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Performance Study of Thirty-five empirical Models for the Estimation of Global Solar Irradiation in the Tropical Savannah Zone of Cameroon

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ABSTRACT
In the present study, thirty five empirical models for estimating monthly horizontal global solar radiation were compared and six new combined models (NM01 to NM06) were developed. Accuracy and applicability of these models were evaluated by using statistical parameters (MBE%, RMSE%, MPE, R^2). Monthly meteorological data during more than 20 years were used for model calibration and the data from 1984 to 2015 were used to validate the models. Models have been implemented using MATLAB and Excel tools. This study shows that the model of Ertekin and Yaldiz 1999 (M20), Togrul and Onat 1999 (M28) and Ertekin and Yaldiz 1999 (M20) performed data better than other models for the city of Ngaoundere (MBE%= 0.00E+00; RMSE%=0.797; MPE=-0.00802; R^2=0.996). The six New developed models shown interesting value according to RMSE%, MBE% and R^2. Indeed RMSE% range between 0.798-7.12, while MBE% and R^2, range respectively between 0.00 to -6.52E-01 and 0.714 to 0.0996. among new developed models the new model 05 (NM05) performed data better for the city of Ngaoundere, these models can be used to evaluate solar radiation in locations with similar climate.

***KEYWORDS*: empirical models; global solar radiation; correlations; Cameroon; performance.**

1-INTRODUCTION

A precise knowledge of the data of the various components of solar radiation for a particular geographical position is crucial as it allows not only to optimize the design of solar energy conversion systems but also to evaluate their performance [1-3]. Reliable solar radiation data sets are essential for energy planners, engineers and agricultural scientists [4,5]. They are fundamental for the designing of the solar energy systems (solar cookers, solar water heaters, solar power). They are essential in agriculture as they allow better analysis of evapotranspiration phenomena and help to better assess the water needs of crops. Techno-economic feasibility of solar projects, thereby allowing the investors, government agencies and the utility operators are well made through a precise knowledge of solar data [6]. Unfortunately we are often confronted with data gaps related to the lack of data records of stations or the continuity of readings. Nowadays there are websites and software (meteoronorm, RETScreen, solargis, PVGIS, homer) that allows us to obtain data of solar resource of a given geographic area [7], but none of them are perfect. In developing countries, lack of financial resources does not allow to have enough measuring station facilities to achieve a precise knowledge of the solar resource [8]. Even in the developed countries there is a dearth of measured long-term solar radiation and daylight data [9] for instance the ratio of weather stations collecting solar radiation data relative to those collecting temperature data worldwide is approximately 1:500. It therefore becomes important to develop calculation procedures to provide radiation estimates for places where measurements are not carried out and for places where there are gaps in the measurement records by using empirical models that, from a number of input meteorological data, will assess how more or less precisely the amount of solar energy received at each point on the surface of a given location. In the open literature, many variables as: extraterrestrial radiation, relative humidity, number of rainy days, altitude, latitude, precipitation, albedo, cloudiness, and evaporation sunshine hours, mean temperature, minimum temperature, maximum temperature, soil temperature, [10-14]. These models appear as hybrid, exponential, logarithmic, power, quartic, quadratic, cubic, and linear forms [15].

Earlier, the most used parameter to assess solar radiation is the sunshine duration. Using sunshine duration, the simplest model to estimate the average of the global radiation on a horizontal surface is the model of Angstrom 1924 [16], and their modified models known as Angstrom-Prescott-Page model establish by Prescott in 1940 [17]. Many researchers have found the value of the regression coefficients of angstrom model for different locations around the world and demonstrate that the relationship of Angstrom is valid within reasonable degree of accuracy [18-30]. However, for some regions of the globe, assessing accurate value of solar irradiation requires more magnitudes than the sunshine hours [8] thus the models of the solar radiation as function of sunshine data are not entirely valid in all regions. Depending on the available data, several models exist nowadays and are grouped into Sunshine-based models, Cloud-based models, Temperature-based models, Relative Humidity-based models, Precipitation-based models, Hybrid Parameter-based models [5, 29, 31-39], the most frequently used approach has been based on empirical relationships that require the development of a set of equations to estimate solar radiation from commonly measured meteorological variables. The number of such equations that have been published and tested is relatively high, these models have shown a good performance in literature for many sites around the world.

Despite the amount of work done on the development of empirical correlation for determination of monthly averaged daily global solar radiation in locations around the world, no empirical correlation have been found for this region of Cameroon apart from angstrom-Prescott model, Hargreaves and Samani model, Annandale et al. Model, Bristow and Campbell model and Goodin et al. Model, [28,40,41]. Among different models encountered in open literature and depending on the available data, thirty-five (35) models were selected. The objective of this study is to evaluate these models for the Sudanese zone of Cameroon and to develop new models which can perform better solar radiation in this specific location. To achieve this, Matlab, Excel and Sigmaplot tools were used to determine on one hand the regression coefficient of the model and another hand the performance statistics named, mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE) and determination coefficient (R^2).

