ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 4 No. 2 December 2018*

Spatial Mapping of Solar Energy Potentials in Kebbi State, Nigeria

Muhammad Isma'il*
Department of Geography and Environmental Management,
Ahmadu Bello University,
Zaria, Nigeria
Email: mgeogjameel@yahoo.com

Abstract

This paper employed geospatial techniques to map and assess solar energy potentials in Kebbi State, North-western Nigeria. Solar radiation and Digital Elevation Model (DEM) of the area were used as input parameters. The DEM was used to generate slope and slope aspect. The slope, slope aspect and solar radiation of the study area were reclassified and weighted using Analytical Hierarchy Process (AHP). The results revealed that about 1912km² of the study area have moderate solar energy potential; 2383km² have good solar energy potential while 12325.48km² have very good solar energy potential. The analysis also revealed that Arewa-Dandi Local Government Area has the highest mean solar radiation energy of 5.53KWh/m²/day; Birnin Kebbi has 5.41KWh/m²/day while Ngaski has the lowest mean solar radiation energy of 4.80KWh/m²/day. The paper has shown the capacity of geospatial techniques in the analysis of solar energy potentials and therefore can be used in the analysis of other renewable energies.

Keywords: Solar Energy, Potentials, Geospatial Techniques, Spatial Mapping, AHP.

INTRODUCTION

The energy reaching the Earth's surface from the sun is called solar energy. Most of this energy is in the form of radiation from the "visible" wavelengths. Visible radiation and radiation with shorter wavelengths, such as ultraviolet radiation are called "shortwave" (Graham, 1999). The Earth's climate system constantly adjusts in order to maintain a balance between the incoming and out-going radiation. This is referred to as Earth's "radiation budget". The components of the Earth system that are essential to the radiation budget are the Earth's surface, atmosphere, and clouds (Graham, 1999). Based on the principle of conservation of energy, the Earth's radiation budget comprises of the incident, reflected, absorbed, and emitted energies by the Earth system. This radiation budget represents the accounting of the balance between incoming radiation, which is almost completely solar radiation, and out-going radiation, which is partly reflected solar radiation and partly terrestrial radiation, including the atmosphere (National Aeronautics and Space Administration, 2010).

Solar energy is the most sustainable renewable energy source (Pettazzi & Salsón, 2012). It is more predictable than wind energy and less vulnerable to changes in seasonal weather patterns (Muneer et al., 2005). However, comprehensive information on the spatio-temporal pattern of monthly mean values of global solar radiation reaching the Earth's surface is required in the design and development of solar energy systems (Rehman & Ghori, 2000). This information on renewable energies such as solar is generally scarce in Africa (Monforti, 2011). Consequently, the level of solar energy development and utilization as an alternative source of power is very low resulting to millions of Africans lacking access to electricity.

*Author for Correspondence

Nigeria is endowed with abundant solar energy potentials which vary spatially and temporally. These potentials can be exploited to increase the energy supply mix in the country.Several studies have been carried out on solar energy potentials in different parts of Nigeria using empirical models such as Akpabio, Udo and Etuk (2004), Chiemeka (2008), Augustine and Nnabuchi (2009), Sanusi and Abisoye (2011), Falayi, Rabiu and Teliat (2011), Ibeh et al. (2012), Musa et al. (2012), Ogbaka and Silikwa (2016). These studies have focused mostly on southern Nigeria and some parts of northern Nigeria.

Few studies have assessed the solar energy potentials for various locations in northwestern Nigeria. Such studies include Sambo (1988) in Kano; AbdulAzeez (2011) in Gusau; Gana and Akpootu (2013) and Gana et al. (2014) in Kebbi; Mohammed et al. (2015) in Sokoto.These studies employed various statistical techniques to model solar radiation directly from insolation data, or, indirectly from other climatic variables.

An alternative approach to analyze solar energy potentials is the application of geospatial techniques (Rehman & Ghori, 2000; Ramachandra, 2007). Geospatial technique has the ability to analyze the spatial variation in solar energy potentials, and to determine the most suitable locations for harnessing solar energy in an area or region (Ramachandra, 2007).This study employs geospatial technique to map the potential sites for exploiting solar energy in Kebbi state; and to determine the spatial extent and the amount of solar energy that can be exploited in the study area.

