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Diurnal and Seasonal Variation of Global Solar Radiation at Anyigba, North-Central Nigeria

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Abstract: ***The seasonal and diurnal variations of solar radiation have been studied by analyzing two years data measured at the ground surface in a tropical wet and dry climatic region and the guinea savanna station Anyigba (7.486N, 7.1836E), in Nigeria using Campbell automatic weather station. The analysis was carried out over two years with each year divided into four seasons (vernal equinox (March), summer solstice (June), autumn equinox (September) and winter solstice (December)). Results obtained shows diurnal variation of solar radiation of varying degree and pattern over the four seasons. The results showed that the surface temperature is not a direct measurement of sun temperature on earth but rather a measure of the atmospheric response to solar radiation. The comparison of solar radiation measured during the two seasons that coincided with rainy period in the study area shows that the measured solar radiation tends to be lower during this period for the year 2012 than 2011. This observation was attributed to higher rainfall in 2012.***

Keywords: **Solar radiation, seasonal variation, diurnal variation, temperature**

I. INTRODUCTION

Solar radiation is the radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy and travels through space to the earth surface in short-wave length. Global solar radiation is the algebraic sum of diffuse solar radiation (due to atmospheric scattering) and direct solar radiation. Solar radiation is the major driver for many physical, chemical and biological processes on the earth's surface [1], [2]. Thus, a complete and accurate solar radiation data at a particular location or region are very pertinent to developmental needs of any nation. It is required for many research and application fields such as meteorology, engineering, ecology, agrology, environmental, architectural and climate studies [3]. Although, other natural energy sources such as, cosmic radiation, the natural terrestrial radioactivity and the geothermal heat flux from the interior to the surface of the Earth etc. exist, these sources are energetically negligible as compared to solar radiation.

The need for the knowledge of both temporal and spatial distribution of solar radiation cannot be overemphasized. The use of solar energy over other alternative energy sources is gaining popularity in different parts of the world. To utilize and harness this energy, a proper knowledge of its behavior has to be known. Solar energy is available at any part of the globe, but the amount made available differs with respect to geographical locations, time and season. The solar energy available at any particular geographical location is a measure of the solar irradiance falling on that location. Solar irradiance is the solar radiation intensity falling on a surface and is measured in N/m^2 or KW/m^2. Solar radiation falling on the earth changes by about 7% between January 1st, when the earth is nearest the sun and July 3rd, when the earth is furthest from the sun. A yearly average value is thus taken and the solar constant equals $1367W/m^2/s$. Though this value is a good estimate, it is however, inaccurate since the output of the sun changes by about 0.25% due to sunspot cycles [4]. Out of the total radiation entering the earth's atmosphere, about 13% is absorbed by the atmosphere and 13% scattered [5]. This implies that the direct radiation available at the earth's surface close to the tropics in the middle of a cloudless day is about 75% of the level of the radiation at the surface of the atmosphere which is about $1{,}000W/ m^2/s$. This assertion is true if the earth is assumed to be a stationary body. From basic knowledge of physics, it is known that we can receive up to 1,367W/m2/s for a part of each day because the earth rotates.

