Spatial framework for site suitability for establishing wind power station in Ibadan city, Nigeria

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Abstract— *Ibadan, located in Nigeria, has a huge demand for electrical energy and as a developing society; many communities do not have access to commercial energy which is a very big challenge to the government. This study aimed at assessing the viability of establishing a wind power station in Ibadan and to identify favorable sites for such stations using Geographic Information Systems (GIS). Based on previous studies and on local requirements, a set of suitability criteria was developed from the Ibadan Master Plan for a sustainable city. These criteria included road network, rail network, high speed rail link, settlement, transmission lines, power substations, slope and wind speed. GIS layers were created, and a weighted overlay GIS model based on the above-mentioned criteria was built to identify the suitable site for a wind power station. Results showed that the highly suitable area appeared at the North Western part of the city in Ido Local Government Area. The obtained results of the analysis showed that the analyzed areas have considerable potential for use of renewable energy resources. The city could benefit from a wind power station that would inherently reduce the local air pollution and help the country to tackle greenhouse gas emissions. Wind power produces clean energy, it doesn't cause water, soil or air pollution; hence it is considered environmentally appropriate which makes it much better than other renewable energy sources that produce much of hard-to-manage wastes. The proposed GIS based multi-criteria spatial analysis of suitable site can be modified and efficiently applied to any other spatial location.*

Index Terms— ***Wind power station, GIS, SDGs, Ibadan, Nigeria***.

1.1 Introduction

The ever-increasing population, rapid industrialization, materialistic living standards, and usage of energy intensive appliances, to name but a few reasons, are causing growing demands on electricity and are resulting in higher global per capita energy consumption (Baseer, 2017). Debate continues about the best strategies for the management of the huge energy challenges anticipated in the coming years so as to meet the requirements of billions of people that still have deficiency to access basic, up-to-date grid-connected energy services, while also addressing the global transition to clean, low-carbon energy systems by mitigating the use of fossil fuels for energy generation. Sustainable Development Goal 7 is one of the most wildly known international policy aims at safeguarding provision to reasonably priced, dependable, workable and efficient energy for all (UNOOSA, 2019). In order to respond to the undesirable environmental impacts, presented by using fossil fuels, many nations all over the world have adopted renewable energy systems as a sustainable substitute to meet the growing energy demands (Aydin *et al*., 2010).

Nigeria has been overwhelmed with series of power outages due to insufficient power supply by the power generating stakeholders to meet the demands of consumers. This has significant implications on the rate of economic development. While power usage by household will typically lead to increase in the general consumer pattern, effective use of power by businesses will surely improve national economic standard (Awosope, 2014).

Due to the increasing population in Ibadan today which is estimated at 6 million, there is an increase in the demand for electrical energy and as a developing society; many communities do not have access to commercial energy which is a big challenge to the government. The total demand load at the primary substations level for the Ibadan City will be around 3001 MW in 2036. Nigeria has an installed electricity generation capacity of 7,000 MW, but capacity utilization currently ranges between 3,500 - 4,500 MW and in June 2013 was as low as 2,200 MW. So far, 70% of Nigeria's current installed capacity is gas-fired, with the remaining 30% coming from hydropower (Dar, 2017). The continued heavy reliance on fossil fuel-powered generators in Nigeria by government institutions, businesses such as the telecommunication sector and households as source of electric power creates a key challenge to the Nigerian climate change plans (Punch, 2017). The 2014 World Climate Change Vulnerability Index classified Nigeria as one of the 10 most climate-vulnerable countries. Therefore, there should be an attempt to promote more sustainable and reliable source of energy for generating power so as to reduce consumption of the nation's fossil fuel reserves. This study attempts to assess the viability for harnessing wind energy by incorporating factors considered to help in deriving best location to source energy for wind power generation in Ibadan City, Oyo State, Nigeria using remote sensing and Geographic Information System thereby, producing the relevant database in a spatial framework for site suitability mapping for locating, identifying and delineating the most suitable spot for establishing wind power station in Ibadan city.

