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Global solar radiation measurement in AbakalikiEbonyi State Nigeria using locally made pyranometer

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Abstract

This research work focused on the variability of global solar radiation over the area of Abakaliki,Ebonyi State (6°20'N, 8°06'E) located in South Eastern part of Nigeria for the rainy and dry seasons. The Pyranometer used for this measurement was locally developed and calibrated against a standard pyranometer, it competed favorably with the standard Einstrain Lungs Sensor. The global solar radiation was measured every five minutes from 08:00hours to 18:00hours during the dry season 2011 and rainy season in 2012. The measurements were carried out near the New Physics Laboratory Complex Ebonyi State University Abakaliki, Nigeria. Maximum Irradiances of 1095.10Wm^{-2} and 689.48Wm^{-2} recorded in Abakaliki during dry and rainy seasons respectively occurred between 12:00 – 14:00hours local time, whereas the minimum values of 9.20Wm^{-2} and 9.86Wm^{-2} respectively are recorded during the sunrise and sunset. Partly cloudy conditions in Abakaliki cause conspicuous oscillations in global solar radiation. This can be attributed to multiple reflections by nearby cloudy layers.The seasonal difference in the observed global solar radiation is 405.62Wm^{-2}. Therefore solar energy devices can operate continuously in Abakaliki for up to 10 hours in a solar day from 8:00hours to 18:00hours which was the period covered during this investigation.

Key words:

Solar Energy, Pyranometer, Measurement, Solar Radiation, Irradiance

1.1 Introduction

One of the greatest challenges we have in the present millennium is the development of renewable sources of energy, which can supplement the dwindling fossil fuels. Solar energy which can be used in one form or the other is definitely the most promising among all other renewable energy sources. This is true because, every hour the earth receives more energy from the sun than is consumed by mankind in a year, (Patz et al., 1983). The energy transferred from the Sun in the form of radiant energy to the earth's surface is called solar radiation. Solar radiation is used in Agriculture for crop drying, electricity generation, house heating, and water purification among others (UNIDO, 2003). It is this energy that allows life to flourish. The beauty of solar energy is that it is free, abundant, inexhaustible and non-pollutant. Solar energy warms our planet and gives us our everyday wind and weather. Without the sun's radiant energy, the earth will gradually cool and become encased in a layer of ice.

Measurement of solar radiation per unit of surface (Wm^{-2}) is called irradiance. Pyranometer is an instrument used for measuring solar radiation on a horizontal surface. Pyranometers are widely used in meteorology, climatology, agriculture, solar energy studies among others, (Rai, 2006). The tropical Nigeria has made solar energy availability unequal and the average is 3.7 KWhm^{-2}day^{-1} along the coastal areas to about 7.0KWhm^{-2}day^{-1} along the semi-arid areas of the North. The Country however, on the average receives solar radiation level of about

$5.3 KWhm^{-2}day^{-1}$, (Nwankwo et al., 2012). Most researchers within the country use these available theoretical values of meteorological data to compute average irradiance of solar radiation for different location within Nigeria, they lack standard measured data obtained from reliable measuring instrument suitable for their local environment and therefore resorted to theoretical prediction using different models for global daily sunshine radiation. There are several examples of such models in the Nigeria environment,(Fagbenle 1983; Doyle and Sambo 1985; Burari and Sambo 2001; Onah and Osuji 2007; Ejeh and Itodo 2010; Augustine and Nnabuchi 2009; Agbo and Ezema 2009; and Taiwo 2010). The need for the collection of authentic irradiance data for comparative evaluation with the theoretical predicted results given by previous researchers becomes a necessity. This major reason among many others prompted the emergence of this research.

1.2 Solar Radiation and Solar Measuring Instrument

Solar radiation is the energy emitted by the Sun. Solar radiation is partly absorbed, scattered and reflected by molecules, aerosols, water vapor and clouds as it passes through the atmosphere, (Rai, 2006). Measurement of solar radiation at some locations has been found to be essential in order to really assess the availability of solar energy arriving on the earth. The sun is the chief source of solar energy and nearly all known elements are present in the sun however, the main constituents are hydrogen and helium. These elements constitute about 80% and 19% respectively. The sun has a mass of 1.9889×10^{30}kg and radius of 6.960×10^{8}m. It is at a mean distance of 150 million km from the earth with a volume and density of $1.412 \times 10^{18} km^3$ and $1.622 \times 10^{5} kgm^{-3}$ respectively. Its core temperature is about 2×10^{7}k while the outermost layer has an equivalent black body temperature of 5760k. The electromagnetic energy radiated by the sun is derived from the two types of nuclear fusion reaction that occur in the sun, which is proton-proton chain and carbon-Nitrogen cycle, (Fraser, 2012).

