IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 3 Ser. V (May - June 2020), PP 49-55
www.iosrjournals.org

Analysis of Solar Energy Resource Potential to Supplement Grid Power in Nigeria

Okoye, A.E., Ofong, I, Nwaji, G.N., and Anyanwu, E.E.
Department of Mechanical Engineering, Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria

Abstract: *Solar Energy resource potential was investigated in six locations in Nigeria using the Hargreaves and Samani model. The study carried out in Sokoto, Maiduguri, Markurdi, Ibadan, Awka and Portharcourt employed maximium and minimum temperature data spanning 10 years. The result of this analysis shows that the mean value of global irradiation at Sokoto, Maiduguri and Markurdi are 18.55±0.54 MJ/m*^{2}*-day, 19.83±0.60 MJ/m*^{2}*-day and 17.80±0.30 MJ/m*^{2}*-day, respectively over the ten years period, while Ibadan, Awka and Portharcourt recorded mean global irradiations of 16.68±0.36 MJ/m*^{2}*-day, 17.68±0.28 MJ/m*^{2}*-day and 17.46±0.19 MJ/m*^{2}*-day, respectively. Therefore, Nigeria has good solar radiation potential with Northern part of Nigeria having a marginal edge over the southern part.*

Keywords: *Solar Energy, Hargreaves and Samani Model, Energy Potential, Power Generation.*

Date of Submission: 30-06-2020 Date of Acceptance: 16-07-2020

I. Introduction

The ever increasing energy consumption, postulated depletion of fossil resources, energy security challenge and climate change concerns emanating from the exploitation and utilization of fossil resources are favouring increased global attention to renewable energy sources like solar, wind, geothermal, tidal, etc for supplemental electricity generation. Gas fired thermal stations have had a large share of primary energy consumption of countries around the globe, Nigeria inclusive. Insufficient gas supplies coupled with social agitations arising from host communities has resulted in gross intermittent power availability from such power outfits. National development, is therefore, threatened seriously due to meager supply of energy grossly inadequate to match the ever increasing energy requirement for growing population. Most of the times, it is either there is no power at all or there is epileptic supply arising from insufficient generation, transmission and distribution to the expanding population. Obviously, the energy needed for sustenance of virile economic activities is nonexistent (Ajayi and Ajanaku, 2009). One of the ways of addressing this challenge is energy diversification to include renewable energy sources which are largely unexplored and have great potential to expand the generation mix with significant cost savings and environmental benefits. Renewable energy has had increasingly significant share in global energy consumption data (EIA, 2011). Some large scale renewable energy projects have been implemented; however, many distributed projects favour remote developing areas with or limited access to the national grid. Legislations and incentives for renewable energy exploitations and deployment are currently receiving prime attention; mostly as there are serious questions as per the sustainability of the ecosystem should the overdependence on conventional fossil resources continue unchecked (UNEP, 2007).

Both the active and passive solar exploiting techniques are germane to ameliorating the power problem since they increase energy supply and reduce the need conventional sources, respectively. Solar technologies, therefore, is highly promising in addressing the energy security challenge, reduce overdependence on conventional fuels and hence reduce pollution and maintain sustainable ecosystem as well as greatly mitigate global warming and climate change through reduction in GHG emissions (IEA, 2011). The amount of solar energy that reaches the earth per hour is far greater than the estimated reserves of all the conventional energy sources (EIA, 2008). Solar heat could be employed for water heating, cooking, water desalination, pasteurization, chicken brooding, chicken and crop drying (Ilenikhena et al, 2008; Nwoke et al, 2008; Animalu and Adekola, 2002; Ileoje, 1997; Okeke, 2002; Oparaku, 2007). Solar power could also be directly harnessed with solar PVs or through indirect means by solar thermal technique employing concentrating solar collectors to harness the heat for driving conventional power plants such as steam turbines.

Despite that Nigeria is a tropical country with attendant high sunshine, there is need to investigate the solar radiation potential of the country because there are other factors which may affect the solar radiation of a region, such as cloud cover, topography and dust. This will aid policy makers, make informed decisions with regards to investments in solar energy technologies as well as development of sustainable energy programmes.

The design and deployment of technologies for harnessing solar energy much depends on the meteorological data of the location of interest. And so, there is need to ascertain the solar resource within a given location through precise and piecewise documentation and analysis of solar radiation under local climatic conditions (Ahmad, 2005). The irradiation at a particular climatic location is an important parameter in the determination of the feasibility or otherwise of the possible deployment of solar energy technology (Anyanwu and Oteh, 2003). Therefore, the focus of the current investigation is evaluation of solar energy potential for grid power improvement or standalone distributed mini power generation in six selected locations, representing the geographical spread of Nigeria.

