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Research Article

Performance Comparison of Empirical Models for Estimating Global Solar Irradiation in the Soudano-Sahelian Zone of Cameroon: The Case of the City of Maroua and Garoua

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Abstract

The main objective of this study is to compare thirty-five (35) solar radiation models available in the open literature in order to predict monthly solar radiation in two main cities of Cameroon. This estimation and comparison are based on selected statistical comparison parameters named, root mean square error (RMSE), mean bias error (MBE), mean percentage error (MPE) and determination coefficient (R^2). These different models are implemented using regression analysis tools named Exel and MATLAB. Estimated values were compared with measured values according to normalized values of statistical parameters, using measured meteorological data of more than 19 years, from 1984 to 2015. All the models have been classified with their associated ranking according to their statistical parameter accuracy. From this study it appears that the models of Ertekin and Yaldiz (MOD20), Togrul and Onat (MOD28), are more accurate than other models. Indeed, for the city of Maroua (MBE%=-2.82E-14; RMSE%=0.862; MPE=-0.00845; R^2=0.985), while for Garoua (MBE%=-9.21E-15; RMSE%=0.806; MPE=-0.00631; R^2=0.959). according to their accuracy these models can be therefore be used to predict monthly solar radiation for soudano-sahelian regions of Cameroon. Correlation equations found in this paper will help solar energy researcher to estimate data with trust because of its fine agreement with the observed one. hence the models presented in this study could be used to evaluate accurately the solar radiation at any locations with similar climate.

Keywords

Meteorological Data, Global Solar Radiation, Empirical Models, Performance, Statistical Parameters, Cameroon

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1. Introduction

As a result of the increasing number of solar energy applications, the need for solar radiation data became more and more important. There is a growing need for quality data to facilitate studies of solar systems around the world. Quality data are important to design and to optimize solar energy conversion systems. Solar data also helpful when evaluating the techno-economic feasibility of the project, thereby helping the investors, government agencies and the utility operators for an informed decision making [1]. Unfortunately, in developing countries, researchers encounter difficulties with data gaps relative to the scarcity of data records of stations or the continuity of readings, even in many developed countries there is a dearth of measured long-term solar radiation data [2]. The amount of global solar radiation at any site is best determined through the installation of measurement instruments, such as the pyranometer, for the monitoring and storing of its day-to-day recording, but it is a very costly and tedious [3]. Thus, it becomes necessary to look up procedures in order to supply solar radiation data estimation for area with the gaps in the measurement records or where measurements are not carried out by using empirical models. Input variables used in empirical models of solar radiation generally include sunshine hours, mean temperature, maximum temperature, minimum temperature, number of rainy days, extraterrestrial radiation, cloudiness, soil temperature, altitude, latitude, relative humidity, albedo, precipitation, and evaporation [4-8]. These related models are generally presented as linear, logarithmic, exponential and hybrid, quadratic, quartic, cubic, power forms [9].

Parameter used earlier to evaluate the overall solar radiation is the effective sunshine duration. This duration is easily measure in hours with Campbell stokes heliograph. the simplest model to estimate solar radiation using sunshine duration, is the model of Angstrom establish in 1924 [10], and their associated models establish by Prescott in 1940 known as Angstrom-Prescott-Page model [11]. With the models mentioned and for different sites around the world many researchers found the regression coefficients within reasonable degree of accuracy [12-19]. One drawback of the model of Angstrom-Prescott-Page is the fact that it took little input data while for many regions around the world evaluation of the solar radiation need more magnitudes than sunshine hours. To fill this gap many others models have been developed by researchers around the world. The models are classified depending on available meteorological data.

Despite the fact that numerous works relative to the development and improvement of empirical correlation for determination of monthly averaged daily global solar radiation in locations around the world, no more correlations are found for the regions of Cameroon, except Hargreaves and Samani model, angstrom-Prescott model, Bristow and Campbell model Annandale et al. Model, and Goodin et al. Model, [20, 21], it is also found that for the city of Garoua and Maroua, the global solar radiation data have not been studied seriously. It is on the basis of these observations and depending on the available collected data, that we decided to select thirty-five (35) representative models amongst those encountered in open literature. This paper deal with the evaluation of the performance of the mentioned models for two different stations in Cameroon. To attain this goal, Excel and Matlab, tools were used to find out at first, the regression coefficient of the models and secondly the strength of statistical performance parameters named, root mean square error (RMSE), mean bias error (MBE), mean percentage error (MPE), and determination coefficient (R^2), in order to know how performant selected models are.

1.1. Study Area and Data

The study area covers two administrative regions of Cameroun the climate is warm semi-arid (BSh) climatic types (according to Köppen-Geiger climate classification system) as presented in table 1. Meteorological data for this study were collected from these stations corresponding to each administrative region. Data and the recorded time period are shown in Table 2.

Table 1. *Geographical coordinates of the different stations.*

location	Climate Zone	Latitude(°N)	Longitude (°E)	Elevation (m)
Maroua	Warm semi-arid (BSh)	10°28’N	14°16’E	423
Garoua	Warm semi-arid (BSh)	9°20’N	13°23’E	241

Table 2. Available measured meteorological data associate with record time.

