Determination of Angstrom Coefficients for Masvingo and Makoholi Stations, Zimbabwe

Brain Mapurisa* and Luckywell Seyitini#

Department of Physics Geography and Environmental Science, Great Zimbabwe University, Zimbabwe

Abstract: Coefficients of the first order and second order Angstrom model were obtained for Masvingo and Makoholi stations in Zimbabwe. Long term average ground measurements of sunshine hours and global horizontal solar radiation from the meteorological services were used as input data. Monthly average values of the clearness index, $\left(\frac{H}{H_0}\right)$ and the fraction of sunshine hours, $\left(\frac{n}{N}\right)$ were determined. Regression analysis was used to obtain the first and second order coefficients of the Angstrom model for the two locations. The estimates from the developed models were tested against measured values and results obtained were in agreement to within +/- 5%. The results also showed that the models performed better with these coefficients compared with coefficients suggested in previous researches. Also the first order model was found to perform better than the second order model for Makoholi station while the second order model works well for Masvingo.

Keywords: Global solar radiation, Monthly average sunshine hours, Clearness index, Fraction of sunshine hours.

INTRODUCTION

The current energy crisis facing the world dictates that alternative sources be sought. Worries about climate change and global warming resulting from the use of fossil fuels seem to suggest the use of clean technologies. Recent disasters in nuclear plants have seen governments halting plans to expand the nuclear power plants. In light of these challenges, solar energy emerges as one the available alternative forms of fuel which can be harnessed for both domestic and industrial applications with little damage to the environment.

Although solar energy can be harnessed for power generation, its availability varies from one location to another. It is therefore important to establish the amount of solar energy received at a location before any meaningful investment can be done. Climatic conditions are also a factor in determining the usability of solar radiation as a source of energy.

The most important parameter that is required for the design of a solar energy conversion system at a particular location is the Global Solar Radiation [1-3]. Unfortunately ground measurements for this parameter are scarce for developing countries. This is usually because weather stations that directly measure solar radiation are very few, and in many cases rely on old out dated equipment. In Zimbabwe, for example, solar radiation is only measured at seventeen locations.

The scarcity of solar radiation data results in the use of empirical models to predict and estimate global solar radiation for a chosen location [1, 2]. These models rely on climate parameters for the location under consideration. These parameters include sunshine hours, relative humidity, declination angle, latitude and longitude, surface albedo, maximum temperature and the number of rainy days among others [1, 4, 5]. The commonly used models are those that are based on sunshine hours. Sunshine hours are dependent on cloud cover as well as the season of the year [2, 4]. Cloud cover determines the fraction of sunshine hours, $\frac{n}{N}$, which is the ratio between the actual number of bright sunshine hours n, to the possible number of sunshine hours for particular day, *N*. Latitude mainly affects the angle of incidence of the sunrays, it contribute to the scattering effect on solar radiation.

METHODOLOGY

Study Area

This study shall focus on developing Angstrom type models for predicting global solar radiation for Masvingo, (latitude 20^o 03' 49'' and longitude30^o 49' 39''E), and Makoholi (latitude 19^o 50' 0'', and longitude 30^o 47' 0''E) shown in Figure **1**. Ground measurements for global solar radiation and sunshine hours obtained from meteorological data shall be used as input data. Regression analysis shall be employed to obtain coefficients for the first order and the second order models. The models are generally valid for estimating

*Address correspondence to this author at the Department of Physics Geography and Environmental Science, Great Zimbabwe University, Zimbabwe; Tel: +263 39 253 681; Fax: +263 39 252 100;
E-mail: bmapurisa@gzu.ac.zw

