A comparative study of the three empirical solar models in North West Province, South Africa.

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Abstract. Energy crisis in South Africa (SA) is causing a lot of problems and has a negative impact on the growth of our economy. There is a dire need to implement the 2020 strategies to harness renewable energy and evidently the knowledge of the amount of solar irradiance received at different sites in SA is . With this knowledge the renewable energy systems can be meaningfully developed so as to sustain the outdoor conditions. The use of pyrheliometers and pyranometers to measure direct and global solar radiation respectively, also play an important role. However these instruments cannot be installed in many areas as they are expensive. In such situation it is economically viable to resort to a suitable theoretical for the estimation of global solar radiation. It is of a vital importance that a model to be selected should give reasonable estimates. This paper gives a comparative study of three modified empirical solar radiation models (Angstrom; Hargreaves & Samani and Glower & McCulloch) on a horizontal surface from sunshine hours and temperatures of different stations in North West Province, SA ($-25.8080^{\circ}; 25.5430^{\circ}$). A five year meteorological data from the four Agricultural research Council (ARC) stations were used to estimate the global solar radiation for this region. The estimated monthly solar irradiance data was compared with observed data using the statistical parameters such as, the mean bias error (MBE) and root mean square (RMSE). The Angstrom and temperature based models give better estimations for North West province.

1. Introduction

Global solar radiation on a horizontal surface passes through several layers of the earth whereby some portion of this radiation is reflected; scattered and or absorbed. Pyranometers can be used to measure the amount of global solar radiation at a particular area or satellite. Due to lack of funds, our country cannot afford to install pyranometers everywhere. The ARC and South African Weather Services (SAWS) have systematic measurements of some meteorological data in some areas at North West Province. The ARC stations are situated far much apart, so it is necessary to predict the global solar radiation at areas where there is no measuring instrumentation. Estimation of solar radiation is possible provided there are suitable empirical models. The knowledge of local global solar radiation is of vital importance for suitable design of energy systems, building photovoltaic (PV) stations, and a good evaluation of the thermal environment within buildings.

In this paper, the Angstrom regression coefficients are determined using Zabara model [1-2] that uses sunshine hours. Three empirical models, Angstrom-Prescott linear model [2 - 5]; Glower and McCulloch model [6] and Hargreaves – Samani equation [7-8] estimated the global solar radiation for the three ARC stations, that is, Koster; Ventersdorp and Delareyville at North West Province in South Africa (SA).

2. Methodology

The main aim of the present work is to compare the three empirical models and select a suitable model for estimating global solar radiation in North West Province, SA. The following models are used :

2.1 Angstrom – Prescott model

The global solar radiation is related to the amount of sunshine hours received in a particular area is given by the relation [2 – 4]:

$$\frac{H}{H_0} = a + b * \frac{S_a}{S_0} \quad (1)$$

Where H is the average daily global solar radiation, H_0 is the average extra-terrestrial solar radiation in MJ.m^-2 day^-1, a and b are regression coefficients, S_a is the daily observed sunshine duration and S_o is the possible sunshine duration or the maximum daylengths in hours. The ratio, $\frac{H}{H_0}$, represents the clearness index – the percentage deflection by the sky of the incident global solar radiation. This indicates the availability of solar radiation and changes in atmospheric conditions. $\frac{S_a}{S_0}$ is the relative sunshine hours – the measure of cloud cover. $\boldsymbol{a}$ and $\boldsymbol{b}$ are the regression coefficients that depend on the latitude and seasonal variation. $\boldsymbol{a}$ is the measure of the overall atmospheric transmission for totally cloudy conditions while $\boldsymbol{b}$ is the rate of increase of the clearness index with relative sunshine hour.

2.2 Glower and McCulloch model

Global solar radiation depends on the latitude and sunshine duration of the particular area under study and it is valid only for latitudes that are less than 60° [6].

$$\frac{H}{H_0} = a * \cos Lat + b * \frac{S_a}{S_0} \quad (2)$$

2.3 Hargreaves and Samani model

The equation given below shows the relationship between the clearness indices and the average daily maximum and minimum air temperatures [7].

$$\frac{H}{H_0} = k_r \sqrt{(T_{max} - T_{min})} \quad (3)$$

where k_r is an empirical constant = 0.16 for inland.

