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# Estimation of Diffuse Solar Radiation in Area between 5˚N and 10˚N 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. This study proposed a multivariate model of monthly mean daily diffuse solar radiation on horizontal surfaces for some cities between 5˚N and 10˚N of Cameroon (Ngaoundéré, Garoua-Boulai, Bafoussam, Nkambé). The estimation was based on a correlation between clearance index and diffusion 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 suggested 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, RMSE; 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 are 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 [1]. In the absence of these data (measured global and diffuse solar radiation data), one has to rely on the available methods and also has to develop new ones.

Several models have been proposed to estimate global solar radiation. Liu and Jordan[1] 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 [2] developed a linear relationship between clearance index and diffuse to global solar radiation ratio, while Iqbal [3] and Lam-Li [4] 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 [5] developed an analytical expression for the ratio of hourly to daily solar radiation, in terms of sunset hour angle. Erbs *et al.* [6] and Muneer *et al.* [7] developed correlations between hourly diffuse and global solar radiation on a horizontal surface as a function of the clearness index. Ulgen and Hepbasli [8] 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 [9] 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.* [10] 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 [11] 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 locations between 5˚N and 10˚N in Cameroon. The diffuse solar radiation was also estimated from other established models, and the results were compared with our estimated results.

## 2. Methods

### 2.1. Geographic Localitions of Cities in Cameroon

Cameroon is located between the latitudes 2˚N and 13˚N and longitudes 8˚E and 16˚E. This territory is globally divided into tree climatic regions. A rainy, very wet southernmost zone, with weak insolation ranging between 2˚N and 5˚N and a dry northern zone, with strong insolation ranging beyong 10˚N. The demarcation between the two zones is not very clear because of the proximity of the sea for the western areas between the 5th and the 6th parallels, Njomo[12]. Following the latitude parameter, we located the region II between the 5˚ and 10˚N as the region interst. **Figure 1** shows the study locations in Cameroon.


**Figure 1. Study locations in Cameroon.**

### 2.2. Method of Study

One usually uses linear relation in solar energy studies. For exemple, 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] [13]. On other hand, modeling solar energy with polynome implies differents asumptions to obtain the best result with the least number of parameters [Box and Jenkins] [14]. 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] [15]. In general, a polynomial model leads to imbedded redundancy in the model.

In order to get the best model for the study locations, besides the established models [2,4,5], we proposed a quadratic relationship between diffuse and global solar radiation of the form

$$H_d = H\left(a_0 + a_1 k_t + a_2 k_t^2\right) \quad (1)$$

where $a_i$ are empirical constant, $H_d$ is the monthly mean daily diffuse solar radiation on a horizontal surface (W·h/m$^2$/day), $H$ is the monthly mean daily global radiation on a horizontal surface (W·h/m$^2$/day), and $k_t$ (=*H*/*Ho*) is the monthly mean daily clearance index. The performance of the proposed model was evaluated using the t-statistic (TS), a statistical indicator proposed by Stone [16], Root Mean Square Error (RMSE), and Mean Bias Error (MBE). These indicators are mainly employed for the adjustment of solar radiation data [17-19]. Detailed analysis of RMSE, MBE, and TS is given in the literature [Almorox] [[17]].

The results of (1) 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.

### 2.3. Data

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 four locations (Ngaoundéré, Garoua-Boulai, Bafoussam, Nkambé) in the 5˚N and 10˚N of Cameroon displayed in **Figure 1**, were obtained from HolioClim-1 Data Base satellite Data [20]. Geiger *et al.* [21] have described the availability of a web based service of quality assurance of solar radiation data. Due to its use of B2 images of reduced spatial and temporal resolutions, the Holioclim-1 database offers good quality for Africa [22]. The clearance index $\left(k_t\right)$ was obtained from observed $H$ and computed $H_0$ for the study locations. $H_0$ is the daily extraterrestrial radiation on the horizontal surface (W·h/m$^2$/day).

### 2.4. Simulation

We developed computer codes in Fortran programming language to compute the empirical constants of (1) using the data discussed above (in Section 2.3) and used open office to perform the regression analyses. Our simulation results are illustrated in [(2)-(5)]. Codes were developed in MATLAB to display de regression fit. In this study, the performance of the t-statistique (TS) was analyzed at the 95% confidence level. A stochastic analysis was performed on the estimation models (proposed and existing [1-3,6]) using one year (1995) monthly mean daily data. The results of the analysis are illustrated in **Table 1** and **Figure 2**.

## 3. Results and Analysis

The results of the simulation of (1) are illustrated in (2)-(5). 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 as follows.