#Co-Author E-mail: lseyitini@gzu.ac.zw

ISSN: 1814-8085 / E-ISSN: 1927-5129/13

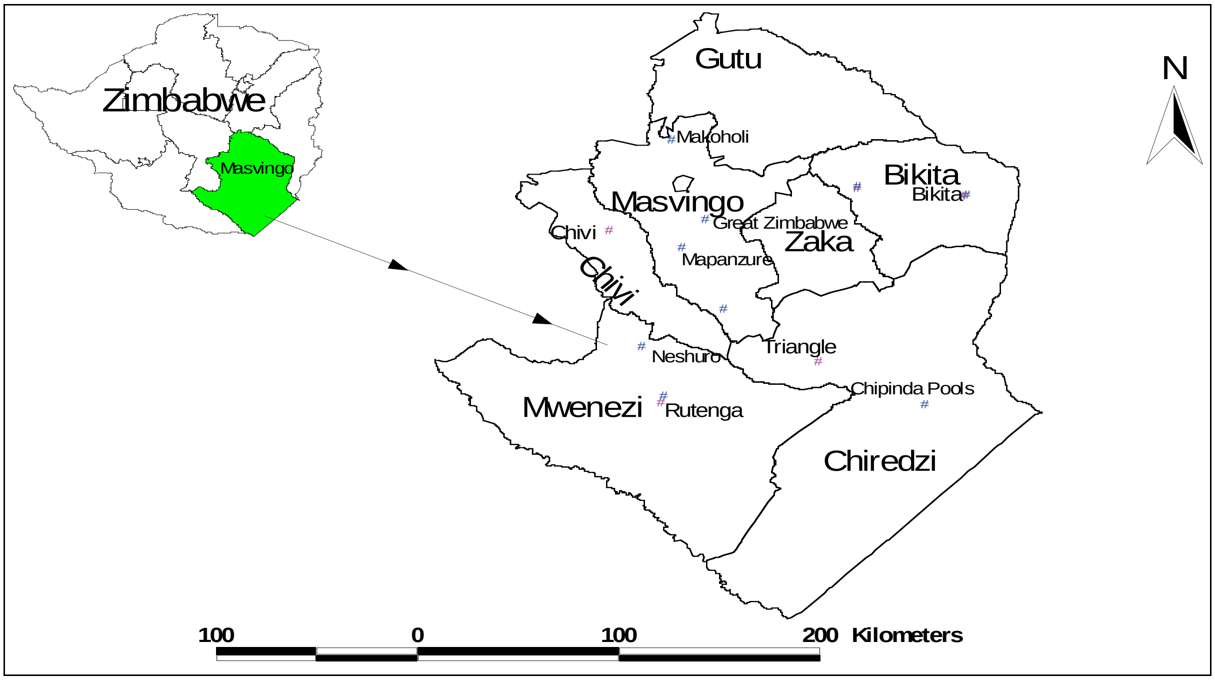

Figure 1: Map of Masvingo province, Zimbabwe showing Masvingo and Makoholi stations.

radiation in locations of similar climate, latitude and altitude [1, 4]. Estimated radiation data obtained from the models would be compared with measured data as well as estimates from data obtained from previous work. This will save to check the suitability of the models for locations with similar climate and latitude.

Calculation Procedure

The Angstrom correlation model is the most commonly used method to estimate monthly average daily global horizontal solar radiation and it was also applied in this study. The model is given as:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_{\max}}\right) \tag{1}$$

Where *H* is the monthly average daily global horizontal solar radiation

H_0 is extraterrestrial global solar radiation defined as (Ahmed *et al.* 2009):

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin\phi \sin\sigma + \cos\phi \cos\sigma \sin\omega_s\right] \tag{2}$$

Where G_{sc} is solar constant = 1367 Wm^{-2}

d_r - inverse relative Earth-Sun distance = $(d_r = 1 + 0.033\cos\left(\frac{2\pi n}{365}\right))$

n is the number of the day in the year between 1 and 365 or 366.

ω_s is sunset hour angle = $arcCos(-\tan\sigma \tan\phi)$

ϕ and σ are latitude and declination angle respectively $\left(\sigma = 0.409\sin\left[\frac{2\pi n}{365} - 139\right]\right)$

a and *b* – Angstrom coefficients

S is measured sunshine hours and

S_{max} is daylight hours defined as: $S_{max} = 24/\pi * \omega_s$ {OR = $2/15 * \omega_s$ (where ω_s is in deg)}

Angstrom coefficients for Masvingo and Makoholi stations are then determined from graphs of $\frac{H}{H_0}$ against $\frac{S}{S_{\max}}$ where *H* and *S* are the actual values measured on the ground.

Using these coefficients, the first and second order Angstrom–type correlations are obtained which will predict monthly average daily global horizontal solar radiation at the two stations.

T. Hove and J. Göttsche [5] recommended the use of Angstrom regression coefficients for Zimbabwe for square pixels centered at given longitude and latitude as given in the Table **1**.

