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Estimation of global solar radiation using cloud cover and surface temperature in some selected cities in Nigeria

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ABSTRACT

This study utilized monthly mean daily values of global solar radiation, temperature and cloud cover at eight locations in Nigeria and developed an empirical correlation for the estimation of global solar radiation at different locations. This research presents the comparison between the observed and the predicted values under different geographical and varied meteorological conditions. The comparisons are made using standard statistical tests, namely mean bias error (MBE), root mean square error (RMSE) and Standard error (SE). A correlation coefficient (r) ranges from 0.823- 0.978 and correlation of determination (R^2) ranges between 0.677 and 0.959 with a maximum standard error of 0.0573 and RMSE values lie in the range from 0.029 to 0.054 with low MBE across the eight stations.

Keywords: Global solar radiation, clearness index, cloud cover, temperature.

INTRODUCTION

Global solar radiation data are necessary at various steps of the design, simulation, engineers, agricultural scientists and performance evaluation of any project involving solar energy. Solar radiation provides the energy for photosynthesis and transpiration of crops and is one of the meteorological factors determining potential yields. Crop growth models, which have been developed since the 1960s, have been regarded as important tools of interdisciplinary research and have since been used in a number of areas such as the assessment of agriculture potential of a given region in the field of crop yield forecasting or as a climate change impact assessment tool. Suppit and Vankkappel (1998) developed a method to provide estimates of daily global radiation as input for the Crop Growth Monitoring of the European Union, from meteorological observation transmitted via Telecommunication System for location where sunshine duration observation are not available.

Several approaches have been used for the estimation of global solar radiation from other climatic parameters such as sunshine duration (Ångström, 1924; Rietveled, 1978; Soler 1990; Udo, 2000; Falayi and Rabiu, 2005; Falayi et al. 2008; Abdulazeez, 2011 and Abdulazeez et al., 2010), air temperature (De Jong and Stewart, 1993; Falayi et al. 2006; and Falayi and Rabiu, 2008) and cloud cover is one of the major factors restricting the availability of solar radiation at the Earth's surface. Various investigations to estimate global solar radiation from observations of various cloud layers amounts and cloud types executed (for example Barker, 1992; Davies and McKay, 1988; Lorente et al., 1996; Hamdy, 2007; Sabziparvar and Shetaee, 2001; Alados et al., 2002). One of the useful ways to determine the extent of cloudiness or the degree of clearness of the sky is through some mathematical relationships among the available solar fluxes like global radiation, diffuse radiation and extraterrestrial radiation.

The total cloud cover amount is estimated at fixed time lags at most meteorological stations in the world. A second (indirect) simple measure of the state of the sky is the daily value of the relative sunshine (sometimes call bright sunshine fraction, or sunshine fraction). Cloud cover and global solar radiation showed a non linear relationship (Paulescu and Badescu, 2011). Clouds and their accompanying weather patterns are among the most important atmospheric phenomena limiting solar radiation at the Earth's surface. Also cloud cover reduces daily maximum temperature because of the smaller short wave radiation input. Moreover the presence of clouds at night increases the minimum temperature because of the greater emissive of clouds compared to a clear sky.

The Ångström formula (1924) improved by Prescott (1960) is the most common choice in crop model studies at sites where no monthly mean of daily total terrestrial solar radiation (H) measurement are available. It is based on the fraction of monthly mean of daily extraterrestrial radiation (Ho), which is determined as a fraction of actual (*S*) the monthly mean daily hours of bright sunshine and potential daily maximum number of hours of insolation (Smax) during the day:

$$\frac{H}{H_O} = a + b\left(\frac{S}{S_{\max}}\right) \qquad (1)$$

The major aim of this paper is to determine the applicability of the Wörner (1967) and Hargreaves et al. (1985) models proposed by Supit and van Kappel (1998) for estimating global solar radiation from cloud cover and surface temperature data for eight locations, viz: Sokoto, Maiduguri, Yola, Enugu, Owerri, Abeokuta, Port-Harcourt, and Jos. The tests of performance of the model were carried out in term of the widely used statistical indicators.

