Estimation of Diffuse Solar Radiation in the South of Cameroon

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Abstract
Abstract The successful design and effective utilization of solar energy systems and devices for application in various facets of human endeavors, such as power and water supply for industrial, agricultural and domestic uses, largely depend on the availability of information on solar radiation characteristic of the location in which the system and devices should be situated. This study proposes a mono-variable model of monthly mean daily diffuse solar radiation on horizontal surfaces for some cities between 2°N and 5°N of Cameroon (Bertoua, Yokadouma, Yaoundé, Kribi, Kumba). The estimation was based on a correlation between clearance index and diffuse to global solar radiation ratio and was computed using monthly mean daily data set for global solar radiation on horizontal surfaces. The predictive efficiency of the proposed model was compared with the observed values and those believed to be universally applicable. The results suggest that the existing methods could be replaced by the developed model for a diffuse solar radiation data generation scheme.
Keywords: clearness index, diffuse fraction, MBE, RSME, t-statistic.

1 Introduction

Global solar radiation data on the earth's surface are required by engineers, farmers, and hydrologists. Their effective harnessing and utilization are of significant importance globally, especially at the time of rising fossil fuel costs and the environmental effects of fossil fuel, such as the climate change problems. Knowledge on diffuse solar radiation and its contribution to global solar radiation is of immense importance since an inclined surface besides getting direct beam of solar radiation also receives diffuse solar radiation (scattered plus reflected). Long-term mean values of hourly or daily beam and diffuse solar radiations on a horizontal surface are often required in many solar energy applications. For example, the computation of insolation on inclined surface requires the corresponding hourly or daily beam and diffuse solar radiation. Global and diffuse solar radiation data are not measured by meteorological stations in Cameroon . In the absence of these data (measured global and diffuse solar radiation data) one has to rely on the available methods and also to develop new ones. Several models have been proposed to estimate global solar radiation. Liu and Jordan(1961) developed a theoretical method for deriving the mean hourly solar radiation from the mean daily total radiation, with the assumption that the atmospheric transmission is constant throughout the day, and this is independent of solar altitude. Page(1964) developed a linear relationship between clearance index and diffuse to global solar radiation ratio, while Iqbal(1979)and Lam-Li(1996) proposed a linear relationship in terms of clearance index for estimating monthly mean diffuse solar radiation. Using collected data for five US stations and Liu and Jordan's curve, Collares-Pereira and Rabl(1979) developed an analytical expression for the ratio of hourly to daily solar radiation, in terms of sunset hour angle. Erbs et al.(1982) and Muneer et al.(1984) developed correlations between hourly diffuse and global solar radiation on a horizontal surface as a function of the clearness index. Ulgen and Hepbasli(2002) correlated the ratio of monthly average hourly diffuse solar radiation to monthly average hourly global solar radiation with the monthly average hourly clearness index in form of polynomial relationships for the city of Izmir, Turkey. In another study, they(Ulgen and Hepbasli 2002) correlated solar radiation parameters (global and diffuse solar radiation) with respect to ambient temperature in the fifth order. In the absence of measured data, Ahmed et al.(2009) applied Liu and Jordan's and Page models to estimate the global and diffuse solar radiation for Hyderabad and Sindh, Pakistan. Recently Okundamiya and Nzeako(2010) proposed a temperature based model for predicting the monthly mean global solar radiation on horizontal surfaces for six geopolitical zones in Nigeria.
In this study, empirical models for estimating the monthly mean daily diffuse solar radiation on horizontal surfaces was developed for locations between 2°N and 5°N in Cameroon. The diffuse solar radiation was also estimated from other established models and the results were compared with our estimated results. The different locations corresponding to geographical zones are listed in Table 1 and displayed in figure 1.

2 Methods

One usually uses linear relation in solar energy studies. For example, different versions of linear Angström model are use extensively in solar energy studies for estimation of the global terrestrial solar radiation amounts from the sunshine duration data. However, atmospheric turbidity and transmissivity, planetary boundary layer turbulence, cloud thickness, and temporal and spatial variations cause embedding of non-linear elements in the solar radiation phenomena. Hence, the use of simple linear models cannot be justified physically except statistically without thinking about obtaining the model parameter estimations (Zekai Sen 2008). On other hand, modeling solar energy with polynome implies different assumptions to obtain the best result with the least number of parameters (Box and Jenkins 1970). It is difficult to explain on physical grounds why a polynomial expression is adopted for modeling purposes apart from the mathematical convenience only. In statistical literature, second-order statistics (variance) subsume first-order statistics (average), and third-order statistics (skewness) include first and second-order statistics (Benjamin and Cornell 1970). In general, a polynomial model leads to imbedded redundancy in the model.

In order to have the best model for study solar radiation in the given locations, we fit a set of regressions functions between the global and diffuse solar radiation of the two forms.

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$$H_d = H*\left(a_0 + a_1 * k_t\right) \quad Linear\,(1)$$

$$H_d = H*\left(a_0 + a_1 * k_t + a_2 * k_t^2\right) \quad Quadratic\,(2)$$

Where $a_i$and $b_i$are empirical constant. $\boldsymbol{k_t}$ is the monthly mean daily clearance index (ratio between the global solar radiation on a horizontal surface $\boldsymbol{H}$(W h/m^2 /day) and the extraterrestrial radiation $\boldsymbol{H_0}$ (W h/m^2 /day) : $k_t = \frac{H}{H_0}$), k_d is the diffuse fraction (ratio between the diffuse solar radiation on a horizontal surface $\boldsymbol{H_d}$ (W h/m^2 /day) and global solar radiation on a horizontal surface H : $k_d = \frac{H_d}{H}$). The extraterrestrial horizontal radiation per day $\mathbf{H_0}$ (M W/m^2 /day) at a given place is the radiation on horizontal surface at the place without the atmospheric effects.