Model for Ngaoundéré :

$$H_{dNga} = H\left(1.2811 - 1.3476k_t - 0.0555k_t^2\right) \quad (2)$$

Model for Garoua-Boulai:

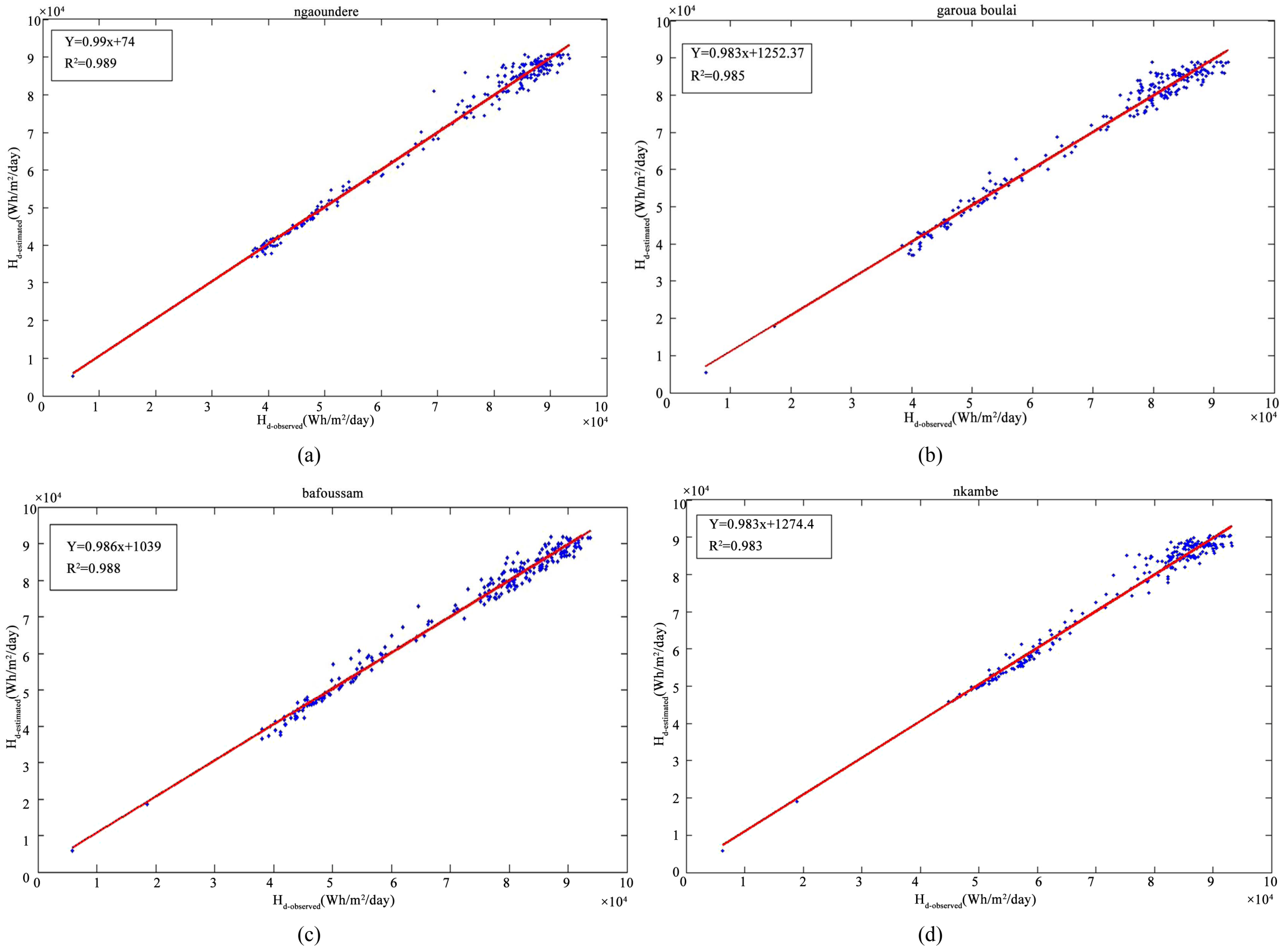


**Figure 2. Correlation between the estimated and observed values of the monthly mean daily diffuse solar radiation using twenty-year (1985 2005) monthly mean daily clearance index.**

 