1.2 Global Wind Power Trends

Wind turbines generate electricity in form of wind energy by converting kinetic energy into electric power without emission with high level of reported eco-friendly impacts around the world (Funabashi, 2016). The movement of air over the blades on a wind turbine results in pressure differences and turning of a rotor. The rotor is in turn connected to a generator, which converts the mechanical energy produced by the blades and the rotor into electrical energy or electricity. Today, the conventional horizontal axis wind turbine typically consists of four main elements: rotor, nacelle (houses the generator and gearbox), tower and footing (SEDA, 2002). According to ET Energy World (2019), the leading 10 nations with regard to wind power generation are China with 221 gigawatts, the United States with 96.4 gigawatts Germany with 59.3 gigawatts, India with 35 gigawatts, Spain with 23 gigawatts, United Kingdom 20.7 gigawatts, France with 15.3 gigawatts, Brazil with 14.5 gigawatts, Canada with 12.8 gigawatts and Italy with 10 gigawatts, all figures representing current onshore and offshore wind farm capacity generation.

In Africa the principal wind farm is the Lake Turkana Wind Plant located in Kenya and the station consists of about 365 turbines. Each of these turbines can produce 850 kilowatts of energy, and the total electricity production at the station is 310 megawatts that represent about 17 % of Kenya's electricity generation presently. The 680-million-dollar development was funded with a 200-million-dollar financial credit facility from the EU and backing from a group of European and African corporations (Lake Turkana Wind Power, 2019). The Zafarana Wind Farm is in Egypt's desert region, 120 kilometers south of Suez on the Red Sea that enjoy wind speeds of about $9ms^{-1}$. The initial stage of the wind power station was built around most part of the year 2000. It comprises of 50 wind turbines generating about 60 megawatts. An extension to the wind farm in 2007 added 142 new turbines and generated an additional 120 megawatts of electricity. Also, the Tarfaya Wind Station is situated in Morocco and the construction price stood at 490 million dollars with combined investments amongst GDF SUEZ and Nareva Holding. The site occupies about 9,000 hectares with 131 wind turbines and each generating 2.3 megawatts with a total electric power above 300 megawatts supplying over 1,500,000 homes (Wind Energy - The Facts, 2009). The Ethiopian Electric Power Corporation manages Adama II Wind Farm sited in Addis Ababa and the project is financed by China investing 340 million dollars. The wind farm consists of 102 wind turbines with total of 153 megawatts with 1.5 megawatt per turbine (Sunil, 2013).

1.3 Wind Energy Regulation in Nigeria

Wind energy exploration in Nigeria has not been properly adopted like other nations because most of the existing wind energy systems are abandoned due to inappropriate evaluation of its potentials, operations and management (Oyedepo, 2012). In a bid to diversify its energy sources and optimize other assets for power production, Nigeria has set a target of meeting 30 per cent of its energy needs from renewables by 2030 which includes wind power. The Nigerian government in the year 2015 introduced the National Renewable Energy and Energy Efficiency Policy (NREEEP). According to the NREEEP document published in 2015 following major initiatives to guarantee the adoption of the policy are stated below:

i. The country intends to profitably utilize its wind energy capacity and combine it with other energy resources to stabilize energy and power.

ii. The country plans to use standard procedures to ensure that the energy is exploited sustainably at best cost nationwide.

iii. The nation shall ensure local capacity development to produce and manage all components needed for wind power generation.

In line with this, the Nigerian Government and Siemens in 2019 introduced the Nigeria Electrification Roadmap aimed to improve and increase electricity generation, transmission and distribution. This strategic plan is in three stages; one to increase electric generation capacity to 7,000 megawatts, then, stage two targeted 11,000 megawatts and the last stage focused on ways the country will hit 25,000 megawatts (Siemens, 2019).

With the huge renewable energy resources, the NREEEP Master Plan as well as the Nigeria Electrification Roadmap certainly, Nigeria now have well positioned strategy to finally adopt the use of wind energy to meet the current energy crisis and at the same time reduce her dependence on fossil fuels.

1.4 Site selection of Wind Power Stations using GIS

There are several studies that have been carried out on the site suitability of wind power stations using GIS analysis to find most suitable locations. These studies showed the importance of using the GIS tools to locate the renewable energy power plants.

In the work by Bili and Vagiona (2018), the mechanism for determining and evaluating the suitability of areas for siting wind power stations, using a combination of Multi-criteria Data Analysis, (MCDA) and GIS was developed. During the assessment of suitable areas, using the Analytic-Hierarchy-Process (AHP) and pairwise comparison scale was used to determine the weightings of the identified major determinant factors before overlaying all the factors to get the final site for the wind station. Also, Baseer (2017) presented a multi-criteria wind farm location suitability analysis by developing a GIS model. The GIS based models provided effective decision support framework for evaluating wind energy farm sites, identifying the criteria or factors that determine the suitability of areas to locate wind energy farm and producing final site suitability maps in the Tirumangalam Taluk of Madurai district, Tamil Nadu, India.