The performance of the proposed model was evaluated using the t-statistic (TS), a statistical indicator proposed by Stone(1993), Root Mean Square Error (RMSE), and Mean Bias Error (MBE). These indicators are mainly employed for the adjustment of solar radiation data[16,17,18]. Detailed analysis of RMSE, MBE, and TS is given in the literature Almorox(2005).

The results of (1-2) were compared with the results proposed by Liu and Jordan [1], Page [2], Iqbal [3], and Erbs et al. [6]. The available parameters informed the choice of the selected models for comparison. We have also considered the ability of these models to generate data from limited mean values and the accuracy (quality) of their results. The accuracy of the results reported by the original authors and those published in reviews were proven satisfactorily.

2.1 Data analysis

The longer the period of record is, the more representative the result will be. The monthly mean of daily global and diffuse radiation on horizontal surface for twenty years (1985-2005) for five locations (Bertoua, Yokadouma, Yaoundé, Kribi, Kumba) is of Cameroon displayed in figure1, were obtained from HolioClim-1 Data Base satellite Data. Geiger et al.(2002) have described the availability of a web-based service for quality control of solar radiation data. The service is available through the web site www.helioclim.net. The quality control procedure is a part of an on-going effort of the Group 'Teledetection and Modelization' of the Ecole des Mines de Paris/Armines to provide tools and information to the solar radiation community through the world wide web. The object of that service is not to perform a precise and fine control but to perform a likelihood control of the data and to check their plausibility. This is achieved by comparing observations with expectations based upon the extraterrestrial irradiation and a simulation of the irradiation for clear skies. It offers a means to check time series of irradiation data. Inputs are provided via an HTML page by a copy and paste procedure and the return is also via similar means. Suspicious data are flagged upon return. Due to its use of B2 images of reduced spatial and temporal resolutions, the HolioClim-1 database offers good quality for Africa(2011). The clearance index (k_t) was obtained from observed H and computed $\boldsymbol{H_0}$ for the study locations. H_0 is the daily extraterrestrial radiation on the horizontal surface (Wh/m^2/day).

2.2 Simulation

We developed computer codes in Fortran programming language to compute the empirical constants of (1-2) using the data discussed above (in Section 2.1) and used open office to perform the regression analysis. Our simulation results are illustrated in table2. The linear or quadratic model was chosen since it produced the best fit. Codes were developed in MATLAB to display de regression fit. In this study, the performance of the t-statistic (TS) was analyzed at the 95\% confidence level. A stochastic analysis was performed on the estimation models (proposed and existing [1,2,3-6]) using one year (1995) monthly mean daily data. The results of the analysis are illustrated in Table1 and Figure 2.

3 Results and discussion

3.1 Results

The results of the simulation of (1-2) are illustrated in table2. These results informed the proposal of empirical's models for estimating the monthly mean daily diffuse solar radiation on a horizontal surface using clearance index for the locations investigated in this study Table2.

Figure2 shows the correlation between the estimated and observed values of the diffuse fraction using table2. The results of the stochastic analysis performed on the estimation models using diffuse solar radiation are illustrated in Table3.

Figure3 shows a comparison of the estimated values of monthly mean diffuse solar radiation obtained using (1-2) with those from the existing models.

Figure4 illustrates the comparison of the estimated values of the monthly mean diffuse solar radiation obtained using the proposed model with the observed values for the study locations.

3.2 Discussion

The following observations were deduced from the analysis of the results presented in Section 3.1. The empirical constants (a_i) and (b_i) of the proposed model (1-2) vary for the study locations. This may be due to seasonal variations of the diffuse solar radiation caused apparently by the degree of cloud cover, atmospheric dust, and presence of water vapor and Ozone and so forth in the atmosphere which differs from one location to another. The south of Cameroon is a various geographic area. It stands from pacific oceans to tropical forest. This vast area of tropical forest comprises islets on which people lives and participates to the atmosphere modification by trees cutting down for firewood, slash and burn cultivation and the influence on the localities near the littoral to the proximity of the ocean. Therefore, there is change and variation of the diffuse radiation. The presence of sea also influences the diffuse fraction (steam, cloud). The coefficient of determination between the estimated and the observed values of diffuse fraction as illustrated in Figure(2) is close to unity (0.92–0.99) for the proposed model. This is an indication of a good agreement of the estimated with the observed diffuse fraction.

The test of MBE provides information on the long-term performance of the proposed model. We observed that all established models are lower than observed values as shown in table1. Almorox et al. (2005) have recommended that a zero value for MBE is ideal. This suggests significant underestimation of established models (Page, Liu and Jordan, Iqbal, Erbs et al.). We remark a low value of the MBE in that entire region, reflecting the relevance of the selected models. This is one of the criterion for assessing the smoothness of the model table3. The proposed model has good long-term performance. the estimates compare at favorably (with negligible overestimation) with their observed values. The result of this comparison is illustrated in Figures3 and Figure4 .

The test of RMSE provides information on the short-term performance of the proposed model. The RMSE values vary from a minimum (from the proposed estimates) to a maximum (Liu and Jordan's estimates). Low RMSE values are desirable [17,18,19]. This indicates that the proposed model has the best short-term performance for the study locations. The use of the MBE and the RMSE statistical indicators is not adequate for the evaluation of model performance [17,18]. This informs the use of the t-statistic(TS) indicator.

The t-statistic (TS) allows models to be compared and at the same time can indicate whether or not a model's estimate is statistically significant at a particular confidence level. It takes into account the dispersion of the results. The TS-values of existing models lie outside the range of the critical TS-values (TSc(0.025) = ±1.96) for the study locations. These results indicate that their estimates should be rejected. This suggest that those estimates are statistically insignificant in the study locations. The TS-values of our proposed models lie within the range of the critical TS-values. That is, our estimated results are statistically significant at the 95% confidence level. However, the low TS-values of the proposed model demonstrate its good performance accuracy.

