COMPARATIVE STUDY OF INSOLATION LEVELS OF TWENTY ONE LOCATIONS USING TEMPERATURE AND SUNSHINE MODEL FOR SUSTAINABLE APPLICATION OF PHOTOVOLTAIC TECHNOLOGY IN NIGERIA

By

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ABSTRACT

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. Thus, Nigeria receives 5.081 x 10^{12}kWh of energy per day from the sun on the average of 5.5kWh/m^2/day, and it is possible to generate 1850 x 10^3 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. Therefore, twenty one (21) locations represent the sample size comprising three (3) major cities from each of the seven states situated between latitudes 8^o and 14^o North of the equator and between longitudes 3.5^o and 11^o East of meridian in Nigeria to make the study area. The long term averages of the Sunshine hours (hrs), Minimum/ maximum ambient temperature (^{o}C) and Monthly average daily global solar radiation on horizontal surface (kWh/m^2/day) were collected from seven (7) locations for the estimations of other location lacking the data. Results show that, insolation values of the locations are the same within the range of 5.0257kWh/m^2/day to11.5337 kWh/m^2/day throughout the year. It is recommended that, the results be used in the design of all solar system, energy efficient buildings and agricultural system design and application.

Key words: Ambient temperature, Estimation, Insolation, Pv- technology, Sunshine hours

INTRODUCTION

Despite the abundant incoming solar radiation (Insolation), solar radiation data is still very scarce for Photovoltaic (PV) applications inspite of the acute shortage of conventional source of energy. The largest solar radiation and other climatologic 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 (Renewable Energy Master Plan for the Federal Republic of Nigeria: REMP, 2005).

The solar system 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 and grid-tied systems application. Therefore, Ojosu (1989); Martinot *et al*, (2001); Tiwari, (2002); Rai, (2005); UNEP, (2011); and CEC, (2001) postulated that, design/sizing, installation and performance of solar system depends and rely on the detailed information of basic energy demand (Load estimation), insolation data and component specification and cost. Perhaps, the application in Nigeria is inhibited by the non availability of insolation data and the design tools, stages or procedures.

According to Sambo and Doyle (1988), three classes of methods are generally used in global solar radiation estimation. The first class uses empirical approach where meteorological data are employed with regression techniques, 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 Solar Photovoltaic (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 to 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, Burari and Abdulazeez 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, 1999; Kuye, Adekunle and Adetunji, 2008; Burari, Abdulazeez and Medugu 2010; and Ogolo, 2010 show that the predictive ability of the Angstrom and Angstrom-Page or Angstrom- 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 1st order Angstrom (1916) models is as in Equation (1) and the Garcia (1994) model, an adaptation of Angstrom-Prescott with slight modification that makes it ambient temperature type is as in Equation (2).

$$\frac{\mathbf{Hs}}{\mathbf{Ho}} = a + b\left(\frac{n_s}{N}\right) \quad \textbf{(1)}$$

$$\frac{\mathbf{Hs}}{\mathbf{Ho}} = a + b\left(\frac{\Delta T}{N}\right. \quad \textbf{(2)}$$

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_s = Monthly average daily bright sunshine hours
N = Maximum possible monthly average daily length ($N = {}^{2}/_{15}\omega_s$)
ΔT =**D**ifference between maximum and minimum temperature values**.**

Other models available include the following: Akpabio, Udo and Etuk (2004) 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. 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 sunshine hours or temperatures for different locations in Nigeria were developed by different researchers to provide solar data for SPV system design and application. The difference is in regression coefficient values between one model and other. 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.

However, Ogolo (2010) pointed out that, third order Angstrom model type does not improve the accuracy of estimation of global radiation and that for improving level of performance, temperature and sunshine hour dependent models are more suitable for the simulation of global radiation in the Sahelian 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 locations 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 from equation (3) as given by Duffie and Beckman (2006).

$$\mathbf{Ho} = \frac{24 \text{ X } 3600 G_{sc}}{\pi} \left\{1 + 0.033 \cos \frac{360n}{365}\right\} \left\{\cos\theta \cos\boldsymbol{\delta} \sin\omega_s + \frac{\pi\omega_s}{180} \sin\theta \sin\boldsymbol{\delta}\right\} \quad \ldots\ldots\ldots\ldots (3)$$

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, $\omega_s = \cos^{-1}(-\tan\theta \tan\boldsymbol{\delta})$.

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 solar system application. The data would also provide a simulation basis in Nigeria just like in the US, where some location data are used to simulate for other locations. The long term benefit can out-weigh the cost constrain and last longer 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

Long term averages of Sunshine hours (hrs), Minimum/ maximum ambient temperature (^oC) and Monthly average daily global solar radiation on horizontal surface ($kWh/m^2/day$) were collected from the meteorological stations of several governmental and non governmental agencies within the North-west region of Nigeria. The study area is 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 study 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 based on the latitude, longitude, altitude and axial location/distances between the cities in order to come up with locations that would adequately represent the whole state. The parameters considered for this purpose are either for a location or a state average.