Various studies have been carried out to evaluate the amount of solar radiation at various parts of Nigeria as reported in [6]. Most of these studies were carried out using various modeling methods to estimate the amount of solar radiation using other meteorological data. This is done due to dearth of data on solar radiation across the country. Chiemeka [7] tried to estimate the solar radiation at Uturu Abia state Nigeria, latitude 5.33˚N and 6.33˚N. the study obtained temperature data from 5th – 31st October 2007 using the maximum and minimum thermometer placed in Stevenson screen at 1.5m after which the Hargreaves equation was employed to obtain the estimate. The mean global solar radiation obtained for the period is 1.89 to 0.82 kWh per day. This poor value was attributed to the fact that Uturu is bounded on the west and south by a hilly escarpment. A model was developed as reported by [8] for prediction of solar energy in Nigeria using an artificial neural network model. Meteorological data of 195 cities in Nigeria for a period of 10 years (1983-1993) from the National Aeronautics and space administration (NASA) geo-satellite data base were used for training and testing the network. Data such as latitude, longitude, altitude, monthly sunshine duration, mean temperature, and relative humidity were used as inputs to the network while the solar radiation intensity was obtained as the output of the network. The result showed that the monthly mean solar radiation potential in northern and southern regions ranged from 7.01-5.62 and 5.43 – 3.54 kWh/m2 respectively. An empirical model as in [9] proposed for estimating global solar radiation on horizontal surfaces for Abuja, Benin, Kastina, Lagos, Nsukka and Yola cities in Nigeria. From the study, these cities experienced a decrease in the horizontal global solar radiation from March through August (during rainy season) with Benin City having the lowest monthly mean daily horizontal global solar radiation of 3.46 kWh/m^2/day in July. It was also reported that the variation of daily horizontal global solar radiation with month of the year in Kastina differs from other cities because Kastina is located at longitude 7.6˚E, and latitude 13.0˚N. Falayi [10] developed a number of multilinear regression equation based on Angstrom equation to predict the relationship between global solar radiations with one or more combinations of some weather parameters for Iseyin Nigeria for five years. The result obtained showed that the equation with the highest value of correlation coefficient (r), least value of root mean square error (RMSE), mean bias error (MBE), and mean percentage error (MPE) was adopted for the estimation of different geographical locations in Nigeria. Other recent studies have employed direct measurement of solar radiation, It was found in [11] that daily mean of solar radiation to be about 146W/m^2/day in Iju Akure using a vantage pro II automatic weather station. Study by [12] shows that solar radiation peaked around noon over Akure. The result obtained also showed that the solar radiation peaked between the month of February and April when monthly average is considered. The study was carried out using Campbell automatic weather station. This study is carried out using data collected with Campbell automatic weather station located inside Kogi State University, Anyigba, Kogi State, North Central Nigeria.

II. SOURCES OF DATA AND INSTRUMENTATION

Data collection was done using Campbell automatic weather station situated at Kogi State University Campus, Anyigba (7.48583N, 7.18362E) in North-Central Nigeria. Two years data 2011 and 2012 of solar radiation and temperature data were collected from the meteorological station to investigate the variation of solar radiation over Anyigba. The meteorological station is part of a network of automatic weather stations across Nigeria. Campbell automatic weather station was employed for the study (Fig. 1).