The variation of diffuse solar radiation with the months of the year is maximal between Mars and October Figure4. The annual mean diffuse solar radiations in Bertoua, Yokadouma, Yaoundé, Kribi and Kumba are 75.822 ; 76.388 ; 80.463; 75.579 and 80.705 KWh/m^2/day, respectively. Our proposed annual mean diffuse solar radiations are 75.884; 76.410; 80.527; 75.647and 80.769 KWh/m^2/day, respectively. The annual mean diffuse solar radiation for the best established model's in Bertoua, Yokadouma, Yaoundé, Kribi and Kumba vary for maximum of 67.597; 68.268; 68.132; 67.771 and 66.938 KWh/m^2/day (Iqbal model's). These compare favorably our proposal model data with the observed data as expected.

4 Conclusion

The study has demonstrated the availability of diffuse solar radiation on horizontal surface for Bertoua, Yokadouma, Yaoundé, Kribi, Kumba employing clearance index. the linear and quadratic models were deduced from those and used to predict the monthly mean daily diffuse solar radiation, which was in agreement with the observed values. The study also verified the diffuse solar radiation models by Page, Liu and Jordan Iqbal and Erbs et al. The results indicate that the proposed model (1-2) compared favorably with the observed values in the four studied locations between 2^{o}N and 5^{o}N in Cameroon (Bertoua, Yokadouma, Yaoundé, Kribi, Kumba), while Page, Liu and Jordan Iqbal and Erbs et al. model's are not in comparison favorably with the observed values in any location.

References

B.Y.H.Liu and R.C.Jordan (1961),"Daily insolation on surfaces tilted towards equator", ASHRAE Transactions, vol. 3, pp. 526- 541, .

J. K. Page (1964), "The estimation of monthly ea values of daily total short wave radiation on vertical and inclined surfaces from sunshine records for latitudes 40°N-40°S",Proceedings of the UN conference on new sources of energy, paper no. 598, 4, pp 378-390.

M. Iqbal (1979), " A study of Canadian diffuse and total solar radiation data, part I. Monthly average daily horizontal radiation", Solar Energy, vol. 23, no. 2, pp. 169-173.

Lam JC, Li DHW (1996). "Correlation between global solar radiation and its direct and diffuse components", Building and Environment; vol. 31 ,6, pp 527-35.

M. Collares-Pereira and A. Rabl (1979), "The average distribution of solar radiation correlations between diffuse and hemispherical and between daily and hourly insolation values", Solar Energy, vol. 22, no. 2, pp. 155-164.

D.G.Erbs, S.A.Klein and J.A.Duffe (1982), "Estimation of the di#use radiation fraction for hourly, daily and monthly average global radiation", Solar Energy, vol. 28, no . 4, pp. 293- 302.

T. Muneer, M. M. Hawas, and K. Sahili (1984), "Correlation between hourly diffuse and global radiation for New Delhi", Energy Conversion and Management, vol. 24, no. 4, p p. 265-267.

K. Ulgen and A. Hepbasli (2002), "Prediction of solar radiation parameters through clearness index for Izmir, Turkey",Energy Sources, vol. 24, no.8, pp. 773-785.

K. Ulgen and A. Hepbasli (2002), "Estimation of solar radiation parameters for Izmir, Turkey", International Journal of Energy Research, vol. 26, no. 9, pp. 807-823.

M. A. Ahmed, F. Ahmad, and M. W. Akhtar (2009), "Estimation of global and diffuse solar radiation for Hyderabad, Sindh, Pakistan",Journal of Basic and Applied Sciences, vol.5, no.2, pp. 73-77.

M. S. Okundamiya and A. N. Nzeako (2010), "Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria", Research Journal of Applied Science, Engineering and Technology, vol.2, no. 8, pp. 805-812.

Zekai Sen (2008), "Solar Energy Fundamentals and Modeling Techniques", Springer, pp. 151. DOI: 10.1007/978-1-84800-134-3.

Box GEP, Jenkins GM (1970) ,"Time series analysis forecasting and control", Holden Day, San Francisco.

Benjamin JR, Cornell CA (1970), "Probability statistics and decision for civil engineers", McGraw- Hill, New York, pp. 684.

R. J. Stone (1993), "Improved statistical procedure for the evaluation of solar radiation estimation models", Solar Energy, vol. 51, no. 4, pp. 289-291.

J. Almorox, M. Benito, and C. Hontoria (2005), "Estimation of monthly Angstrom-Prescott equation coefficients from measured daily data in Toledo, Spain", Renewable Energy, vol. 30, no. 6, pp. 931-936.

Falayi, E.O Rabiu, A.B and Teliat (2011), R.O, "Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria", Advances in Applied Science Research, 2 (4), pp. 480-490.

A. M. Al-Salihi, M. M. Kadum, and A. J. Mohammed (2010), "Estimation of global solar radiation on horizontal surface using meteorological measurement for different cities in Iraq", Asian Journal of Scientific Research, vol. 3, no. 4, pp. 240-248, 2010.

www.HelioClim.net, "HolioClim-1 Data Base satellite Data".

Geiger M, Diabate L, Menard L, Wald L (2002). "A web service for controlling the quality of measurements of global solar irradiation", Solar Energy; 73(6), pp. 475-80.

Blanc P, Gschwind B, Lefèvre M. and Wald L (2011). "The HelioClim Project: Surface Solar Irradiance Data for Climate Applications", Remote Sens,3, pp. 343-361; doi:10.3390/rs3020343 .

