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ANALYSIS OF SKY CONDITION USING SOLAR RADIATION DATA OVER A TROPICAL STATION

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ABSTRACT

Radiation data in Nigeria are very sparse because radiation is not routinely measured. The data used for this work are from the physics Department of Obafemi Awolowo University, Ile-Ife which is one of the few stations that collect radiation data in Nigeria. The daily, global and diffuse radiation measurements have been used to characterize the atmosphere of Ile-Ife (7^0 14` N, 40 35` E) during January to December 1994. The clearness index k_y (=H/H_0) which gives the percentage depletion by the sky of the incoming global radiation and the relative sunshine (s/s_0) gives the measure of cloud in the atmosphere has been adopted for use in this study. Also investigated are the diffuse radiation K_{diff} (=H_{diff}/H) and the diffuse coefficient K_{coef} (= H_{diff}/H_0) that mirror the effectiveness of the sky in the scattering of the incoming radiation. Results show an average K_t value of 0.57 for year 1994 with maximum clearness index occurring in June (K_t= 0.68) and minimum in Dec (K_t =0.42). This present study also shows that the relative sunshine s/s_0 has its minimum in August which indicates reduced hours of sunshine and solar insolation during the monsoon month of August in the tropical Nigeria station.

Keywords: Daily, global and diffuse radiation, clearness index, diffuse coefficient, relative sunshine

INTRODUCTION

The need for a comprehensive analysis of basic solar radiation data over a station for both preliminary design and performance evaluation of solar radiation utility devices (solar dryers, sprayer, hot water systems as well as electricity generating system) cannot be overemphasized (Liou, 1980). No matter diverse national objectives, the central goal for mankind is the *development of appropriate technology to harness the vast renewable sources of energy all over* the world. Furthermore despite growing awareness about the importance of cloud to the availability of solar radiation, no ground based instrumentation or estimation procedures have been developed to monitor the sky and cloud conditions routinely and objectively (Zangvil and Lamb, 1997). The only methods available for sky condition characterization are cloud photography and synoptic cloud observation. The first method is very expensive and is not practiced routinely at most meteorological observation stations and the second method cannot form an objective basis for the comprehensive sky condition at different location (Zangvil and Lamb, 1997). Because of these difficulties the simplest and perhaps the most appropriate way of estimating the incident solar radiation is by establishing the sky conditions at such locality. These conditions can be quantified by estimating the clearness index, the relative sunshine, which gives the measure of the cloud cover (Igbal, 1983, Ideriah and Suleiman, 1989), the diffuse ratio and the diffuse coefficient for the area under study which mirror the effectiveness of the sky in the scattering of the incoming radiation (Ideriah and Suleiman, 1989; Kuye and Jagtap, 1989; Udo, 2000). It is a well known fact that clouds determine the solar radiation received at the ground. Other atmospheric constituent like aerosols and water vapor also affect the transmission of solar radiation Liu and Jordan, (1960) characterized the sky condition by estimating the monthly variation of clearness index as a function of its cumulative frequency (f) called the monthly clearness index curves. Their study was based on several stations in the United States and Canada. These monthly clearness index curves can be utilized to determine the approximate statistical distribution of the daily total radiation for other cities that are in the same weather zone when the monthly average daily radiation is known for such cities. In Nigeria only few studies on sky condition using

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solar radiation data have been carried out. Ideriah and Suleiman, (1989) studied the sky condidtion for Ibadan and Kuye and Jagtap, (1992) did similar study for Port Harcourt in Southeastern Nigeria.

This paper is focused on the studies of sky condition at Ile-Ife (Lat. 7^0 14'N, 4^0 35'E). The result of analysis from this study is compared with similar studies that had been done in Nigeria.

Data Acquisition and Methodology

Individual daily mean values of global and diffuse irradiance data measured at Ile-Ife (7^0 14'N, 4^0 35'E) have been used to demonstrate the sky condition during January to December, 1994.