The research by Yang (2013) attempts to evaluated the possible wind energy station in Minnesota by investigating the technical, ecological and regulatory government criteria for developing local renewable wind energy plant. The work also incorporated Multi-Criteria Analysis (MCA) and AHP along with various forms of spatial and sensitivity analysis to identify areas that have an excellent suitability for future wind turbine placement in Minnesota. Saleous *et al* (2016) assessed the feasibility of creating wind power stations offshore in the Emirate of Abu Dhabi, UAE and identified favorable positions for such stations using Geographic Information Systems (GIS) methods and algorithms.

The pairwise comparison method was introduced by Saaty (1980), for determining factor weights in the Analytic Hierarchy Process (AHP). This rule-based method is one of the most commonly used by decision-makers and planners for evaluating multi-criteria decisions (Pohekar and Ramachandran, 2004), and it provides a calculable consistency factor (in the form of a ratio) that provides decision-makers with a considerably higher level of confidence in the criteria weighting process. IRENA (2016) presented site suitability map for West Africa which was calculated at approximately 1km resolution off-grid energy systems. The pixel values showed a suitability score varying from 0 to 100% suitability. The score added the suitability levels for 6 factors: distance to electric networks, residential density, terrain, landcover, conservation areas, solar and wind energy potentials. The map indicated that Ibadan have suitability values between 60 and 70% for potential off-grid energy systems.

2.1 Study Area

Ibadan City is in the south-western part of Nigeria, see figure 2.1. It lies approximately on latitude 7° 15' 00" N, longitude 3° 45' 00" E and latitude 7° 34' 00" N, longitude 4° 05' 00" E of the Greenwich Meridian. With a population of over 6 million, it is the third most populous city in

Nigeria, after Lagos and Kano. It is the country's largest city with an area of 3,145.96 sq. km, which is nearly 11 per cent of Oyo State (Azeez *et al.*, 2016). Ibadan is in the tropical rain forest zone with rugged terrain noticeably steep slopes creating a dense network of streams with wide valley plains. The elevation in Ibadan varies from 150 meters in the basin area, to 275 meters mostly in the north/south hills that traverses the central part of Ibadan.

The measured annual mean wind speed in Ibadan is 2.75 ms^{-1}. The wind speed at any given place is extremely related to the local terrain and other features, this means that wind speed in Ibadan varies spatially and temporally (Fadare, 2008). The table 2.1 below shows a detailed wind speed measurements and data carried out in Ibadan to show wind potential for implementation of wind power stations by (Agbetuyi *et al.*, 2012).

Station	Mean wind speed at 25m Level (m/s)	Monthly mean Wind Energy (kWh)	Annual Wind Energy (kWh)	Annual Energy from a Wind Turbine (kWh)	
				10m Blade Diameter	25m Blade Diameter
Ibadan	2.620	4.15	49.78	3,.909.79	24,436.19

Table 2.1: Wind Energy Density Estimates at 25m Height. Source: (Agbetuyi *et al.*, 2012)