II. Methodology

Air temperature data of six locations comprising Sokoto, Maiduguri, Markurdi, Awka, Ibadan and Portharcourt, Nigeria, spanning 2001 to 2010 were sourced from NIMET, Oshodi Lagos. Monthly mean temperatures were obtained for the period under study. Also, the temperature data was used to estimate the global irradiation, H and the extraterrestrial radiation, H_0 for the locations using Hargreaves and Samani model. The data for the six study locations were statistically analyzed to get mean monthly maximum and minimum temperatures for the 10 years duration.

2.1 Estimation of Global Irradiation

Irradiation is a measure of solar energy capture potential that determines the economic viability of deploying solar energy conversion systems or solar power plants at any location (Chineke, 2007). Recourse to empirical correlations derived from measured meteorological data becomes necessary in the event of unavailability of radiation data. In this study, Hargreaves and Samani (1982) correlation is used to estimate the global irradiation of the data from the six selected locations, using the commonly measured maximum and minimum temperature data. It is based on empirical relations and suitable for all locations.

The global irradiation is given by the expression (Hargreaves and Samani, 1982):

$$H = H_0 K (T_{max} - T_{min})^{1/2} \quad 1$$

Where K is an empirical coefficient which takes different values for coastal and interior regions, H_0 is extraterrestrial radiation (i.e. radiation above earth's atmosphere), and T_{max} and T_{min} are the mean daily maximum and minimum air temperatures in (^{0}C).

According to Duffie and Beckmann (2013), the extraterrestrial radiation, H_0 is given as:

$$H_0 = \frac{86400}{\pi} I_{sc} d_r \left(\frac{\pi}{180} \omega_s Sin\lambda Sin\delta + Cos\lambda Cos\delta Sin\omega_s \right) \quad 2$$

Where I_{sc} is the solar constant which takes the value, 1367W/m^2, λ is the location latitude, δ is the declination, ω_s is the hour angle at sunset and d_r is the earth's eccentricity correction factor.

d_r is a correction factor for the eccentricity of the earth that takes care of the variation of earth-sun distance and it is estimated from Eq. 3.

$$d_r = 1 + 0.033 Cos\left(\frac{360n}{365}\right) \quad 3$$

The term ω_s is the hour angle at sunset, given as (Kalogirou, 2009):

$$\omega_s = cos^{-1}(-tan\lambda tan\delta) \quad 4$$

δ is the solar declination angle, expressed as

$$\delta = 23.45 Sin \frac{360}{365}(284 + n) \quad 5$$

III. Results and Discussion

A summary of the radiation values for the study locations as well as for the entire Northern and Southern Nigeria is shown in table 1.

Table 1: Summary of mean radiation values for all six study locations

	Sokoto		Maiduguri		Markurdi		Ibadan		Awka		Portharcourt		Nothern Region		Southern Region	
	Ho	H	Ho	H	Ho	H	Ho	H	Ho	H	Ho	H	Ho	H	Ho	H
Mean	35.16	18.55	35.39	19.83	35.74	17.80	36.23	16.68	35.85	17.40	35.94	17.46	35.43	18.73	36.00	17.18
Max	38.30	22.46	38.26	24.45	37.67	19.80	38.53	19.10	37.55	18.84	37.59	18.52	38.30	24.45	38.53	19.10
Min	29.52	16.46	30.16	16.66	32.19	16.00	32.52	14.38	32.86	15.59	33.55	16.29	29.52	16.00	32.52	14.38
SD	3.1709	1.8864	2.8623	2.0816	1.8086	1.0503	1.6655	1.6655	1.5131	0.9811	1.2529	0.6454	2.6888	1.9231	1.4960	1.0531

The monthly variations of temperatures for the study locations in Northern Nigeria, comprising Sokoto, Maiduguri and Makurdi is presented in Fig.1, while Fig.2 depicts the monthly variations of temperatures for the study locations in Southern Nigeria, comprising of Ibadan, Awka and Portharcourt.