**Table 1. Analysis of estimation (proposed and existing) models using twenty-year (1985-2005) monthly mean daily data obtained for the study locations.**

| Models | Errors Terms | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MBE ( $Wh/m^2/day$ ) | | | | RMSE ( $Wh/m^2/day$ ) | | | | t-statistique (TS) | | | |
| | Ngaoundéré | Garoua Boulai | Bafoussam | Nkambé | Ngaoundéré | Garoua Boulai | Bafoussam | Nkambé | Ngaoundéré | Garoua Boulai | Bafoussam | Nkambé |
| quadratic | −15.75 | 83.07 | 27.90 | 42.7 | 2165.62 | 2364 | 2128 | 2259.88 | 0.115 | 0.556 | 0.207 | 0.298 |
| Page | −12,874 | −12,550 | −13,298 | −15,053 | 14,699 | 14,026 | 14,936 | 16,002 | 28.701 | 31.691 | 30.917 | 43.84 |
| Liu and Jordan | −8434 | −18,067 | −18,710 | −21683 | 22,093 | 21,084 | 21,867 | 23,673 | 23.935 | 26.282 | 26.142 | 36.082 |
| Iqbal | −5291 | −4722 | −5342 | −8449 | 11,851 | 10,457 | 11,175 | 11,850 | 7.889 | 8.00 | 8.60 | 16.073 |
| Erbs | −16,198 | −15,993 | −16,716 | −19,261 | 19,541 | 18,763 | 19,617 | 20,942 | 23.431 | 25.775 | 25.743 | 37.045 |

$$H_{dGar} = H\left(1.1927 - 1.0756k_t - 0.426k_t^2\right) \quad (3)$$

Model for Bafoussam:

$$H_{dBaf} = H\left(1.3661 - 1.5854k_t - 0.2191k_t^2\right) \quad (4)$$

Model for Nkambé:

$$H_{dNka} = H\left(1.237 - 1.1974k_t - 0.331k_t^2\right) \quad (5)$$

**Figure 2** shows the correlation between the estimated and observed values of the diffuse fraction using (2)-(5). The results of the stochastic analysis performed on the estimation models using diffuse solar radiation are illustrated in **Table 1**.

**Figure 3** shows a comparison of the estimated values of monthly mean diffuse solar radiation obtained using (2)-(5) with those from the existing models. **Figure 4** 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.

## 4. Discussion

The following observations were deduced from the analysis of the results presented in Section 3. The empirical constants $(a_i)$ of the proposed models (2)-(5) 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 coefficient of determination between the estimated and the observed values of diffuse fraction as illustrated in **Figure 2** is close to unity (0.983 - 0.989) 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 **Table 1**. Almorox *et al.* [16] 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.*). The proposed model has good long-term performance; the estimates compare at favourably (with negligible overestimation) with their observed values. The result of this comparison is illustrated in **Figures 3** and **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 (Liu and Jordan's estimates). Low RMSE values are desirable [17-19]. 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 TS (t-statistique) indicator.

The t-statistque (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 insignifiant 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 April and September **Figure 4**. The annual mean diffuse solar

 

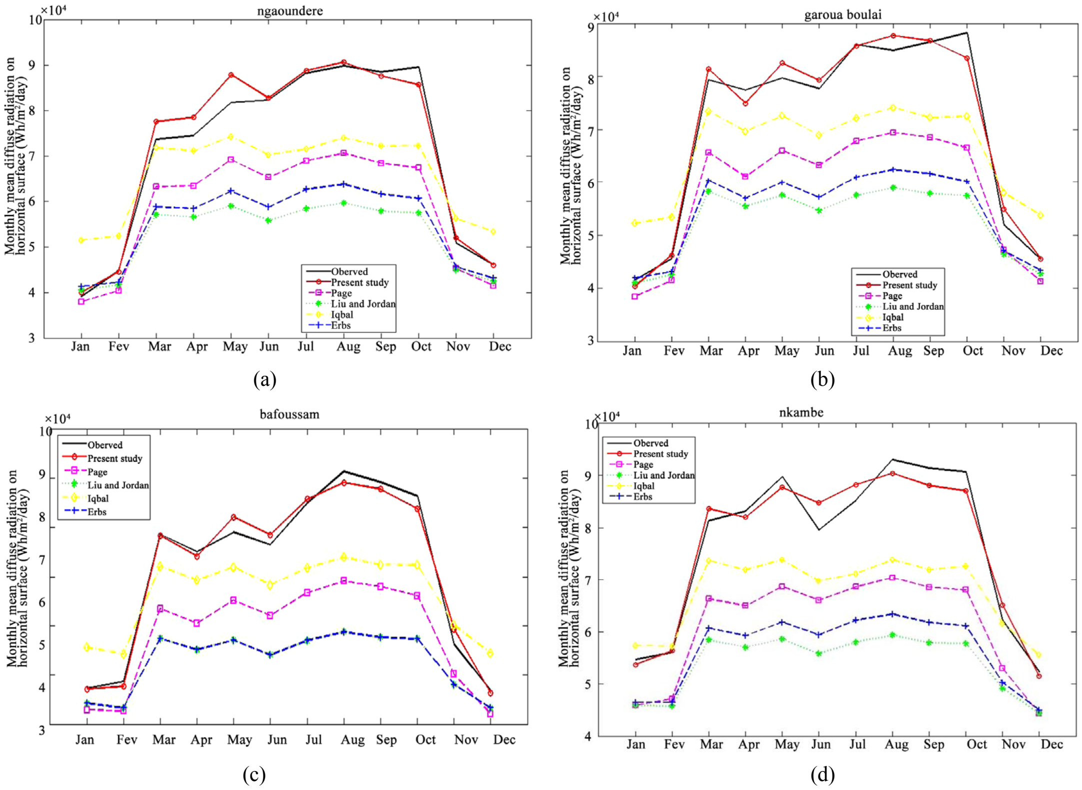


**Figure 3. Comparison of the observed and estimated values of monthly mean diffuse solar radiation obtained using proposed (2)-(5)and existing models.**

