Global Solar Radiation of Some Regions of Cameroon using the linear Angstrom and non-linear Polynomial Relations (Part I) Model Development

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Abstract-The aim of this paper is to evaluate the global solar radiation of some representative cities of Cameroon using the linear Angstrom and non-linear polynomial relations. The choice of these cities which include: Bamenda in the North West region, Douala in the littoral region, Yaounde in the centre region, Ngaoundere in the Adamawa region, and Bertoua in the eastern region; is determined mostly by the availability of data. The Angstrom correlation coefficients for the linear, quadratic and cubic polynomial models are calculated using the least square method for the different regions. The input data for the analyses are the measured global solar radiation and mean number of monthly sun shine hours. The data for the analyses is obtained partly from the archives of National Aeronautics and Space Administration (NASA) and partly from the archives of the Cameroon Department of Meteorology, Douala. The data used covers a period of 23 years from 1983 to 2005. We demonstrate the validity of the developed models by comparing the evaluated values of global solar radiation with the measured ones. Hence the regression equations can be used to confidently predict the global solar radiation of the representative regions in the absence of experimental data.

Keywords-Global Solar Radiation, Angstrom, least square method, regression analysis, sun shine hours

1. Introduction

This paper contributes to the global trend in diversifying the energy sources from the traditional fossil fuels which are still dominant over the environmentally friendly renewable alternative sources. The renewable energy supply map of Cameroon is overshadowed by biomass estimated at 81.2% while hydro energy supplies 3.4%. The remaining 15.4% is supplied by oil which of course is not renewable. Biomass mostly in the form of wood is the main source of energy in the rural areas for cooking, heating and lighting. Electricity is generated mainly from hydropower and to a lesser extent from oil and supplies only 48% of the population mostly in the urban areas [1].

A recent publication of the Government of Cameroon "The Growth and employment strategy paper [2] which presents the "Cameroon vision 2035" a strategic development plan aimed at transforming Cameroon into an emerging nation by 2035 highlights some challenges which must be overcome. They include principally: the need for economic growth, jobs creation and a sustainable environment. The fulfilment of this vision entails an improvement on the level of energy sustainability and stability. Therefore efforts must be made to augment the present energy infrastructure and supply which is presently inadequate and very erratic.

The solar energy share in the Cameroon renewable energy exploitation is minimal. Solar energy remains however abundantly distributed all round the year especially in the dry season which runs from November to march every year. Even in the rainy season the solar resource is always richly available.

The aim of this paper is to use the available experimental data on global solar irradiation and sunshine duration hours to derive the linear and non-linear polynomial relations that can be used to predict the global solar irradiation even in the absence of experimental data. Many such analyses have been carried out in different parts of the world successfully.

The estimation of daily global solar radiation has been reviewed in most of the researches that have used the duration of sunshine as the input parameter. In these works, mathematical or regression analyses are done with the aim to identify the best model and to determine different correlation coefficients for some given locations. The models mostly used are the Angstrom models either in the linear [3-6], or in the modified quadratic[7-9] and polynomial[10-11] forms because they have proven to be reliable and feasible for solar energy potential evaluation in different parts of the world; with different climatic conditions [3, 7, 8, 10-20]. The models have been shown to be dependent on the locality [7,12,13] as a result there is a need to calculate the regression coefficients for different parts of the world. This has led to a lot of literature on the subject given the abundance of solar radiation over the surface of the globe. In some cases, the linear Angstrom model was proven satisfactory while in others it was the quadratic model, while still in others it was the higher order polynomial model. However mathematical intuition will confer higher precision and reliability to the higher order polynomial models given that they are better approximations of the lower order models. Che et al. [10] in addition to the polynomial models successfully used trigonometric functions in conjunction with sine and cosine wave for estimating daily global solar radiation.

In the different approaches, some models used the mean daily global solar radiation and mean daily duration of sun shine hours data [3]. Others make use in addition of : mean clearness index, mean daily maximum temperature, mean relative humidity, mean daily sea level pressure, and the mean daily vapour pressure [3, 5,14,21, 22].

Other successful approaches to evaluate the global solar radiation have used artificial intelligence[23] or the application of atmospheric optics to meteosat imagery[24].

To ascertain the accuracy of the models, statistical evaluation of the models has been done in most cases using: mean bias error (MBE), root mean square error (RMSE) and t-statistics [4, 8, 15, 17-19, 25- 30]. In [4] it was shown that these statistical tools blend together to guarantee the reliability of the models.

From the foregoing literature we see that most of the models for the estimation of global solar radiation express the average global solar radiation as a function of average daily sunshine duration [3,4].

The main objective of this study is to establish (estimate) monthly-average daily global solar radiation for Bamenda, Bertoua, Douala, Ngaoundere and Yaounde, the five major cities in Cameroon (Fig. 2) using three polynomial models: the linear, quadratic and cubic Angstrom's models.

