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***Full length Research Paper***

# Empirical Correlation Between Total Solar Radiation, Ambient Air Temperature, Relative Humidity and Sunshine Hours-Based Models for Barkin Ladi, Nigeria

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**Abstract:** This paper presents the correlation between total solar radiation, ambient air temperature, relative humidity and sunshine hours for Barkin Ladi, Nigeria, latitude 9.5oN and longitude 8.9oE. The total solar radiation (H), maximum and minimum ambient temperature, relative humidity and sunshine hour's data were obtained from the meteorological unit of Yakubu Gowon Air Port, Heipang, Barkin Ladi L.G.A. of Plateau State, Nigeria. The correlation and plots of clearness index (H/H0) versus maximum ambient air temperature (Tmax), H/H0 versus the ratio of maximum and minimum ambient air temperature (Td), H/H0 versus maximum relative humidity (RHmax), H/Ho versus the difference between maximum and minimum relative humidity (RHd), H/Ho versus the ratio of maximum and minimum relative humidity (RHr) and H/Ho versus relative sunshine hours (ns/N) were undertaken to determine the correlation coefficient (R) and the linear equations. The corresponding R-values obtained were 0.387, 0.550, 0.515, 0.761, 0.654, 0.532 and 0.540 respectively. The analysis showed that the model based on H/Ho versus RHmax is best for predicting the total solar radiation for the Barkin Ladi location. It is concluded further that in the absence of ambient air temperature and sunshine hours, the relative humidity data that are commonly measured in meteorological stations can be used to estimate the global solar radiation of the location.

Keywords: Correlation, total solar radiation, temperature, relative humidity, sunshine hours, Barkin

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## INTRODUCTION

Solar radiation is essential at the earth's surface for the development and utilization of solar devices. It is the energy transmitted from the sun and the earth receives about one-half of one billion of total output. The sun is largely responsible for about all the conventional energy sources (Yohanna et al., 2011). For example photosynthesis of plants and algae supported ancient life that later become fossil fuels. Even hydroelectric power wouldn't be possible without the evaporation of water. The time is ripe, however for the country, Nigeria (if not all developing countries of the world), to become aware of the direct contribution of solar energy can make to the lives and economy, most especially during this time of erratic power supply by the Electric Power Distribution Authority/Company.

Solar radiation data are often required in agro-meteorological calculations to complete a water budget for irrigation or to run a crop growth formulation model, but these are measured at few weather stations (Binchi and Migliette, 1991). Unfortunately, solar radiation measurements are not easily available for many developing countries for not being able to afford the measurement equipment and techniques involved (Chegaar *et al.,* 1998). Therefore, it is rather important to elaborate methods to estimate the solar radiation on the basis of more readily meteorological data. Several empirical formulae have been developed to calculate the solar radiation using various parameters. Some works used the sunshine duration (Baar *et al.,* 1996) others used the sunshine duration, relative humidity and temperature (Fagbenle, 1994), while others used the number of rainy days, sunshine hours and a factor that depends on latitudes and altitude (Canada, 1988).

The global solar radiation on any surface of the earth is influenced by the sunshine hours, 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 Angstrom-Page equation used the hours of bright sunshine (Yohanna *et al*., 2011), while the Hargreaves model used the difference between the maximum and minimum ambient temperatures (Alomorox, 2009; Sanusi and Abisoye, 2011). Others models used the maximum ambient temperature (Sanusi and Aliyu, 2005). The Angstrom-Prescott-Page model used the hours of bright sunshine and relative humidity (Hussaini *et al.,* 2005). Agbo *et al* (2007) used relative humidity models. The correctness of these models in estimating the global solar radiation depends largely on the correlation between global solar radiation and these parameters. A low correlation normally indicates the poor predictability of the resulting model.

