Delineation of Suitable Sites for Wind Farm: A Geospatial Study in Jigawa State Nigeria

Auwal S. Abdulwahab, Kamalanandhini M

Abstract*: *Excessive use of fossil fuel contribute more carbon-dioxide to the ozone more than it can maintain which in turn leads to environmental/ecological unsustainability and global warming. The most effective strategy for de-carbonization is by substituting the power generation from fossil fuels with available sources of renewable energy. Determining suitable location for such project which will socially be acceptable and economically feasible largely depends on many factors such as environmental, economic, social and technical. The main objective of this study is to analyze and identify a better location for a utility scale wind farm to be connected to the national grid using GIS-based multi-criteria decision-making method. The designed methodology for this study considers seven factors which were classified into two main classes: environmental and economic where maximum power output and minimum cost of the project will be achieved. An analytical hierarchy process (AHP) was used for weighing the criteria and computation of land suitability index (LSI) to evaluate probable locations. In this study, the whole of Jigawa State of Nigeria was considered. In conclusion, the resultant output index was classified into four as "Low suitable", "moderately suitable", "suitable" and "highly suitable". As a result, the total area of 2721.33km2 (11.8%) is "Highly suitable", 14927.02km2 (65.02%) is "Suitable", 5299.34km2 (23.08%) is "Moderately suitable" and 10.75km2 (0.05%) is "Low suitable".

Keywords: Analytical hierarchy process, Geographical Information System, Land suitability index, Multi-criteria decision making, Suitability analysis.

I. INTRODUCTION

The global trends towards the risk associated with climatic change receive an increasing awareness, this result in transition strategies to low carbon emission economy endorsed by many countries of the world and the most effective strategy for de-carbonization is by substituting power generation from fossils with available renewable sources of energy. [1] Energy usage stands to be among the clear measures of development and social wellbeing as such it requires balanced increased in the energy demand to be sustainable. However fossil fuels (that contribute more than 80 percent of the world primary source of energy requirement) are found to be a better Source and this discloses the fact about the energy predicament in the global economy. Also, extreme use of fossil fuels such as crude oil, contribute more carbon dioxide (CO_2) to the ozone more than the amount it can maintain and to environmental/ecological unsustainability and global warming. However, continuous exhaustion of fossil fuel and increasing consciousness concerning environmental degradation and pollution leads to exploitation of sustainable sources of energy. As a result, most countries in the world bring forward a renewable system of energy in their supply domain to avail environmental friendly and reliable energy sources that will play a vital role in the feature. [2]

Nigeria being an oil producing country, relies on fossil fuel for its Electricity generation with approximately 70% from fossil fuel and 30% from hydropower regardless of its diverse sources of energy. In recent years, power generation within Nigeria witnessed week production due to the increase in pipeline destruction and dilapidated infrastructure, besides the privatization of the division and construction of modern power plants. Owing to prevailing difficulties arising from the generation and subsequent transmission and delivery within the Nigerian States, an alternative source of energy to the conventional hydropower and gas plants is being explored. Wind energy will be an auspicious origin of reliable and sustainable substitute of power within the country as being established in numerous countries around the globe.

Wind power has been regarded among the sources of renewable energy found to be economically feasible on the basis of its Levelized Cost of Energy (LCOE) [11]. The lower price of wind energy is related to frequent available wind at comparatively higher speeds at the installation locations. As an alternative, wind farms ought to be located where the wind is relatively accessible. Additionally, location of a wind farm is related to the assessment of the wind resources, wherever the wind turbines works on average directly beyond 3 ms-1 of wind speed. Thus, it is of paramount importance to select the suitable site for the establishment of the wind farm through precise deliberations, such as communications, electrical infrastructures and economic and environmental feasibility. [2]

Jigawa state is among the Nigerian states where wind resources is abundantly available owing to its geographical location, this energy source is found to be one of the most accessible, cleanest and potent sources of energy on Earth. This clean, safe and renewable source of energy is of specific benefit for areas having shallow subversive resources and for arid and semi-arid regions. In recent decades, attention has been towards environmental contamination and the trend of the fossil fuels reserve which makes renewable energy a global trend [4].

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Auwal Salis Abdulwahab, Department of Civil engineering, SRM IST, Kattankulathur 603-203, Chennai India.