The comparison of the three models with measured values by using statistical methods: MRE, MBE, RMSE and t-statistics will constitute a future work in order to render the present paper concise.

2. Solar Radiation Data and Model Development

In the course of its journey from the sun to the earth through the atmosphere, solar radiation undergoes a number of perturbations. Air particles, aerosols, water vapour and clouds absorb or scatter some of it. Three components of the solar radiation can be distinguished; the reflected, the direct and the diffuse solar radiation. When these three components are incident onto a horizontal surface, they constitute the global solar radiation. Hourly data on the intensity of the global solar radiation is necessary for energy application.

A model that has proven its effectiveness through numerous investigations makes use of monthly average global solar radiation expressed as a function of average daily sunshine duration as follows [3,4]:

$$\frac{H}{H_0} = f\left(\frac{S}{S_0}\right) \quad (1)$$

H is the monthly average daily global solar radiation (MJ/m^2), H_0 is the monthly average daily extraterrestrial radiation (MJ/m^2), S is the monthly average daily measured sunshine duration in hours (h) and S_0 is the monthly average daily maximum sunshine duration in hours (h). The first mathematical expression of this type developed by Angstrom [4] was a linear regression equation and was later modified by Page [3]. The model was developed between the global solar radiation and the sunshine duration. It is the most convenient and widely used, given by:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \quad (2)$$

In the quest of greater accuracy especially at extreme points, the nonlinear polynomial relation models, were derived from the Angstrom linear equation. This form is given as follows [21,29, 34-36,38-41]:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3 + \cdots \quad (3)$$

where *a*, *b*, *c* and *d* are correlation coefficients called Angstrom constants and they are empirical. *H* and *S* are the experimentally measured values of monthly average daily global solar radiation (MJ/m^2) and the monthly average daily measured sunshine duration (h), respectively. The empirically obtained values of a, b, c and d vary depending on location and month of observation. Their values may be affected by air pollution stemming from urban activity and factory operation. As the daily total amount of global solar radiation and sunshine duration vary widely from day to day, daily totals averaged over a month are used to derive the values of a, b, c and d.

Although it is not possible to estimate the daily total amount of global solar radiation on a particular day from sunshine duration using this method, it does enable an estimation of a monthly value. In this study, the experimental data of monthly average global solar radiation for the towns of Douala, Yaounde, Bertoua, Bamenda and Ngaoundere were obtained from the archives of NASA [39] while those of sunshine duration in Cameroon were taken from the archives of the Department of Meteorology (Directorate of National Meteorology) located in Douala recorded by the various meteorological stations in the respective cities over a 23-year period (Jul 1983-Jun 2005). For each of these cities, mean values of the sum of the monthly average daily global solar radiation and sunshine duration were calculated. The geographical parameters and measurement periods for the cities are given in Table 1 while the cities considered are shown in Figure 1**.** The monthly measured values of the monthly average daily global solar radiation and sunshine duration are also illustrated in Tables 2 and 3 respectively.

H_0 and S_0 are the theoretical values calculated from mathematical equations. The monthly average daily extraterrestrial radiation values on a horizontal surface for the five cities were calculated from the following equations [28,38]:

$$H_0 = \frac{24x3600}{\pi} G_0 \left(cos\varphi \cdot cos\delta \cdot sin\omega_s + \frac{\pi}{180}\omega_s \cdot sin\varphi \cdot sin\delta\right) \quad (4)$$

where G_0 is the extraterrestrial radiation (solar radiation incident outside the earth's atmosphere) and is obtained from:

$$G_0 = I_{sc} \cdot \left(1 + 0.034cos\left(\frac{360 \cdot n_{day}}{365.25}\right)\right) \quad (5)$$

where I_{sc} is the solar constant and has a value of 1.367 kWm^{-2} [34,35], φ is the latitude of the site, δ is the solar declination angle (that is, the angle between a plane perpendicular to a line between the earth and the sun and the earth's axis), ω_s is the sunshine hour angle for the month and n_{day} is the number of days of the year starting from January 1st. For January 1st, $n_{day} = 1$ and for December 31st, $n_{day} = 365$.

The solar declination (δ), the mean sunshine hour angle for the month (ω_s) and the maximum possible sunshine duration (S_0) may be computed from the Cooper formula [26,40,41]:

$$\delta = 23.45sin\left(\frac{360(n_{day}+284)}{365}\right) \quad (6)$$

$$\omega_s = cos^{-1}(-tan\delta \cdot tan\varphi) \quad (7)$$

$$S_0 = \frac{2}{15}\omega_s \quad (8)$$

Table 1. Geographical parameters and measurement periods for the five cities considered in Cameroon.