## METHODOLOGY

Daily data were obtained from the Heipang meteorological station of the Yakubu Gowon Air Port, Barkin Ladi L.G.A. of Plateau State, Nigeria. Barkin Ladi L.G.A lies between Latitudes 9.5$^o$N and Longitude 8.9$^o$E with an altitude of 1515m above sea mean level (ASML). The L.G.A. has a total land area of 1032km$^2$. The climate of the area is tropical with two distinct seasons: the rainy and the dry seasons. The temperature ranges from 16-28$^o$c while the element relative humidity ranges from 42-46%. The mean annual total rainfall varies from 1520mm to 2050mm (Wikipedia, 2015).

The following meteorological variables are currently recorded in the meteorological unit daily data base: actual global solar radiation (ml), maximum and minimum relative humidity (%), precipitation (mm), maximum and minimum air temperature ($^o$c), wind speed (km/hr, m/s) and sunshine duration (hr). Measurements of global solar radiation were taken by Gan-Bellani instrument graduated in milliliter (ml) and converted to watts per square metre (W/m$^2$) using the formula: 1ml = 15.706 W/m$^2$ (Yohanna *et al.,* 2015). All parameters were checked, maintained and calibrated periodically for quality control. All data were recorded hourly and averaged in a data logger.

A number of methods have been reported using empirical relationships to estimate global solar radiation from commonly measured meteorological variables. Daily total extra-terrestrial radiation ($H_o$) is often included in the relationships and its values were calculated using the standard procedures (Almorox, 2009).

The monthly average daily extra terrestrial radiation ($H_o$), hour angle (ω) and hours of possible sunshine (ns), daylight between sun rise and sun set (N) were determined from equations 1, 2 & 3 respectively. The angle of declination was obtained from Itodo *et al* (2004). The correlation between $H/H_o$ and Tmax, H/Ho and Td, H/Ho and Tr, H/Ho and RHmax, H/Ho and RHd, $H/H_o$ and $RH_r$ and $H/H_o$ and $^{NS}/_{N}$ were determined using Microsoft office excel 2007 and 2010 and were plotted to obtain the straight line equation. The $H/H_o$ was plotted on the Y-axis while the meteorological parameters were plotted on the x - axis.

$$H_o = \frac{24}{\pi} Sc \left[1 + 0.033 \cos\left(\frac{360 ny}{365}\right)\right] \left[\cos\varphi \cos\delta \sin\omega_s + \frac{2\pi}{360}\omega_s \sin\varphi \sin\delta\right] \quad \ldots.1$$

$$\cos\omega = -\tan\varphi \tan\delta \quad ----- 2$$

$$N = \frac{2}{\pi}\cos^{-1}(-\tan\varphi \tan\delta) = 2\omega \quad ----- 3$$

Where

Sc – solar constant, w/m$^2$ or KJ/m$^2$hr $^{-1}$

φ – latitude of the location, degree = 9.5$^o$

ω – hour angle for the typical day of each month, degrees = average of 89.66$^o$ (calculated) ny – day number of each month.