Kamalanandhini M., Department of Civil engineering, SRM IST, Kattankulathur, Chennai India.

However, the location of wind energy plant plays a very important functionality in the ultimate production, operating cost and efficiency. The instances in which the adoption of justifiable power, and more explicitly wind energy, serves as the absolute remedy to the proposed application. In the initial stage, finding locations where the high wind is accessible found to be of utmost advantage and additional demand of such a system can be met. [5]

Wind Power requires an area where the amount of wind power density is very high, to select suitable locations for such an installation, specific aspect should be explored, such aspect include minimization of the cost of construction by analyzing its proximity to present infrastructure and maximizing the output to be generated from the wind turbines. Comprehensive study for optimum location is tactical step for ensuring a well performing and costs effective project. [6]

Ohunakin evaluated the wind distribution in northern Nigeria for 36yrs (1971-2007) at a given height of 10 m. as stated by him, the average of the annual wind speed of Kano where Jigawa was curved out (12.05°N, 8.53°E) is 7.7669 ms-1 and the extreme wind speed and power density are 9.15 ms-1 (368.917 Wm-2) respectively. In his conclusion, Kano is one of the two states that can allow wind turbines to yield electrical energy throughout the year. [8]

Optimum location for the implementation of renewable energy plants such as wind within the state has never been explored and to the best of my knowledge this has been the first time whereby a wind farm systems is investigated. The intension of this research is to curtail the over dependence on the fossil fuel for electricity generation of which the feature appeared to be bleak and uncertain leading to hike in price of fuels in the global market, though Nigeria is an oil producing country. to avail the natural resources (alternate source of energy) such as wind which is abundant in the country due to its geographical location yet to be explored, to bring to an end the Poor and devastating electricity generation in the country owing to pipe line vandalism and obsolete infrastructure that resulted in inadequacy of required energy for the common benefit of the people.

II MATERIALS AND METHODOLOGY

A. *Study Area*

Jigawa is among the 36 Nigerian states located in the northwestern part of the country having Dutse as its capital. The state lies within latitudes 11.00°N - 13.00°N and long 8.00°E - 10.15°E, The state has 27 local government councils divided into 3 senatorial districts covering a total land area of 22,958.44 km^2 with a population of 4,361,002. The topography of the state is characterized by undulation in the terrain and sand dunes having a span of several kilometers in some part of the state. Basement complex occupies southern part of the state and the north east occupied by sedimentary rocks of the chad basin. [11]

Jigawa state is characterized with a semi-arid climate with most of its area covered with Sudan Savannah and some sparsely Guinea savannah vegetation are found in parts of the states. The annual average rain fall ranges from 600mm – 1000mm and mean annual temperature of 25^o.

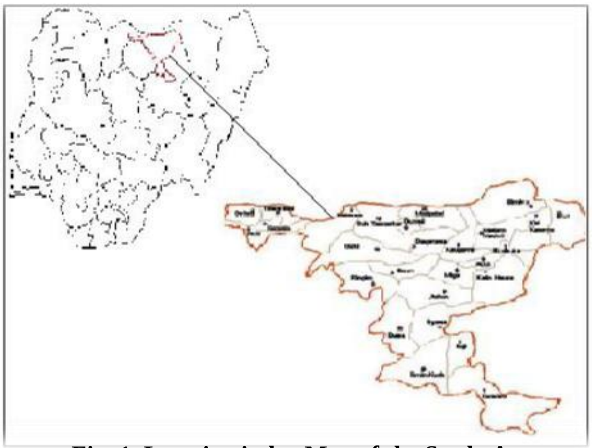

Fig. 1. Location index Map of the Study Area

B. *Criteria for wind farm site selection*

Prior to building any wind power plant, the proposed area ought to be located such that maximum energy could be explored and also be cost effective throughout the project. Most of the wind farm projects take into consideration environmental, economic and social factors to determine better location for the construction of wind farm. Geographic Information Systems has always been employed as a collective tool for integrating such criteria. Factors to be analyzed in the location identification for wind farm selection method for this study are: Wind speed and power density, distance from settlements, distance from road network, distance from transmission lines, land use and slope. The criteria to be determined were categorized into two major groups. Group one contains environmental factors and Group two comprises economic factors. For the purpose of this study, six criteria from these main groups were set for location identification procedure for the study location Table 2. Each criterion is described below:

