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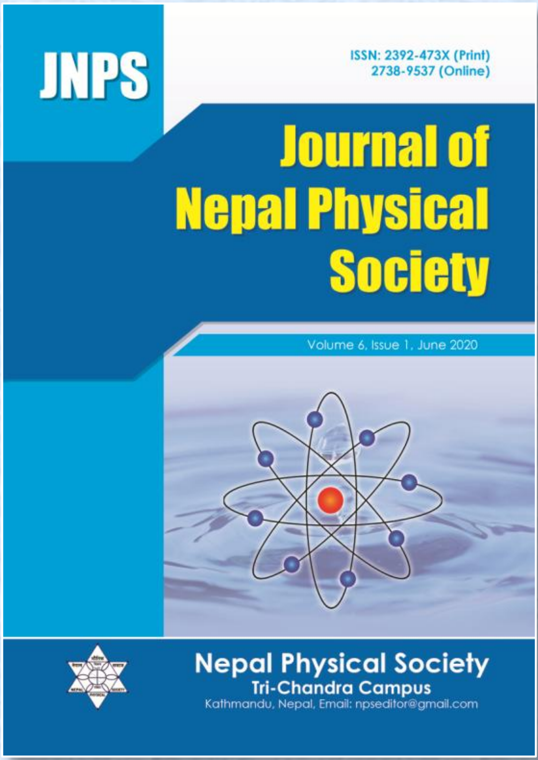

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Evaluation of Global Solar Radiation using Sunshine Hour, Temperature and Relative Humidity at Low Land Region of Nepal

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Abstract

The accurate knowledge of solar energy potential is essential for agricultural scientists, energy engineers, architects and hydrologists for relevant applications in concerned fields. It is cleanest and freely available renewable energy measured using CMP6 Pyranometer. However, it is quite challenging to acquire accurate solar radiation data in different locations of Nepal because of the high cost of instruments and maintenances. In these circumstances, it is essential to select an appropriate empirical model to predict global solar radiation for the use of future at low land, Nepalgunj (28.102°N, 81.668°E and alt. 165 masl) for the year 2011-2012. In this paper, six different empirical models have been used based on regression technique, provided the meteorological data. The empirical constants (a = 0.61, b = 0.05, c = -0.0012 and d = -0.017) are obtained to predict Global solar radiation. The values of statistical tools such as mean percentage error, mean bias error, root mean square error, and coefficient of determination obtained for Abdalla model are 1.99%, 0.003 MJ/m^2/day, 2.04 MJ/m^2/day and 0.74 respectively. Using the error analysis, it is concluded that the Abdalla model is better than others. So the empirical constants of this model are utilized to predict the global solar radiation to the similar geographical sites of Nepal for the years to come and it can be used to estimate the missing data of solar radiation for the respective sites.

Keywords: Empirical models, Error analysis, Global solar radiation, Regression technique.

1. INTRODUCTION

Global solar radiation is the fundamental input for designing, optimization and performance evaluation of numerous applications of solar technologies such as photovoltaic and thermal solar systems, solar cooking for many more specific locations [1]. The best way of measuring the amount of global solar radiation at a site is to install Pyranometer with a data logger at many locations in different regions of Nepal [2]. However, it is extremely expensive due to lack of skillful manpower and instruments for a longer time in developing countries like Nepal. Thus solar radiation measurements are not readily available because of financial constraint and lack of technical manpower. Nepal is situated between 26.367°-30.450° N latitude and 80.683°-88.200° E longitude. So it is closer to the solar belt. The National average global solar radiation is 4.23 kWh/m^2/day and sunshine hour is about 300 days in a year [3]. The national average sunshine duration is 6.8 hr/day. Hence solar energy is one of the best options in developing countries like Nepal [1, 3, 4].

In this condition, it is the only way to develop the best possible methods or select the appropriate models to correlate GSR with different meteorological parameters at a place where data is collected [5, 6]. The better model then used for a location of similar metrological and geographical characteristics at which solar data are not available [7, 8, 9]. It is shown that Angstr*ö*m proposed the first correlation model for estimating the monthly average daily global solar radiation on a horizontal surface using the sunshine duration [11]. Prescott has put this relation more convenient form for all sky condition as [12],

$$\frac{H_g}{H_o} = a + b\frac{n}{N} \quad (1)$$

where, H_g (MJ/m^2/day) the monthly average daily global solar radiation on a horizontal surface, H_o (MJ/m^2/day) is the monthly average daily extraterrestrial solar radiation, n is a monthly average daily bright sunshine hour, N is the monthly average maximum possible daily sunshine hour or day length and a & b are empirical constants.