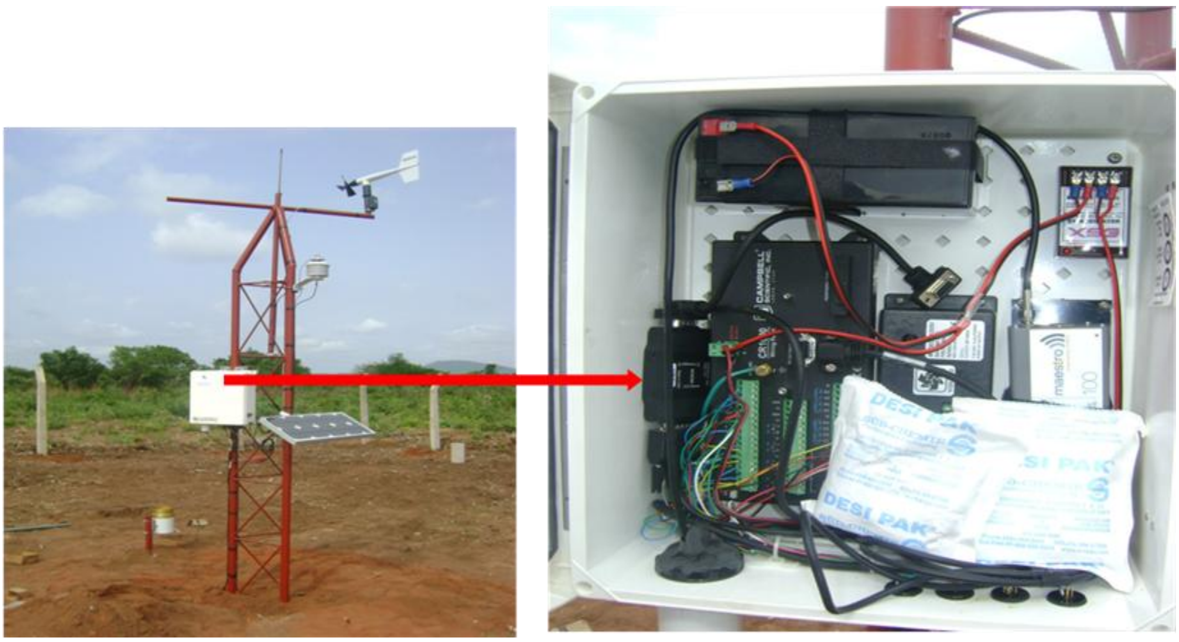

Fig 1: Typical Installed Campbell Scientific Automatic Weather Station and Enclose Box interior

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III. METHODOLOGY

In-situ measurement of meteorological parameters of solar radiation and air temperature are employed. The data was collected from (January 2011- December 2012). The records cover 24hours each day from 00 hours to 2300 hours local time at five minutes update cycle. The values of solar radiation are in W/m^2 and air temperature is in degree Celsius.

The data were obtained from the source described above and is at twenty-four hours interval local time, it is then processed into monthly average for every month of the years considered using MATLAB software R2010a. This is achieved by first, averaging the five minutes interval data into hourly values then into daily values and lastly into monthly values for each of year considered.

For the purpose of data analysis, the year is divided into four seasons, vernal equinox (March), summer solstice (June), autumn equinox (September) and winter solstice (December) to take care of sun tilting about its axis round the sun rather than the customary rainy and dry season obtainable in Nigeria.

IV. RESULTS AND DISCUSSION

Fig. 2 depicts the diurnal variation of solar radiation over the study area during the vernal equinox (March). It shows almost zero solar radiation during the night hours which gradually rise from dawn to peak around noon for the two years under consideration. The solar radiation for the year 2011 peaked at exactly noon while that of 2012 peaked around 13:00hr. The value of solar radiation for 2012 also appears to be generally slightly higher than that of 2011 for this season. The peak values for this season for the two years under consideration is slightly lower than $700W/m^2$. The slightly higher value of solar radiation observed for this period in 2012 is likely due to the fact that it coincide with first peak (66.9) of the current solar cycle which occur in February 2012.

Fig. 3 shows the diurnal variation of surface temperature for vernal equinox for 2011 and 2012. The temperature for both years shows a post noon peak which lag behind the solar radiation peak for both years. This shows that it takes a while for the atmosphere to react to heating from the sun. The temperature for 2012 is also slightly higher than 2011. This can be attributed to the solar radiation.