THE STUDY AREA

The study area is Kebbi State located in North-western part of Nigeria. It lies between Latitudes 10º15´N and 14º0´N and Longitudes 2º01´E and 6º0´E. It is bounded to the North-East by Sokoto and Zamfara states, to the South by Niger state and to the North-west by Niger Republic and Benin Republic (See Figure1).

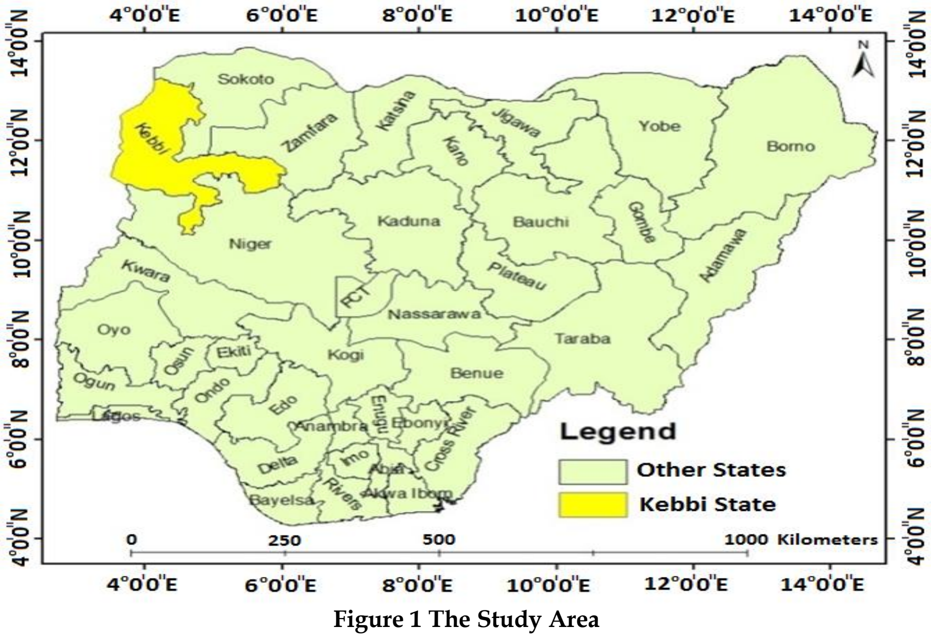

Figure 1 The Study Area
Source: Open Street Map of the Study Area (2017)

The relief in Kebbi state is generally gently rolling to undulating. In general, elevations throughout the state are mostly less than 300m (Birnin Kebbi Master Plan, 1980-2000). The natural vegetation of the study area consists of Northern Guinea Savannah in the south and southeast. The landscape of Kebbi is dominated by extensive flood plains (Birnin Kebbi

Master Plan, 1980-2000). The relief and drainage of the environment have a great influence to solar radiation.

Kebbi State enjoys a Tropical Continental type of climate characterized by distinct wet and dry seasons. The wet season lasts from April to October in the south and May to September in the north; while the dry season lasts for the remaining period of the year. Mean annual rainfall is about 800mm in the north and 1000mm in the south (Abubakar, 2015). In the northern part of the State, two groups of soils can be identified, the upland and fadama soils. These two soil groups are generally characteristic of the entire Sokoto Rima Basin.

Kebbi State has a population of 3,802,500.00 in 2011. Recently, the State population density is estimated at 103.3 per km². The projected population of Kebbi in 2018 is 4, 723 968 (National Population Commission, 2006).

METHODOLOGY

Types and sources of data

The types of data used include solar radiation with spatial resolution of 30sec of an arc downloaded from Global Climate Data website. The average solar radiation was converted from KJ/m²/day to KWh/m²/day and plotted in ArcGIS as presented in Figure 2.

