Correlation of Cloudiness Index with Clearness Index for Four Selected Cities in Nigeria.

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ABSTRACT

The relationship between the cloudiness index and the clearness index has been studied for four selected cities in Nigeria. As a result of this relationship, several linear regression equations were developed. They are:

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.493 - 0.264\frac{\bar{c}}{\overline{C}},$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 1.178 - 11.605\frac{\bar{c}}{\overline{C}},$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.230 - 2.016\frac{\bar{c}}{\overline{C}}, \text{ and}$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.730 - 4.701\frac{\bar{c}}{\overline{C}}$$

for Port harcort, Calabar, Warri, and Uyo, respectively. The values of the correlation coefficient (R) and coefficient of correlation (R^2) were determined for each equation. These values however, reveal that correlations based on cloudiness index are less reliable than the corresponding sunshine correlation. The model can be applied to other locations which have similar climatological characteristics as the four selected cities.

(Keywords: clearness index, cloudiness index, solar radiation, linear regression)

INTRODUCTION

Beam radiation is attenuated by the presence of clouds in its path, and by the various elements of the cloudless atmosphere such as dust, smoke, and water vapor. The depletion of the direct beam by clouds depends on the type of cloud, their thickness, and the number of cloud layers.

The radiation arriving on the ground directly in line with the solar disk is called direct or beam radiation. A portion of the scattered and reflected radiation goes back to space and a portion reaches the ground from the sky hemisphere as diffuse radiation. The sum total of direct and diffuse radiation is called global radiation (Igbal, 1983).

The amount of total (global) solar radiation, H, eventually obtained on the ground surface is found to be a fraction of the extraterrestrial radiation, H_O, at the top of the atmosphere of the site. Extraterrestrial radiation is the maximum amount of solar radiation available to the Earth at the top of the atmosphere, and H is the amount of the radiation eventually available at the ground surface after scattering, reflection, and absorption in the atmosphere. The ratio, H/H_O, is a possible measure of the transparency of the atmosphere to solar radiation. Thus, the ratio is used to define the coefficient of transmission or the transmittance of the atmosphere. The ratio is known as the “clearness index” of the atmosphere and is used as a solar radiation measurement variation (Liu and Jordan, 1960) and (Babatunde and Aro, 1990).

It is also known that scattering and reflection of solar radiation in the atmosphere produce diffuse solar radiation obtained on the ground surface. The diffuse solar radiation, H_d, is also found to be a fraction of the total (global) solar radiation, H. The amount of the diffuse radiation in the total depends on the effectiveness of the scattering agents and reflection of solar radiation by clouds and atmosphere towards the ground; and re-radiation of the sky. The ratio, H_d/H, therefore, is an appropriate parameter to define a coefficient, that is, cloudiness or turbidity of the atmosphere.

The ratio is therefore, termed "cloudiness index" and is also used as solar radiation measurement variable (El- Salam and Sayigh, 1976). The two ratios, H/H_o, and H_d/H, therefore describe different atmospheric conditions related to radiative transfer in the atmosphere.

Although sunshine measuring stations are more numerous than those measuring insolation, there are still too few of them to provide good geographical coverage. Therefore, investigators in the field of insolation climatology have looked at other estimators of insolation. It appears that the total cloud-cover (also called sky-cover) data are more numerous and, in some instances, geographically better-distributed than sunshine data. For example, in some regions of the high north latitudes, cloud-cover data are available, but not sunshine data (Iqbal, 1983).

The cloudiness index has been used in developing solar radiation data and regression equations for a large number of stations in the United States (Solmet, 1978, 1979). Black (1956), using data from many parts of the world, proposed a quadratic equation for correlating cloudiness index with clearness index. The mathematical relationship between the cloudiness index and clearness index for four selected cities in Nigeria is examined in this work.

MATERIALS AND METHODS

The monthly mean daily cloud cover data for four selected cities in Nigeria (Port Harcourt, Calabar, Warri, and Uyo) were collected from the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, Lagos. The global solar radiation data were collected courtesy of Renewable Energy for Rural Industrialization and Development in Nigeria. The data obtained covered a period of 17 years (1991 – 2007). The monthly averages data processed in preparation for the correlations are presented in Tables 1 - 4.

The cloud cover data is published in percents, tenths, or in eighths of sky covered by clouds by meteorologists. The data are based on 24 hour or day–time observations. It is available for nearly all the meteorological stations in Nigeria. For the correlation of cloud cover with global solar radiation, the value of the cloudiness index, $\frac{\bar{c}}{\bar{C}}$ should be some fraction of unity of the daytime – sky covered by clouds.