The minimum/ maximum ambient temperature (^oC) 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 of sunshine hours (hrs) and daily global solar radiation on horizontal surface (kW/m^2 /day) were received as ground measurements from the Nimet data bank.

Two models represented in Equations (1) and (2) that utilize ambient temperatures and sunshine hours were 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 ($kW/m^2/day$) of all the locations were also computed based on equation (3). The following hypotheses were also considered for the validation of the results in addition to other statistical validation tools.

- **I.** There is no significant difference between the estimated (predicted) average monthly solar radiation value using sunshine hours and ambient temperature based prediction models.
- **II.** There is no significant difference between the monthly variations of average mean daily solar radiation data of each city within the North-Western Nigeria cities.

Microsoft 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. 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.

$$R^2 = \frac{\sum_1^N (PHs - MPHs)^2}{\sum_1^N (MHs - MMHs)^2} \quad \text{...(3)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MHs - PHs)^2} \quad ....(4)$$

$$CRM = \sum_{i=1}^{N} PHs - \sum_{i=1}^{N} MHs \quad ....(5)$$

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

Statistical Package for Social Scientist (SPSS) was also used for testing the hypotheses raised for the validation of result. The analysis was based on the following criterion and assumptions for each of the hypothesis.

Hypothesis 1: Paired sample t-statistics test was used here under the following
Criterion: Reject the H_o if $p \leq 0.05$, and Accept the H_o when $p > 0.05$

Hypothesis 2: One-way analysis of variance (ANOVA) test, was also used under the following
Criterion: Reject the H_o if $p \leq 0.05$, and Accept the H_o when $p > 0.05$

RESULTS AND DISCUSSION

The data collected from the field were sorted, analyzed and presented in a long term average of 22years for satellite measurements of sunshine, ambient temperature and insolation values while, 10years ground measurements of ambient temperature and sunshine hours with 30years insolation values. It is therefore, presented in Tables 1.1 - 1.7 for comparison between the ground and satellite measurement.

It can be noted from Table 1.4 that, Insolation data is not available in Jigawa state as there is no Airport where the airdrome station is located and there is no ground measurement of ambient temperature in Kebbi state due to lack of proper record management of the data. Thus, satellite measurements were used in the two (2) locations where there is no ground measurement.

Table 1.1: Long Term Average of Meteorological Data in Kaduna State

Location: Kaduna			Latitude: 10.52							
Months	**Sunshine (hrs)**		**Ambient Temperature (ºc)**						**Insolation (KwH/m²/day)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	7.9000	11.5	18.7	30.2	11.5	17.2	40.4	23.2	6.1	5.73
Feb	8.1333	11.8	16.2	30.4	14.2	18.7	42.9	24.2	6.6	6.00
Mar	7.1222	12.0	20.0	35.0	15.0	21.2	42.6	21.4	6.8	6.38
Apr	7.9778	12.3	18.0	35.0	17.0	22.0	36.0	14	6.6	6.84
May	8.0000	12.6	19.0	34.0	15.0	21.9	32.4	10.5	6.0	6.65
Jun	8.2444	12.7	18.0	33.0	15.0	21.4	29.8	8.4	5.6	6.36
Jul	6.2556	12.6	17.0	32.0	15.0	20.8	28.2	7.4	5.2	6.48
Aug	5.4000	12.4	16.0	35.0	19.0	20.4	28.8	8.4	5.2	6.65
Sep	6.7778	12.2	15.0	29.0	14.0	20.6	30.6	10	5.6	6.46
Oct	8.1444	11.9	13.0	32.0	19.0	19.4	32.6	13.2	5.9	6.13
Nov	9.0222	11.6	28.1	36.8	8.7	17.9	38.5	20.6	6.4	6.20
Dec	8.6333	11.5	16.4	32.9	16.5	17.3	39.2	21.9	6.1	5.58

Table 1.2: Long Term Average of Meteorological Data in Kano State

Location: Kano							Latitude: 12.00			
Months	**Sunshine (hrs)**		**Ambient Temperature (ºc)**						**Insolation (KwH/m^2/day)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	7.5556	11.5	13.8	31.1	17.3	**14.3**	**41.8**	**27.5**	5.9	5.57
Feb	7.0444	11.7	16.6	32.8	16.2	**15.4**	**44.8**	**29.4**	6.6	6.42
Mar	7.0111	12.0	20.2	36.3	16.1	**19.7**	**50.0**	**30.3**	6.9	6.97
Apr	6.9000	12.3	24.3	40.1	15.8	**22.8**	**48.9**	**26.1**	7.0	7.39
May	7.7667	12.6	24.7	38.9	14.2	**23.6**	**42.7**	**19.1**	6.6	7.34
Jun	7.3556	12.8	23.2	34.8	11.6	**22.5**	**35.0**	**12.5**	6.1	7.06
Jul	7.1000	12.7	21.5	31.8	10.3	**21.9**	**31.0**	**9.1**	5.6	6.76
Aug	7.5333	12.5	21.0	30.8	9.8	**21.8**	**31.5**	**9.7**	5.6	6.69
Sep	7.5111	12.2	21.7	32.1	10.4	**21.6**	**33.8**	**12.2**	5.9	6.41
Oct	7.3111	11.8	20.8	34.4	13.6	**20.6**	**43.0**	**23**	6.2	6.15
Nov	8.0889	11.5	16.3	33.9	17.6	**17.9**	**45.2**	**27.3**	6.1	5.81
Dec	7.3889	11.4	14.2	30.2	16.0	**15.0**	**41.4**	**26.4**	5.7	5.37