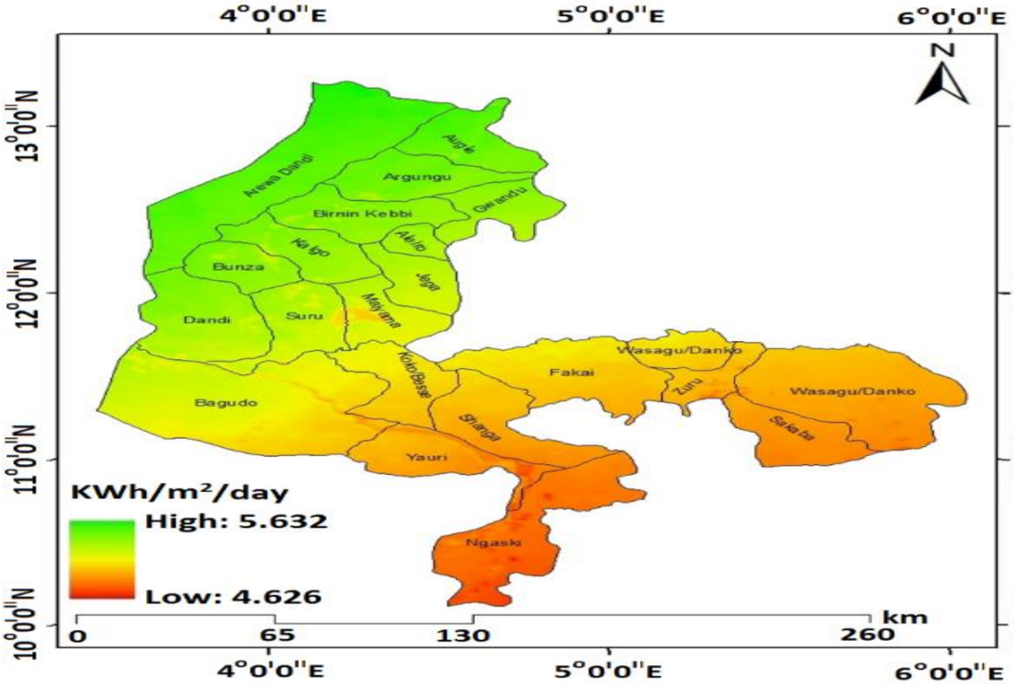

Figure 2 Average Monthly Solar Radiation in Kebbi
Source: WorldClim 2.0 Beta version 1

The Digital Elevation Model (DEM) presented in Figure 3 was obtained from Shuttle Radar Topographical Mission (SRTM) data with 90m resolution, which was downloaded from the United States Geological Survey (USGS) website, www.glovis.usgs.gov. The temporal scope of the study covers 30-year period (1970-2000). The slope and slope aspect as presented in Figures 4 and 5 were generated from the DEM of the study area using the spatial analyst extension of ArcGIS.

