A LEGACY OF LEADERSHIP: A SPECIAL ISSUE HONOURING THE TENURE OF OUR VICE CHANCELLOR, PROFESSOR ARMAYA'U HAMISU BICHI, *OON, FASN, FFS, FNSAP*

FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 April Special Issue, 2025, pp 189 - 194
DOI: https://doi.org/10.33003/fjs-2025-09(AHBSI)-3464

ASSESSMENT OF SOLAR ENERGY POTENTIALS IN PARTS OF NORTHCENTRAL NIGERIA USING GEOSPATIAL METHOD

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ABSTRACT

Despite the seemingly abundance of solar energy potential in the Northcentral region of Nigeria, only a few studies have been carried out; a few attempts used empirical method which has a lower degree of trustability compared to the geospatial technique. This study conducts a comprehensive geospatial analysis of solar energy potential in the Federal Capital Territory (FCT) and Benue State. Solar radiation and temperature data covering a period of thirty years (1993 – 2022) were obtained from the Nigerian Meteorological Agency (NIMET) and analysed. The solar radiation, temperature, elevation, slope and aspect were ranked based on the analytical hierarchy process (AHP) and the weighted overlay tool was used to produce solar energy potential map for FCT and Benue state. The result shows higher potentials around the beginning and end of the year and lower during the middle months with the lowest radiation values recorded in the month of August in the study areas. The months of January, February, March, November, and December typically offer the highest solar radiation values, making them optimal for solar energy production. The maximum solar radiation values of 4.76 kWh/m^2/day and 4.72 kWh/m^2/day were recorded in FCT and Benue respectively in the month of February. Areas of high, moderate and low solar energy potentials within the study locations were identified and mapped. Understanding the solar radiation spread can guide policymakers in making informed decisions about where to invest in solar infrastructure.

Keywords: Solar Radiation, Temperature, Geospatial, Weighted Overlay, AHP

INTRODUCTION

The quest for sustainable energy solutions to combat the ever-escalating global energy demand and mitigate the environmental consequences of conventional energy sources has never been more urgent. This demand, particularly for renewable energy sources has been steadily rising as parts of efforts to curb emissions of greenhouse gases and adhere to global warming regulations (Fakhraian *et al*., 2021). The price of fossil fuel continues to escalate, and the products are becoming more elusive and rarely available.

Nigeria, as the most populous country in Africa grapples with both a burgeoning energy requirement and need for eco-friendly energy sources to cater for her fast-growing population. The demand for electricity is rapidly increasing as the nation grossly suffers from epileptic power supply due to the erratic and inadequate electricity generation (Adoghe *et al*., 2023), and the recurrent national electricity grid collapse which has repeatedly left the nation in total darkness. Nigeria has abundant sunlight resources (Abdurrahman *et al.*, 2023) particularly in the northern parts of the country, making solar power a feasible and sustainable solution for fulfilling its energy requirements. About 5.25 kWh/m^2/day of solar radiation is averagely recorded daily with more solar potentials in the northern region (Oji *et al*., 2012).

Only a few studies have attempted to investigate the potentiality of solar energy in this region particularly through the integration of ground-based solar radiation and temperature data which is the most reliable data source (Janjai *et al.*, 2009; Pandey and Katiyar, 2013; Huanga *et al.*, 2019) and a few attempts were done using empirical method which has a lower degree of trustability when compared with the geospatial technique (Bashir *et al*., 2022).