Table 1.3: Long Term Average of Meteorological Data in Katsina State

Location: Katsina								Latitude 13.06		
Months	**Sunshine (hrs)**		**Ambient Temperature (ºc)**						**Insolation (KwH/m^2/day)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	7.8333	11.4	10.7	36.9	26.2	13.4	41.1	27.7	5.9	5.60
Feb	8.6444	11.7	12.3	37.8	25.5	14.7	44.8	30.1	6.6	6.47
Mar	8.3222	12.0	16.0	39.2	23.2	18.8	50.8	32.0	7.1	7.12
Apr	8.2667	12.4	19.4	40.6	21.2	22.3	51.4	29.1	7.1	7.56
May	8.3556	12.7	19.3	42.0	22.7	23.6	44.9	21.3	6.7	7.54
Jun	7.7556	12.8	18.5	39.9	21.4	22.7	36.9	14.2	6.3	7.48
Jul	7.2333	12.8	18.3	37.0	18.7	22.1	31.8	9.7	5.8	7.30
Aug	7.5667	12.5	19.1	37.0	17.9	21.8	32.3	10.5	5.7	7.01
Sep	7.1444	12.2	18.0	36.4	18.4	21.5	35.3	13.8	5.8	6.67
Oct	8.2444	11.8	18.3	37.3	19.0	20.3	45.3	25.3	5.7	6.26
Nov	8.4222	11.5	14.1	37.9	23.8	17.2	45.5	28.3	6.2	5.90
Dec	6.9000	11.3	11.7	36.0	24.3	14.2	41.1	27.0	5.8	5.38

Table 1.4: Long Term Average of Meteorological Data in Jigawa State

Location: Jigawa						Latitude: 11.78				
Months	**Sunshine (hrs)**		**Ambient Temperature (ºc)**						**Insolation (KwH/m^2/day)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	8.6111	**11.5**	12.0	29.6	**17.6**	**15.1**	**42.1**	**27.0**	**Absent**	5.64
Feb	8.7667	**11.7**	13.2	31.3	**18.1**	**16.4**	**45.1**	**28.7**	**Absent**	6.34
Mar	8.3556	**12.0**	18.5	35.5	**17.0**	**20.6**	**49.2**	**28.6**	**Absent**	6.77
Apr	8.1333	**12.3**	22.9	38.2	**15.3**	**23.2**	**46.8**	**23.6**	**Absent**	7.14
May	8.4000	**12.6**	24.3	37.2	**12.9**	**23.4**	**40.8**	**17.4**	**Absent**	7.05
Jun	9.0333	**12.8**	23.8	35.9	**12.1**	**22.3**	**34.1**	**11.8**	**Absent**	6.73
Jul	7.8667	**12.7**	22.6	33.3	**10.7**	**21.7**	**30.6**	**8.9**	**Absent**	6.63
Aug	7.1222	**12.5**	20.1	29.9	**9.8**	**21.5**	**31.1**	**9.6**	**Absent**	6.67
Sep	8.3889	**12.2**	20.1	31.8	**11.7**	**21.4**	**33.3**	**11.9**	**Absent**	6.46
Oct	8.8667	**11.8**	20.2	33.9	**13.7**	**20.5**	**40.6**	**20.1**	**Absent**	6.10
Nov	9.0889	**11.5**	16.6	33.1	**16.5**	**18.3**	**44.1**	**25.8**	**Absent**	5.71
Dec	8.9333	**11.4**	12.0	29.6	**17.6**	**15.8**	**41.4**	**25.6**	**Absent**	5.34