City	Latitude (^{0}N)	Longitude (^{0}E)	Altitude(m)
Bamenda	5.96	10.15	1400
Bertoua	4.58	13.68	720
Douala	4.06	9.71	2
Ngaoundere	7.32	13.58	1200
Yaounde	3.87	11.52	720

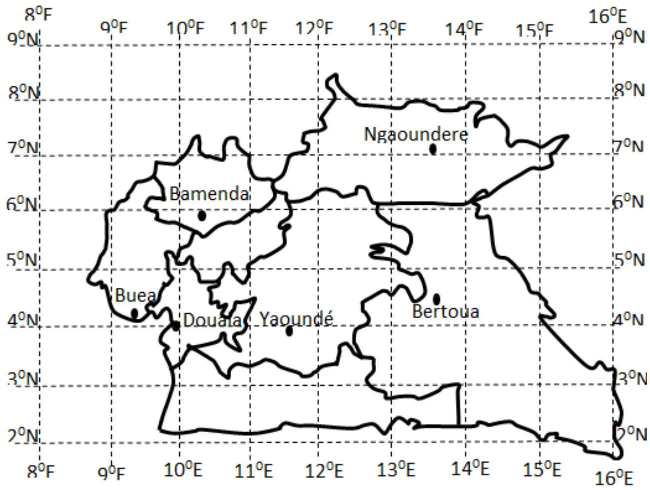

Fig.1. Region of study

Table 2. Measured values of the monthly average daily global solar radiation on a horizontal surface for five cities of Cameroon in MJ/m^2-day

Month	City					Monthly average daily values
	Bamenda	Bertoua	Douala	Ngaoundere	Yaounde	
January	23.004	22.860	20.484	23.076	21.276	22.140
February	23.616	23.616	20.808	24.444	22.068	22.896
March	21.348	21.060	18.864	23.400	20.124	20.952
April	19.008	19.584	17.712	20.304	18.612	19.044
May	18.000	18.144	17.100	19.080	17.244	17.928
June	16.452	16.632	15.840	17.640	16.416	16.596
July	15.192	15.444	14.148	16.020	15.948	15.336
August	15.012	15.912	13.500	16.092	16.344	15.372
September	15.768	16.884	14.652	17.244	17.064	16.308
October	16.668	17.064	14.868	18.504	16.488	16.704
November	20.160	19.836	16.884	21.960	18.000	19.368
December	22.032	21.636	19.224	22.464	19.872	21.060

Source: Archives of National Aeronautics and Space Administration (NASA)

Table 3. Measured values of the monthly average daily sunshine duration for five cities of Cameroon in hours per month.

Month	City					Monthly average daily values
	Bamenda	Bertoua	Douala	Ngaoundere	Yaounde	
January	276.5	161.1	260.9	285.5	179.1	232.6
February	265.0	177.4	241.5	258.2	180.6	224.5
March	264.5	174.4	215.5	225.3	165.0	208.9
April	231.2	184.1	197.5	169.3	168.7	190.2
May	246.4	205.7	209.5	180.6	172.0	202.8
June	201.0	145.5	177.8	148.2	126.5	159.8
July	182.4	104.3	118.8	118.2	103.7	125.5
August	163.9	83.0	117.8	102.7	81.8	109.8
September	184.6	113.8	129.5	124.5	101.7	130.8
October	258.7	141.0	183.7	166.6	129.6	175.9
November	278.4	184.4	138.3	260.0	177.0	207.6
December	292.1	176.6	270.9	296.9	188.8	245.1

Table 4. Measured values of the monthly average daily sunshine duration for five cities of Cameroon in hours per day.

Months	Cities					Monthlyaverage daily values
	Bamenda	Bertoua	Douala	Ngaoundere	Yaounde	
January	8.9194	5.1968	8.4161	9.2097	5.7774	7.5032
February	9.4643	6.3357	8.6250	9.2214	6.4500	8.0179
March	8.5323	5.6258	6.9516	7.2677	5.3226	6.7387
April	7.7067	6.1367	6.5833	5.6433	5.6233	6.3400
May	7.9484	6.6355	6.7581	5.8258	5.5484	6.5419
June	6.7000	4.8500	5.9267	4.9400	4.2167	5.3267
July	5.8839	3.3645	3.8323	3.8129	3.3452	4.0484
August	5.2871	2.6774	3.8000	3.3129	2.6387	3.5419
September	6.1533	3.7933	4.3167	4.1500	3.3900	4.3600
October	8.3452	4.5484	5.9258	5.3742	4.1806	5.6742
November	9.2800	6.1467	4.6100	8.6667	5.9000	6.9200
December	9.4226	5.6968	8.7387	9.5774	6.0903	7.9065

Source: Archives of the Department of Meteorology, Douala

3. Determination of the Regression Parameters: a, b and c

The monthly mean daily global solar radiation on horizontal surfaces were obtained from the archives of National Aeronautics and Space Administration (NASA) for the 23-year period while the sunshine duration were obtained from the archives of the Department of Meteorology (Direction de la Meteorologie Nationale) located in Douala, for the five cities: Bamenda, Bertoua, Douala, Ngaoundere and Yaounde, located respectively in the North West, East, Littoral, Adamawa and Centre regions of Cameroon as shown in Fig. 2. Stochastic (statistical) analysis was employed on these data to deduce a set of linear and non linear models using the 23-year period monthly average daily data set.