Dankassoua *et al.* (2017) evaluated solar energy potential at Niamey using two years solar insolation data to evaluate the variation in potentiality of solar energy as a function of time and concluded that the sunning variation in Niamey is between 5.1 kWh/m^2 and 6.3kWh/m^2. Isma'il *et al.* (2016) also carried out a geospatial analysis of solar energy potential in Kaduna state in the northwestern part of Nigeria with the primary objective of identifying optimum sites for harnessing solar energy in the area. A positive correlation between the ground and satellite insolation data was reported. The ground data showed a maximum insolation of 7.00 kWh/m^2/day in March and minimum insolation value of 4.92 kWh/m^2/day in August. The satellite data on the other hand showed that maximum insolation in the study area is possible in March/April with recorded value of 6.32 kWh/m^2/day and the minimum value of 4.47 kWh/m^2/day was found in August. The study conclusively divided the location of consideration into areas of very high solar energy potentials, high solar energy potentials, and areas of moderate solar energy potentials. Isma'il (2018) extended the same method to determine spatial extent and estimated the amount of solar energy that can be exploited in Kebbi state. The study adopted the analytical hierarchy process (AHP) to make a pairwise comparison of the factors influencing solar energy potentials which include solar radiation, slope, slope aspect and elevation and then used the zonal statistics tool in arcGIS to extract the values of the average, minimum and maximum solar radiation of all the local government areas in Kebbi state. Similarly, Bashir *et al.,* (2022) carried out a spatial and temporal analysis of solar energy potential in Niger state using the GIS tools and the hierarchical analytical process. The study also classified solar potentiality in the area into moderate, good and very good but failed to account for the factors responsible for the spatial variation.

To adequately harness the full solar potential of any location, knowledge of the amount of solar radiation that reaches the location and the temporal variation are important factors to be considered (Rehman and Ghori, 2000; Olomiyesan *et al.,* 2014, Olubusade *et al.*, 2022). In this present study, the geospatial technique is adopted with the analytical hierarchical process to assess the spatial distribution of solar energy potentials and the temporal variation in the amount of solar energy that can be harnessed in FCT and Benue state. Furthermore, the study investigated the possible factors that is responsible for the spatial and temporal variation.

The multi-criteria decision making (MCDM) are methods that can be utilised to design, prioritise and evaluate more than one conflicting criterion to support decision making (Albraheem and Alabdulkarim, 2021). MCDM such as CRITIC, PROMETHEE, WASPAS, and EDAS has been used to support decision making in aspect of site suitability analysis, including for wind, water and telecom towers (Zeleny, 2012). However, in the field of solar energy, decision making analysis method such as WLC, TOPSIS, FAHP, and AHP has been applied. The AHP is the most method used in site suitability assessments for solar energy because it offers more accurate results in comparison with other MCDM methods (Albraheem and Alabdulkarim, 2021). This study weighted solar radiation, temperature, elevation, slope and aspect based on AHP.

Study Areas

FCT is geographically located at the center of Nigeria and it lies within latitudes 8.25°N and 9.20°N and longitudes 6.45°E and 7.39°E. FCT is bounded to the west and northwest by Niger state, to the northeast by Kaduna, Nasarawa to the east and south and Kogi state to the southwest. Benue state lies within latitudes 6.5°N and 8.5°N and longitude 7.47°E and 10°E. The state shares boundaries with Nasarawa to the North, and to the East is Taraba. Enugu and Kogi states are to the West while Cross-River and Ebonyi states are to the South. The state also shares international boundary to the South-East with the Republic of Cameroon (See Figure 1).