Table 1: Angstrom Regression Coefficients for Zimbabwe for Square Pixels Centered at Given Longitude and Latitude

Pixel	1	2	3	4	5	6	7	8
Longitude (^{0}E)	33.75	31.25	31.25	31.25	28.75	28.75	28.75	26.25
Latitude (^{0}S)	18.75	16.25	18.75	21.25	21.25	18.75	17.25	18.75
a	0.32	0.36	0.27	0.24	0.29	0.32	0.35	0.25
b	0.45	0.43	0.48	0.49	0.46	0.47	0.48	0.58

From Table **1** the recommended Angstrom equation for Masvingo becomes:

$$\frac{H}{H_0} = 0.24 + 0.49\left(\frac{S}{S_{\max}}\right) \quad (3)$$

and for Makoholi is: $\frac{H}{H_0} = 0.27 + 0.48\left(\frac{S}{S_{\max}}\right)$ (4)

Values of monthly average daily global horizontal solar radiation at the two stations were calculated using equations (3), (4), (5a), (5b), (6a) and (6b) and were compared with the actual measured data. Percentage error and the root mean square error were determined for all predicted values in order to find the most reliable model to use for the two stations.

RESULTS AND DISCUSSIONS

The Angstrom constants which lead to first and second order equations 5(a), 6(a) and 5(b), 6(b) respectively were determined using ground measured long term average sunshine hours and global solar radiation data shown in Table **2**.

First and second order Angstrom correlations for Masvingo are:

$$\frac{H}{H_0} = 0.2335 + 0.559\left(\frac{S}{S_{\max}}\right) \quad (5a)$$

$$\frac{H}{H_0} = 0.2439 + 0.5288\left(\frac{S}{S_{\max}}\right) + 0.0217\left(\frac{S}{S_{\max}}\right)^2 \quad (5b)$$

First and second order Angstrom correlations for Makoholi are:

$$\frac{H}{H_0} = 0.1625 + 0.6758\left(\frac{S}{S_{\max}}\right) \quad (6a)$$

$$\frac{H}{H_0} = 2.1191 - 5.0122\left(\frac{S}{S_{\max}}\right) + 4.0595\left(\frac{S}{S_{\max}}\right)^2 \quad (6b)$$

Comparisons of estimated monthly average daily global horizontal solar radiation data from models developed in this study and the ground measured values together with values estimated by equations 3

Table 2: Data for (a) Masvingo and (b) Makoholi (H and H_o Values are in Units of $MJm^{-2}day^{-1}$)

(a)					(b)				
Month	H	H_o	S/S_{max}	H/H_o	Month	H	H_o	S/S_{max}	H/H_o
Jan	24.3	41.9	0.604	0.580	Jan	24.4	41.8	0.566	0.584
Feb	22.7	40.0	0.593	0.568	Feb	22.9	40.0	0.633	0.573
Mar	22	36.3	0.653	0.605	Mar	22.1	36.4	0.637	0.607
Apr	20.3	31.0	0.731	0.655	Apr	20.9	31.1	0.774	0.672
May	18.4	26.3	0.799	0.700	May	19.2	26.4	0.807	0.727
Jun	16.3	23.9	0.789	0.681	Jun	17.8	24.1	0.824	0.739
Jul	17	25.0	0.789	0.679	Jul	18.3	25.2	0.787	0.727
Aug	20.1	29.1	0.838	0.690	Aug	21.3	29.3	0.819	0.728
Sep	22.3	34.5	0.772	0.647	Sep	22.9	34.5	0.772	0.663
Oct	22.9	38.8	0.688	0.591	Oct	23.3	38.8	0.744	0.601
Nov	23.4	41.3	0.600	0.567	Nov	23.7	41.2	0.601	0.575
Dec	22.9	42.2	0.560	0.543	Dec	23.1	42.1	0.606	0.549

Table 3: Estimated Monthly Average Daily Global Horizontal Solar Radiation for Masvingo (All Values are in Units of $MJm^{-2}day^{-1}$)

Month	Measured *H* value	First order model (Eqn 5a)	Second order model (Eqn 5b)	Equation 3
Jan	24.3	23.907	23.911	22.435
Feb	22.7	22.600	22.604	21.223
Mar	22	21.754	21.752	20.353
Apr	20.3	19.902	19.900	18.541
May	18.4	17.870	17.874	16.593
Jun	16.3	16.137	16.139	14.990
Jul	17	16.883	16.885	15.683
Aug	20.1	20.456	20.466	18.961
Sep	22.3	22.914	22.914	21.303
Oct	22.9	23.949	23.945	22.362
Nov	23.4	23.495	23.499	22.054
Dec	22.9	23.045	23.058	21.690

Table 4: Estimated Monthly Average Daily Global Horizontal Solar Radiation for Makoholi (All Values are in Units of $MJm^{-2}day^{-1}$)

