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ESTIMATING DIFFUSE SOLAR RADIATION FROM GLOBAL SOLAR RADIATION

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Abstract

This study considers the estimation of diffuse solar radiation from global solar radiation. This involves investigating the correlation of the fraction of diffuse solar radiation in the global solar radiation (or diffuse fraction) with cloud index. The cloud index is defined in terms of the clear-sky index. Beam solar radiation is sometimes derived from diffuse and global solar radiation. The variation of the ratio of beam to clear-sky radiation with estimated diffuse fraction solar radiation has been investigated for this reason. The results show that the best fit for the plot for fraction of diffuse solar radiation against cloud index and the plot for the ratio of beam to clear-sky radiation against the estimated diffuse fraction are linear and second degree polynomial respectively with respective correlation coefficients of 0.800 and 0.840. The results show that diffuse solar radiation can be estimated from global solar radiation and that beam solar radiation can be calculated from the estimated diffuse radiation.

Keywords:- diffuse solar radiation, global solar radiation, beam solar radiation, cloud index

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1. Introduction

The amount of solar energy at the Earth's surface is important for solar energy conversion systems. The Sun's energy that reaches the Earth's surface comprises beam and diffuse components. The diffuse radiation makes up part of the energy utilized by some solar converters. The diffuse component is sometimes used to estimate the beam component of solar radiation which is needed for some applications. The diffuse fraction of the total hemispherical solar radiation plays an active role in thermal, chemical and biological processes on the Earth's surface (Maduekwe and Chendo, 1994).

The efforts at estimating diffuse solar radiation from global solar radiation include those of Liu and Jordan (1960), Collares-Pereira and Rable (1979), Iqbal (1980) and Chendo and Maduekwe (1994). Liu and Jordan (1960) obtained relationships for calculating diffuse solar radiation on horizontal surface on clear days. They obtained the relations for long term average hourly and daily sums of diffuse radiation as well as for various categories of days with different degrees of cloudiness. Some of the methods presented by other authors involve the use of the ratio of diffuse radiation to global solar radiation in the same manner as was proposed by Liu and Jordan (1960). Maduekwe and Chendo (1994) introduced other parameters such as solar elevation and turbidity into the Liu and Jordan equation to estimate the diffuse fraction for Lagos - Nigeria. They reported an improvement in the estimates for diffuse fraction from the introduction of the other parameters.

This study considers the correlation between the fraction of diffuse solar radiation in the global solar radiation and cloud index; this is with a view to estimate the diffuse solar radiation from global solar radiation. The cloud index is defined in terms of the clear-sky index as is applied in remote sensing methods (Cano et al., 1986).

The estimated fraction of diffuse solar radiation is then applied in the estimation of the of beam solar radiation.

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2. Methodology

The process involves the use of data for instantaneous values of global and diffuse solar radiation for our location, Akoka - Lagos. The data consists of measurements of global solar radiation and diffuse solar radiation taken at fifteen minutes interval; it covers the period 7:00UT to 5:00UT for some days in the first four months of the year 2010. The beam radiation, cloud index and the beam to clear-sky ratio were calculated from the diffuse and global radiation.

The physical limits from Reindl et al. (1990) were applied as follows:

$$Limit\ .1: \frac{G_d}{G} < 0.90 \ ..and.. \ \frac{G}{G_O} < 0.20$$

$$Limit\ .2: \frac{G_d}{G} > 0.80 \ ..and.. \ \frac{G}{G_O} > 0.60$$

From limit 1, if during the fifteen minutes interval the measured diffuse fraction was less than 0.90 for a clearness index less than 0.20, it was eliminated from the data set. Likewise, the diffuse fraction under clear sky conditions is restricted under limit 2. This action was meant to negate the effect of spurious data on our results.

2.1 Cloud index

The cloud index, n, is defined as:

$$n = 1 - k_C \qquad \text{(eq. 1)}$$

where k_c is the clear-sky index which is defined as the ratio of measured global solar irradiance, G, to the clear-sky irradiance, G_C . The clear-sky irradiance was calculated from a clear-sky model. The clear-sky model adopted is the World Meteorological Organization (WMO1) model (Rigollier and Wald, 2000).

$$G_C = \frac{0.95\, \varepsilon I_O \sin\, \nu}{1 + 0.2 \cos\, ec\, \nu} \qquad \text{(eq. 2)}$$

where ν is solar altitude, I_o is solar constant and ε corrects for Sun - Earth distance. The ratio of measured diffuse solar irradiance, G_d, to global solar irradiance, G, was computed. This was plotted against the cloud index in figure 1.