MATERIALS AND METHOS

2.1 Data Analysis

Daily global solar radiations, cloud cover, maximum and minimum temperature data, were obtained from the Archives of Nigeria meteorological Agency, Federal Ministry of Aviation, Oshodi, Lagos. The data obtained covered a period of 16 years (1995 – 20010) for eight locations in Nigeria listed in Table 1 and displayed in Figure 1.

Table 1. Geographical location of the stations

Stations	Locations LAT.	LONG.	Altitudes
Sokoto	13.01N,	05.15E	350.8
Maiduguri	11.51N,	13.05E	353.8
Port-Harcourt	04.51N,	07.01E	19.50
Enugu	06.28N,	07.33E	141.8
Owerri	05.29N,	07.00E	91.0
Abeokuta	07.01N ,	03.20E	104.0
Yola	09.14 N,	12.28E	186.1
Jos	09.52N,	08.45E	192.2

Figure 1: Map of Nigeria

In this study, we used simple model of the Wörner (1967) and Hargreaves et al. (1985) models modified by Supit and van Kappel (1998)

$$H = H_O\left[a\sqrt{(T_{\max} - T_{\min})} + b\sqrt{(1 - C_w/8)}\right] + c \qquad (2)$$

Where C_w is the mean of the total cloud cover of the daytime observation in percents, tenths, or in eighths of sky covered by clouds, T_{max} and T_{min} are maximum and minimum temperature. Also H is the monthly mean of daily total terrestrial solar radiation falling on horizontal surface at a particular location in MJ/m^2. Ho is the monthly mean of daily total extraterrestrial solar radiation a horizontal surface in the absence of atmosphere and a, b, and c are empirical constants.

$$H_o = \frac{24\times3600}{\pi} Gsc\left(1+0.033Cos\frac{360n}{365}\right)\left(Cos\phi Cos\delta Sin W_S + \frac{2\pi W_S}{360} Sin\phi Sin\delta\right) \quad (3)$$

Were Ho = monthly mean daily extraterrestrial radiation MJ/m^2
Gsc = Solar constant = 1367 W/m^2
Ws = Sunset hour angle for the typical day n for each month in degrees

$$= Cos^{-1}(-\tan\theta\tan\delta) \quad (4)$$

$\theta =$ Latitude angle for the location in degrees
δ = declination angle for the month in degree and n is mean day of each month

$$\delta = 23.45Sin\left(360\left(\frac{284+n}{365}\right)\right) \quad (5)$$

2.2 Method of model evaluation
The models are evaluated in terms of mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE). These error terms are calculated using the following equations:

$$MBE = \frac{1}{n}\left[\sum\left(H_{pred} - H_{obs}\right)\right] \quad (6)$$

$$RMSE = \left\{\left[\frac{1}{n}\sum\left(H_{pred} - H_{obs}\right)^2\right]\right\}^{\frac{1}{2}} \quad (7)$$

$$MPE = \left[\sum\left(\frac{H_{obs} - H_{pred}}{H_{obs}}\times100\right)\right]/n \quad (8)$$

Statistical tests, the Root Mean Square Error (RMSE) and Mean Bias Error (MBE) were used to evaluate the accuracy of the predicted global radiation. Using the MBE and RMSE, models were tested under various meteorological and climatic conditions (Togrul et al., 2000).The RMSE test gives the information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the estimated and measured values. The lower the RMSE, the more accurate is the estimate. A positive value of MBE shows an over-estimate while a negative value an under-estimate by the model According to Iqbal (1983), a draw-back with this method is that an over-estimation of an individual observation will cancel an underestimation in a separate observation. The values of the MBE represent the systematic error or bias, while the RMSE is a non-systematic error (Onier, 1994).

