ESTIMATION OF DIFFUSE SOLAR RADIATION IN THE NORTH AND FAR NORTH OF CAMEROON

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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. The diffuse radiation of four stations in North and Far North of Cameroon was estimated. A statistical analysis of monthly mean correlation was examined, using a 20 years recorded (1985-2005) of monthly mean diffuse solar radiation obtained at the four selected meteorological stations throughout the area of North and
Far North of Cameroon. The accuracy of the candidate correlations were performed in terms of the three widely used statistical indicators, mean bias (MBE), root mean square errors (RMSE) and t-statistic (TS). The results indicated the correlations relating the diffuse fraction (k_d) with the clearness index (k_t) and the estimated diffuse monthly solar radiation.

Keywords: Clearness index, diffuse fraction, MBE, RSME, t-statistic

Introduction

A reasonably accurate knowledge of the availability of the local solar radiation is required by solar engineers, architects, agriculturists and hydrologists in many applications of solar energy. In this respect, the importance of climatological and solar radiation data for the design and efficient operation of solar energy systems and associated energy storage systems has been recognized. The measured values of solar radiation data are not available for large number of stations. Thus, accurate estimation of values of global and diffused solar radiation data is essential for the design and performance evaluation of solar energy systems. The values of diffuse solar radiations are indispensable for research and the engineering applications. Diffuse solar radiation is not measured by the meteorological stations in Cameroon. Indeed, to have the information on diffuse solar radiation on a horizontal surface may be considered as an essential requirement to conduct feasibility studies for solar energy systems. For those regions lacking 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(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 and Page model's 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, an empirical model for estimating the monthly mean daily diffuse solar radiation on horizontal surfaces was developed for four different cities in north and far north of Cameroon. The diffuse solar radiation was also estimated from other established models, and the results were compared with our estimated results. The diffuse solar radiation was also estimated from other established models, and the results were compared with our estimated results. Figure1 shows the study locations in Cameroon.

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 polynomial 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 many cases diffuse solar radiation is not available and must be estimated knowing only the global radiation. In order to get the best model for the study locations, besides the established models (Iqbal,979) , we proposed linear, quadratic, logarithmic and exponential relationship between diffuse and global solar radiation of the form:

$$H_d = H*\left(a_\mathbf{0} + a_\mathbf{1} * k_t\right) \quad Linear\left(\mathbf{1}\right)$$

$$H_d = H*\left(a_\mathbf{0} + a_\mathbf{1} * k_t + a_\mathbf{2} * k_t^\mathbf{2}\right) \quad Quadratic\left(\mathbf{2}\right)$$

$$H_d = H*\left(a_\mathbf{0} + \mathbf{exp}\left(a_\mathbf{1} * k_t\right)\right) \quad Exponential\left(\mathbf{3}\right)$$

$$H_d = H*\mathbf{ln}\left(a_\mathbf{0} + a_\mathbf{1} * k_t\right) \quad Logarithm\left(\mathbf{4}\right)$$

The result of test is in the table 2.

Where a_i are empirical constant, H_d is the monthly mean daily diffuse solar radiation on a horizontal surface (Wh/ m^2 /day), H is the monthly mean daily global radiation on a horizontal surface (Wh/m^2 /day), k_t (=H/Ho) is the and monthly mean daily clearance index. 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 [(J. Almorox,2005), (Falayi,2011), (A. M. Al-Salihi,2010)]. Detailed analysis of RMSE, MBE, and TS is given in the literature (J. Almorox,2005).

The results of (1-4) were compared with the results proposed by

Iqbal(1979). The available parameters informed the choice of the selected model 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.

Data analysis

The longer the period of record is, more representative the result will be. The monthly mean of daily diffuse radiation on horizontal surface for twenty years (1985-2005) for four locations (Kousseri, Maroua, Garoua, Touboro) in the north and far north of Cameroon displayed in figure1, were obtained from HolioClim-1 Data Base satellite Data (www.HelioClim.net). 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 Modelisation' 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 (Blanc et al.,2011). The clearance index (k_t) was obtained from observed H and computed H_0 for the study locations. H_0 is the daily extraterrestrial radiation on the horizontal surface (Wh/m^2/day).

Accurate knowledge of diffuse solar radiation is needed for many solar energy applications. It is common that the clearness index of global solar radiation is measured. However, the diffuse fraction (k_d) of solar radiation can be calculated in terms of clearness index (k_t).

