Estimation of Global Solar Radiations using Meteorological Data for Five Cities in India

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Abstract— A lot of models had been formulated by various researchers to estimate the Global Solar Radiation (GSR) over a particular region from the available meteorological data. This data mainly includes measured GSR from site, sunshine hours and air temperature data. The models which were studied had considered sunshine hour data and temperature data separately. In the present work, the new models are developed based on sunshine hours, air temperature and a combined model is also proposed containing both sunshine hours and air temperature values to estimate GSR over Amritsar, Bhopal, New Delhi, Srinagar and Varanasi regions of India. Evaluation of proposed models has been made in terms of Mean Bias Error (MBE), Mean Percentage Error (MPE) and Root Mean Square Error (RMSE). The results shows an improvement in RMSE value when GSR is estimated by considering both sunshine hours and air temperature together.

Key word: Mean Bias Error (MBE), Mean Percentage Error (MPE), Root Mean Square Error (RMSE)

I. INTRODUCTION

Solar radiation is a huge source of energy and in present time of energy crisis, solar energy is considered as a potential source to fulfil the future energy demands. Solar energy is a renewable source of energy but till date, we are not able to harness even a small fraction of it. In India, we still rely on energy from conventional sources like wood, coal etc. solar energy can be effectively utilized by using the technology like solar photovoltaic but to efficiently design the system to fulfil our energy demands, we require the solar radiation data to determine the potential power that can be generated and it can also be used at the commercial levels. Potential of solar energy can be determined from the available solar radiation data which is available with the meteorological agencies but it is not possible to have this data for every place. Although sunshine hour data and air temperature data is easily available for almost every site which is taken from [1] in present work. In this work, we have developed three models: 1) Linear Model Based on Angstrom Prescott Relation [2]; 2) Linear Model Based on Air temperature data [3]; 3) Linear Model Based on both sunshine hour and air temperature. The main focus of this work is to evaluate the performance of model developed based on both the sunshine hours and air temperature data.

II. LITERATURE REVIEW

A. *Angstrom Prescott Model:*

The various models developed to estimate the GSR are based on the Angstrom Prescott model which is given as,

$$\frac{H}{Ho} = a + b\left(\frac{n}{N}\right)$$

Where H= Estimated Monthly Mean GSR, KJ/m^2/day, H_0= Extra-terrestrial solar radiation, KJ/m^2/day, n= Average no. of daily sunshine hours, N= Maximum no. of daily sunshine hours, a,b = constants

A relation to calculate H_0 is available in literature which is given as,

$$Ho = 24 * 3.6 * Io * \frac{\left[\frac{\pi}{180} * \omega * sin\phi sin\delta + cos\phi sin\omega\right]}{\pi}$$

Where Io= Solar constant= 1367 W/m^2, Φ= Latitude of place in degrees

δ= Solar declination angle $=23.45 * \sin\left[\frac{360(d+284)}{365}\right]$

ω= Mean sunshine hour angle= $\arccos[-tan\phi tan\delta]$

d= Julian days starting from January 1

Chandel et. al [5] developed a model to estimate the regression coefficients a and b of Angstrom Prescott model using the available sunshine hours data as,

$$a = 0.352\ cos\emptyset\ (\frac{P}{P_o})^{0.5}$$

$$b = 0.3(\frac{P}{P_o})^{0.5}/\sqrt{sin\emptyset}$$

$$\frac{P}{P_o} = e^{(-0.0001184*h)}$$

P/P_0 is the pressure at a location concerned relative to a standard atmosphere and h is the altitude of the location in meters.

Gopinathan [4] proposed that *a* and *b* are related to three parameters, the latitude, the elevation and the sunshine hours given as,

$$a = -0.309 + 0.539cos\emptyset - 0.0693h + 0.29(\frac{n}{N})$$

$$b = 1.527 - 1.027cos\emptyset + 0.0926h - 0.359(\frac{n}{N})$$

Srivastava [6] developed a model to estimate the GSR over India as,

$$\frac{H}{Ho} = 0.1382 + 0.5564\left(\frac{n}{N}\right)$$

Hargreaves and Samani [7] suggests a relation for estimation of GSR using air temperature data which is given as,

$$\frac{H}{H_o} = a(\Delta T)^{0.5}$$

Where ΔT= Average of difference of daily maximum and minimum temperatures, a= Constant

III. PROPOSED MODELS

Using the data available from [1] for the cities of Amritsar, Bhopal, New Delhi, Srinagar and Varanasi, three simple models have been developed of the form which is given as,

Model I: $\frac{H}{Ho} = a + b\left(\frac{n}{N}\right)$

Model II: $\frac{H}{H_o} = a + b(\Delta T)^{0.5}$

Model III: $\frac{H}{Ho} = a + b\left(\frac{n}{N}\right) + c(\Delta T)^{0.5}$

These models for all the five cities are presented in table 1.