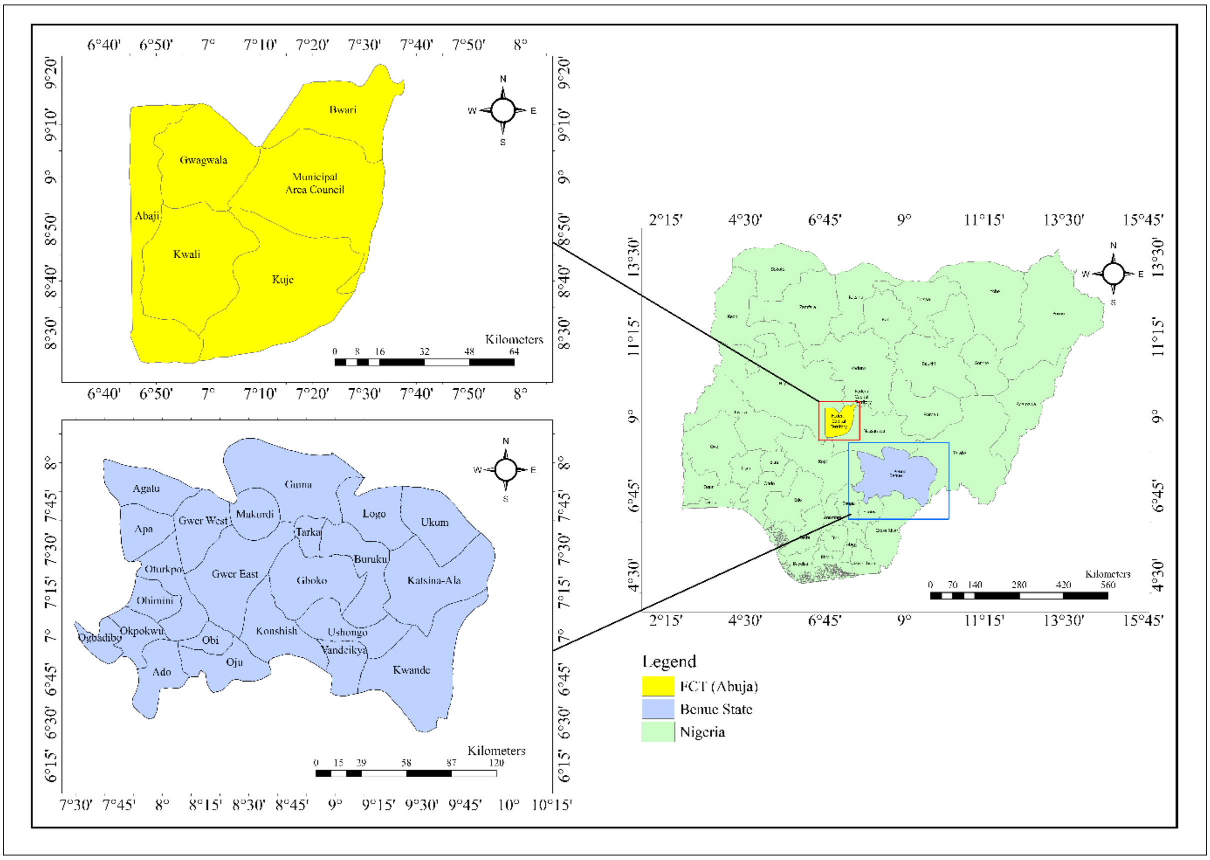

Figure 1: The Study Areas

MATERIALS AND METHODS

Sources of Data

The solar radiation and the daily average temperature data used for this study were obtained from the Nigerian Meteorological Agency (NIMET). NIMET stations use solarimeter to measure total solar radiation in watt per meter squared (W/m^2) and the mercury thermometer device to measure temperature.

Daily average solar radiation data covering a period of thirty years (1993 – 2022) was collected in megajoule per metre squared per day (MJ/m^2/day). This data was then converted into kilowatt hour per metre square per day (kWh/m^2/day) using the International Energy Agency (IEA) General Converter for Energy. This conversion is necessary because solar radiation values are generally expressed in kWh/m^2/day, which is the amount of solar energy that strikes a square meter of the Earth's surface in a single day.

Methods of Data Analysis

The ground measured global solar radiation and temperature data was computed in Microsoft Excel. The monthly average of the global solar radiation and the mean monthly trend of temperature in both the FCT and Benue state for the entire study period was computed. The minimum and maximum values of solar irradiance and temperature were identified and the trend across the study period were observed.

To identify the optimum solar energy potential sites and values for solar energy development in FCT and Benue state, this study utilised the ArcGIS weighed overlay and the AHP method. The study areas were delineated in Google Earth Pro using the base map of the locations. Several points within the study areas were marked and the coordinates and elevations of the marked areas were extracted and recorded in Microsoft Excel spreadsheet. Thereafter, the points were imported into ArcGIS environment as X, Y, and Z data. The 3D Analyst Tool in ArcGIS was used for the interpolation process in order to create a digital elevation model (DEM) of the area, and the slope and aspect maps of the areas were then generated from the DEM. The Surface Analyst Tool in ArcGIS was used to create slope map of the area as an output raster while using the DEM as input raster and the output measurement units and the z-factor were specified. Similarly, the same tool was used to create the aspect of the study area as output raster; whereby the DEM served as input raster for the analysis. The solar radiation, temperature, elevation, slope and aspect were weighted using AHP and the final weights of each criterion was assigned to produce a spatial map of solar energy potential across the study areas using the weighted overlay tool in ArcGIS.