Month	Measured *H* value	First order model (Eqn 6a)	Second order model (Eqn 6b)	Equation 4
jan	24.4	22.799	24.356	22.656
feb	22.9	23.611	22.915	22.952
mar	22.1	21.576	20.877	20.952
apr	20.9	21.325	20.881	19.957
may	19.2	18.701	18.963	17.368
jun	17.8	17.333	17.964	16.035
jul	18.3	17.496	17.365	16.320
aug	21.3	20.966	21.597	19.416
sep	22.9	23.622	23.090	22.117
oct	23.3	25.798	24.709	24.316
nov	23.7	23.455	23.636	23.035
dec	23.1	24.090	24.098	23.618

and 4 are presented in Tables **3**, **4** and **5**, and Figures **2** and **3**.

At Masvingo station there is close agreement to the measured data by values predicted by first and second models developed in this study as illustrated in Figure **2**. The percentage errors in first and second order models range from -2.88 to 4.58 and -2.86 to 4.56 while values estimated from equation 3 have a minimum percentage error of -2.35 and a maximum of -9.82% as shown in Table **5a**. In addition the root mean square error for the two models from present work is 0.02 as compared to 0.07 for values from equation 3 which was arrived at using coefficients recommended by Hove and Göttsche [5].

For Makoholi station the second order model from this study gives results that are closest to the measured data with a percentage error range of -5.53 to 6.05 as compared to ranges -6.56 to 10.72 and -10.82 to 4.36 for the first order model and equation 4 respectively. Also, the second order model has the

Table 5: Percentage Error and Root Mean Square Error for various models for (a) Masvingo and (b) Makoholi

(a)				(b)			
Month	**First order model**	**Second order model**	**Equation 3**	**Month**	**First order model**	**Second order model**	**Equation 4**
Jan	-1.62	-1.60	-7.67	Jan	-6.56	-0.18	-7.15
Feb	-0.44	-0.42	-6.51	Feb	3.11	0.07	0.23
Mar	-1.12	-1.13	-7.49	Mar	-2.37	-5.53	-5.19
Apr	-1.96	-1.97	-8.67	Apr	2.03	-0.09	-4.51
May	-2.88	-2.86	-9.82	May	-2.60	-1.23	-9.54
Jun	-1.00	-0.99	-8.03	Jun	-2.63	0.92	-9.92
Jul	-0.69	-0.68	-7.75	Jul	-4.39	-5.11	-10.82
Aug	1.77	1.82	-5.67	Aug	-1.57	1.39	-8.84
Sep	2.75	2.75	-4.47	Sep	3.15	0.83	-3.42
Oct	4.58	4.56	-2.35	Oct	10.72	6.05	4.36
Nov	0.41	0.42	-5.75	Nov	-1.04	-0.27	-2.81
Dec	0.63	0.69	-5.28	Dec	4.29	4.32	2.24
RMSE	0.020398	0.020394	0.069049	RMSE	0.044930	0.031239	0.066258

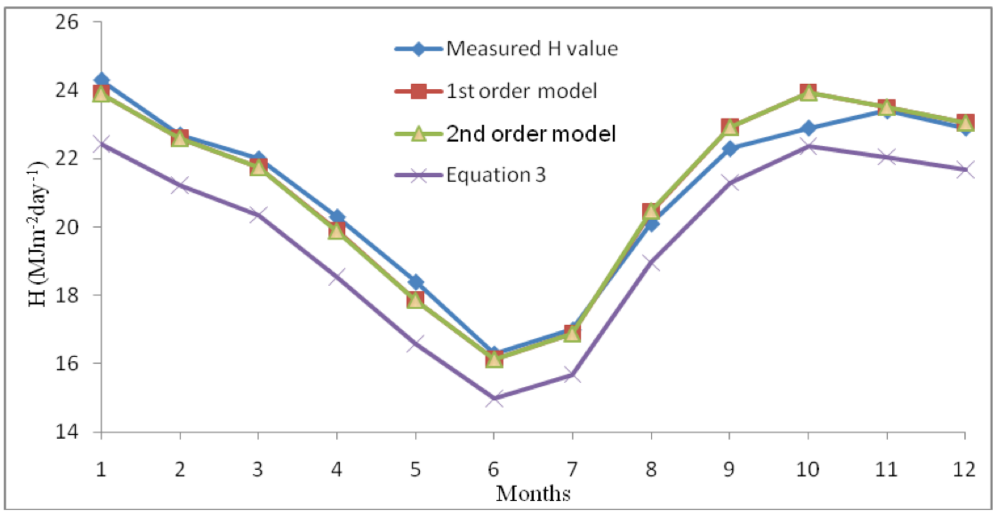

Figure 2: Comparison of estimated values of monthly average daily global solar radiation from different models with ground measured data for Masvingo station.