2.2 Ratio of beam to clear-sky radiation and atmospheric turbidity

One application of diffuse solar radiation is the estimation of beam solar radiation. The ratio of beam to clear-sky irradiance was computed for the purpose of investigating the correlation with estimated diffuse fraction. The beam radiation was calculated from the global solar radiation and the diffuse solar radiation. The calculated beam was employed in determining the atmospheric turbidity at approximately airmass 2 by using the following equation (Rigollier et al. 2000):

$$B_C = I_O \varepsilon \sin \gamma_S \exp(-0.8662\ T_L(AM\ 2).m.\delta_R(m)) \qquad \text{(eq. 3)}$$

where I_0 is the solar constant (i.e the extraterrestrial irradiance normal to the solar beam at the mean solar distance), ε is the correction for the Sun - Earth distance from the mean value, γ_S is the solar attitude angle, T_L(AM2) is Linke turbidity factor at airmass equal to 2, m is the relative optical airmass, $\delta_R(m)$ is the integral Rayleigh optical thickness. Equation 3 was expressed in terms of Linke turbidity coefficient.

2.3 Indicators for assessment of models

The following indicators were applied to determine the performance of the model with respect to estimated diffuse and beam solar radiation.

i. Mean Bias Error (MBE):

$$MBE = \sum_{i=1}^{n} (G_{i.est} - G_{i.meas}) \quad \text{(eq. 4)}$$

ii. Root Mean Square Error (RMSE):

$$RMSE = R\left\{\frac{1}{n}\sum_{i=1}^{n} (G_{i.est} - G_{i.meas})^2\right\}^{0.5} \quad \text{(eq. 5)}$$

where the subscripts i.est and i.meas indicate the i^{th} estimated value and i^{th} measured value respectively.

3. Results

The variation of the ratio of diffuse to global solar irradiance (G_d, / G) with cloud index is shown in figure 1. The following linear equation (equation 6) is the best fit for the curve while the coefficient of determination is 0.800.

$$\frac{G_d}{G} = 1.316\, n - 0.0859 \quad \text{(eq. 6)}$$

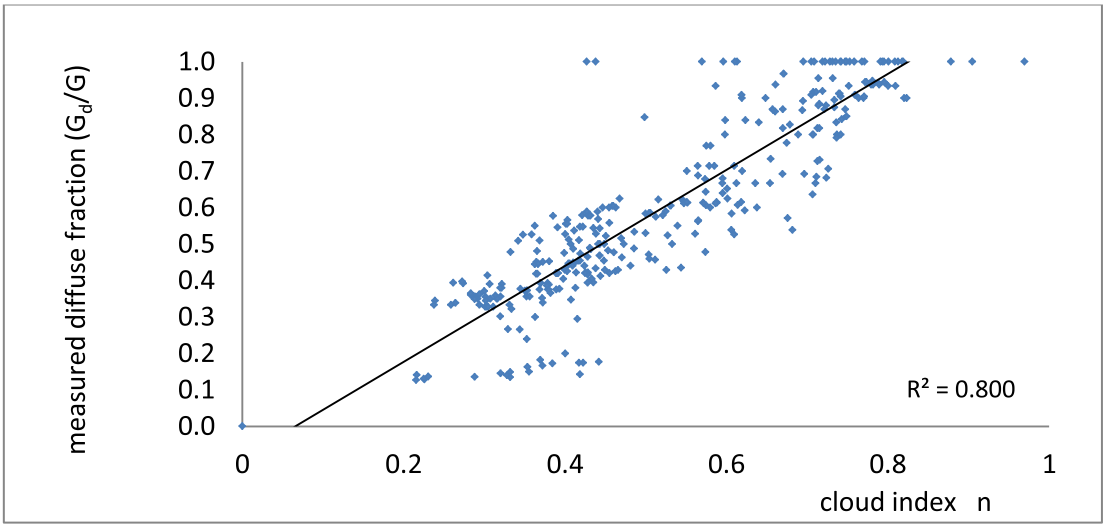

Figure 1. Variations of the ratio of diffuse to global solar radiation (G_d/G) with cloud index n.