TABLES

Table 1: Locations

Stations	Latitude(°)	Longitude(°)	Altitude(m)
Bertoua	4.580	13.60	637
Yokadouma	3.510	15.050	488
Yaoundé	3.860	11.510	546
Kribi	2.950	9.910	0
Kumba	4.640	9.430	223

Table 2: **proposal of estimating models for monthly mean daily diffuse solar radiation on a horizontal surface for investigated locations**

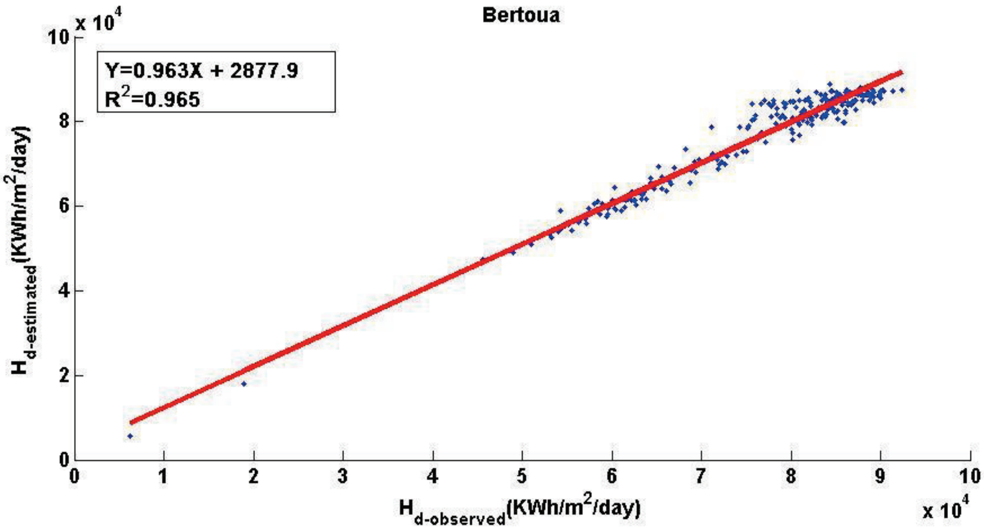
Locations	Correlations Terms Diffuse Solar Radiation	
	Linear $H_d=H(a_0=+a_1k_t)$	Quadratic $H_d=H(a_0+a_1k_t+a_2k_t^2)$
Bertoua	$H\,(1.297-1.510k_t)$	$H\,(1.267-1.40k_t-0.107k_t^2)$
Yokadouma	$H\,(1.265-1.463k_t)$	$H\,(1.282-1.53k_t+0.063k_t^2)$
Yaoundé	$H\,(1.332-1.547k_t)$	$H\,(1.271-1.304k_t-0.236k_t^2)$
Kribi	$H\,(1.185-1.331k_t)$	$H\,(1.233-1.545k_t+0.230k_t^2)$
Kumba	$H\,(1.276-1.438k_t)$	$H\,(1.109-0.7k_t-0.774k_t^2)$

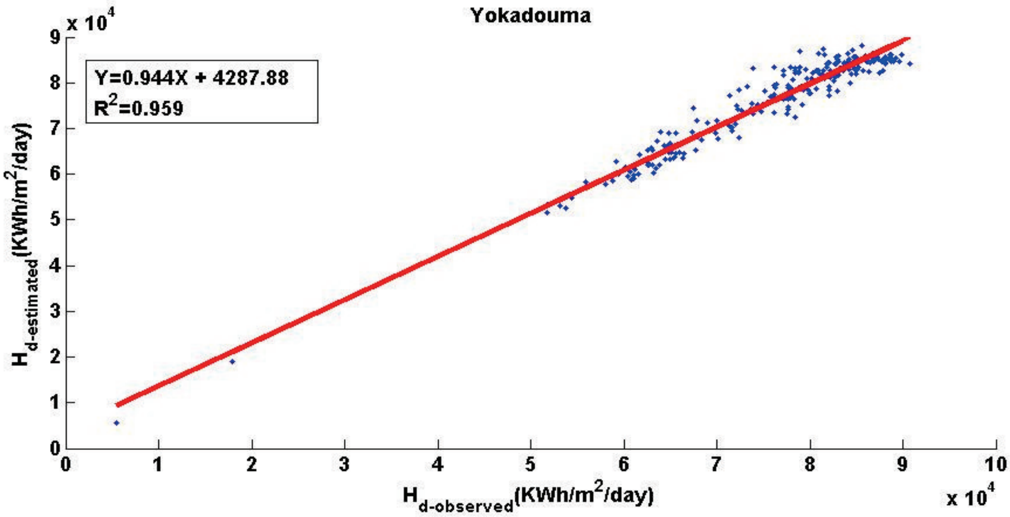
Table 3: Analysis of estimation (proposed and existing) models using twenty-year (1985–2005) monthly mean daily data obtained for the study locations

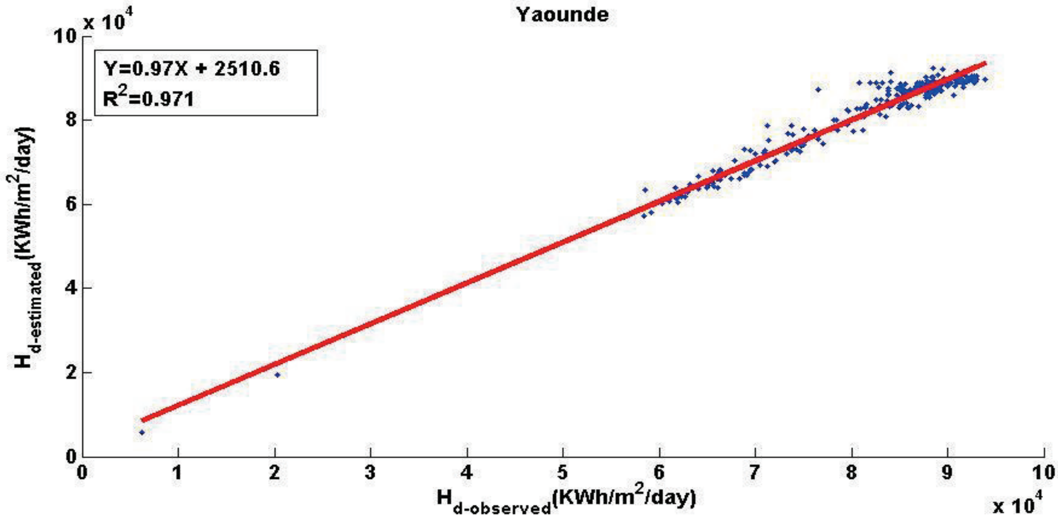
ERRORS TERMS															
Models	MBE($Wh/m^2/day$)					RMSE($Wh/m^2/day$)					t-statistique (TS)				
	Bertoua	Yokadouma	Yaoundé	Kribi	Kumba	Bertoua	Yokadouma	Yaoundé	Kribi	Kumba	Bertoua	Yokadouma	Yaoundé	Kribi	Kumba
Linear	107.54	37.8	30.56	100.3	0.99	2670.7	2615.4	2322.3	3093.6	2094	0.637	0.228	0.208	0.513	0.007
Quadratic	62.42	-29.73	64,5	81.6	62.21	2668.56	2613	2329.9	3054	1957.6	0.37	0.18	0.44	0.422	0.502
Page	-14374	-13781	-17528	-12185	-17653	15012	14261	17997	12582	17936	52.5	59.37	67.86	61.44	87.86
Liu and Jordan	-21795	-21751	-25684	-20480	-25786	23007	22612	26557	20878	26338	46.75	55.63	60.15	79.8	76.03
Iqbal	-8341	-8092	-12344	-7784.5	-13751	10676.8	9824	13845	8839.8	14643	19.80	22.91	31.13	29.38	43.2
Erbs et al.	-19212	-19039	-22769	-17334	-22443	20212	19737	23460	17711	22894	48.37	57.84	63.67	75.35	78.48