The above Angstrom- Prescott model has been found to be very appropriate for a large number of locations and most extensively used correlational model [7, 13, 14]. There are number of correlational models including more meteorological parameters such as latitude, maximum ambient temperature, minimum temperature, precipitation, relative humidity, elevation, amount of cloud cover etc. has been developed by different researchers [7-14]. They developed quadratic correlation models and multiple linear regression form. Karsten [15] proposed a new method to evaluate the coefficient of Angstr*ö*m- Prescott model. In the paper, he assumed that the physical meaning of 'a' is monthly average daily diffused radiation transmittance H_g/H_o that of b is rate of increase of H_g/H_o with n/N [16].

In this paper we use the modified Angstr*ö*m formula (1) and linear and multiple technical relation method used to estimate the regression coefficients for the estimation of global solar radiation (GSR) using different meteorological parameters.

2. METHODS AND INSTRUMENTATION

The daily data of total solar radiation, sunshine hours, relative humidity, rainfall and maximum & minimum temperature on the horizontal surface were collected from the Department of Hydrology and Meteorology (DHM), Government of Nepal for Nepalgunj (lat. 28.10^{o}N, lon. 81.67^{o}E and Alt. 165.0 masl). It is located at the mid-western part of Nepal at providence No. 5, in Banke district, Bheri zone. Nepalgunj has a sub-tropical climate. The highest temperature recorded in Nepalgunj was 45.0°C on 16 June 1995 on the summer season, while the minimum temperature recorded was −0.3°C on 9 January 2013, on the winter season. The rainy season starts from June and lasting into September, during which there is less hot and very humid. The sunny day of winter is usually pleasant. It is sometimes foggy and overcast and then it can be chilly with temperatures below 10°C [17].

The total radiation of the horizontal surface was measured by using Kipp and Zonen CMP6 Pyranometer. The CMP6 Pyranometer consists of black surface and gets heated exposed to the solar radiation then we get global solar radiation in the form of W/m^2. This typical Pyranometer has a wide spectral range of the instrument from 280 nm to 2800 nm. The operating temperature is from -40^{o}C to 80^{o}C. The sensitivity of instrument and field of view is 5 to 15 µV/W/m^2 and 180^o respectively. In this instrument, the measuring data is recorded by LOGBOX SD data logger within a minute resolution for 24 hours. The special features of this instrument are low noise high resolution and low power consumption. It works in all weather conditions which collects the data at real-time for needs of Meteorological parameters [18].

The extraterrestrial solar radiation (H_o) can be calculated from the following equation [14],

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360 n_d}{365}\right)\right]\left[\cos\emptyset \cos\delta \sin\omega + \frac{\pi}{180}\omega \sin\emptyset \sin\delta\right] \quad (2)$$

Where I_{sc} is the solar constant (=1367 W m^{-2}), ∅ the latitude of the site (rad), δ the solar declination (rad), ω the mean sunrise hour angle for the given month, and n_d the Julian day number of the year starting from the first of January. The solar declination (δ) and the mean sunrise hour angle (ω) can be calculated by the following equations.

$$(\delta \text{ degree}) = 23.45\sin\left[\frac{360}{365}(284 + n_d)\right] \quad (3)$$

$$\omega = \cos^{-1}(-\tan\emptyset \tan\delta) \quad (4)$$

The relation of the day length is

$$N = \frac{2}{15}\omega = \frac{2}{15}\cos^{-1}(-\tan\emptyset \tan\delta) \quad (5)$$

The clearness index (K_T) as the ratio of the measured global solar radiation (H_g) to the extraterrestrial solar radiation H_o.