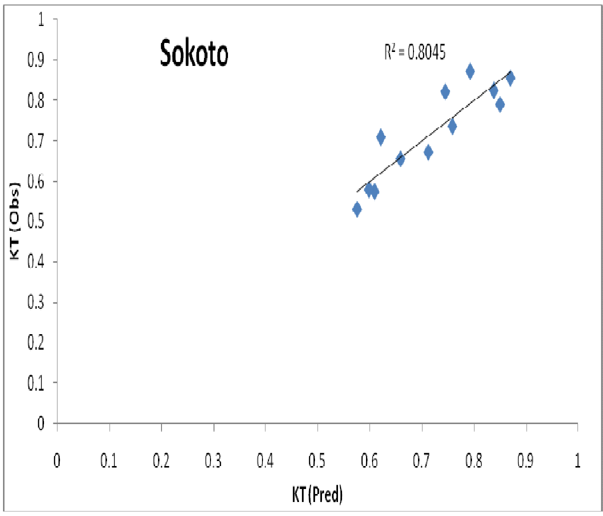
The use of MBE and RMSE is not enough as statistical indicator for the evaluation of the model performance and we suggested that MPE should be used in order to give more reliable results. MPE gives long term performance of the examined regression equations, a positive MPE values provides the averages amount of overestimation in the calculated values, while the negatives value gives underestimation. A low value of MPE is desirable.

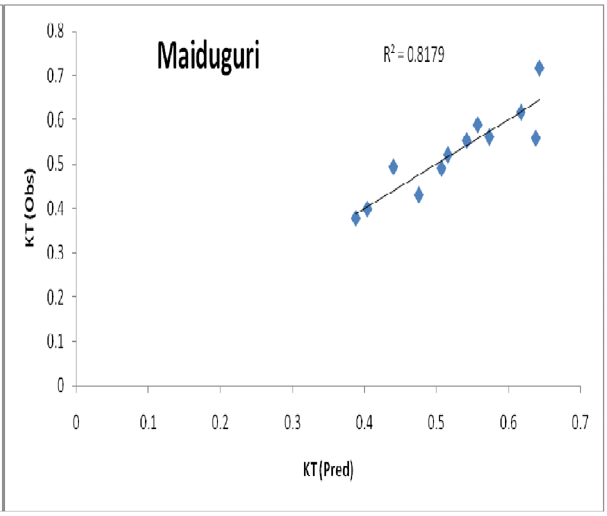
The regression and correlation analyses were performed between the clearness index (K_T=H/H_O), the root of monthly mean of daily temperature and root of monthly mean of daily total cloud cover. We can define clearness index (KT) as the ratio of the observation/measured horizontal terrestrial solar radiation (H), to the calculated/predicted horizontal extraterrestrial solar radiation (Ho).

Table 2 shows the values of regression coefficients (r), coefficients of determination (R^2) and regression constants (a and b). Figure 2 further illustrate the Wörner (1967) and Hargreaves et al. (1985) models regression relationship.

Table 2. Shows equation with regression and statistical indicators for eight stations

Stations	**r**	**R^2**	SE	MBE	RMSE
Sokoto	0.8969	0.8045	0.05739	0.000075	0.0470
Maiduguri	0.9044	0.8179	0.04526	- 0.0000108	0.0392
Jos	0.9790	0.9585	0.03357	0.000042	0.0291
Yola	0.8258	0.6819	0.05144	0.000075	0.0542
Owerri	0.9778	0.9559	0.01958	0.000075	0.0170
Port-Harcourt	0.8899	0.7919	0.04339	0.000017	0.0376
Enugu	0.8227	0.6768	0.05701	0.000011	0.0494
Abeokuta	0.8258	0.6819	0.05144	0.0000108	0.0445