The variation of the ratio of beam to clear-sky irradiance (G_b /G_C), with estimated diffuse fraction is shown in figure 2. The following second degree polynomial (equation 7) is the best fit for the curve while the coefficient of determination is 0.840.

$$\frac{G_b}{G_C} = 1.058\left(\frac{G_d}{G}\right)^2 - 1.632\left(\frac{G_d}{G}\right) + 0.985 \qquad \text{(eq. 7)}$$

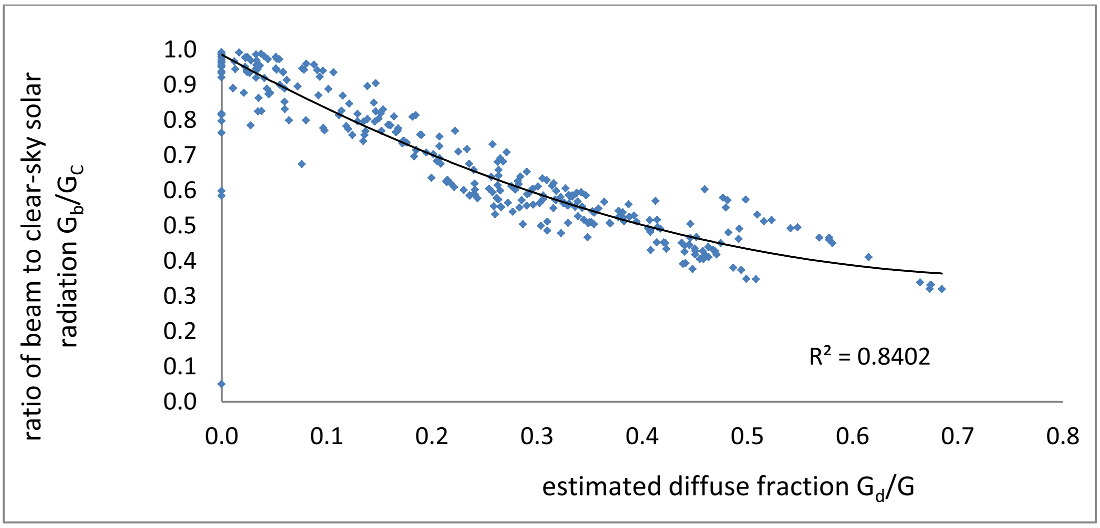

Figure 2. Variations of beam to clear-sky radiation (G_b / G_C) with diffuse fraction (Gd,/ G) estimated using equation 7.

The mean bias error (MBE) and root-mean-square error (RMSE) for the estimated diffuse solar radiation from equation 6 are 56.50Wm^{-2} and 73.66Wm^{-2} respectively while the mean bias error (MBE) and root-mean-square error (RMSE) for the estimated beam solar radiation from equation 7 are 8.04Wm^{-2} and 94.62Wm^{-2} respectively.

Figure 3 shows the variation of estimated diffuse fraction (G_d/G) with measured diffuse fraction while figure 4 shows the variation of Linke turbidity coefficient at approximately airmass 2 with cloud index.

