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ANALYSIS OF SOLAR RADIATION IN THE AREAS USING GROUND MEASURED DATA IN SOME PARTS OF SOUTH – EASTERN NIGERIA

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ABSTRACT

This study used geospatial techniques to investigate ground-measured solar radiation data in Anambra, Enugu and Ebonyi states of South-Eastern Nigeria over a five year period, 2013 – 2017 in order to determine the optimum periods for harnessing solar energy in the areas. Results showed that in March 2013, highest monthly average solar radiation values of 7.00 kWh/m^2/day and 6.90 kWh/m^2/day were recorded in Anambra and Ebonyi respectively. 7.45 kWh/m^2/day was observed in Enugu in April of the same 2013. In 2014, we had the highest monthly average solar radiation values of 6.66 kWh/m^2/day in Anambra, 6.98 kWh/m^2/day in Enugu and 6.39 kWh/m^2/day in Ebonyi, all in March. In the month of March 2015, we had the highest monthly average solar radiation values of 7.00 kWh/m^2/day in Anambra state, 6.99kWh/m^2/day in Enugu state and 6.40kWh/m^2/day in Ebonyi state. In 2016, we had the highest monthly average solar radiation values of 7.01 kWh/m^2/day and 7.00 kWh/m^2/day in Anambra and Ebonyi respectively in the month of March. Enugu State had maximum value of 6.83 kWh/m^2/day in the month of April in the same year. In 2017, we had the highest monthly average solar radiation values of 6.98 kWh/m^2/day in Anambra, 7.00 kWh/m^2/day in Enugu state and 7.02 kWh/m^2/day in Ebonyi State, all in March. Hence, based on the analysis of the results, it may be concluded that, the optimum periods for harnessing solar energy in the study areas falls within March and April. However, these periods should be used to harness and conserve solar power for maximum output. The information provided in this study can be used to diversify the energy supply mix in Nigeria in a bid to address the power problem in the country.

Keywords: *Solar radiation, Geospatial technique, Insolation, Ground measured solar radiation.*

1.1 INTRODUCTION

Radiation within the Earth's atmosphere consists of the solar and the terrestrial radiations. While terrestrial radiation is infrared-based and belongs to the long-wave radiations, solar radiation is based on the visible and near-infrared with a small portion in the near-ultraviolet. It is a shortwave radiation. The visible spectrum of radiation energy in solar radiation accounts for 44% of the total energy, ultraviolet accounts for 8% and infrared region accounts for 48% (Liao, J. and Zhao, 2012).

Solar energy is the use of sun radiation as fuel, either directly or indirectly. Generating energy from the Sun can be done through a direct method using Photovoltaic (PV) technology which converts sunlight into electricity; or using indirect method referred to as Concentrating Solar Power (CSP) where the sunlight is used to generate heat which is used to drive a turbine which powers a generator that provides electricity.

Comprehensive knowledge of the behaviour of monthly mean daily values of global solar radiation reaching the Earth's surface, is required in the design and development of solar conversion devices (Rehman and Ghori, 2000), which are used in solar energy systems. Traditionally, solar radiation data is acquired through ground-based measurements in meteorological stations. However, very few of such stations are available to provide comprehensive solar radiation data of the desired locations in South-Eastern Nigeria. In Nigeria, researchers have assessed solar energy potentials in different parts of the country. However, attempt has not been made to use geospatial techniques to analyse ground measured solar radiation in the aforementioned areas of South-Eastern Nigeria; in spite of the capability of the methods in estimating solar radiation with high degree of reliability. Reliable assessment of the available solar radiation in the region is needed and will reveal the optimum periods for harnessing solar energy, which can be used to facilitate socioeconomic development and also revive industrialization in the region. Therefore, this study applied geospatial techniques to analyse solar energy potentials in three states; Anambra, Enugu and Ebonyi of South-Eastern Nigeria using ground-measured insolation data.