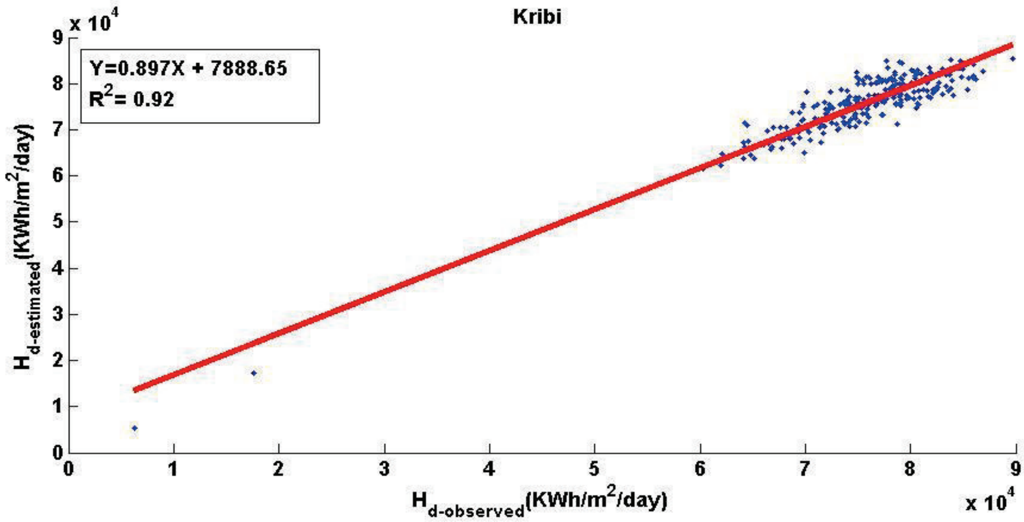
Figures

Figures 1: Correlation between the estimated and observed values of the monthly mean daily diffuse solar radiation using twenty-year (1985 - 2005) monthly mean daily clearance index.




Yokadouma
Y=0.944X + 4287.88
R2=0.959
x 10^4
H d-estimated (KWh/m2/day)
H d-observed (KWh/m2/day)
x 10^4


Yaounde
Y=0.97X + 2510.6
R2=0.971
x 10^4
H d-estimated (KWh/m2/day)
H d-observed (KWh/m2/day)
x 10^4


Kribi
Y=0.897X + 7888.65
R2= 0.92
x 10^4
H d-estimated (KWh/m2/day)
H d-observed (KWh/m2/day)
x 10^4