Meteorological data denomination	period	Record time (years)
Daily temperature (maximum)	1980 to 2013	21
Daily temperature (minimum)	1980 to 2013	21
Daily temperature (mean)	1980 to 2013	21
Soil Temperature (mean)	1980 to 2013	21
relative humidity (mean)	1980 to 2013	21
precipitation (mean)	1980 to 2013	21
Effective day length (mean)	1961 to 2015	33
Monthly Solar radiation (mean)	1984 to 2015	4

1.2. Sources of Solar Radiation Databases

There are three types of measurement of the solar radiation data, in practice none of them appear to be perfect. It is therefore significant to know the strengths and weaknesses of each type. The three main sources of data on solar radiation at the earth surface are: Ground measurements, satellite data-based calculations, and empirical models based on mathematical equations. These mathematical equations use meteorological data as input parameters (relative humidity, temperature, sunshine hours, soil temperature, altitude, number of rainy days, total precipitable water, albedo, latitude, cloudiness and evaporation) [22, 23] The advantages and limitations of these different data sources are presented in Table 3.

Table 3. Strengths and weaknesses of radiation databases [22-25].

Type of measurement	Advantages	Limitations
Ground measurements	1) High accuracy at the point of measurement 2) Good measurements frequency 3) High-quality data (in the rigorously controlled and managed conditions) 4) Redundant measurements enable more stringent quality control	1) Limited measurement time 2) Number of measurement sites limited 3) Unknown accuracy (in historical data) 4) Different periods of measurement 5) Maintenance Operation of a ground station (6) Regular maintenance and calibration) 7) Management of data from many different providers 8) Representation is limited by geography and the level of data aggregation. 9) High costs for acquisition and operation
Satellite-derived data	1) Available everywhere (continuous global coverage) 2) Spatial resolution from 3 km 3) Frequency of measurements from 15 minutes 4) Spatial and temporal consistency 5) High calibration stability	1) Poor instantaneous accuracy for the point estimate (in comparison to high quality ground measurements) 2) Time step 15 and 30min 3) Representation of the area (typically a grid cell 3 to 6 km)
Mathematical Models	1) Available according to the model and data involve in the model 2) Models can be extended to other similar sites 3) No direct measurements needed	1) Low accuracy 2) Accuracy depending on the type of model and local climate

2. Materials and Methods

Depending on the meteorological data, thirty-five models are selected amongst those available in open literature for the regression analysis. Regression coefficients are then generated from regression analysis for each model. The normalized values of MBE, RMSE, MPE and determination coefficient (R^2), are determined in order to know the performance of each model. This is made possible by using Excel and Matlab regression tools.

2.1. Studied Models

Global solar radiation from empirical models can be classified into four subgroups (temperature-based, cloud-based, sunshine based, and hybrid parameter-based models). Models selected usually takes into consideration two features: (1) available meteorological input data (2) the model accuracy. Selected models are presented in the "Table 4."

Table 4. *Thirty-five selected (35) empirical models, their equation and types of variables.*

N °	Mathematical equation	equation type	Authors and reference
MOD01	$\frac{H}{H_0} = m + n\left(\frac{S}{S_0}\right)$	Linear equation	Page 1961 [27]
MOD02	$\frac{H}{H_0} = mcos\varphi + n\left(\frac{S}{S_0}\right)$	Linear equation	Glower and McCulloch 1958 [12]
MOD03	$\frac{H}{H_0} = m + n\left(\frac{S}{S_0}\right) + o\left(\frac{S}{S_0}\right)^2 + p\left(\frac{S}{S_0}\right)^3$	Cubic equation	Samuel 1991 [15]
MOD04	$\frac{H}{H_0} = m + n * log\left(\frac{S}{S_0}\right)$	Logarithmic equation	Ampratwum and Dorvlo 1999 [16]
MOD05	$\frac{H}{H_0} = m + \left[n\left(\frac{S}{S_0}\right) + o\right]\varphi + p\left(\frac{S}{S_0}\right)$	Linear equation	Dognimaux and Lemoine 1983 [13]
MOD06	$\frac{H}{H_0} = m + n * \left(\frac{S}{S_0}\right) + o * log\left(\frac{S}{S_0}\right)$	Logarithmic equation	Newland 1989 [28]
MOD07	$\frac{H}{H_0} = m + exp\left(n * \left(\frac{S}{S_0}\right)\right)$	Exponential equation	Elagib and Mansell 2000 [29]
MOD08	$\frac{H}{H_0} = m + n(\frac{S}{S_0})^c$	Hybrid equation	Elagib and Mansell 2000 [29]
MOD09	$\frac{H}{H_0} = m + n\varphi + oZ + p\left(\frac{S}{S_0}\right)$	Hybrid equation	Elagib and Mansell 2000 [29]
MOD10	$\frac{H}{H_0} = m + nZ + o\left(\frac{S}{S_0}\right)$	Hybrid equation	Elagib and Mansell 2000 [29]
MOD11	$\frac{H}{H_0} = m + ncos\varphi + o\left(\frac{S}{S_0}\right)$	Linear equation	Raja and Twidell 1990 [14]
MOD12	$\frac{H}{H_0} = m(\Delta T)^{0.5}$	Power equation	Allen 1997 [30]
MOD13	$\frac{H}{H_0} = m + n(\Delta T)^{0.5}$	Hybrid equation	Hargreaves 1985 [31]
MOD14	$\frac{H}{H_0} = m[1 - exp(-n\Delta T^{o})]$	Hybrid equation	Bristow and Campbell 1984 [32]
MOD15	$\frac{H}{H_0} = m + n * ln(\Delta T)$	Logarithmic equation	Chen et al. 2004 [33]
MOD16	$H = m + n\left(\frac{S}{S_0}\right) + osin\delta + pT_{max}$	Linear equation	Chen et al. 2004 [33]
MOD17	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + psin\delta + qT_{max} + rRH$	Linear equation	Chen et al. 2004 [33]
MOD18	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + pRH + qST + rT_{max}$	Linear equation	Chen et al. 2004 [33]
MOD19	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + psin\delta + qRH + rST + sT_{max}$	Linear equation	Chen et al. 2004 [33]
MOD20	$H = m + nH_0 + o\delta + pRH + q\frac{S}{S_0} + rT + sST + tP$	Linear equation	Ertekin and Yaldiz 1999 [34]