1.1a SOLAR GEOMETRY

The sun's position relative to the observer on the earth's surface is an important input required when modelling PV system performance. The position of the sun is described using the convention shown in figure 1.1, (Basha, 2012). In the figure, $\theta_Z$is the zenith angle of the sun, $\theta_{AZ}$is the surface azimuth angle, $\gamma_s$is the solar azimuth angle, $\alpha_s$is the solar elevation angle equal to 90° - $\theta_Z, \theta_T$is the surface tilt angle and $\theta_{AOI}$is the angle of incidence of the sun. In order to have a clear understanding of the angles in figure 1.1, we define the following parameters:

- The **solar azimuth angle (γ_s)** is the angle of the sun's position relative to the north-south axis.
- The **solar elevation angle (α_s)** is defined as the height of the sun that is the angle between the local horizon directly under the sun and the centre of the sun's disc. It is expressed using the declination angle (δ) and the local latitude ($\emptyset$) of the site as follows:

$$\alpha_s = 90^0 - \emptyset + \delta \qquad 1.1$$

- **Declination angle (*d*)** is defined as the angle between the sun and the equator (Masters, 2004). Its value varies between -23.45° to 23.45° in relation to the day of the year assigned (Basha, 2012). The declination angle is expressed as follows:

$$\delta = 23.45\sin\left(\frac{360}{365}(284 + \mathrm{NOD})\right) \qquad 1.2$$

where; *NOD* or number of days is the day of year starting from the 1st of January.

- **Local Solar Time (LST)** is defined as the exact time at the longitude where the observer is positioned and it is expressed as follows:

$$LST = time_h + EQT + \frac{lon_{act} - lon_{ref}}{15} \qquad 1.3$$

where,
lon_{act} is the actual longitude,
lon_{ref} is the reference longitude, and
EQT is the **equation of time** which is defined as the difference between the true and mean solar times and it is expressed as follows (Basha, 2012):

$$EQT = \left[0.123cos\left(\frac{360}{365}(88 + NOD)\right) - 0.167sin\left(\frac{720}{365}(10 + NOD)\right)\right], \qquad 1.4$$

and

$$time_h = hour + \frac{minutes}{60} + \frac{seconds}{3600}. \qquad 1.5$$

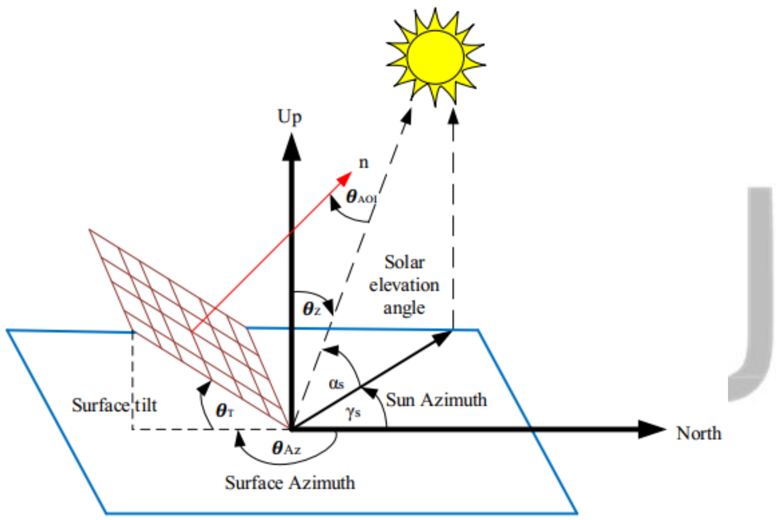

Fig. 1.1: Solar position (Basha, 2012).

1.1b GEO-STATISTICAL APPROACH TO SOLAR RADIATION MODELLING

The use of geo-statistics to study the spatial variation of global solar radiation on a horizontal surface has an advantage over other methods of solar radiation data analysis and modelling. This is due to the fact that solar radiation itself is location dependent, making it compliant to the geo statistical method (Rehman and Ghori, 2000). The section that follows review of some geo-statistical techniques applied to solar radiation modelling.

Geo-statistics is a class of statistical techniques developed to analyse and predict values of a geographical phenomenon. Geo-statistics is a subset of statistics specialized in analysis and interpretation of geo-referenced data (Goovaerts, 1997) with a focus on inherently continuous fields (Hengl, 2009). The term geo-statistics is generally applied to a set of data, which is characterized by spatial continuity using statistics. A data set may appear chaotic to the eye but may possess strong spatial correlation (Rehman and Ghori, 2000).

It begins with a type of autocorrelation analysis called semi-variance variogram which is a useful tool for estimating the spatial behaviour of a property distribution such as ore grades and solar radiation (Rehman and Ghori, 2000).

1.1c. STUDY AREA

The study area comprises of the three states namely; Anambra, Enugu, and Ebonyi in South-Eastern Nigeria. The area is located between the latitudes of 04°17’ N and 07°06’N and longitudes of 05°23’ E and 09°28’ E as shown in Figure1.2.