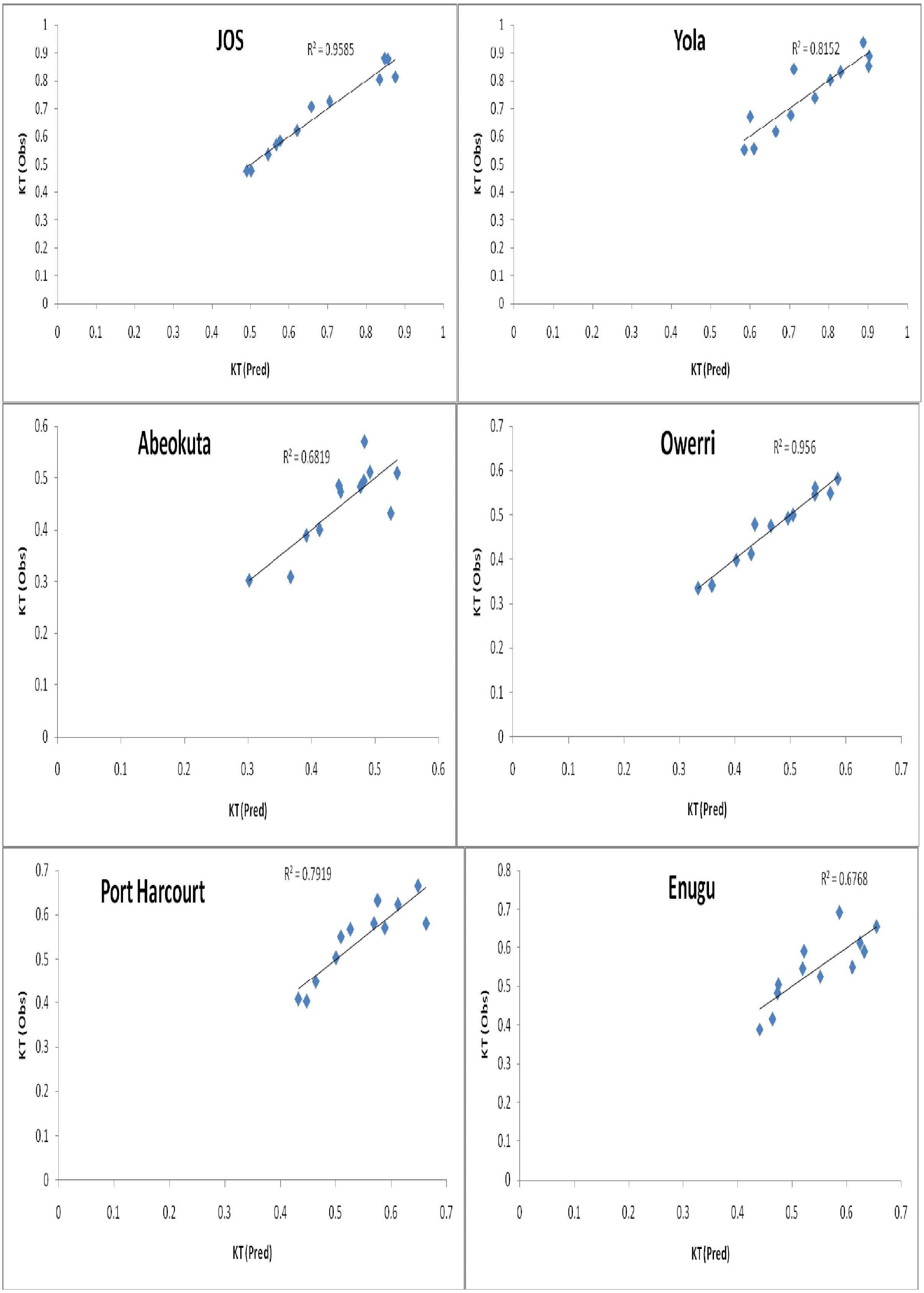


Figure 2: Comparison between the observed and predicted values of the correlations for eight stations in Nigeria