3.1. Models for Estimating Global Solar Radiation

In this paper, three models are used to estimate monthly average global solar radiation. The models are grouped and examined according to the type of equation as outlind below.

3.1.1. Linear angstrom-prescott equation (Model 1)

This equation takes the form:

$$y = a + bx \quad \text{or} \quad \frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \qquad (9)$$

where $y = \frac{H}{H_0}$ and $x = \frac{S}{S_0}$

The regression constants 'a' and 'b' are obtained from the linear fit equation by the least square method in statistics (line of best fit) as follows:

$$\sum y = na + b\sum x \qquad (10)$$

$$\sum xy = a\sum x + b\sum x^2 \qquad (11)$$

where n is the number of data points

Applying these equations to the city of Bamenda say, we obtain

$$6.3403 = 12a + 7.826b \qquad (12)$$

$$4.2653 = 7.826a + 5.2946b \qquad (13)$$

Solving the equations (12) and (13), gives the values of the regression coefficients as:

a = 0.0826 and b = 0.6835

Hence the linear equation for Bamenda is re-written as follows:

$$\frac{H}{H_0} = 0.0826 + 0.6835\frac{S}{S_0} \quad (14)$$

Similar computations were done for the other cities using this linear fit model, thus obtaining the following regression coefficients presented in Table 5.

Table 5. Regression coefficients using Model 1

City	a	b
Bamenda	0.0826	0.6835
Bertoua	0.2861	0.5791
Douala	0.2530	0.4266
Ngaoundere	0.3025	0.4844
Yaounde	0.3142	0.4785

3.1.2. Polynomial or second order quadratic equation (Model 2)

This model takes the form:

$$y = a + bx + cx^2 \text{ or } \frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 \quad (15)$$

where $y = \frac{H}{H_0}$ and $x = \frac{S}{S_0}$

The regression constants 'a', 'b' and 'c' are obtained from the cubic fit equation by the least square method of statistics.

$$\sum y = na + b\sum x + c\sum x^2 \quad (16)$$

$$\sum xy = a\sum x + b\sum x^2 + c\sum x^3 \quad (17)$$

$$\sum x^2y = a\sum x^2 + b\sum x^3 + c\sum x^4 \quad (18)$$

Using the city of Bamenda for example, these equations are written as:

$$6.3403 = 12a + 7.826b + 5.2946c \quad (19)$$

$$4.2653 = 7.826a + 5.2946b + 3.6939c \quad (20)$$

$$2.9645 = 5.2946a + 3.6939b + 2.6424c \quad (21)$$

Solving the equations (19), (20) and (21) simultaneously, we get

a = 0.5396, b = -0.8253 and c = 1.1944

Hence the quadratic equation for Bamenda is re-written as follows:

$$\frac{H}{H_0} = 0.5396 - 0.8253\frac{S}{S_0} + 1.1944\left(\frac{S}{S_0}\right)^2 \quad (22)$$

Similar computations were carried out for the other cities using this quadratic fit model (Model 2) and the regression coefficients were obtained as presented inTable 6.

Table 6. Regression coefficients using Model 2

City	a	b	c
Bamenda	0.5396	-0.8253	1.1944
Bertoua	0.1665	1.2340	-0.8444
Douala	0.2990	0.2375	0.1793
Ngaoundere	0.2120	0.8502	- 0.3254
Yaounde	0.5619	1.2454	-0.9684

3.1.3. Polynomial equation of third order or Cubic equation (Model 3).

This model takes the form:

$$y = a + bx + cx^2 + dx^3 \text{ or } \frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3 \quad (23)$$

where $y = \frac{H}{H_0}$ and $x = \frac{S}{S_0}$ and a, b, c and d are the regression coefficients.

