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Geospatial Analysis of Solar Energy Potentials in Niger State, Nigeria

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Abstract: Solar energy has been identified as the largest renewable resource on earth, and it is more evenly distributed in Sunbelt locations than wind or biomass use. In this paper, geospatial methods were used to examine solar energy potentials in Niger State Northcentral Nigeria. Observed insolation data from Nigeria meteorological station was used over the study period 1988–2018. A Digital Elevation Map (DEM) and solar radiation of the area were used as input parameters. Slope and slope aspect were calculated using the DEM. Slope, slope aspect, and solar radiations of the study area were reclassified and weighted using a Hierarchical Analytical Process (AHP). The variability analysis was done using a standardized variable index. It was observed that the months of February, March, and April were the highest with average solar radiation of 6kWh/m^2/day, while July and August, on average, had the lowest solar radiation of 4.4kWh/m^2/day. The results showed the areas with moderate solar energy potential; good solar energy potential and very good solar energy potential. It was revealed that the amount of available solar power in Niger is 414.651 X 10^6 MWh. The study has demonstrated the potential of geospatial technology in the analysis of solar energy potentials, making it suitable for the investigation of other renewable energies. The results also identified the enormous availability of solar energy potentials in the state as well as the most suitable site for solar energy farms.

Keywords: Solar Radiation, Solar Energy Potentials, Geospatial Methods, DEM, AHP

1. Introduction

All over the world, energy is critical for economic and socio-development activities. There are different types of renewable and non-renewable energy which are obtained from various sources. Most African countries, especially those in the process of development, are not able to produce enough energy, despite the potential of the continent. This insufficiency of energy causes the poverty and under development activities for less privileged peoples.

The objective of the energy system is to provide energy services which begin with the extraction of primary energy, which is then converted into energy carriers suitable for various end-uses. These energy carriers are used in energy end-use technologies to provide the desired energy services [1].

It is widely recognized that solar energy is the most reliable renewable energy source [2]. Solar power is more dependable than wind energy and is not as affected by changes in the climate across the year [3]. However, a large amount of data is needed to design and create solar energy systems, including information on the monthly average of solar radiation on the Earth's surface [4]. Unfortunately, there is a lack of this kind of information on renewable energies, especially in Africa [5]. As a result, the utilization of solar power as a substitute power source is very poor, leaving millions of African people without access to electricity.

In terms of solar energy development and usage, countries of Africa vary significantly. For example, in Morocco in 2013, the world's largest solar power plant was built. Aswan City in Egypt recently built forty solar power stations with the ability to generate 2000 megawatts of power. Tanzania and Kenya have gone far ahead of Nigeria in terms of solar energy development and use. Despite the fact that solar is now a viable source of power in Nigeria, most studies have concentrated on Southern Nigeria, in spite of the fact that Northern Nigeria has even more potential solar energy that can be utilized to partially address the country's original power problem. To study the potential solar energy in Northcentral Nigeria, in spite of the fact that Northern Nigeria has even more potential solar energy that can be utilized to partially address the country's original power issue.

Finding a long-term solution to Nigeria's energy shortage is possible by tapping into the country's abundant solar energy resources. Nigeria's energy mix is not getting any more energy, so finding a long-term solution is crucial. Solar energy is now considered to be the most effective alternative energy resource [6]. There are other alternative energy sources in Nigeria, but solar energy is now the most effective one. Nigeria has an average daily solar radiation of about 5.25 kWh/m^2/day, which varies between 3.5 and 9.0 kWh/m^2/day at coastal as well as northern locations. This indicates that Nigeria has the greatest opportunity to harness its renewable energy potentials by employing effective strategies to harness renewable energy at a reasonable cost and minimise dependence on fossil fuels [7].

In developing nations where the number of radiation data collection stations is limited and direct measurements of solar radiation aren't sufficient, global solar radiation and sunshine duration can be estimated or deduced according to Rehman, S & Ghori, S. G. [4]. Radiation data can be calculated from other meteorological information in addition to real measured data to provide the required data content for a location or region [8]. This requires empirical modelling.