The hourly global radiation data (H) were measured with high precision CM11 Kipps and Zonnen pyranometer logged into a data logger for continuous measurement. The diffuse radiation data (Hd) used are the original measured data of another CM11 Kipps and Zonnen pyranometer with a shadow band. The shade band correction recommended by Kipps and Zonnen laboratory was applied to the daily mean data. Recalibration of the RSR sensors is done every two years as recommended by the manufactures. The cosine correction error is less than ± 5% for angles less than 80^0 from the normal axis of the sensor and at 90^0 the cosine error is infinite. The daily sunshine duration (s) is obtained from the Nigerian Meteorological Service, Oshodi using the strokes Campbell Sunshine Recorder that employs the principle of light by focusing solar radiation on a heat sensitive paper of the instrument.

All measurements taken were done every 10 minutes and logged into a Campbell 21X data logger. The sky conditions at Ile-Ife are characterized by clearness index, relative sunshine, diffuse ratio and diffuse coefficient. The clearness index K_t (= H/H_0) gives the percentage depletion by the sky of the incoming global radiation where K_t is the clearness index. H is the measured daily global radiation and H_0 is the daily extraterrestrial radiation given as

$$H_0 = 24/\Pi\, I_{so}E_0 \, \text{Sin}Ø \, \text{Sin}\, \delta(\text{TI}/180)\, w_s - \tan w_s \quad \ldots(1)$$

Where

$$I_{so} = \text{Solar constant} * 3.6 = 1367\ W/m^2 * 3.6 = 4921 kjm^2h^{-1} \quad \ldots(2)$$

E_0= Eccentricity correction factor, Ø= station Latitude, δ=Declination angle or each day of the year, w_s = sunrise Hour angle.

The relative sunshine (s/s_0) gives the measure of cloud in the atmosphere. S is the daily sunshine duration as measured by the sunshine record and s_0 is the computed maximum possible hour called the day length given as

$$S_0 = 2/15\,(\cos^{-1}(-\tan Ø \tan \delta)) \quad \ldots(3)$$

The diffuse ratio K_{diff} and the diffuse coefficient K_{coef} is given as H_d/H and H_d/H_c respectively where H_d is the diffuse radiation.

Statistical monthly clearness index curves (K_t curves) will be established for the purpose of this paper. Following the work of Liu and Jordan (1960), Ideriah and Suleiman (1992) the cumulative frequency f in percentage may be

Table 1: Monthly values of relative sunshine (s/S_0), diffuse ratio (K_{diff}), diffuse coefficient (K_{coef}), and clearness index (K_t) at Ile –Ife for January –December 1994.

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
S/S_0	0.526	0.459	0.554	0.468	0.219	0.435	0.469	0.167	0.284	0.393	0.584	0.546
K_{diff}	0.256	0.245	0.269	0.459	0.298	0.306	0.285	0.297	0.300	0.293	0.33	0.218
K_{coeff}	0.492	0.509	0.568	0.646	0.478	0.457	0.574	0.619	0.628	0.456	0.545	0.506
K_t	0.525	0.5.9	0.543	0.600	0.628	0.692	0.54	0.512	0.508	0.682	0.625	0.433

Table 2: Seasonal clearness index values

Months (Various seasons)	Average clearness index K_t
Dry Months	
JAN, FEB & MAR	0.53
DEC	0.43
Rainy Months	
APR & MAY	0.61
JUN, OCT & NOV	0.67
JUL & AUG	0.53
SEPT	0.51