N°	Mathematical equation	equation type	Authors and reference
MOD21	$\frac{H}{H_0} = m + n\left(\frac{S}{S_0}\right) + oT_{max} + pRH + qT_{max}(\frac{S}{S_0})$	Linear equation	Ododo et al.1995 [35]
MOD22	$H = m + nH_0 + oT_{max} + pT_{min} + qV$	Linear equation	El-Metwally 2004 [36]
MOD23	$H = m + n\left(\frac{S}{S_0}\right) + osin\delta + pT$	Linear equation	Togrul and Onat 1999 [37]
MOD24	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + psin\delta + qT + rRH$	Linear equation	Togrul and Onat 1999 [37]
MOD25	$H = m + n\left(\frac{S}{S_0}\right) + osin\delta + pT + qRH$	Linear equation	Togrul and Onat 1999 [37]
MOD26	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + pST + qRH$	Linear equation	Togrul and Onat 1999 [37]
MOD27	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + pRH + qST + rT$	Linear equation	Togrul and Onat 1999 [37]
MOD28	$H = m + nH_0 + o\left(\frac{S}{S_0}\right) + psin\delta + qT + rST + sRH$	Linear equation	Togrul and Onat 1999 [37]
MOD29	$H = m\left(\frac{S}{S_0}\right)^n RH^0$	Power equation	Swartzman and Ogunlade 1967 [38]
MOD30	$\frac{H}{H_0} = m + n\left(\frac{S}{S_0}\right) + oRH$	Linear equation	Swartzman and Ogunlade 1967 [38]
MOD31	$\frac{H}{H_0} = m + n\left(\frac{S}{S_0}\right) + oW$	Hybrid equation	Garg and garg 1982 [39]
MOD32	$\frac{H}{H_0} = m + n\delta + oW$	Hybrid equation	Garg and garg 1982 [39]
MOD33	$\frac{H}{H_0} = m(\Delta T)^n\,(1 + o * P + pP^2)$	Power equation	De Jong and Stewart 1993 [40]
MOD34	$H = m + n(\Delta T)^{0.5}H_0 + oT_{max} + pP + qP^2$	Hybrid equation	Hunt et al. 1998 [41]
MOD35	$H = m + nH_0 + o\frac{S}{S_0} + pRH + qT_{max} + rsin\delta$	Linear equation	Coulibaly and Ouedraogo 2016 [42]

Here RH, T_{max} and T_{min} are respectively the mean monthly relative humidity (in percentage), maximum and minimum air temperature (℃), $W(cm)$ is the atmospheric precipitable water vapor per unit volume of air (cm) computed according to Leckner 1978 [26], H is the measured mean monthly global solar radiation, H_0 the computed monthly average of daily extraterrestrial radiation, S the effective day length, S_0 the computed maximum possible sunshine duration, P the precipitation in (mm), ST is the mean soil temperature (℃), $\Delta T = (T_{max} - T_{min})$ is the temperature difference (℃), Z is the Altitude (Km) and C the cloudiness (cloud cover)

$$W = 0.0049RH\left[\frac{\exp(26.23-5416/T_k)}{T_k}\right] \quad (1)$$

T_k is the air temperature (in Kelvin).

$$H_0 = \frac{24*G_{SC}}{\pi}\left(1 + 0{,}033cos\frac{360n}{365}\right)\left(cos\phi cos\delta sin\omega_s + \frac{\pi\omega_s}{180}sin\phi sin\delta\right) \text{ in Wh/m}^2 \quad (2)$$

$$\delta = 23.45sin\left[\frac{360}{365}(284 + n)\right] \quad (3)$$

$$\omega_s = cos^{-1}(-tan\phi tan\delta) \quad (4)$$

$$S_0 = \frac{2}{15}\omega_s \quad (5)$$

G_{sc}= is the solar constant (1367 W/m^2), ϕ=latitude (deg), n= day of year $1 \le n \le 365$, δ is the declination (deg) and ω_s is the hour angle (deg)

2.2. Evaluation Parameters of the Model Performance

In the present study statistical performance parameters, mentioned are used the strength of models. The RMSE measures the average difference between a statistical model's predicted values and the measured values. Mathematically, it represents the distance between the regression line and the data points. the RMSE is always positive. Low RMSE values indicate that the model fits the data well and has more precise predictions. A zero value is ideal [43]. Mean percentage error (MPE), is described as the measure of the extent of the error of values in terms of percentage of the observed or measured value, The MBE therefore evaluate underestimation and over estimation, underestimation results in a negative value of MBE while a positive value represents an overestimation. MBE has a low desirable value and ideally its value should be zero. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation [43, 44]. The coefficient of determination R^2 determine how well the regression line approximates the real data points. R^2 range between 0 and 1 ideal value is 1 which means the best goodness of fit of model [44]. Statistical parameters are defined as follows in table 5.