Several studies have been done to assess the solar energy potentials for various locations in northwestern Nigeria. The studies, include Sambo, A. S. [9] in Kano; AbdulAzeez, M. A. [10] in Gusau. Gana and Akpootu employed Angstrom model for predicting global solar radiation in kebbi State [11, 12]. These studies employed various statistical techniques to model solar radiation directly from solar data, or, indirectly from other climatic variables.

There are no many research conducted at regional and local scales in East Africa related to solar radiation features. However, spatial and temporal variability in global, diffuse, and horizontal direct irradiance and sunshine duration has been examined at eight stations in South Africa and two stations in Namibia, where the time series range between 21 and 41 years. Global and direct irradiance and sunshine duration decrease from Northwest to Southeast, whereas diffuse irradiance increases toward the East [13]. A study was conducted in Kenya in 2013 to investigate the potential of solar energy as a local source of clean and renewable resource for Nakuru city. Nakuru is a moderately high solar energy potential region. The study concluded that Nakuru is rich with abundant solar energy resources, favorable for tapping at both small and medium scale levels [14].

A tool that uses geographical techniques to manage and analyse geographic data in Geographic Information System (GIS) is gaining in popularity as a territorial planning tool and as a choice of optimal sites for a range of activities and installations [8, 15]. Juhi, J. [16] in a study conducted, used GIS to create thematic maps of monthly global horizontal irradiance (GHI) in Uttarakhand by mapping them district by district. The solar potential analysis discovered the maximum and minimum monthly GHI in every district of Uttarakhand. The map was created in Map Info and linked to the databases for the individual district. Asakereh *et al.* [17] utilised Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and GIS to find the best locations for solar energy farms in Shodirwan region of Iran. GIS interpolation revealed that the annual solar insolation in Shodirwan was the most appropriate.

GIS models were used to map potential harvesting solar energy sites in Niger State and determine prospective energy potential areas based on this research. In addition, the major factors influencing solar radiation in the study area were identified.

2. Study Area

Niger State is a state in the Northcentral region of Nigeria and the largest state in terms of land mass in the country, with the capital in Minna. The area is found to between latitude 10°00'N and longitude 6°00'E of the Greenwich meridian. It is bounded by the states of Kebbi and Zamfara to the North, Kaduna to the North and Northeast, Kogi to the Southeast, and Kwara to the South. The Federal Capital Territory (FCT), Abuja is on Eastern border, and the Republic of Benin is its Western border (See Figure 1).

3. Materials and Methods

3.1. Types and Sources of Data

1. The data used for this research was collected by Nigerian Meteorological Agency (NIMET) weather stations at Nigerian airports. Until now, data was recorded using Gunn-Bellani pyranometers at NIMET weather stations, but currently Solarimeter is used to measure solar radiation in Watt per metre square (W/m^2) and Campbell-strokes sunshine recorders to log sunshine duration in hours. Thirty years, daily solar radiation data in millijoules per metre square (MJ/m^2/day) was provided by NIMET. The data was converted into kilowatt hour per metre square per day (kWh/m^2/day) using the International Energy Agency (IEA) General Converter for Energy. This was because solar radiation values are normally presented in kWh/m^2/day, which is the amount of sunlight that strikes a square metre of Earth's surface in one day.
2. The temporal scope covers 30 year period (1988-2018).

3.2. Methods of Data Analysis

1. The study area's solar energy potential was affected by slope, elevation, slope angle, and slope aspect. The input

variables were solar radiation, elevation, slope, and slope aspect. A multi-criteria analysis was executed to create a pairwise comparison map. Weighted overlaying was used in the ArcGIS 10.3 spatial analyst extension to produce a stability distributed network. To generate a stability distributed network, a method was adapted from Sadeghi, M. & Karimi, M. [18] assessed suitable locations for solar farms and wind turbines in Tehran to increase power transmission in the area. A tabular report displays the mean, minimum, and greatest solar radiation values in the study area. This is a popular technique that is successfully used across the world.