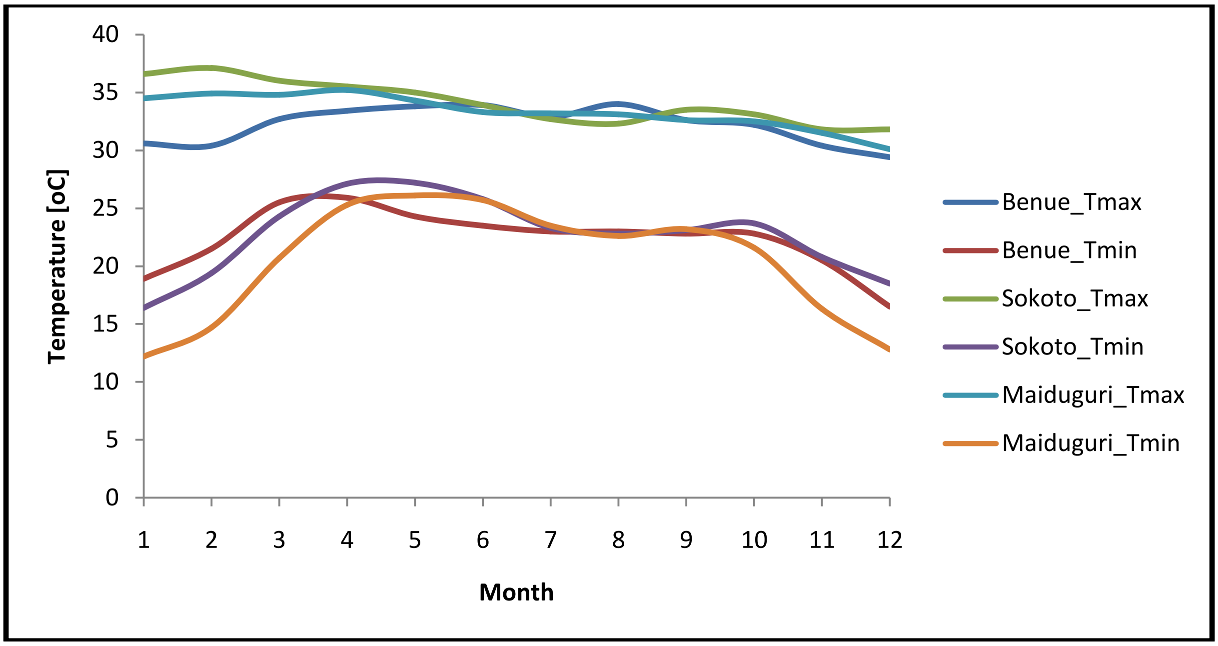

Fig. 1: Monthly variation of temperatures in Markurdi, Sokoto, and Maiduguri

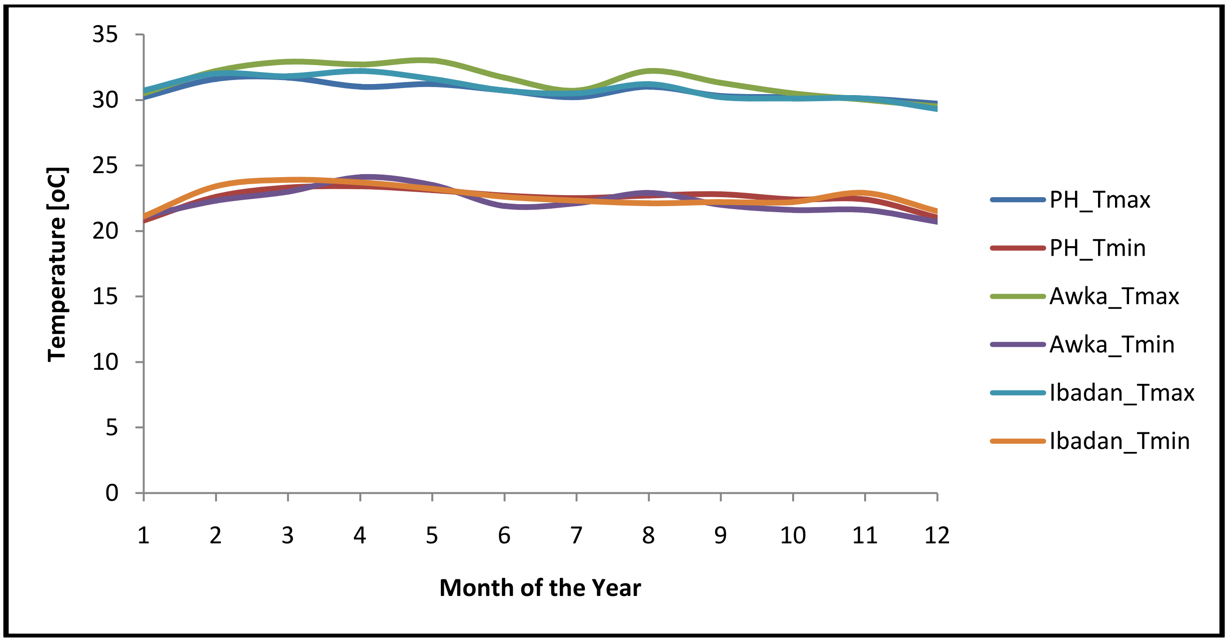

Fig. 2: Monthly variation of temperatures in PH, Awka and Ibadan.

