CORRELATION BETWEEN GLOBAL SOLAR RADIATION, AMBIENT AIR TEMPERATURE AND SUNSHINE HOURS FOR MAKURDI, NIGERIA

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A study was undertaken to determine the correlation between global solar radiation, ambient air temperature and sunshine hours for Makurdi, Nigeria (latitude 7°7' N and longitude 8°6' E). The global solar radiation (H), maximum and minimum ambient air temperature, hours of bright sunshine (n) and cloudiness were measured hourly from 0600 H to 1800 H daily for 18 months. The correlation and plots of clearness index (H/H_o) versus fraction of sunshine hour (n/N), H/H_o versus maximum ambient air temperature (T_{max}), H/H_o versus the difference between maximum and minimum ambient air temperature (T_d) and H/H_o versus the ratio of maximum and minimum ambient air temperature (T_r) were undertaken to determine the correlation coefficient (R) and the linear equations. The corresponding R-values obtained were 0.8, 0.5, 0.2 and 0.1 respectively. The analysis showed that the model based on H/H_o versus n/N is best for predicting the global solar radiation for the location. Therefore, the Angstrong-Page equation, which is based on n/N best predict the global solar radiation for the location.

1. Introduction

The global solar radiation on any surface is influenced by the hours of sunshine, ambient air temperature and relative humidity of the location (Montero et al., 2009: Polo et al., 2009). Many models have been developed to estimate the global solar radiation using these factors. The Angstrong-Page equation used the hours of bright sunshine (Yohanna et al., 2011) while the Hargreaves model uses the difference between the maximum and minimum ambient temperature (Taiwo, 2010). Other models use the maximum ambient temperature (Sanusi and Aliyu, 2005). The Angstrong-Prescot-Page model uses the hours of bright sunshine and relative humidity (Aliyu and Sambo, 1991; Husaaini et al, 2005). Agbo et al (2006) used relative humidity models. The correctness of these models in estimating the global solar radiation depends largely on the correlation between the global solar radiation and these parameters. A low correlation usually indicates the poor predictability of the resulting model.

The use of solar energy is becoming increasingly popular and attractive, particularly in tropical locations where the sun is vertically overhead twice in a year in the months of March and September. There is thus abundance of solar energy in these locations. Importantly, the use of solar devices for such applications as drying and water heating requires estimating the available solar radiation incident upon the collector of the device. These predictive models estimate the amount of solar radiation in the design of these devices without the need for direct measurement.

It is important to determine the meteorological parameters that best correlate with the global solar radiation in order to know the best model to use for the location. This will eliminate the faulty design of solar devices, which has been the bane of solar technologies in developing countries. This is discouraging governments, policy makers and end-users from patronizing solar energy devices. Makurdi, Nigeria (latitude 7°7' N and longitude 8°6' E) is located in the tropics and has a huge potential for the use of solar energy in providing its energy needs. Although, some models have been developed and verified for use in this location, some of them performed poorly and therefore have no practical significance (Yohanna et al, 2011).

The objective of this study is to correlate the global solar radiation with some commonly used meteorological parameters (n/N, T_{max}, T_d and T_r) so as to determine the parameters that has the best correlation with the global solar radiation. This will enable the recommendation of the type of model that should be used in this location.

2. Materials and methods

Makurdi, Nigeria is located on latitude 7°7' N and is 111 m above sea level. The global solar radiation (W/m^2), maximum and minimum ambient temperature, hours of bright sunshine and cloudiness were measured hourly from 0600 H to 1800 H daily for 18 months. The solar radiation was measured from a Daystar DS-05 sun meter at the College of Engineering, University of Agriculture, Makurdi, Nigeria. The hours of solar radiation of less than 120 W/m^2 was considered cloudy and was not considered in determining the hours of bright sunshine (Coulson, 1975). The monthly average daily extraterrestrial radiation (H_o), hour angle (ω) and the hours of possible sunshine, daylight between sunrise and sunset (N) were determined from equations 1, 2 and 3 respectively. The angle of declination (δ) was obtained from Itodo et al (2004). The maximum and minimum ambient temperatures were measured from a maximum and minimum thermometer. The correlation between H/H_o and n/N, H/H_o and T_{max}, H/H_o and T_d, and H/H_o and T_r were determined using Microsoft Office Exel 2007 and were plotted to obtain the straight line equations. The H/H_o was plotted on the y-axis while the meteorological parameters were plotted on the x-axis.