2. Variability Analysis of solar Irradiance.

The standardised variable index (I) was created by McKee *et al.* [19] and can be found in many articles [20, 21]. It was used to determine the degree of discrimination between high and low values of each climate parameter. It can be found by the following equation:

$$I(i) = \frac{X_i - \overline{X}_m}{\sigma} \quad (1)$$

where $X_{i,}$ is the value for the considered years or months i; $\overline{X}_m$ is the mean for the considered years or months m; σ is the standard deviation for the considered years and months.

To sum up, in this experiment, it was concluded that a month and year are normal if their standardized variable index is between -0.5 and +0.5. If their index is greater than +0.5, they are said to be excessive, and if their index is less than -0.5, they are considered deficient. This interval is not very wide but can be used to distinguish between years and months that are deficit or surplus [21].

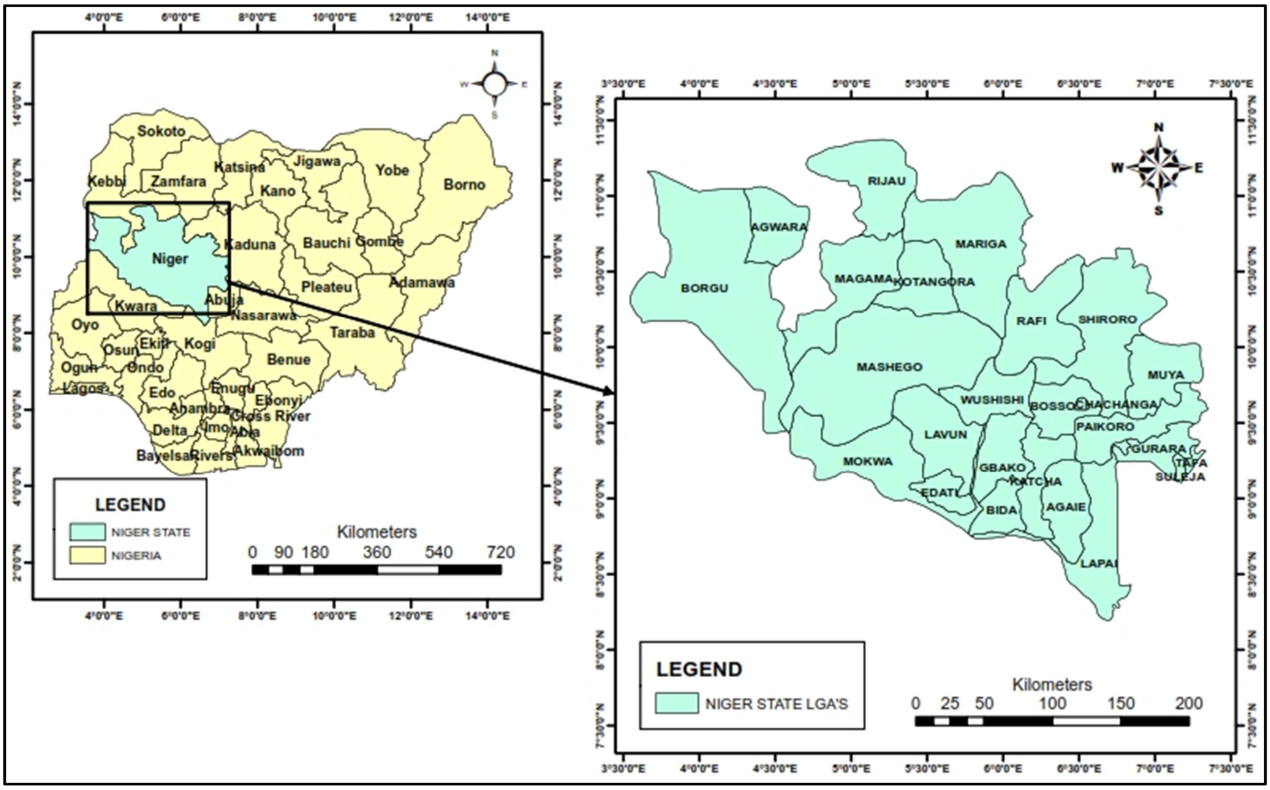


Figure 1. *The Sudy Area.*

4. Results and Discussion

4.1. Seasonal Solar Energy Potentials in Niger State

Figure 2 presents the monthly solar irradiance structures and respective standardised solar irradiance at Niger State over the period of 1988-2018. The analysis of figure 2a depicts a bimodal seasonal cycle with peak value attained in February, March, and April. The month of August shows the lowest mean value of solar radiation, while the month of March shows the highest mean value of solar radiation as shown in Figure 2a.