For long time, data of solar radiation has not been sufficient to evaluate magnitude of total solar radiation distribution. Then many methods have been tried to deduce its value. The most widely used relationship to estimate daily average hourly global radiation on a horizontal surface H is that given by Angström - Prescott formula, equation (1). The six different empirical models based on sunshine hour, ambient temperature and relative humidity in the form of a single meteorological parameter and multiple meteorological parameter are used to analyze GSR [8, 10, 19, 20].

$$\frac{H_g}{H_o} = a + b\frac{n}{N} \quad \text{(A) Angstrom − prescott Model} \quad \text{.......(6)}$$

$$\frac{H_g}{H_o} = a + b\frac{n}{N} + c\left(\frac{n}{N}\right)^2 \quad \text{(B) Oglman et al.} \quad \text{.......(7)}$$

$$\frac{H_g}{H_o} = a + b(T_1) \quad \text{(C) Temperature based Model} \quad \text{.......(8)}$$

$$\frac{H_g}{H_o} = a + b(RH) \quad \text{(D) Humidity based Model} \quad \text{.......(9)}$$

$$\frac{H_g}{H_o} = a + b\left(\frac{n}{N}\right) + c(T_1) + d\,(RH) \quad \text{(E) Abdalla Model} \quad \text{.......(10)}$$

$$\frac{H_g}{H_o} = a + b\frac{n}{N} + c(RH) \quad \text{(F) Swarthman − Oguniade model} \quad \text{.......(11)}$$

The most widely used ORIGIN, Microsoft Office Excel software and MATLAB is used for data analysis. The finding the coefficients a, b, c and d should be used to find the predicted value of GSR. Finally compare the estimated and measured value of GSR and for the validation of data on the basis of statistical parameters like root mean square error (RMSE), mean bias (MBE) and mean percentage error (MPE) and coefficient of determination (R^2). Those predicted GSR and measured data of GSR are compared and at the end analyses the data and finally the better model will be selected [7]. The statistical tools are given as,

$$RMSE = \sqrt{\frac{1}{N}\sum(H_m - H_c)^2} \quad \text{.......(12)}$$

$$MBE = \frac{1}{N}\sum(H_m - H_c) \quad \text{.......(13)}$$

$$MPE = \frac{1}{N}\left[\sum\left(\frac{H_m - H_c}{H_m}\right) \times 100\right] \quad \text{.......(14)}$$

$$R^2 = \left\{\frac{1}{N}\sum\frac{(H_m - \overline{H_m})(H_c - \overline{H_c})}{\sigma_m \cdot \sigma_c}\right\}^2 \quad \text{.......(15)}$$

Where, N is the total number of observations, H_m and H_c are measured and estimated values and $\overline{H_m}$ and $\overline{H_c}$ are mean of measured and mean of estimated values respectively. In general, low values of root mean square error (RMSE), mean bias (MBE) and mean percentage error (MPE) are expected for the better performance of the model. RSME test provides information on the short-term performance at the same time MBE and MPE test provide information on the long-term performance. The positive and negative values of MBE represent the overestimation and the underestimation respectively of the radiations [16]. Preferably, for the best performance coefficient of determination (R^2) should be unity.

3. RESULTS AND DISCUSSION

The correlation of global solar radiation and clearness index (K_T) with the sunshine hour (n), maximum temperature (T_{max}), relative humidity and rainfall is shown are Table 1. It shows that the global solar radiation is directly correlated with sunshine hour, maximum temperature as 0.81 & 0.75 and as 0.85 & 0.88, and it is inversely correlated with relative humidity as -0.72 and -0.76 for the year 2011 and 2012, respectively. Again, the clearness index is also correlated significantly with given parameters. So we choose these correlation models based on these meteorological parameters to estimate GSR.

Table 1: Correlation coefficient of global solar radiation and clearness index with meteorological parameters

Year	GSR correlate with parameters				K_T correlate with parameters			
	n	T_{max}	Relative Humidity	Rainfall	n	T_{max}	Relative Humidity	Rainfall
2011	0.81	0.75	-0.72	0.14	0.71	0.18	-0.55	-0.26
2012	0.85	0.88	-0.76	0.21	0.68	0.24	-0.57	-0.39

By using regression technique, the empirical constants a, b, c, and d are found for different correlation models. Those values are used for estimation of daily GSR on these relations for different years at the Trans – Himalaya region separately. The estimated GSR was compared with corresponding values of measured radiation. To analyze the validity of used model we perform different statistical tests. The statistical tools implemented in all applied models are RMSE, MPE, MBE, and R^2. The outcomes of these statistical tools and values of empirical constants are introduced in table 2.

