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Insolation Levels Using Temperature Model for Sustainable Application of Photovoltaic Technology in Some Selected Locations of Nigeria

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Abstract

The need to balance between energy security, economic development and environmental protection through technology is becoming enormous. Nigerians are experiencing lack of adequate meteorological data such as monthly average of incoming solar radiation and clearness index except for few locations. While, photovoltaic technology applications depends solely on the availability of insolation data and efficient energy appliances. Therefore, twenty one (21) locations were considered within the North-western Nigeria for the estimation of global solar radiation (kWh/m^2/day) using sunshine hours based on Angstrom correlation model. It was achieved through derived empirical constants based on the 30 years long term average of ground insolation measurement and 10 years long term average of sunshine hour's measurement. The measured and estimated values of insolation were tested using coefficient of determination (R^2), root mean square error (RMSE) and coefficient of residual mass (CRM) and high percentages of the R^2, low value of RMSE and positive value of CRM close to unity shows remarkable agreements. The difference between the monthly variations of average mean daily insolation of the locations was also shown to have no significant difference based on One-way analysis of variance (ANOVA). It is concluded that, the insolation data can be used in the design of solar installations for the locations and in locations with similar climatic conditions for sustainable application photovoltaic technology in Nigeria.

Key words: Nigeria, Estimation, Insolation, Sunshine hours, Photovoltaic technology,

Introduction

More than 70 percent of Nigerians do not have access to reliable electricity for their domestic needs; this is in spite of the fact that, Nigeria receives abundant solar energy that can be usefully harnessed, with an annual average daily solar radiation of about 5.2KwH/m^2/day (Chineke, Nwafor and Okoro, 2010; Victor, Okey, Chidieze and Ugochukwu, 2010). Thus, Nigeria receives 5.081 x 10^{12} KwH of energy per day from the sun on the average of 5.5 KwH/m^2/day, and with 5% efficiency of SPV system covering 1% Nigerian land. A 2.541 x 10^6MwH of electricity equivalent to 4.656 million barrels of oil per day which is about 3.88 times country's 1089 oil production level. Sambo (2009b) also revealed that, it is possible to generate 1850X10^3 GWH of solar electricity per year if SPV systems were used to cover 1% of Nigeria's land area of 923,773km^2. This is over one hundred times the current grid electricity consumption level in the country.

Notwithstanding, solar radiation data is still very scarce for PV applications despite the acute shortage of conventional source of energy. The largest solar radiation and other climatologically database available in Nigeria reside with the Nigerian Meteorological Agency (NIMET), mostly from airport and aerodrome weather stations that were originally set up to aid civil Aircraft navigation. To obtain a good solar radiation database there is the need to create more purpose-built radiation measurement stations all over the country (REMP, 2005).

With rapid population growth and increase in industrial activities, more energy (usually fossil fuel generated) is consumed resulting in increased environmental pollution and economic difficulties. Therefore, the need for utilizing renewable energy resources emerged globally. The SHS works within the limited power density of their location's insolation apart from their own efficiency figures. A storage or complimentary power system is required for both the off-grid, supported-grid and building integrated photovoltaic home systems application.

However, Ojosu, 1989, Martinot, Cabraal and Mathur, (2001); Tiwari, (2002); Rai, (2005); UNEP, (2011); and CEC, (2001) postulated that, design/sizing, installation and performance of SHS depends on the detailed information of basic energy demand (Load estimation), insolation data and component specification and cost. According to Sambo and Doyle (1988), three classes of methods are generally used in global solar radiation. The first class uses empirical approach where meteorological data are employed with regression techniques. The second class uses solar constant by considering the depletion of insolation value due to clearness index variation and the third class is based on satellite measurements. Measured data is important to give realistic and accurate information on the performance of SPV system under actual operating environments and for places where it is not directly measured. The expense of radiometric stations and high maintenance make impossible the spatially continuous mapping of solar radiation.

Availability of qualitative global radiation data remains the pre-requisite for comprehensive design and application of SPV systems. Due to the scarcity of real data however, the use of representative sites where irradiance data are measured or modeled has been a common practice for engineering calculations which usually employs empirical correlations. Resort is being made on the use of reliable estimation model despite the fact that, best radiation data are those procured from the experimental measurements. (Malik and Roslan, 1996; Sambo and Doyley, 1988; Ojosu, 1989; Rai, 2005; Danny, Tony, Lam and Cheung, 2009; Ogolo, 2010; Madugu *et al*, 2010; Robert, Majid and Alma, 2010).