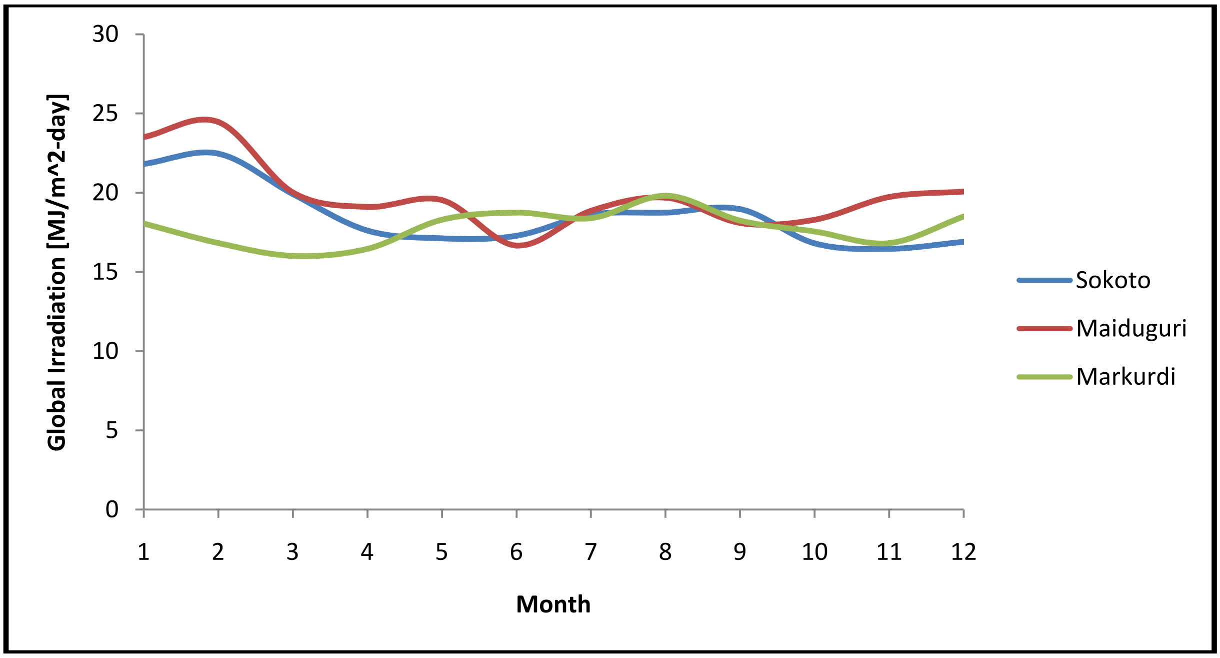

Fig. 3: Monthly variation of global irradiation in Sokoto, Maiduguri and Markurdi.