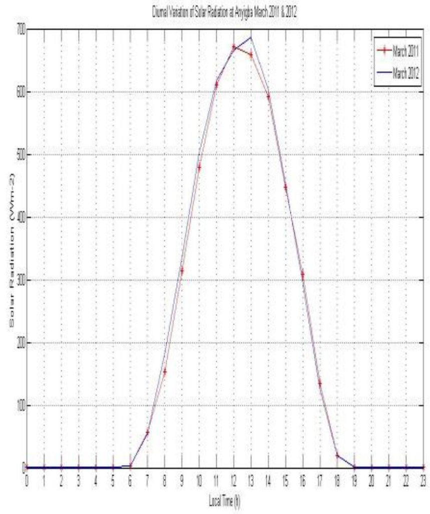

Fig. 2: Diurnal Variation of Solar Radiation for March 2011 and 2012

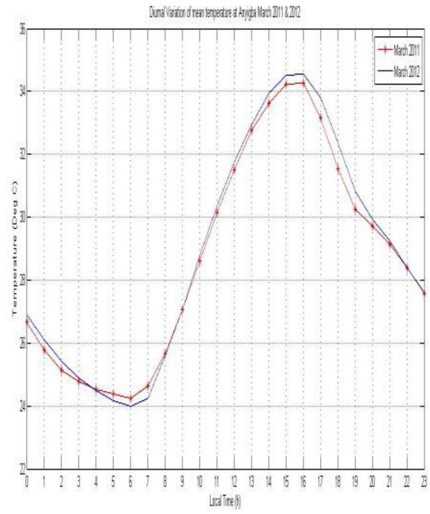

Fig. 3: Diurnal Variation of Surface Temperature for March 2011 and 2012

The diurnal variation of solar radiation for summer solstice (June) is shown in Fig. 4. Just as was observed for vernal equinox, the amount of solar radiation for 20011 also lag behind that of 2012 in summer solstice. However, the 2011 solar radiation peaked earlier than that 2012 during this period. The peak value of solar radiation for this season also lies between $500W/m^2$ and $600W/m^2$ which is lower than the observation for vernal equinox. This drop in solar radiation can be attributed to the tilting of the earth about its axis relative to the sun during this period. The period of solar irradiation in this season is slightly longer than that of vernal equinox (05:00hr – 19: 00hr).

The temperature variation during this season as shown in Fig. 5 also have post noon peak. It was however observed that despite higher solar radiation in 2012, the temperature in 2011 is higher. This variation in temperature cannot be explained using solar radiation pattern. The temperature difference between the two years is therefore assumed to be as a result of higher rainfall in 2012. This will be further considered in subsequent studies.

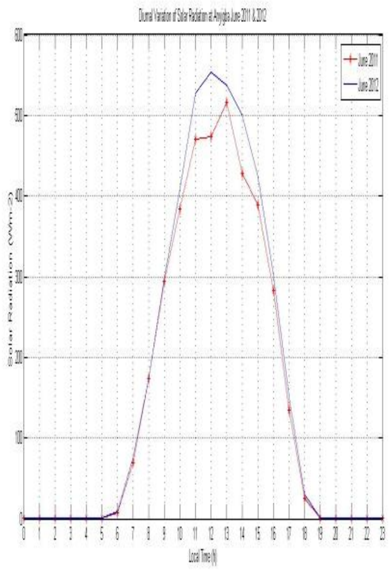

Fig. 4: Diurnal Variation of Solar Radiation for June 2011 and 2012

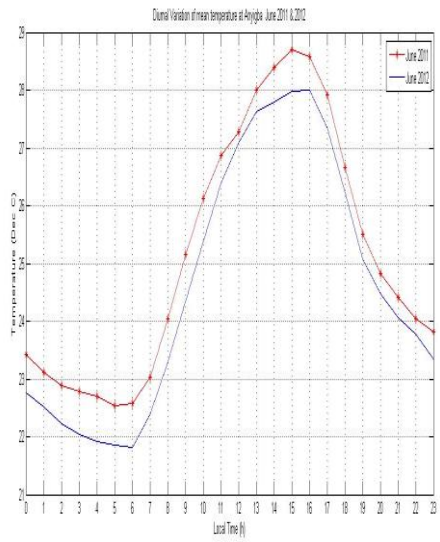

Fig. 5: Diurnal Variation of Surface Temperature for June 2011 and 2012

The solar activity in 2012 gradually dropped from the peak observed in February [13] and by September, it was lower than what was observed in 2011. The decrease in solar activity coupled with higher rainfall which increased the atmospheric absorption of solar radiation accounted for the solar radiation for 2012 to be lower than the solar radiation for 2011 for autumn equinox as shown in Fig. 6. The peak value also dropped to between 400W/m2 and 500W/m2. The solar radiation for 2012 peaked at exactly noon while that of 2012 peaked at 13:00hr. The solar irradiation period for this season is exactly 12hrs like vernal equinox but slightly shorter than that of summer solstice.

The temperature variation for this season also follows the same pattern with the previous seasons (Fig. 7). The temperature for the year 2012 is lower than that of 2011. This can be attributed to lower solar activity and higher rainfall.