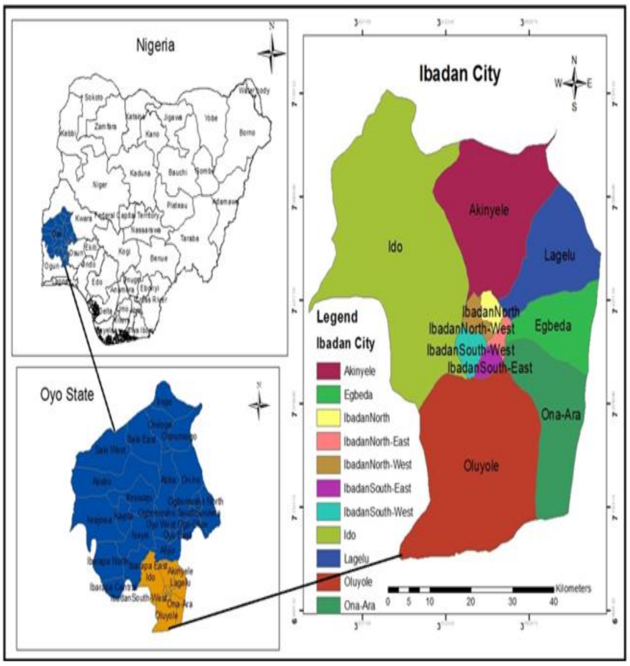

Figure 2.1: Map showing the study area – Ibadan City

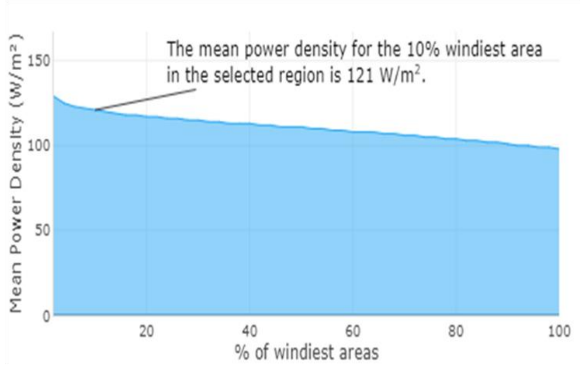

Figure 2.2: Graph showing the mean power density of Ibadan. Source: (Global Wind Atlas, 2018)

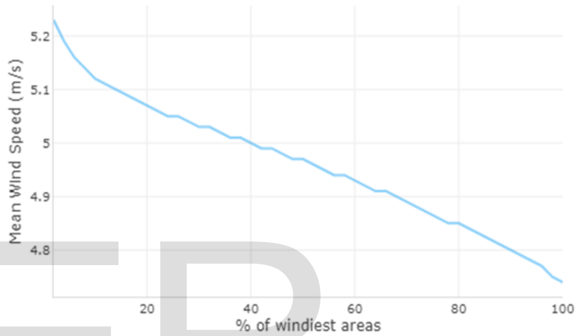

Figure 2.3: Graph showing the mean windspeed of Ibadan. Source: (Global Wind Atlas, 2018)

2.2 Methodology

This study depends on many types of datasets in order to locate the wind power station. Majority of the data used in this study was digitized from the Ibadan Master Plan. The coordinate system of the airport, high speed rail link, railway network, power substations, power lines, wind speed, settlement and slope were in WGS 1984 31°N. Next, Euclidean distance was performed to the vector layers. The Euclidean distance analysis establishes the relationship between each pixel to a location, or different locations based on the direct-line distance (ESRI, 2016). The Euclidean distance output raster contains the measured distance from every raster pixel to the nearest source. The SRTM data was integrated into ArcMap. This integration was done to generate the slope map for the study area using the slope tool in the arc toolbox of the ArcGIS environment. The windspeed data was downloaded for the study area from the Global Wind Atlas website at a height of 200m above ground level. The settlement density map of Nigeria was downloaded from the WorldPop website and the study area was clipped out. The settlement map will help to avoid the unpleasant effects of shadows from the blades of the wind turbines on people in the settlements and to avoid the noise of the wind turbine as stated by Talinli *et al* (2011).

The multicriteria analysis involved the weighted overlay tool. All reclassified vector and raster layer of the airport, roads, railway network, highspeed rail link, power substations, transmission lines, settlement, slope and windspeed were combined by using the weighted overlay tool to depict the result for the most suitable area(s). The weighted overlay function was used to overlay all the raster data using a common measurement scale and weighed according to its importance. The weighted overlay analysis was finally run according to the work of Kazemi and Haghyghy (2014).

3.1 Results and Discussion

The determination of criteria and classification of factors for the selection of suitable wind power station site and other results, in line with the objectives of this study will be presented at this stage. The suitability of a site for a wind power station is influenced by the various characteristics of the site. The set of spatial information on the system criteria for a wind power station site selection have been identified based on different literature reviews and relevant experts' opinion. Different criteria were prepared using remote sensing and GIS techniques for the identification of suitable zones. Each criterion was assigned a weight and rank for its fields depending on its influence on the siting of a wind power station. The relative ranking of each criterion was assigned an AHP using Spatial Analyst tool of ArcGIS.

