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CHARACTERIZATION OF SKY CONDITIONS USING CLEARNESS INDEX AND RELATIVE SUNSHINE DURATION FOR ISEYIN, NIGERIA

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ABSTRACT: *The global solar radiation and sunshine duration data collected over a period of 8 years (2000 - 2007) was examined. The mean monthly clearness index and sunshine duration was calculated and used to develop an Angstrom- page equation for the region. It was observed that the equation has a high correlation coefficient, which gives good results when it was tested with statistical indicators of MBE, MABE and RMSE. Statistical analysis of monthly clearness index showed that the sky conditions at Iseyin were most of time partly cloudy (partly cloudy sky occurred in eight months of the year which is about 66% most of these months falls in the rainy season months). Cloudy sky was only noticed in the month of August which is about 8% and it occurs at the peak of the rainy season. The region has three months of clear sky which is about 25% of the months of the year and they are months in the Harmattan period. The prevailing sunshine condition in Iseyin is predominantly scattered clouds sky except during August and September where a cloudy sky condition is experienced.*

KEYWORDS: Global solar radiation, Sunshine duration, Clearness index, Iseyin

INTRODUCTION

The availability of solar radiation and other meteorological parameters are important to solar engineers in order to give an accurate estimate of the available solar energy resource. In assessing the performance of system utilizing solar energy, an important parameter to note is the extraterrestrial radiation Ho reaching the top of the Earth's atmosphere from the sun, which is found to be considerably depleting in the atmosphere due to absorption, reflection and scattering. The amount of radiation that eventually gets to the Earth's surface is known as the global solar radiation H. The ratio of these two radiations (H/H_o) is known as the clearness index (K_T) of the atmosphere.

The clearness index is a measure of solar radiation extinction in the atmosphere, which includes effects due to clouds but also effects due to radiation interactions with other atmospheric parameters. The scattering and reflection of some of the solar beam as it passes through the atmosphere, gives rise to diffuse solar radiation (H_d). The ratio of the diffuse to global solar radiation (H_d/H) is known as the cloudiness index of the atmosphere. The clearness index and the diffuse fraction of solar radiation have been used to describe the sky conditions at different places around the world among which are Liu and Jordan (1960); Choudhury, (1963); Barbaro et al., (1981); Saunier et al., (1987); Al-Riahi et al., 1990; Akuffo and Brew-Hammond (1993) and Muneer, (1998). In Nigeria researchers have also work on the aforementioned parameters among which are Ideriah and Suleman (1989); Kuye and Jagtap (1992); Udo (2000); Okogbue and Adedokun (2002b) where carried out for Ibadan, Port Harcourt, Ilorin and Ile-Ife respectively.

One of the ways of estimating the incident solar radiation required for designers, is by establishing the sky conditions of that region. These conditions are imbedded in the clearness index, cloudiness index and the relative sunshine duration of that region. The relation between the clearness and sunshine duration was first demonstrated by Angstrom (1924) using a linear model:

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right) \quad (1)$$

Where a and b are the model parameters. The S is the measured sunshine duration hours and S_o is the potential day length astronomical length. From a mathematical point of view, a is the intercept and b is the slope parameter of a linear equation. When the sky is completely clear, the sunshine duration hour become equal to day length ($S = S_o$). For completely overcast sky, the sunshine duration hour, S, is equal to zero.

The main purpose of this paper is to characterize the atmospheric condition of Iseyin based on the clearness index and using this index with relative sunshine duration to predict the amount of solar radiation received in the region.

METHODOLOGY

Site Description

The global solar radiation and sunshine hours data used in this study were obtained from the Archives of Nigeria Meteorological Agency Oshodi, Lagos. The data collected covered a period of 8 years (2000 - 2007) for Iseyin located at latitude 7.98°N and longitude 3.6°E. The global solar radiation data were captured using Gun-Bellani distillate, calibrated in milliliter and were converted and standardized into MJ/m^2 using equation proposed by Folayan (1988)

$$H = (1.35 \pm 0.176)H_{GB} \quad (2)$$

Where H_{GB} is the data measured using the Gun-Bellani distillate.