2- STUDY AREA AND WEATHER DATA

The study area is located between the latitude 6˚N and 8˚N and between longitude 11˚E and 16˚E and covers the administrative region of Adamawa cameroon. It shares its boundaries with Nigeria and the Central African Republic. The Adamawa region is mainly constituted of plateau which is around 1100 m altitude. In it's southern part the region is surrounded by volcanic mountains reaching up to 2400 m. the climate is Sudano-Guinean and is under the influence of the African monsoon which brings rains between May and October and by the Harmattan winds coming from Sahara which brings dryness between November and April [42,43].

In this research, weather data are used and contain many parameters recorded daily through several years. These parameters are solar radiation, mean daily sunshine duration, mean daily temperature in ° C, Maximum daily temperature in ° C, Minimum daily temperature in ° C, mean soil Temperature, mean visibility. Mean total precipitable water (mm) and Mean relative humidity. These data and their record period time are presented in table 1.

Table 1: Meteorological data recorded and their minimal record time

Parameters	**period**	**Maximum Missing year**	**Minimum Record time (years)**
Maximum daily temperature	1980-2013	13	21
Minimum daily temperature	1980-2013	13	21
Mean daily temperature	1980-2013	13	21
Mean Soil Temperature (ST)	1980-2013	13	21
Mean daily visibility	1980-2013	13	21
Mean relative humidity	1980-2013	13	21
Mean precipitation	1980-2013	13	21
Effective day length	1961-2015	21	33
Solar radiation	1984-2015	29	4

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4- METHODOLOGY

The work began with collection of detailed weather data in the study area. The regression analysis is employed to generate the regression coefficients of different suggested models depending on the meteorological parameters involved in each model selected. Among different models proposed in literature, thirty-five (35) are subject to our study. For each model, regression coefficients have to be known as well as percentage of MBE, RMSE, MPE and determination coefficient (R^2). This is made possible by using Matlab, Excel and Sigmaplot tools. Using new meteorological parameter as visibility *(V)* new models have developed and are considered here as modified models.

4.1- Studied Models

The number of correlations published and tested to estimate global solar radiations is relatively high, which makes it difficult to select the best method for a particular site and purpose [3].
Global solar radiation models are classified into four categories (sunshine based, cloud-based, temperature-based, and hybrid parameter-based models). The selection of these models usually takes into account two features: (1) the availability of meteorological and other kind of data used as input by the model and (2) the model accuracy. The models selected for the purpose are given into details in Table 2. Here $W(cm)$ is the atmospheric precipitable water vapor per unit volume of air (cm) computed according to Leckner 1978 [44]. RH and T_k are respectively the monthly daily mean humidity (in percentage) and air temperature (in Kelvin.).

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

Table 2: Equation and types of variables for the 35 empirical models for the estimation of the monthly solar radiation