Instruments for measuring solar radiation are generally called Solarimeters. A simple whole sky Solarimeter which measures global solar radiation is known as Pyranometers. A Solarimeter that measures beam or direct solar radiation is called Pyrheliometer. The one that measures the intensity of solar radiation is called Vane-type radiometer. The sun photometer is used for measuring atmospheric turbidity. Turbidity is the scattering of solar radiation by matter other than dry air molecules. The instrument which is used for determination of the coefficient of atmospheric turbidity is known as Volz Sun, (Igbal, 1983).

2.1 Materials and Method

This study describes the measurement of global solar radiation in Abakaliki, Nigeria with a local solar Pyranometer. Abakaliki is a mainland in South Eastern part of Nigeria which lies within latitude 6°20'N and longitude 8°06'E of the Equator and Prime meridian respectively, (Collins, 2012). The Pyranometerused in this research was constructed using a silicon photodiode which was chosen for its local availability and high sensitivity. Following the development of the local instrument, it was calibrated at the National Centre for Energy Research and Development, Nsukka Nigeria using the Kipp and Zonen calibration equation, (Kipp and Zonen, 2004).

$$C_x = \frac{X+X'}{Y+Y'} \, x \, C_y \qquad 1$$

The silicon photodiode used is a solid-state device that converts light energy (photons) to electric current, (Agbo and Nweke (2007) and Nweke, 2008). When radiation at a specific energy level that is capable of ionizing the atoms is incident on the P-N junction photodiode, an electrical current arises from the continuous movement of excess electrons and holes. According to Brooks in 2012, this electric current produced by the photodiode is directly proportional to the amount of global solar radiation reaching its surface, (Brooks, 2012). The developed pyranometer generates an electrical signal proportional to the irradiance received, (Abdulazeez et al., 2010).

Following the correlation of the output irradiances from both Pyranometers using SPSS software, the newly developed instrument was then used to measure solar irradiance at Abakaliki. The measurement was carried out during dry season in 2011 and rainy season in 2012. The measurement was taken near the New Physics Laboratory Complex, Ebonyi State University, Abakaliki from 06:00hours to 18:00hours local time in every five minutes interval. The reading obtained in millivolt (mv) were converted to Wm^{-2} with a conversion factor of 1mv = 15.3374Wm^{-2} as obtained during its calibration with reference to a Standard Einstrian – Lungs Pyranometer.

3.0Results and Discussion

3.1Correlation of the Output Irradiance

The correlation of the output Irradiance of both instruments is shown in figure 1 where each dot represents the value of the measured global solar radiation. The position of the dot with respect to Y-axis gives the amount of irradiance measured by the Standard Pyranometer while the position of the dot with respect to X-axis indicates the amount of irradiance measured by the locally developed Pyranometer. From figure 1, the correlation between both Pyranometers is positive and strong with a correlation coefficient of 0.896 as can be observed in the regression equation of the estimated parameters shown in table 1. The significance difference between both Pyranometers was 0.000 indicating that the newly developed instrument competes favorably with the standard instrument. Thus any prediction based on the above will tend to be very good as the points in figure 1 are fairly close to the regression line.

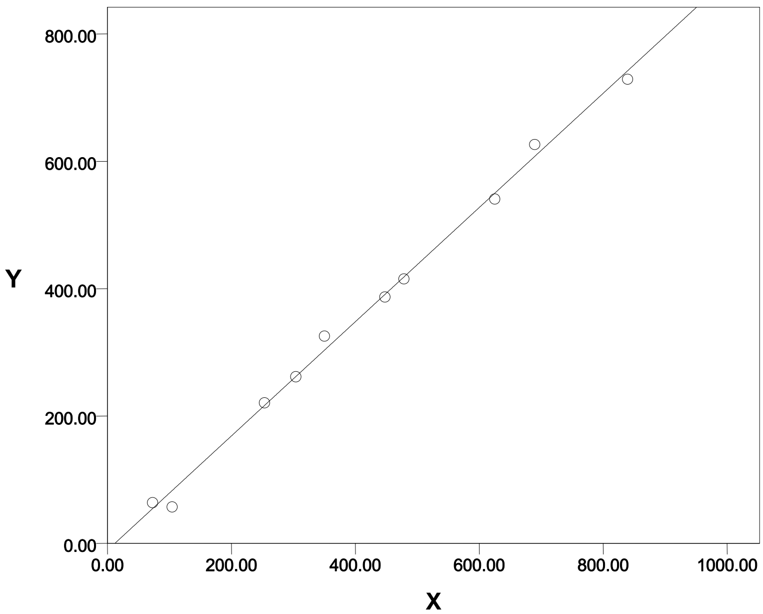

Figure 1: Correlations between Reference and Constructed Pyranometers using SPSS software.