Wind power estimation: In any wind farm site analysis, wind speed turn out to be the most important environmental factor to be taken into consideration. This parameter largely depends on the geographical location, and altitude. The average annual wind speed and wind power density need to be determined before embarking on any wind farm project. Based on the suggestion of many researchers, for any location to be suitable for wind farm, annual average wind speed must be of minimum 4m/s to rotate small wind turbine and a minimum average of 6m/s is required for a utility-scale wind farm to generate electricity. However, for maximum generation of power, a wind speed of 10-15m/s is required. [4] The data obtained were available at 10m height above the ground level in all the seven locations in the study area and this need to be performed at the final height of the turbine rotor to be installed because the wind speed tends to increase with the increase of height above the ground level.

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It is well known fact that wind speed close to ground varies with height above the ground level, hence the utmost expression for wind speed variation with height is the power law in Eqn (1). For the purpose of this project, to obtain the annual wind speed and wind power density at these locations, detailed analysis was carried at the height of 50m, 100m and 165m respectively. The wind speed at these height were obtained using wind speed profile power law in the equation bellow:

$$v_2 = V_1(\frac{h2}{h1})\alpha \quad \ldots 1$$

Where: V_2 is the wind speed at the required height, V_1 is the wind speed obtained, h_2 is the height at which V_2 is to be determined, h_1 is the height at which V_1 has been obtained i.e. 10m and α is the power law index (0.54 for non-hilly areas). This power law index tends to increase with decreasing wind speed. Hence for a relatively flat terrain with lower wind speed of say 2-5m/s, α = 0.54 and for a higher wind speed of say 6m/s, α = 0.14. [17] The inverse distance weighted method (IDW) of the spatial interpolation technique was used to determine the approximate wind speed at various locations where the data were not available The average annual wind speed for the study area are presented in Figure.2. However the average annual wind speed and wind power density in m/s at different height in the selected location are presented in Table: 1 and Figures. 3 and 4 Respectively. For a given area of cross-section (A), The precise power accessible that is found to be perpendicular to the wind course moving at a given speed v (m/s) having air density ρ (kg/m^3) is considered and expressed per unit area as given bellow: [4]

$$P_{wind} = \frac{1}{2}\rho\,\overline{V}^3 \quad \ldots .2$$

Where ρ is the standard air density, having a value of 1.225 kg/m^3, v is the mean wind speed (m/s). The map showing this criteria was obtained using ArcGIS as shown in Figure: 6 (f).

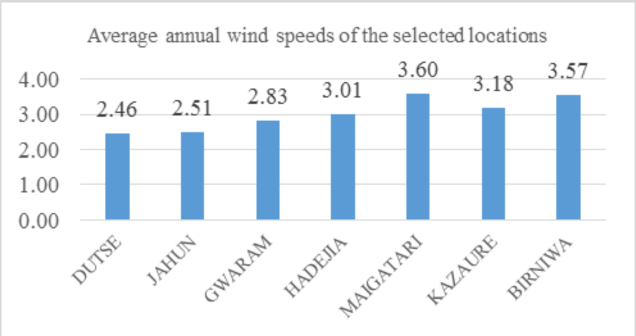

Fig. 2. Average annual wind speed of the selected locations

Distance to settlements: This turns to be among the most important criterion of the environmental factor in site suitability analysis. Proximity of any renewable energy farm such as wind to the city create adverse impact such as noise, nuisance and unrest on the environment and the populace. As such a buffer of specified distance has to be defined. Different studies suggest flexible distances based on the experiences and what was obtained from the planning authority. However, the distances has to be within a reasonable threshold to avoid energy lost due to long transmission time. In this study, a buffer of 500m was considered as constrained area and was given a score of 1, buffer zone of 500–2000m has been given a score of 2, buffer zone of 2000– 5000m been given a score of 3 and buffer zone of more than 5000m has been given a score of 4. Weightage of all the buffers ware determined using AHP and the map showing the criteria were obtained using ArcGIS as shown in Figure: 6 (a)

Land use: The Land demand stands out to be among the most significant factors for wind power site location. Hence, land use has been considered as one of the environmental factors for location identification of wind farms. In this regard, land use has been assessed for two criteria as barren land and agricultural land. Weightage of these factors were obtained using AHP and the map showing the criteria were obtained using ArcGIS as shown in Fig: 6 (b)