The regression constants 'a', 'b', 'c' and 'd' are obtained from the cubic fit equation by the least square method of statistics.

$$\sum y = na + b\sum x + c\sum x^2 + d\sum x^3 \quad (24)$$

$$\sum xy = a\sum x + b\sum x^2 + c\sum x^3 + d\sum x^4 \quad (25)$$

$$\sum x^2y = a\sum x^2 + b\sum x^3 + c\sum x^4 + d\sum x^5 \quad (26)$$

$$\sum x^3y = a\sum x^3 + b\sum x^4 + c\sum x^5 + d\sum x^6 \quad (27)$$

Using the city of Bamenda forexample, we obtain

$$6.3403 = 12a + 7.826b + 5.2946c + 3.6939d \quad (28)$$

$$4.2653 = 7.826a + 5.2946b + 3.6939c + 2.6424d \quad (29)$$

$$2.9645 = 5.2946a + 3.6939b + 2.6424c + 1.9280d \quad (30)$$

$$2.1156 = 3.6939a + 2.6424b + 1.9280c + 1.4289d \quad (31)$$

Solving the equations (28) to (31) simultaneously, we obtain

a = 0.4240, b = - 0.1695, c = 0.0024, and d = 0.6947

Hence, the cubic equation for Bamenda is re-written as follows:

$$\frac{H}{H_0} = 0.4240 - 0.1695\frac{S}{S_0} + 0.0024\left(\frac{S}{S_0}\right)^2 + 0.6947\left(\frac{S}{S_0}\right)^3 \quad (32)$$

Similar computations were done for the other cities using this cubic model and the regression coefficients were obtained as presented in Table 7:

Table 7. Regression coefficients using Model 3

Cities	a	b	c	d
Bamenda	0.4240	- 0.1695	0.0024	0.6947
Bertoua	1.0758	- 6.6503	20.7825	- 18.883
Douala	- 0.6034	5.9653	- 11.3126	7.3260
Ngaoundere	0.2770	0.4270	0.5306	- 0.5374
Yaounde	0.5172	- 0.5617	0.9345	0.7000

3.2. Estimation of the Monthly Average Daily Global Radiation on a Horizontal surface

To estimate the monthly average daily global radiation on a horizontal surface at each of the cities, for example at Bamenda during the month of June 2005, we use the following parameters.

Average sunshine hour per day = 6.7

Solar constant, I_{sc} = 1367Wm^{-2}

Latitude of site, φ = 5.96^{0}N

Longitude of site = 10.15^{0}E

Constants a and b (linear regression) = 0.19 and 0.52

The other parameters are calculated as follows:

Declination, δ from eqn (6) = 23.18^0

Sunshine hour angle, ω_s from eqn (7) = 92.56^0

Day length (mean sunshine hour), from eqn (8) = 12.34 hours

H_0 is the monthly average daily extraterrestrial radiation from eqn (4) = 35.6068 MJ/**m^2/day**

So using the correlation coefficients 'a' and 'b' calculated from the linear model by least square method, one gets the estimated global solar radiation for Bamenda for the month of June 2005 as H = 16.7756MJ/m^2/day, opposed to the measured value of 16.452MJ/m^2/day**.**

Considering the example solved above, the same approach can be used for each month and for each city to estimate the monthly average daily global radiation on a horizontal surface.

From the tables 6, 7 and 8, values for the regression coefficients for each city calculated from the respective models 1, 2 and 3 are presented. In addition, these regression coefficients can be used in writing the various equations for each city using the respective models as in the case of Bamenda. The nonlinear polynomial relation models (models 2 and 3) derived from the Angstrom linear equation is suggested for increasing the accuracy of models at extreme points.

4. Results

Table 8 shows the values of measured monthly average global radiation (MJ/m^2/day) compared with those estimated from Models 1, 2 and 3 for the city of Bamenda.

Table 8. Measured Monthly Average global radiation H, compared with those calculated using Models 1, 2 and 3 for the city of Bamenda

Months	H measured	H0	S	S0	$\frac{H}{H_0}$	$\frac{S}{S_0}$	H from LinearModel	H from quadraticModel	H from cubicModel
Jan	23.004	34.713	8.9194	11.7442	0.6627	0.7595	20.8871	20.8887	20.8624
Feb	23.616	36.672	9.4643	11.8784	0.6440	0.7968	23.0011	23.4815	23.5397
Mar	21.348	37.7321	8.5323	12.0504	0.5658	0.7081	21.3785	20.9068	20.8217
April	19.008	37.1526	7.7067	12.2076	0.5116	0.6313	19.0999	18.3758	18.3064
May	18.000	35.9650	7.9484	12.3207	0.5005	0.6451	18.8286	18.1355	18.0600
June	16.452	35.6068	6.7000	12.3417	0.4620	0.5429	16.1538	16.7946	16.8040
July	15.192	36.3803	5.8839	12.2618	0.4176	0.4799	14.9382	15.2794	15.2293
Aug	15.012	37.2557	5.2871	12.1136	0.4029	0.4365	14.1925	15.1604	15.2095
Sept	15.768	36.8856	6.1533	11.9468	0.4275	0.5151	16.0331	15.9123	15.9446
Oct	16.668	35.0956	8.3452	11.7854	0.4749	0.7081	16.8847	16.4459	16.3668
Nov	20.160	33.3343	9.2800	11.6782	0.6048	0.7946	20.8576	21.2655	21.3127
Dec	22.032	33.0827	9.4226	11.6599	0.6660	0.8081	21.0054	21.5914	21.6756

The linear relationship between the monthly average values of H/H_0 versus S/S_0 for Bamenda is shown in figure 8. The calculated H_0 values for Bamenda were between 33.0827 and 37.7321MJ/m^{2}day, as shown in Figure 9.