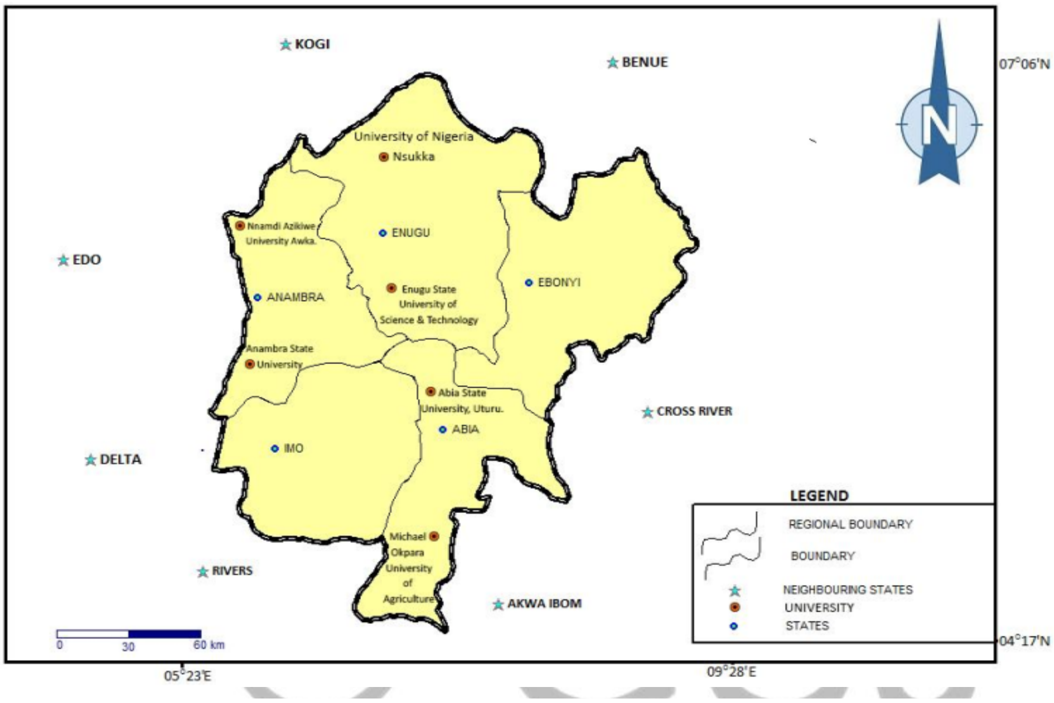

Fig. 1.2: The study area in South Eastern Nigeria (Administrative Map of South Eastern States), (Google satellite map)

1.2 RESULTS AND DISCUSSION

The ground-measured solar radiation data used for this study were obtained from the Nigerian Meteorological Agency (NIMET), www.nimet.gov.ng. This is because NIMET stations used the same calibrations for all the stations. NIMET has several weather stations located mostly at airports across Nigeria. The solar radiation values are generally expressed in kWh/m^2/day, which is the amount of solar energy that strikes a square metre of the Earth's surface in a single day. This study used geospatial techniques to analyse solar energy data in the study areas. Time – series graph was used in order to show variations of the ground-measured solar radiation data in the three states of study. OriginPro_2018_v9.5.1 was used as a programming tool, to analyse the data.

1.2a INSOLATION GRAPHS BASED ON GROUND MEASUREMENTS

The monthly mean daily values of solar radiation obtained from ground measurement in the whole study area for each year (2013 - 2017) were shown on figures 1.3a to 1.3e.

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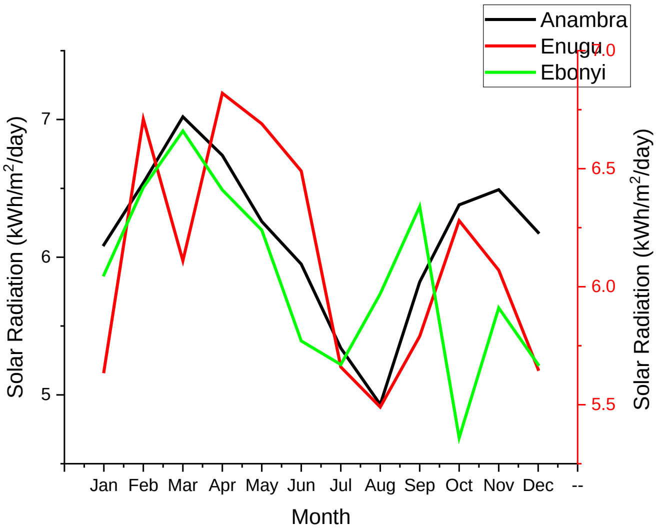