Table 5. Performance metrics for model evaluations.

parameters	equations
Root mean squared error (RMSE)	$\left(\frac{1}{n}\sum_{i=1}^{n}(Y_{i,m}-Y_{i,c})^2\right)^{1/2}$
Normalised Root mean squared error RMSE (%)	$\left(\frac{RMSE}{\bar{Y}_m}\right)*100$
Mean bias error (MBE)	$\frac{1}{n}\sum_{i=1}^{n}(Y_{i,c}-Y_{i,m})$
Normalised Mean absolute bias error MBE (%)	$\left(\frac{MBE}{\bar{Y}_m}\right)*100$
Mean percentage error MPE (%)	$\frac{1}{n}\sum_{i=1}^{n}(\frac{Y_{i,m}-Y_{i,c}}{Y_{i,m}})*100$
Determination coefficient (R^2)	$1-\frac{\sum_{i=1}^{n}(Y_{i,m}-Y_{i,c})^2}{\sum_{i=1}^{n}(Y_{i,m}-\bar{Y}_m)^2}$

These metrics are preferred to comparing the predictive performance of the models over different datasets, where $Y_{i,m}$ is the i[th] measured data, $Y_{i,c}$ is the i[th] calculated data, $\bar{Y}_m$ is is the mean of the measured values and n is the total number of the observations.

3. Results and Discussion

3.1. Performance Statistics of Models

For the two cities of Garoua and Maroua models are compared using regression analysis by considering mentioned statistical parameters *MBE, MPE, RMSE, R^2*, and their associated ranking as shown in table 6 and table 7 respectively for Garoua and Maroua. these tables present informations on the accuracy of each model involved. Through these informations one can be able to select the best model for a specific application. indeed, from these data tables it is easily seen that the MBE (%), which is the metering of underestimation (negative data) and overestimation (positive data) with respect to the measured ones, lies between -0.269% and +0.162% for the city of Maroua; -1.41% and +0.571% for the city of Garoua. Likewise, the *RMSE (%)*, lies between 0.862% and 6.343% for the city of Maroua; 0.809% and 13.637% for the city of Garoua. (R^2) however, lies between 0.15 to 0.985 for Maroua and between 0.04 to 0.958 for Garoua. Regarding MPE (%) the predicted values are between - 0.00845 and -0.43614 for the site of Maroua, -0.00631 and 1.45545 for Garoua. Indeed, when we consider *MBE (%)* as accuracy criteria, the most performant models are: Tugrul and Onat 1999(MOD27) for Maroua (*MBE =1,34E-15%*), Tugrul and Onat 1999 (MOD23) for Garoua,(*MBE= 1,32E-15%)*. However, taking into account *RMSE, MPE and R^2*, the most performant models are: Ertekin and Yaldiz 1999 (MOD20) for Maroua (*RMSE*=0,86221%, *MPE=-0.00845*, R^2=0,98522), Tugrul and Onat 1999 (MOD28) for Garoua (*RMSE*=0,80631%, *MPE=-0.00631*, R^2=0,95934).

Table 6. Statistical parameters comparison for the city of Maroua with their associated ranking (+is overestimation and –is under estimation).

Models	MBE (%)	Ranking	RMSE (%)	Ranking	R^2	Ranking	MPE (%)	Ranking	Statute	Number of Variables
MOD01	1.62E-02	18	5.39206	29	0.42207	29	-0.30831	29	+	3
MOD02	1.62E-02	20	5.39206	31	0.42207	31	-0.30831	31	+	4
MOD03	3.30E-02	25	3.79059	17	0.71438	17	-0.14033	16	+	5
MOD04	2.28E-02	23	5.28211	25	0.44540	25	-0.29549	26	+	3
MOD05	2.23E-02	22	5.39208	32	0.42206	32	-0.31439	32	+	6
MOD06	5.47E-02	32	4.06724	19	0.67117	19	-0.16673	18	+	4
MOD07	8.30E-03	15	5.39716	34	0.42098	34	-0.30176	27	+	3
MOD08	1.62E-01	34	5.28700	26	0.44437	26	-0.43614	35	+	3
MOD09	1.62E-02	19	5.39206	30	0.42207	30	-0.30831	30	+	5
MOD10	-3.88E-02	26	5.39204	28	0.42207	28	-0.25306	24	-	4
MOD11	2.59E-02	24	5.39212	33	0.42206	33	-0.31805	33	+	4