## RESULTS AND DISCUSSIONS

**Table 1:** Summary of measured meteorological parameters

| Months | $H/H_o$ | $T_{min}$ | $T_{max}$ | $T_d=T_{max}-T_{min}$ | $Tr = \frac{T_{max}}{T_{min}}$ | $RH_{min}$ | $RH_{max}$ | $RH_d$ | $RH_r$ | $^{ns}/_N$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.86 | 10 | 28.3 | 18.3 | 2.83 | 19 | 21 | -02 | 0.91 | 0.79 |
| Feb | 0.86 | 14.7 | 31.2 | 16.5 | 2.12 | 30 | 23 | 07 | 1.30 | 0.69 |
| Mar | 0.80 | 15.5 | 31.7 | 15.7 | 2.05 | 27 | 24 | 03 | 1.13 | 0.89 |
| Apr | 0.66 | 18.5 | 29.9 | 11.4 | 1.62 | 44 | 29 | 15 | 1.52 | 0.44 |
| May | 0.58 | 17.7 | 27.7 | 10.2 | 1.58 | 67 | 49 | 18 | 1.37 | 0.46 |
| Jun | 0.65 | 16.6 | 26.2 | 9.6 | 1.58 | 73 | 57 | 16 | 1.28 | 0.49 |
| Jul | 0.66 | 16.4 | 24.0 | 7.6 | 1.46 | 77 | 72 | 05 | 1.07 | 0.27 |
| Aug | 0.55 | 16.8 | 28.8 | 12.0 | 1.71 | 76 | 70 | 06 | 1.09 | 0.33 |
| Sep | 0.65 | 16.9 | 24.9 | 8.0 | 1.47 | 65 | 58 | 07 | 1.12 | 0.38 |
| Oct | 0.67 | 17.0 | 28.5 | 11.5 | 1.68 | 52 | 53 | -01 | 0.98 | 0.32 |
| Nov | 0.88 | 17.2 | 28.2 | 11.0 | 1.64 | 25 | 44 | -19 | 0.57 | 0.36 |
| Dec | 0.93 | 17.0 | 28.5 | 11.5 | 1.68 | 20 | 22 | -02 | 0.91 | 052 |
| Total | 8.75 | 194 | 338 | 143.3 | 21.42 | 575 | 435 | 53 | 13.18 | 5.94 |
| Mean | 0.73 | 16.2 | 28.17 | 11.94 | 1.785 | 47.92 | 43.5 | 4.42 | 1.10 | 0.50 |

**Table 2:** Summary of correlation values and equations for the various $^H/_{H_o}$ versus the meteorological parameters.

| $H/H_o$ vs Parameters | Equation (or model) | R | $R^2$ |
|---|---|---|---|
| $H/H_o$ vs Tmax | $H/H_o$ = 0.021 Tmax + 0.113 | 0.387 | 0.150 |
| $H/H_o$ vs Td | $H/H_o$ = 0.021 Td + 0.472 | 0.550 | 0.303 |
| $H/H_o$ vs Tr | $H/H_o$ = 0.171 Tr + 0.422 | 0.515 | 0.265 |
| $H/H_o$ vs RHmax | $H/H_o$ = -0.005 RHmax + 0.952 | 0.761 | 0.579 |
| $H/H_o$ vs RHd | $H/H_o$ = -0.008 RHd + 0.766 | 0.654 | 0.092 |
| $H/H_o$ vs RHr | $H/H_o$ = -0.273 RHr + 1.030 | 0.532 | 0.283 |
| $H/H_o$ vs $^{ns}/_N$ | $H/H_o$ = 0.354 ($^{ns}/_N$)+ 0.554 | 0.540 | 0.292 |