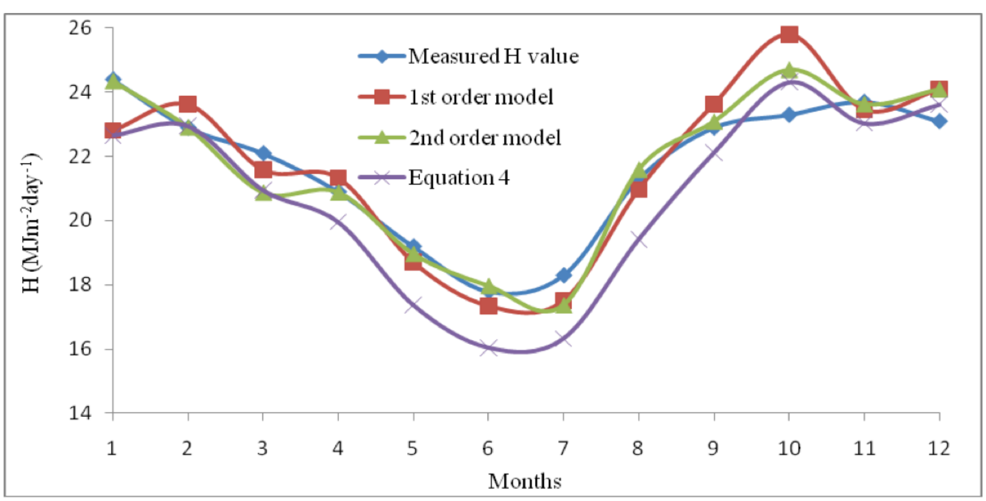

Figure 3: Comparison of estimated values of monthly average daily global solar radiation from different models with ground measured data for Makoholi station.

least root mean square error of 0.03 while for the first order model and equation 4 the errors are 0.05 and 0.07 as illustrated in Table **5b**.

CONCLUSION

The maximum percentage error of values predicted by both models developed in the present work for all months for Masvingo station is less than 5% and for Makoholi the second order model provides results with a maximum percentage error of 6%. This is an improvement to results obtained using an Angstrom model with coefficients recommended by Hove and Göttsche which has percentage errors of 9.82% and 10.82% for Masvingo and Makoholi stations respectively. It is therefore concluded that these models can be used with confidence to estimate monthly average daily global solar radiation received in these stations and other locations with similar climate conditions where there are no measured radiation data. The results from this article will provide reliable data that can be used for further research work in solar energy. In addition, the results can be used by potential investors in solar energy to make informed decisions when planning to install solar systems.

REFERENCES

[1] Ahmed A, Akhla Que M, Ahmad F, Akhtar MW. Estimation of global and diffuse solar radiation for Hyderabad, Sindh, Pakistan. J Basic Appl Sci 2009; 5(2): 73-77. Available from: www.jbaas.com/html/Previous

[2] Augustine C, Nnabuchi MN. Correlation between sunshine hours and global solar radiation in Warri, Nigeria. Pacific J Sci Technol 2009; 10(2). Available form: www.akamai-university.us/PJST10_2_574.pd

[3] Kolebaje OT, Mustapha LO. On the performance of some predictive models for global solar radiation estimate in tropical stations: Port Harcourt and Lokoja The African Review of Physics 2012; 7: 0015 Available from: www.aphysrev.org/index.php/aphysrev/article/download/542/235

[4] Bakirci K. Estimation of solar radiation by using ASHRAE clear-sky model in Erzurum, Turkey. Energy Sources, Part A, 2009; 31: 208-216 Available from: www.scribd.com

[5] Hove T, Göttsche J. Mapping global, diffuse and beam solar radiation over Zimbabwe. Renewable Energy 1999; 18: 535-56 Available from: www.sciencedirect.com/science/journal/09601481/18
http://dx.doi.org/10.1016/S0960-1481(98)00782-4

Received on 13-03-2013 Accepted on 12-04-2013 Published on 15-05-2013

http://dx.doi.org/10.6000/1927-5129.2013.09.52