Table 1.5: Long Term Average of Meteorological Data in Zamfara State

Location Zamfara									Latitude: 12.16	
Months	**Sunshine (hrs)**		**Ambient Temperature (°c)**						**Insolation ($KwH/m^2/day$)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	7.6333	11.5	22.1	36.5	14.4	14.9	42.2	27.3	6.0	5.57
Feb	8.2556	11.7	25.5	38.2	12.7	16.2	45.2	29.0	6.7	6.35
Mar	7.500	12.0	29.0	40.5	11.5	19.8	49.2	29.4	7.1	6.86
Apr	7.8444	12.4	31.3	41.8	10.5	22.5	47.1	24.6	7.0	7.21
May	7.7778	12.6	28.9	40.9	12.0	23.3	40.8	17.5	6.4	7.25
Jun	8.2333	12.8	26.3	39.4	13.1	22.5	33.8	11.3	6.0	7.14
Jul	7.0556	12.7	24.9	38.9	14	22.0	30.7	8.7	5.5	6.82
Aug	6.7889	12.5	24.5	36.5	12.0	21.8	31.1	9.3	5.4	6.72
Sep	7.9444	12.2	26.3	36.2	9.9	21.6	33.0	11.4	5.8	6.51
Oct	8.5778	11.8	27.0	36.9	9.9	20.2	40.5	20.3	6.4	6.15
Nov	8.2556	11.5	26.7	37.4	10.7	17.7	45.1	27.7	6.6	5.71
Dec	8.0111	11.4	26.6	38.2	11.6	15.4	42.0	26.6	5.9	5.32

Table 1.6: Long Term Average of Meteorological Data in Sokoto State

Location : Sokoto								Latitude: 13.05		
Months	**Sunshine (hrs)**		**Ambient Temperature (°c)**						**Insolation ($KwH/m^2/day$)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	8.1778	**11.4**	17.14	33.26	16.1	**14.9**	**42.0**	**27.1**	5.8	**5.56**
Feb	8.5000	**11.7**	19.85	35.86	16.0	**16.2**	**45.6**	**29.4**	6.4	**6.47**
Mar	7.5444	**12.0**	23.45	39.72	16.3	**20.0**	**51.4**	**31.4**	6.8	**7.06**
Apr	7.2556	**12.4**	27.19	41.43	14.2	**23.2**	**52.7**	**29.5**	6.8	**7.49**
May	8.3889	**12.7**	27.40	39.67	12.3	**24.6**	**46.5**	**21.9**	6.2	**7.42**
Jun	8.6889	**12.8**	25.59	36.39	10.8	**23.6**	**38.8**	**15.2**	6.0	**7.45**
Jul	7.9000	**12.8**	23.83	32.65	8.8	**22.8**	**33.3**	**10.5**	5.3	**7.24**
Aug	8.5000	**12.5**	22.93	31.03	8.1	**22.3**	**32.9**	**10.6**	5.3	**6.96**
Sep	8.0889	**12.2**	26.26	32.56	6.3	**22.1**	**35.3**	**13.3**	5.6	**6.66**
Oct	8.4333	**11.8**	22.94	35.58	12.6	**21.1**	**44.8**	**23.7**	5.9	**6.24**
Nov	8.4667	**11.5**	20.44	36.82	16.4	**18.2**	**46.3**	**28.1**	5.9	**5.88**
Dec	8.0000	**11.3**	17.72	33.89	16.2	**15.7**	**42.2**	**26.5**	5.6	**5.36**

Table 1.7: Long Term Average of Metrological Data in Kebbi State

Location: Kebbi									Latitude: 12.45	
Months	**Sunshine (hrs)**		**Ambient Temperature (°c)**						**Insolation ($KwH/m^2/day$)**	
	Ground (10yrs LTA)	**Satellite (22yrs LTA)**	**Ground**			**Satellite (22yrs LTA)**			**Ground (30yrs LTA)**	**Satellite (22yrs LTA)**
			Min	**Max**	**Δ T**	**Min**	**Max**	**Δ T**		
Jan	8.9889	11.4	Absent	Absent	Absent	16.8	43.7	26.9	9.6	5.41
Feb	8.4333	11.7	Absent	Absent	Absent	18.0	46.5	28.5	10.3	6.34
Mar	7.5111	12.0	Absent	Absent	Absent	21.6	50.7	29.1	10.7	6.86
Apr	7.8444	12.4	Absent	Absent	Absent	24.5	50.7	26.2	10.6	7.12
May	7.8667	12.7	Absent	Absent	Absent	25.0	44.6	19.6	9.8	7.18
Jun	7.7556	12.8	Absent	Absent	Absent	23.7	37.6	13.9	9.2	7.13
Jul	6.2222	12.7	Absent	Absent	Absent	22.9	32.9	10.0	8.6	6.87
Aug	5.8111	12.5	Absent	Absent	Absent	22.5	32.5	10.0	8.5	6.79
Sep	7.1222	12.2	Absent	Absent	Absent	22.3	34.4	12.1	8.7	6.60
Oct	8.4889	11.8	Absent	Absent	Absent	21.7	42.4	20.7	9.3	6.17
Nov	8.2667	11.5	Absent	Absent	Absent	19.5	46.3	26.8	9.9	5.76
Dec	8.5000	11.4	Absent	Absent	Absent	17.3	43.3	26.0	9.6	5.30

Extraterrestrial Radiations (Ho) of the twenty one (21) Locations of the study area was computed using Equation (4) in $MJ/m^2/day$ and converted to $kWh/m^2/day$ for homogeneity and that of Kaduna state is presented in Table 2.