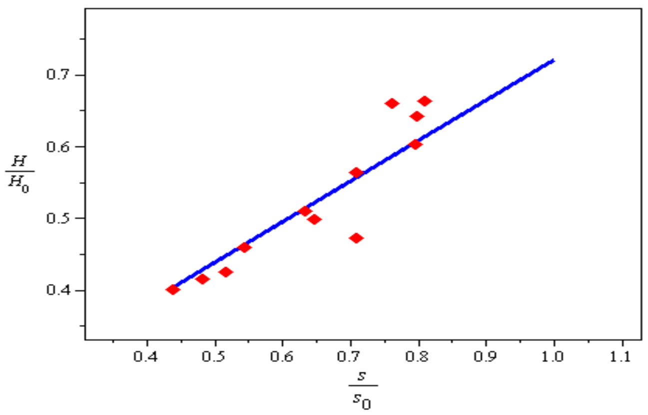

Fig. 8. Linear relationships between the monthly average values (H/H_0 versus S/S_0)

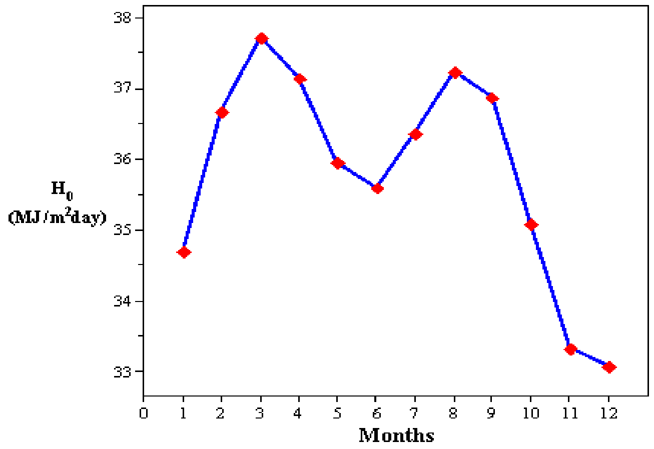

Fig. 9. The monthly average daily extraterrestrial radiation H_0 (MJ/m^2day)

The comparisons of the values of the monthly average global solar radiation measured and calculated from the Models (linear, quadratic, and cubic) for Bamenda are shown in Figures 10 to 12.

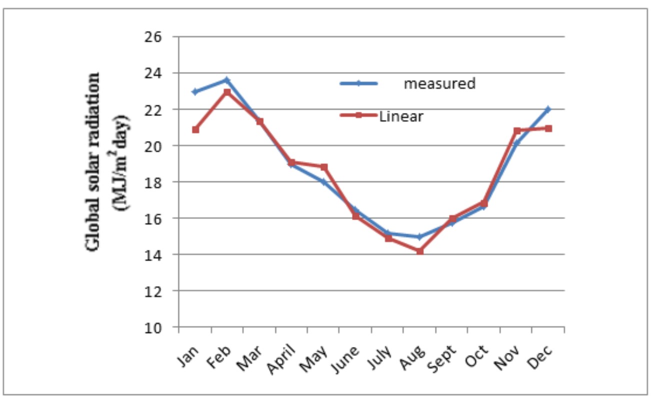

Fig. 10. Comparison of the estimated and observed monthly average daily horizontal global solar radiation data for Bamenda using model 1

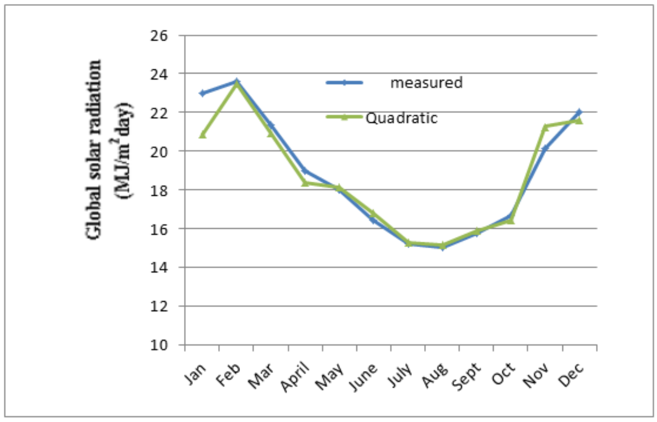

Fig. 11. Comparison of the estimated and observed monthly average daily horizontal global solar radiation data for Bamenda using model 2