Table 2: Statistical indicators and empirical constants for different correlation models used in research for year 2011/2012 using daily measured data (Optimal values are bold-faced)

Year	Model	Statistical tools				Empirical constants				
		RMSE (MJ/m^2-d)	MBE (MJ/m^2-d)	MPE (%)	R^2	a	b	c	d	a + b
2011	A	2.330	-0.025	2.388	0.651	0.40	0.117			0.514
	B	2.327	-0.024	2.383	0.651	0.42	0.019	0.088		0.438
	C	2.450	-0.012	2.659	0.614	0.48	-0.0004			0.475
	D	2.270	0.060	2.240	0.669	0.61	-0.002			0.610
	E	**2.220**	**0.003**	**2.187**	**0.683**	0.61	0.046	-0.0012	-0.002	**0.653**
	F	2.250	0.039	2.198	0.675	0.55	0.055	-0.002		0.602
2012	A	2.062	-0.078	2.083	0.732	0.38	0.093			0.476
	B	2.060	-0.076	2.073	0.732	0.41	-0.016	0.095		0.394
	C	2.100	-0.016	2.146	0.721	0.39	0.002			0.393
	D	2.060	**-0.011**	2.040	0.732	0.52	-0.001			0.514
	E	**2.040**	-0.026	**1.992**	**0.738**	0.46	0.060	-0.0001	-0.001	**0.520**
	F	2.038	-0.023	1.992	0.737	0.46	0.060	-0.001		0.517

In the study for the estimation of GSR, we have taken various single and multiple meteorological parameter correlation models. Among those models, model-E, Abdalla model, multiple parameter correlation model of a sunshine hour, maximum temperature, and average relative humidity perform better result than other models due to its least value of RMSE, MBE and MPE and higher value of coefficient of determination. The Fig. 1 gives the bar diagram of statistical tools. The RMSE, MBE, MPE and R^2 for model-E is 2.22, 0.003, 2.187, 0.683 and 2.04, -0.026, 1.992, 0.738 for year 2011 and 2012 respectively. All the values are within a valid range.