N°	Models (equation type)	Authors	Mathematical relations
M01	Angstrom-Prescott-Page **(linear)**	Angstrom 1924, Prescott 1940, Page 1961[16,17,45]	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$
M02	Glower and McCulloh model **(linear)**	Glower and McCulloch 1958[19]	$\frac{H}{H_0} = acos\varphi + b\left(\frac{S}{S_0}\right)$
M03	model of Samuel **(cubic)**	Samuel 1991	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3$
M04	Ampratwum and Dorvlo model **(logarithmic)**	Ampratwum and Dorvlo 1999[25]	$\frac{H}{H_0} = a + b * log\left(\frac{S}{S_0}\right)$
M05	Dognimaux and Lemoine model **(linear)**	Dognimaux and Lemoine 1983[22]	$\frac{H}{H_0} = a + \left[b\left(\frac{S}{S_0}\right) + c\right]\varphi + d\left(\frac{S}{S_0}\right)$
M06	Newland model **(logarithmic)**	Newland 1989[46]	$\frac{H}{H_0} = a + b * \left(\frac{S}{S_0}\right) + c * log\left(\frac{S}{S_0}\right)$
M07	Elagib and Mansell model 1 **(exponential)**	Elagib and Mansell 2000[47]	$\frac{H}{H_0} = a + exp\left(b * \left(\frac{S}{S_0}\right)\right)$
M08	Elagib and Mansell Model 2 **(hybrid)**	Elagib and Mansell 2000[47]	$\frac{H}{H_0} = a + b(\frac{S}{S_0})^c$
M09	Elagib and Mansell Model 3 **(hybrid)**	Elagib and Mansell 2000[47]	$\frac{H}{H_0} = a + b\varphi + cZ + d\left(\frac{S}{S_0}\right)$
M10	Elagib and Mansell Model 4 **(hybrid)**	Elagib and Mansell 2000[47]	$\frac{H}{H_0} = a + bZ + c\left(\frac{S}{S_0}\right)$
M11	Raja and Twidell model **(linear)**	Raja and Twidell 1990	$\frac{H}{H_0} = a + bcos\varphi + c\left(\frac{S}{S_0}\right)$
M12	Allen Model **(power)**	Allen 1997[48]	$\frac{H}{H_0} = a(\Delta T)^{0.5}$
M13	Hargreaves model **(hybrid)**	Hargreaves 1985[49]	$\frac{H}{H_0} = a + b(\Delta T)^{0.5}$
M14	Bristow and Campbell Model **(hybrid)**	Bristow and Campbell 1984[50]	$\frac{H}{H_0} = a[1 - exp(-b\Delta T^c)]$
M15	Chen *et al*. model 1**(logarithmic)**	Chen et al. 2004[60]	$\frac{H}{H_0} = a + b * ln(\Delta T)$
M16	Chen *et al*. model 2 **(linear)**	Chen et al. 2004[51]	$H = a + b\left(\frac{S}{S_0}\right) + csin\delta + dT_{max}$
M17	Chen *et al*. model 3 **(linear)**	Chen et al. 2004[51]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dsin\delta + eT_{max} + fRH$
M18	Chen *et al*. model 4 **(linear)**	Chen et al. 2004[51]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dRH + eST + fT_{max}$
M19	Chen *et al*. model 5 **(linear)**	Chen et al. 2004[51]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dsin\delta + eRH + fST + gT_{max}$
M20	Ertekin and Yaldiz Model **(linear)**	Ertekin and Yaldiz 1999[52]	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP$
M21	Ododo et al. Model **(linear)**	Ododo et al.1995[53]	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + cT_{max} + dRH + eT_{max}(\frac{S}{S_0})$
M22	El-Metwally Model **(linear)**	El-Metwally 2004[54]	$H = a + bH_0 + cT_{max} + dT_{min} + eV$
M23	Togrul and Onat model 1 **(linear)**	Togrul and Onat 1999[55]	$H = a + b\left(\frac{S}{S_0}\right) + csin\delta + dT$
M24	Togrul and Onat model 2 **(linear)**	Togrul and Onat 1999[55]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dsin\delta + eT + fRH$
M25	Togrul and Onat model 3 **(linear)**	Togrul and Onat 1999[55]	$H = a + b\left(\frac{S}{S_0}\right) + csin\delta + dT + eRH$
M26	Togrul and Onat model 4 **(linear)**	Togrul and Onat 1999[55]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dST + eRH$
M27	Togrul and Onat model 5 **(linear)**	Togrul and Onat 1999[55]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dRH + eST + fT$
M28	Togrul and Onat model 6 **(linear)**	Togrul and Onat 1999[55]	$H = a + bH_0 + c\left(\frac{S}{S_0}\right) + dsin\delta + eT + fST + gRH$
M29	Swartzman-Ogunlade 1 **(power)**	Swartzman and Ogunlade 1967[56]	$H = a\left(\frac{S}{S_0}\right)^b RH^c$
M30	Swartzman-Ogunlade 2 **(linear)**	Swartzman and Ogunlade 1967[56]	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + cRH$
M31	Garg and garg model 1**(hybrid)**	Garg and garg 1982[67]	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + cW$
M32	Garg and garg model 2 **(hybrid)**	Garg and garg 1982[57]	$\frac{H}{H_0} = a + b\delta + cW$
M33	De Jong and Stewart model **(power)**	De Jong and Stewart 1993[58]	$\frac{H}{H_0} = a(\Delta T)^b\ (1 + c * P + dP^2)$
M34	Hunt et al. Model **(hybrid)**	Hunt et al. 1998[59]	$H = a + b(\Delta T)^{0.5}H_0 + cT_{max} + dP + eP^2$
M35	Coulibaly and Ouedraogo Model **(linear)**	Coulibaly and Ouedraogo 2016[60]	$H = a + bH_0 + c\frac{S}{S_0} + dRH + eT_{max} + fsin\delta$

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In table 2 above H is the monthly average daily global radiation, H_0 the monthly average daily extraterrestrial radiation, S the day length, S_0 the maximum possible sunshine duration. The extraterrestrial radiation H_0 is given by:

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

G_{sc}= is the solar constant (W/m^2)

ϕ=latitude (deg)

n= day of year $1 \leq n \leq 365$

δ is the declination (deg)