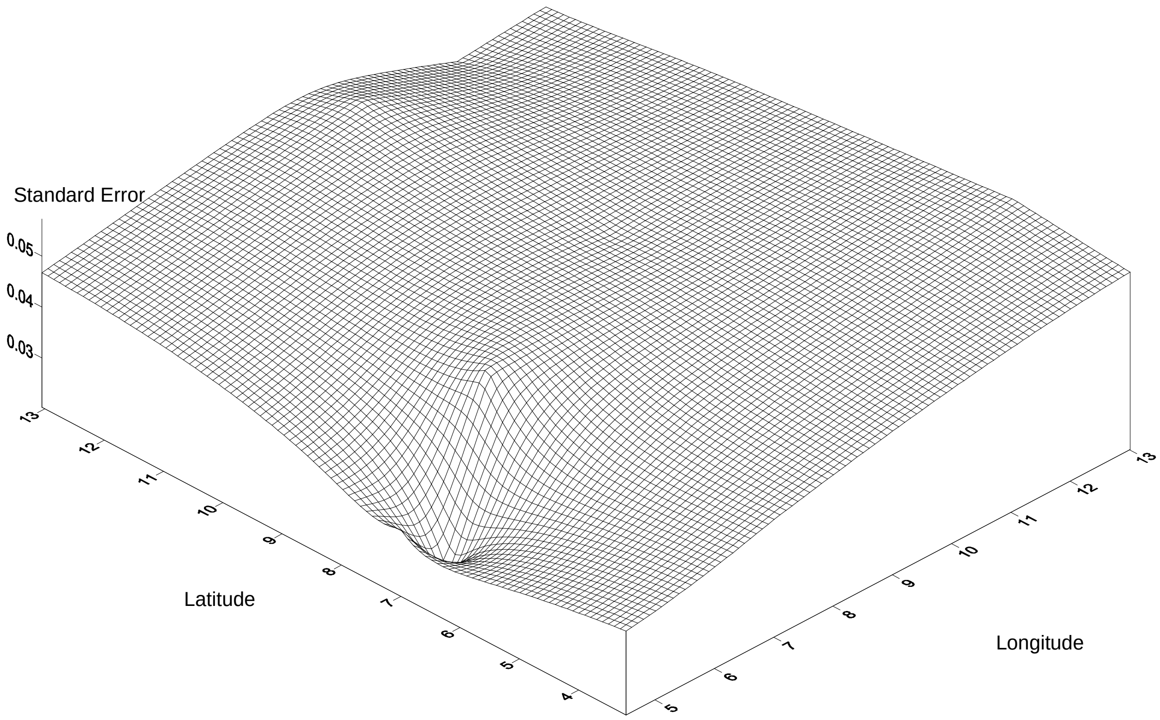


Figure 3: Dependence on latitude and longitude of the standard error associated to Eq. (2) for eight stations in Nigeria

RESULTS AND DISCUSSION

Solar energy is one of the most important alternative energy sources. For designing any solar energy device, solar energy parameters and components have important role. Solar energy offers us clean and sustainable energy for the future. Due to energy demand of the world in these days, correct predictions and using solar energy models have big importance. It was aim at to supply correct models calculation in this study for using solar energy truly.

Table 2 contain summaries of regression statistics obtained from equation (2). The correlation coefficient r, coefficient of determination R^2, MBE (MJ/m^2), RMSE (MJ/m^2) varies from one station to another station. The RMSE is a measure of the variation of predicted values around the measured values, while the MBE is an indication of the average deviation of the predicted values from the measured values. The low MBE values exhibited by the model imply that it has a good long-term representation of the physical problem. The RMS values lie in the range of 2.91% to 5.42%, which indicates a good agreement between observed and predicted values of monthly mean of daily global solar radiation. The reason for the overestimation could be due to increased reflection of solar radiation from snow cover or a decreasing role of atmospheric scattering.

Correlation coefficients (0.823 - 0.978) are high for all the stations. This implies that, there are statistically significant relationships between the clearness index, the root of monthly mean of daily temperature and root of monthly mean of daily total cloud cover and this is further demonstrated by high values of coefficient of determination R^2 (0.677 - 0.959) across the eight stations. Clouds are the primary variable that determines the amount of direct beam solar radiation reaching the surface of the earth. Consequently, regions with higher cloud density (e.g., humid regions) receive less solar radiation than the cloud-free climates (e.g., deserts)