$$H_o = \frac{24}{\pi} sc \left[1 + 0.033\, cos\left(\frac{360 n_d}{365}\right)\left(\cos\emptyset cos\delta sin\omega + \frac{2\pi}{360}\omega sin\emptyset sin\delta\right)\right] \quad (eq. 1)$$

$$\cos\omega = -tan\emptyset tan\delta \quad \text{(eq. 2)}$$

$$N = \frac{2}{5}\, cos^{-1}(-tan\emptyset tan\delta) \quad \text{(eq. 3)}$$

Where:

sc – Solar constant

Ø – Latitude of the location, degree

ω- Hour angle for the typical day n of each month

n_d – Day of each month

3. Results and discussion

The extraterrestrial radiation (H_o), which is the maximum amount of radiation to the earth, is attenuated as it passes through the atmosphere to the ground surface as global solar radiation (H). The attenuation is caused by cloud, air molecules, aerosols, water vapour and ozone. The global solar radiation is therefore a fraction of the extraterrestrial radiation. The ratio H/Ho, which is referred to as the clearness index of the atmosphere is a measure of the transparency of the atmosphere to solar radiation and is used to define the coefficient of transmission or the transmittance of the atmosphere (Babatunde, 1995). A high H/H_o means clearer atmosphere indicating that the radiation has a shorter path to the earth's surface and a greater transmission. The attenuation of extraterrestrial radiation causes a variation in the number of hours of sunshine and its intensity on the earth's surface from latitude to latitude. The ratio n/N, which is known as fraction of sunshine hours is the actual number of hours of sunshine received at a location to the number of hours of possible in the day (length of the day).

The variation of n/N is largely influenced by atmospheric conditions like clearness and turbidity rather than the movement of the sun around the earth (Babatunde, 1995). Table 1 showed that n/N increased with increasing H/H_o indicating that the fraction of sunshine hours increased with increased availability of the global solar radiation due to a clearer atmosphere. The n/N values were lowest during the months of rainfall (May to October) because of the corresponding low values of H/H_o due to periodic cloudiness of the atmosphere. The lowest n/N of 0.39 occurred in the month of August, which is the period of peak rainfall and high cloud cover for this location. The corresponding H/H_o for this month is also 0.39. The higher n/N with the corresponding H/H_o occurred in the dry season (November to April). The low H/H_o of 0.48 in November may have been due to harmattan haze in the atmosphere at this location. The high proportionality between H/H_o and n/N may have accounted for high correlation (R = 0.8) between them (Fig. 1). This agrees with the findings of Hussaini et al (2005) that n/N remains the most important single parameter for characterizing solar radiation in Nigeria locations.

Tab. 1: Summary of measured meteorological parameters

Month	H/H_o	n/N	T_{max}	$T_d = T_{max} - T_{min}$	$T_r = T_{max}/T_{min}$
January	0.59	0.59	31	3	1.11
February	0.63	0.63	34	4	1.13
March	0.61	0.64	35	4	1.13
April	0.55	0.61	33	2	1.06
May	0.56	0.56	32	1	1.03
June	0.53	0.50	32	4	1.14
July	0.47	0.40	30	2	1.07
August	0.39	0.39	31	3	1.11
September	0.51	0.49	32	2	1.07
October	0.51	0.58	32	2	1.07
November	0.48	0.63	31	2	1.07
December	0.67	0.64	31	2	1.07
Mean	0.54	0.54	32	2.6	1.19

The correlation between H/H_o and T_{max} seems to have been influenced by both the movement of the earth around the sun and the clearness of the atmosphere for this location. The yearly movement of the earth around the sun showed that the sun is vertically overhead on this location in March and September. This may be why the highest maximum ambient temperature of 35°C occurred in March in a clear atmosphere (H/H_o = 0.61) in the dry season. The lower maximum ambient temperatures of 30-32°C with corresponding lower H/H_o (0.39 – 0.56) may have been due to cloudiness in the raining season (May – October) at this location (Sanusi et al., 2005). The lowest maximum ambient temperature of 30°C occurred in this period in July. Table 2 shows a fair proportionality between H/H_o and T_{max}, which may have accounted for the fair correlation (R = 0.5) between these parameters (Fig. 2). This result supports the recommendation of Hussaini et al (2005) that models based on T_{max} can be used to predict the global solar radiation in some northern locations of Nigeria. The low proportionality between H/H_o and T_d, and H/H_o and T_r may have accounted for the corresponding low R-values of 0.2 (Fig. 3) and 0.1 (Fig. 4) respectively.