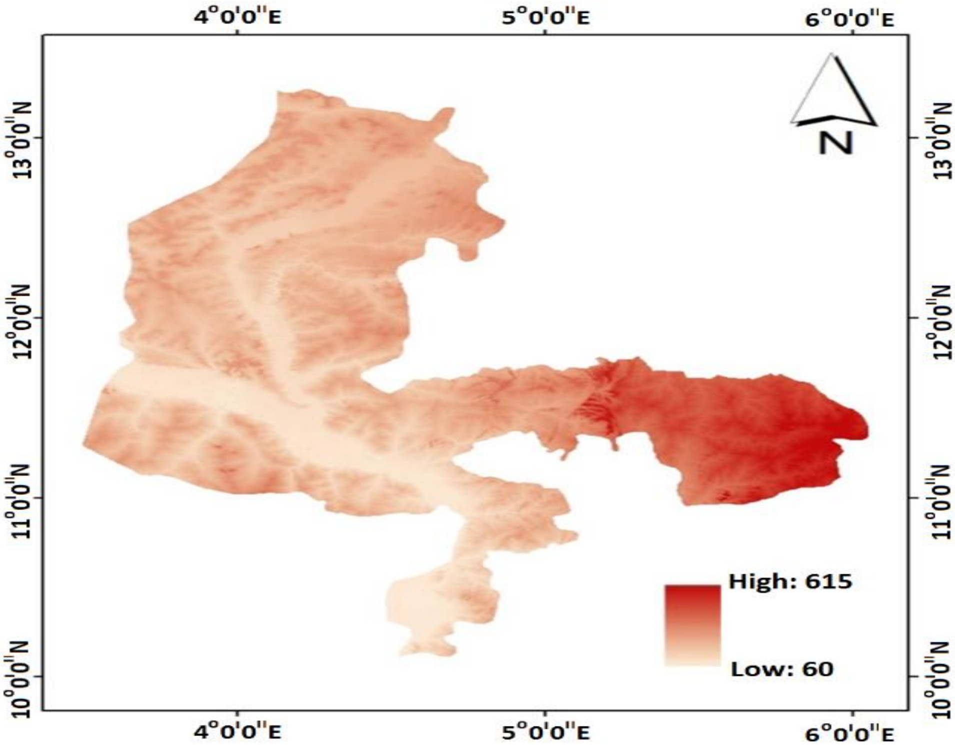

Figure 3 DEM of the Study Area

2.2 Methods of Data analysis

The factors influencing solar energy potential which are solar radiation, elevation, slope and slope aspect were reclassified and used as input parameters (Figures 2-5). The analysis involved a combination of the reclassified factors. Multi-criteria analysis known as Analytic Hierarchy Process (AHP) was used to rank the factors by pairwise comparison. Weighted overlay tool in ArcGIS 10.3 spatial analyst extension was used to combine the three factors based on their weight. This method was adapted from Sadeghi and Karimi (2017) who determined suitable sites for solar farm and wind turbine using GIS and AHP in Tehran, in order to generate a distributed network to increase power network stability in the area.

The average, minimum and maximum solar radiation values of all the LGAs in the study area were extracted using ArcGIS Zonal statistics tool and weighted overlay tool and the results are presented in a tabular format. This is a popular tool that has efficiently being utilized worldwide.