Models	MBE (%)	Ranking	RMSE (%)	Ranking	R^2	Ranking	MPE (%)	Ranking	Statute	Number of Variables
MOD12	-2.69E-01	35	6.54365	35	0.14885	35	0.39683	34	-	3
MOD13	5.35E-02	30	4.47961	22	0.60111	22	-0.21607	22	+	3
MOD14	6.03E-02	33	3.97852	18	0.68536	18	-0.17544	19	+	3
MOD15	5.44E-02	31	4.42747	21	0.61035	21	-0.21081	21	+	3
MOD16	-1.75E-14	5	1.94234	12	0.92501	12	-0.03617	10	-	4
MOD17	-3.09E-14	11	1.45003	5	0.95821	5	-0.02259	4	-	6
MOD18	-2.42E-14	7	1.69333	9	0.94300	9	-0.03134	9	-	6
MOD19	-3.23E-14	13	1.45003	4	0.95821	4	-0.02259	6	-	7
MOD20	-2.82E-14	8	0.86221	1	0.98522	1	-0.00845	1	-	8
MOD21	4.80E-02	29	2.46654	15	0.87907	15	-0.06946	15	+	6
MOD22	-3.90E-14	14	1.92510	10	0.92633	10	-0.04064	13	-	5
MOD23	-1.48E-14	4	1.97613	14	0.92238	14	-0.03671	12	-	4
MOD24	-1.88E-14	6	1.30978	3	0.96590	3	-0.01845	3	-	6
MOD25	-3.09E-14	12	1.93499	11	0.92557	11	-0.03639	11	-	5
MOD26	-1.34E-14	3	1.96217	13	0.92347	13	-0.04378	14	-	5
MOD27	1.34E-15	1	1.61230	7	0.94833	7	-0.02827	8	+	6
MOD28	1.34E-15	2	1.23958	2	0.96946	2	-0.01581	2	+	7
MOD29	1.25E-02	17	5.08758	24	0.48550	24	-0.28579	25	+	3
MOD30	3.91E-02	27	4.34836	20	0.62415	20	-0.20995	20	+	4
MOD31	1.86E-02	21	5.36998	27	0.42679	27	-0.30772	28	+	4
MOD32	-1.14E-02	16	4.60543	23	0.57839	23	-0.23276	23	-	4
MOD33	4.69E-02	28	3.54179	16	0.75065	16	-0.14315	17	+	4
MOD34	-2.82E-14	9	1.61718	8	0.94801	8	-0.02477	7	-	5
MOD35	-2.82E-14	10	1.45003	6	0.95821	6	-0.02259	5	-	6

Table 7. Statistical parameters comparison for the city of Garoua with their associated ranking (+is overestimation and –is under estimation).

Models	MBE (%)	Ranking	RMSE (%)	Ranking	R^2	Ranking	MPE (%)	Ranking	Statute	Number of variables
MOD01	6.80E-02	25	4.10866	27	-0.05574	25	-0.17394	28	+	3
MOD02	6.80E-02	24	4.10866	26	-0.05574	27	-0.17394	27	+	4
MOD03	7.70E-02	31	3.63587	18	0.17326	18	-0.13255	19	+	5
MOD04	7.08E-02	28	4.12084	32	-0.06200	22	-0.17526	31	+	3
MOD05	-5.32E-01	33	4.13393	33	-0.06876	21	0.42599	33	-	6
MOD06	8.02E-02	32	3.63834	19	0.17213	19	-0.13331	20	+	4
MOD07	7.46E-02	29	4.10903	29	0.01440	33	-0.18054	32	+	3
MOD08	5.71E-01	34	4.16641	34	0.00520	34	-0.67415	34	+	3
MOD09	6.80E-02	26	4.10866	28	-0.05574	26	-0.17394	29	+	5

Models	MBE (%)	Ranking	RMSE (%)	Ranking	R^2	Ranking	MPE (%)	Ranking	Statute	Number of variables
MOD10	6.26E-02	21	4.10849	25	-0.05565	28	-0.16855	24	+	4
MOD11	6.10E-02	19	4.10844	24	-0.05563	29	-0.16696	23	+	4
MOD12	-1.41E+00	35	13.63798	35	NaN	/	1.45545	35	-	3
MOD13	6.72E-02	23	4.10462	23	-0.05366	30	-0.17324	25	+	3
MOD14	4.12E-02	18	3.90222	22	0.04769	32	-0.11025	16	+	3
MOD15	6.87E-02	27	4.11402	31	-0.05850	23	-0.17425	30	+	3
MOD16	-1.84E-14	8	1.53924	9	0.85183	9	-0.02377	9	-	4
MOD17	-2.50E-14	12	0.99261	4	0.93838	4	-0.00954	5	-	6
MOD18	-1.32E-14	6	2.39040	13	0.64265	12	-0.05881	13	-	6
MOD19	-6.58E-15	2	0.97779	3	0.94021	3	-0.00933	3	-	7
MOD20	-2.10E-14	10	1.51477	8	0.85650	8	-0.02351	8	-	8
MOD21	7.63E-02	30	3.45200	16	0.25476	16	-0.12084	17	+	6
MOD22	-6.58E-15	3	2.27739	12	0.67564	12	-0.05371	12	-	5
MOD23	1.32E-15	1	1.23965	7	0.90389	7	-0.01547	7	+	4
MOD24	1.18E-14	5	0.80925	2	0.95904	2	-0.00637	2	+	6
MOD25	-1.97E-14	9	1.07212	6	0.92811	6	-0.01127	6	-	5
MOD26	-2.24E-14	11	2.41242	14	0.63603	14	-0.06002	14	-	5
MOD27	2.76E-14	13	2.08012	11	0.72940	11	-0.04461	11	+	6
MOD28	-9.21E-15	4	0.80631	1	0.95934	1	-0.00631	1	-	7
MOD29	-3.99E-03	15	3.69038	20	0.14828	20	-0.13383	21	-	3
MOD30	6.69E-02	22	4.10971	30	-0.05628	24	-0.17380	26	+	4
MOD31	6.15E-02	20	3.89063	21	0.05334	31	-0.15382	22	+	4
MOD32	2.65E-02	16	3.46197	17	0.25045	17	-0.12182	12	+	4
MOD33	3.79E-02	17	2.58807	15	0.58110	15	-0.06547	15	+	4
MOD34	-1.32E-14	7	1.98244	10	0.75421	10	-0.03996	10	-	5
MOD35	-3.29E-14	14	0.99261	5	0.93838	5	-0.00954	4	-	6