3.2 Slope

As previously mentioned, the slope data was generated by using the Shuttle Radar Topography Mission (SRTM) elevation image with a spatial resolution of 90m. The purpose of using such layer in this study is to consider the areas which have a high slope area. The slope raster was reclassified in to 3 classes: unsuitable, suitable and highly suitable. The result of the reclassified slope map is shown on Figure 3.1. A 16% influence was assigned to the slope during the pairwise comparison as shown in Table 3.1

Raster Layer	Influence (%)	Field Value (°)	Level of Suitability	Scale Value
Slope	16	0 - 2 2 - 6 6 - 27	Unsuitable Suitable Highly Suitable	3 2 1

Table 3.1: Pairwise comparison table for Slope

3.2 Wind Speed

The average wind speed was reclassified using the opinions of past literatures and as per the nature of the study area. The average wind speed raster layer was reclassified to 3 categories with unsuitable, suitable and highly suitable as shown in figure 3.2.

Logically, the wind turbines performance depends on the wind speed. Therefore, the average wind speed was considered a key criterion in the pairwise comparison in determining the economic performance of a wind turbine as shown in table 3.2. The influence of the windspeed was assigned 20%. In addition, the wind energy potential criterion is incorporated in almost every study and is mainly considered the most important criteria (Bennui *et al.*, 2007). The mean power density for the 10% windiest area in Ibadan is 121wm^{-2} as shown in figure 2.1. At a height of 200m, the wind speed is at 5.12 ms^{-1} which is illustrated in figure 3.2.

Raster Layer	Influence (%)	Field Value (wm^{-2})	Level of Suitability	Scale Value
Windspeed	20	56 - 121 44 - 56 26 - 44	Highly Suitable Suitable Unsuitable	9 2 1

Table 3.2: Pairwise comparison table for Windspeed

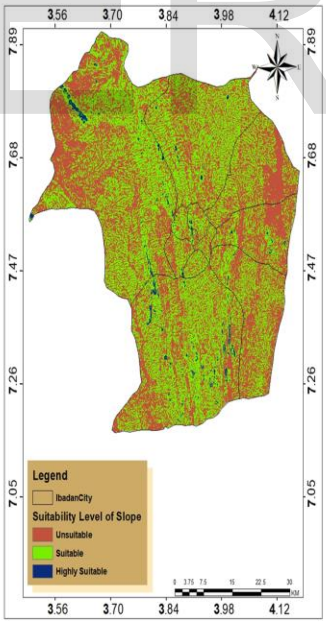

Figure 3.1: Reclassified slope map of the study area

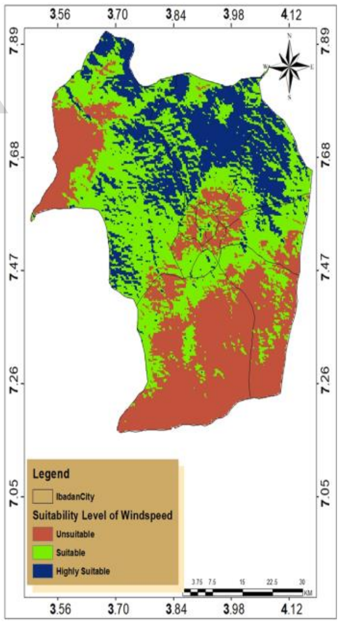

Figure 3.2: Reclassified windspeed map of the study area

3.3 Transmission lines and Substations

Transmission lines and substations are economically considered an important factor because they can increase or decrease the cost of production. It is important to be close to substations and the existing transmission lines to minimize production costs (Bartnicki and Willamson, 2012). With this regard, the transmission lines and substations were assigned 16% influence respectively on the pairwise comparison table as shown in table 3.3.

Transmission lines are a necessity in order to distribute the energy created by the wind turbines and the land that is connected to an electrical grid. The local distribution company may also allow direct power injections from the wind turbines into the medium voltage networks as per its distribution across the study area. The transmission lines and substations were reclassified to 3 categories as highly suitable when the distance is 5km, suitable when the distance is more than 10 km and unsuitable when the distance is more than 25km.

Areas which are nearer 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 figure 3.3 and figure 3.4.