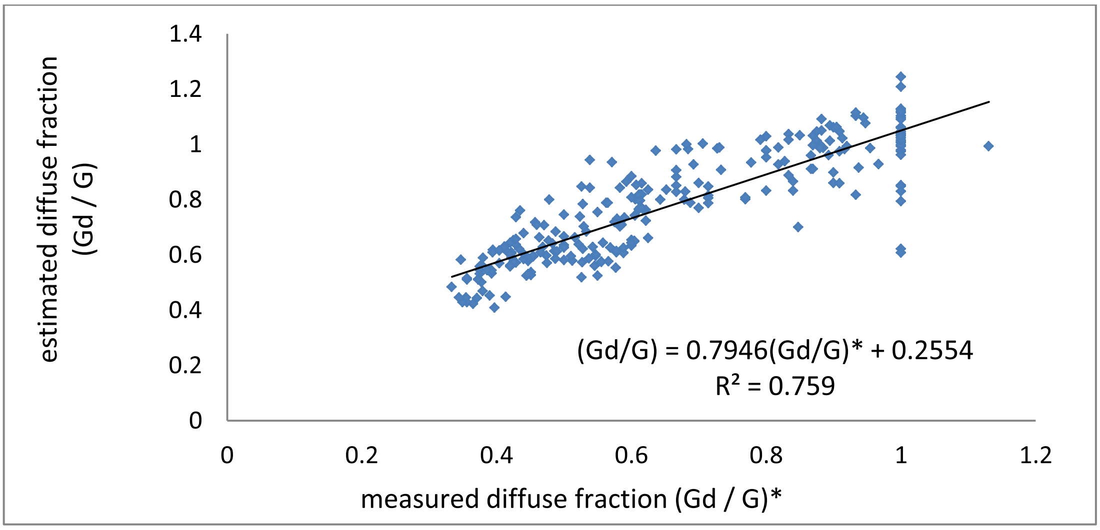

Figure 3. Variation of estimated diffuse fraction (G_d/G) with measured diffuse fraction (G_d/G)*

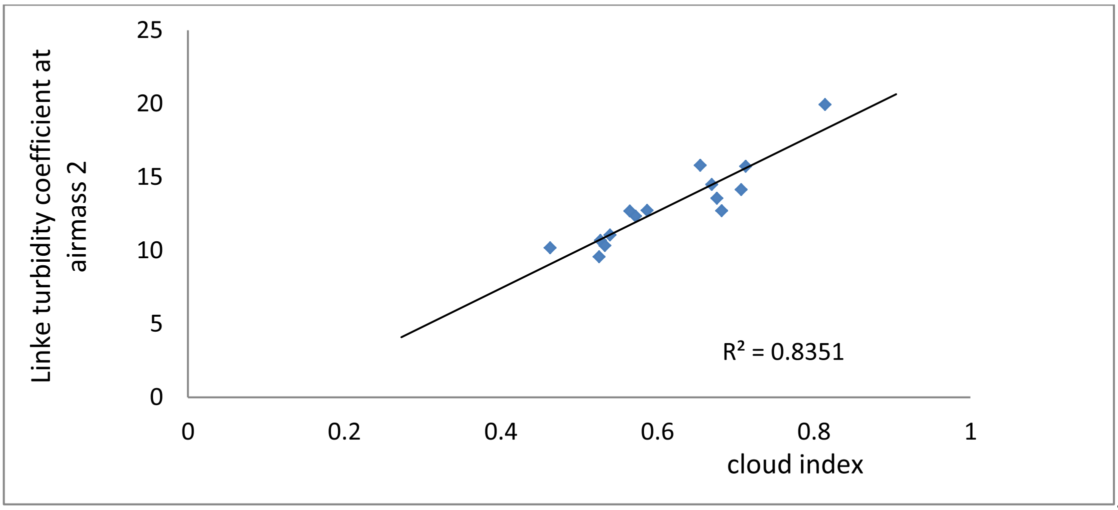

Figure 4. Variation of Linke turbidity coefficient at airmass 2 with cloud index

4. Discussion and Conclusion

The results obtained show that diffuse solar radiation can be estimated from global solar radiation. The error indices for the results of this study are on the high side when compared with the result obtained for the same location by Maduekwe and Chendo (1994). They applied the Liu – Jordan type equation with the inclusion of atmospheric turbidity and solar elevation and obtained the smallest RMSE of 0.05 for the diffuse fraction for two of the four models they employed in their study. Their result may also be attributed to the approach they adopted which involved analyzing the data according to intervals. This was not considered in this work. The method presented here however provides a ready tool for use for the assessment of diffuse solar radiation at the point of application where only global solar radiation data is available.

The relationship between diffuse solar radiation and global solar radiation have been studied using the ratio of diffuse to global solar irradiance and the cloud index defined in terms of the clear-sky index. An equation was obtained for the relationship. This equation has been applied in the estimation of beam solar radiation.

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