According to performance criteria, it appears that most of the models provide good performance since values of statistical parameters obey to performance criterion. Indeed, *-5% < MBE < +5% and RMSE(%)* is less than *15%*. This shows in general that models could be helpful for the prediction of global solar irradiation in each city. In fact, goodness of the model associate to their ranking are important since they show how accurate the data are. From these results we can notice that models which more detailed atmospheric information fulfill performance better than those with less or no such inputs. Thus two criteria can be retained for models performance evaluation (1) the best models according MBE criterion (*RMSE* and *MPE* are fulfilled) (2) the best model according to *RMSE*, *MPE* and R^2 criteria. However, for the most accurate model's selection, criteria according to *RMSE*, *MPE* and R^2 is more significant. The reports are shown in the Table 8.

Table 8. *Best models according to two criteria for each city.*

City	Ranking	MBE criterion Best model	Authors	RMSE and R^2 criterion Best model	Authors
Maroua	1	MOD27	Togrul and Onat 1999 [28]	MOD20	Ertekin and Yaldiz 1999 [43]
	2	MOD28	Togrul and Onat 1999 [28]	MOD28	Togrul and Onat 1999 [28]
Garoua	1	MOD23	Togrul and Onat 1999 [28]	MOD28	Togrul and Onat 1999 [28]
	2	MOD19	Chen et al. 2004 [42]	MOD24	Togrul and Onat 1999 [28]

3.2. Regression's Coefficients of Models

In order to help experienced solar radiation developer, engineers as well as new comer, regression coefficient for different models are presented in Table 9 and Table 10 respectively for different cities.

Table 9. *Coefficients of Regression for models (city of Maroua).*

	Regression coefficients							
Models	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
MOD01	0,50195	0,08354	-	-	-	-	-	-
MOD02	-0,99476	0,08354	-	-	-	-	-	-
MOD03	-2,45841	12,86417	-17,94068	8,21964	-	-	-	-
MOD04	0,58445	0,14654	-	-	-	-	-	-
MOD05	0,63980	-0,07334	-0,01317	0,85120	-	-	-	-
MOD06	2,40452	-1,92038	3,07752	-	-	-	-	-
MOD07	-0,49590	0,07812	-	-	-	-	-	-
MOD08	-4,24200	4,82700	0,01311	-	-	-	-	-
MOD09	0,50195	0,00000	0,00000	0,08354	-	-	-	-
MOD10	-3,61500	9,73200	0,08354	-	-	-	-	-
MOD11	0,81550	0,62130	0,08354	-	-	-	-	-
MOD12	0,16281	-	-	-	-	-	-	-
MOD13	0,32766	0,06764	-	-	-	-	-	-
MOD14	0,57190	0,00313	3,07600	-	-	-	-	-
MOD15	0,28045	0,26159	-	-	-	-	-	-
MOD16	0,92146	1,30876	-0,07061	0,10798	-	-	-	-
MOD17	-0,46146	0,23174	0,77475	-0,09324	0,09453	-0,00161	-	-
MOD18	-0,03309	0,26264	0,64479	-0,00746	-0,06859	0,14336	-	-
MOD19	-0,46494	0,23126	0,77677	-0,09332	-0,00156	0,00056	0,09417	-
MOD20	-2,83785	0,51644	0,02808	0,00732	2,42812	-0,05528	0,10088	-0,00256
MOD21	-0,28335	0,82476	0,02429	-0,00007	-0,02346	-	-	-
MOD22	-0,36681	0,20886	0,16381	-0,07969	-	-	-	-
MOD23	0,67449	2,02037	-0,08645	0,12187	-	-	-	-

	Regression coefficients							
Models	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
MOD24	-0,85031	0,25937	1,31109	-0,10799	0,10580	-0,00193	-	-
MOD25	1,27373	1,62879	-0,08461	0,11458	-0,00264	-	-	-
MOD26	-1,21914	0,06755	1,39162	0,15549	0,01040	-	-	-
MOD27	-0,23736	0,38164	1,42327	-0,01496	-0,14584	0,21356	-	-
MOD28	-0,39010	0,38106	1,28143	-0,10351	0,18635	-0,11602	-0,01198	-
MOD29	8,33400	-0,02159	-0,11270	-	-	-	-	-
MOD30	0,73035	-0,13818	-0,00162	-	-	-	-	-
MOD31	0,52984	0,05641	-0,00312	-	-	-	-	-
MOD32	0,64045	0,00175	-0,02710	-	-	-	-	-
MOD33	1,21900	-0,29230	-0,00060	0,00000	-	-	-	-
MOD34	0,29359	0,07710	0,07405	0,00311	-0,00001	-	-	-
MOD35	-0,46146	0,23174	0,77475	-0,00161	0,09453	-0,09324	-	-