Table 2: Monthly Average Daily Extraterrestrial Radiations (kWh/m²/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 whole 21 locations and therefore same solar declination ($\boldsymbol{\delta}$) 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 state covered in the research were derived based on Micro soft plotter. Monthly ratio of $\frac{\mathbf{Hs}}{\mathbf{Ho}}$ against that of $\frac{\boldsymbol{\Delta T}}{N}$ and $\frac{n_s}{N}$ for all the seven states ware plotted in order to obtain the empirical constants and the trend line that display equation and R-square value on chart using scatter mode plotter. The constants *a* and *b* of both the temperature and sunshine base estimation model were derived and figure 1 and 2 present the details of the plot for Kaduna state with Table 3 presenting the summary of the empirical constants.

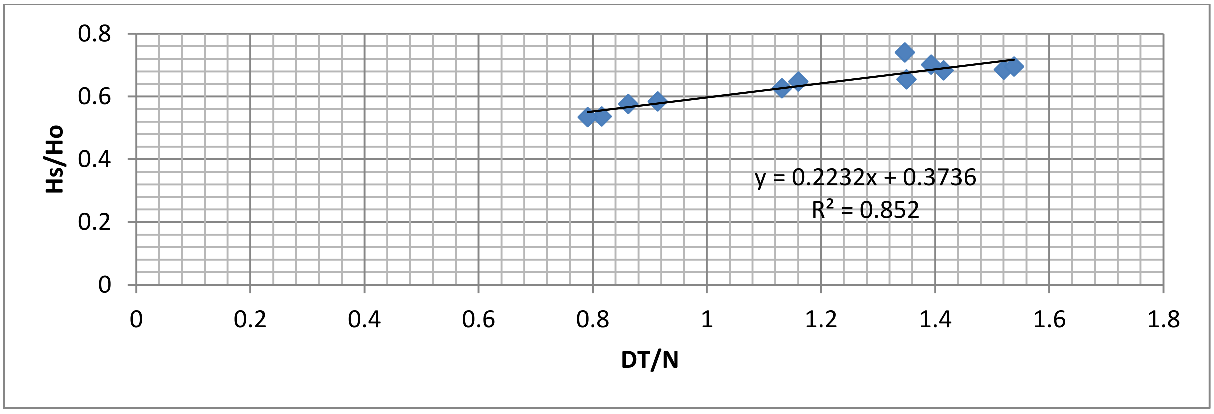

Figure 1: Derived empirical constants of Kaduna state for the temperature based

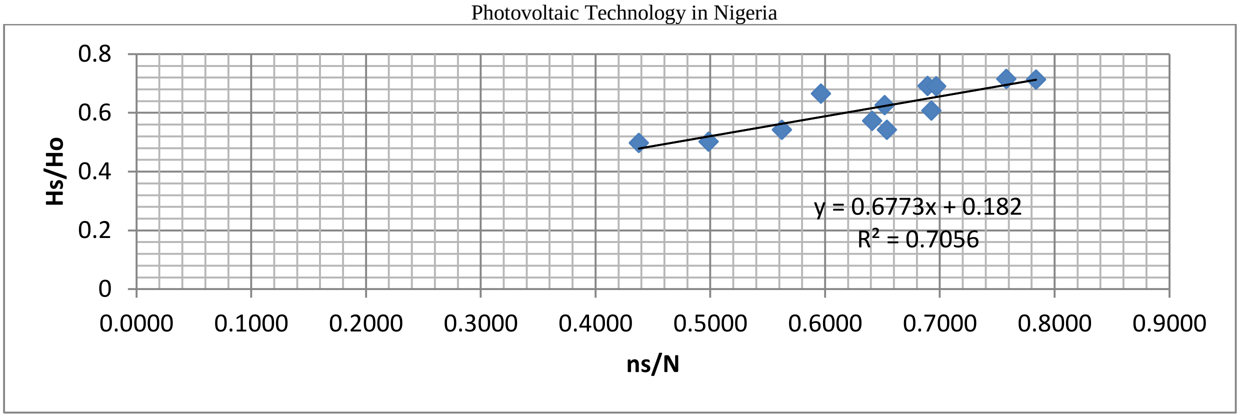

Figure 2: Derived empirical constants of Kaduna state for the sunshine based model

Table 3: Summary of Derived Empirical Constants of Location

S/n	Location or State	Empirical Constants			
		Temperature based		Sunshine based	
		A	b	a	B
1	Kaduna	0.373	0.223	0.182	0.677
2	Kano	0.373	0.223	0.192	0.721
3	Katsina	0.277	0.201	0.069	0.873
4	Jigawa	0.616	0.033	0.657	0.000
5	Zamfara	0.624	0.022	0.076	1.102
6	Sokoto	0.546	0.085	0.178	0.664
7	B/kebbi	0.654	0.195	0.245	1.162

Based on the empirical constants derived summarized in Table 3 for each states, Equations (1) and (2) were used for the estimation of insolation levels of the seven (7) locations using the sunshine and temperature based models respectively and the results is in Table 4.