A five year daily data of sunshine hours, maximum and minimum air temperatures and global solar radiation data on the horizontal surface are provided by ARC and SAWS. The average daily extra-terrestrial solar radiation, H_0 and maximum possible sunshine hours, S_0 are computed using the relations given by Muzathik, Mulaudzi,et al [8-10] . The average daily extra-terrestrial solar radiation depends on the declination angle, δ, sunset hour angle, ω_s and the latitude [11-14].
The regression coefficients are computed monthly for the period of 5 years (2007 – 2011) using the following relations [12, 14]:

$$a = 0.395 - 1.247 * \left(\frac{S_a}{S_0}\right) + 2.680 * \left(\frac{S_a}{S_0}\right)^2 - 1.674 * \left(\frac{S_a}{S_0}\right)^3 \quad 4(a)$$

$$b = 0.395 + 1.384 * \left(\frac{S_a}{S_0}\right) - 3.429 * \left(\frac{S_a}{S_0}\right)^2 + 2.055 * \left(\frac{S_a}{S_0}\right)^3 \quad 4(b)$$

To compute the extra-terrestrial solar radiation and the maximum possible sunshine hours, we have used Mat-Lab software. We have also written the programme in order to determine the daily regression coefficients of each station under study using equations 4(a) and (b).

3. Results and discussion

The graphs below show the comparison of the estimated global solar radiation (H) determined from the three selected models with the ground measured data received from ARC. The study has been carried out for five years and some samples of the curves are presented below. The three empirical models mentioned in section 2 were used to calculate the estimated global solar radiation of each of the three selected stations in North West Province. Due to seasonal variations, the annual regression coefficients per station are as follows: Ventersdorp (a = 0.2153, b = 0.53480), Koster (a= 0.2156, b = 0.5254) and Delareyville (a = 0.2155, b = 0.5267). The average regression coefficients of North West Province are $a = 0.216$ and $b = 0.525$. The observed minimum and maximum temperature data requested from ARC were the input in equation 3 to estimate the daily global solar radiation Comparisons of the estimated and the measured global solar radiation are represented in Figures 1-6.

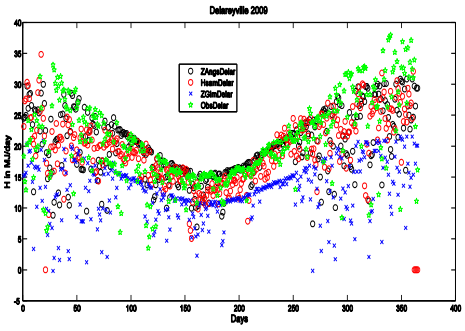

Figure 1: H Delareyville 2009 versus days of the year.

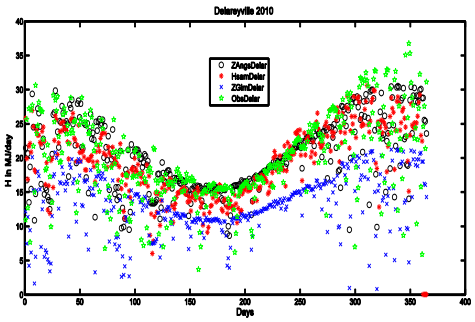

Figure 2: H Delareyville 2010 versus days of the year.

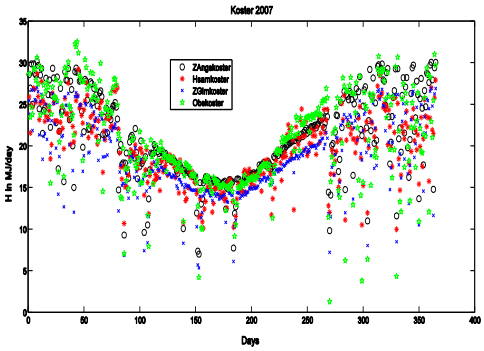

Figure 3: H Koster 2007 versus days of the year.