RESULTS AND DISCUSSION

The Table 1 presents the monthly average global solar radiation for the FCT and Benue state in Nigeria over a 30-year period (1993 to 2022). This data provides an understanding into the seasonal variations, geographical influences, and implications for solar energy harnessing in the study areas. A significant variation is observed throughout the year. The solar radiation values are higher around the start and end of the year and lower during the middle months with the lowest radiation values of 2.85 kWh/m^2/day and 2.96 kWh/m^2/day recorded in the month of August in FCT and Benue state respectively. The months of January, February, March, November, and December which are dry season period typically offer the highest solar radiation values, making them optimal for solar energy production. This further justify the conclusion of Lawin *et al*., (2019) that period of excess solar irradiance in any location typically coincide with the dry season and thus, high production of solar energy is expected during this period.

The FCT generally has slightly higher solar radiation values compared to Benue state throughout most of the months. The maximum solar radiation value of 4.76 kWh/m^2/day was recorded in FCT in the month of February. Similarly in the same month, Benue state recorded the highest solar radiation value of 4.72 kWh/m^2/day. The maximum insolation recorded in the FCT and Benue state is lower than that of Niger and Kaduna as reported by Bashir *et al*., (2022) and Isma'il *et al*., (2016) respectively. The difference can be attributed to geographical factors such as latitude, altitude, and local weather patterns. The values of solar radiation highlighted in the Table 1 shows that FCT generally offers higher solar radiation values, making it potentially more suitable for solar energy projects. The FCT is at a higher altitude which generally leads to increased solar radiation due to less atmospheric interference. Furthermore, the tilt of the Earth's axis also causes seasonal changes in solar radiation. This is evident in the higher values during the northern hemisphere's Harmattan period in Nigeria (December, January) and lower values during rainy season (June, July, August) (Ojosu, 1990).

Table 1: Monthly Average Global Solar Radiation kWh/m^2/day (1993 - 2022) (NIMET, 2024)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FCT	4.66	4.76	4.67	4.31	3.76	3.25	2.97	2.85	3.26	3.72	4.40	4.56
Benue	4.69	4.72	4.46	4.01	3.52	3.13	3.01	2.96	3.14	3.38	4.07	4.52

The mean monthly trend of temperature in the study areas is presented in Table 2. The result shows a continuous increase in temperature from the month of September to the month of March in both locations with highest values of 30.79 °C and 30.65 °C recorded in the month of March in the FCT and Benue state respectively and coinciding with the dry season period which have high solar radiation values. This further shows that the FCT is the hottest of the two locations considered. A steady reduction in temperature is observed from the month of April to August with the lowest of the temperature values recorded in the month of August representing the period of peak rainfall.

Table 2: Monthly Average Temperature (°C) (1993 - 2022) (NIMET, 2024)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FCT	28.06	29.84	30.79	29.67	27.76	26.06	25.04	24.74	25.15	26.01	27.49	27.73
Benue	28.40	29.98	30.65	29.57	27.98	26.56	25.69	25.48	25.76	26.41	27.59	27.85

The elements that influence solar energy potentials in an area and how much of the energy that can be harnessed include the intensity of the insolation, temperature, topography, slope, and aspect of the area (Bashir *et al*., 2022). Different topography characterised the study locations. The altitude is an important parameter that contribute to how much of a solar energy that can be harnessed in any location. A photovoltaic system installed in a high-altitude region can receive more solar radiation than a system installed in low altitude regions (Aldobhani, 2014; Opeyemi *et al.*, 2022). The Figure 2 and 3 depict the topography of FCT and Benue state respectively. The highest elevations in the FCT which is about 850 m above sea level are found around the northeastern part of the region while the lowest points are found in the southeastern part with the lowest elevation recorded as 61 m above sea level. Similarly, the lowest elevation in Benue state is about 49 m while a small portion of the state has the highest elevation of about 939 m.