Table 4: Estimated Insolation Levels of States KwH/m^2/day

Month	Kaduna		Kano		Katsina		Jigawa		Zamfara		Sokoto		Kebbi- Yawuri	
	Temp.	Sun shine	Temp.	Sun Shine	Temp.	Sun shine	Temp.	Sun shine	Temp.	Sun shine	Temp.	Sun shine	Temp.	Sun shine
Jan	5.6526	5.7149	6.1375	5.7814	6.2940	5.7079	5.7695	5.6830	5.6189	7.0268	5.6552	5.5771	9.6993	9.9747
Feb	5.9034	6.2440	6.4328	5.9162	6.6961	6.7043	6.2932	6.1955	6.0981	8.0825	6.0895	6.1044	10.4407	9.6444
Mar	6.2731	5.9871	7.1101	6.4958	6.7456	6.8477	6.7363	6.6751	6.5488	7.8032	6.6876	6.0388	11.4407	9.8928
Apr	6.3158	6.5691	6.3624	5.8223	5.9987	6.4143	6.2346	6.2152	6.0765	7.6743	6.0753	5.5169	10.3434	9.6240
May	6.4830	6.4430	6.5972	6.7329	6.7811	6.8744	6.8507	6.9247	6.8114	8.0088	6.6734	6.5790	10.0788	10.2666
Jun	6.4105	6.4460	6.0223	6.3675	6.4480	6.2959	6.7469	6.8459	6.7515	8.2519	6.5008	6.6291	9.0091	9.9830
Jul	6.4163	5.3711	5.7927	6.2359	6.0300	5.9607	6.7167	6.8525	6.7756	7.2274	6.3640	6.2211	8.4130	8.5575
Aug	6.0827	4.9929	5.7629	6.6126	5.9615	6.3210	6.7102	6.8853	6.7628	7.1245	6.3271	6.6531	8.4940	8.2903
Sep	6.4418	5.8080	5.7888	6.5643	5.9566	5.9804	6.6422	6.7342	6.5747	8.2117	6.0335	6.3669	8.7177	9.5265
Oct	5.5704	6.3133	6.0523	6.1481	5.7263	6.4926	6.2836	6.3072	6.1559	8.4548	4.7021	5.5877	9.6175	10.3734
Nov	5.9929	6.3855	6.2872	6.1617	6.1616	6.3164	5.8394	5.7816	5.6529	7.6408	5.7748	5.8024	9.8379	9.4712
Dec	5.0494	5.9226	5.7488	5.5363	5.8275	4.9542	5.592	5.5056	5.3925	7.1495	5.4809	5.3314	9.3021	9.2899

Thus, to analyze or evaluate 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 in temperature and sunshine based models as described in the methodology. The details of the plots with slopes, intercept and R^2 for Kaduna state as a sample is presented in Figure 3 and 4.

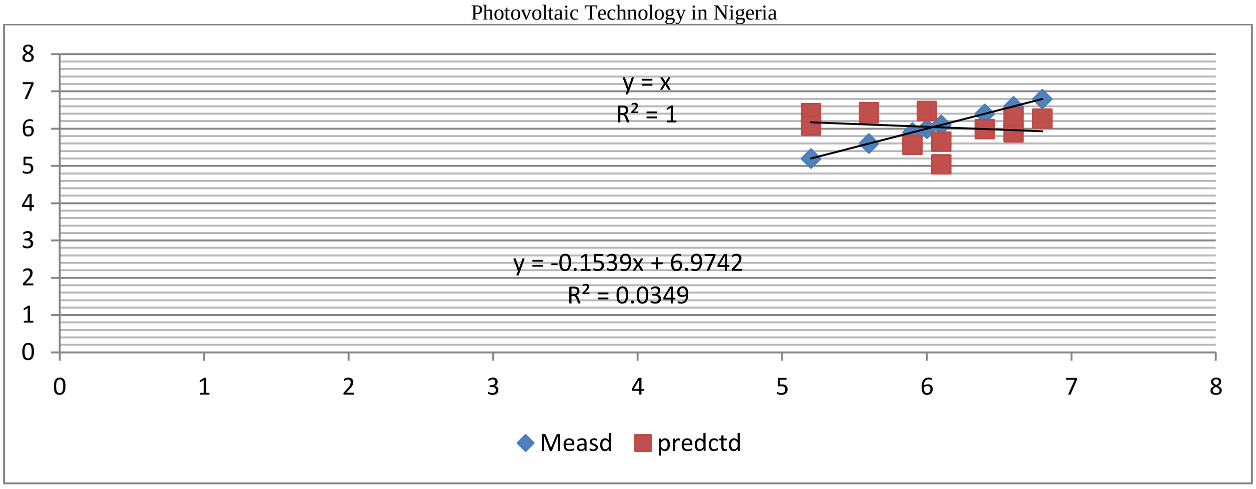

Figure 3: Measured and estimated temperature based insolation levels of Kaduna state