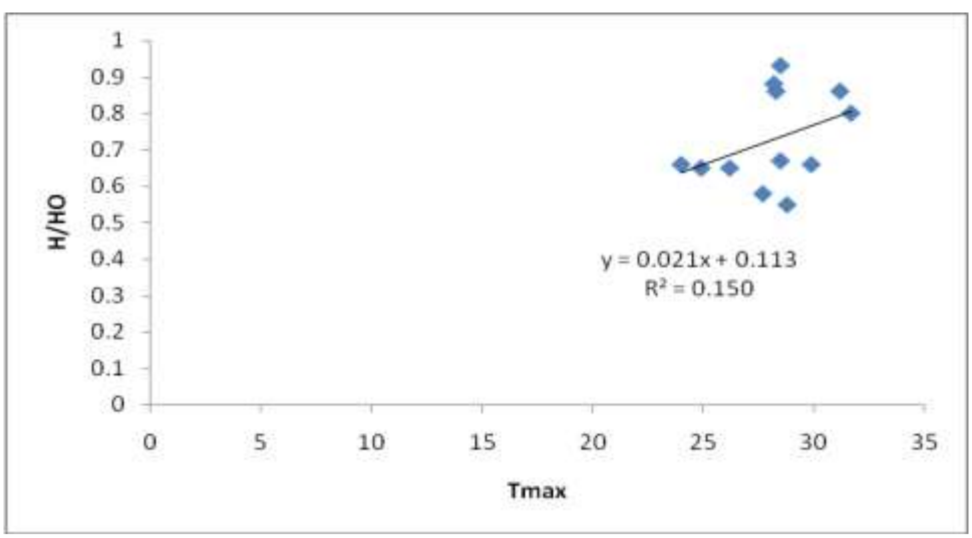


**Figure 1** Correlation and plot of H/Ho vs Tmax

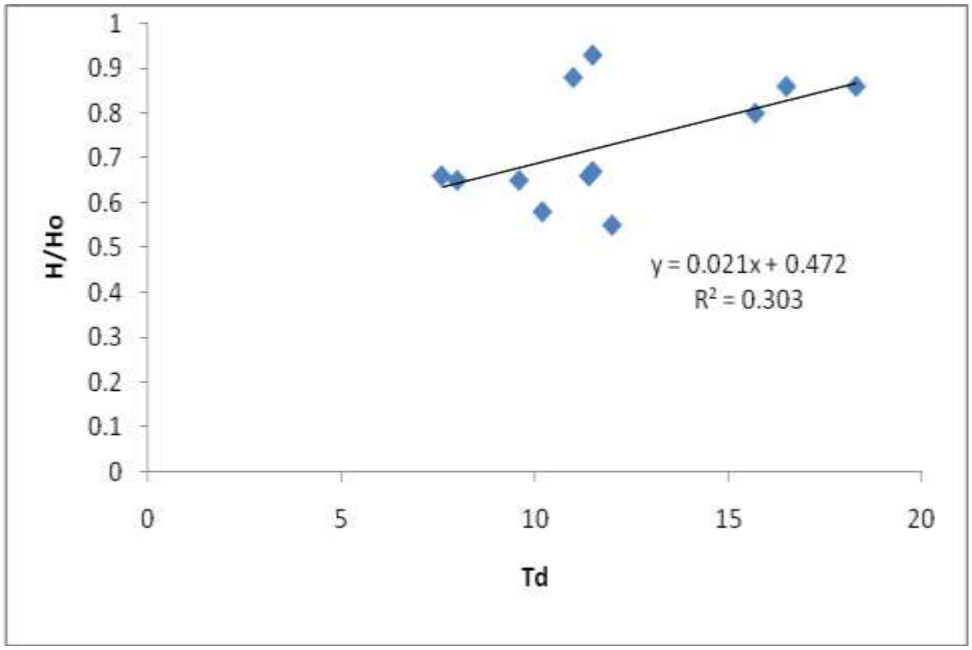


**Figure 2:** Correlation and plot of H/Ho vs Td

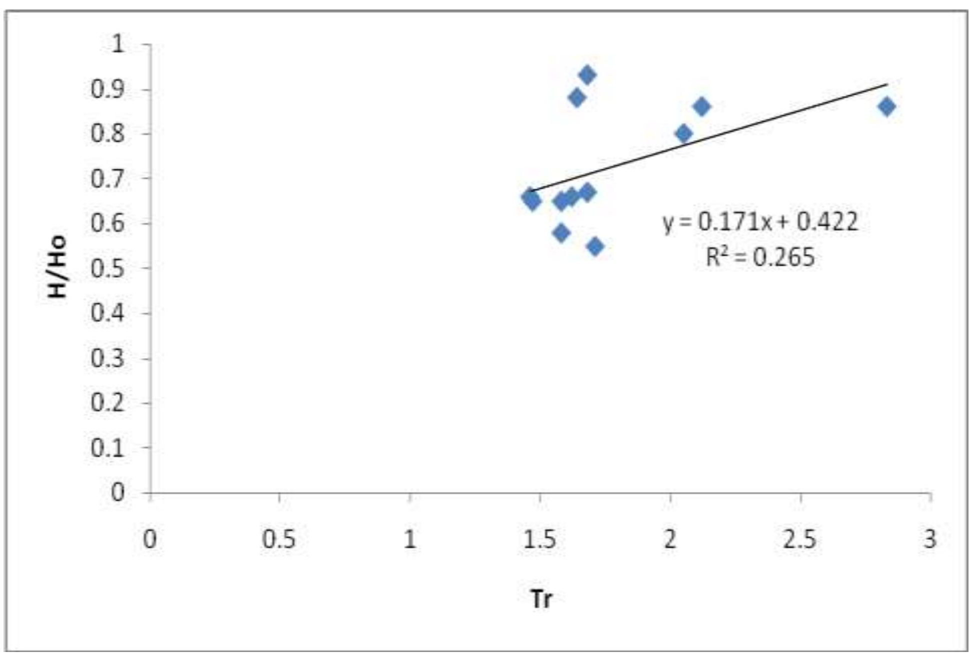


**Figure 3:** Correlation and plot of H/Ho vs Tr

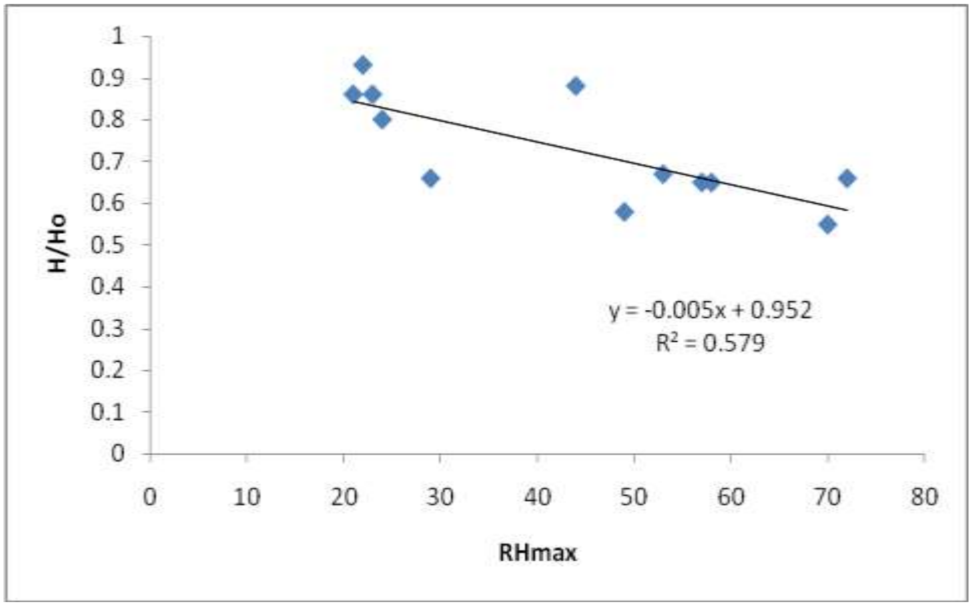


**Figure 4:** Correlation and plo of H/Ho vs RHmax

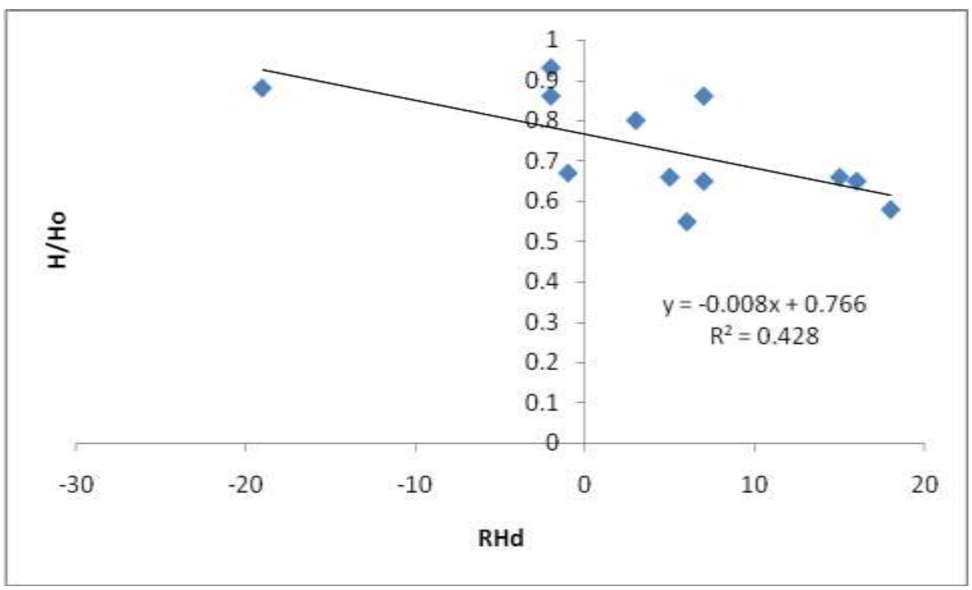


**Figure 5:** Correlation and plot of H/Ho vs RHd

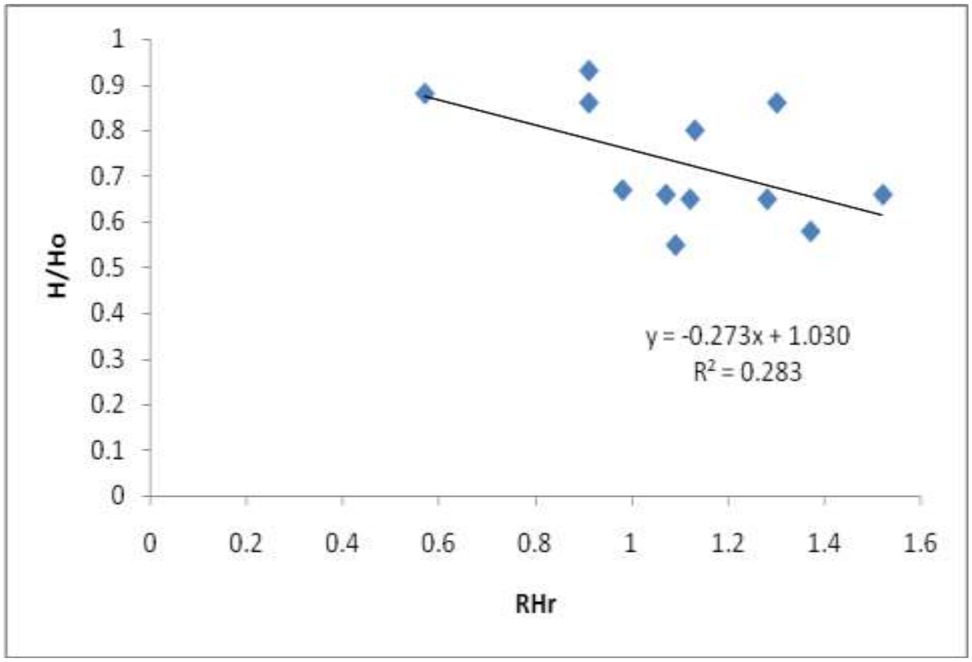


**Figure 6:** Correlation and plot of H/Ho vs RHr

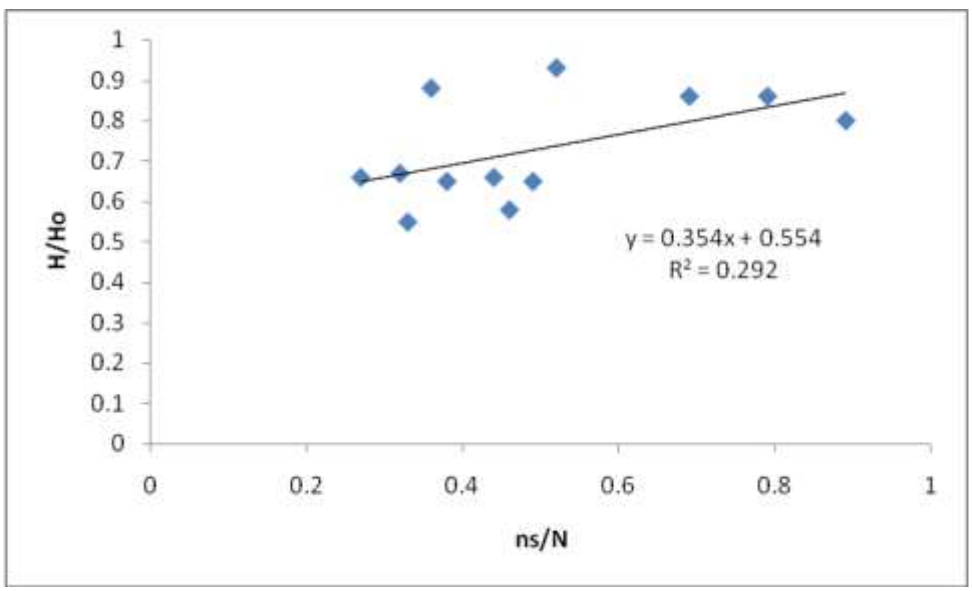


**Figure 7:** Correlation and plot of H/Ho vs ns/N

The monthly average daily extraterrestrial irradiation values are calculated using equation1.The results and summary of measured meteorological parameters are presented in Table 1. Table 2 shows a fair proportionality between $H/H_o$ & Td, $H/H_o$ & Tr, $H/H_o$ & RHr, $H/H_o$ & $^{ns}/_{N}$, which may have accounted for the fair correlation (R= 0.55, 0.51, 0.53 and 0.54) respectively between these parameters (Fig. 2, 3, 6, 7). These results support the recommendations of Hussaini at el (2005) and Agbo et al (2007) that models based on temperature data and relative humidity can be used to predict the global solar radiation in some Northern location of Nigeria. The low proportionality between $H/H_o$ and Tmax may have accounted for the corresponding low R-values of 0.387 (Fig.1).

Empirical models to estimate solar radiation are a suitable tool since these models have the advantage of using meteorological data that are commonly available. The obtained results showed that estimation of solar radiation using relative humidity data explained the highest proportion of the solar radiation (Fig.4) out of all the tested models followed by the difference between the maximum and minimum temperature (Td) (Fig.2) and then the model based of relative sunshine hour ($^{NS}/_{N}$) (Fig 7). The results demonstrated that most of the tested models used were able to adequately or averagely estimated daily global solar radiation from maximum relative humidity (RHmax), difference between maximum and minimum temperatures (Td), relative sunshine hours (ns/N), ratio of maximum relative humidity to maximum relative humidity (Fig.4) and ratio of maximum to minimum temperature (Tr) (Fig.3) in this order. Using maximum temperature (Tmax) based model (Fig 1) will not give a good estimate of global solar radiation of Barkin Ladi location. Therefore, using meteorological variables such as maximum R.H (RHmax), relative humidity differential (RHd), ambient air temperature differential (Td), relative sunshine hour ($^{NS}/_{N}$), ratio of maximum to minimum R.H (RHr) and ratio of maximum to minimum temperature to estimate the global solar radiation could get good results at most conditions as stated by Hussaini et al (2005) that models based on Tmax, $^{NS}/_{N}$ and R.H can be used to predict the global solar radiation in some Northern location of Nigeria.

The new and the best proposed method (RHmax) in this work to estimate global solar radiation from more commonly and reliably meteorological data can be useful to provide data which could otherwise be unavailable. This method is applicable for estimating the daily global solar radiation on a horizontal surface at any site in the community of Barkin Ladi, Plateau State of Nigeria. Although, these developed models were based on the meteorological data of one specific station, it is hope they could be applicable in other locations which are climatically similar.

## CONCLUSION

In the absence of global solar radiation data, reliable estimate can be made from easily available meteorological observations of Relative humidity (R.H) along with extraterrestrial solar radiation using different models. The maximum relative humidity model is simple and has the best correlation (R= 0.7609) of the meteorological parameters investigated. It will best predict the global solar radiation with relatively high accuracy than those models based on ambient air temperature and hours of bright sunshine for the location. It is therefore, recommended to estimate the daily global solar radiation when ambient air temperature and sunshine hours are unavailable, when only relative humidity (R.H) data are available and when the model coefficient cannot be determined directly from available data or by extrapolation. This model can also be used to determine missing values of measured global solar radiation of the location in question.

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