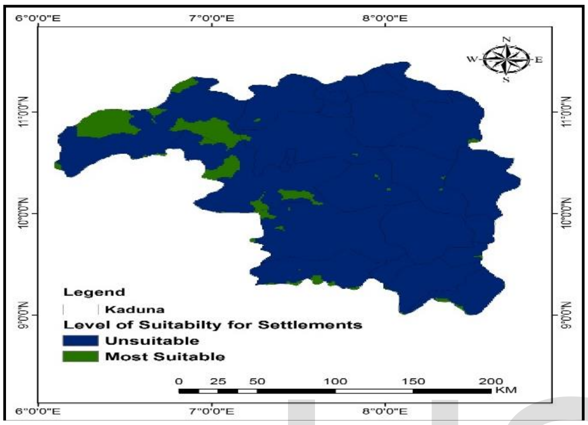

Fig. 2 levels of Suitability for Settlements

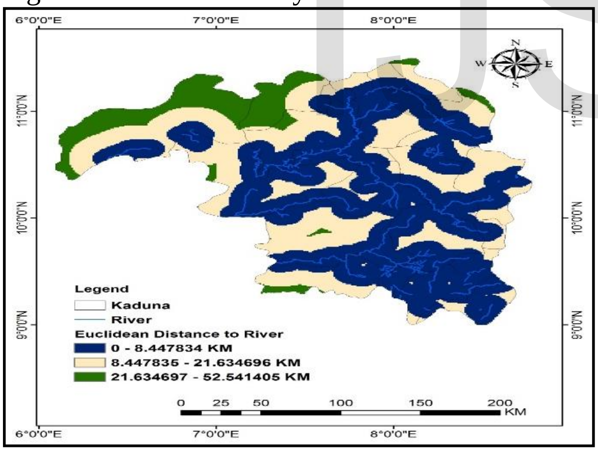

Fig.3 Euclidean distance of river

Waste to Energy Power Plant Suitability

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 3 (Most Suitable). Each parameter was given a value based on its suitability for waste to energy power plant site selection. The weighted value of each factor was added and the average value of them was taken to determine the suitability of land for waste to energy power plant establishment.

In conclusion, the result for the waste to energy power plant suitability analysis reveals that approximately 83686 Hectares of the study area is most suitable and this is represented by 26 % of the study area. The area moderately suitable is 18 % represented by 58794 Hectares. Also, approximately 45% of the study area is unsuitable and is represented by 14241 Hectares. The most suitable areas are sabon Buruku jaji, Ganga, Buruku, chikun, Dokwa, Ikara , Kuban, Birinin-gwari, kaura, and sabon gari. All of the criterion layers are integrated at this point in order to find a viable location for a waste-to-energy generating plant in the research region.

Overlay analysis was performed on the waste to energy power plant using ArcGIS 10.4.1's weighted overlay tool. The towns, river, roads, transmission lines, market, dumpsites, and slope were all reclassified raster datasets that were aggregated at the end of these operations. The Weighted Overlay tool combines all raster layers according to their weights. To depict the data as clearly as possible, the final raster was classed manually. The wastes generated in Kaduna metropolis are deposited in the following ways: the first and most common practice within the slums, ghetto, and sprawl neighborhoods of Ungwar residential areas is the open ranges, are used as refuge dump sites, these are carried out along major routes, footpath and piece of undeveloped land or abandoned residential structure, the second method, is collection sites are employed among those that lives in Government Reserved Areas or Ungwar extension where necessary town plan layout are done but these collection sites have often located far away into the Ungwar areas. Third group are the combination of the first two groups that normally use the bank of River Kaduna as their dumping sites, while the fourth group area the two institutionally designated areas as dumping sites. These are areas that are specially created so waste can be put into the ground with little or no harm to the natural environment through pollution. They are located outskirt the Metropolis. One is along Birinin-Gwari road in the northern part and another along Abuja highway in the southern part of the Metropolis.

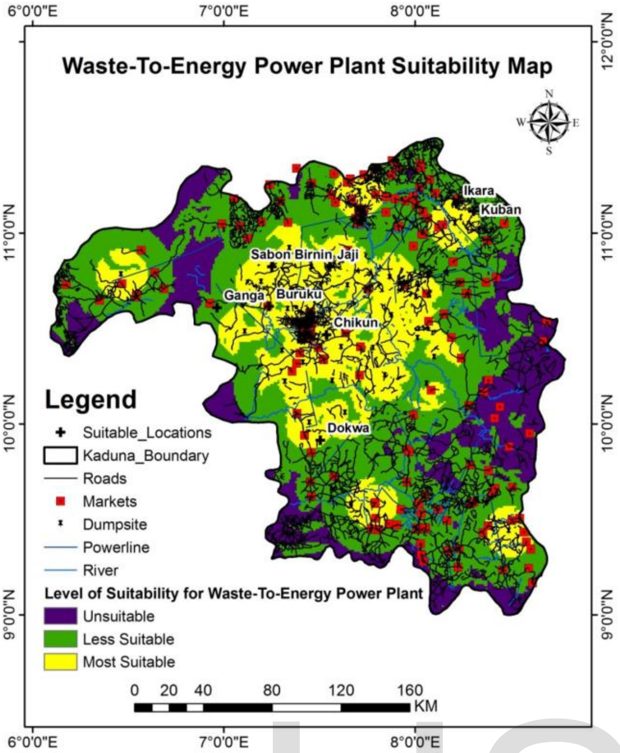

Fig. 4 Waste to Energy Power Plant Suitability Map

IV. CONCLUSION

The criteria were represented in GIS layers, and the GIS analysis was run to obtain several potential sites. The criteria were then classified based on their weight values. The site suitability map is useful for determining the suitability of a site for a waste-to-energy power plant. The results of the site suitability assessment revealed that the Makafia local government, located in the city's northern outskirts, was the most suitable area for locating the waste-to-energy power plant, covering 73686 hectares, or 26% of the total area. In addition, the map lays the groundwork for decision-makers to locate a waste-to-energy generating plant.

By minimizing the amount of solid trash that must be disposed of and so extending the landfill's lifespan, the use of municipal solid waste in the generation of power in Kaduna may contribute to the city's sustainability. Furthermore, as a result of this, the supply of electrical energy would be boosted. Increasing the efficiency of the municipal solid waste management system, on the other hand, may make the power plant more profitable by ensuring a constant flow of solid waste.

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