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Table 1: SPSS Model Summary and Parameter Estimates

Y = dependent variable; X = independent variable
Regression equation: $Y = -10.872 + 0.897X, R^2 = 0.896$

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.896	1913.816	1	8	.000	-10.872	.897

Figure 2 shows the correlation between the developed Pyranometer and time.This shows a correlation coefficient of 0.892 as observed in table 2 indicating that the strength of the association is strong and positive and hence the measured output irradiance followed a global solar radiation pattern as all the points which did not match with the regression line are very close to it.

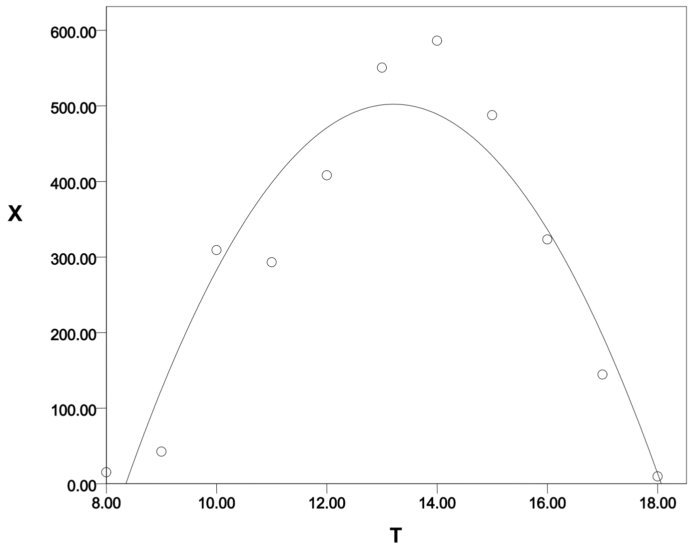

Figure 2: Correlations between developed Pyranometer and timeusing SPSS software.

Table 2: Model Summary and Parameter Estimates

X = dependent variable; T = independent variable
Regression equation: $X = -3216.967 + 563.041T - 21.309T^2$, $R^2 = 0.892$

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	Constant	b1	b2
Quadratic	.892	32.933	2	8	.000	-3216.967	563.041	-21.309

3.2 Irradiance Measurement

The irradiance variation over AbakalikiEbonyi State is mostly influenced by humidity and cloudiness conditions. In the dry season illustrated in figure 3, the reduction in cloudiness presented a very small variation specifically on sunny days with exception in week 4 where there was an intermitted sunshine.The variations in weeks 1, 2 and 3 are attributed to the Sun elevation. The maximum global solar radiation observed in Abakaliki during this dry season was 1095.10Wm^{-2} which is 80.17% of the solar constant (1366Wm^{-2}), whereas the minimum value of the irradiance measured was 9.20Wm^{-2} which occurred during the sunrise.

On the other hand, during the rainy season illustrated in figure 4 there are high variations of the measured global solar radiation in Abakaliki. The maximum irradiance measured during the rainy season was 689.48Wm^{-2} which is 50.47% and 62.96% of the solar constant (1366Wm^{-2}) and highest irradiance observed in dry season (1095.10Wm^{-2}) respectively. The minimum irradiance of 9.86Wm^{-2} was obtained during the rainy season. The seasonal difference in the observed global solar radiation was 405.62Wm^{-2}.

Conclusion

A locally developed Pyranometer can compete favorably with foreign standard Pyranometer when calibrated using Kipp and Zonen equation.The correlations between both instruments are strong and positive. Maximum Irradiances of 1095.10Wm^{-2} and 689.48Wm^{-2} recorded in Abakaliki during dry and rainy seasons respectively occurred between 12:00 – 14:00hours local time, whereas the minimum values of 9.20Wm^{-2} and 9.86Wm^{-2} respectively are recorded during the sunrise and sunset. Partly cloudy conditions in Abakaliki cause conspicuous oscillations in global solar radiation. This can be attributed to multiple reflections by nearby cloudy layers.The rising concern for the survival of our environment and way of life, effects of global warming, consequences of climate change and together with the desire for harnessing alternative sources of energy, makes it necessary to have available precise information on incoming radiation in Abakaliki,Ebonyi State and other parts of the Country.