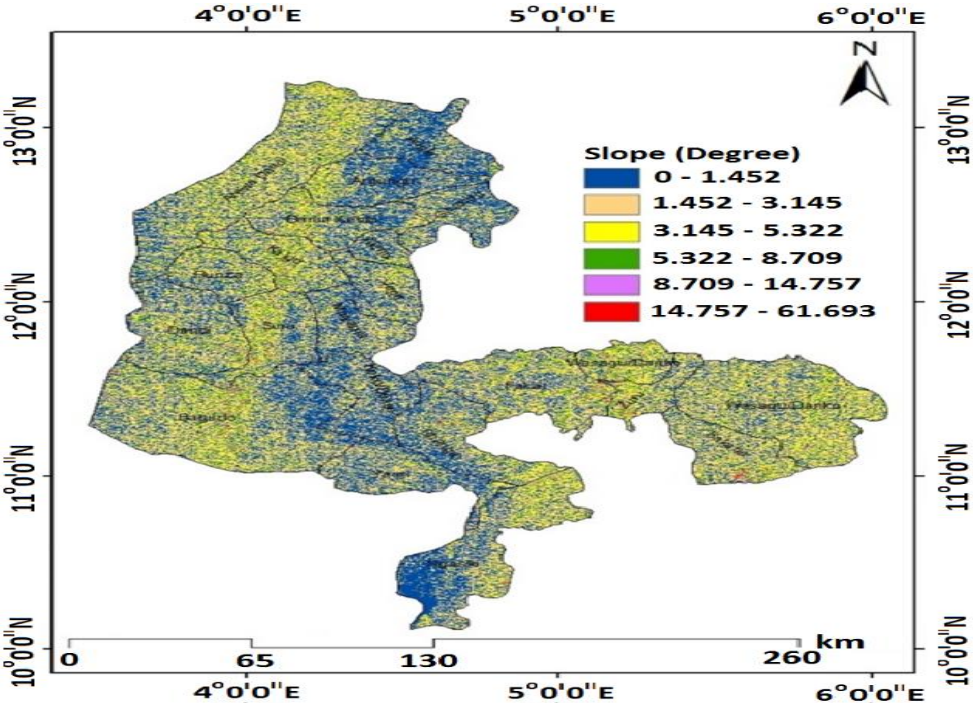

Figure 4 Slope of the Study Area

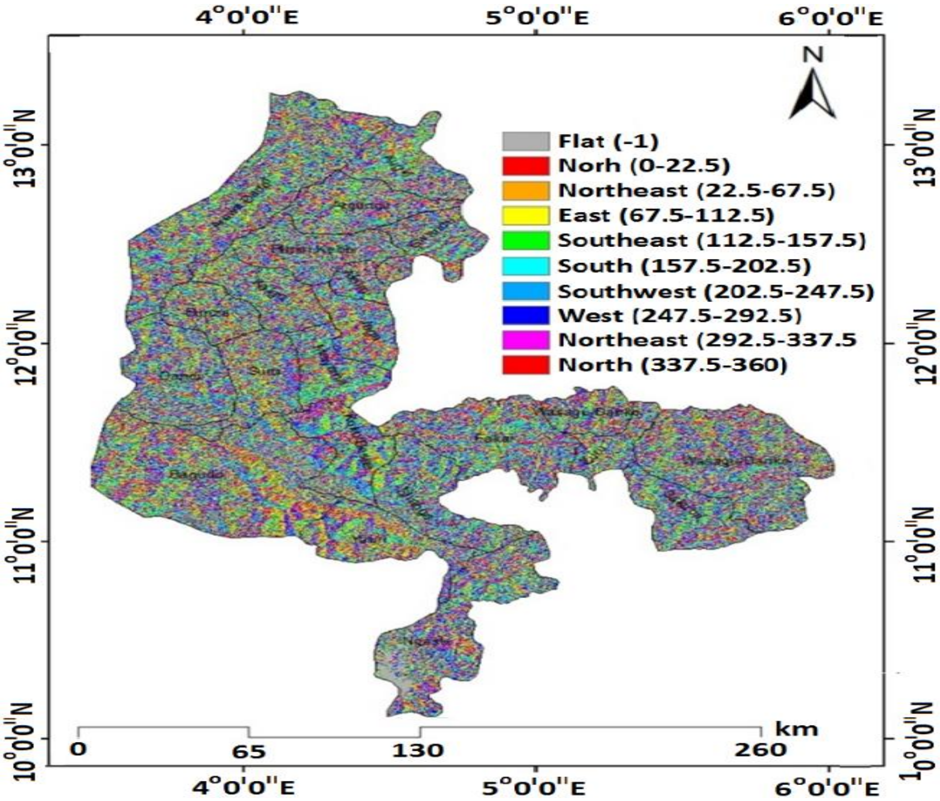

Figure 5 Slope Aspect of the Study Area

RESULTS AND DISCUSSION

Spatial Extent of Solar Energy Potentials in Kebbi State

This study integrated solar radiation data and other geographic factors in a GIS environment to determine solar energy potentials in Kebbi State. The results showed the spatial extent and variation in solar energy in the area; and also identified solar energy potential sites are presented in the area.

Table 1 revealed the spatial extent of solar energy potential sites in the study area; it can be seen from the Table 1 that about 1912Km^2 of the study area has moderate solar energy potential, 2383Km^2 has good solar energy potential, while 12325.48Km^2 has very good solar energy potential. Based on this, it is revealed that all the areas in Kebbi State can be used for solar energy projects. This suggests that each part of the study area has minimum average requirement for solar energy exploitation. In addition, it can be observed from Table 1 that about 60% of the land area of the state is classified to have good solar energy potentials, which is an indication of enormous solar energy which can be exploited for economic development in the state. Figure 6 shows the solar energy potential sites in the study area, which is classified into moderate energy potential, good energy potential and very good energy potential.

Table 1 Areal Extent of Solar Energy Potential Sites in Kebbi State

Description	Value	Area (Km^2)	%
Moderate Energy Potential	2	1912.8 4	5.1
Good Energy Potential	3	23484.01	62.3
Very Good Energy Potential	4	12325.48	32.7

The Amount of Exploitable Solar Energy Potentials in Kebbi State

In view of the fact that the solar radiation received in an area is a function of such factors as topography, slope and aspect, findings revealed that there is spatial variation in solar energy potentials received in the Local Government Areas (LGAs) of Kebbi State as shown in Table 2.

The results in Table 2 showed that Arewa-Dandi LGA received the highest mean solar radiation of 5.53KWh/m^2/day; followed by Augie and Argungu LGAs which receive 5.50 and 5.46KWh/m^2/day respectively. Birnin Kebbi LGA being the state capital receives 5.41KWh/m^2/day while Ngaski LGA receives the lowest mean solar radiation of 4.8KWh/m^2/day in the study area. The maximum value of solar radiation (5.63KWh/m^2/day) in the area was recorded in Arewa-Dandi while the minimum value (4.62KWh/m^2/day)was recorded by Ngaski LGA. From this it was found that in Kebbi State there are areas with moderate, good and very good solar energy potentials.

