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SOLAR ENERGY RESOURCE ASSESSMENT FOR GHANA

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ABSTRACT

The Meteorological Services Department (MSD) of Ghana has been the main source of solar energy data for several years now. Upon the establishment of the Solar Energy Applications Laboratory in the Kwame Nkrumah University of Science and Technology (KNUST) and similar laboratories in other parts of the country, there has been the need to collect and analyse data from KNUST to properly assess the solar energy potential of the country. The major objective of the study is therefore to develop adequate, accurate and reliable solar energy resources data as an integral part of the nation's energy planning and policy framework. Specifically, the study involved collecting, analysing and comparing solar data from KNUST and the MSD. KNUST has used both the Licor sensor and the Kipp and Zonen pyranometer for measuring solar radiation. These are both second-class instruments with an accuracy of 5 %. On the other hand, MSD had used Bellani Distillation Pyranometers and Bimetallic Actinographs which are third-class instruments according to the World Meteorological Organisation (WMO) with an error estimated to be 15 %. Since KNUST is using higher accuracy equipment, the MSD measurements were validated using the KNUST data. The estimated average percentage error margin was found to be about 12 % after validation.

Keywords: Solar energy potential, measurement, Angstrom-Page correlation, validation, KNUST, MSD, Ghana.

NOMENCLATURE

a, b = Regression coefficients
A, B = Constants
D = Monthly average diffused radiation (kWh/m^{2}day)
G = Monthly average daily global irradiation (kWh/m^{2}day)
G_{ON} = Monthly average daily global irradiation on the horizontal (kWhm^2-day)
G_{SC} = Solar Constant = 1367 W/m^2
H_{SS} = Sunset hour angle
N = Day number, Jan 1 = 1
R_b = Monthly mean tilt factor
S = Monthly average daily sunshine duration (h)
So = Maximum possible monthly average daily sunshine duration (h)
δ = Solar declination
λ = latitude
ρ = Ground reflectance
β = Angle of tilt

1. INTRODUCTION

Solar energy technologies are gradually making significant inroads onto the world energy market. The success of solar energy technologies however, depends largely on the availability of accurate and reliable solar energy data for the design of systems and evaluation of solar energy conversion devices. This study therefore, focused on data collection and subsequent analysis to fully assess the solar energy resources of the country. Akuffo (1991) undertook a similar study. The major new dimensions incorporated in this study include validating the solar radiation measurements from all 22 meteorological synoptic stations across the country and comparing these ground measurements with satellite generated solar radiation measurements. The MSD used to measure global solar radiation but discontinued when most of their equipment broke down. In the absence of direct solar radiation measurements from the synoptic stations, Angstrom – Page's empirical correlation was used to convert the measured sunshine duration hours into monthly mean global irradiation. In addition, the following studies were also undertaken: establishment of frequency distribution of the solar radiation, estimation of solar radiation on inclined planes and development of time series data for a 10 year period.

2. DATA SOURCES

Data for the study was collected from the Solar Energy Application Laboratory (SEAL) at KNUST and the 22 synoptic stations of the Meteorological Services Department (MSD). The types of data collected included solar radiation, sunshine hour duration, relative humidity and air temperatures. KNUST measures hourly solar radiation (global and diffuse) using Kipp and Zonen radiometers connected to a data logger. These instruments are generally classified as second-class equipment according to the World Meteorological Organisation.

The instruments are estimated to have a 5 % margin of error. The MSD used to collect global solar radiation data until their instruments (Bellani Distillation Pyranometers, classified as third-class instruments with 15 % error) broke down. As a result they are currently only measuring the duration of bright sunshine using Campbell-Stokes sunshine recorders.

3. ANALYTICAL FRAMEWORK

3.1 Conversion of sunshine hours into global irradiation

Except for 1988 when measured solar radiation data was available at both institutions, which facilitated a straightforward comparison, there was the need to convert the measured sunshine hours into global irradiation before the results were compared.

Although many empirical correlations exist for this conversion, the Angstrom – Page correlation was chosen because it is the simplest and the most widely used for estimating global irradiation (Duffie and Beckman, 1980). Research has been carried out extensively on Angstrom – Page's correlation to establish suitable regression coefficients for Ghana. One such research was carried out by Jackson and Akuffo (1992) for Kumasi in which 0.25 and 0.45 were assigned for the coefficients *a* and *b*, respectively. Danquah (1990), undertook a similar study for the whole country and obtained regression coefficients of 0.27 and 0.45 for the constants *a* and *b*, respectively. The two results were fairly consistent, however values of 0.25 and 0.45 were used in the computations for this study.