Simulation

We developed computer codes in FORTRAN programming language to compute the empirical constants of (1- 4) using the data discussed above (in Section2.1) and used open office to perform the regression analysis. Our simulation results are illustrated in table1. The linear or quadratic model was chosen since it produced the best fit. Code were developed in MATLAB to display the regression fit. In this study, the performance of the TS was analyzed at the 95% confidence level. A stochastic analysis was performed on the estimation models (proposed and existing (Iqbal,1979) using one year (1995) monthly mean daily data. The results of the analysis are illustrated in Table2 and Figure2.

Results and discussion

Results

The results of the simulation of (1-4) are illustrated in table1. These results informed the proposal of an empirical model for estimating the monthly mean daily diffuse solar radiation on a horizontal surface using clearance index for the locations investigated in this study.

- Table1 gives a set of correlations for the diffuse solar radiation for different locations.
- The results of the stochastic analysis performed on the estimation models are illustrated in Table2.
- Figure2 shows the best correlation between the estimated and observed values of the diffuse solar radiation using (1)-(4).
- Figure3 shows a comparison of the estimated values of monthly mean diffuse solar radiation obtained using the best (1)-(4) 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.

Discussion

The following observations were deduced from the analysis of the results presented in Section3.1. The empirical constants (ai) of the proposed model (1)-(4) 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, so forth in the atmosphere which differs from one location to another. The coefficient of determination between the estimated and the observed values of the monthly mean daily diffuse solar radiation data as illustrated in Figure2 is close to unity (0.979-0.989) for the proposed model. This is an indication of a good agreement of the estimated with the observed diffuse solar radiation.

The test of MBE provides information on the long-term performance of the proposed model. Except the location of Touboro where all study models have a slight overestimation, these models study have a slight underestimation. Logarithm correlation have a worth long-term estimation comparison with the Iqbal model. Almorox et al. (2005) has recommended that a zero value for MBE is ideal. This suggests significant underestimation (from Page, Liu and Jordan, Erbs's model) and slight underestimation (linear and quadratic's models) for all locations, except the location of Touboro where we have a slight overestimation (linear and quadratic's models) of the diffuse solar radiation. The proposed model has good long-term performance; the estimates compare favorably (with negligible underestimation and overestimation) with their observed values. The result of this comparison is illustrated in Figures (3-4) .

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 (Iqbal's estimates). Low RMSE values are desirable [15,18]. 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 [16,17]. This informs the use of the TS (t-statistic) indicator.

The 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 Logarithm and existing model lie outside the range of the critical TS-values ($TSc_{(0.025)} = \pm 1.96$) for the study locations. These results indicate that their estimates should be rejected. The TS-value of Iqbal lie within the range of critical value only for Kousseri. This suggest that his estimates are statistically insignificant in others 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 April and September Figure 4. The annual mean diffuse solar radiations in Kousseri, Maroua, Garoua, Touboro are 62.204, 64.580, 64.016 and 66.584 KW h/m^2 /day , respectively. Our proposed annual mean diffuse solar radiations are 62.170, 64.576, 64.005 and 66.563 KW h/m^2 /day ,respectively. The annual mean diffuse solar radiation for established model's in Kousseri, Maroua, Garoua, and Touboro vary for maximum of 64.984, 65.431, 65.070 and 66.496 KW h/m^2 /day (Iqbal model's). These compare favorably our proposal model data with the observed data as expected.

Conclusion

The study has demonstrated the availability of diffuse solar radiation on horizontal surface for Kousseri, Maroua, Garoua and Touboro, employing clearance index. A quadratic model was deduced from this 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 model Iqbal. The results indicate that the proposed model [1-3] compared favorably with the observed values in the four studied locations in Cameroon (Kousseri, Maroua, Garoua and Touboro), while Iqbal model only compared favorably with the observed values in Kousseri.