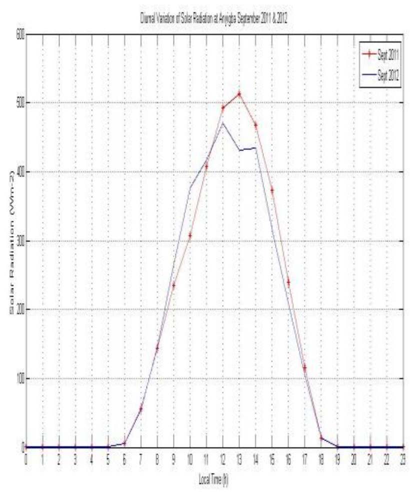

Fig. 6: Diurnal Variation of Solar Radiation for September 2011 and 2012

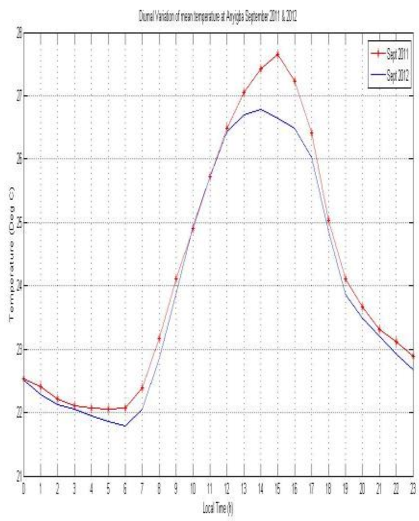

Fig. 7: Diurnal Variation of Surface Temperature for September 2011 and 2012

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The solar radiation for winter solstice shows a distinct pattern of variation that is different for the three previous seasons. A drop in solar radiation at noon observed in this season (Fig. 8) is only peculiar to the season. This observation is attributed to the inclination of the sun to the earth during this period. The solar radiation peaked at 13:00hr for both years under consideration. The peak value of solar radiation for both years is between 600W/m^2 and 700W/m^2. This is because the solar activity towards the end of 2011 increased towards the peak that was observed in February 2012 and also increased towards the end of 2012 for the second peak that occur around August 2013 [13]. The solar radiation for 2011 is higher than that of 2012 because there was higher rainfall in 2012 around this period than was observed for 2011. The period of solar irradiation during this season is shorter than the three previous seasons (06:00hr – 18:00hr).

The drop in solar radiation observed during this season was not observed on the temperature signature. This shows that the surface temperature is not as a result of direct heating from sun but as a result of heat retained in the atmosphere (Fig. 9).

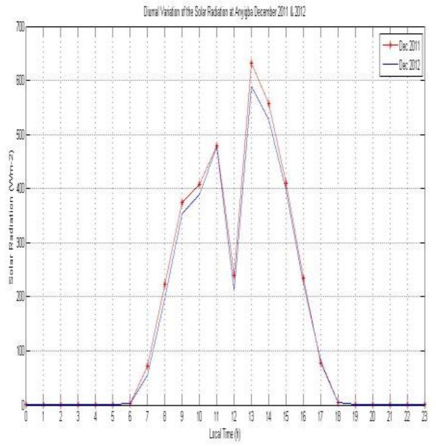

Fig. 8: Diurnal Variation of Solar Radiation for December 2011 and 2012

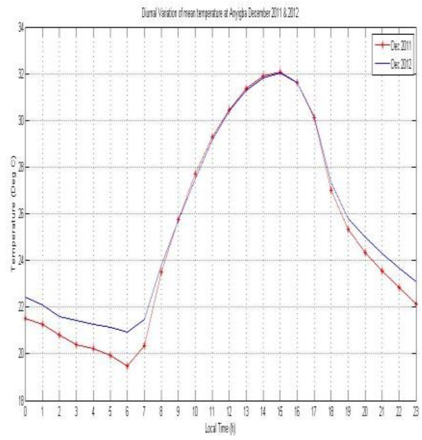

Fig. 9: Diurnal Variation of Surface Temperature for December 2011 and 2012

V. CONCLUSION

The seasonal and diurnal variation of global solar radiation over Anyigba is presented in this work. The results shows that solar global radiation have different pattern of diurnal variation form one season to the other. The result also show that the amount of solar activity and the local meteorological condition plays a significant role in the amount of solar radiation received at any given time and location. The surface temperature was shown to be a function of solar radiation heating of the atmosphere rather than a direct measurement of the solar temperature at the earth surface. The solar radiation value increases from zero in the early morning to a maximum at about 13:00hr LT in the afternoon, while the value decrease steadily to a minimum and a fairly constant value throughout the evening.

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