Several models have been developed using some available data, especially the sunshine hours, for the estimation of the daily solar insolation needed in the design and application of SPV systems. For example, the results from Nigeria, according to Ojo, 1977; Bugaje, 1998; Kuye, Adekunle and Adetunji, 2008; Suleiman, Kulla, Jumare and Anafi (2008) Burari, Abdulazeez and Medugu 2010; and Ogolo, 2010 show that the predictive ability of the Angstrom and Angstron-Page or Angstron- Prescott type model, correlate the global solar radiation to relative sunshine duration in a simple linear regression form.

Other investigations also demonstrated the predictive ability of temperature based models where sunshine hour data is not available or used simultaneously for reliability and validation of results. The temperature based models as suggested by Chiemeka, 2008; Ogolo, 2010; and Augustine and Nnabuchi, 2010 were that of Garcia (an Angstrom-Prescott model with slight modification) and Hargreaves & Samani that proposed an empirical equation expressed in the form of linear regression between the clearness index and the square root of the change in temperatures. The Garcia (1994) model, an adaptation of Angstrom-Prescott with slight modification that makes it ambient temperature type is in Equation 1.

$$\frac{Hs}{Ho} = a + b\left(\frac{\Delta T}{N}\right) \qquad \text{.......................................} (1)$$

Where,

H_s = Monthly average daily global solar radiation on horizontal surface (MJ/m^2 day)
H_o = Monthly average daily extraterrestrial radiation (MJ/m^2 day)
N = Maximum possible monthly average daily length (N = $^2/_{15}\omega_s$)
ΔT =Difference between maximum and minimum temperature values.
a, b = Derived empirical constant

Akpabio, Udo and Etuk, (2004) is another model based on multiple linear regression using ten parameters of meteorological data of Onne, Nigeria, Okundamiya and Nzeako (2010) model based on stochastic analysis that employed linear regression theory using monthly mean daily data set for minimum and maximum ambient temperatures of six selected cities in Nigeria is also available. There were also models based on quadratic correlation approach developed by Augustine and Nnabuchi (2010), Udo (2002), and Akpabio *et al* (2004); which were tested, validated and ensured reasonable for predicting solar radiation with adequate conformity to other models in all the climatic zones of Nigeria.

It is imperative to note that, a number of correlations involving global solar radiation using several parameters such as sunshine hours and temperatures for different locations in Nigeria were developed by different researchers to provide solar data for SPV system design and application in most Nigerian cities. Perhaps, difference in regression coefficient values is also what differentiates one model from another.

Augustine and Nnabuchi (2010) and Ogolo (2010) studied the coefficients of several models and observed that the regression coefficients are not universal but depend on the climatic conditions. While, Suleiman *et al* and Ogolo (2010) pointed that, third order Angstrom model type does not improve the accuracy of estimation of global radiation and for improving level of performance, temperature and sunshine hour dependent models are more suitable for the simulation of global radiation in the Shelia and Guinea Savannah climatic conditions respectively. In addition to classical techniques, new methods such as satellite-based techniques have been investigated. Although they are less accurate than ground-based measurements, they may be more suitable to generate site- or time-specific data at arbitrary location and times (Robert *et al*, 2010).

Thus, prediction, estimation or computation of the monthly average daily global solar radiation on horizontal surface cannot be realized without the monthly average daily extraterrestrial radiation on horizontal surface (MJ/m^2/day) termed H_0 which is important in assessing variability of insolation and can be computed for the n^{th} from the following equation as given by Duffie and Beckman (2006).

$$Ho = \frac{24 \times 3600 G_{sc}}{\pi}\{1 + 0.033 \cos\frac{360n}{365}\}\{\cos\theta \cos\boldsymbol{\delta} \sin\omega_s + \frac{\pi\omega_s}{180}\sin\theta \sin\boldsymbol{\delta}\} \quad \text{………... (2)}$$

Where,

G_{sc} = Solar constant(equivalent to $1367W/m^2$)
θ = Location latitude
$\boldsymbol{\delta}$ = Solar declination
ω_s = Hour angle
n = Solar design day

The declination ($\boldsymbol{\delta}$) is the angular position of the sun at solar noon, with respect to the plane of the equator and its value in degrees is given by Cooper's equation (1969) as given by Duffie and Beckman (2006):

$$\boldsymbol{\delta} = 23.45\sin\{360\frac{284+n}{365}\}$$

Where n is the day of year (i.e n =32 for 1st February)and the declination ($\boldsymbol{\delta}$) varies between -23.45^o on December 21and $+23.45^o$ on 21st June. While, $\omega_s = \mathbf{Cos}^{-1}(-\tan\theta \tan\boldsymbol{\delta})$.