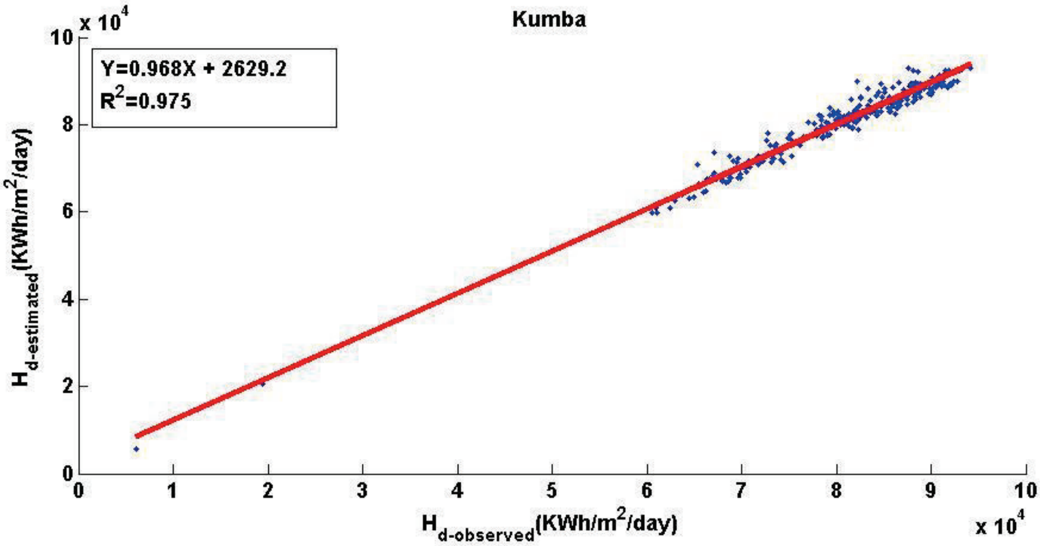
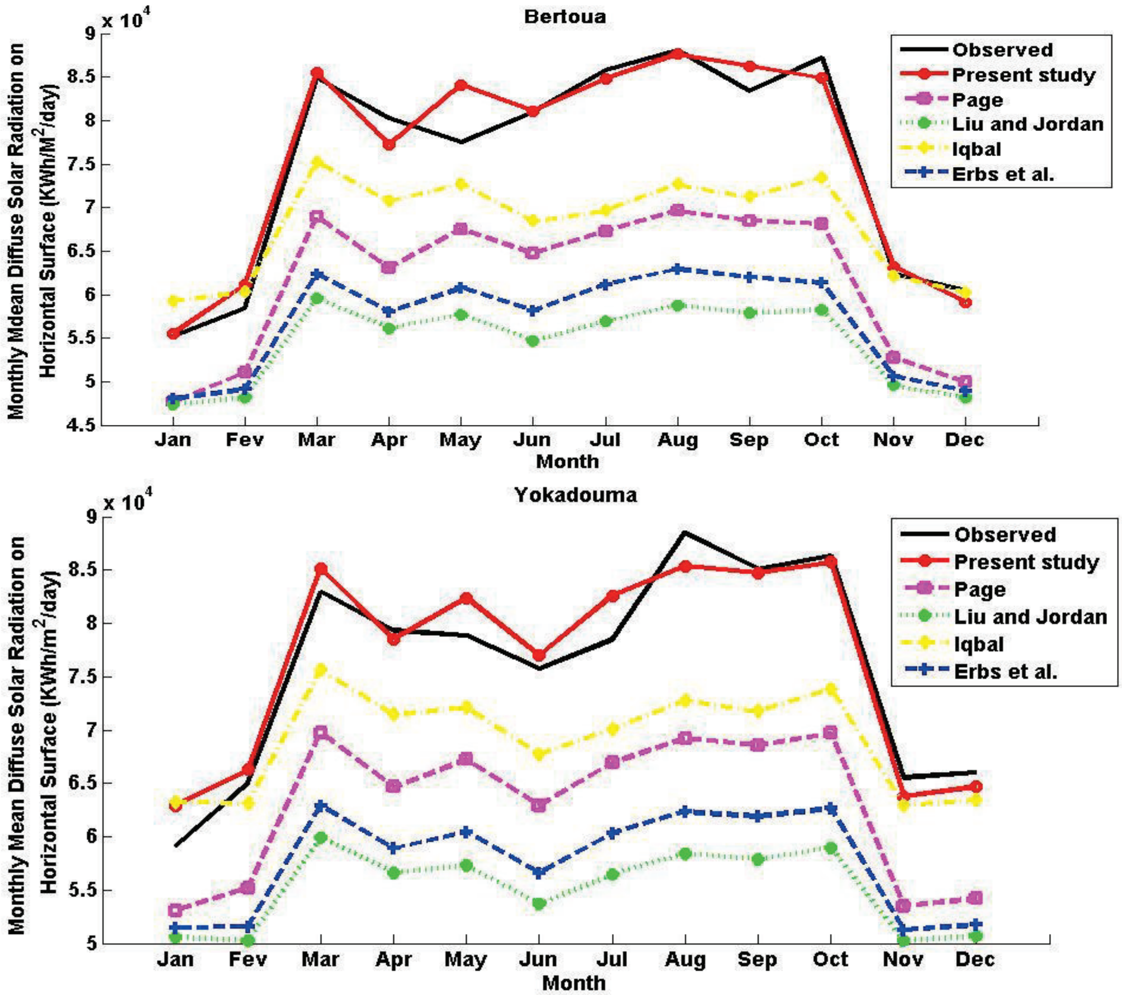


Figure 2: Correlation between the estimated and observed values of the monthly mean daily diffuse solar radiation using twenty-year (1985 - 2005) monthly mean daily clearance index.