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Tables

Locations	Correlations terms Radiation diffuse H_d			
	$H.(a_0+a_1.k_t)$	$H.(a_0+a_1.k_t+a_2.k_t^2)$	$H.(a_0.\exp(a_1.k_t))$	$H.(Ln(a_0+a_1.k_t))$
Kousseri	$H.(1.239-1.424k_t)$	$H.(0.644+0.602k_t-1.694k_t^2)$	$H.(3.97\exp(-3.96k_t))$	$H.ln(2.72-2.08k_t)$
Maroua	$H.(1.232-1.412k_t)$	$H.(0.602+0.788k_t-1.874k_t^2)$	$H.(3.57\exp(-3.8k_t))$	$H.ln(2.73-2.09k_t)$
Garoua	$H.(1.263-1.466k_t)$	$H.(0.824+0.059k_t-1.293k_t^2)$	$H.(3.93\exp(-3.99k_t))$	$H.ln(2.78-2.18k_t)$
Touboro	$H.(1.238-1.424k_t)$	$H.(0.824+0.007k_t-1.211k_t^2)$	$H.(3.64\exp(-3.83k_t))$	$H.ln(2.75-2.11k_t)$

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Table1: Correlations terms

Models	Errors Terms											
	MBE ($Wh/m^2/day$)				RMSE ($Wh/m^2/day$)				t-Statistic (TS)			
	kousseri	Maroua	Garoua	Touboro	kousseri	Maroua	Garoua	Touboro	kousseri	Maroua	Garoua	Touboro
linear	-109.55	-88.22	- 41.3	3.43	2690.14	2932	2600	2477.1	0.63	0.47	0.25	0.02
quadratic	-35.61	-3.88	-10.83	11.41	2057.7	1913.3	2092.3	2097.5	0.26	0.031	0.08	0.09
Logarithmic	-795.8	-548.5	-1147.7	789	2344	2298.6	2432.9	2256.8	5.57	3.8	8.25	5.9
Exponential	-100.9	-258.6	-158.4	112.8	5060	5778	5726.3	4710	0.31	0.7	0.43	0.38
Iqbal	-262.27	-1512	-1062.06	-2184	6285	7117	8130.73	7159.15	0.65	3.36	2.04	5.07