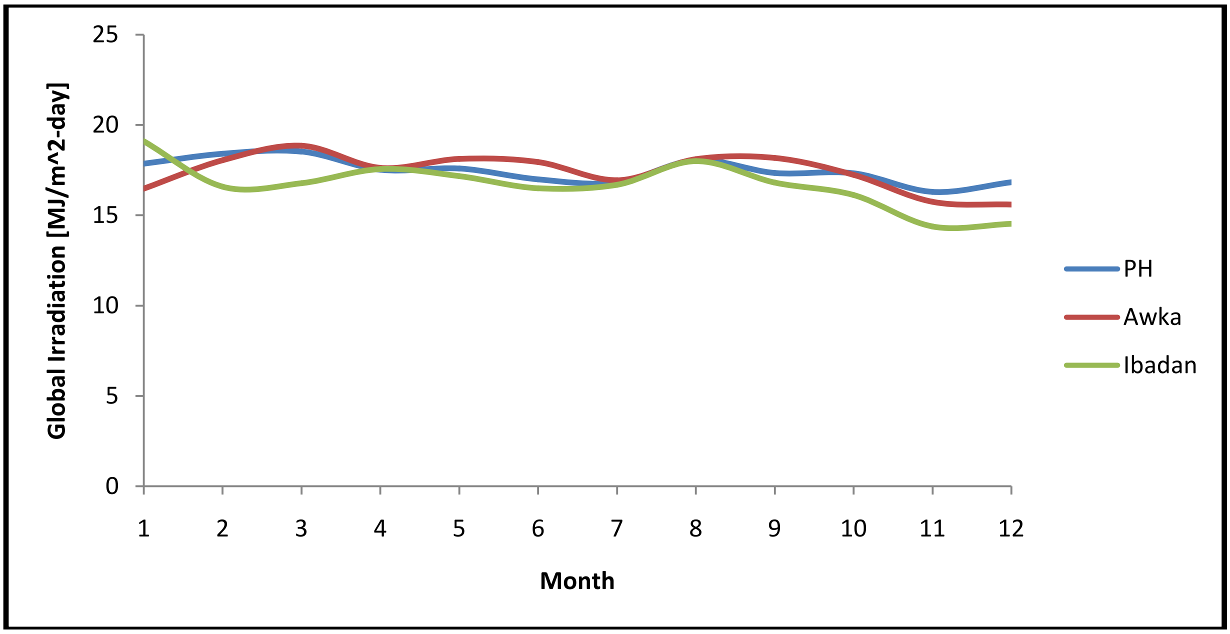

Fig. 4: Monthly variation of global irradiation in PH, Awka and Ibadan.

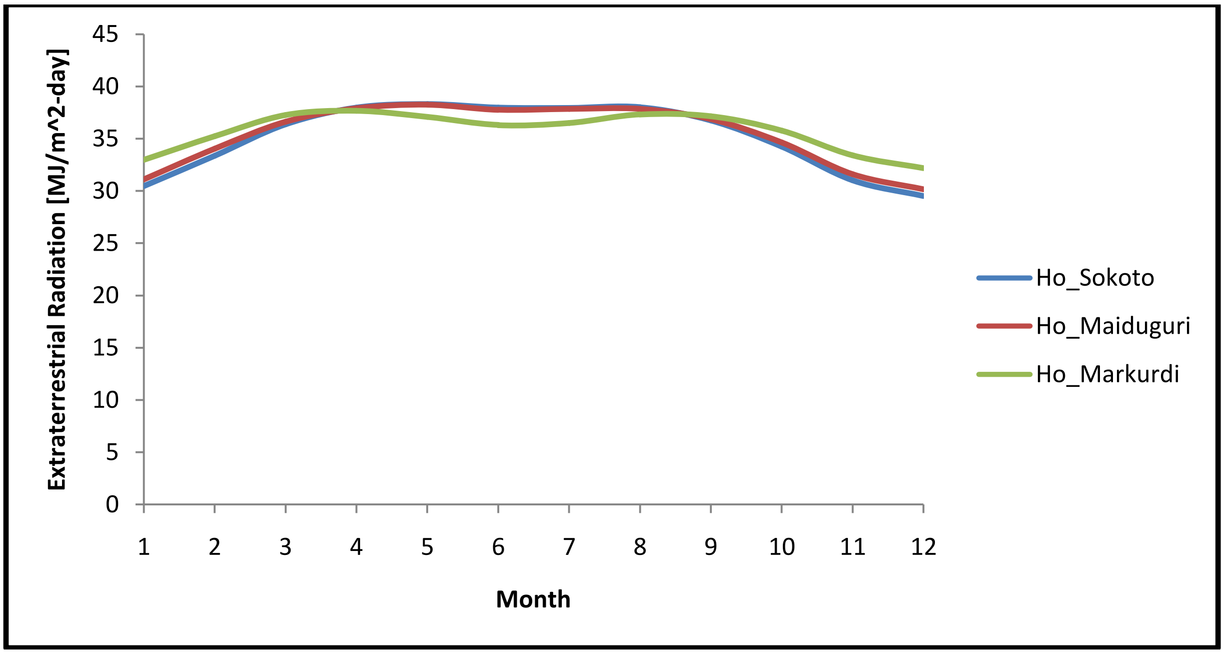

Fig. 5: Monthly variation of extraterrestrial radiation in Sokoto, Maiduguri and Makurdi.