However, before reaching the surface of the earth, radiation from the sun is attenuated by the atmosphere and the clouds. The ratio of solar radiation at the surface of the earth to extraterrestrial radiation is called clearness index. Thus, the monthly average clearness index K_T, is defined as $K_T = \frac{H}{Ho}$ …………………………………… (3)

Where,

H = Monthly average daily global solar radiation on a horizontal surface.
H_o = Monthly average extraterrestrial daily global solar radiation on a horizontal surface.
K_T = Values depends on the location and the time of year considered.

Nevertheless, equation (3) can also be used for computing the Monthly average daily global solar radiation on horizontal surface (kW/m^2 /day) where the clearness index of a location is obtainable. Folayan (1988), postulated that Nigeria falls within 25% - 70% clearness index for the year round estimates with most cities having 20% variation from minimum to maximum. Perhaps, the values usually lie between 0.3 for very overcast climates and 0.8 for very sunny location (Robert, Majid and Alma, 2010).

In line with the above background, this study is set to examine the meteorological data of Nigeria with a view to establishing the available solar radiation data for sustainable implementation of SHS. The data would also provide a simulation basis in Nigeria just like in the US, and the long term benefit can out-weigh the cost constrain, since the system will last for long without changing any system component or pay any power supply bill. The cost will continue to be high if there is no utilization and patronage, and if the research and development of the system and its components are not done locally (Sambo, 2009a; Robert *et al*, 2010).

Methodology

Data from the meteorological stations of several government and non governmental agencies within the study area was collected with the view of ascertaining the source of variation between the measured or estimated and ground, satellites or predicted solar radiation data. The study area (North-west) situated between latitudes 8^o and 14^o north of the equator and between longitudes 3.5^o and 11^o east of meridian, comprises seven states namely; Kaduna, Kano, Jigawa, Katsina, Zamfara, Sokoto and Kebbi. It is also imperative to note that the area has a higher potential of solar energy than the southern part due to its proximity to the arid Sahel (Victor *et al*, 2010).

Twenty one (21) locations represent the sample size comprising three (3) major cities from each of the seven states where urbanization and development are considerably more than the other locations. The sampling is achieved through the stratification method in order to come up with locations that would adequately represent the whole state, in each case the latitude, longitude, altitude and axial location/distances between the cities are considered. The parameters considered for this purpose are either for a location or a state average. The long term averages of the parameters used in the analysis include:

1. Minimum/ maximum ambient temperature (^oC).

2. Monthly average daily global solar radiation on horizontal surface (KwH/m^2 /day).
3. Clearness Index

The minimum/ maximum ambient temperature (^{o}C) ground measurement data were collected from the Agricultural meteorological (Agricmet) Stations of Agricultural Development Projects of the states except in the case of Katsina where the data were collected from the Ministry of Water Resources and there was no available data in Kebbi State. All set of satellite measurement data required were downloaded online from the NASA SSE Home page available at (http://eosweb.larc.nasa.gov/sse/).
The monthly average daily global solar radiation on horizontal surface (kW/m^2 /day) of all the locations were received as ground measurements from the Nimet data bank except that of the Jigawa state that has no airdrome stations/air port.

Equations (1) that utilize ambient temperatures was employed for the estimation using empirical constants based on the monthly average daily global solar radiation on horizontal surface (kW/m^2 /day). The monthly extraterrestrial radiations Ho (kW/m2/day) of all the locations were also computed based on the equation (2). The following hypothesis was also considered for the validation of the results. There is no difference between the observed (Ground measurement) and the estimated (ambient temperature based prediction models) of solar radiation of the locations within the North-Western Nigeria.

Micro soft plotter was used to plot monthly ratio of $\frac{\mathbf{Hs}}{\mathbf{Ho}}$ against that of $\frac{\Delta T}{N}$ and $\frac{n_s}{N}$ for all the seven states in order to obtain the empirical constants based on the trend line that display equation and R-square value on chart using scatter mode plotter. While, Statistical Package for Social Scientist (SPSS) was also used for testing the hypothesis raised using One-way analysis of variance (ANOVA) test, under the criterion that; Reject the H_o if $p \leq 0.05$, and Accept the H_o when $p > 0$.