Equation used

For clearness index to be determined, H_o, S and S_o must be firstly be determined. Ho is evaluated from the equation given by Iqbal, (1983)

$$H_o = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180} W_s sin\emptyset Sin\delta + cos\emptyset cos\delta Sin W_s\right) \quad (3)$$

Where I_{sc} is the solar constant with a value of 1367Wm^{-2}, E_o is the eccentricity correction factor of the Earth's orbit, δ the solar declination, Ws is the sunrise hour angle and Ø is the geographical latitude. E_o is evaluated from Spencer, 1871

$$E_o = 1.000110 + 0.034221 \cos \gamma + 0.0001280 \sin \gamma + 0.000719 \cos 2\gamma + 0.000077 \sin 2\gamma \quad (4)$$

where $\gamma = 2\pi/360(N-1)$.

N is the day of the year, starting with 1 for January 1st and 365 for December. The solar declination angle can be determined according to Spencer, 1871

$\delta = (0.006918 - 0.399912 \cos \gamma + 0.070257 \sin \gamma - 0.006758 \cos 2\gamma + 0.000907 \sin 2\gamma - 0.002697 \cos 3\gamma + 0.00148 \sin 3\gamma)(180/\pi)$ (5)

The sunrise hour angle, W_s, is given as:

$$W_s = cos^{-1}(-\tan \emptyset \tan \delta) \quad (6)$$

The daylength hour is given as:

$$S_o = \frac{2}{15} W_s = \frac{2}{15} cos^{-1}(-tan\emptyset\ tan\delta) \quad (7)$$

Comparison of correlation model

The performance of the correlation model in eqn (1) was evaluated and compared using the following statistical error parameters: Mean bias error (MBE), mean absolute bias error (MABE) and root mean square error (RMSE). The MABE is an overall measure of prediction accuracy while the MBE is an overall measure of prediction bias. The MBE provide information relating to overestimation or underestimation of the estimated parameter. Positive and negative MBE show overestimation and underestimation respectively. The MBE can mislead the user because errors of different signs may cancel out each other. The RMSE provides information on the short-term performance of the correlations by allowing a term-by-term comparison of deviation between the calculated and the measured values. The lower the error terms, the more accurate the estimate. The error parameter can be obtained by the following equations:

$$\text{MBE} = \left[\sum\left(H_{i,c} - H_{i,m}\right)\right]/n \quad (8)$$

$$\text{MABE} = \left[\sum\left(\left| H_{i,c} - H_{i,m} \right|\right)\right]/n \quad (9)$$

$$\text{RMSE} = \left\{\left[\sum\left(H_{i,c} - H_{i,m}\right)^2\right]/n\right\}^{1/2} \quad (10)$$

where $H_{i,c}$ and $H_{i,m}$ are the calculated and measured values of monthly global solar radiation respectively and n is the total number of observation.

In sky conditions classification, the clearness index is often used because it depends mainly on global solar irradiance (Li et al., 2004; Muneer, 1995). Low clearness index implies low global solar radiation, which is usually a function of a cloudy sky with a high portion of diffuse component of solar radiation. Large clearness index implies high global solar radiation, dominated by direct component of solar radiation. Many researchers have adopted different values, for the classification of the sky conditions. Among which are Reindl et al. (1990) who proposed $K_T > 0.6$ and $K_T < 0.2$ for clear sky and cloudy sky respectively. Kuye and Jagtap (1992) used $K_T > 0.65$ and $0.12 \leq K_T \leq 0.35$ for very clear skies and cloudy skies respectively for sky conditions of Port Harcourt in Nigeria. Li and Lam (2001) and Li et al. (2004) proposed K_T values of 0-0.15, >0.15 – 0.7 and >0.7 to represent overcast, partly cloudy and clear skies

respectively for Hong Kong. In this research work the classifications of Kuye and Jagtap (1992) were applied to classify the sky condition of Iseyin with little modification.