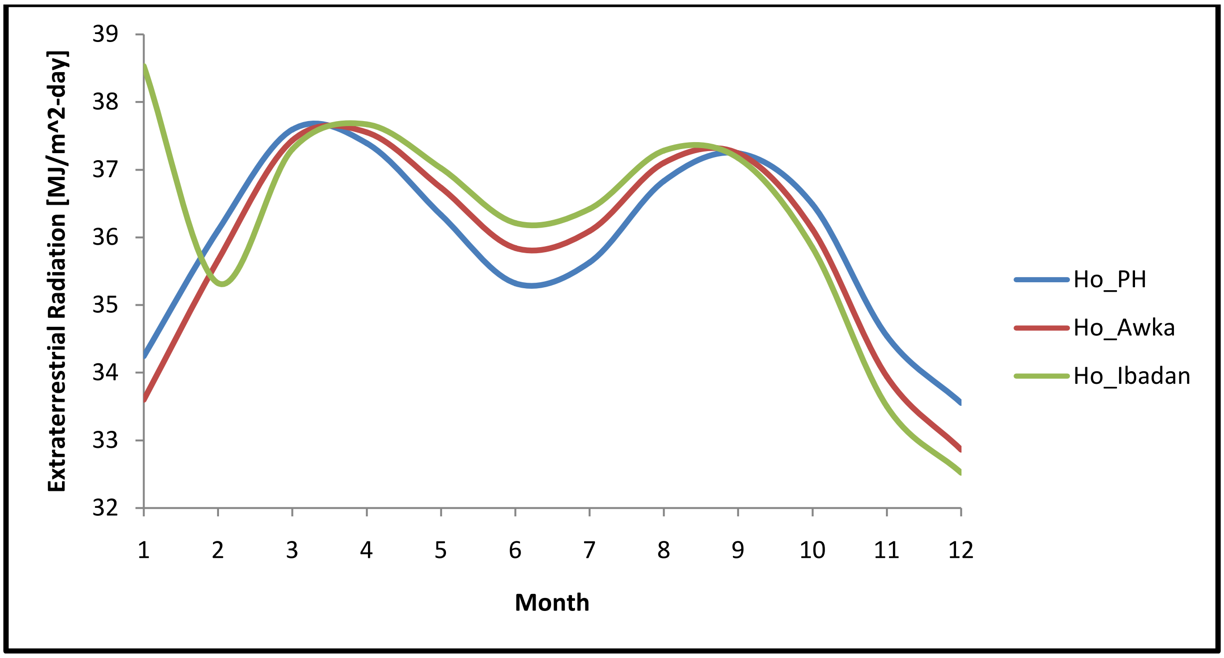

Fig. 6: Monthly variation of extraterrestrial radiation in PH, Awka and Ibadan.

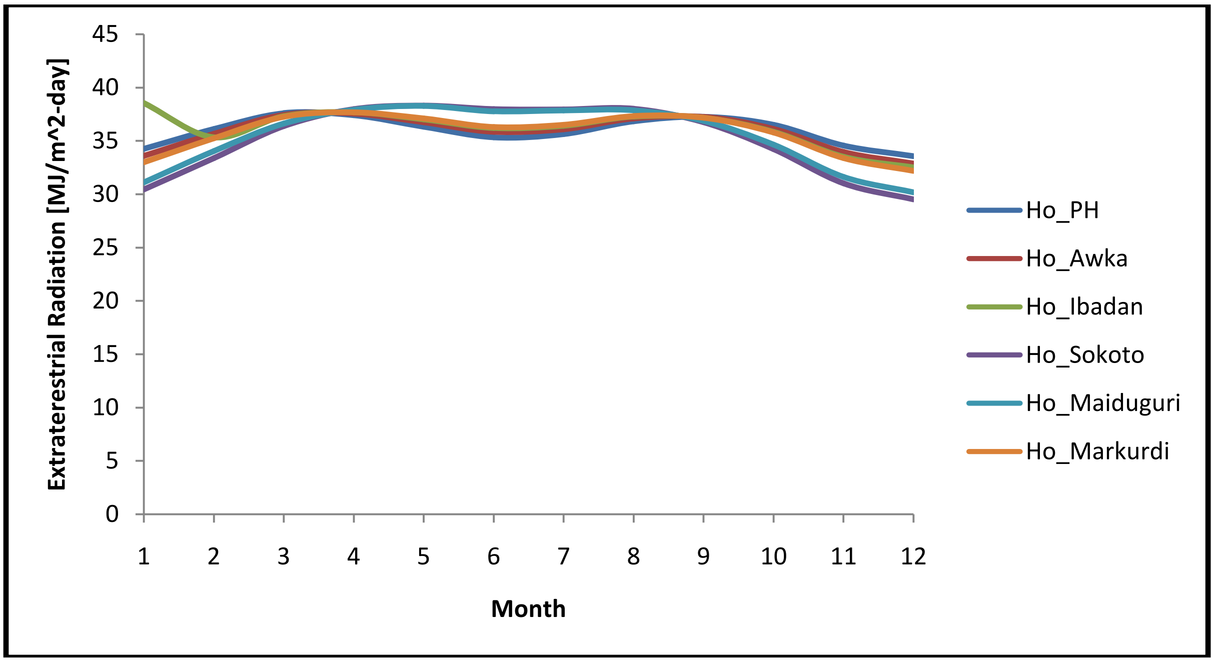

Fig. 7: Monthly variation of extraterrestrial radiation in all six study locations