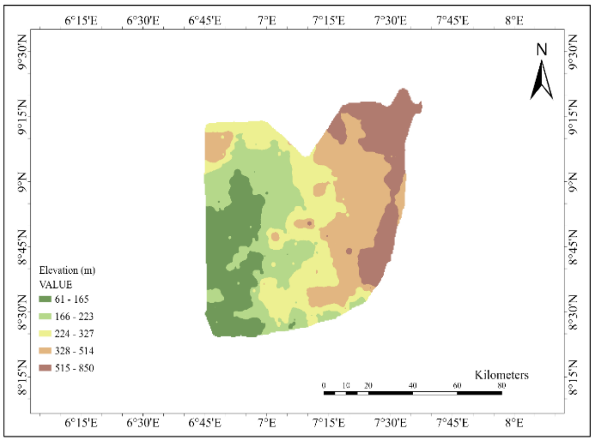

Figure 2: FCT DEM

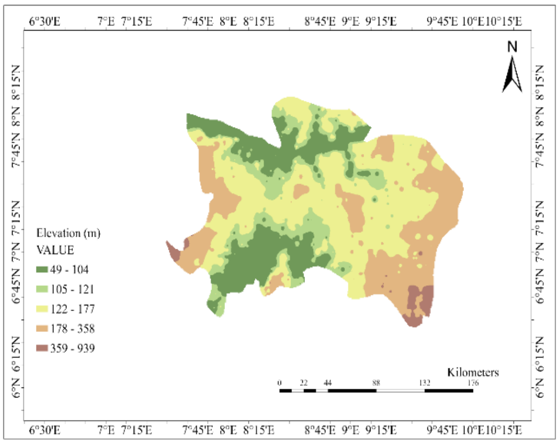

Figure 3: Benue DEM

The Figure 4 shows the potentials of solar energy across FCT and Benue state based on the parameters listed above. The northeastern part of FCT shows a region with very high potential while high potential generally spread across the city center to the eastern and southern part of FCT. A small portion of the northwestern part of the region shows moderate and low potential. The pattern of solar potentials in Benue state is different from that of the FCT. The sites with the highest potentials are generally found in the northeastern parts of the state followed by sites with moderate potential spreading from the eastern parts of the state across the center to the north and northwestern parts of the region while lower solar energy potentials are concentrated in the southern parts of Benue state.

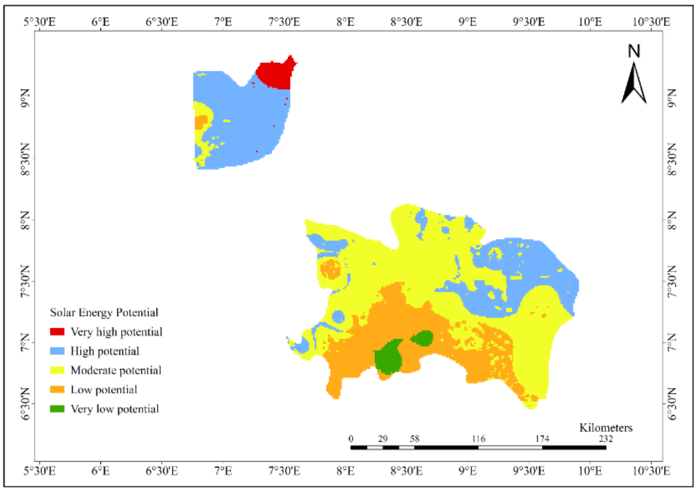

Figure 4: Solar Energy Potential Sites in FCT and Benue State

The distinct distribution of high and low potential zones in both regions reinforces the need for site-specific solar feasibility studies rather than blanket deployment strategies. These insights can guide stakeholders, including policymakers and private sector investors, in prioritizing locations for solar infrastructure development, thereby enhancing energy equity, reducing diesel dependence, and promoting sustainable energy access in the regions.