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

ω_s is the hour angle (deg)

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

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

4.2- Evaluation parameters of the model performance

All the different models presented above to assess the amount of solar energy reaching a given surface have to be validated. There are many statistical methods available in solar energy literature, which deal with the assessment and comparison of solar radiation estimation models [2-4, 47, 61-63]. In the present study statistical indicators, namely mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE) and determination coefficient (R^2) have been used. MBE helps to have an idea about the long-term performance of the model, a low MBE is desired. Ideally a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation [64, 65]. The RMSE provides information on the short-term performance of the correlations by allowing a term-by-term comparison of the deviation between the calculated and measured values, the RMSE is always positive, a zero value is ideal. However, a few large errors in the sum can produce a significant increase in RMSE [5,64]. The coefficient of determination R^2 is used to determine how well the regression line approximates the real data points. A model is more efficient when R^2 is closer to 1 [65]. These error parameters are defined as follows:

The Mean Bias Error (MBE) in percentage is:

$$MBE(\%) = \left(\frac{MBE\ (kWh/m^2)}{\bar{H}_m}\right) * 100 \text{ ; With } MBE = \frac{1}{n}\sum_{i=1}^{n}(H_{i,c} - H_{i,m}) \text{ ;} \quad (6)$$

The Root Mean Square Error (RMSE) in percentage is:

$$RMSE(\%) = \left(\frac{RMSE\ (kWh/m^2)}{\bar{H}_m}\right) * 100 \text{ ; With } RMSE = \left(\frac{1}{n}\sum_{i=1}^{n}(H_{i,m} - H_{i,c})^2\right)^{1/2} \text{ ;} \quad (7)$$

The Coefficient of determination (R^2) is:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(H_{i,m}-H_{i,c})^2}{\sum_{i=1}^{n}(H_{i,m}-\bar{H}_m)^2} \quad (8)$$

The mean percentage error is:

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{i,c}-H_{i,m}}{H_{i,m}}\right) * 100 \quad (9)$$

The models used to compute solar irradiation provides good performance if the MBE and RMSE have as low values as possible. The following quantitative recommendations are sometimes used. For global irradiation, MBE within ±10% and RMSE less than 20% indicate good fitting between model results and measurements [33,66]. Here more stringent criteria for model performance can be adopted. A model to compute solar global irradiation provides good performance if the model is well calibrated with MBE within ± 5% and the scatter in the results is such that RMSE < 15 %. [33].

5-RESULTS AND DISCUSSION

5.1- Performance statistics of Models

To appreciate the performance and the accuracy of each model equations (1) to (9) have been used. Statistical analysis has been conducted (*MBE,MPE, RMSE,* R^2,) using measured data as validation data indeed a model is assumed as the best model when RMSE, MBE and MPE are near zero and R^2 is close to one comparison of models is made considering in one side MBE(%) and in other side RMSE(%), MPE(%) and R^2 as accuracy criteria. Hence, *MBE,MPE, RMSE,* R^2, and their associated ranking are presented in the table 4 for site, this table contains systematic information on the accuracy of each model involved. This information allows the user to choose the best available estimating model for an application when considering available data and demands for accuracy. Thus, from these tables it is easily seen that the MBE (%), a measure of the overestimation (positive data) or underestimation (negative data) of the computed values with respect to the measured ones, lies between -0.652% and +0.094%. In the same way, the *RMSE(%)* estimator, which is a measure of the power contained in the estimated values in excess to that possessed by the real ones, lies between 0.796% to 7.121%. The determination coefficient (R^2) lies between 0.797 to 0.996 for the site. For the MPE(%) which is the measure of the extent of the error of values in terms of percentage of the observed or measured value, the computed values lies between -0.00802 and 0.76649. Considering *MBE(%)* as accuracy criteria, the most accurate model is: Ertekin and Yaldiz 1999 (M20) (*MBE= 0,00E+00%*). Considering *RMSE, MPE and* R^2, the most accurate model is : Ertekin and Yaldiz 1999 (M20) (*RMSE*=0,79677%, *MPE*= -0.00802, R^2=0,99642).