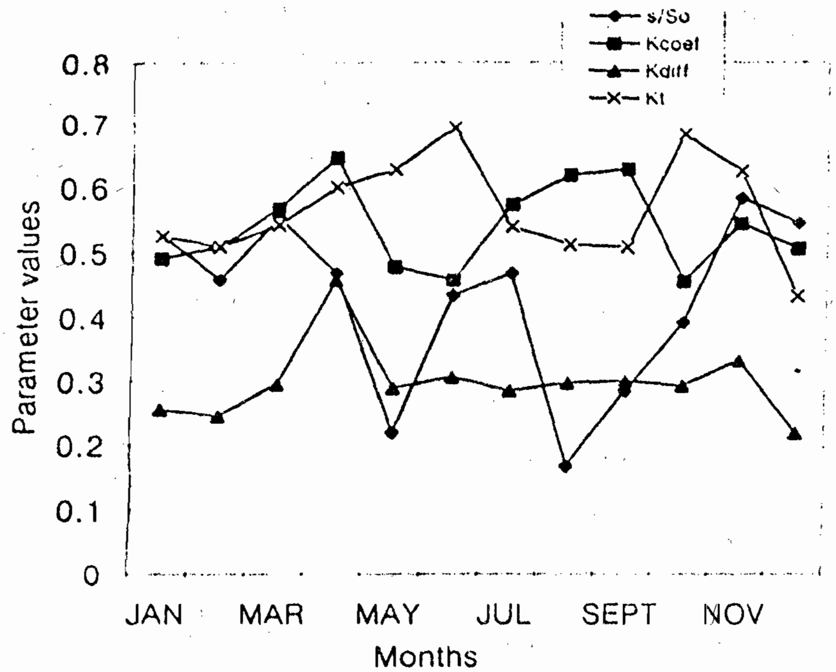


Fig1: Monthly values of s/So, K_{corr}, K_{diff} and K_t (January-December 1994)

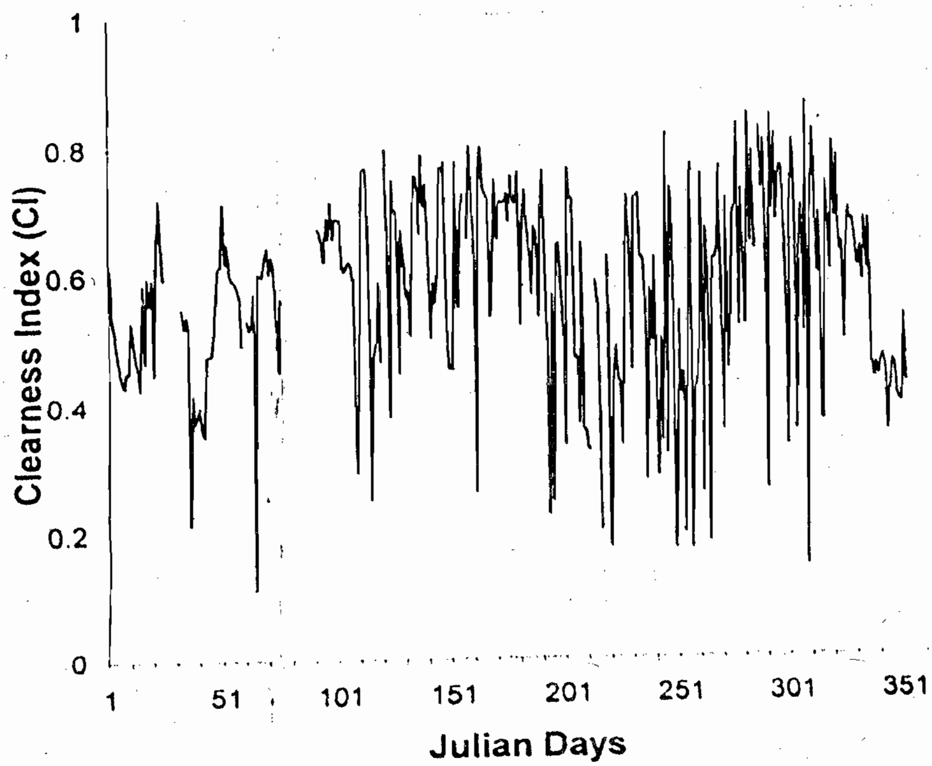


Figure 2: **Daily Average Variation of clearness index at Ile-Ife (January-Dember1994).**