Fig. 1.3a: Monthly variation of ground – measured solar radiation for the year 2013

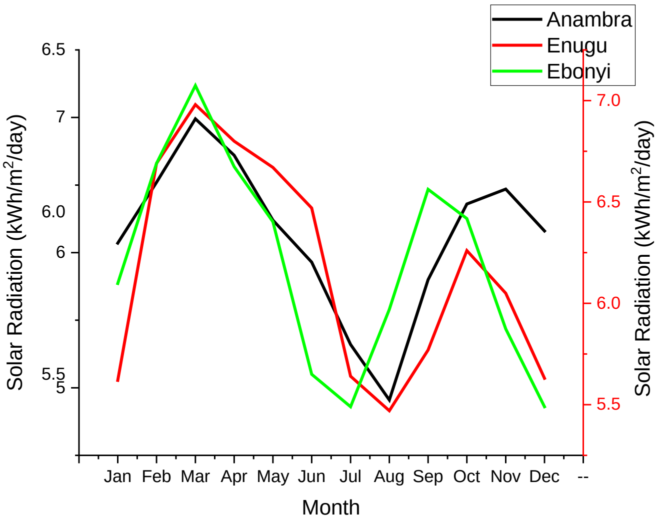

Fig. 1.3b: Monthly variation of ground – measured solar radiation for the year 2014

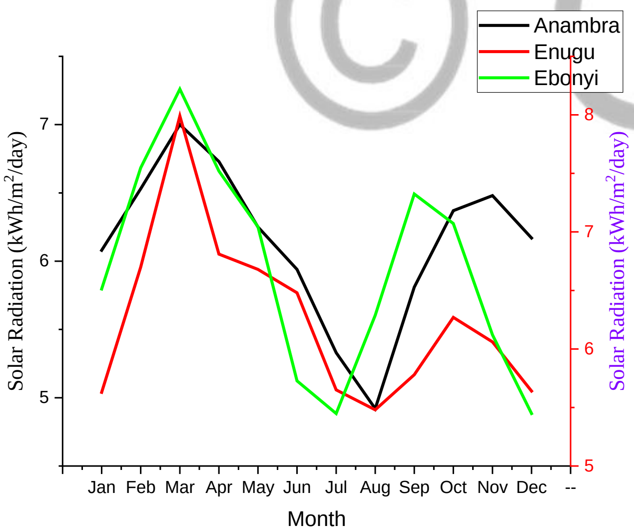

Fig. 1.3c: Monthly variation of ground – measured solar radiation for the year 2015

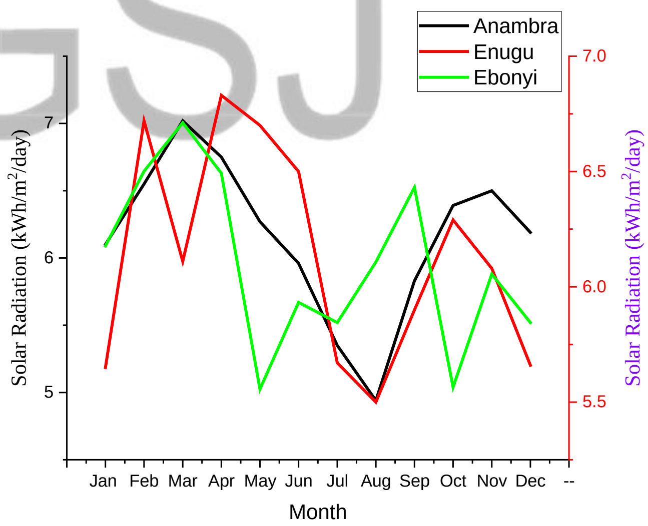

Fig. 1.3d: Monthly variation of ground – measured solar radiation for the year 2016