Figure 2b presents the monthly standardised solar irradiance in Niger State over the study period.

The analysis of this figure shows that four months (July, August and September) are in deficit of solar irradiance. The month with the lowest index value of -2.00 is August. The analysis shows also that three months (February, March and April) are in excess of solar irradiance. Normal months are January, May and December. The Month with highest index value of solar irradiance is March with 1.23.

The estimated monthly standardised variable index for Niger State is 5.43 kWh m^{-2} d^{-1}, based on the monthly mean solar irradiance of 5.43 kWh m^{-2} d^{-1}. The monthly standard deviation is 0.62. This information indicates that the months with the highest solar irradiance are likely to be the dry season months, resulting in an excess of solar energy. Indeed, due to the scarcity of water in the dry season, crop production is constrained.

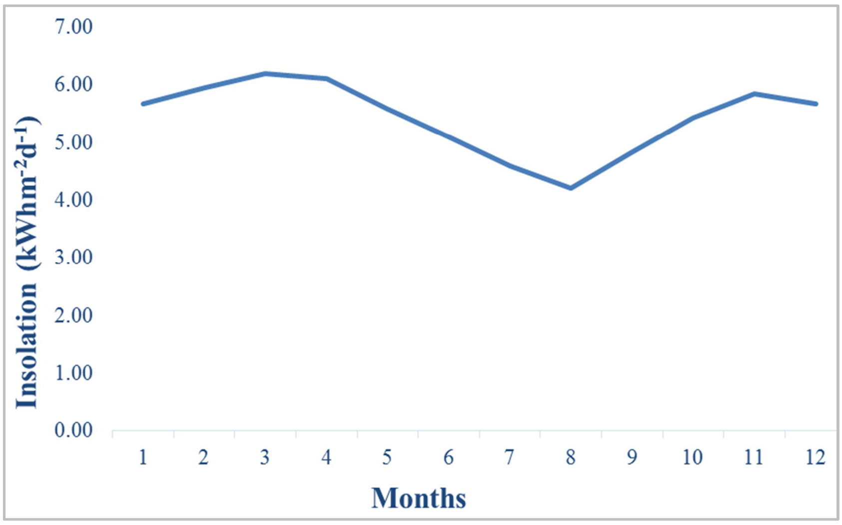
4.2. Spatial and Temporal Extent of Solar Energy Potential in Niger State

From Table 1, we can see that the highest monthly mean solar radiation values of 6.19 kWh/m^2/day, 6.10 kWh/m^2/day and 5.94 kWh/m^2/day were recorded in March, April, and February, respectively. The longer days and shorter nights in the sahelian region of Nigeria account for the maximum insolation received during these months. Cloud attenuation reduction during these months results in higher insolation, which is received over the study area.