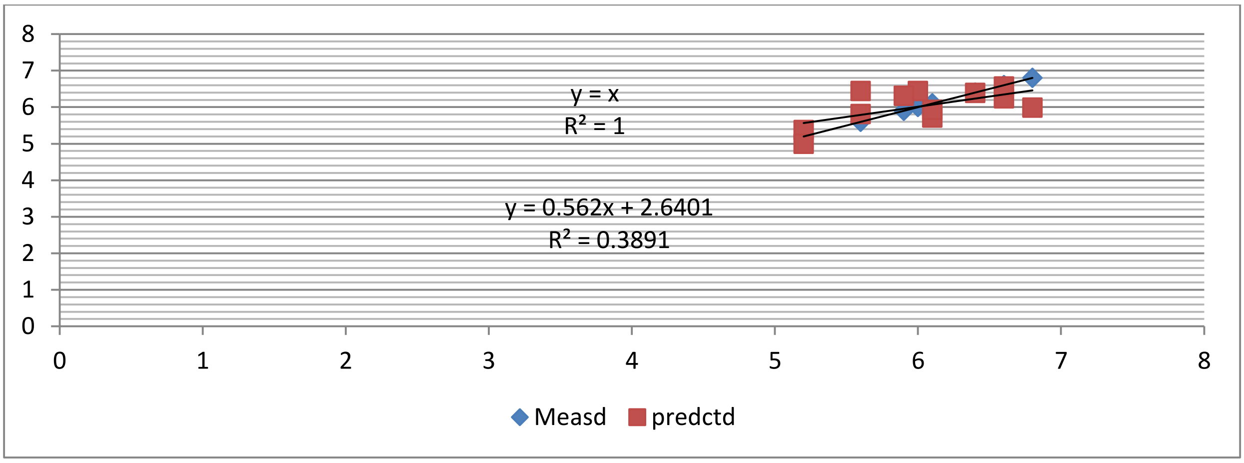

Figure 4: Measured and estimated sunshine based insolation levels of Kaduna state

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), Mean Square Error (MSE), Root mean square (RMSE) and Coefficient of Residual Mass (CRM). The results of validation based on each state are presented in Table 5.

Table 5: Model Validation Indicators

State	R^2		RMSE		CRM	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Kaduna	0.6797	0.8117	0.7233	0.4249	0.4919	0.0982
Kano	0.6210	0.5184	0.2374	0.5792	-0.105	0.1755
Katsina	0.6045	0.8433	0.5242	0.3928	2.527	0.6704
Jigawa	0.8693	0.8503	0.8547	0.6835	4.3153	2.4062
Zamfara	0.9046	0.6210	0.9038	0.2374	3.1196	-0.105
Sokoto	0.9969	0.8964	0.7655	0.7002	0.2642	-1.7914
Kebbi	0.3583	0.6891	3.6320	3.4283	43.2942	40.6947

It is therefore noticed 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 with the case of temperature base model in Kebbi state. The values of RMSE show low and high precisions depending on the locations and more generous in the temperature base model. The models under estimate only in the case of Zamfara and Sokoto sunshine base estimation and Kano temperature base estimation 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 two (2) hypotheses raised using SPSS package. The test result in Table 6 for hypothesis 1 shows there is no significant difference between the estimated (predicted) average monthly solar radiation value using sunshine hours and ambient temperature models in all the seven (7) locations. The conclusion was based on the paired sample t-statistic test that accept the H_o when $p > 0.05$.

Table 6: Paired Sample t-statistic Test Results

Between Sunshine and Temperature base estimation	Paired Differences					T	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Kaduna State	.03287	.63289	.18270	-.36925	.43499	.180	11	.861
Kano State	-.24175	.42073	.12146	-.50907	.02557	-1.990	11	.072
Katsina State	.20153	.72327	.20879	-.25801	.66108	.965	11	.355
Jigawa State	.12767	.63433	.18311	-.27536	.53071	.697	11	.500
Zamfara State	.00615	.44726	.12911	-.27803	.29033	.048	11	.963
Sokoto State	-.04592	1.01358	.29259	-.68992	.59807	-.157	11	.878
Kebbi State	.17921	.78147	.22559	-.31732	.67573	.794	11	.444

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 7 disclosed no significant difference as $P< 0.05$ and the null hypothesis was accepted.

Table 7: One-way Analysis of Variance (ANOVA) Test

	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 based on temperature base model and the highest was 11 5337 KwH/m^2/day in Zuru based on temperature base model.

These seems to be in conformity with what Ojosu (1989), measured and presented as the average 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. Consequently, 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 base models respectively.

It is also interesting to note that, even the highest estimation value 'more in the case of temperature based estimations in Kebbi state does not greatly over estimate the monthly average global solar radiation based on the validations and comparison with the measured values.