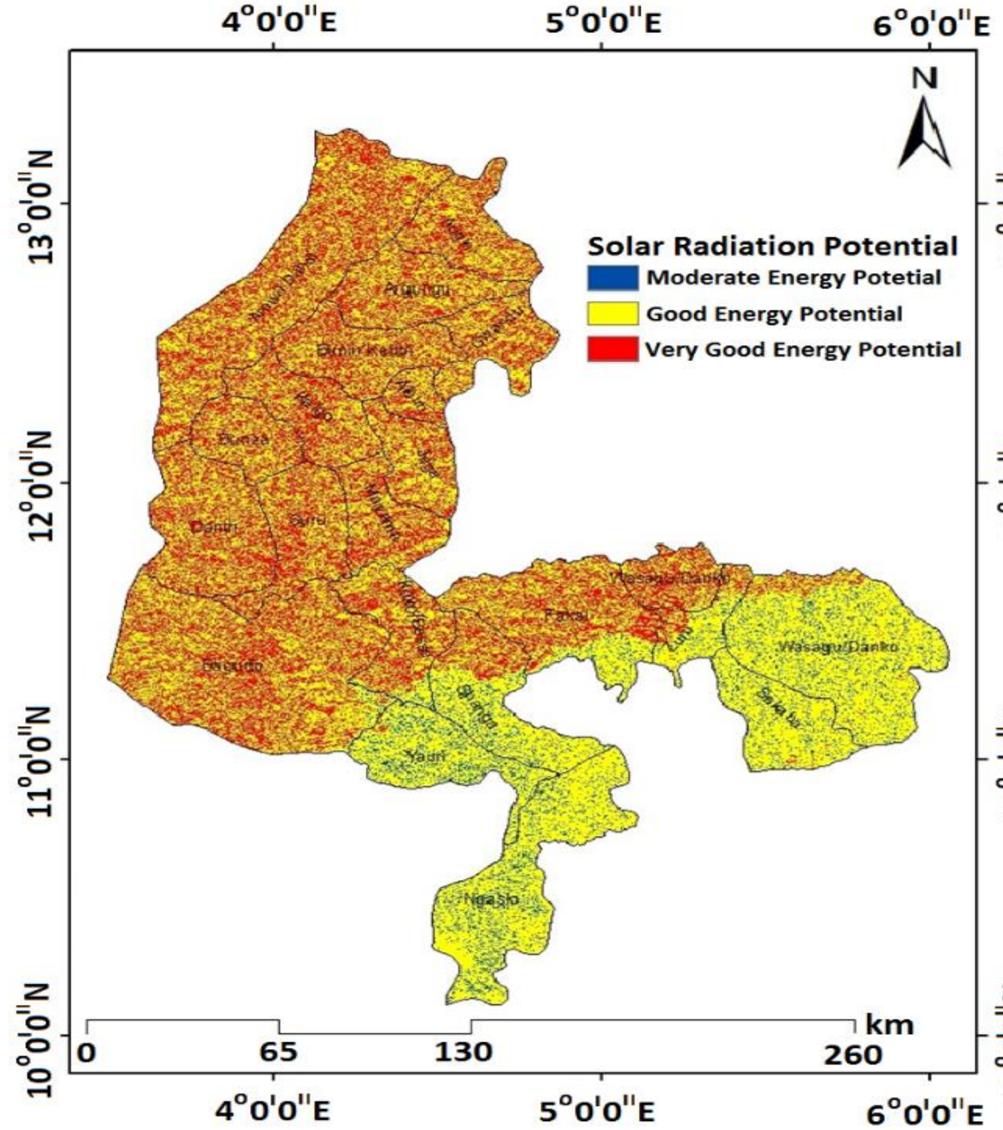

Figure 6 Solar Energy Potential Sites in Kebbi State

Table 2 also shows the maximum, minimum and mean solar radiation values in the study area. Gana et al. (2014) observed that the maxima of direct solar radiation in Kebbi State are quite significant for the months of February, March and April. However, they reported that the diffuse solar radiation in the state was found to be maxima during the months of July and August as well as minima during the months of November, December and January. This is due to the fact that the months of July and August in Northern Nigeria fall within the rainy season when the sky is overcast and the clouds intercept the amount of insolation in the area. Likewise, the months of November, December and January fall within the Harmattan season, characterized by very low temperature wind which envelopes the Northern Nigeria.