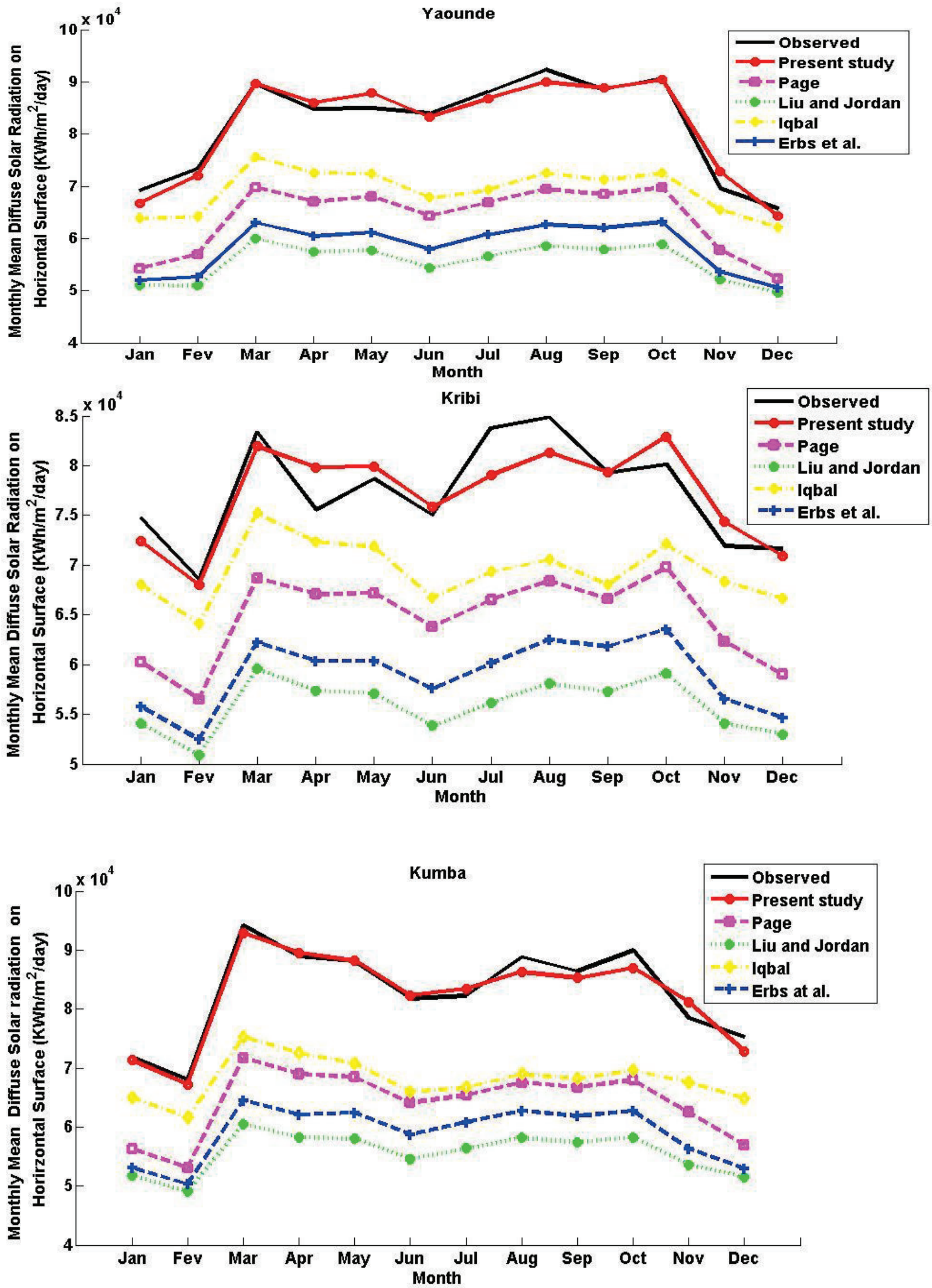
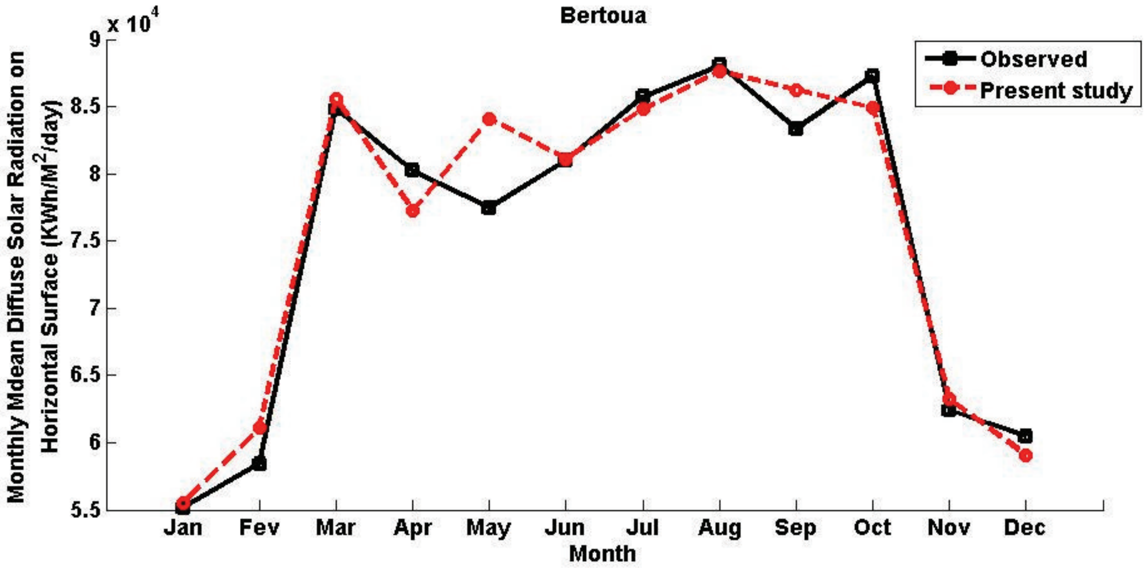
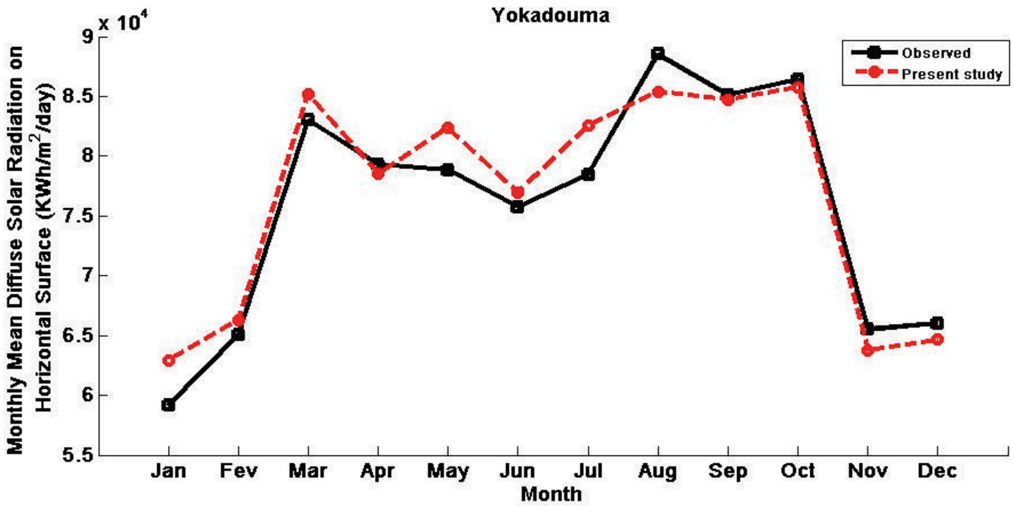
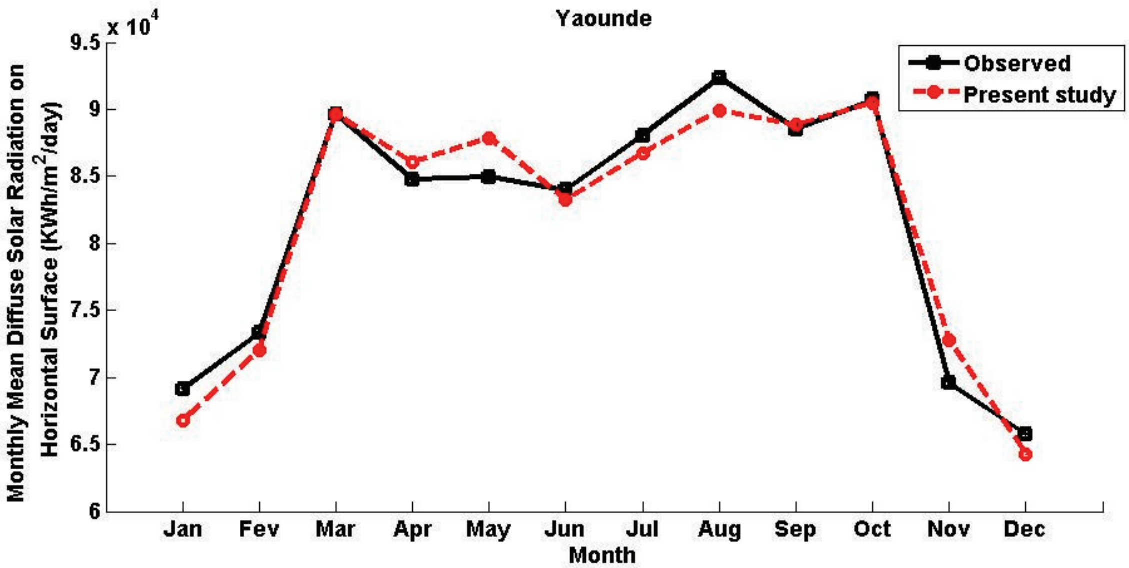
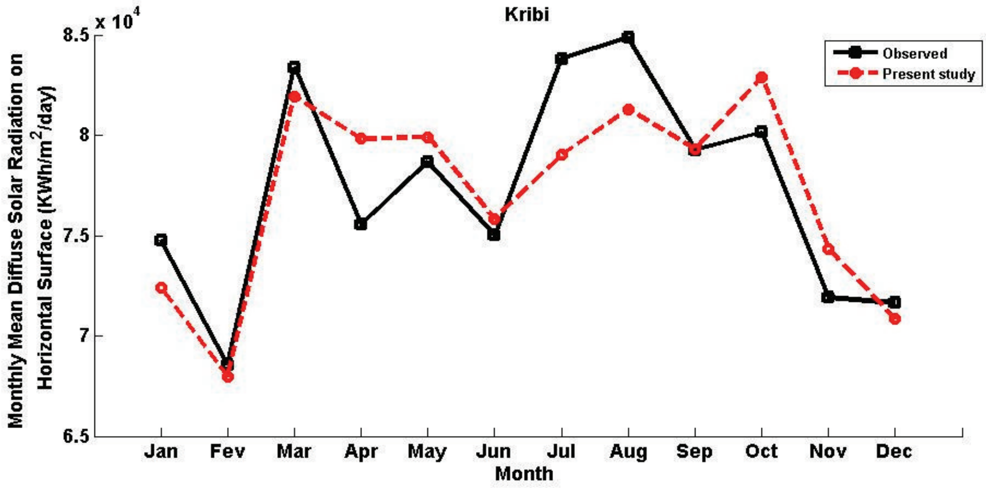