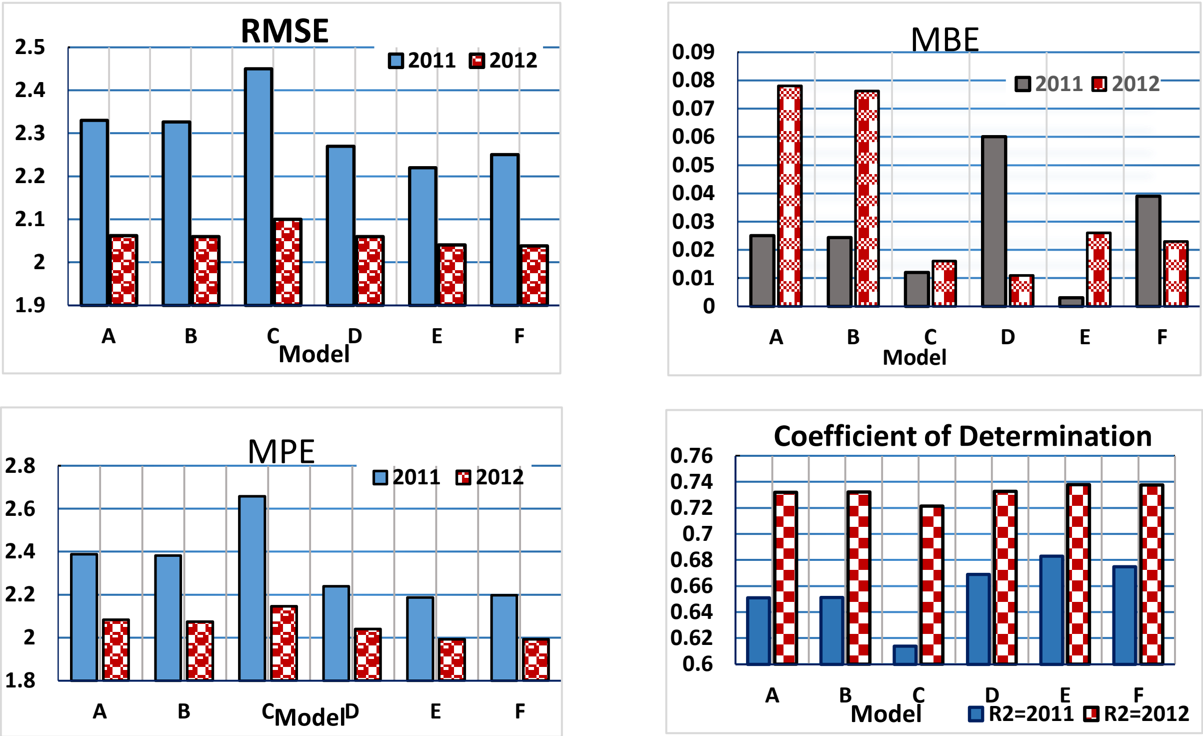
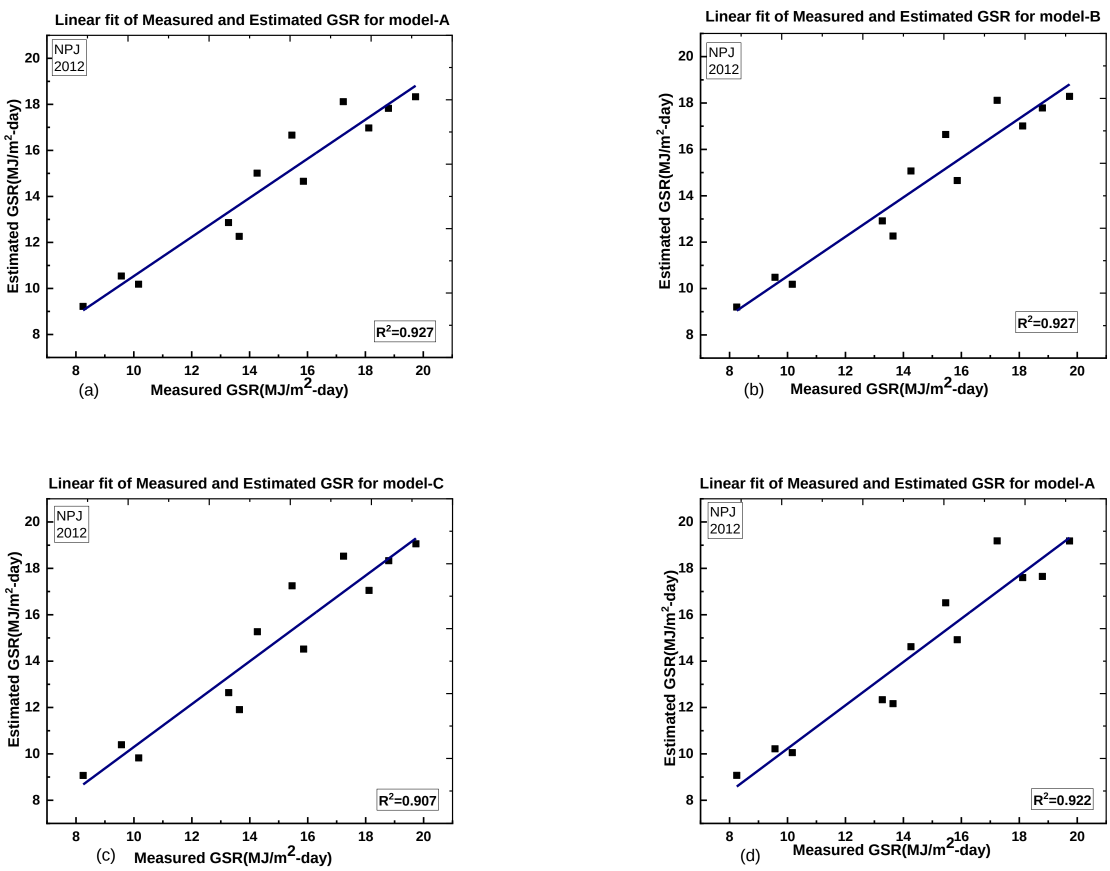


Fig. 1: *Statistical indices for given six models for year 2011-2012 at Nepalgunj*