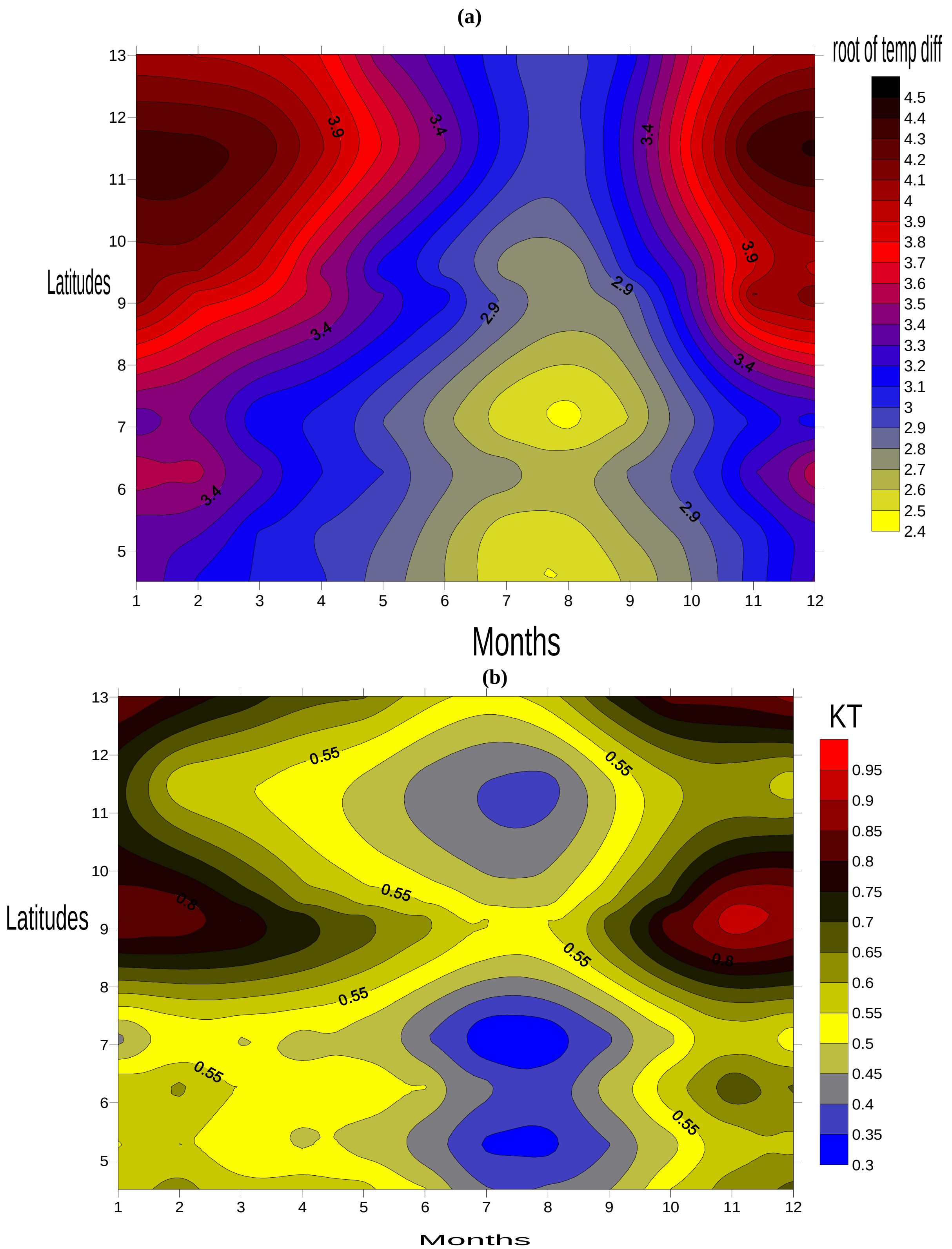


Fig.4: (a) Variation of Monthly means of daily diffuse fraction (square root of the temperatures) and (b) Variation of Monthly means of clearness index (KT) for eight locations in Nigeria.

To demonstrate the proposed model for equation (2) does not systematically over or under estimate for different stations in Nigeria, monthly mean values of global solar radiation were estimated and compared with observed values. Plots of estimated versus observed values for selected stations are given in Figure 2. There is a good agreement between observed values and data estimated by the above mentioned equation, which makes it useful in estimating global solar radiation (where there is no data) in Nigeria. This agreement may be considered as an indication of the applicability of the proposed method. Dependence on latitude and longitude of the standard error associated to Eq. (2) for eight stations in Nigeria (Figure 3). A positive standard error means that Eq. (2) over-estimates the value of the clearness Index. Sometimes the estimation result is overestimating the solar radiation and sometimes underestimates the solar radiation. Again, it is probably caused by the cloudy sky which cloud sometimes suddenly come and disappears. In rainy season, normally the intensity of the cloud is higher than dry season

The data used is more than one year to characterize the seasonal patterns in spatial variability. In this research a 16 years period was assumed to be sufficient to eliminate the possible effects due to changes in atmospheric transparency as a result of changes in air pollution. In Figure 4a low temperature was noticed between the months of June to September across the latitudes. The KT values are low during June to September but high during October to February are shown in Figure 4b. Some stations near coast may experience low clearness index like Port Harcourt, Owerri Enugu and Abeokuta which implies that the clearness index is a measure of solar radiation extinction in the atmosphere, which includes effects due to clouds but also effects due to radiation interaction with other atmospheric constituents. Different values of the clearness index at different stations may be as a result of different atmospheric contents of water vapour and aerosols.