CONCLUSION

It is now evident that, the study is able to come up with the insolation data necessary for sizing/designing the solar system for efficient utilization of insolation 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 5.0257kWh/m^2/day and 11.5337kWh/m^2/day in the case of estimations throughout the year.
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 two estimation models can be used with respect to the empirical constant described by computing the location extraterrestrial radiation (H_o) for their closest locations. The contributions of these 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	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Jan	5.5500	5.6218	5.7360	5.7740	6.1802	6.0034	6.1375	5.9695	6.2940	5.7516	6.4424	5.8501	5.7094	5.6239
Feb	5,8724	6.2152	5.9590	6.2912	6.4670	6.5822	6.4328	6.5515	6.6961	6.3460	6.8040	6.4233	6.2531	6.1561
Mar	6.2547	5.9696	6.2915	6.0013	6.8607	6.3364	6.8405	6.3177	6.7456	5.9608	6.7991	6.0080	6.7164	6.6554
Apr	5.7286	6.1342	5.7765	6.1705	6.3893	6.4717	6.3700	6.4552	5.9987	6.2128	6.0820	6.2846	6.2016	6.1824
May	6.5016	6.4507	6.4458	6.4206	6.5784	6.8626	6.5972	6.8744	6.7811	6.6131	6.7236	6.5895	6.8637	6.9379
Jun	6.4354	6.4602	6.3609	6.4178	5.9992	6.8760	6.0223	6.8948	6.4603	6.6644	6.3866	6.6255	6.7792	6.8788
Jul	6.4411	5.3836	6.3728	5.3486	5.7761	5.7074	5.7983	5.7382	6.0243	5.2482	5.9669	5.2302	6.7489	6.8854
Aug	6.0943	4.9975	6.0652	4.9539	5.7574	5.3107	5.7629	5.3104	5.9615	4.7189	5.9388	4.7170	6.7423	6.8985
Sep	6.4106	5.7767	6.4230	5.7912	5.8001	6.1273	5.7888	6.1154	5.9682	5.7209	5.9857	5.7418	6.6292	6.7211
Oct	5.5475	6.2911	5.6164	6.3576	6.0776	6.6629	6.0523	6.6393	5.7263	6.4219	5.8047	6.4949	6.0610	6.0838
Nov	6.0063	6.4081	6.0665	6.4431	6.0223	6.3885	6.2729	6.6630	5.9106	6.4492	6.2104	6.7332	5.7864	5.7290
Dec	5.0257	5.9063	5.1502	6.0175	5.7901	6.2351	6.0861	6.1913	5.8346	6.0593	5.9912	6.1722	5.5320	5.4465

Months	Kazaure		Mafara		Kauran namoda		Issah		Tambuwal		Birnin Kebbi		Zuru	
	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine	Temperature	Sunshine
Jan	6.6894	5.6042	5.5667	7.1995	5.5667	7.1995	5.6419	5.4296	5.7086	5.4764	9.5542	9.0205	9.7998	9.1205
Feb	6.3733	6.1430	6.0657	7.9373	6.0540	7.9288	6.1625	5.9824	6.2155	6.0264	10.2643	9.3825	10.5068	10.0026
Mar	6,5971	6.5372	6.5259	7.4343	6.5295	7.4270	7.0782	6.1404	6.7074	5.9117	11.4433	9.5092	11.5337	9.5561
Apr	6.2016	6.1824	6.0507	7.7656	6.0507	7.7656	6.0688	5.4626	6.1142	5.9345	10.2562	9.7485	10.4088	9.8186
May	6.8832	6.9576	6.8243	8.2126	6.7662	8.2185	6.6797	6.3641	6.6483	6.3483	10.1172	10.3967	10.0405	10.3822
Jun	6.7922	6.8919	6.7773	8.2760	6.7967	8.2839	6.5070	6.3884	6.4699	6.3696	9.0785	10.4506	8.9658	10.4078
Jul	6.7554	6.8919	6.7951	6.5031	6.8145	6.5217	6.3701	5.3210	6.3880	5.3016	8.4694	8.5897	8.3482	8.5560
Aug	6.7487	6.9051	6.7822	5.8385	6.7822	5.8385	6.3271	4.9072	6.3151	4.9052	8.5183	7.8858	8.4615	7.8762
Sep	6.8107	6.9051	6.5683	7.1080	6.6015	7.1080	6.0279	5.6243	6.0394	5.6385	8.6919	9.1871	8.7343	9.2140
Oct	6.2378	6.2612	6.1238	8.0285	6.1367	7.7973	5.2380	6.0692	5.2767	6.1103	9.5276	10.0473	9.6674	10.1222
Nov	5.7664	5.7093	5.5369	7.4419	5.6078	8.2422	5.7681	6.0792	5.8350	6.1336	9.6934	10.1415	9.9268	10.2573
Dec	5.5120	5.4268	5.3473	7.6099	5.3408	7.6007	5.4675	5.6279	5.5410	5.6886	9.1476	9.4038	9.4014	9.5229