Table 3: Percentage root mean square error (RMSE), Mean bias error, Mean percentage error and determination coefficient with their associated ranking for global irradiance for the city of Ngaoundere (+is overestimation and –is under estimation)

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Models	MBE(%)	Rank	RMSE(%)	Rank	R^2	Rank	MPE(%)	Rank	Statute	Number of Variables
M01	2.60E-02	**18**	3.31943	**23**	0.93792	**23**	-0.13460	**22**	+	3
M02	2.60E-02	**19**	3.31943	**24**	0.93792	**24**	-0.13460	**23**	+	4
M03	4.60E-02	**28**	2.86001	**16**	0.95392	**16**	-0.09517	**17**	+	5
M04	4.19E-02	**26**	2.98392	**18**	0.94984	**18**	-0.09929	**18**	+	3
M05	-6.52E-01	**35**	3.38757	**28**	0.93535	**28**	0.53040	**33**	-	6
M06	4.13E-02	**24**	2.98369	**17**	0.94985	**17**	-0.09984	**19**	+	4
M07	2.37E-02	**17**	3.42383	**29**	0.93396	**29**	-0.14724	**27**	+	3
M08	-1.29E-02	**15**	2.98436	**19**	0.94982	**19**	-0.05306	**13**	-	3
M09	2.60E-02	**20**	3.31943	**25**	0.93792	**25**	-0.13460	**24**	+	5
M10	2.60E-02	**21**	3.31943	**26**	0.93792	**26**	-0.13460	**25**	+	4
M11	2.60E-02	**22**	3.31943	**27**	0.93792	**27**	-0.13460	**26**	+	4
M12	-4.12E-01	**34**	5.28326	**34**	0.84274	**34**	0.76649	**35**	-	3
M13	7.11E-02	**30**	3.97117	**33**	0.91115	**33**	-0.19643	**31**	+	3
M14	9.40E-02	**33**	3.92811	**32**	0.91307	**32**	-0.19876	**32**	+	3
M15	7.98E-02	**31**	3.92221	**31**	0.91333	**31**	-0.18737	**30**	+	3
M16	-5.41E-15	**4**	1.24071	**7**	0.99133	**7**	-0.01300	**6**	-	4
M17	-8.11E-15	**9**	1.13082	**4**	0.99280	**4**	-0.01164	**5**	-	6
M18	-3.11E-14	**14**	1.03191	**3**	0.99400	**3**	-0.01164	**3**	-	6
M19	-4.05E-15	**3**	1.02670	**2**	0.99406	**2**	-0.00850	**2**	-	7
M20	0.00E+00	**1**	0.79677	**1**	0.99642	**1**	-0.00802	**1**	-	8
M21	6.01E-02	**29**	2.44475	**14**	0.96633	**14**	-0.07006	**16**	+	6
M22	5.41E-15	**5**	1.49512	**8**	0.98741	**8**	-0.03224	**9**	+	5
M23	-6.76E-15	**7**	2.63538	**15**	0.96087	**15**	-0.06864	**15**	-	4
M24	-6.76E-15	**8**	1.97014	**12**	0.97813	**12**	-0.04265	**12**	-	6
M25	-1.35E-14	**11**	2.26247	**13**	0.97116	**13**	-0.06121	**14**	-	5
M26	-1.22E-14	**10**	1.67897	**11**	0.98412	**11**	-0.03476	**10**	-	5
M27	-5.41E-15	**6**	1.49898	**9**	0.98734	**9**	-0.03104	**8**	-	6
M28	1.49E-14	**13**	1.13881	**6**	0.99269	**6**	-0.01604	**7**	+	7
M29	4.17E-02	**25**	3.28640	**22**	0.93915	**22**	-0.18279	**29**	+	3
M30	3.57E-02	**23**	3.26011	**21**	0.94012	**21**	-0.13342	**21**	+	4
M31	1.66E-02	**16**	3.16308	**20**	0.94363	**30**	-0.11560	**20**	+	4
M32	4.31E-02	**27**	7.12188	**35**	0.71424	**35**	-0.57972	**34**	+	4
M33	8.75E-02	**32**	3.85647	**30**	0.91621	**30**	-0.17741	**28**	+	4
M34	-1.35E-15	**2**	1.62270	**10**	0.98517	**10**	-0.03490	**11**	-	5
M35	-1.35E-14	**12**	1.13082	**5**	0.99280	**5**	-0.01218	**4**	-	6

Taking into account criteria of performance it is observed that most of the models provide good performance since $-5\% < MBE < +5\%$ and $RMSE < 15\%$. This shows that these models can be used to evaluate global solar irradiation in the sudanese zone of Cameroon. However, goodness of the model and the ranking are essential since they shows how precisely the data are. In table 3, it is observed that models are classified depending on their accuracy for this purpose some models are more accurate than others. It is also observed that models in which more detailed atmospheric information are involved perform data better than those with