Thus, the Coefficient of determination (R^2), Root mean square (RMSE) and Coefficient of Residual Mass (CRM) are the most often used quantities for validation, and were calculated using the following formulas.

$$R^2 = \frac{\sum_{1}^{N}(PHs - MPHs)^2}{\sum_{1}^{N}(MHs - MMHs)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (a)$$

$$RMSE = \sqrt{1/N \sum_{i=1}^{N}(MHs - PHs)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (b)$$

$$CRM = \sum_{i=1}^{N} PHs - \sum_{i=1}^{N} MHs \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (d)$$

Where: PHs = predicted insolation values

MHs = measured insolation values

MPHs = means of Predicted insolation values

MMHs = means of measured insolation values

N = number of observations

Major findings
The data collected from the field were sorted, analysed and presented in a long term average of 22years for satellite measurements of ambient temperature and insolation values. 10years ground measurements of ambient temperature and 30years insolation values. The sorted data for Kaduna is presented in Table 1 as an illustration.

Table 1: Long term Average of metrological data in Kaduna state

Months	Ambient Temperature (^{o}c)						Insolation (KwH/m^2/day)	
	Ground			Satellite (22yrs LTA)			Ground	Satellite
	Min	Max	Δ T	Min	Max	Δ T	(30yrs LTA)	(22yrs LTA)
Jan	18.7	30.2	11.5	17.2	40.4	23.2	6.1	5.73
Feb	16.2	30.4	14.2	18.7	42.9	24.2	6.6	6.00
Mar	20.0	35.0	15.0	21.2	42.6	21.4	6.8	6.38
Apr	18.0	35.0	17.0	22.0	36.0	14	6.6	6.84
May	19.0	34.0	15.0	21.9	32.4	10.5	6.0	6.65
Jun	18.0	33.0	15.0	21.4	29.8	8.4	5.6	6.36
Jul	17.0	32.0	15.0	20.8	28.2	7.4	5.2	6.48
Aug	16.0	35.0	19.0	20.4	28.8	8.4	5.2	6.65
Sep	15.0	29.0	14.0	20.6	30.6	10	5.6	6.46
Oct	13.0	32.0	19.0	19.4	32.6	13.2	5.9	6.13
Nov	28.1	36.8	8.7	17.9	38.5	20.6	6.4	6.20
Dec	16.4	32.9	16.5	17.3	39.2	21.9	6.1	5.58

Extraterrestrial Radiations (Ho) for each of the 21Locations of the study area was also computed in MJ/m^2/day, using Equation (2). They were converted to kWh/m^2/day for homogeneity. Table 2 shows that of Kaduna state.

Table 2: Monthly Average Daily Extraterrestrial Radiations (kWh/m^2/day) of Locations (Ho) Kaduna State

Mnts	N	Δ	Kaduna Lat. 10.52			Zaria Lat. 11.07			Kafanchan Lat. 9.58		
			N	ω_s	H_o	N	ω_s	H_o	N	ω_s	H_o
Jan	17	-20.91	11.46	85.93	**8.81**	11.43	85.71	**8.65**	11.53	86.30	**8.94**
Feb	47	-12.94	11.67	87.55	**9.55**	11.66	87.42	**9.50**	11.70	87.77	**9.64**
Mar	75	-2.40	11.94	89.55	**10.22**	11.94	89.53	**10.19**	11.95	89.60	**10.25**
Apr	105	-9.43	12.24	91.77	**10.54**	11.75	88.14	**9.56**	11.79	88.39	**9.64**
May	135	18.81	12.48	93.63	**10.46**	12.51	93.82	**10.49**	12.44	93.30	**10.40**
Jun	162	23.09	12.61	94.54	**10.32**	12.64	94.79	**10.36**	12.55	94.13	**10.24**
Jul	198	21.17	12.55	94.13	**10.34**	12.58	94.35	**10.38**	12.50	93.75	**10.27**
Aug	228	13.43	12.34	92.54	**10.44**	12.36	92.68	**10.46**	12.44	93.31	**10.41**
Sep	258	2.19	12.05	90.41	**10.32**	12.06	90.43	**10.27**	12.05	90.37	**10.29**
Oct	288	-9.63	11.76	88.19	**9.70**	11.75	88.10	**9.66**	11.78	88.36	**9.78**
Nov	318	-18.93	11.51	86.35	**8.96**	11.49	86.15	**8.98**	11.56	86.68	**9.07**
Dec	344	-23.06	11.39	85.46	**8.52**	11.36	85.22	**8.48**	11.45	85.88	**8.69**