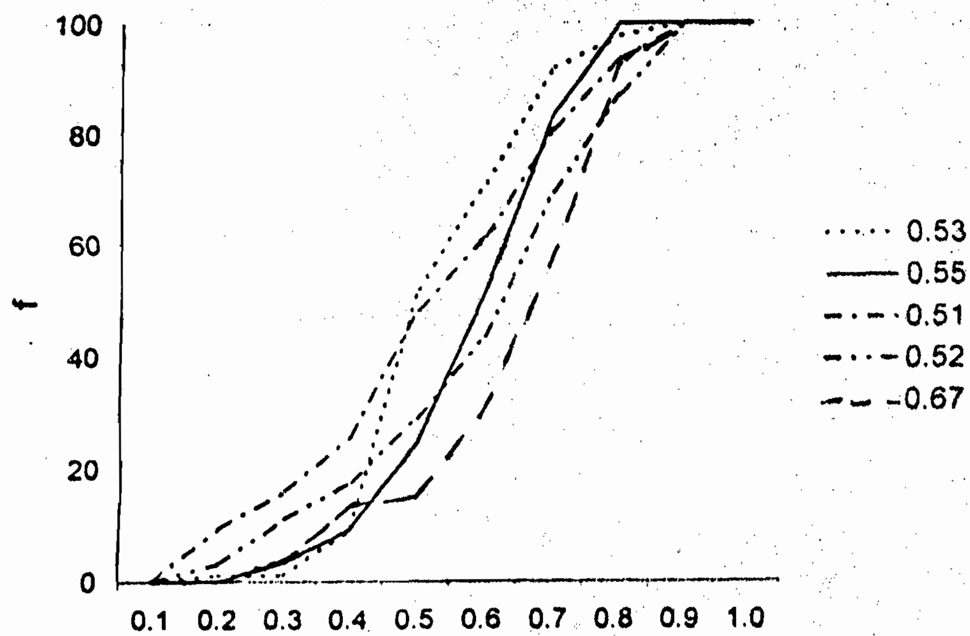
defined as

$$F = \frac{\text{number of days with } K_t < K_t \text{ (fixed value)}}{\text{Number of days in the month}} \times 100\% \quad .....(4)$$

These monthly curves can be utilized to determine the approximate statistical distribution of the daily total radiation for other cities that are in the same weather zone when the monthly average daily radiation is known for such cites

RESULT AND DISCUSSION

The set of parameters for the determination of sky condition are shown in Table 1 for each month under consideration.' These



Clearness index (K_t)

Fig 3 : Monthly Statistical clearness index curves (Kt curves)

parameters are plotted seasonally in figure 1. Fig. 1 shows that the relative sunshine (s/s_0) has its minimum in August which indicates reduced hours of sunshine and solar insolation during the monsoon August month (Jegede, 1997). Except for a sharp increase in April (transition month from dry to wet season), the diffuse coefficient K_{diff} has an almost constant value of 0.30 for all the months. This pattern is in agreement with the finding of Ideriah and Suleiman (1979) for Ibandan with constant K_{diff} = 0.24 and Collares-Percia and Rabi (1979) for stations in United States with a constant value of K_{diff} = 0.23. This indicates that the transmission characteristic of diffuse radiation is independent of cloud condition and incidence angle of the sun (Ideriah and Suleiman 1979). Figure 2 shows the daily distribution of clearness index (K_t) at Ile-Ife. There are more clear days in the dry seasons of January, February and March and it surprising that there is some measure of clear days even during the cloud rainy period of April – June at Ile-Ife. This observation is in agreement with the works of Kuye and Jagtap, (1992) and Udo (2000) in which they found some clear days with high values of clearness index in port Harcourt (Southeast Nigeria) and Ilorin (central Nigeria) respectively in the cloudy rainy days. One distinct daily characteristics of the sky condition at Ile-Ife there are two broad seasonal patterns namely the dry season (November – April) and rainy season (May-October). The dry seasons in itself has two periods identified. This include the harmattan period of November –January when cold and dust laden North easterly trade winds from the Sahara desert keep the atmosphere heavily polluted with dust for many day and the dust free period (February – April) with high solar insolation and clear weather condition. It is expected that attenuation by clouds is minimal during this transition period. During the rainy seasons the clearness index is minimum because of the important role played by clouds, which is very pronounced during the wet (monsoon) months in Nigeria. The presence of convective clouds occurring within the high humid atmosphere is mainly responsible for the marked reduction of the intensity of incoming radiation during the wet months (Jegede, 1997). The two months immediately before and after August have approximately the same value of CI (0.69), which is relatively higher than the monsoon month of August. The works of Ideriah & Suleiman (1989) for Ibadan (Lat 7^0 28' N, Long 3^0 54' E) and also Udo (2000) for Ilorin (Lat 8^0 32' N Long 4^0. 34' E) corroborate the seasonal pattern at Ile-Ife. Table 2 shows the monthly clearness index K_t values of Ile-Ife at various seasons of the year with an average K_t value of 0.578. The weather condition of the station can therefore be subdivided into dry and wet seasons under six zones of similar weather cloudy conditions. Results can be compared with the findings of Kuye and Jagtap (1992). The average clearness index K_t is higher for the wet months of April –November than the dry months in Ile-Ife and showed a reverse