To develop the model, the global solar radiation data measured in ($Kwhm^{-2}day^{-1}$) was converted to ($MJm^{-2}day^{-1}$) using a factor of 3.6 proposed by Iqbal (1983). It has long been known that a relationship exists between insolation and the amount of sky covered by clouds (Kimball, 1919). The linear correlation usually proposed is:

$$\frac{\bar{H}}{\bar{H}_o} = a - b\frac{\bar{c}}{\bar{C}} \quad \textbf{(1)}$$

where a and b are regression constants, $\frac{\bar{H}}{\bar{H}_o}$ is the clearness index, $\bar{H}_O$ is the extraterrestrial solar radiation, $\bar{H}$ is the measured global solar radiation, $\frac{\bar{c}}{\bar{C}}$ is the cloudiness index, $\bar{c}$ is the cloud cover. Here, $\bar{C}$ = 100. The extraterrestrial solar radiation on horizontal surface is given by Iqbal (1983) as follow:

$$\bar{H}_O = \frac{24}{\pi} I_{sc} E_O \left(\frac{\pi}{180} W_s \sin\phi \sin\delta + \cos\phi \cos\delta \sin w_s \right) \textbf{(2)}$$

where I_{sc} is the solar constant, E_O is the eccentricity correction factor, ϕ is the latitude, δ is the solar declination, and W_s is the hour angle.

The expressions for I_{sc}, E_O, δ, and W_s are given by Iqbal (1983) :

$$I_{sc} = \frac{1367 X 3600}{1000000} \quad \textbf{(3)}$$

$$E_O = 1 + 0.033\cos\left(\frac{360N}{365}\right) \quad \textbf{(4)}$$

$$\delta = 23.45 Sin\left[\frac{360(N+284)}{365}\right] \quad \textbf{(5)}$$

$$W_s = Cos^{-1}(-\tan\phi\tan\delta) \quad \textbf{(6)}$$

The measured global solar radiation and cloud cover were correlated using SPSS computer software program for regression analysis.

Table 1: Meteorological Data and Global Solar Radiation for Port Harcourt.

MONTH	$\bar{c}$ (%)	$\frac{\bar{c}}{\bar{C}}$	$\bar{H}_M$ ($MJm^{-2}day^{-1}$)	$\bar{H}_O$ ($MJm^{-2}day^{-1}$)	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
JAN	7.32	0.0732	14.40	34.28	0.4201
FEB	7.33	0.0733	16.26	36.06	0.4509
MAR	7.39	0.0739	15.16	37.52	0.4041
APR	7.41	0.0741	16.68	37.48	0.4450
MAY	7.41	0.0741	15.16	36.24	0.4183
JUN	7.41	0.0741	13.96	35.13	0.3974
JUL	7.48	0.0748	12.99	35.61	0.3506
AUG	7.51	0.0751	12.52	37.05	0.3516
SEPT	7.49	0.0749	14.02	37.26	0.3763
OCT	7.49	0.0749	14.29	36.18	0.3949
NOV	7.41	0.0741	14.00	34.38	0.4072
DEC	7.28	0.0728	14.37	33.19	0.4329

Table 2: Meteorological Data and Global Solar Radiation for Calabar.

MONTH	$\bar{c}$ (%)	$\frac{\bar{c}}{\bar{C}}$	$\bar{H}_M$ ($MJm^{-2}day^{-1}$)	$\bar{H}_O$ ($MJm^{-2}day^{-1}$)	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
JAN	6.47	0.0647	14.0004	34.25	0.4084
FEB	6.10	0.0610	16.3656	35.50	0.4538
MAR	6.72	0.0672	15.4512	36.52	0.4118
APR	6.78	0.0678	16.3584	37.28	0.4365
MAY	6.79	0.0679	15.1416	36.54	0.4178
JUN	6.88	0.0688	13.0896	35.13	0.3726
JUL	6.99	0.0699	11.6388	35.71	0.3268
AUG	7.01	0.0701	12.2940	37.15	0.3318
SEPT	6.97	0.0697	13.4892	37.56	0.3620
OCT	6.86	0.0686	14.1300	35.18	0.3905
NOV	6.81	0.0681	14.3388	34.48	0.4171
DEC	6.71	0.0671	13.2624	32.39	0.3996

Table 3: Meteorological Data and Global Solar Radiation for Warri.

MONTH	$\bar{c}$ (%)	$\frac{\bar{c}}{\bar{\bar{C}}}$	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{\bar{H}}_O}$
JAN	6.50	0.0650	11.02	35.56	0.3099
FEB	6.84	0.0684	12.55	36.01	0.3485
MAR	6.94	0.0694	13.76	36.54	0.3766
APR	6.95	0.0695	15.94	35.44	0.4498
MAY	6.78	0.0678	11.30	33.41	0.3382
JUN	7.00	0.0700	12.31	33.55	0.3669
JUL	7.07	0.0707	12.91	34.95	0.3694
AUG	7.06	0.0706	12.19	35.77	0.3408
SEPT	6.97	0.0697	13.55	36.85	0.3677
OCT	6.83	0.0683	14.56	37.93	0.3839
NOV	6.64	0.0664	13.91	35.33	0.3937
DEC	6.56	0.0656	12.46	35.12	0.3548

Table 4: Meteorological Data and Global Solar Radiation for Uyo.