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little or no such inputs. The main disturbing fact, however is the ranking disagreements between *MBE (%)* in one side and *RMSE (%), MPE* and R^2 in order side. Thus two criteria for the evaluation of models accuracy are considered: the best models according to the MBE criterion (*RMSE* and *MPE* are fulfilled) and the best model according to *RMSE, MPE* and R^2 criteria. However for the best models selection, criteria according to *RMSE, MPE* and R^2 is more significant indeed, *MBE* which is the measure of the overestimation and underestimation have a major drawback in its use due to the fact that error effect related to overestimation by the model is cancelled by the model's underestimation that is why, it is characterized by unfair error cancellation. In an ideal scenario where *MBE* is zero, it implies that the developed model has an excellent long term performance, but also bearing in mind that *MBE* is not a good statistical tool for evaluating model performance in terms of error computation due to its intrinsic unfair error cancellation. This means that a model with a very small *MBE* does not really imply that it has a good performance in terms of its prediction. Advantages of the different models depend on the number of variables, on the equation type (Linear, cubic, logarithmic, hybrid, exponential, power), the simplicity and consequent operational efficiency, the facility to compute equations and their accuracy determined by *MBE, RMSE, MPE and* R^2. Models can also be generalised since it can be used for another location elsewhere. Once models are known there is no need for ground solar radiation data. The main limitations of the methods are related to the need of meteorological data and calibration related to these data, the need for ground solar radiation data for validation and the lack of generality. It must be remembered that the same regression equation coefficients, determined for the locations corresponding to the ground solar radiation data, are also used to estimate the solar radiation reaching the ground throughout the region studied. Furthermore, there is no guarantee that they would have the same values in other areas. Limitation can be also related to the space and time since validation data used at different record time and space would not give the same correlations. Complexity of equations are also the main drawback of models. The summary of these result are presented in the table 4.

Table 4: The two best models according to the MBE and RMSE criteria for each city.

Cities	Rank	Best model according to MBE	Authors	Best model according to RMSE and R^2	Authors
Ngaounderé	1	M20	Ertekin and Yaldiz 1999 [44]	M20	Ertekin and Yaldiz 1999 [44]
	2	M34	Hunt et al. in 1998 [51]	M19	**Chen et al. 2004**

5.2- Regressions coefficients of Models

In order to help new comer as well as experienced solar radiation developer, tester, or users, all regression coefficient for different models are presented in table 5.

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Table 5: Regression coefficients of the models for the city of Ngaoundéré

Models	a	b	c	d	e	f	g	h
M01	0,36325	0,34102	X	X	X	X	X	X
M02	0,36325	0,00000	0,34102	X	X	X	X	X
M03	0,36740	0,07490	0,96006	-0,80709	X	X	X	X
M04	0,67141	0,42293	X	X	X	X	X	X
M05	-19,47000	-9,41800	2,72300	68,93000	X	X	X	X
M06	0,65868	0,01418	0,40563	X	X	X	X	X
M07	-0,62230	0,28770	X	X	X	X	X	X
M08	-0,92860	1,60300	0,12390	X	X	X	X	X
M09	0,36325	0,00000	0	0,34102	X	X	X	X
M10	0,36325	0,00000	0,34102	X	X	X	X	X
M11	0,36325	0,00000	0,34102	X	X	X	X	X
M12	0,00000	0,15182	X	X	X	X	X	X
M13	0,13670	0,11473	X	X	X	X	X	X
M14	0,79300	0,18220	0,73810	X	X	X	X	X
M15	0,01983	0,48039	X	X	X	X	X	X
M16	-0,68757	2,38065	-0,02285	0,16796	X	X	X	X
M17	-0,90044	0,08586	2,35685	-0,03207	0,14991	-0,00152	X	X
M18	0,03748	-0,00285	2,19267	-0,00696	-0,10989	0,26142	X	X
M19	-0,05736	0,00898	2,21654	-0,01148	-0,00639	-0,10122	0,25113	X
M20	-0,41284	0,25716	0,01041	0,01162	1,11586	-0,11252	0,19089	-0,00409
M21	0,01323	0,36747	0,01135	0,00063	-0,00223	X	X	X
M22	-0,24652	-0,07215	0,28391	-0,11333	X	X	X	X
M23	0,51315	3,73198	-0,05124	0,13402	X	X	X	X
M24	-0,08373	0,21565	3,10788	-0,05819	0,10047	-0,00685	X	X
M25	2,25624	2,88746	-0,03405	0,11481	-0,01245	X	X	X
M26	-1,56887	0,18786	2,52194	0,14034	0,00288	X	X	X
M27	-3,04847	0,20129	1,83482	0,01405	0,29285	-0,13588	X	X
M28	-3,95879	0,24528	1,63848	-0,10161	-0,19379	0,34743	0,02045	X
M29	12,38000	0,28120	-0,15140	X	X	X	X	X
M30	0,41199	0,30973	-0,00046	X	X	X	X	X
M31	0,27785	0,39561	0,01850	X	X	X	X	X
M32	0,77136	-0,00045	-0,07373	X	X	X	X	X
M33	0,32940	0,22060	-0,00026	-6,509E-07	X	X	X	X
M34	2,60849	-0,01140	0,13761	-6,946E-03	6,840E-06	X	X	X
M35	-0,90044	0,08586	2,35685	-1,522E-03	1,499E-01	-0,03207	X	X