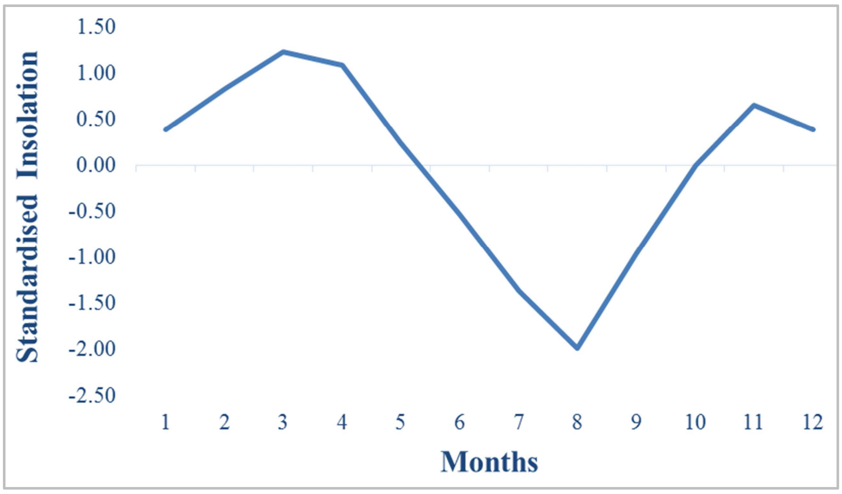
Results from the study also showed that the minimum monthly mean solar radiation values of 4.49kWh/m^2/day and 4.20kWh/m^2/day were recorded in Niger state in July and August, as presented in Table 1.

However, the study found that lower insolation levels are due to the presence of clouds, which significantly reduce the intensity of solar radiation reaching the Earth's surface in July and August. The minimum insolation recorded in both months is also attributed to the rainy season. Ojosu, J. O. [22] found similar results in Nigeria, where the rainy season records low solar radiation levels in July and August.

The study also found that harnessing solar energy in February, March and April is peak time in the area. However, there are other months of the year that offer good times for doing so, which vary with locations.



a



b

Figure 2. *a. Monthly Insolation Pattern (Niger State); b. Monthly Standardised Insolation.*

Table 1. *Solar Radiation Values in Niger State (kWh/m^2/day).*

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	5.67	5.94	6.19	6.10	5.58	5.10	4.59	4.20	4.84	5.43	5.84	5.66
Min	5.37	5.02	5.45	5.67	5.17	4.73	4.52	3.79	4.49	5.53	5.47	5.19
Max	5.41	5.76	6.26	6.13	5.71	5.43	4.70	3.95	5.03	5.67	5.60	5.40

4.3. Available Solar Power in Niger State

To determine the available solar power in an area, you will need to know the average solar radiation received and the cross-sectional area of the location. This is illustrated below:

Since Niger state's cross-sectional area =76,363 km^2;

and the average solar radiation in Niger State= 5.43 kWh/m^2/day;

Cross sectional area X the average power intercepted at any time (Electropaedia, 2016).

Thus, the average power intercepted at any time in the state = 76,363 X5.43

=76,363 X 5.43 = 414651.09 X 10^6= 414.651 X 10^9 kWh = 414.651 X 10^6 MWh

= 35,653,568.40 tonne of oil equivalent.

4.4. Solar Energy Potential Sites in Niger State

Figure 3 below shows the spatial variation of solar energy potentials in Niger State highlighting the areas with very high, moderate and low solar energy potentials in the state.

Areas with very high solar energy potentials are: Agwara, Agaie, Bida, Edati, Gbako, Katcha, Kontagora, Lapai, Lavun, Mashegu and Mokwa Local Government Areas (LGAs). These are the most suitable potential sites for exploiting solar energy in the state. Areas with high potentials are: Bosso, Borgu, Chanchaga, Gurara, Paikoro, Suleja and Tafa LGAs.

Areas with moderate solar energy potentials are: Magama, Munya, Rijau, Rafi, Shiroro and Wushishi Local Government Areas. Areas with low potentials is Mariga LGA.

Descriptions of location qualities that should be considered when identifying suitable locations for PV and concentrating solar power projects are given in [23]. The amount of direct, horizontal solar radiation at a site should be ≥5 kWh/m^2/day to be of real interest. Many locations in Niger state could be utilised in this way.