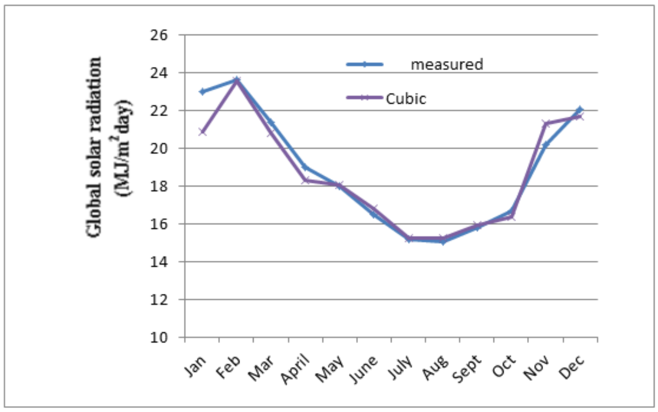

Fig. 12. Comparison of the estimated and observed monthly average daily horizontal global solar radiation data for Bamenda using model 3

As observed from figures 10 to 12, the city of Bamenda experienced a decrease in the horizontal global solar radiation from March through August (during the rainy season), with the lowest value of the monthly average mean horizontal global radiation of 15.012MJ/m^{2}day recorded in August (8th month). During the commencement of the dry season (September to October) the city of Bamenda experienced a gradual increase in solar radiation, an increase which became rapid from November. We also observe from the three graphs (figs 10 to 12) that the predicted and measured values are very close showing the strength of the Angstrom relations derived.

5. Conclusion

The aim of this paper was to evaluate the global solar radiation of some representative cities of Cameroon using the linear and non-linear Angstrom polynomial relations. The correlation parameters for the linear Angstrom, and the later modified quadratic and cubic models were calculated using the least square method. The 23 years data for the analysis came from two sources: Measured values of the monthly average daily global solar radiation on a horizontal surface for five cities of Cameroon in MJ/m^2/day was obtained from the archives of National Aeronautics and Space

Administration (NASA) while the measured values of the monthly average daily sunshine duration for five cities of Cameroon in hours per day was obtained from the archives of the Department of Meteorology, Douala. Based on the correlation coefficients, the global solar radiation of Bamenda were calculated and compared with the measured values. It was observed that the predicted values obtained through linear regression were very close to the measured ones. The second part of this paper will present the predicted values for the other five cities followed by a statistical validation

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References

[1] Emmanuel, N, Elie, T: Energy Systems:Vulnerability – Adaptation – Resilience (VAR), Helio International, Regional Focus: sub-Saharan Africa-Cameroon, 2009.

[2] Growth and employment strategy paper 2010/2020, August 2012. In: Cameroon: Poverty Reduction Strategy Paper. IMF Country Report No. 10/257.www.imf.org/external/pubs/ft/scr/2010/cr10257.pdfPolicy DB Details: Cameroon (2012), Renewable Energy & Energy Efficiency Partnership (REEEP), http://www.reeep.org/index.php?id=9353&text=&special=viewitem&cid=67

[3] J. K. Page, The estimation of monthly mean values of daily short-wave radiation on vertical and inclined surfaces from sunshine records for latitude 40^0N – 40^0S, in Proceedings of the UN Conference on New Sources of Energy 4:378-390, 1964.

[4] A. S. Angstrom, Solar and terrestrial radiation. Quart Journal of the Royal Meteorological Society 50:121-126, 1924.

[5] E. O. Falayi and A. B. Rabiu, Modeling global solar radiation using sunshine duration data. Nigeria Journal of Physics 17:181-186, 2005.

[6] B. Safari and J. Gasore, Estimation of global solar radiation on horizontal surface in Rwanda using empirical models. Asian Journal of Science Research 2: 68-75, 2009.

[7] V. Badescu, Correlations to estimate monthly mean daily global solar irradiation: application to Romania. Energy 24(10):883-893, 1999.B. Aksoy, Estimated monthly average global radiation for Turkey and its comparison with observations. Renewable Energy 10:625-633, 1997.

[8] M. Sekar, M. Sakthivel, S. S. Kumar & C. Ramesh, Estimation of global solar radiation for Chennai. European Journal of Scientific research 73(3):415-424, 2012.

[9] H. Z. Che, G. Y. Shi, X. Y. Zhang, J. Q. Zhao, Y. Li, Analysis of sky condition using 40 years records of solar radiation data in China. Theoretical and Applied Climatology 89:83-94, 2007.

[10] K. Ulgen and A. Hepbasli, solar radiation models. Part 2: Comparing and developing new models. Energy Sources 26:521-530, 2004.

[11] R. J. Stone, Improved statistical procedure for the evaluation of solar radiation estimation models. Solar Energy 51(4) :289-291, 1993.