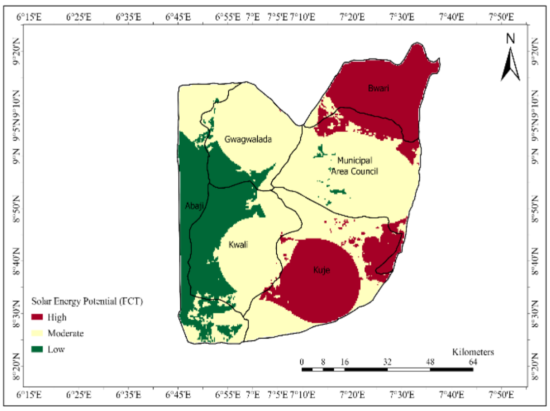

Figure 5: Solar Energy Potential in FCT

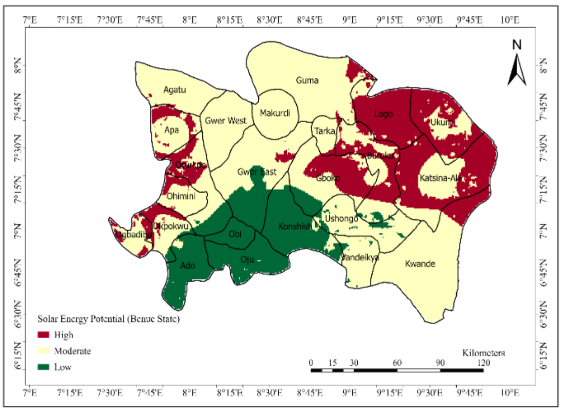

Figure 6: Solar Energy Potential in Benue State

The spatial variation of solar energy potential across the Federal Capital Territory and Benue State is shown in Figures 5 and 6 respectively. The figures depict areas of high, moderate and low solar energy potential in the areas. The Bwari and the center of Kuje area councils of the FCT constitute areas of high solar energy potential. This can be attributed to high insolation and annual average temperature, and higher elevation in this region. These sites are most suitable for the exploitation of solar energy in FCT. Other areas such as Abuja municipal, Gwagwalada, parts of Kwali and other parts of Kuje areas have moderate potentials while the western parts, which basically comprises of some parts of Kwali and most parts of Abaji are concentrated with low solar energy potential in FCT. The spatial distribution of solar energy potential across Benue State also shows variations across different areas of the state. Areas with high potentials include Logo, Ukum, Buruku, Otukpo, and parts of Gboko and Katsina-Ala Local Government Areas. Moderate solar energy potential areas include Guma, Makurdi, Tarka, Kwande, Vandeikya, Ushongo, Gwer West, some parts of Gwer East, Agutu, Ohimini, Okpokwu, and Ogbadibo while areas such as Konshishi, Obi, Oju, Ado and some parts of Gwer East have the lowest solar energy potential in Benue state.

CONCLUSION

This study provides a comprehensive geospatial analysis of solar energy potential in FCT and Benue State, regions within the Northcentral Nigeria that have received limited attention in previous renewable energy research. The findings offer location-specific insights critical for optimal siting and deployment of solar energy systems. The geospatial method provides a more efficient approach of mapping solar energy potentials in the study area. The solar radiation maps produced in this study depict a spatial view of solar radiation potential spread across the study areas. The ground-measured insolation and temperature data provides a more accurate result in the analysis of solar energy potential and also provides insights into the climatic conditions of FCT and Benue state.

The variation in solar energy across the different periods of the year necessitates a seasonal approach to energy planning. Solar energy systems in FCT and Benue should be designed to maximize energy capture during high-radiation periods and mitigate the effects of reduced radiation during the rainy season. The knowledge of the solar radiation spread across different locations in the Federal Capital Territory and Benue state has depicted in this study can guide policymakers, solar energy expert and stakeholders in making informed decisions about where to invest in solar infrastructure. Areas with consistently higher radiation should be prioritized for solar farm installations, while regions with lower radiation might require supplementary energy sources that will contribute to energy security and sustainability in the region.

ACKNOWLEDGEMENT

The researcher wishes to acknowledge the support of IHS Towers Nigeria through the Tuition Assistance Program (TAP 2024).

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