MONTH	$\bar{c}$ (%)	$\frac{\bar{c}}{\bar{\bar{C}}}$	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{\bar{H}}_O}$
JAN	6.37	0.0637	14.47	34.56	0.4187
FEB	6.55	0.0655	15.50	36.17	0.4285
MAR	6.86	0.0686	15.09	37.67	0.4006
APR	6.91	0.0691	17.19	37.45	0.4590
MAY	6.92	0.0692	16.28	36.98	0.4402
JUN	6.92	0.0692	14.54	35.86	0.4055
JUL	7.00	0.0700	13.10	35.67	0.3673
AUG	6.92	0.0692	13.42	37.09	0.3618
SEPT	6.85	0.0685	14.43	37.34	0.3864
OCT	6.63	0.0663	14.81	36.41	0.4068
NOV	6.75	0.0675	15.41	34.59	0.4455
DEC	6.22	0.0622	14.84	33.79	0.4391

RESULTS AND DISCUSSION

The correlation coefficient of 0.581 exists between the clearness index and monthly mean daily cloudiness index and coefficient of determination of 0.338 implies that 33.8% of the clearness index can be accounted using the cloudiness index. The results of the regression analysis from Equation (1) shows that the regression coefficients are a = 3.623 and b = -43.473. Hence, the monthly mean daily solar radiation on a horizontal surface for any month of the year for Port Harcourt can be estimated using the formula:

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.493 - 0.264\frac{\overline{c}}{\overline{C}} \quad \textbf{(7)}$$

The correlation coefficient of 0.753 exists between the clearness index and monthly mean daily cloudiness index and coefficient of determination of 0.566 implies that 56.6% of clearness index can be accounted using cloudiness index. The results of the regression analysis from Equation (1) shows that the regression coefficients a = 1.178 and b = -11.605. Hence, the monthly mean daily solar radiation on a horizontal surface for any month of the year for Calabar can be estimated using the formula:

$$\frac{\overline{H}_P}{\overline{H}_O} = 1.178 - 11.605\frac{\overline{c}}{\overline{C}} \quad \textbf{(8)}$$

The correlation coefficient of 0.113 exists between the clearness index and monthly mean daily cloudiness index and coefficient of determination of 0.013 implies that 1.3% of clearness index can be accounted using cloudiness index. The results of the regression analysis from Equation (1) shows that the regression coefficients a = 0.230 and b = -2.016. Hence, the monthly mean daily solar radiation on a horizontal surface for any month of the year for Warri can be estimated using the formula

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.230 - 2.016\frac{\overline{c}}{\overline{C}} \quad \textbf{(9)}$$

The correlation coefficient of 0.377 exists between the clearness index and monthly mean daily cloudiness index and coefficient of determination of 0.142 implies that 14.2% of clearness index can be accounted using cloudiness index. The results of the regression analysis from Equation (1) shows that the regression coefficients a = 0.730 and b = -4.701. Hence , the monthly mean daily solar radiation on a horizontal surface for any month of the year for Uyo can be estimated using the formula:

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.730 - 4.701\frac{\overline{c}}{\overline{C}} \quad \textbf{(10)}$$

From the values of the correlation coefficients and coefficient of determinations for all correlations involving the cloudiness index and clearness index for four different cities in Nigeria. It therefore implies that correlations based on the cloudiness index are known to be less reliable than the corresponding insolation-sunshine correlations.

Some of the factors that led to the above conclusion are noted below (Norris, 1968):

Insolation and sunshine measurements are integrated over the entire day whereas the mean cloud cover are simply averages of observations taken at definite times from sunrise to sunset, quite often every three hours.

The index $\frac{\overline{c}}{\overline{C}}$, in itself does not directly give information as to which part of the sky is covered by the clouds. One small cloud could keep the Sun obscured by slowly transversing the sky in an extreme case.

It is also possible that a small hole in the clouds could remain open to the Sun for a long period. The reflection of solar radiation from the edges and sides of clouds can increase the insolation to even more than that received above the atmosphere.

It appears difficult to circumvent these disadvantages with respect to the use of cloudiness index as an estimator of insolation. However, Bennett (1969) has shown that it is possible to improve on the disadvantages mentioned above with respect to the use of cloudiness index to estimate global solar radiation by introducing a new variable called the opaque sky cover which is being observed at a number of stations. It differs from the total cloud cover in that it includes only the amount of sky visually obscured by clouds.

CONCLUSION

The relationship between cloudiness index and clearness index have been established for four selected cities in Nigeria. The correlation equations for Port Harcourt, Calabar, Warri, and Uyo are:

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.493 - 0.264\frac{\bar{c}}{C},$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 1.178 - 11.605\frac{\bar{c}}{C},$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.230 - 2.016\frac{\bar{c}}{C} \text{ and}$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.730 - 4.701\frac{\bar{c}}{C}, \text{ respectively.}$$

The values of the correlation coefficients and coefficient of determination were found for each equation. The values show that correlations based on cloudiness index are less reliable than the corresponding sunshine correlation. The model can be applied to other locations that has the similar climatological characteristics as the four selected cities in Nigeria.

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