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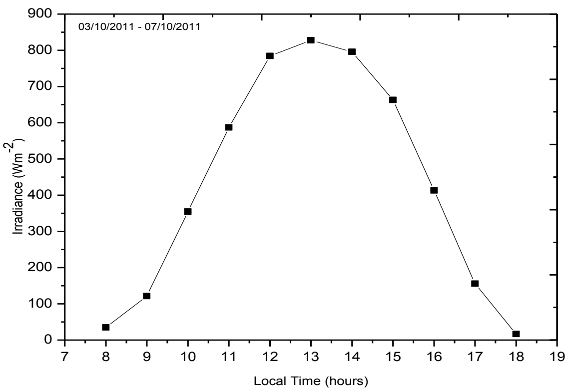
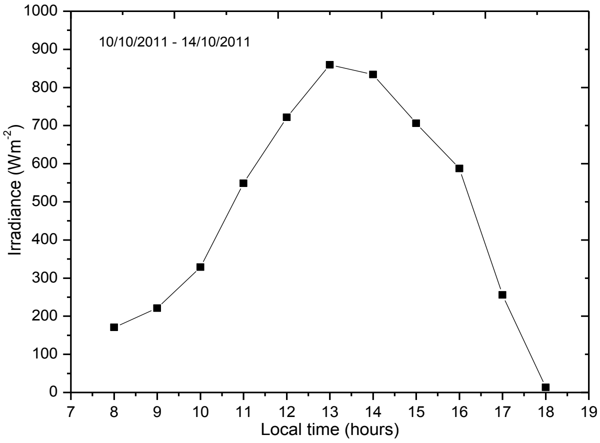




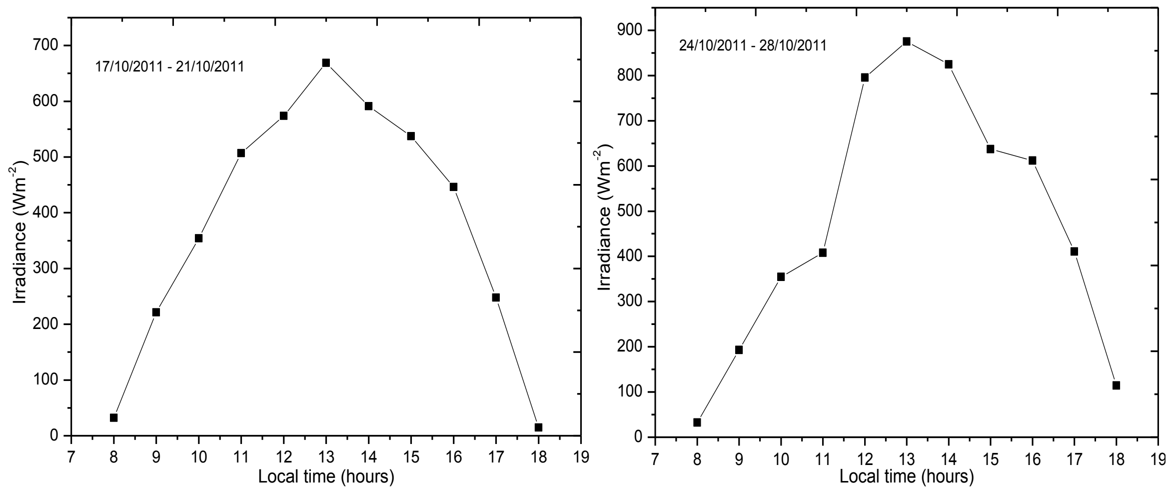
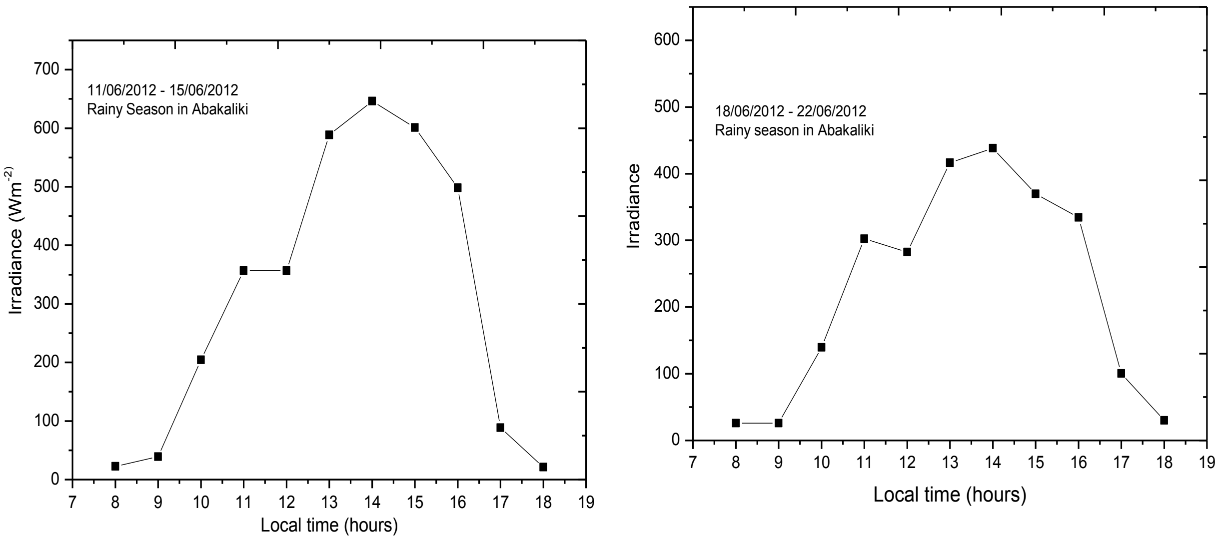