The study was designed to have the same solar design day (nth) in the whole 21 locations and therefore same solar declination (δ) values, while each location had its own hour angle (ω_s) and maximum monthly average daily length (N) values defined by their locations as in Table 2.

The empirical constants of each of the seven states covered in the research were derived based on Micro soft plotter. Monthly ratio of $\frac{Hs}{Ho}$ against that of $\frac{\Delta T}{N}$ for all the seven states ware plotted in order to obtain the empirical constants. The trend line that display equation and R-square value on chart using scatter mode plotter is also obtained. The constants *a* and *b* were derived and figure 1 show the plot for Kaduna state with Table 3 presenting the summary.

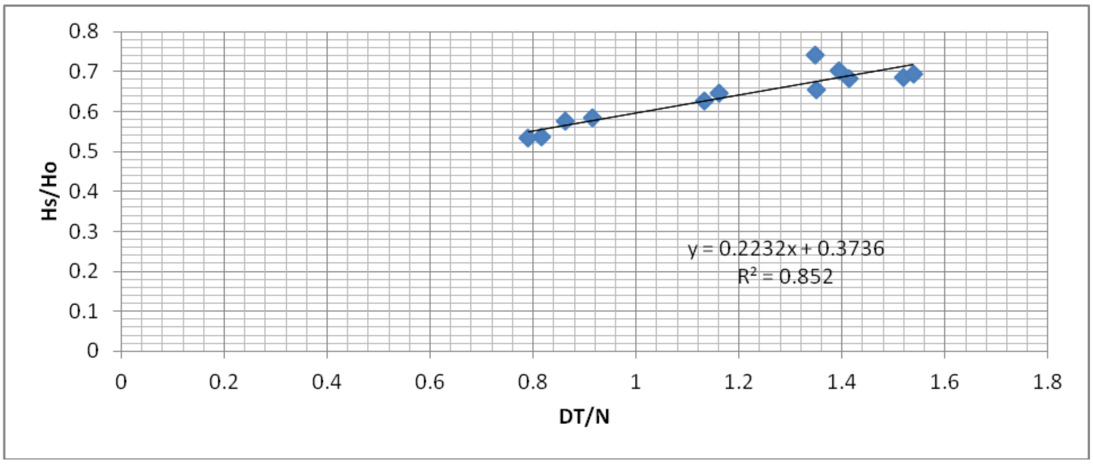

Figure 1: Derived Empirical Constants of Kaduna state

Table 3: Summary of Derived Empirical Constants of Location

Location or State	a	b
Kaduna	0.373	0.223
Kano	0.373	0.223
Katsina	0.277	0.201
Jigawa	0.616	0.033
Zamfara	0.624	0.022
Sokoto	0.546	0.085
B/Kebbi	0.654	0.195

Based on the derived empirical constants summarized in Table 3, Equations (1) was used for the estimation (prediction) of insolation levels of the seven (7) states using the temperature based models and the results are presented in Table 4.

Table 4: Estimated insolation levels of states KwH/m^2/day

Months	Kaduna	Kano	Katsina	Jigawa	Zamfara	Sokoto	Kebbi
Jan	5.6526	6.1375	6.2940	5.7695	5.6189	5.6552	9.6993
Feb	5.9034	6.4328	6.6961	6.2932	6.0981	6.0895	10.4407
Mar	6.2731	7.1101	6.7456	6.7363	6.5488	6.6876	11.4407
Apr	6.3158	6.3624	5.9987	6.2346	6.0765	6.0753	10.3434
May	6.4830	6.5972	6.7811	6.8507	6.8114	6.6734	10.0788
Jun	6.4105	6.0223	6.4480	6.7469	6.7515	6.5008	9.0091
Jul	6.4163	5.7927	6.0300	6.7167	6.7756	6.3640	8.4130
Aug	6.0827	5.7629	5.9615	6.7102	6.7628	6.3271	8.4940
Sep	6.4418	5.7888	5.9566	6.6422	6.5747	6.0335	8.7177
Oct	5.5704	6.0523	5.7263	6.2836	6.1559	4.7021	9.6175
Nov	5.9929	6.2872	6.1616	5.8394	5.6529	5.7748	9.8379
Dec	5.0494	5.7488	5.8275	5.592	5.3925	5.4809	9.3021

For Analysing or Evaluating the models the measured values against estimated values were plotted and the correlation between them is used for validating the models for all the states. The details of the plots with slopes, intercept and R^2 are presented in Figure 2.

