# ESTIMATION OF SOLAR RADIATION FOR NIGERIA AND CAMEROON

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## ABSTRACT

Data are presented for global solar radiation on a horizontal plane, H and of duration of sunshine, n, on a monthly basis and their regression coefficients, for various stations in Nigeria and the Republic of Cameroon. It is concluded that the individual station regression equations would be reasonably accurate for most applications particularly when the raw data are not available. Overall regression equations, while giving general average values do not accurately predict the insolation in a particular area.

## INTRODUCTION

In order to appraise the economics of a proposed solar-energy application in a particular area and to design a conversion device which will meet a potential demand, it is necessary to know the amount of solar radiation obtainable at the pertinent location. There are other uses of such information such as a meteorological forecasting, determination of agricultural potential and estimates of evaporation rates from bodies of water. Thus solar energy, like any other national resource, demands detailed information on its availability.

Previous surveys of the availability of solar energy in various areas of the world have been based on data available in the more developed countries. While these items of information have been of some use, they do not provide a complete picture particularly for developing countries. Since the availability of the solar resource is essentially site-specific so too must monitoring of the resource. Unfortunately, the less-developed countries have very few monitoring stations which is attributable to the high costs of monitoring devices. In recent times, however, many new stations have been started throughout the world, thus increasing the amount of data available. In addition to these are the more extensive meteorological stations which routinely measure other useful parameters such as air temperature, relative humidity, sunshine hours, rainfall etc. which can be used, selectively in estimating solar radiation intensities.

The present paper describes part of a project which aims to provide an extensive study of solar energy economics for Nigeria and Cameroon and in particular to provide solar-radiation maps for the two countries. Specifically, this paper provides a means of estimating solar radiation on horizontal surfaces for several areas of Nigeria and Cameroon. While there are several types of solar radiation data, each with its own particular utility, the form of data most readily available and most frequently reported is global radiation on a horizontal surface. It is also the most useful form in that methods are available for estimating other types of data from them.

The present project is motivated by the near total absence of accurate solar radiation data bases for Nigeria and Cameroon and also the need to develop solar energy conversion devices particularly for rural application. Within Nigeria, there are five stations with a reasonably reliable record of insolation - Lagos, Ibadan, Benin, Nsukka and Kano. In Cameroon, there are ten - Yaounde, Yoko, Ambam, Batouri, Douala, Mafe, Koundja, Ngaoundere, Garoua and Maroua-Salak. The Nigerian stations have data for up to five years, the Cameroonian stations for less then one year with the exception of Yaounde and Garoua which have data for nearly two years. Instruments used are predominantly Kipp and Zonen and Eppley pyranometers for global radiation and the Campbell-Stokes Sunshine Recorder for sunshine hours. Details of all stations are shown in Table 1.

## PROCEDURE

Various empirical relations have been developed for estimating solar radiation using common meteorological variables such as air temperature, relative humidity, duration of bright sunshine, altitude and latitude. The degrees of successes have been equally varied.

To obtain a survey of solar economics in Nigeria and Cameroon and to prepare solar radiation maps based on good estimates, the following forms of the empirical relations were examined:

$$H' = a \exp (b(S-R)) \qquad (1)$$
$$H' = AS^a R^b \qquad (2)$$
$$H' = a + bS \qquad (3)$$
$$H' = a + bR \qquad (4)$$
$$H' = a + bT \qquad (5)$$
$$H' = a\ bS + cR \qquad (6)$$
$$H' = a + Bs + cR + dT \qquad (7)$$

where H' is the ratio of the observed insolation H to its extraterrestrial value $H_o$, R is the relative humidity, T is the ratio of the observed air temperature to its local maximum value and A, a, b, c, d are constants of the regression equations. The various meteorological parameters being readily available, the task was to determine the regression constants and hence deduce the best and the simplest of the equations. All these relations have been used by previous authors with the exception of equation 7 which is relatively new.

Data were sought from the appropriate institutions and from the literature. Those from the Cameroon, albeit few, were used to examine the problems.

### The regression equation

As noted above, solar radiation and other data obtained from the Republic of Cameroon were used to test equations 1-7 above and hence to determine the regression equations for that country. Results obtained are shown in Table 2. Values for $H_o$ here are the local maximum global radiation as measured. The correlation coefficient for equation 7 is in the form of a 3 x 3 matrix.

To determine the appropriateness of the equations, results were obtained of values of H/Ho as predicted by the equations and compared with actual values for each of the 10 stations in the Cameroon (Table 3).