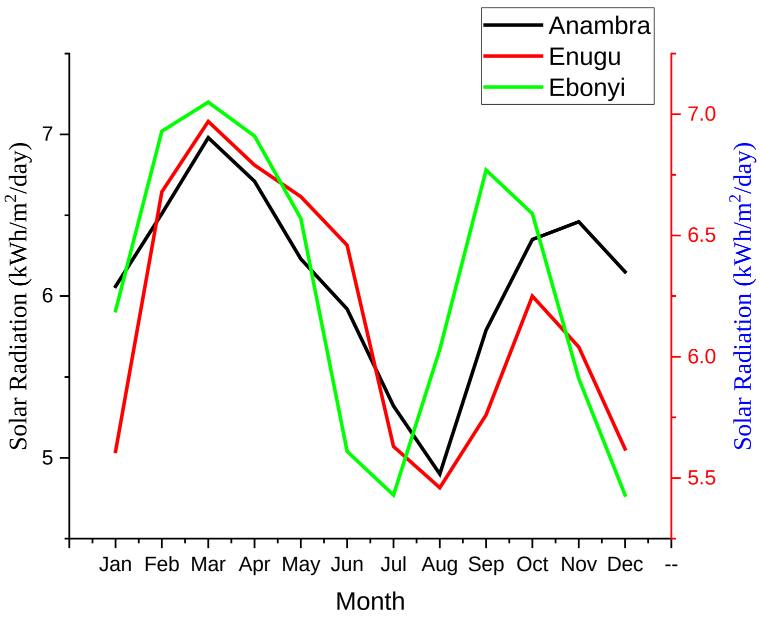

Fig. 1.3e: Monthly variation of ground – measured solar radiation for the year 2017

Figure 1.3a, is the monthly variation of ground – measured solar radiation for the year 2013. It was observed that maximum monthly average solar radiation value of 7.00 $kWh/m^2/day$ was recorded in Anambra state in the month of March, 6.71$kWh/m^2/day$ in Enugu in April and 6.40$kWh/m^2/day$ in Ebonyi state in March. In Anambra state, the lowest solar radiation value of 4.93 $kWh/m^2/day$ was observed in the month of August.

Figure 1.3b is the monthly variation of ground – measured solar radiation for the year 2014. Peak solar radiation of 6.66 $kWh/m^2/day$ was observed in Anambra state in the month of March, 6.98$kWh/m^2/day$ in Enugu and 6.39$kWh/m^2/day$ in Ebonyi state. In Anambra, least measured solar radiation was 4.91 $kWh/m^2/day$ in the month of August. These observations were similar to that of 2013.

Figure 1.3c, is the monthly variation of ground – measured solar radiation for the year 2015. Maximum radiation value of 7.00 $kWh/m^2/day$ was observed in Anambra State, 6.99$kWh/m^2/day$ in Enugu state and 6.40$kWh/m^2/day$ in Ebonyi state; all in the month of March. 4.94 $kWh/m^2/day$ was the least radiation value observed in the month of August in Anambra State.

In figure 1.3d, the monthly variation of ground – measured solar radiation for the year 2016, showed the maximum value of 7.01 $kWh/m^2/day$ and 7.00 $kWh/m^2/day$ in Anambra and Ebonyi respectively in the month of March. Enugu State had the maximum value of 6.83 $kWh/m^2/day$ in the month of April. 4.94$kWh/m^2/day$ was the least radiation observed in the month of August in Anambra State.

Figure 1.3e is the variation of ground – measured solar radiation for the year 2017. Maximum radiation of 6.98 $kWh/m^2/day$ was recorded in Anambra, 7.00 $kWh/m^2/day$ in Enugu state and 7.02 $kWh/m^2/day$ in Ebonyi State, all in March. 4.90 $kWh/m^2/day$ was the least value of radiation observed in the month of August in Anambra State.

CONCLUSION

It was observed from the analysis that maximum monthly average solar radiation value of approximately 7.00 $kWh/m^2/day$ was recorded in Anambra state between the months of March and April and it varied between 6.39$kWh/m^2/day$-6.99$kWh/m^2/day$ in other states. This can be attributed to the fact that the months of March, April and May fall within the period of longer days and shorter nights experienced in the Southern hemisphere. A longer day implies longer sunshine hours per day. Under normal conditions, the longer the period of sunshine and shorter the night, the greater the amount of solar radiation received in an area (Rajan, 2017).

Results also showed that based on the ground measurements of solar radiation all over the study area as presented in figure 3.1a to 3.1e, a minimum monthly mean solar radiation value of 4.92 $kWh/m^2/day$ was recorded in Anambra state in the month of August. The lowest solar radiation values were observed in the months of July and August in all the three states, as well as December and January in Enugu and Ebonyi states. This is due to the rainy season which is characterized by clouds in the area, which have high capacity to intercept the incident solar radiation received in the area. A similar conclusion was reached by Ojosu (1990) who observed that in Nigeria, the rainy season also records low levels of solar radiation especially in the months of July and August.

Finally, the study showed that the optimum period for harnessing solar energy in the study areas were in the months of March and April, since the highest insolation was recorded within these months.

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