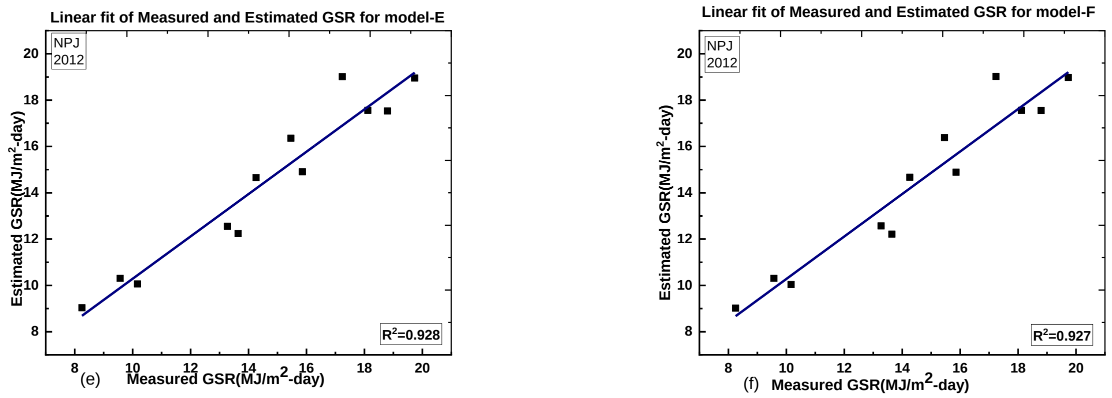
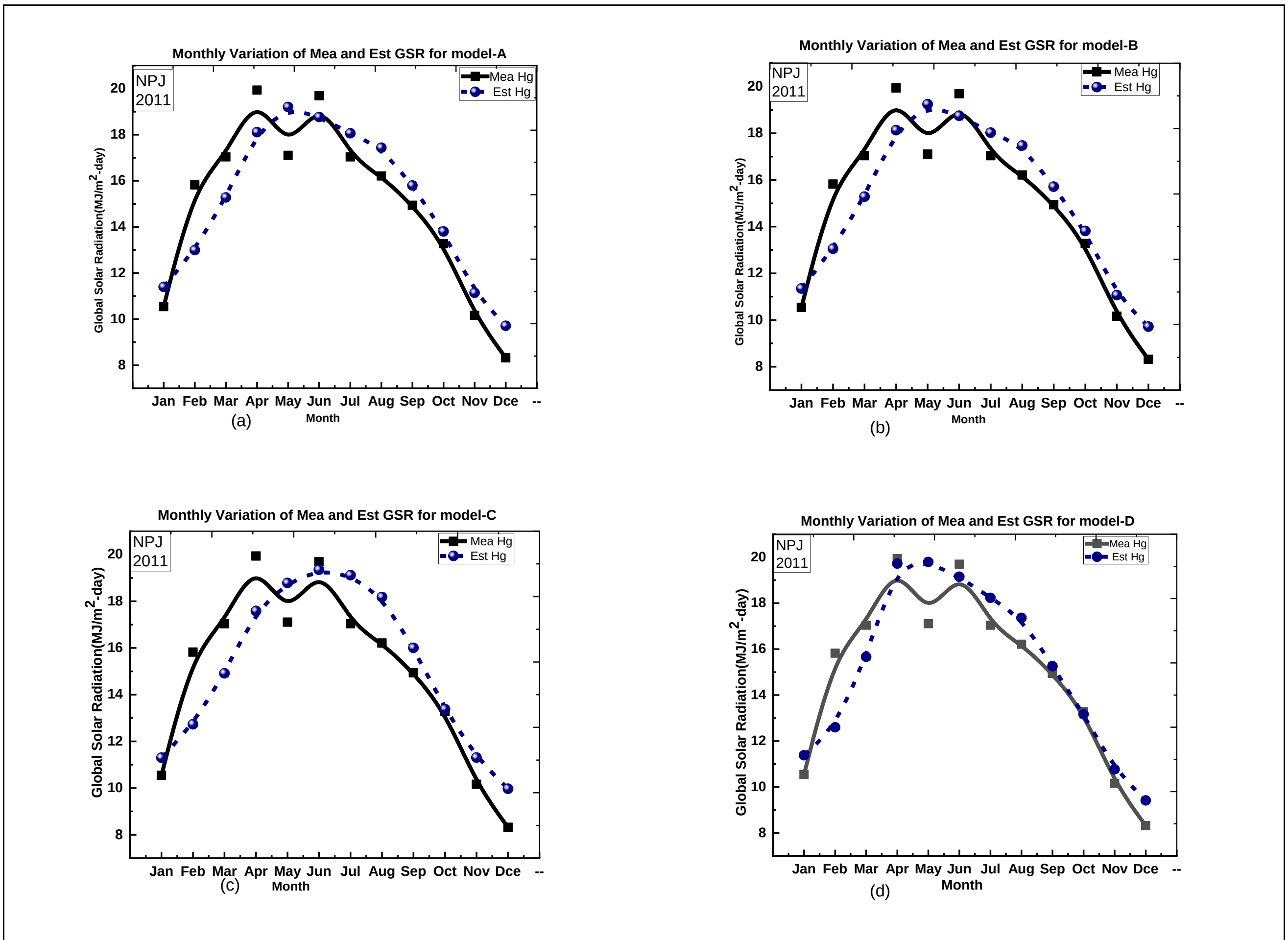