Table 10. *Coefficients of regression for the models (city of Garoua).*

	Regression coefficients							
Models	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
MOD01	0,58530	-0,02287	-	-	-	-	-	-
MOD02	-0,58776	-0,02287	-	-	-	-	-	-
MOD03	-0,38856	4,00975	-5,34915	2,28116	-	-	-	-
MOD04	0,56572	-0,02265	-	-	-	-	-	-
MOD05	-14,50000	2,61600	1,61600	-24,44000	-	-	-	-
MOD06	1,58615	-1,08172	1,59972	-	-	-	-	-
MOD07	-0,41470	-0,02300	-	-	-	-	-	-
MOD08	-13,08000	13,65000	-0,00045	-	-	-	-	-
MOD09	0,58530	0,00000	0,00000	-0,02287	-	-	-	-
MOD10	0,39370	0,79490	-0,02287	-	-	-	-	-
MOD11	0,59190	0,00667	-0,02287	-	-	-	-	-
MOD12	0,16277	-	-	-	-	-	-	-
MOD13	0,59559	-0,00755	-	-	-	-	-	-
MOD14	0,57230	0,00000	8,15800	-	-	-	-	-
MOD15	0,59543	-0,02423	-	-	-	-	-	-
MOD16	3,97413	-0,41133	-0,19924	0,05552	-	-	-	-
MOD17	1,92743	0,14616	-0,10226	-0,21833	0,05933	0,00451	-	-
MOD18	1,98090	0,05794	0,05706	0,00547	0,04372	0,04263	-	-
MOD19	1,72338	0,12160	-0,10084	-0,21818	0,00629	0,03927	0,03737	-

	Regression coefficients							
Models	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
MOD20	-0,74307	0,78370	0,04067	0,00256	1,63266	-0,08328	0,00530	-0,00474
MOD21	-0,21992	0,95016	0,02375	0,00030	-0,02934	-	-	-
MOD22	2,65880	0,08881	0,04149	0,02815	-	-	-	-
MOD23	3,75063	0,11129	-0,18481	0,06256	-	-	-	-
MOD24	2,12299	0,13217	0,32632	-0,20191	0,06221	0,00323	-	-
MOD25	3,21838	0,44816	-0,18992	0,06750	0,00280	-	-	-
MOD26	1,63268	0,01509	0,06074	0,11705	0,00867	-	-	-
MOD27	3,11028	0,12989	0,93031	-0,00377	-0,10492	0,13117	-	-
MOD28	2,22119	0,13934	0,37764	-0,20013	0,06971	-0,01330	0,00245	-
MOD29	6,09100	0,05135	-0,01490	-	-	-	-	-
MOD30	0,57573	-0,01439	0,00007	-	-	-	-	-
MOD31	0,50463	0,04478	0,00938	-	-	-	-	-
MOD32	0,58757	0,00110	-0,00495	-	-	-	-	-
MOD33	0,46820	0,06392	0,00190	-0,00001	-	-	-	-
MOD34	2,06496	0,04671	0,04757	0,00895	-0,00003	-	-	-
MOD35	1,92743	0,14616	-0,10226	0,00451	0,05933	-0,21833	-	-

3.3. Comparison of the Best Predicted Models with Measured and Satellite Derived Data

Nowadays different databases are used by solar energy planners and engineers for the designing of PV solar power in the absence of measured data. These databases are sometimes used in developing countries due to the lack of measured data. To better understand the behavior of predicted data, Figure 1 and Figure 2, respectively for the city of Maroua and Garoua, compared these data.

From above figures, we can see best models predict the trend of the measured global solar radiation in these regions indeed, there is no visible differences between measured and predicted data from best models named BestModel1MOD28, Bestmodel2MOD23 for the city of Garoua, and BestModel1MOD20, BestModel2MOD27 for Garoua. nevertheless, using comparison of predicted data with others resources data like Retscreen, Solargis, and PVgis which are commonly used for energy planning and management, we can easily make decision on how projects are overdesigned or under designed according to real dataset. Overestimation and underestimation are presented in Table 11.

Table 11. *Comparison of others solar resources with best predicted model data.*

	Maroua city			Garoua city		
Month	**Retscreen**	**pvgis**	**Solargis**	**Retscreen**	**pvgis**	**Solargis**
January	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation
February	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation
March	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation
April	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation
May	over-estimation	over-estimation	over-estimation	under-estimation	over-estimation	over-estimation

	Maroua city			Garoua city		
Month	**Retscreen**	**pvgis**	**Solargis**	**Retscreen**	**pvgis**	**Solargis**
June	over-estimation	over-estimation	over-estimation	under-estimation	over-estimation	under-estimation
July	over-estimation	over-estimation	over-estimation	under-estimation	under-estimation	under-estimation
August	over-estimation	over-estimation	over-estimation	under-estimation	under-estimation	under-estimation
September	over-estimation	over-estimation	over-estimation	under-estimation	under-estimation	under-estimation
October	over-estimation	over-estimation	over-estimation	under-estimation	over-estimation	under-estimation
November	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation	over-estimation
December	over-estimation	under-estimation	over-estimation	over-estimation	over-estimation	over-estimation