Slope: The amount of inclination of the surface has direct impact on the cost of construction and maintenance and also hinders the accessibility due to steep slope of the terrain. The maximum threshold defined by many researchers' ranges from 2% to 3% though many do not even consider slope as a criterion. Slope needs to be gentle for all the aspects in order to have an appropriate wind farm locations Thus for this study, it has been classified into four, 0 - 2% has been given a score of 4, 2–3% has been assigned a score of 3, 3–5% has been assigned a score of 2 and more than 5% has been assigned a score of 1. Weightage of all the buffers ware determined using AHP and the map showing the criteria were obtained using ArcGIS as shown in Figure: 6 (c).

Distance to roads: As an economic factor, distance from renewable energy farm to road has to be minimum in order to reduce cost of construction and maintenance. However there is no general definition of acceptable distance from the road to the farm hence, different researchers suggest different distances based on their experiences and for the purpose of this study, a buffer of <100m was considered the best and was assigned a score of 4, 100–1000m has been given a score of 3, 1000–3000m has been given a score of 2 and buffer of more than 4000m has been given a score of 1. Weightage of all the buffers ware determined using AHP and the map showing the criteria were obtained using ArcGIS as shown in Figure: 6(d).

Distance to transmission network: Proximity to the presently available energy transmission routes are found to be of paramount economic importance. Long distance from the renewable energy farm to the grid (transmission network) result in high cost of cabling and construction and also loss in the energy. Thus, renewable energy farms need to be sited close to the grid. Different studies suggest flexible distances based on the experiences and what was obtained from the planning authority hence for this study, a buffer of <3000m has been given a score of 4, buffer of 3000–6000m has been given a score of 3, buffer of 6000–10,000m has been given a score of 2 and buffer >10,000m has been given a score of 1.

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Weightage of all the buffers ware determined using AHP and the map showing the criteria were obtained using ArcGIS as shown in Figure: 6(e).

Table: 1. wind speed and wind power density at different height above the ground

Location	Wind Speed 10m	WPD W/m^2	Wind Speed 50m	WPD W/m^2	Wind Speed 100m	WPD W/m^2	Wind Speed 165m	WPD W/m^2
Dutse	2.46	9.12	5.87	123.89	8.53	380.15	11.18	855.92
Jahun	2.51	9.69	5.98	130.98	8.70	403.33	11.40	907.45
Gwaram	2.83	13.88	6.74	187.54	9.81	578.25	12.85	1299.62
Hadejia	3.01	16.70	7.19	227.66	10.45	698.96	13.69	1571.51
Maigatari	3.60	28.58	8.59	388.23	12.49	1193.42	16.37	2686.90
Kazaure	3.18	19.70	7.58	266.76	11.02	819.69	14.44	1844.20
Birniwa	3.57	27.87	8.51	377.48	12.37	1159.35	16.21	2608.89