Fig. 2(a), (b), (c), (d), (f), (g): *linear variation of monthly average measured and estimated GSR for given models for year 2012 at Nepalgunj.*

The linear variation of monthly average measured and estimated GSR for given correlation models is shown in Fig.2 for the year 2012. It shows that there is a remarkable agreement between monthly average daily GSR for different models and better agreement found for model-E with highly acceptable coefficient of determination (R^2) equal to 0.928.



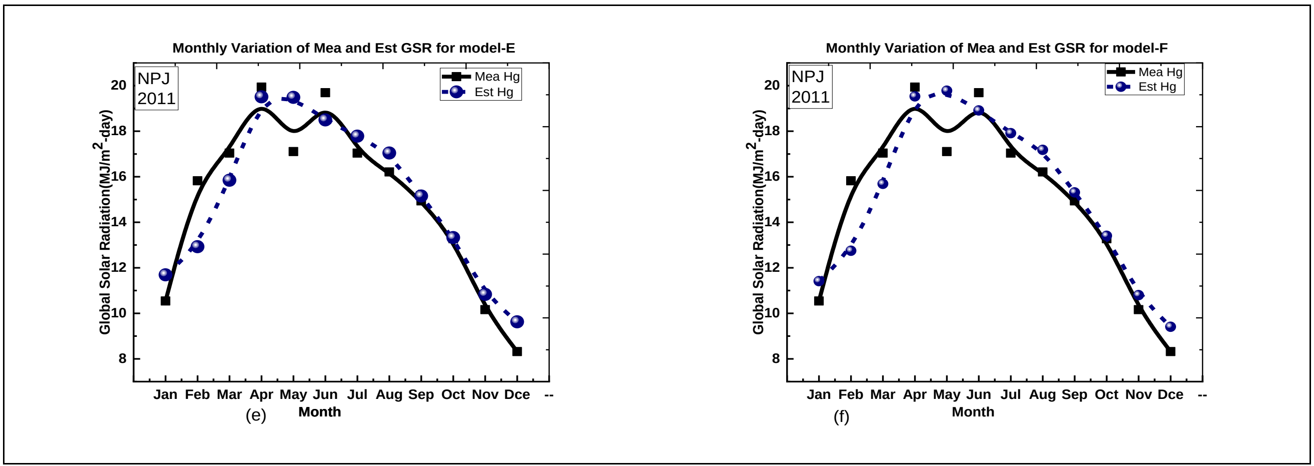


Fig.3 (a), (b), (c), (d), (e), (f): *Monthly variation of measured and estimated GSR for given models for year 2011 at Nepalgunj*

The Monthly variation of measured and estimated GSR for given correlation models is shown in Fig.3 for year the 2011. It shows that there is a remarkable agreement between monthly average daily GSR for different models for Nepalgunj and better agreement found for Abdalla model. However, minor variations can be observed during the rainy season. The values of empirical constants 'a' and 'b' depend on latitude, relative sunshine hours, altitude, relative humidity, maximum air temperature, and so on. Reflecting upon the physical significance, 'a' represents the case of overall atmospheric transmittance for an overcast sky condition, i.e. (n/N=0), while the coefficient 'b' is the rate of increase of H_g/H_o with n/N. The sum of two correlation coefficient (a + b) significantly represents the overall transmittance under clear sky condition or clear sky index suggested by [16]. We found (a + b) for given models vary from 0.393 to 0.653. The Abdalla model secured (a + b) as 0.653 and 0.52 for the years 2011 and 2012 respectively, greater than other models. The maximum GSR is (19.94 ±1.97)MJ/m^2/day in April and minimum GSR (8.32±0.6) MJ/m^2/day in December in the year 2011. Similarly, for the year 2012, the maximum GSR is (19.74 ± 2.74) MJ/m^2/day in June and minimum GSR (8.25 ± 0.71) MJ/m^2/day in December. The annual average global solar radiation is about (12.74 ± 0.25) MJ/m^2/day, which is a significant amount to operate many more energy based devices.