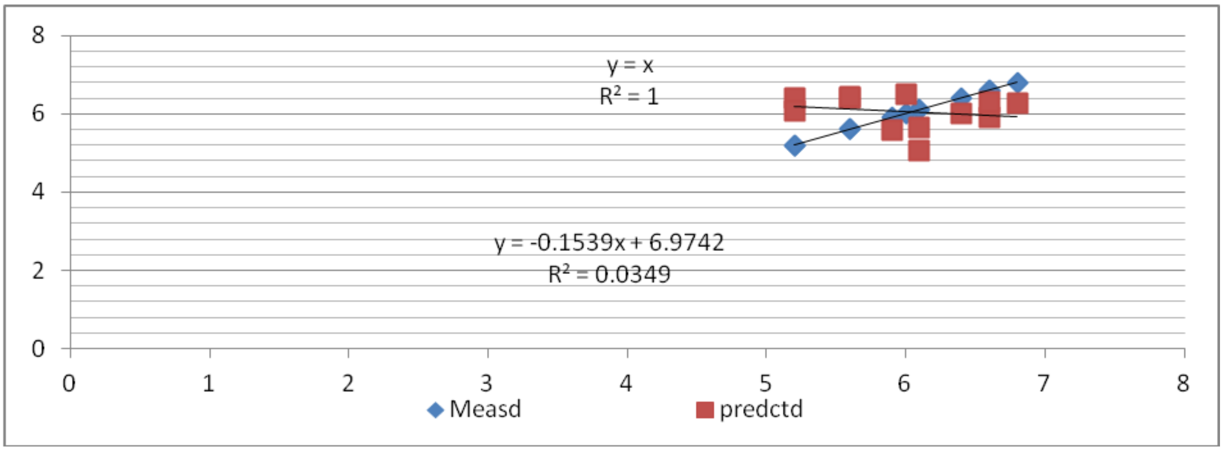

Figure 2: Measured and Estimated insolation levels of Kaduna state

As the accuracy of estimation is measured by the bias and the precision of its standard deviation earlier described in the methodology, the model validation was achieved through the values of the following quantities; Coefficient of determination (R^2), Root mean square (RMSE) and Coefficient of Residual Mass (CRM). The result of the validation for each state is presented in Table 5.

Table 5: Model Validation Indicators

State	R^2	RMSE	CRM
Kaduna	0.6797	0.7233	0.4919
Kano	0.6210	0.2374	-0.105
Katsina	0.6045	0.5242	2.527
Jigawa	0.8693	0.8547	4.3153
Zamfara	0.9046	0.9038	3.1196
Sokoto	0.9969	0.7655	0.2642
Kebbi	0.3583	3.6320	43.2942

It may be seen from Table 5 that, the model estimation is as accurate as the means of the observation based on the high percentages of the coefficient of determination (R^2), except for Kebbi state. The values of RMSE show low and high precisions depending on the locations. While the models under estimate only in the case of Kano due to negative values of CRM as shown in Table 5.

The models are therefore found suitable for estimating insolation values for any location in each of the states and Appendix 1 presents the insolation levels of other locations. These also imply that they can fit well in estimating insolation values in all locations within each of the state and locations with similar climatic variables.

The estimated insolation levels of the twenty one (21) locations were also used to test the hypothesis rose, using SPSS package. Thus, the difference between the monthly variations of average mean daily solar radiation data of each city within the North-Western Nigeria cities under study was also tested. It is tested using One-way analysis of variance (ANOVA) to validate whether the difference is significant i.e hypothesis 2. The test based on SPSS package Table 8.2 disclosed no significant difference as $P< 0.05$ and the null hypothesis was accepted.