Table 2 Solar Radiation Values in LGAs of Kebbi State (KWh/m²/day)

LGA	Mean	Minimum	Maximum
Arewa-Dandi	5.533	5.396	5.632
Augie	5.498	5.363	5.586
Argungu	5.460	5.298	5.524
Birnin Kebbi	5.412	5.248	5.513
Bunza	5.405	5.256	5.487
Kalgo	5.388	5.216	5.500
Gwandu	5.367	5.284	5.453
Dandi	5.343	5.108	5.488
Aleiro	5.341	5.293	5.419
Jega	5.269	5.182	5.376
Suru	5.258	5.043	5.384
Maiyama	5.197	5.022	5.332
Bagudo	5.143	4.897	5.371
Koko/Besse	5.071	4.918	5.220
Fakai	5.043	4.931	5.143
Zuru	4.983	4.806	5.052
Wasagu/Danko	4.964	4.753	5.123
Shanga	4.958	4.773	5.095
Yauri	4.919	4.717	5.009
Sakaba	4.889	4.814	4.958
Ngaski	4.799	4.626	4.900

The results in Figure 6 and Table 2 also showed that areas like Arewa-Dandi, Augie, Argungu, Birnin Kebbi, Bunza, Kalgo and Gwandu with mean solar radiation of 5.50-5.37KWh/m^2/day are located in the northern part of Kebbi State. These areas with high solar energy potentials offer the most suitable sites for developing solar farms which can be used for generating utility scale solar energy.

It is also observed that areas with moderate solar energy potentials are found in the central part of the state, while areas with relatively good solar energy potentials are found in the south-eastern and the southern fringes of the state. Even the areas with relatively good potentials have mean solar radiation of 4.98-4.80KWh/m^2/day, which is sufficient to generate large amount of solar energy which can be used to increase the energy supply mix and address the electricity problem in Nigeria.

The spatial variation in solar energy potentials observed in the study area is attributed to geographical factors that influence the amount of solar radiation received in an area or region. Effat (2016) reported that several factors such as variation in elevation, orientation (slope and aspect) and shadows cast by topographic features, all affect the amount of insolation received at different locations; but topography is a major factor that determines the spatial variability of insolation.

CONCLUSION

This study used geospatial techniques to analyse solar energy potentials in Kebbi State. The results identified the enormous available solar energy potentials in the state as well as the most suitable sites for large scale solar farms. These are Arewa-Dandi, Augie, Argungu, Birnin Kebbi, Bunza, Kalgo and Gwandu which are located in the northern part of Kebbi State with mean solar radiation ranging from 5.50-5.37KWh/m^2/day. It was found that about 60% of the land area of the state is classified to have good solar energy potentials, which is an indication of high solar energy which can be exploited for economic development in Kebbi state and to increase the energy supply mix in Nigeria.

REFERENCES

AbdulAzeez, M.A. (2011). Artificial neural network estimation of global solar radiation.*Applied Science Research*, 3(2): 586–595.

Abubakar, A.Z. (2015). Effects of Urbanization on Landuse/Landcover Changes in Birnin Kebbi, Kebbi State, Nigeria. An unpublished M.Sc. thesis, Department of Geography,Ahmadu Bello University, Zaria.

Akpabio, L.E., Udo, S.O. & Etuk, S.E. (2004). Empirical Correlations of Global Solar Radiation with Meteorological data for Onne, Nigeria. *Turk J Phys,* 28, 205-212.

Augustine, C. & Nnabuchi, M.N. (2009). Relationship between global solar radiation and Sunshine hours for Calabar, Port Harcourt and Enugu, Nigeria, *International Journal of Physical Sciences*, 4(4): 182-188.

Birnin Kebbi Master Plan, 1980-2000 (1983). Final report, Sokoto: Ministry of Housing and Environment, Sokoto State. Dar Al-Handasah Consultants (Shair & Partners).