Figure 5 shows that the spatial distribution of regression constant **c** of the proposed method for Nigeria for the selected stations in Nigeria, which show a smooth gradient for the regression constant.

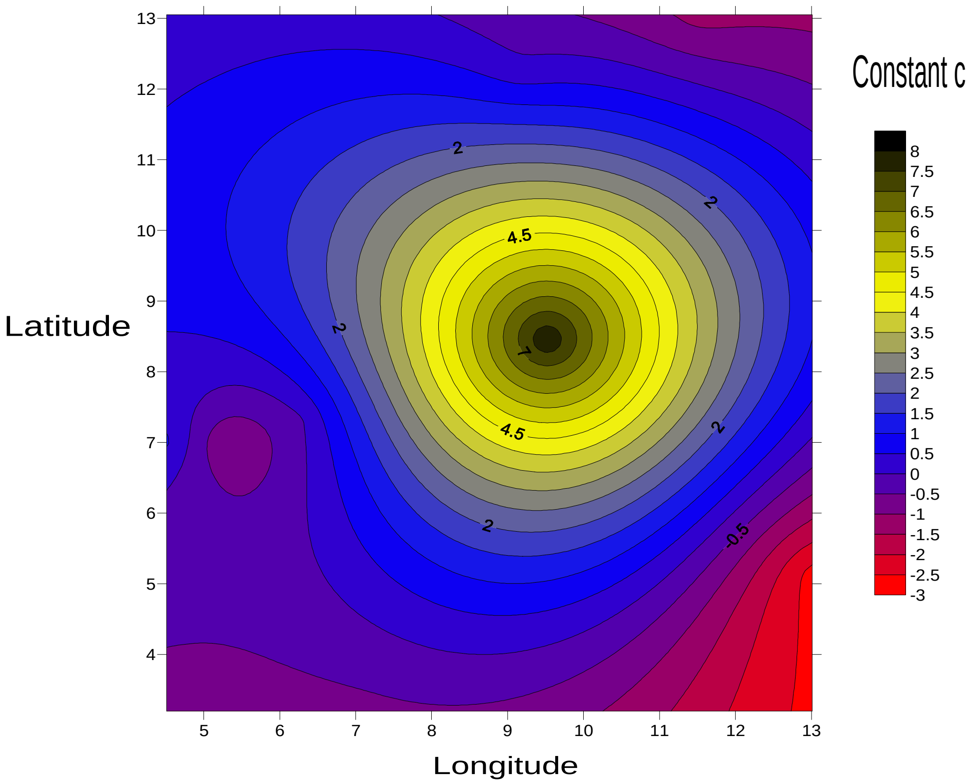


Figure 5: Variation of the constant c of the proposed method over selected stations in Nigeria

The solar radiation reaching the Earth's surface decreases with increasing cloud cover. The range in daily temperature extremes was assumed to be an important factor in determining the presence or absence of clouds (Mahmood and Hubbard 2002), along with precipitation. Thus, solar radiation is a deterministic quantity that can be used for improving current efforts on weed seed germination and growth modelling. This solar radiation prediction tool can be integrated into dormancy, germination, and growth models to improve microclimate-based simulation of development of weeds and other plants.

CONCLUSION

The present study provides new evidence regarding the utilization of global solar radiation measurements for the reliable estimation of global solar radiation. Moreover, it seems that the model of Supit and van Kappel (1998) can be applied for this region of Nigeria with considerable success. Good agreements were evident between measured values and data calculated by Supit and van Kappel (1998). The values of the correlation coefficients and coefficient of determination were found for each station. Also, the performances for the model for eight stations have been done in terms of widely used statistical indicators, Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The estimated values of global solar radiation reveals that solar radiation can be very efficiently used to compensate for energy inadequacy.

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