Table 6: One-way analysis of variance (ANOVA) test for the Average Mean Daily Radiation

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	36.316	11	3.301	1.932	.049
Within Groups	123.036	72	1.709		
Total	159.353	83			

It therefore, follows that any minimum value taken for the design of SPV system would be sufficient within the study area, except where specificity and exact precision is required. Generally, the least monthly average insolation value estimated was 5.0257 kWh/m^2/day in December at Zaria and the highest was 11 5337 kWh/m^2/day in Zuru. These seems to be in conformity with what Ojosu (1989), measured and presented as the average of monthly average radiation level range in Nigeria of between 3.56kwH/m^2/day in harmattan period to about 8.05kwH/m^2/day during the hot seasons.

There is over estimation in the case of three Location Insolation data of Kebbi state as confirm by coefficient of residual mass (CRM) being high up to 43.2942 and 40.6947 for temperature and sunshine based models respectively. It is also interesting to note that, even the highest estimation value 'more in the case of Kebbi state does not greatly over estimate the monthly average global solar radiation based on the validations and comparison with the measured values. However, this make it possible to come-up with the monthly average of the clearness index $K_T = \frac{H}{Ho}$ (equation 3) of the locations in Table 7.

Table 7: Monthly average clearness index of locations

Months	Kaduna	Kano	Katsina	Jigawa	Zamfara	Sokoto	Kebbi
Jan	0.6416	0.7120	0.7422	0.6670	0.6518	0.6669	1.1161
Feb	0.6182	0.6836	0.7192	0.6674	0.6480	0.6633	1.1025
Mar	0.6138	0.6739	0.6679	0.6630	0.6452	0.6621	1.1296
Apr	0.5992	0.6733	0.6409	0.6590	0.6437	0.6491	1.0899
May	0.6198	0.6253	0.6391	0.6500	0.6450	0.6290	0.9581
Jun	0.6212	0.5768	0.6141	0.6475	0.6467	0.6179	0.8671
Jul	0.6205	0.5549	0.5732	0.6440	0.6484	0.6049	0.8081
Aug	0.5826	0.5494	0.5667	0.6403	0.6453	0.6014	0.8113
Sep	0.6242	0.5653	0.5834	0.6480	0.6421	0.5904	0.8496
Oct	0.5743	0.6318	0.6034	0.6545	0.6426	0.5525	0.9987
Nov	0.6689	0.7161	0.6970	0.6636	0.6446	0.6684	1.1116
Dec	0.5927	0.6885	0.7115	0.6673	0.6466	0.6684	1.1034

The clearness index (K_T) of the locations in Appendix 2 conform with what was postulated by Folayan (1988) that, Nigeria falls between 25% - 70% from minimum to maximum and within the variation of 20%. It also conform with varying between 0.3 in very overcast climates to 0.8 for very sunny locations as postulated by Robert *et al* (2010) except in the case of three (3) locations namely; Birnin kebbi, Yawuri and Zuru that are sunny enough to go beyond his postulations and due to overestimation.

Conclusions

The study is able to come up with the insolation data for sizing/designing the SHS for efficient utilisation of incoming solar radiation within the twenty one (21) locations and their surroundings. The validations also show that, the insolation values of the locations are the same within the range of 5.0257 KwH/m^2/day to 11.5337 KwH/m^2/day in the case of estimations throughout the year from January to December.

It is also imperative to note that, the least monthly average daily solar radiation is what is used as insolation level in the design, application and performance evaluation of SPV system. It is therefore recommended for locations that are lacking insolation data and not covered by this study, to use the data of location very close to them. Otherwise, the model can be used with respect to the empirical constant described by computing the location's extraterrestrial radiation (H_o) or to use the clearness index (K_T) computed by this study for their closest locations. The contribution of this study is also recommended for use in the design of energy efficient buildings, weather forecasting, agricultural system design and application, and in the forecast of evaporation from lakes and reservoirs.