Chiemeka, I.U. (2008). Estimation of solar radiation at Uturu, Nigeria. *International Journal of Physical Sciences*, 3(5): 126-130.

Effat, H.A. (2016). Mapping Solar Energy Potential Zones, using SRTM and Spatial Analysis, Application in Lake Nasser Region, Egypt. *International Journal of Sustainable Land Use and Urban Planning*, 3(1): 1-14.

Falayi, E.O., Rabiu, A.B. & Teliat, R.O. (2011). Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. *Advances in Applied Science Research*, 2(4): 480-490.

Gana, N.N. & Akpootu, D.O. (2013). Estimation of global solar radiation using four Sunshine based models in Kebbi, North-Western, Nigeria. *Advances in Applied Science Research*, 4(5): 409-421.

Gana, N.N., Jitendra, K.R. & Momoh, M. (2014). Estimation of Global and Diffuse Solar Radiation for Kebbi, North-Western, Nigeria. *International Journal of Scientific & Engineering Research*, 5(1): 1654-1661.

Graham, S. (1999). *Clouds & Radiation*. NASA Retrieved on 21/03/2017 from https://earthobservatory.nasa.gov/Features/Clouds/.

Ibeh, G.F., Agbo, G.A., Ekpe, J.E. & Isikwue, B.C. (2012). Estimation of global solar radiation at Calabar using two models. *Journal of Natural Sciences Research,* 2(5): 17-25.

Muneer, T., Asif, M. & Munawar, S. (2005). Sustainable production of solar electricity with particular reference to the Indian economy. *Renewable Sustainable Energy Review*, 9:44-73.

Mohammed, G., Abubakar, A.G., Umar, B.A., Mustapha, A. & Manga, P.J. (2015). Modelling of Cloudiness Index with Maximum Temperature and Relative Humidity of Sokoto Northwestern, Nigeria. *International Journal of Marine, Atmospheric & Earth Sciences*, 3(1): 28-46.

Monforti, F. (2011). Renewable energies in Africa- Current knowledge, *JRC Scientific and Technical Reports*.European Union, Italy.

Musa, B., Zangina, U. & Aminu, M. (2012). Estimation of global solar radiation in Maiduguri, Nigeria using angstrom model. *ARPN Journal of Engineering and Applied Science,* 7(12): 1623-1627.

National Aeronautics and Space Administration, Science Mission Directorate. (2010). *The Earth's Radiation Budget*. Retrieved [insert date - e.g. August 10, 2016], from NASA Science website: http://science.nasa.gov/ems/13_radiationbudget

National Population Commission (NPC, 2006). Population and Housing Census: Population Distribution by Age & Sex, (State & Local Government Area). NPC, Abuja.

Ogbaka, D.T. & Silikwa, N.W. (2016).The Use of Sunshine Based Models to Estimate Global Solar Radiation in Yola, Nigeria. *Journal of Scientific and Engineering Research*, 3(4): 334-338.

Pettazzi, A. & Salsón, S. (2012). Merging remote sensing data with in-situ measurements of global solar radiation: the right path to estimate the solar resource in Galicia. *International Conference on Renewable Energies and Power Quality (ICREPQ'12).* Santiago de Compostela (Spain).

Ramachandra, T.V. (2007). Solar energy potential assessment using GIS.*Energy Education Science and Technology*, 18(2): 101-114.

Rehman, S. & Ghori, S.G. (2000). Spatial estimation of global solar radiation using geostatistics. *Renewable Energy*, 21, 583-605.

Sadeghi, M. & Karimi, M. (2017). GIS-Based Solar and Wind Turbine Site Selection usingMulti-Criteria Analysis: Case Study Tehran, Iran. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-4/W4.

Sambo, A. S. (1988). The measurement and prediction of global and diffuse components of solar radiation for Kano in Northern Nigeria. *Solar and Wind Technology,* 5(1): 1-5.

Sanusi, Y.K. & Abisoye, S.G. (2011). Estimation of Solar Radiation at Ibadan, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences,* 2(4): 701-705.

Shuttle Radar Topographical Mission (SRTM).Available atwww.glovis.usgs.gov. Accessed on 03/01/2018.

WorldClim - Global Climate Data. Free climate data for ecological modelling and GIS.Available at http://worldclimate.org/versio. Accessed on 03/01/2018.