Location	Model I	Model II	Model III
Amritsar	0.24+0.61(n/N)	$0.37+0.066(\Delta T)^{0.5}$	$0.18+0.51(n/N)+0.032(\Delta T)^{0.5}$
Bhopal	-0.13+0.88(n/N)	$-0.16+0.21(\Delta T)^{0.5}$	$0.21+0.49(n/N)+0.11(\Delta T)^{0.5}$
New Delhi	0.35+0.42(n/N)	$0.12+0.14(\Delta T)^{0.5}$	$0.19+0.18(n/N)+0.086(\Delta T)^{0.5}$
Srinagar	-0.15+0.88(n/N)	$0.24+0.202(\Delta T)^{0.5}$	$0.19-0.14(n/N)+0.28(\Delta T)^{0.5}$
Varanasi	0.14+0.57(n/N)	$0.101+0.123(\Delta T)^{0.5}$	$0.04+0.19(n/N)+0.11(\Delta T)^{0.5}$

A. Variation of Calculated v/s Measured GSR:

The calculated values of GSR are compared with the measured values on the site. The results are presented in Fig. 1 to Fig. 5 for all five locations using the three models developed here. Here Hm represents the measured GSR on the site.

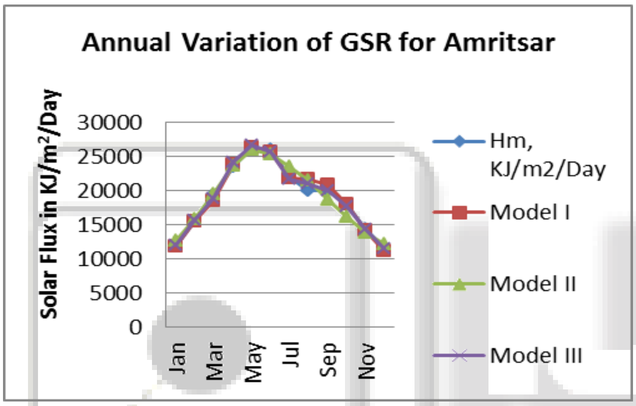

Fig. 1: Annual Variation of GSR for Amritsar

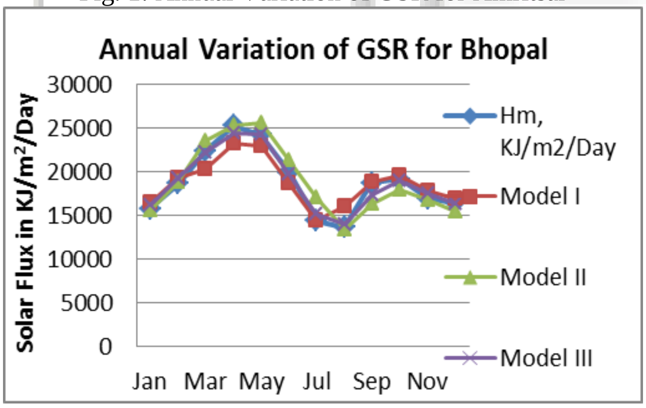

Fig. 2: Annual Variation of GSR for Bhopal

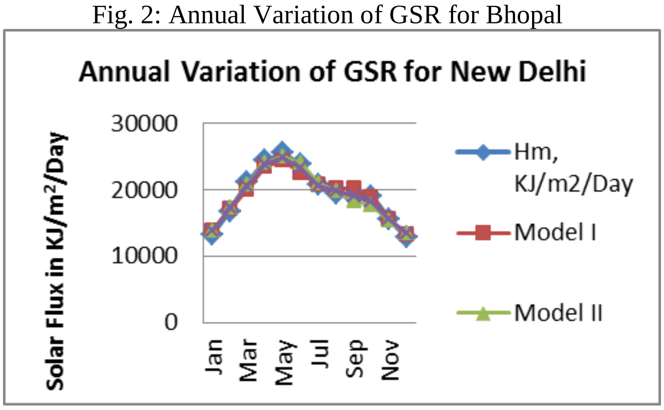

Fig. 3: Annual Variation of GSR for New Delhi

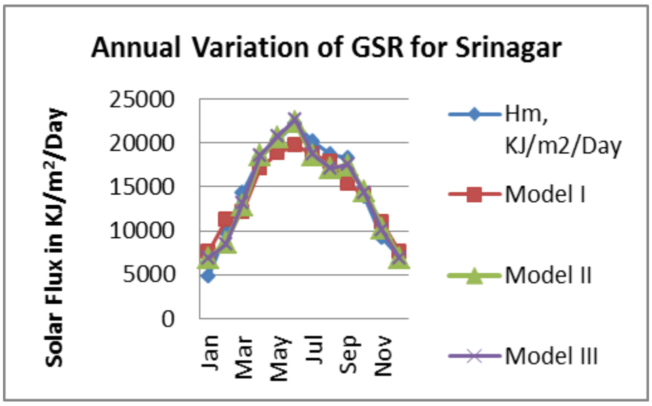

Fig. 4: Annual Variation of GSR for Srinagar

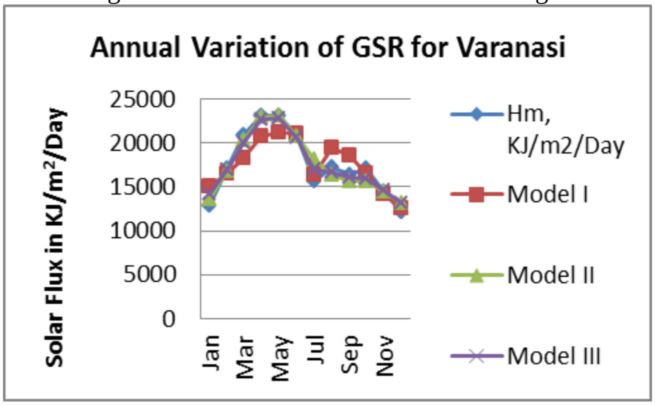

Fig. 5: Annual Variation of GSR for Varanasi

IV. EVALUATION AND COMPARISON

To evaluate the performance of each model developed here and to compare these models, three basic techniques of error estimation is used here which are given as,

$$MPE = \frac{1}{N}\Sigma\left[\frac{Hm - Hc}{Hm}\right] * 100$$

$$MBE = \frac{1}{N}\Sigma[Hc - Hm], \text{ KJ/m}^2\text{/day}$$