**TABLE 1: Details of stations**

| Stations | | Latitude | Longitude | Altitude (metres) | Duration (months) |
|---|---|---|---|---|---|
| NIGERIA | | | | | |
| Lagos | 1973 - 76 | 6° 27'N | 3° 24'E | 3 | 48 |
| Ibadan | 1973 - 78 | 7° 26'N | 3° 54'E | 228 | 72 |
| Benin | 1958 - 62 | 6° 33'N | 5° 37'E | 78 | 60 |
| Nsukka | 1975 - 78 | 6° 52'N | 7° 24'E | 488 | 45 |
| Kano | 1953 - 57 | 12° 3'N | 8° 32'E | 472 | 81 |
| CAMEROON | | | | | |
| Yaounde | 1982 - 83 | 3° 52'N | 11° 32'E | 753 | 24 |
| Yoko | 1982 - 83 | 5° 33'N | 12° 22'E | 1028 | 24 |
| Ambam | 1982 - 83 | 2° 23'N | 11° 17'E | 602 | 24 |
| Batouri | 1982 - 83 | 4° 25'N | 14° 14'E | 650 | 24 |
| Douala | 1982 - 83 | 4° 1'N | 9° 44'E | 5 | 24 |
| Mamfe | 1982 - 83 | 5° 43'N | 9° 17'E | 126 | 24 |
| Koundja | 1982 - 83 | 5° 37'N | 10° 45'E | 1208 | 24 |
| Ngaoundere | 1982 - 83 | 7° 17'N | 13° 19'E | 1115 | 24 |
| Garoua | 1982 - 83 | 9° 20'N | 13° 23'E | 241 | 24 |
| Marouwa-Salak | 1982 - 83 | 10° 28'N | 14° 16'E | 423 | 24 |

**TABLE 2: Regression equations for Cameroon Republic**

| Equation | Regression equation | Correlation index |
|---|---|---|
| 1. | $H/Ho = 0.713 \exp(-0.142(S-R))$ | 0.626 |
| 2. | $H/Ho = 0.885\ R^{-0.77} S^{0.582}$ | 0.778 |
| 3. | $H/Ho = 0.62 + 0.26S$ | 0.992 |
| 4. | $H/Ho = 0.806 - 0.09R$ | -0.863 |
| 5. | $H/Ho = 0.849 - 0.136T$ | -0.01 |
| 6. | $H/Ho = 0.571 + 0.019R + 0.336T$ | 0.0992 |
| 7. | $H/Ho = 1.19S + 0.567R + 3.0T - 2.46$ | |

**TABLE 3: Estimates of solar radiation from tested equation**

| Station | H/Ho | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Eqn.1 | Eqn.2 | Eqn.3 | Eqn.4 | Eqn.5 | Eqn.6 | Eqn.7 |
| Yaounde | 0.718 | 0.759 | 0.580 | 0.713 | 0.735 | 0.745 | 0.676 | 0.632 |
| Garoua | 0.805 | 0.706 | 1.06 | 0.780 | 0.757 | 0.745 | 0.768 | 0.833 |
| Ambam | 0.700 | 0.758 | 0.588 | 0.715 | 0.735 | 0.745 | 0.678 | 0.645 |
| Nkoundja | 0.725 | 0.733 | 0.784 | 0.760 | 0.740 | 0.749 | 0.739 | 0.725 |
| Ngaoundere | 0.791 | 0.716 | 0.929 | 0.785 | 0.752 | 0.749 | 0.772 | 0.807 |
| Maroua | 0.784 | 0.697 | 1.21 | 0.783 | 0.764 | 0.748 | 0.772 | 0.760 |
| Mamfe | 0.730 | 0.758 | 0.575 | 0.709 | 0.736 | 0.741 | 0.671 | 0.687 |
| Batouri | 0.709 | 0.749 | 0.661 | 0.732 | 0.736 | 0.743 | 0.702 | 0.750 |
| Douala | 0.702 | 0.764 | 0.541 | 0.706 | 0.732 | 0.738 | 0.666 | 0.776 |
| Yoko | 0.776 | 0.735 | 0.768 | 0.756 | 0.740 | 0.743 | 0.732 | 0.854 |

The following conclusions may be drawn:

1. Equation 4 shows that relative humidity has negative correlation as earlier reported by Ahmad et al (1983) which is high in absolute value and hence may be used for solar radiation estimation.

2. Air temperature, on its own, cannot be used for solar radiation estimation since it is insensitive to location (Table 3).

3. Equation 2 appears to predict rather high values for solar radiation in the northern areas (arid and semi-arid) while giving correspondingly lower figures for the southern or rain-forest areas.

From the present analysis the modified Angstrom relation (Equation 3) is as good as any, for the prediction of global solar radiation in a tropical area like Cameroon and Nigeria. It is simpler to use than either Equations 6 or 7. Hence, it is used for the rest of the work described here.