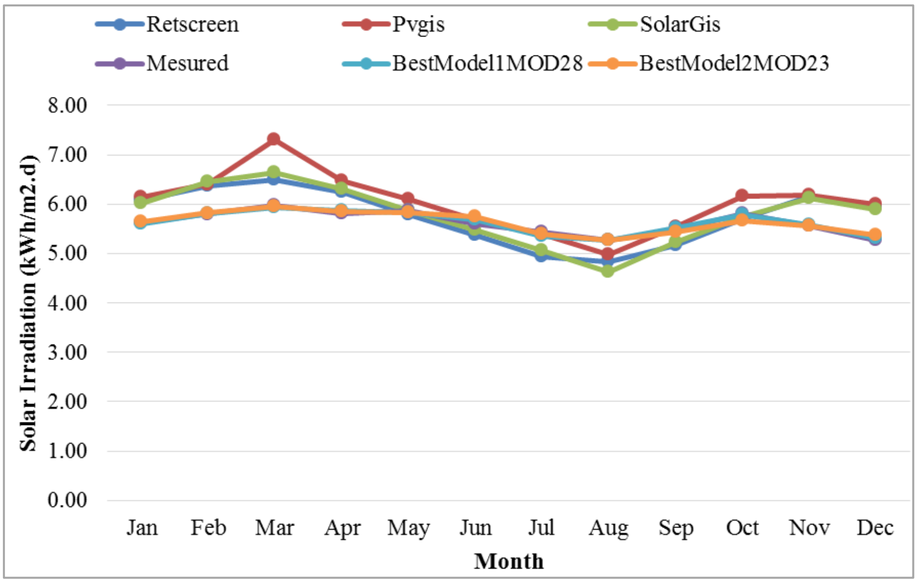

***Figure 1**. Others resources data and best models for the city of Maroua.*

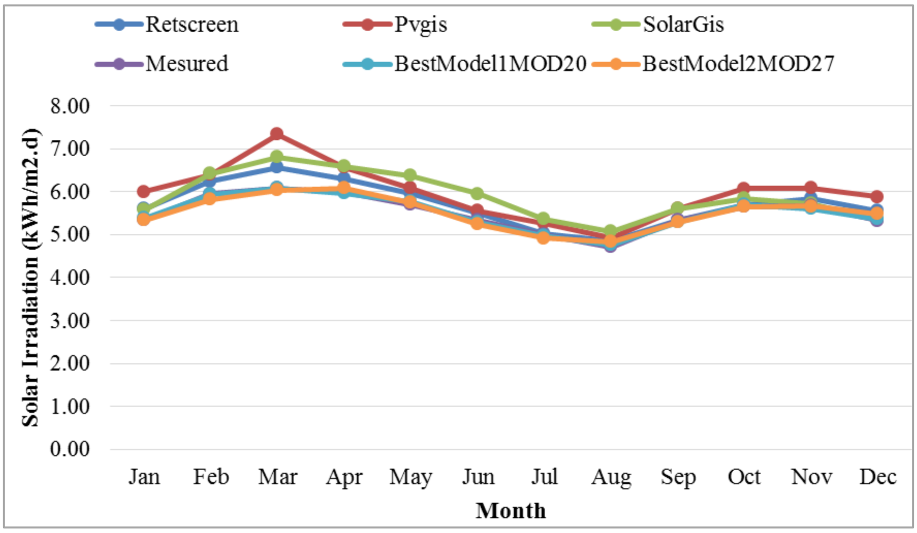

***Figure 2**. Others resources data and best models and for the city of Garoua.*

4. Conclusion

Solar radiation resources data are one of the keys to energy projects success. This research was conducted to evaluate performance of some representative empirical models encountered in the open literature. The comparison is made possible using statistical evaluation parameters deduced from regression analysis realized using Excel and Matlab tools. Amongst the thirty-five (35) empirical models studied, accuracy of the models was verified by comparing estimated values with measured values in terms of the following statistical evaluation parameters named root mean square error (RMSE, mean bias error (MBE),), and the determination coefficient (R^2). It is observed that more meteorological data are needed for the precise evaluation of the global solar radiation. The results shows that the models of Togrul and Onat 1999 (MOD28), Ertekin and Yaldiz 1999 (MOD20) appear to be more accurate and performed data better. Through the results obtained we clearly demonstrate that formulated models are good enough to be used to predict monthly average daily radiation for these two cities in Cameroon. It may be concluded that the models presented in this study could be used to estimate accurately the solar radiation at any semi-arid region around the world.

Abbreviations

BSh	Semi-Arid Climate Zone
G_{sc}	Solar Constant (W/m^2)
H_0	Extraterrestrial Solar Radiation (kWh/m^2)
H	Measured Solar Radiation (kWh/m^2)
MBE	Mean Bias Error (kWh/m^2)
MPE	Mean Percentage Error (kWh/m^2)
P	Precipitation in (mm)
PV	Photovoltaic
RH	Relative Humidity in Percentage
$RMSE$	Root Mean Square Error (kWh/m^2)
R^2	Determination Coefficient
S	Effective Sunshine Duration (h)
S_0	Day Length (h)
ST	Mean Soil Temperature (℃)
T	Monthly Mean Temperature (℃)
T_k	Monthly Daily Mean Air Temperature (K.)
T_{max}	Mean Maximum Temperature (℃)
T_{min}	Mean Minimum Temperature (℃)
W	Precipitable Water Vapor from the Atmosphere (cm).
$\bar{Y}_m$	Mean Annual Solar Radiation (kWh/m^2)
$Y_{i,c}$	Calculated Solar Radiation (kWh/m^2)
$Y_{i,m}$	Measured Solar Radiation (kWh/m^2)
Z	Altitude (Km)

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Conflicts of Interest

The authors declare no conflicts of interest.

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