Raster Layer	**Influence (%)**	**Field Value (km)**	**Level of Suitability**	**Scale Value**
Substations	16	0 – 4.807229 4.807229 – 10.31651 10.31651 – 25.31551	Highly suitable Suitable Unsuitable	3 2 1
Transmission lines	16	0 - 4.897141 4.897141 - 10.57656 10.57656 - 25.492288	Highly suitable Suitable Unsuitable	5 2 1

Table 3.3: Pairwise comparison table for transmission lines and substations

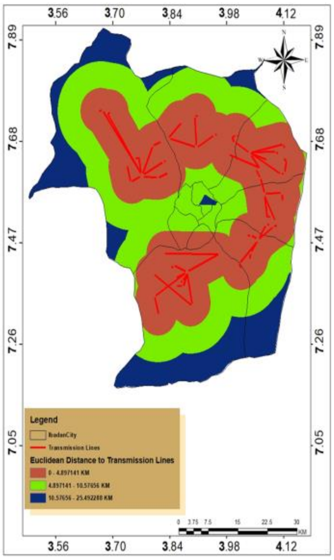

Figure 3.3: Reclassified electricity Transmission line map of the study area

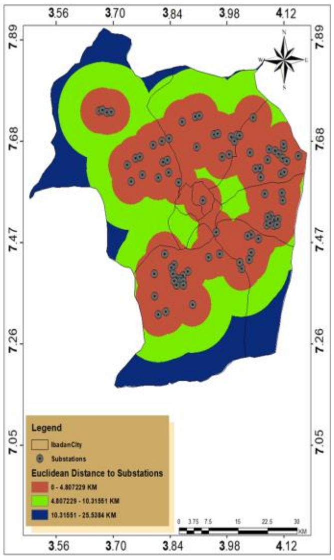

Figure 3.4: Reclassified electricity substations map of the study area

3.4 Transportation Network

There is no doubt that roads, high speed rail link and railway network access is considered an important factor regarding the wind power station. For technical and commercial purposes, access to these networks is essential in siting a wind power station. As indicated in Table 3.4, the high-speed rail link, 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 reclassified as highly suitable, those at approximately 4km were considered suitable and those approximately at 7km were considered least suitable. This is shown in figure 3.4.

Raster Layer	**Influence (%)**	**Field Value (km)**	**Level of Suitability**	**Scale Value**
Railway and road networks	16	0 – 1.27827 1.27827 – 3.523082 3.523082 – 7.127188	Highly Suitable Suitable Unsuitable	3 2 1

Table 3.4: Pairwise comparison table for Transportation Networks.

3.5 Settlements

Due to the various unfavourable environmental impacts on the populated centres and urban growth in this study, distance from residential areas is considered a key factor as one of the criteria in wind power station site selection. The settlement area was reclassified as unsuitable and suitable as shown in figure 3.6. Settlements for the study area were given a 16% influence as shown in table 3.5. The settlements covered 49960.954611 hectares in the study area while other areas which include vegetation and bare land covered about 276053.22122 hectares.

Raster Layer	% Influence	Field Value	Level of Suitability	Scale Value
Settlement	16	Others Built-up	Suitable Unsuitable	2 1

Table 3.5: Pairwise comparison table for settlements

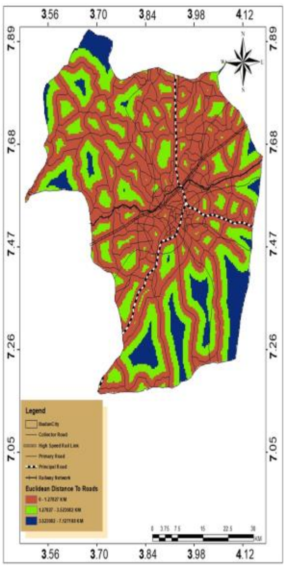

Figure 3.5: Reclassified transport network map of the study area

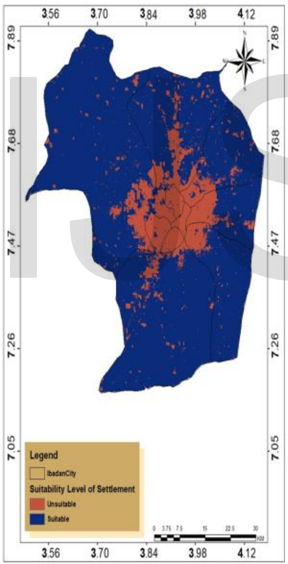

Figure 3.6: Reclassified settlement map of the study area

3.6 Final Suitability Map

At this stage, all the criteria layers are combined in order to identify suitable site for a wind power station location in the study area. As regards the wind power station, overlay analysis using the weighted overlay tool in ArcGIS was carried out. The final step of these processes was to aggregate all reclassified raster datasets that include the settlements, high speed rail link, railway network, roads, transmission lines, substations, wind speed and slope.