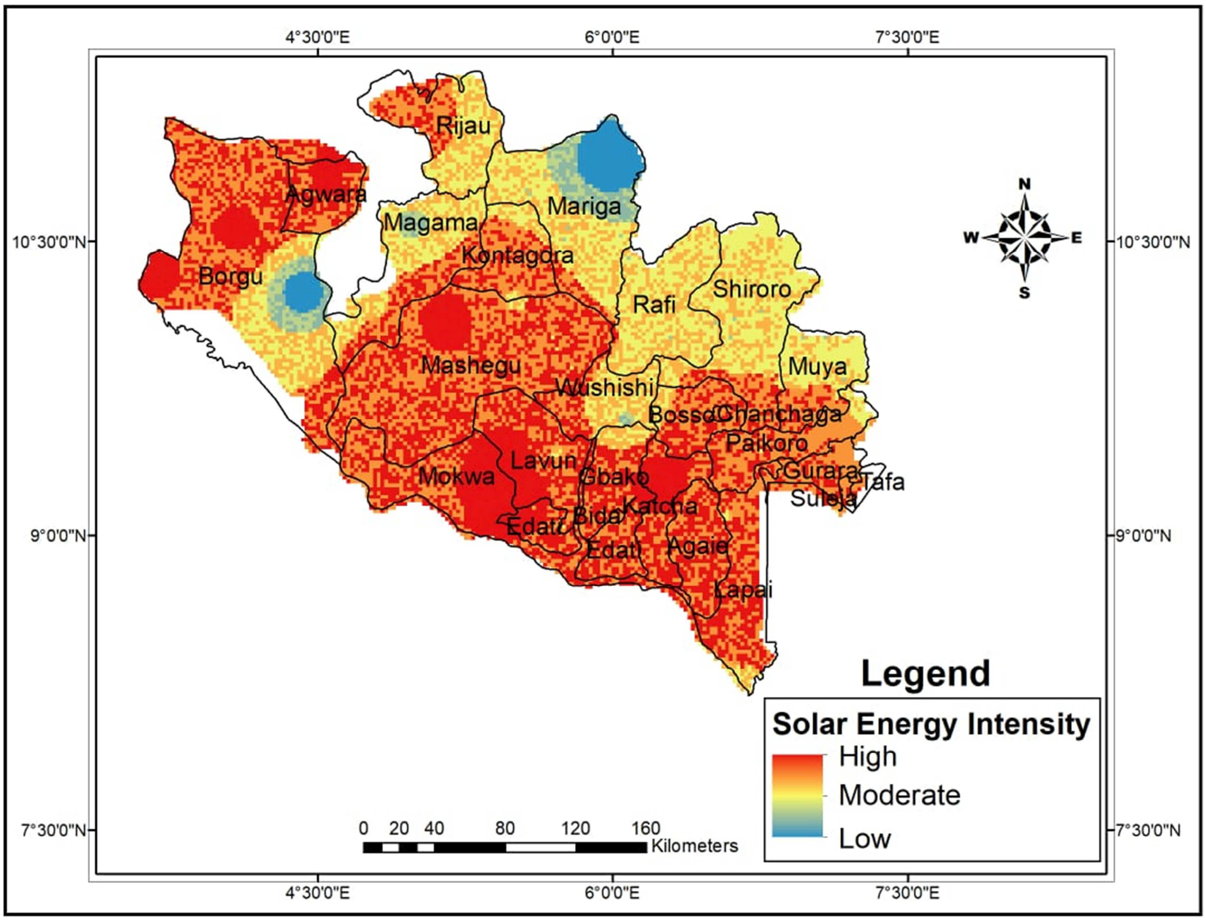


Figure 3. *Solar Energy Potential Sites in Niger State.*

5. Conclusion

Studying the potential of solar energy in Niger State, this research used geospatial techniques. The result discovered an immense solar energy potentials in the state and the most suitable locations for solar energy installations were identified. It was found that despite Niger State being characterised by high solar energy potentials, spatial variations in the amount of utilisable solar potentials exist across the study area, resulting in moderate, good and very good solar energy potentials. To investigate the factors behind the spatial variation in solar energy potentials, further research is required.

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