## Global solar radiation for Nigeria and Cameroon

In the Angstrom-type of regression equation, mean daily insolation for monthly periods, H is derived from the amount of extraterrestrial solar radiation, $H_o$, the number of measured sunshine hours at a station, n, and the maximum number of sunshine hours possible at the station, N, from the expression

$$H = H_o (a + b\, n/N) \qquad (8)$$

where a and b are coefficients of the regression equation. $H_o$ is obtained from the equation

$$H_o = \frac{24}{\pi} G_{sc} (1 + 0.33\cos (360\,\delta /365)) (\cos \phi \cos \delta \sin W_S + 2\,\pi W_S \sin \phi \sin \delta /360) \qquad (9)$$

where $G_{sc} = 1370\ W/m^2$, the solar constant

$\delta = 23.45 \sin (360(284 + d)/365)$, the declination (10)

d = day of the year

$\phi$ = latitude (north positive)

w = hour angle

$w_S = -\tan \phi \tan \delta$, the sunset hour angle (11)

$$N = \frac{2}{15} \cos^{-1} W_S \qquad (12)$$

In the above, all angles are in degrees. Equation 8 is based on a development of Angstrom and used in modified forms by Fritz and MacDonald (1949), Black et al (1954), Mateer (1955) and Page (1961) among others. With particular reference to West Africa, the Angstrom relation has also been used by Davies (1965), Swartman and Ogunlade (1967), Akinsete (1974), Harry (1978), Ezekwe and Ezeilo (1981), Bamiro (1983) and Neba-Fabs (1984). Davies worked on data from two Nigerian stations (Kano and Benin) while supplementing his work with data from

Niamey (Niger Republic), Accra (Ghana) and Fort Lamy. Swartman and Ogunlade obtained relationships in dimensional form for Nigera from data from Ikeja (Lagos), Benin and Kano. The other local investigations have been for definite locations - Nsukka (Ezekwe and Ezeilo 1981), Ibadan (Bamiro 1983) and Lagos (Harry 1978). Neba-Fabs (1984) dealt entirely with the Cameroon.

As with the work by Davies (1965) the present study takes a broad view of the Nigerian and Cameroonian solar climate. Regression coefficients a and b are determined for the two countries and for specific locations within them. - Lagos, Ibadan, Benin, Nsukka, Kano and Yaounde and Garoua.

## RESULTS

Results of the analyses are shown in Tables 4 and 5 as well as those obtained by Bamiro (1983) for Ibadan and Ezekwe and Ezeilo (1981) for Nsukka.

The figures obtained for Nigeria as a whole underestimate the solar radiation for the northern areas and the south. Thus, estimates from this equation can, at best, be said to give an average for the country. For more serious work, the regression equation for each station must be used. The coefficients obtained for Kano, Northern Nigeria ($a = 0.11$, $b = 0.67$) are rather different from those quoted by Davies (1965) ($a = 0.26$, $b = 0.54$). This may be attributed to the progressive change and a more arid climate in Kano. For Nigeria, there continues to be a latitudinal trend with values of a decreasing and b increasing as one moves from south to north.

The values of $a = 0.62$ and $b = 0.26$ obtained for Cameroon are rather puzzling. There is no valid explanation for this behaviour. Values obtained from the regression equation are in good agreement with these values. Generally, data for the Cameroon are few in number thus prompting further investigation in the future.

## ACKNOWLEDGEMENT

The authors wish to thank the Meteorological Departments of Nigeria and the Cameroon Republic, and DGRST, Yaounde for their cooperation in providing some of the data used for this work. Most of the computation was done on the University of Lagos, Mechanical Engineering Department computer.

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**TABLE 4: Regression coefficients for Nigeria and Cameroon and for individual stations**

| Grouping | a | b | r | t | Lat. |
|---|---|---|---|---|---|
| Nigeria | .20 | .52 | .81 | .70 | |
| Cameroon | .62 | .26 | .99 | .88 | |
| Individual stations | | | | | |
| Lagos | .29 | .33 | .86 | .62 | 6° 27'N |
| * Ibadan | .35 | .37 | | .72 | 7° 26'N |
| Benin | .28 | .33 | .84 | .61 | 6° 33'N |
| + Nsukka | .28 | .65 | | .93 | 6° 52'N |
| Kano | .11 | .67 | .89 | .79 | 12° 3'N |
| Yaounde | .27 | .30 | .86 | .57 | 3° 52'N |
| Garoua | .28 | .43 | .78 | .71 | 9° 20'N |

* Bamiro (1983); + Ezekwe & Ezeilo (1982).

**TABLE 5: Regression coefficients for Lagos by months**

| Month | a | b | t |
|---|---|---|---|
| January | .29 | .24 | .53 |
| February | .24 | .34 | .58 |
| March | .23 | .36 | .59 |
| April | .25 | .26 | .51 |
| May | .42 | .12 | .54 |
| June | .36 | .01 | .37 |
| July | .32 | .09 | .41 |
| August | .31 | .14 | .45 |
| September | .33 | .11 | .44 |
| October | .48 | -.13 | .35 |
| November | .05 | .68 | .73 |
| December | .39 | -.02 | .37 |