5.3- Prospected Models

Another goal of this paper is to develop new models and prospect the more accurate model beyond a large number of developed solar radiation models for these reasons six new models were proposed using a call number (NM01 to NM06) to estimate daily global solar radiation. Mathematical equations

of these models are developed by combining a new meteorological data named Visibility with different forms of other readily available meteorological data. These new models are similar to Ertekin and Yaldiz model [19], Togrul and Onat model [47] and Ododo et al. Model [45] and can be considered as modified models. Among these new prospected models the model (NM05):

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with equation : $H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + iT_{max} + jsin\delta + kV$,and statistical parameter *(MBE(%)=5.27E-14, RMSE(%)=0.01540,* R^2*=1.00),* appear to be the best model among those prospected. Statistical parameters of the model and the associated ranking is presented in table 6.

Table 6: New models prospects for better MBE, RMSE and R^2 in the city of Ngaoundere

News Models	Equations	MBE(%)	Rank	RMSE(%)	Rank	R^2	Rank
NM01	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + iT_{max} + ksin\delta$	-1,22E-14	1	0,13889	5	0,99989	5
NM02	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + i\frac{T_{min}}{T_{max}} + jsin\delta$	4,05E-14	3	0,09373	4	0,99995	4
NM03	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + i\frac{T_{min}}{T_{max}} + jsin\delta + kV$	5,00E-14	4	0,03277	2	0,99999	2
NM04	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + cT_{max} + dRH + eT_{max}\left(\frac{S}{S_0}\right) + fT + gST + hP + i\delta$	2,26E-03	6	0,54489	6	0,99833	6
NM05	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + iT_{max} + jsin\delta + kV$	5,27E-14	5	0,01540	1	1,00000	1
NM06	$H = a + bH_0 + c\delta + dRH + e\frac{S}{S_0} + fT + gST + hP + iT_{max} + jT_{min} + ksin\delta$	1,49E-14	2	0,05161	3	0,99998	3

All models prospected perform better *RMSE* and R^2 than 35 models studied above indeed, the smallest value of RMSE (%) is 0.15% (NM05 model) while maximum value is 0.545% for NM04 model, where R^2 range from 0.998 (NM04 model) to 1.00 (NM05 model). Table 6, shows a more detailed information about the performance of the six developed models.

5.4- Comparison of estimated Models with measured and NASA observed data, developed new models with measured data.

Many other resources are commonly used to design PV solar power in the absence of measured data. These data sources are sometimes used in developing countries due to the lack of measured data. It is therefore important to compare in this paper, data computed from the best models to those obtained from Retscreen, Solargis, and PVgis software with measured data, in order to know how precise are those different models compare to measure one. These data sources are plotted in the figure 1.

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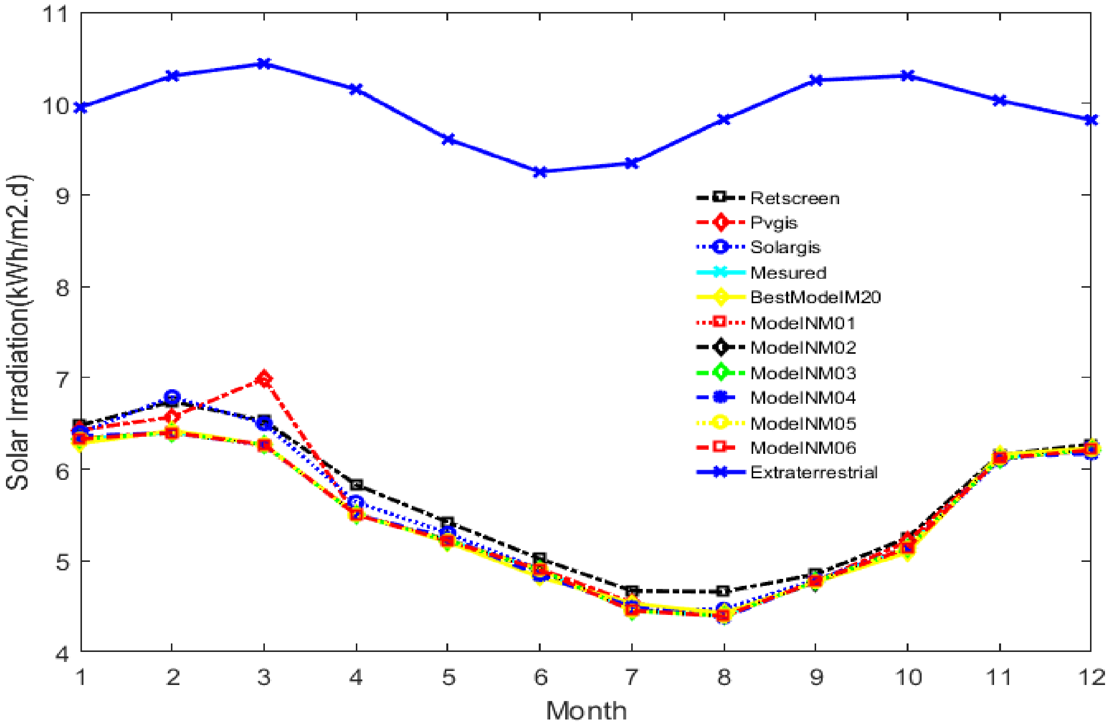