According to the results of the wind power station suitability criteria, three suitability classes were identified with varying degrees of suitability. For each factor, a weight value was given from 1 (Unsuitable) to 3 (Highly Suitable). Each parameter was given a value based on its suitability for wind power station 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 wind power station establishment.

The result for the wind power station suitability analysis reveals that approximately 9070 hectares of the study area is highly suitable, and this is represented by nearly 2% of the study area. The area suitable is 1% represented by 5062 hectares. In addition, approximately 95% of the study area is unsuitable and is represented by 305448 hectares. This is shown in figure 3.7. The most suitable areas for a wind power station in the study area are in Ido local government area which is in the North Western part of the city.

3.7 The Overall Suitability Map

The suitability of a wind power station site can be expressed in terms of the existing features. Figure 3.8 shows the composite suitability of the criteria maps. The areas are labeled as Unsuitable, Suitable and Highly Suitable. The parts of the selected areas that are near the existing roads are more suitable than those located farther, as far as only the road network, railway network and high-speed rail link is considered. The highly suitable area appeared at the North Western part of the town in Ido Local Government Area. Generally, highly suitable areas of the wind power station can be summarized in terms of the specific objectives set at the beginning of the study. In other words, locating the wind power station within this site ensures minimizing the impact of the station on the surrounding environment.

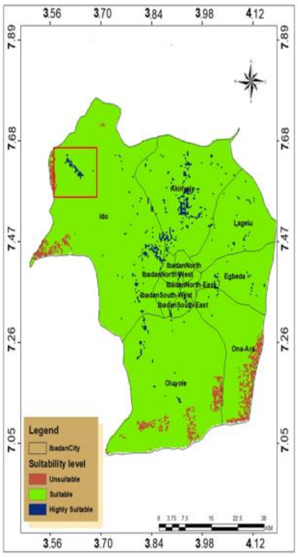

Figure 3.7: Wind Power station site suitability map

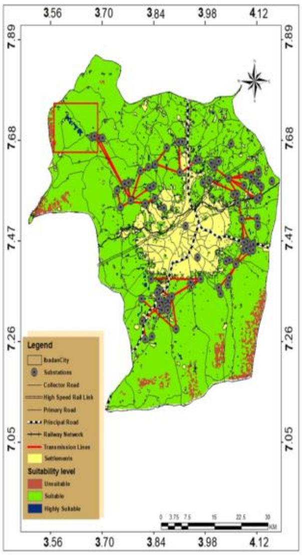

Figure 3.8: The overall wind power station site suitability map

4.0 CONCLUSIONS

This research evaluated the suitability of a wind power station in Ibadan. This was done using the different criteria available to ascertain the suitability of a potential site where wind power station can be located within Ibadan. The eight criteria include: road network, rail network, high speed rail link, settlement, transmission lines, power substations, slope and windspeed. The final suitability map was created after the overlay analysis of all these criteria was analyzed. This study has been able to prove that GIS is a potential tool for the site suitability mapping and analysis of a wind power station because of its capabilities to manage and analyze the volumes of diverse multidisciplinary data used in the application.

The study area was deduced to have adequate wind resource potential for grid-based electricity generation. The planners and the decision makers of the Ibadan Master Plan can get useful information about the possible locations of wind power station using this methodology. More so, the site ranking process (AHP) allows for easy modification of the criteria weights in case a sensitivity analysis is required. Getting public agreement on any candidate site is a must and cannot be avoided.

The development of wind energy is one of the most important tasks for the future, not only because greenhouse gas emissions will likely continue to impact on global warming, but also because fossil fuels are the most widely used energy source and as such, getting limited in abundance by the day.

Also, with regards to the proposed Ibadan Master Plan slated for 2036, a sustainable form of electricity was not considered. A sustainable form of electricity should fall in line with a sustainable city. Wind, an alternative energy source, is clean and widely distributed around the world. It is providing a big share of the world's electricity so, it is becoming a significant component of renewable energy establishment plans, because it is a practically regenerating natural source. Wind power produces clean energy since it does not cause water, soil or air pollution; hence it is considered environmentally appropriate which make it much better than other renewable energy sources that produce much of hard-to-manage wastes.

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