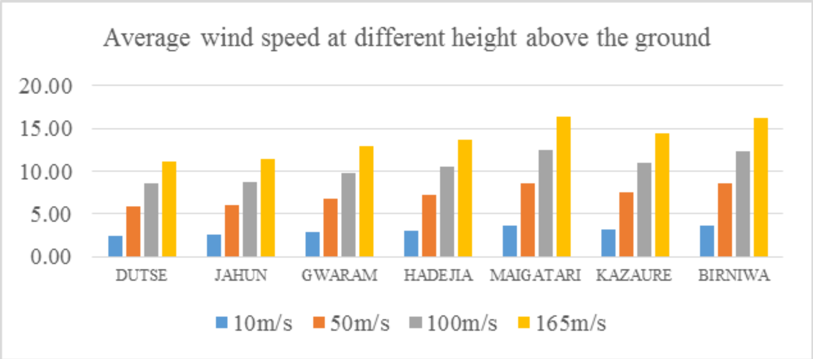

Figure. 3 Average wind speed at different heights in the study area

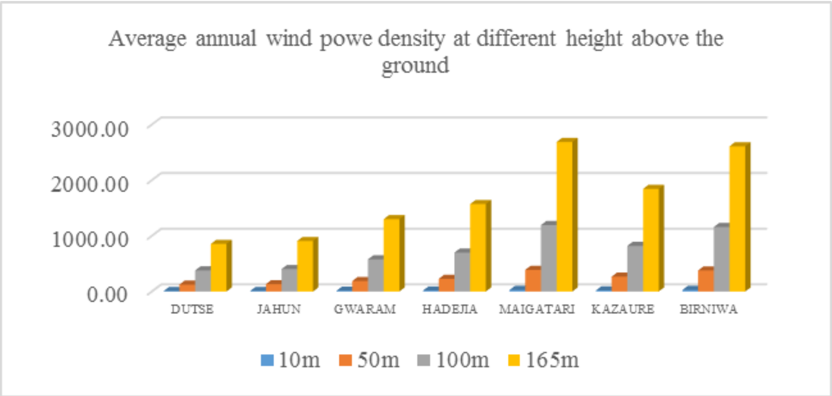

Figure. 4 Average wind power density at different heights in the study area

D. *Weighting the Criteria using AHP*

In this study, Analytical Hierarchical Process has been used for weighting various criteria. The Analytical Hierarchical Process (AHP) comprises of three stages: first is the analysis stage, second is the comparison stage and last is the priority composition stage. In the initial stage, criteria and sub-criteria were determined and their hierarchical structures were executed. From the second stage, comparison matrix was determined and the criteria were related using a comparison matrix hence they were scored based on the Saaty 1980 scale. Comparison matrix for a given number of criteria (n) has been collected and normalized and also consistency index has been determined. [18]

$$A = \begin{pmatrix} 1 & p & q \\ 1/p & 1 & \vdots r \\ 1/q & 1/r & 1 \end{pmatrix} \quad \ldots 3$$

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Criteria weightage has been determined from **eqn: 3** by the process of normalization which involve dividing individual element by the sum of the element in that column from which the desired weightage was determined by averaging the raw of the normalized matrix. [1][14].

E. *Checking for the Consistency*

To determine whether the specified entries are consistent and to control the estimated weightage, the consistency ration needs to be calculated. It is quite abnormal to have consistent comparison all the times, a considerable amount of inconsistency has to be tolerated due to human nature. In order to determine the level of inconsistency, we used the methodology developed by saaty.

In the first stage, the maximum eigenvalue has to be determined from which the approximate consistency index will be estimated as

$$\lambda_{max} = \frac{\sum \frac{Ws}{Wc}}{n} \quad \ldots 4$$

Where n = number of criteria used
Ws = weighted sum
Wc = weight of criteria

$$CI = \frac{\lambda max - n}{n-1} \quad \ldots 5$$

λ_{max} = Eigen values of the matrix

To have better assurance for the consistency of our comparison, the consistency ratio has to be checked in order to give a better judgment.

$$CR = \frac{CI}{RI} \quad \ldots ..6$$

Where CI= Consistency index
RI = random consistency index which was estimated using the result obtained from Table: 3.

In any of the case, when the value of CR $\leq$ 0.1, then the consistency degree is satisfactory. However, if in any situation the value of CR > 0.1, then the comparison matrix is not consistent and not acceptable hence needs to be revised, [1][14].

The overall weightage of criteria and the assigned score for the sub-criteria were summarized in Table: 2.

Table: 3. Random consistency index

n	3	4	5	6	7	8	9	10
RI	0.058	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2. Summary of sub-criteria and their rankings

Criteria	Sub-criteria	Ranking
Land Use	Barren land	4
	Agric land	3
Distance from Built-up	< 500	1
	500 - 2000	2
	2000 - 5000	3
	> 5000	4
Slope	0 - 2%	4
	2 - 3%	3
	3 - 5%	2
	> 5%	1
Distance from road	< 100	4
	100 - 3000	3
	3000 - 5000	2
	> 5000	1
Distance from transmission line	< 3000	4
	3000 - 5000	3
	5000 - 10000	2
	> 10000	1
Wind speed	< 2	1
	2 - 2.5	2
	2.5 - 3.5	3
	> 3.5	4