RESULTS AND DISCUSSIONS

Clearness index and sunshine duration

The monthly average clearness index and the sunshine duration for Iseyin is presented in table 1. The clearness index – a fraction of solar radiation at the top of the atmosphere that reaches a location on the earth's surface varies between 0.34 in August and 0.65 in November, with an annual average of 0.53. These values provide information on the level of availability of solar radiation and sky conditions at a particular location on the earth's surface. Applying the sky conditions classification proposed by Kuye and Jagtap (1992), which states that for cloudy sky ($0.12 \leq K_T \leq 0.35$), partly cloudy sky ($0.35 \leq K_T \leq 0.65$) and for clear sky ($K_T > 0.65$), the sky condition in Iseyin is partly cloudy throughout the months except August which is cloudy with clearness index of 0.34 and a clear sky in February, November and December with clearness index of 0.65, 0.67 and 0.68 respectively. The climate of Nigeria is influenced by the north-south movement of the Inter-Tropical Discontinuity as is broadly divided into two seasons, namely, dry season (November to March/April) and wet season (April/May to October). The dry seasons has three classifications: the Harmattan period (December to January) when the cold and dust-laden north-easterly trade winds from the Sahara desert keep the atmosphere dusty with characteristic hazy cloud conditions. November, February and March are cloud and dust-free months of high irradiation and clear sky condition. April is a transition between the dust free period and the rainy season. During the rainy season, August stands out as month of least average monthly clearness index.

The relative sunshine duration varies between 0.23 in August and 0.65 in November with an annual average of 0.47.The world meteorological organization, in 2008, proposed and classified the sky conditions with respect to sunshine hour, it states that for cloudy sky ($0 \leq S/S_o < 0.3$), scattered clouds sky ($0.3 \leq S/S_o < 0.7$) and cloudy sky ($0.7 \leq S/S_o < 1.0$). From these classification the sunshine condition in Iseyin throughout the months of the year is majorly of scattered clouds sky except during August and September where a cloudy sky condition is experienced with relative sunshine duration of 0.23 and 0.29 respectively.

Table 1: Monthly variation of clearness index and sunshine duration for Iseyin

Month	K_T	S/S_o
Jan	0.56	0.45
Feb	0.65	0.57
Mar	0.60	0.55
Apr	0.56	0.56
May	0.57	0.53
Jun	0.48	0.48
Jul	0.38	0.30
Aug	0.34	0.23
Sep	0.41	0.29
Oct	0.50	0.46

Nov	0.67	0.65
Dec	0.68	0.59

Clearness index and sunshine hour based model

From the Angstrom-page model of equation 1, the scattered plots showing the variation of the clearness index with the relative sunshine duration is presented in Fig 1.