$$RMSE = \sqrt{\left[\frac{1}{N}\right]\Sigma(Hc - Hm)^2}, \text{ KJ/m}^2\text{/day}$$

Where H_c= Calculated GSR, KJ/m^2/day

The results are presented in table 2.

Location	Parameter	Model		
		I	II	III
Amritsar	MBE	53.08	-3.07	14.31
	MPE	-0.1	-0.28	-0.05
	RMSE	627.39	964.17	462.67
Bhopal	MBE	-93.49	113.08	-28.04
	MPE	-0.1	-0.59	-0.17
	RMSE	1258.95	1304.67	587.17
Delhi	MBE	-82.7	-45.37	-77.31
	MPE	-0.1	-0.12	-0.09
	RMSE	820.67	585.75	516.5
Srinagar	MBE	-450.33	-177.59	-157.93
	MPE	-0.1	-1.65	-1.66
	RMSE	1792.94	1113.23	1102.68
Varanasi	MBE	-60.48	-23.91	-65.75

	MPE	-0.1	-0.36	-0.26
	RMSE	1617.58	967.57	772.83

Table 2: Comparison of Models with Measured Radiations in Terms of MBE, MPE and RMSE

V. RESULTS AND DISCUSSION

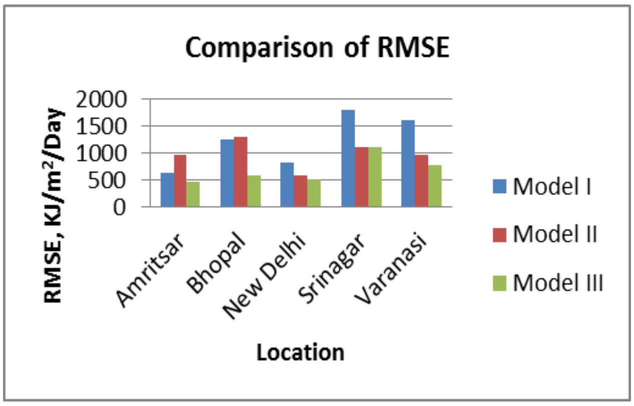

Fig. 6:

VI. CONCLUSION

From the results obtained, it could be concluded that the GSR have a strong dependence on the air temperature data as the deviation of calculated GSR from the measured values is lowest when estimated from model developed on the basis of only temperature data. However highest deviation is there when using only the sunshine our data. In the present work, the model which we have developed by combining both factors shows little deviation which is very less as compared to that from sunshine hours, however little more than that using air temperature. But improvements in RMSE using the proposed Model III, as is clear from fig. 6 shows that it can be effectively utilized for the estimation of GSR.

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