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III RESULT AND DISCUSSION

The combination of AHP with GIS in multi-criteria decision making proven to be effective in locating suitable location index. In this study, it has been found to be of immense importance and act as a tool to assist the decision-makers in evaluating and implementing reliable spatial Decision. The method proven to be one of the best in determining weightage of criteria and sub-criteria by pairwise comparison for ultimate location identification for the establishment of sustainable energy project such as wind farm. To determine the suitable location, we consider six criteria based on our study area which were evaluated. The evaluated criteria were divided into two factors i.e. Environmental and economic factors. The environmental factors include wind speed and power density, slope, distance from residential area and land use, whereas the economic factors comprises of distance to transportation network and distance to transmission line. In this study, wind speed turns out to be the most important factor which was found to be sufficiently abundant in the area, moderate priority was given to the availability of land and slope Table: 5. It will be observed that distances from the road network and transmission line were considered to be of less importance in establishing wind farm as far as Jigawa state is concerned. The result of weightages of all the criteria obtained after applying the AHP method is presented in Table: 4. The ranking of sub-criteria was made based on their influence in the analysis and are presented in Table: 2. the criteria used in the evaluation are displayed in Figure: 6. maps of all the criteria used were prepared in the GIS domain and sub-criteria maps were re-classified. Criteria maps along with their weightage values were combined using weighted overlay analysis of the spatial analyst tool in arc Map.

Resultant output index map Fig. 7 was classified into four as “low suitable”, “moderately suitable”, “suitable” and “highly suitable”. Thus, based on our findings, vast area of land accounting for almost 77% of study area found to be suitable for wind farm in the Jigawa state hence, the amount of low suitable and moderately suitable area is only 23% Table: 6.

It is imperative to note that the concentration of highly suitable and suitable area increases as we move away from the state capital “Dutse” towards the northern and north eastern part of the state and this depends largely on the influence and availability of high wind in the area Table: 6. Finally, based on this analysis and methodology, we come to the conclusion that Jigawa state is suitable enough for wind energy generation that will carter for its electrical energy requirement and even sell the excess to the neighboring state.

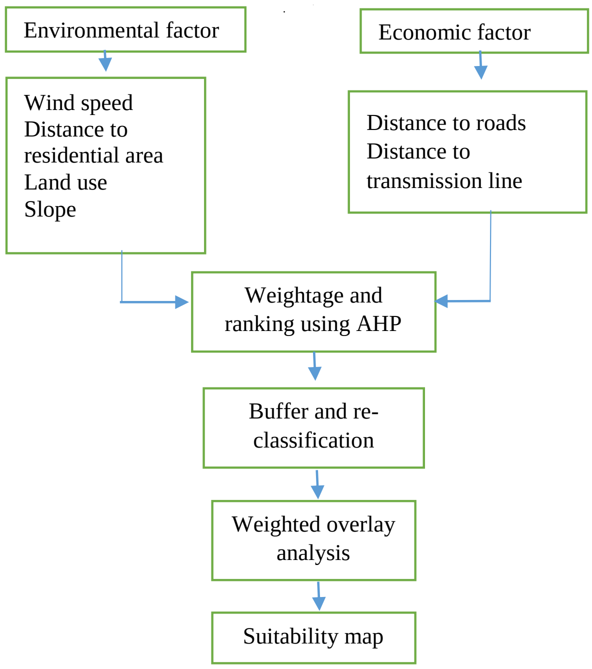

Fig. 5 Model for the wind farm suitability index.

Table: 4. criteria weight and percentage

Criteria	Weightage	Percentage %
Wind speed	0.469	46.9
Land use	0.212	21.2
Slope	0.093	9.3
Built-up area	0.130	13
Road	0.059	5.9
Transmission line	0.038	3.8

Table: 5. Normalized Pair wise comparison matrix

Criteria	Land use	Slope	Built-up area	Road network	Transmission line	Wind speed
W/ speed	0.53	0.71	0.39	0.50	0.36	0.32
Land use	0.11	0.14	0.24	0.30	0.26	0.23
Slope	0.11	0.05	0.08	0.03	0.16	0.14
Built-up area	0.11	0.05	0.24	0.10	0.16	0.14
Road network	0.08	0.03	0.03	0.03	0.05	0.14
Transmission line	0.08	0.03	0.03	0.03	0.02	0.05