As revealed by Fig.1, Sokoto recorded the highest temperature followed by Maiduguri and Markurdi respectively around the months of January to April. The three locations hovered around the same temperature with minimal differences from May to October and thereafter witnessed marked difference again from October to December. On the other hand, the minimum temperature variations follow same trend with Maiduguri recording the least temperature throughout the year, apart from the months of April to July that Markurdi (Benue) recorded the least. While Sokoto recorded about 38^{o}C maximum temperature, Maiduguri recorded about 12^{o}C minimum temperature. For the Southern locations as revealed by Fig.2, both the minimum and maximum temperatures remained fairly stable with little or almost no perturbations. The maximum temperature remains at about 32^{o}C while the minimum remained at about 21^{o}C.

The monthly variation of mean global solar radiations over a ten year period for the Nothern and Southern study locations are presented in figures 3 and 4, respectively. From Fig.3, Maiduguri consistently recorded the highest global solar radiation between January and mid May, with a maximum value in the order of 24.45 $\pm$ 0.60 MJm^{-2}day^{-1} occurring in February and 16.66 $\pm$ 0.60 MJm^{-2}day^{-1} minimum global radiation June with an average radiation of 19.83 $\pm$ 0.60 MJm^{-2}day^{-1}. This could be attributable to high prevalence of rain bearing wind and heavy cloud. From mid September to December also it overshot Sokoto and Markurdi. While Markuri recorded the least global radiation from January to April, it overshot Sokoto between April and June and in August as well as from October to December with minimal amounts. Sokoto also recorded the highest global radiation in February with a value of 22.46 $\pm$ 0.54 MJm^{-2}day^{-1} and the lowest value was obtained in November with the value of 16.46 $\pm$ 0.54 MJm^{-2}day^{-1}, with a mean global radiation of 18.55 $\pm$ 0.54 MJm^{-2}day^{-1}. Both Maiduguri and Sokoto maintained fairly high global solar radiation in the first quarter of the year from January to March. The value reduces slightly while being fairly steady in the second and third quarters due to the prevailing raining season with its attendant cool, moist and aerosol laden winds as well as the gradual developing clouds. However, for Sokoto, the last quarter witnessed the lowest values of global radiation. Markurdi recorded a maximum value of global radiation of 19.80 $\pm$ 0.30 MJm^{-2}day^{-1} around August and maintained least radiation between January and April with a minimum in March, with an average of 17.80 $\pm$ 0.30 MJm^{-2}day^{-1}. However, it overshot Sokoto during the months of October all through to December. For the representative southern locations as shown in Fig.4, there seem to be little variations in global radiation for most of the periods of the year. Ibadan has the highest global solar radiation of 19.10 $\pm$ 0.36 MJm^{-2}day^{-1}, which occurred in January and a minimum radiation of 14.38 $\pm$ 0.36 MJm^{-2}day^{-1} in November, with an average value of 16.68 $\pm$ 0.36 MJm^{-2}day^{-1}. Awka has 18.84 $\pm$ 0.28 MJm^{-2}day^{-1} maximum radiation in March while Portharcourt has 18.52 $\pm$ 0.19 MJm^{-2}day^{-1} maximum in March also, with minimum values occurring in December and November respectively.

Figs 5, 6 and 7 represent the extraterrestrial solar radiation for the representative northern, southern and all six studied locations, respectively. From Fig. 5, the extraterrestrial radiation for Sokoto and Maiduguri follow the same trend, exceeding Markurdi only between April and September, with a maximum value of 38.26 $\pm$ 0.83 MJm^{-2}day^{-1} in May and minimum of 30.16 $\pm$ 0.83 MJm^{-2}day^{-1} in December. Markurdi recorded a maximum of 37.67 ± 0.52 $MJm^{-2}day^{-1}$ in April and a minimum of 32.19 ± 0.52 $MJm^{-2}day^{-1}$ in December also. Fig. 6 shows that Awka and Portharcourt follow similar trend with Portharcourt leading from January to late March and then lagged from early April to September and overshot again from September to December. In Awka, the maximum value of extraterrestrial radiation is 37.55 ± 0.44 $MJm^{-2}day^{-1}$ April with a minimum of 32.86 ± 0.44 $MJm^{-2}day^{-1}$ in December, whereas in Portharcourt, a maximum extraterrestrial radiation of 37.59 ± 0.36 $MJm^{-2}day^{-1}$ occurred in March and a minimum of 33.55 ± 0.36 $MJm^{-2}day^{-1}$ in December as well. Ibadan is the most unstable peaking in January, late March and mid August and has a minimum value of 32.52 ± 0.48 $MJm^{-2}day^{-1}$ December. Fig.7 shows clearly that the atmospheric characteristic of Markurdi is similar to the southern characteristics throughout the year for the period under investigation.