Figure 3: Comparison of the observed and estimated values of monthly mean diffuse solar radiation obtained using proposed [1-4] and existing models .


Bertoua
x 10^4
Monthly Mdean Diffuse Solar Radiation on Horizontal Surface (KWh/M^2/day)
9
8.5
8
7.5
7
6.5
6
5.5
Observed
Present study
Jan Fev Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Yokadouma
x 10^4
Monthly Mean Diffuse Solar Radiation on Horizontal Surface (KWh/m^2/day)
9
8.5
8
7.5
7
6.5
6
5.5
Observed
Present study
Jan Fev Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month


Yaounde
x 10^4
Monthly Mean Diffuse Solar Radiation on Horizontal Surface (KWh/m^2/day)
9.5
9
8.5
8
7.5
7
6.5
6
Observed
Present study
Jan Fev Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Month



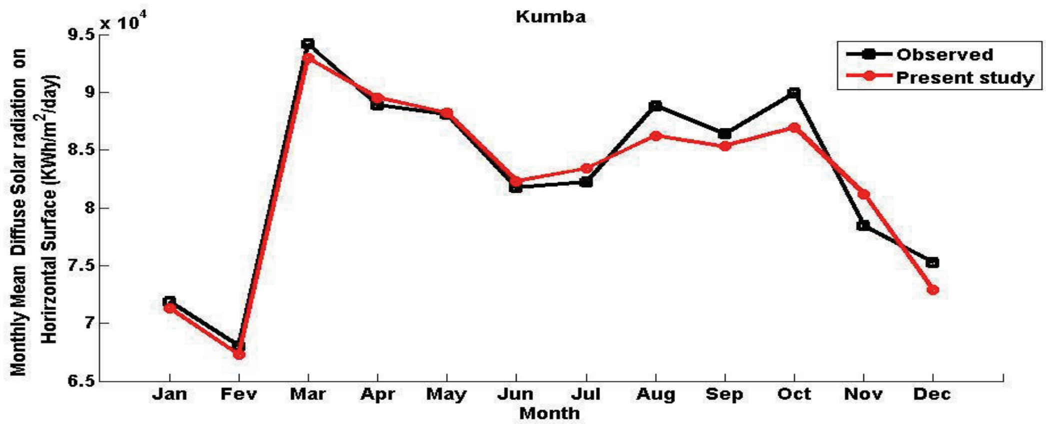


Figure 4: Comparison of the estimated values of the monthly mean diffuse solar radiation obtained using the proposed model with the observed values .