Figure 1: Solar irradiation with measured data, different best models and others resources data for the city of Ngaounderé.

It is clear that these models predict the trend of the global solar radiation compared to the measured data since there is no visible differences between measured and predicted data. However, when comparing predicted data with others resources data like Retscreen, Solargis, and PVgis which are commonly used for designing solar systems, decision can be easily made on how projects are overdesigned or under designed through the use of any of these data Overestimation and underestimation are presented in table 7.

Table 7: Comparison of Retscreen, PVGIS and SOLARGIS with measured and best predicted models (+ is over-estimation; - is under-estimation and ≅ is coincident value)

	Ngaounderé city		
Month	Retscreen	pvgis	Solargis
Jan	+	+	+
Feb	+	+	+
Ma	+	+	+
Apr	+	≅	+
May	+	≅	+
Jun	+	≅	≅
Jul	+	≅	≅
Aug	+	≅	+
Sep	+	≅	+
Oct	+	≅	≅
Nov	+	≅	≅
Dec	+	≅	≅

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6- Conclusion

The study aimed at comparison of empirical models developed and reported in the literature for the assessment of the monthly global Solar radiation data in tropical savannah (Aw) climate (according to Köppen-Geiger climate classification system) in Cameroon. This comparison is made possible using statistical evaluation of empirical models for predicting monthly mean global solar radiation. A total of thirty five (35) empirical models found in the literature are used in statistical analysis. New models have been developed to perform better solar radiation. In this regard, empirical correlations are developed to estimate the monthly average daily global radiation on a horizontal surface. The accuracy of the models were verified by comparing estimated values with measured values in terms of the following statistical error tests: mean bias error (MBE), root mean square error (RMSE), and the determination coefficient (R^2). The values of the determination coefficient for the formulated models are between the ranges of 0.714 to 0.996, when RMSE and MBE range respectively between 0.796% to 7.122% and 0.0% to -0.652%. For new developed model determination coefficient (R^2) range between 0.998 to1.0, when RMSE and MBE range respectively between 0.0145% to 0.138% and -1,22E-14% to 2,26E-03%. It is also observed that for the accurate estimation of the global solar radiation more meteorological data are needed. The results shows that the models of Togrul and Onat 1999 (M28), Ertekin and Yaldiz 1999 (M20) performed data better than the other models. However, for the new models developed the models NM06, NM03 and NM05 are the best models. Results also shows that the formulated models are good enough to be used to predict monthly average daily radiation for tropical savannah zones of Cameroon.

Abbreviations and Nomenclature

RH = relative humidity in percentage
P = precipitation in (mm)
T_{max} = mean maximum temperature (°C)
T_{min}= mean minimum temperature (°C)
T_k= monthly daily mean air temperature (K.)
ST = mean soil temperature (°C)
T = monthly mean temperature (°C)
V=visibility(Km)
$\Delta T = (T_{max} - T_{min})$ = the temperature difference (°C)
Z= Altitude (Km)
W= the precipitable water vapor from the atmosphere (cm).
C = cloudiness (cloud cover)
N = Angstrom sunshine duration(h)
H_0 = extraterrestrial solar radiation (kWh/m^2)
$H_{i,c}$ = calculated solar radiation (kWh/m^2)
$H_{i,m}$ = measured solar radiation (kWh/m^2)
$\bar{H}_m$ = mean annual solar radiation (kWh/m^2)
$RMSE$ = root mean square error (kWh/m^2)
MPE = mean percentage error (kWh/m^2)
MBE = mean bias error (kWh/m^2)
R^2 = determination coefficient
S_0 = day length (h)
S = sunshine duration (h)
G_{sc}=is the solar constant (W/m^2)
ϕ=latitude (deg)
δ = solar declination (°)
n= day of year $1 \le n \le 365$
ω_s is the hour angle (deg)

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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