[12] L. E. Akpabio, S. O. Udo, S. E. Etuk, Empirical correlation of global solar radiation with meteorological data for Onne, Nigeria. Turkish Journal of Physics 28(3):222-227, 2004.

[13] A. A. El-Sebaii, F. S. Al-Ghamdi, Al-Hazmi and Adel S. Faidah, Estimation of global solar radiation on horizontal surfaces in Jeddah, Saudi Arabia. Energy Policy 37:3654-3669, 2009.

[14] K. Bakirci, Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey. Energy 34:485-501, 2009.

[15] R. T. Ogulata and S. N. Ogulata (2002). Solar radiation in Adana, Turkey. Applied Energy 71:351-358.

[16] H. Aras, O. Balli and A. Hepbasli, Global Solar Potential. Part 1: Model Development. Energy Sources, Part B, 1(3):303-315, 2002.

[17] K. Ulgen and A. Hepbasli, estimation of solar radiation parameters for Izmir, Turkey. International Journal of Energy Resources 24:773-785, 2002.

[18] B. G. Akinoglu and A. Ecevit, Construction of a quadratic model using modified Angstrom coefficients to estimate global solar radiation. Solar Energy 45(2):85-92, 1990.

[19] E. C. Okogbue and J. A. Adedokun The estimation of solar radiation at Ondo, Nigeria. Journal of Physics 14:97-99, 2002.

[20] A. A. Trabea and M. A. M. Shaltout, Correlation of global solar radiation with meteorological parameters over Egypt. Renewable Energy 21(2):297-308, 2000.

[21] M. S. Okundamiya and A.N. Nzeako, Estimation model for estimating solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria. Journal of Control Science and Engineering. Hindawi Publishing Corporation, 2011.

[22] A. Sfetsos and A. H. Coonick, Univariate and multivariate forecasting of hourly solar radiation with artificial intelligence techniques. Solar Energy 68:169-178, 2000.

[23] D. Njomo and L. Wald, Solar irradiation retrieval in Cameroon from meteosat satellite imagery using Helio_2

method. ISESCO Science and Technology Vision 2(1):19-24, 2006.

[24] M. Gunes, Analysis of daily total horizontal solar radiation measurements in Turkey. Energy Sources 23:563-570, 2001.

[25] A. Kilic and A. Ozturk, Solar Energy. Istanbul, Turkey: Kipas Distribution, 1983.

[26] H. Ogelman, A. Ecevit, and E. Tasdemiroglu, A new method for estimating solar radiation from bright sunshine data. Solar Energy 33:619-625, 1984.

[27] I. T. Togrul and H. Togrul, Global solar radiation over Turkey: Comparison of predicted and measured data. Renewable Energy 25:55-67, 2002.

[28] M. Kaya, Estimation of global solar radiation on horizontal surface in Erzincan, Turkey. International Journal of Physical Sciences 7(33):5273-5280, 2012.

[29] M. Sekar, M. Sakthivel, S. S. Kumar & C. Ramesh, Estimation of global solar radiation for Chennai. European Journal of Scientific research 73(3):415-424, 2012.

[30] T. D. M. A. Samuel, Estimation for global solar radiation for Sri Lanka. Solar Energy 47:333-337, 1991.

[31] S. Tarhan and A. Sari, Model selection for global and diffuse radiation over the Central Black Sea (CBS) region of Turkey. Energy Conversion and Management 46(4):605-613, 2005.

[32] E. Tasdemiroglu and R. Sever, Monthly and yearly average maps of total and direct solar radiation in Turkey. Solar Energy 37:205-213, 1986.

[33] E. Tasdemiroglu and R. Sever, Maps for average bright sunshine hours in Turkey. Energy Conversion and Management 31:545-552, 1991.

[34] E. Tasdemiroglu and R. Sever, Estimation of monthly average daily diffuse radiation in Turkey. Energy 16:787-790, 1991.

[35] M. Tiris, C. Tiris and I. E. Ture, Diffuse solar radiations: Applications to Turkey and Australia. Energy 20:745-749, 1995.

[36] M. Tiris, C. Tiris and I. E. Ture, Correlations of monthly average daily global, diffuse and beam radiations with hours of bright sunshine in Gebze, Turkey. Energy Conversion and Management 37:1417-1421, 1996.

[37] K. Ulgen and A. Hepbasli, Comparison of solar radiation correlation for Izmir, Turkey. International Journal of Energy Resources 26:413-430, 2002.

[38] NASA (2010). Surface Meteorology and Solar Energy Data and Information, 2010.http://eosweb.larc.nasa.gov/sse/.

[39] P. I. Cooper (1969). The absorption of radiation in solar stills. Solar Energy 2(3):333-346, 1969.

[40] J. A. Duffie, W. A. Beckman, Solar Engineering of Thermal Processes. John Wiley and Sons Inc. New York, 1991.