The Angstrom – Page correlation between monthly mean global irradiation and monthly mean relative duration of sunshine is written as:

$$G = G_O\left(a + \frac{bS}{S_O}\right) \qquad (1)$$

$$G_O = 24G_{ON}\left(\frac{AH_{ss} + B\,sin H_{ss}}{\pi}\right)$$

where,

$$G_{ON} = G_{SC}\left(1 + 0.033cos\frac{360N}{365}\right)$$

$$a = sin\lambda sin\delta$$

$$b = \cos\lambda\cos\delta$$

$$\delta = 23.45sin\left(360\frac{284 + N}{365}\right)$$

$$H_{SS} = cos^{-1}(-\tan\delta\tan\lambda)$$

$$S_o = \frac{2}{15}cos^{-1}(-\tan\delta\tan\lambda)$$

All other symbols are defined in nomenclature.

3.2 Solar Radiation on Inclined Surfaces

To increase the energy intercepted and to minimise the angle of incidence, practical solar collectors are tilted at some angle to the horizontal. However, due to the absence of tilt surface measurements a model proposed by Liu and Jordan (1962) was used to obtain the estimates. In the Liu and Jordan's model, the total radiation is decomposed into three components; beam, diffuse and ground reflected radiation. Since KNUST is the only institution that measures diffuse radiation in the country, the model was used to obtain estimates for Kumasi only.

The isotropic model proposed by Liu and Jordan is suitable for cloudy climates such as pertains in Ghana and, according to Klein (1977), it is given by:

$$H_T = \frac{G - D}{R_b} + D\left(\frac{1+\cos\beta}{2}\right) + \rho G\left(\frac{1-\cos\beta}{2}\right) \qquad (2)$$

where, $R_b = \dfrac{H_{SS}\sin(\lambda - \beta)\sin\delta + \cos(\lambda - \beta)\cos\delta\sin H_{SS}}{H_{SS}\sin\lambda\sin\delta + \sin H_{SS}\cos\lambda\cos\delta}$

$$H_{ss} = \min\begin{cases}\cos^{-1}\ (-\ \tan\ (\lambda\ -\ \beta)\ \tan\ \beta \\ \cos^{-1}\ (-\ \tan\ \lambda\ \tan\ \delta)\end{cases}$$

and H_{SS} the smaller of the terms in the brackets (Gopinnathan, 1990).

4. RESULTS AND DISCUSSION

4.1 Validation of MSD data using KNUST data

In comparing the MSD solar radiation data with the KNUST data, it was observed that MSD monthly averages were always higher than the KNUST monthly averages. The average percentage error margin was found to be 4.51% for 1988 when both institutions measured the measuring global solar radiation. The major disparities in the measurements occurred at 1800 GMT.

This is due to the fact that the Bellani distribution pyranometers store energy and therefore even when the intensity of the sun is low, enough alcohol is evaporated leading to comparatively higher readings recorded at the synoptic stations at 1800 GMT. The 1800 GMT results were therefore not used in estimating the monthly averages.

The eight (8) years from 1995 to 2002 saw KNUST recording higher values with the average percentage error margin increasing to + 11.80 %. This could be attributed to errors introduced in the use of empirical formulae to convert the measured sunshine hour duration to monthly mean global irradiation. Table 1 below shows the results of the monthly comparison for 1988 when both institutions measured actual global solar irradiation.

The KNUST data was measured with a Licor Pyranometer on the University campus whilst the MSD data was measured with Bellani Distillation Pyranometer at the Kumasi Airport. Table 2, on the other hand shows results of the comparison with the KNUST data after the conversion of the MSD data from sunshine hours to irradiation.

4.2 Time Series data

The time series data was developed for a 10-year duration for 19 synoptic stations using the MSD data. This showed a similar trend in the variation of the monthly averages of global irradiation. January to April for each synoptic station saw a steady increment in global irradiation results. The average percentage increase from January to April is 13% followed by a steady reduction from April to August with an average of 17%. This was followed by a steady rise from August to November with an average increment estimated to be 20% and finally a steep drop from November to December of 70%. Ten-year monthly averages were computed for all 19 synoptic stations using MSD data.