Table2: Statistical indicators for the four locations

Figures

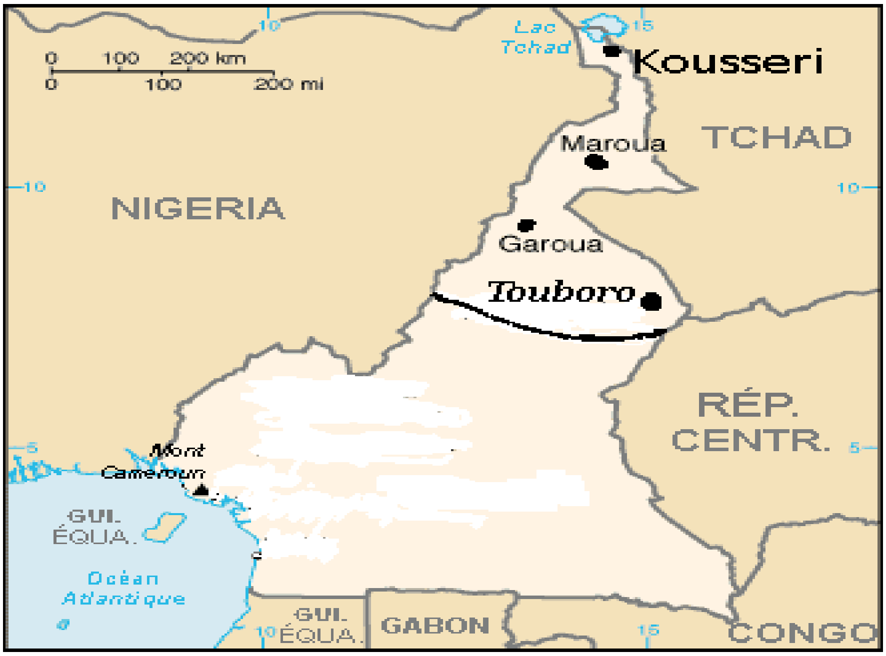

Figure1: North and Far North of Cameroon

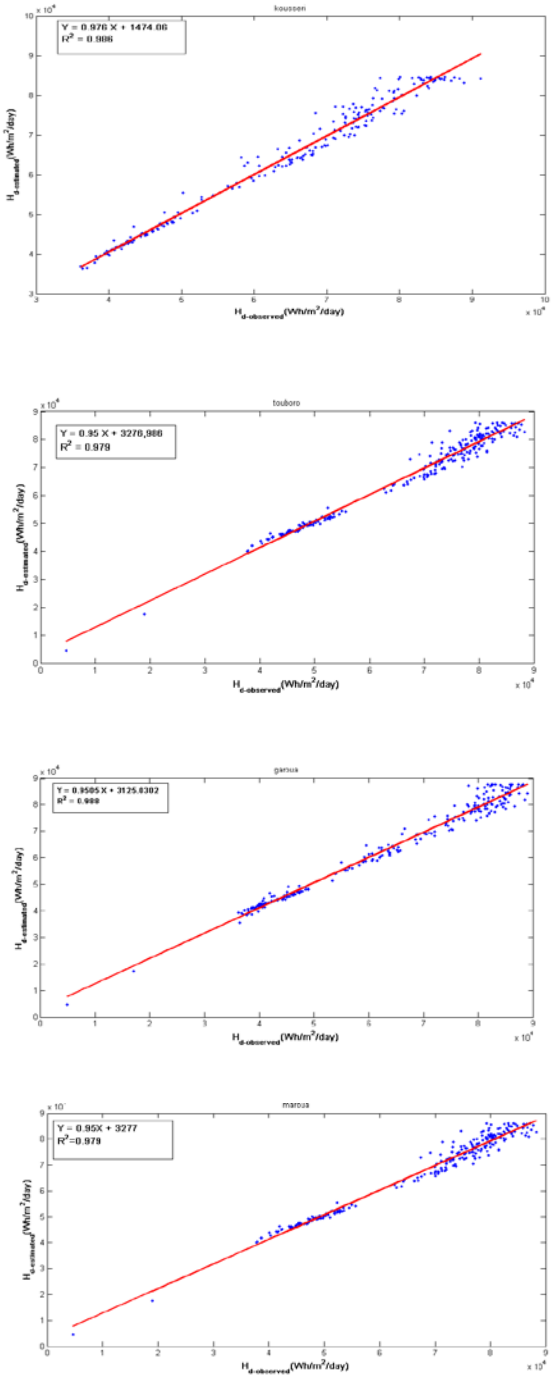

Figure 2: Correlation between the estimated and observed values of the monthly mean daily diffuse solar radiation using twenty-year (1985- 2005) monthly mean daily clearance index.