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Appendix 1

Estimated insolation levels of other locations kWh/m^2/day

Months	Zaria	Kafanchan	Gwarzo	Tudun wada	Daura	Funtua	Hadeja	Kazaure	Mafara	Kauran namoda	Issah	Tambuwal	Birnin Kebbi	Zuru
Jan	5.5500	5.7360	6.1802	6.1375	6.2940	6.4424	5.7094	6.6894	5.5667	5.5667	5.6419	5.7086	9.5542	9.7998
Feb	5,8724	5.9590	6.4670	6.4328	6.6961	6.8040	6.2531	6.3733	6.0657	6.0540	6.1625	6.2155	10.2643	10.5068
Mar	6.2547	6.2915	6.8607	6.8405	6.7456	6.7991	6.7164	6,5971	6.5259	6.5295	7.0782	6.7074	11.4433	11.5337
Apr	5.7286	5.7765	6.3893	6.3700	5.9987	6.0820	6.2016	6.2016	6.0507	6.0507	6.0688	6.1142	10.2562	10.4088
May	6.5016	6.4458	6.5784	6.5972	6.7811	6.7236	6.8637	6.8832	6.8243	6.7662	6.6797	6.6483	10.1172	10.0405
Jun	6.4354	6.3609	5.9992	6.0223	6.4603	6.3866	6.7792	6.7922	6.7773	6.7967	6.5070	6.4699	9.0785	8.9658
Jul	6.4411	6.3728	5.7761	5.7983	6.0243	5.9669	6.7489	6.7554	6.7951	6.8145	6.3701	6.3880	8.4694	8.3482
Aug	6.0943	6.0652	5.7574	5.7629	5.9615	5.9388	6.7423	6.7487	6.7822	6.7822	6.3271	6.3151	8.5183	8.4615
Sep	6.4106	6.4230	5.8001	5.7888	5.9682	5.9857	6.6292	6.8107	6.5683	6.6015	6.0279	6.0394	8.6919	8.7343
Oct	5.5475	5.6164	6.0776	6.0523	5.7263	5.8047	6.0610	6.2378	6.1238	6.1367	5.2380	5.2767	9.5276	9.6674
Nov	6.0063	6.0665	6.0223	6.2729	5.9106	6.2104	5.7864	5.7664	5.5369	5.6078	5.7681	5.8350	9.6934	9.9268
Dec	5.0257	5.1502	5.7901	6.0861	5.8346	5.9912	5.5320	5.5120	5.3473	5.3408	5.4675	5.5410	9.1476	9.4014

Appendix 2

Months	Zaria	Kafanchan	Gwarzo	Tudun wada	Daura	Funtua	Hadeja	Kazaure	Mafara	Kauran namoda	Issah	Tambuwal	Birnin Kebbi	Zuru
Jan	5.5500	5.7360	6.1802	6.1375	6.2940	6.4424	5.7094	6.6894	5.5667	5.5667	5.6419	5.7086	9.5542	9.7998
Feb	5,8724	5.9590	6.4670	6.4328	6.6961	6.8040	6.2531	6.3733	6.0657	6.0540	6.1625	6.2155	10.2643	10.5068
Mar	6.2547	6.2915	6.8607	6.8405	6.7456	6.7991	6.7164	6,5971	6.5259	6.5295	7.0782	6.7074	11.4433	11.5337
Apr	5.7286	5.7765	6.3893	6.3700	5.9987	6.0820	6.2016	6.2016	6.0507	6.0507	6.0688	6.1142	10.2562	10.4088
May	6.5016	6.4458	6.5784	6.5972	6.7811	6.7236	6.8637	6.8832	6.8243	6.7662	6.6797	6.6483	10.1172	10.0405
Jun	6.4354	6.3609	5.9992	6.0223	6.4603	6.3866	6.7792	6.7922	6.7773	6.7967	6.5070	6.4699	9.0785	8.9658
Jul	6.4411	6.3728	5.7761	5.7983	6.0243	5.9669	6.7489	6.7554	6.7951	6.8145	6.3701	6.3880	8.4694	8.3482
Aug	6.0943	6.0652	5.7574	5.7629	5.9615	5.9388	6.7423	6.7487	6.7822	6.7822	6.3271	6.3151	8.5183	8.4615
Sep	6.4106	6.4230	5.8001	5.7888	5.9682	5.9857	6.6292	6.8107	6.5683	6.6015	6.0279	6.0394	8.6919	8.7343
Oct	5.5475	5.6164	6.0776	6.0523	5.7263	5.8047	6.0610	6.2378	6.1238	6.1367	5.2380	5.2767	9.5276	9.6674
Nov	6.0063	6.0665	6.0223	6.2729	5.9106	6.2104	5.7864	5.7664	5.5369	5.6078	5.7681	5.8350	9.6934	9.9268
Dec	5.0257	5.1502	5.7901	6.0861	5.8346	5.9912	5.5320	5.5120	5.3473	5.3408	5.4675	5.5410	9.1476	9.4014