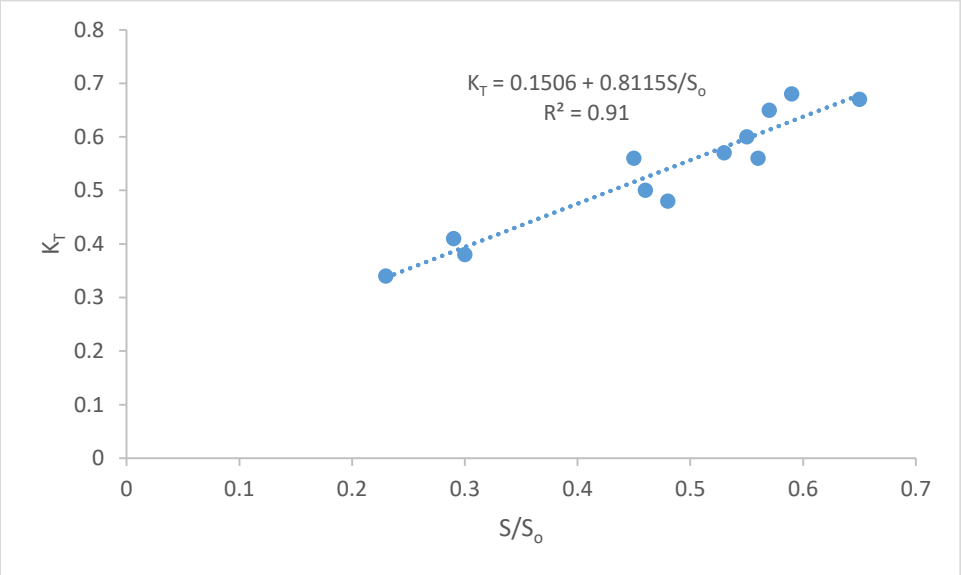

Fig 1. The variation of clearness index with sunshine duration

From the linear model, the correlation coefficient of 0.91 exist between the clearness index and the sunshine duration. The values of a and b are determined as 0.151 and 0.812, respectively, so the Angstrom-page expression for Iseyin is given as:

$$\frac{H}{H_o} = 0.151 + 0.812\frac{S}{S_o} \qquad (11)$$

The value of a is related to the fraction of the global radiation under overcast sky condition while b represents the sensitivity of normalized global radiation to normalized sunshine duration. The sum of these constants (a + b) which is put at 0.963 for Iseyin represents the fraction of global solar radiation under clear sky condition.

Error Analysis

The performance of the model was evaluated and compared using statistical indicators MBE, MABE and RMSE. Table 2 presents the mean monthly error analysis for the model. It was observed that that error parameters varies from one month to another. The MBE obtained lie between -6.453 and 8.178 for the months of January and October respectively with mean value of 0.137. From the table, the MBE values are positive in some cases and negative in others, these shows that the model vary between over and under estimation of the solar radiation. The

model underestimated the solar radiation for the months of January to May, July and August, while other months were overestimated. The mean value of MABE is put at 3.486 with highest value of 6.754 in December and lowest value of 0.407 in July. The RMSE, which is a measure of the accuracy of estimation, have been found to be lowest in April with a value of 0.001 and highest in October with a value of 0.304, while the mean value is put at 0.079. It can be seen that there is good agreement between the measured and estimated data.

Table 2: Statistical error analysis for the model.

	MBE	MABE	RMSE
Jan	-6.453	6.453	0.300
Feb	-3.470	3.470	0.053
Mar	-5.342	5.342	0.046
Apr	-1.021	1.021	0.001
May	-1.452	1.452	0.002
Jun	0.643	0.643	0.000
Jul	-0.407	0.407	0.001
Aug	-1.953	1.953	0.002
Sep	5.421	5.421	0.021
Oct	8.178	8.178	0.304
Nov	6.742	6.742	0.211
Dec	0.754	0.754	0.002
Mean	**0.137**	**3.486**	**0.079**

CONCLUSIONS

The global solar radiation and sunshine hours data were obtained from the Archives of Nigeria Meteorological Agency Oshodi, Lagos. The data collected covered a period of 8 years (2000 - 2007) for Iseyin, South West of Nigeria was used to calculate the mean monthly clearness index and sunshine duration from these an Angstrom- page equation was developed for the region under consideration. It was observed that the equation has a high correlation coefficient, which gives good results when it was tested with statistical indicators of MBE, MABE and RMSE. The equation can be employed to estimate the global radiation for Iseyin and other location that has similar geographical properties with this region

The sky conditions at Iseyin as characterized by clearness index and sunshine duration are presented on monthly bases. Statistical analysis of monthly clearness index showed that the sky conditions at Iseyin were most of time partly cloudy (partly cloudy sky occurred in eight months of the year which is about 66% most of these months falls in the rainy season months). Cloudy sky was only noticed in the month of August which is about 8% and it occurs at the peak of the rainy season. The region has three months of clear sky which is about 25% of the months of the year and they are months in the Harmattan period. The prevailing sunshine condition in Iseyin is predominantly scattered clouds sky except during August and September where a cloudy sky condition is experienced.

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