Table 1. Comparison of KNUST and MSD Monthly Hourly Mean Solar Radiation (W/m²) Data for Kumasi for 1998

Month	KNUST	MSD	%ERROR
JAN	266.67	314.08	+17.78
FEB	333.33	371.00	+11.30
MAR	380.25	416.42	+9.51
APR	405.08	403.67	-0.35
MAY	413.75	400.25	-3.26
JUN	341.33	350.33	+2.64
JUL	300.42	321.50	+7.02
AUG	236.75	242.75	+2.53
SEP	292.00	298.58	+2.25
OCT	374.67	378.25	+0.96
NOV	351.50	364.33	+3.65
DEC	303.83	319.00	+4.99
Average	333.30	348.35	+4.51

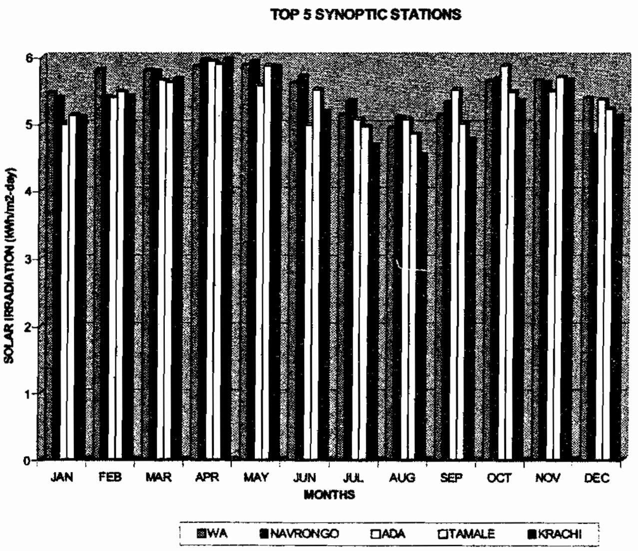
These averages revealed that, for the whole country, Wa has the highest level of solar irradiation (annual average of 5.524 kWh/m^2 –day), as shown in Figure 1. May is the month with the highest solar irradiation(5.873 kWh/m^2- day), with August recording the lowest measurement (4.937 kWh/m^2- day) in Wa. Akim-Oda on the contrary is the location that records the lowest irradiation (4.567 kWh/m^2- day) based on measurements taken across the country. The highest measurement in Akim-Oda is recorded in the month of April (5.176 kWh/m^2- day) and lowest is in August (3.802 kWh/m^2 - day).

Table 2: Comparison of KNUST and MSD Solar Irradiation Data (kWh/m² - day) for Kumasi (1995 – 2002)

YEAR	KNUST	MSD	% ERROR
2002	4.30	4.83	+ 12.33
2001	4.364	4.82	+ 10.45
2000	4.233	4.715	+ 11.38
1999	4.311	4.759	+ 10.38
1998	4.354	4.652	+ 6.80
1997	4.019	4.630	+ 15.20
1996	3.908	4.565	+ 16.80
1995	4.355	4.861	+ 11.61
AVERAGE	4.231	4.729	+ 11.80

A similar eight-year monthly averages were computed for Kumasi using KNUST data, as presented in Table 3. The highest level of solar irradiation occurred in June (5.36 kWh/m^2-day), which was surprising since this is the middle of the rain season, and the minimum occurred in August (2.77 kWh/m^2-day). This raised a number of issues, like possible influence from a major climatic phenomenon like El Ninor, which need to be addressed in a separate study.

Figure 1: Monthly distribution of solar irradiation for the five highest locations in Ghana



5. CONCLUSION

Although the MSD is using lower accuracy equipment in measuring sunshine hour duration, the comparison with the KNUST data indicates that the MSD data is fairly accurate and can be relied upon. The estimated average error margin ranged between +4.5 % for the 1988 data and + 11.8 % for the 8-year data set (1995-2002).

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Table 3. Solar Irradiation (kWh/m^{2-}day) Data for Kumasi from KNUST

MONTH	1995	1996	1997	1998	1999	2000	2001	2002	8-YEAR AVERAGE
JAN	3.534	3.565	3.767	3.768	3.767	3.775	3.790	3.906	3.734
FEB	4.727	3.515	3.422	-	4.727	4.923	4.520	3.905	4.248
MAR	4.151	2.728	4.622	5.335	4.151	5.028	5.197	5.114	4.541
APR	3.445	4.940	4.895	3.445	4.826	5.406	5.360	5.198	4.689
MAY	5.335	5.139	4.897	5.335	5.333	5.151	5.335	5.169	5.211
JUN	4.943	4.043	4.272	4.950	4.940	4.178	5.361	4.401	4.636
JUL	3.905	3.934	2.981	3.936	3.905	3.590	3.759	3.610	3.703
AUG	3.635	3.232	3.635	3.323	3.637	3.243	2.773	3.047	3.316
SEP	3.445	3.358	3.712	4.926	3.444	3.294	3.358	3.633	3.646
OCT	5.287	4.212	3.801	4.022	4.151	4.196	4.615	4.856	4.393
NOV	4.563	4.939	4.94	4.824	4.826	4.581	4.654	4.832	4.770
DEC	5.287	3.285	3.285	4.030	4.027	3.436	3.640	3.969	3.870
Annual Average	4.355	3.908	4.019	4.354	4.311	4.233	4.364	4.303	4.231