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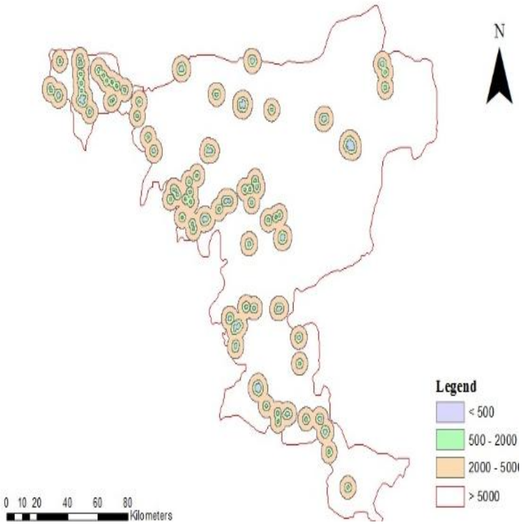


Fig. 6 (a) distance from residential area

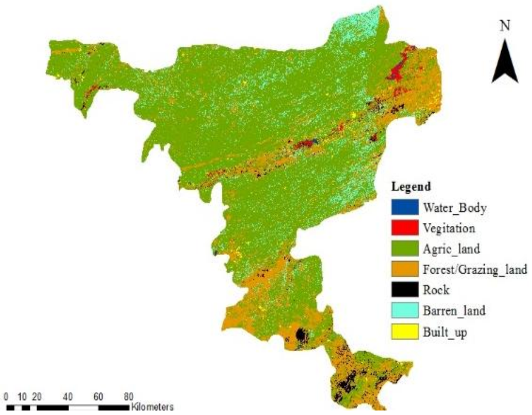


Fig. 6 (b) Land use and land cover

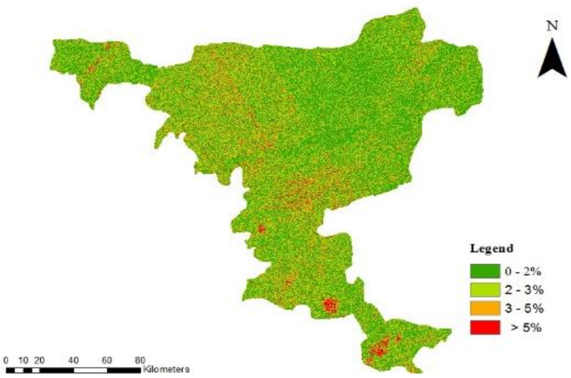
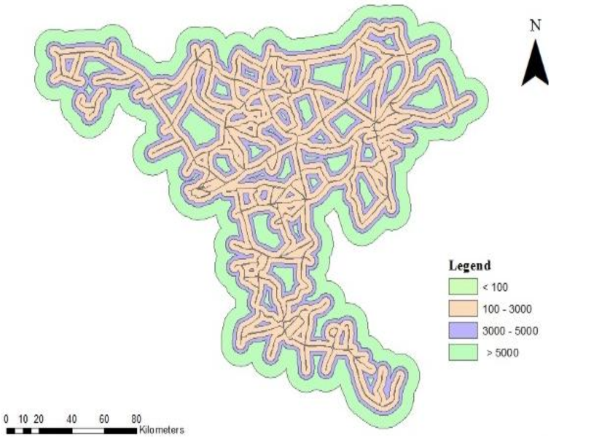