Figure 3: Average weekly Irradiance measured in Abakaliki,Ebonyi State Nigeria during dry season for the weeks 1, 2, 3 and 4 of October, 2011 as observed near the New Physics Laboratory Complex, Ebonyi State University, Abakaliki.



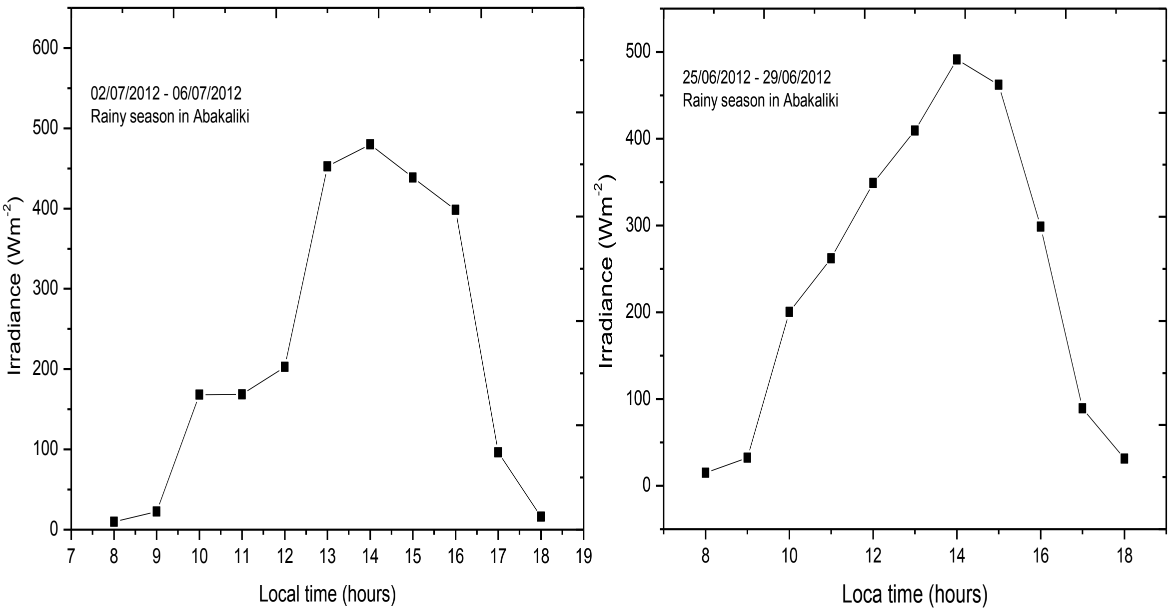


Figure 4: Average weekly Irradiance measured in Abakaliki,Ebonyi State Nigeria during the rainy season in 2012 as observed near NPLC.

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