IV. Conclusion

The solar energy potential of six locations in Nigeria, three each chosen from Northern and Southern regions, has been analyzed using the Hargreaves and Samani model. The global and extraterrestrial radiations at the six study locations comprising Sokoto, Maiduguri, Makurdi, Ibadan, Awka and Portharcourt, which are representative locations in the six geo-political zones of the country, within a ten year period under investigation exhibit widespread variations. For the Northern locations, the mean global and extraterrestrial radiations over period of investigation are 18.73 ± 0.32 $MJm^{-2}day^{-1}$ and 35.43 ± 0.45 $MJm^{-2}day^{-1}$, respectively while in the Southern locations, the average values are 17.18 ± 0.18 $MJm^{-2}day^{-1}$ and 36.00 ± 0.45 $MJm^{-2}day^{-1}$ respectively. This shows that Nigeria has enormous solar radiation potential, with the Northern part having a marginal edge over the southern part.

Acknowledgments

The support and cooperation of the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos, Nigeria is highly acknowledged.

References

[1]. Ahmad, A.S., Renewable Energy Applications for Sustainable Development, Saarbrueken Germany, VDM Publishing House Ltd (2005).

[2]. Ajayi, O.O., Ajanaku, K.O., Nigeria's Energy Challenge and Power Development: The Way Forward, Energy and Environment 20 (3) (2009) 411-413, DOI: 10.1260/095830509788066448.

[3]. Animalu, A.E.O., Adekola, S.A., Science Today in Nigeria, The Nigerian Academy of Science, Abuja, (2002) 190-208.

[4]. Anyanwu, E.E., Oteh, U.U., Analysis of solar radiation measurement at Owerri, Nigeria, African Journal of Science, 4(1), (2003) 893-906.

[5]. Chineke, T.C., Equations for estimating global solar radiation in data sparse regions, Nigerian Journal of Renewable Energy, (2007) 1-13.

[6]. Duffie, J.A., Beckmann, W.A., Solar Engineering of Thermal Processes, 5nd ed., Wiley-Interscience, New York (USA) (2013).

[7]. EIA (2008) Country Analysis Briefs, Energy Information Administration [www] Available from: http://www.eia.doe.gov/emeu/cab/Nigeria/Background.htm. (Accessed 23rd April, 2011)

[8]. EIA (2011), Country analysis brief: Nigeria [www] Energy Information Administration Available from: http://www.eia.doe.gov/cabs/Nigeria/background.html, (Accessed 23rd April, 2011).

[9]. Hargreaves, G.H., Samani, Z.A., J. Irrigation and Drainage Engineering, (1982) 223

[10]. IEA (2011) Deploying Renewables: Best and Future policy Practice [www] International Energy Agency Available from: http://www.iea.org/publications/freepublication/pulication/Deploying_Renewables2011.pdf, [Accessed 30/04/2011].

[11]. Ilenikhena, P.A., Harding, E.E., Chinedu, J.A., Thermal Emittance properties of polished and solution Grown Cobalt sulphide (CoS) Thin Films on stainless steel 430 for solar Energy collection, Nigerian Journal of solar Energy 19(1), (2008) 1-5.

[12]. Ileoje, O.C., Potentials for Renewable Energy Application in Nigeria, Energy Commission of Nigeria, (1997) 5-16.

[13]. Kalogirou, A. S., Solar Energy Engineering: Processes and Systems, Academic Press Publications, USA, 1st Edition (2009).

[14]. Nwoke, O.O., Okonkwo, W.I., Oparaku, O.U., Solar Energy use in Nigeria, Journal of Solar Energy, 19 (1), (2007) 90-93

[15]. Okeke, C.E., Activities at a Glance, The presidency, Energy Commission of Nigeria, National centre for Energy Research and Development, University of Nigeria, Nsukka, (2002) 3-5

[16]. Oparaku, O.U., Rural area power supply in Nigeria: A cost comparison of photovoltaic, diesel/gasoline generator and grid utility options. Renewable Energy 28, (2007) 2089-2098.

[17]. UNEP, The millennium development goals report [www] The United Nations Development Programme, Available from: http:/www.un.org/milleniumgoals/pdf/MDG Report, [Accessed 22/09/2012.

Okoye, A.E. "Analysis of Solar Energy Resource Potential to Supplement Grid Power in Nigeria." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 17(3), 2020, pp. 49-55.