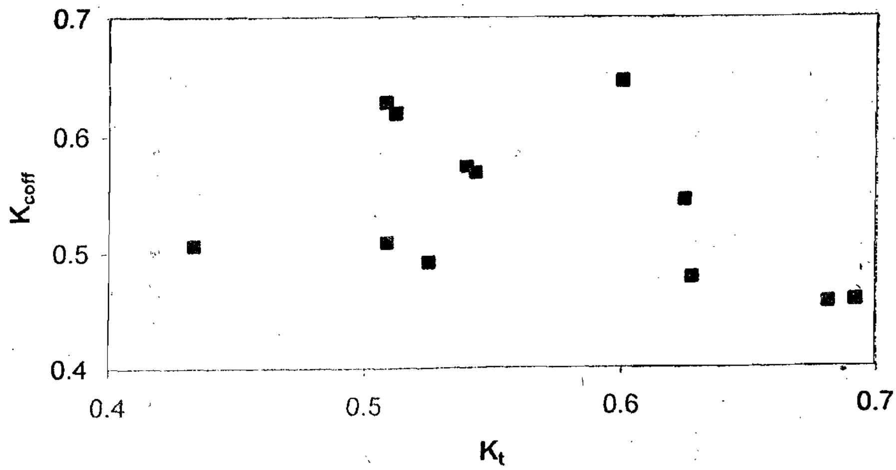


Fig 4: Monthly variation of Diffuse coefficient (Kcoff) against Clearness index (Kt)

condition to the other two stations (Ibadan and Port Harcourt). This shows that Port Harcourt and Ibadan have similar weather condition, and more cloudy days than Ile-Ife. The dry months which include the harmattan period (January and February) when dust laden northeasterly trade winds from the Sahara desert keep the atmosphere heavily polluted with dust at Ile- Ife. These months are associated with low global insolation as a result of heavy scattering of insolation during these two months. Also a dust free period of May and June with very high insolation depicts a clear weather condition. As mentioned in methodology, the cumulative frequency (f) corresponding to each month is plotted in Figure 3. The shapes of the curves are in agreement with earlier work of Liou and Jordan, (1960) and Kuye and Jagtap, (1992) for stations in Canada and Ibadan respectively. Figure 4 shows the scatter plot of H_{diff} and K_t at Ile-Ife on a K_t-K_{diff} graph. It is noticed that the large scatter of points suggests changes in the zenith angle of the sun with the time of the days in each months of the year (Zahgvil and Lamb, 1987).

CONCLUSION

A method is herein proposed to characterize the sky condition by using monthly global radiation, diffuse radiation and sunshine duration hour.

The clearness index K_t (= H/H_0) gives the percentage depletion by the sky of the incoming global radiation while the relative sunshine (s/s_0) gives the measure of cloud in the atmosphere.

The diffuse ratio (K_{diff}) and the diffuse coefficient (K_{coef}) for the area under study mirror the effectiveness of the sky in the scattering of the incoming radiation.

The calculated clearness index values indicate that Ile-Ife has clearer days than Port Harcourt and Ibadan. The study also shows that there is a total of 115 clear days during the year 1994 at Ile-Ife. During the rainy seasons at Ile-Ife, the clearness index is minimum because of the important role played by clouds, which is very pronounced during the wet (monsoon) months in Nigeria. The relative sunshine s/so has its minimum in August which indicates reduced hours of sunshine and solar insolation during the monsoon month of August.

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