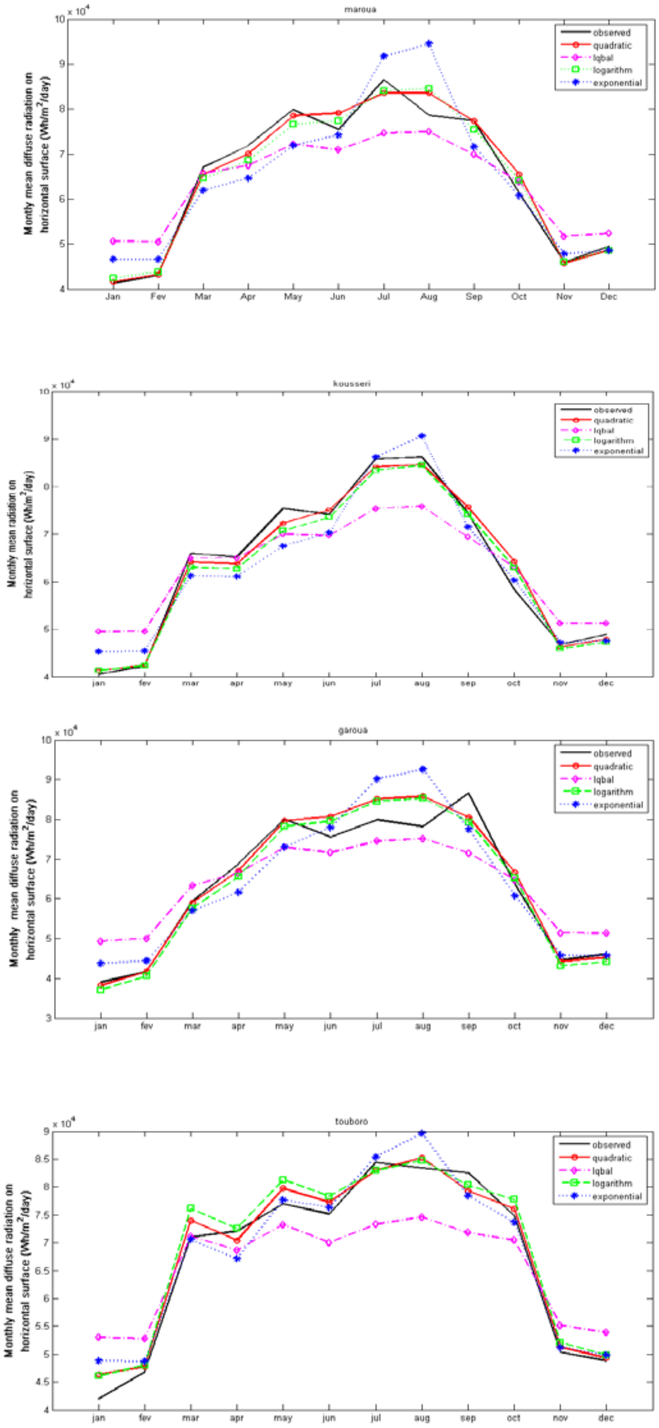

Figure 3: Comparison of the observed and estimated values of monthly mean diffuse solar radiation obtained using proposed [1-4] and existing models

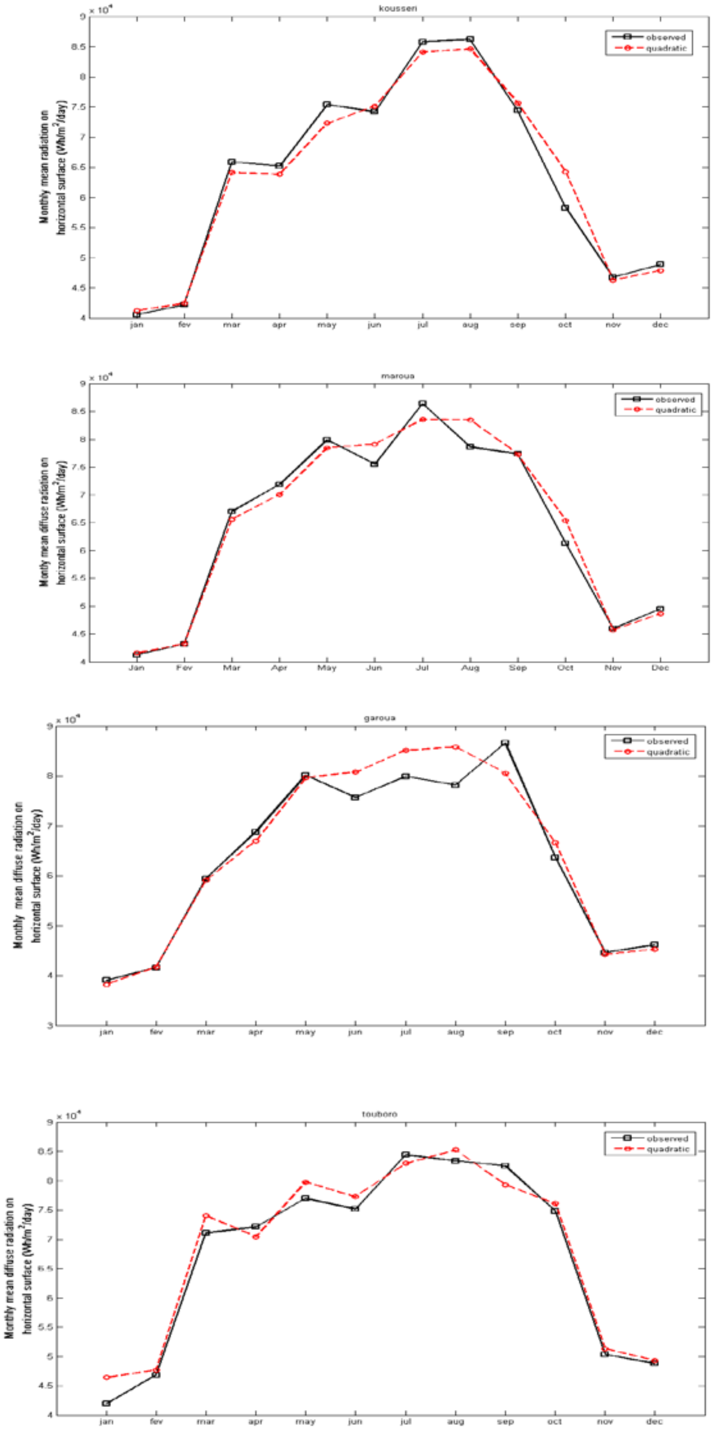

Figure 4: Comparison of the estimated values of the monthly mean diffuse solar radiation obtained using the best proposed model with the observed values.