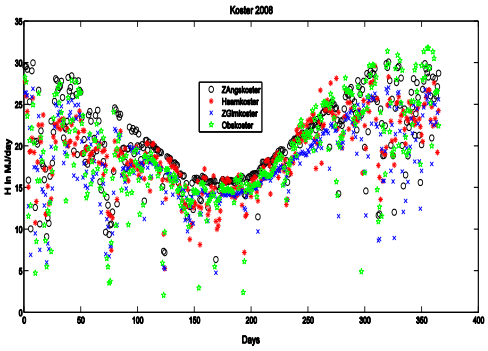

Figure 4: H Koster 2008 versus days of the year.

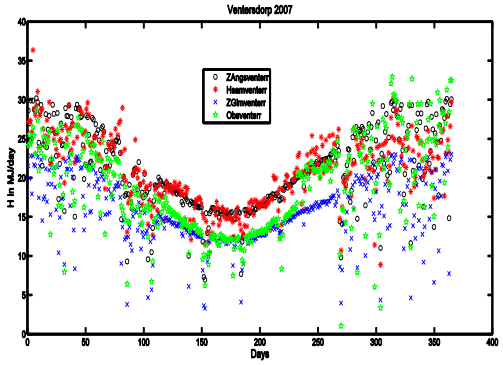

Figure 5: H Ventersdorp 2007 versus days of the year.

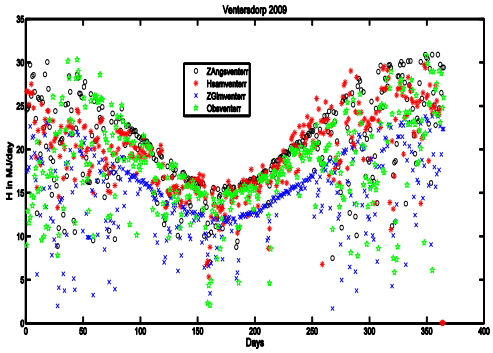

Figure 6: H Ventersdorp 2009 versus days of the year.

It is observed from the graphs that Angstrom and Hargreaves – Samani models give better estimation data for the stations almost every year. Variation of estimated global solar radiation data is compared with the ground measured data and we found that these two models have more accuracy than Glower and McCulloch model. Glower and McCulloch model underestimates the global solar radiation at Ventersdorp and Delareyville. All these models are suitable for Koster station. So, it is advisable to employ Glower & McCulloh model for the estimation of global solar radiation at the neighbourhood of Koster station. Figures 1-6 show that the global solar radiation data varies from (5.00 – 30.0) MJ.m^-2 day^-1 in summer. This variation is caused by the change in weather conditions. It is due to wind and water droplets since the rain fall during summer.

The statistical analysis for the Angstrom model was performed using the following equations [15]:

$$\text{Mean bias Error (MBE)} = \frac{1}{n}\sum_{i=1}^{n}(H_{est} - H_{obs}) \quad (5)$$

$$\text{Root Mean Square error (RMSE)} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(H_{est} - H_{obs})^2} \quad (6)$$

where H_{est} and H_{obs} are the estimated and observed global solar radiation respectively.

The average annual MBE and RMSE data for each station at North West are tabulated below:

Table 1: The MBE and RMSE of Ventersdorp; Koster and Delareyville stations.

	Ventersdorp (RMSE)	Ventersdorp (MBE)	Koster (RMSE)	Koster (MBE)	Delareyville (RMSE)	Delareyville (MBE)
2007	0.0103	-0.0065	0.0083	-0.0011	0.0115	0.0001
2008	0.0221	-0.0134	0.0109	-0.0036	0.0108	-0.0038
2009	0.0150	-0.0056	0.0166	-0.0101	0.0138	0.0000
2010	0.0227	-0.0107	0.0175	-0.0158	0.0101	0.0011
2011	0.0114	-0.0026	0.0179	-0.0146	0.0115	0.0000

4. Conclusion

The average daily global solar radiation of the observed and the predicted data were compared graphically. The modified Angstrom and Hargreaves – Samani models are more suitable for the estimation of global solar radiation at North West Province of South Africa the observed and the predicted daily global solar radiation values are comparable.

5. Acknowledgement

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