Tab. 2: Summary of correlation values and equations for the various H/H_o versus meteorological parameters

H/H_o vs parameter	Equation	R	R^2
H/H_o vs n/N	$H/H_o = 0.17 + 0.66\ (n/N)$	0.8	0.6
H/H_o vs T_{max}	$H/H_o = -0.41 + 0.03\ T_{max}$	0.5	0.3
H/H_o vs T_d	$H/H_o = 0.50 + 0.02\ T_d$	0.2	0.04
H/H_o vs T_r	$H/H_o = 0.24 + 0.28\ T_r$	0.1	0.02

The Angstrom-Page model for predicting global solar radiation uses the n/N parameter. The high correlation between H/H_o and n/N indicated that this model will be most applicable for this location.

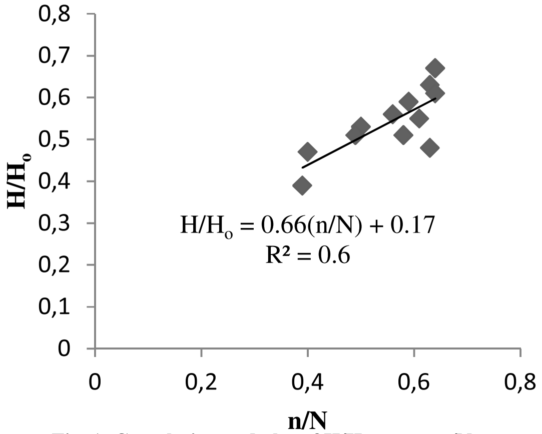

Fig. 1: Correlation and plot of H/Ho versus n/N

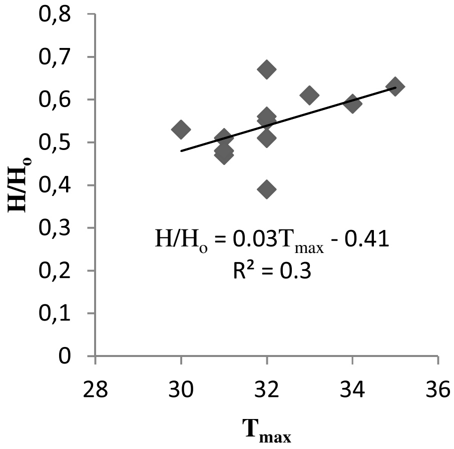

Fig. 2: Correlation and plot of H/H_o versus T_{max}

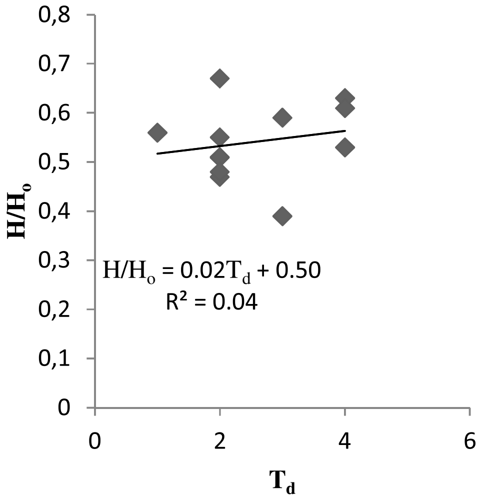

Fig. 3: Correlation and plot of H/H_o versus T_d

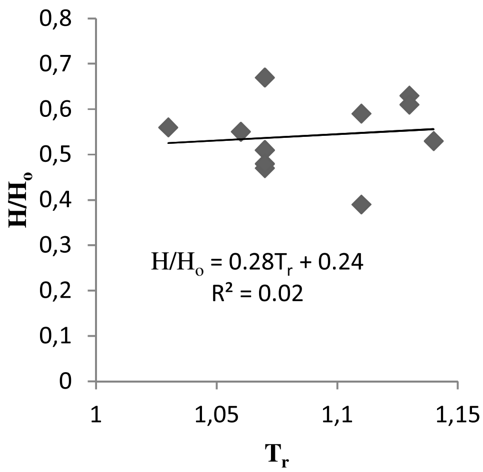

Fig. 4: Correlation and plot of H/H_o versus T_r

4. Conclusion

It is concluded that:

1. H/H_o versus n/N had the best correlation (R = 0.8) of the meteorological parameters investigated.
2. Models based on hours of bright sunshine (n/N) will best predict the global solar radiation than those based on ambient temperature for the location.

5. References

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