Fig. 6 (c) Slope map



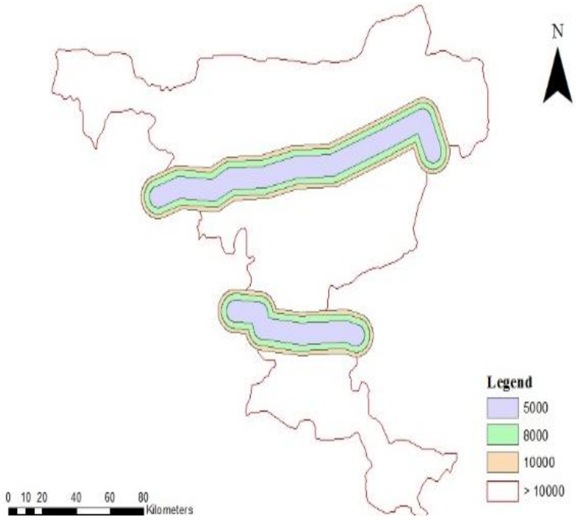


Fig. 6 (e) Distance to transmission network

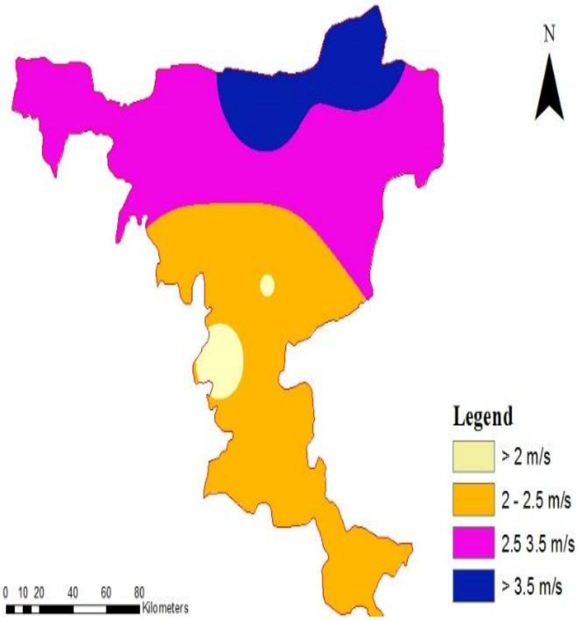


Fig. 6 (f) Wind speed map

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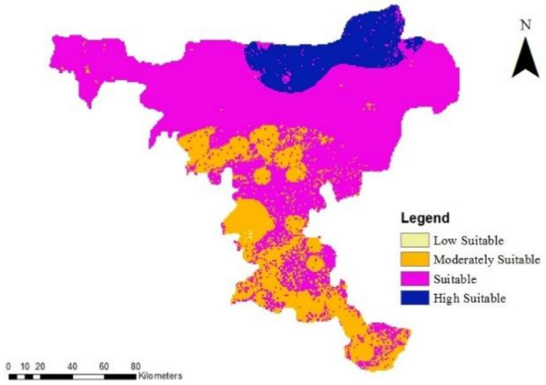

Figure: 7 Land Suitability index map for wind farm

Table: 6. Suitability location map of the study areas

S/N	Land Suitability	Area (Km^2)	Area (%)
1	Low Suitable	10.75	0.05
2	Moderately Suitable	5299.34	23.08
3	Suitable	14927.02	65.02
4	High Suitable	2721.33	11.85
	Total	**22958.44**	**100**

IV CONCLUSION

Renewable energy sources such as wind are found to be environmental friendly because they have low carbon emission, secure and sustainable. Such energy sources contribute immensely in energy generation.it can also serve as an alternative for conventional energy generation from fossils. Locating a suitable site can save much of the construction cost and improve future infrastructural development.

As the population of Jigawa keeps increasing, the energy demands also increases as such requires balanced increased in demand and supply to meet its energy requirement, hence, wind was identified as one of the rapidly growing sources of alternate energy.

From the analysis, it was observed that the mean of the annual wind speed varies with location and altitude and the minimum speed in all the study location found to be > 5m/s at 50m, >8.5m/s at 100m and > 11m/s at 165m respectively. The variation in the wind speed was not much except in the month of November, December, January, February, March and April where it was found to be reasonable, and the lowest was observed in the month of September.

Integrating GIS with Multi-Criteria and AHP decision methods found to be useful technique to systematically deal with geographical data and also manipulate the importance of each criteria for obtaining the best location for siting wind farms. Moreover, incorporating the designed criteria into the decision-making process was found to give better result and make the project to be economically and technically feasible. We considered environmental and economic factors as wind speed, distance from built-up areas, distance from the road network, distance from transmission lines, slope and land use.

We interpolated the wind speed to 50m, 100m and 165 using power law index formula. Inverse distance weightage technique (IDW) was used to determine the wind speed at locations were not available.

The result of the suitability index was categorized into “low suitable”, “moderately suitable”, “suitable” and “highly suitable”. However, influence of high wind in the area and availability of flat terrain in most of the areas in the state makes it a fitting choice for exploitation of wind energy which will leads to reliability, greater efficiency, reduced cost of maintenance, operation and infrastructure. It was found that, abundant suitable sources of renewable energy significantly increases towards the northern and north-eastern part of the state.

The limitation of this study is associated with the absence of meteorological stations across the state which leads to inadequate accurate data for wind resource analysis. In conclusion, this research will provide adequate information to the stake holders in selecting suitable location for the construction of sustainable energy project in Jigawa state and will add to the stock of literature for any other relevant work.

ACKNOWLEDGMENT

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