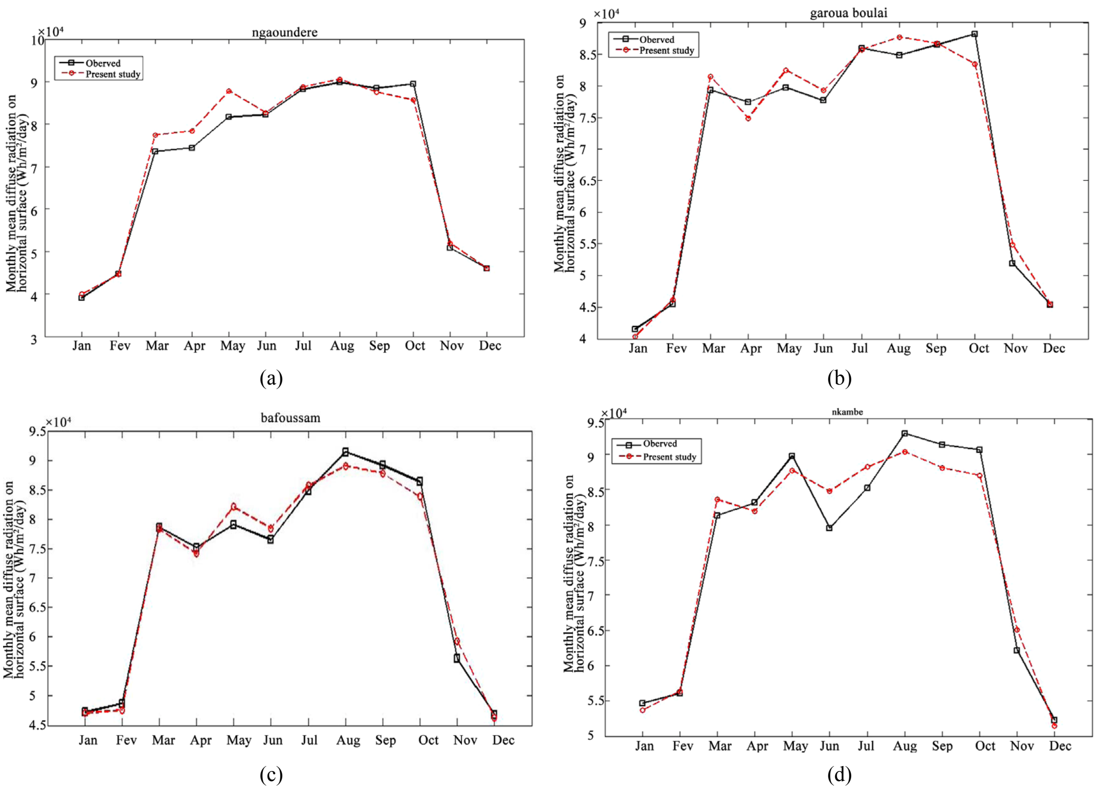


**Figure 4. Comparison of the estimated values of the monthly mean diffuse solar radiation obtained using the proposed model with the observed values.**

radiations in Ngaoundéré, Garoua-Boulai, Bafoussam and Nkambé are 70.176; 70.100; 70.786 and 474.887 KW·h/m$^2$/day, respectively. Our proposed annual mean diffuse solar radiations are 70.191; 70.182; 70.999 and 75.03 KW·h/m$^2$/day, respectively. The annual mean diffuse solar radiation for established model's in Ngaoundéré, Garoua-Boulai, Bafoussam and Nkambé vary for maximun 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.

## 5. Conclusion

The study has demonstrated the availability of diffuse solar radiation on horizontal surface for Bafoussam, Garoua Boulai, Ngaoundéré and Nkambé, 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 models by Page, Liu and Jordan Iqbal and Erbs *et al.* The results indicate that the proposed models (2)-(5) compared favorably with the observed values in the four studied locations between 5˚N and 10˚N in Cameroon (Bafoussam, Garoua Boulai, Ngaoundéré and Nkambé), while models of Page, Liu and Jordan Iqbal and Erbs *et al.* are not in comparison favorably with the observed values in any location.

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