Table 3: Comparison between measured and estimated monthly average daily global solar radiation (MJ/m^2-day) at Nepalgunj for model-E

year / month	2011			2012		
	MeaHg	**EstHg-E**	**PE (%)**	**MeaHg**	**Est Hg-E**	**PE (%)**
Jan	10.54	11.69	-10.89	10.17	10.06	1.04
Feb	15.82	12.93	18.31	13.64	12.23	10.34
Mar	17.04	15.85	7.01	15.86	14.90	6.04
Apr	19.94	19.51	2.15	18.12	17.56	3.08
May	17.11	19.49	-13.91	17.24	19.02	-10.31
Jun	19.69	18.50	6.08	19.74	18.95	3.99
Jul	17.04	17.78	-4.37	18.80	17.53	6.76
Aug	16.21	17.04	-5.13	15.46	16.35	-5.77
Sep	14.94	15.15	-1.41	14.26	14.65	-2.72
Oct	13.27	13.33	-0.40	13.27	12.56	5.40
Nov	10.16	10.83	-6.60	9.57	10.31	-7.68
Dec	8.32	9.63	-15.73	8.25	9.03	-9.48

The monthly average estimated GSR for model E(EstHg-E) is compared with that measured GSR(MeaHg) in Table 3 for the correlation model E. There is tentatively equal GSR data is found in Table 3. The relative percentage difference between measured and estimated GSR varies numerically from 0.4% to 18.3%. The PE is less than 7% at the time of clear days around post-monsoon which was due to fair weather at that time. At the time when the sky is cloudy, hazy, relatively less sunshine hour, and less transmittance at the month of December, the PE is numerically high. The value of relative sunshine hour is large at post-monsoon due to cleaning of weather after rain and also due to a large zenith angle and there is increase of transmittance, and the PE is low at that time. In the months of June, July, and August relative sunshine hour and transmittance are moderate valued due to cloud cover and clear sky after rain. Then the result is that GSR is large and PE is less than 7%. These variations can also be observed in Fig. 4, which gives the monthly variation of percentage error, relative sunshine hour, and transmittance. There is approximately good agreement among all parameters.

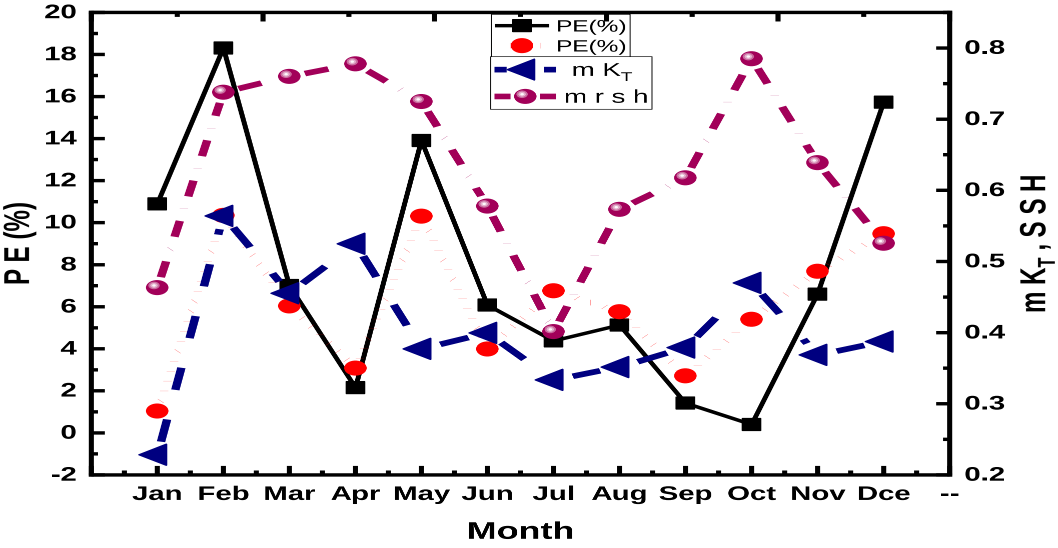


***Fig. 4:** Monthly variation of percentage change of GSR, transmittance and relative sunshine hour.*

4. CONCLUSIONS

On the basis of using the regression technique in different models, the Abdalla model is better than other models, and its absolute values of MPE, MBE, RMSE and R^2 are about 2.7%, 0.003 MJ/m^2/day, 2.04 MJ/m^2/day and 0.74 respectively. It is concluded, the linear and quadratic modified Angstrom model and other temperature and relative humidity based models do not significantly improve the accuracy of estimation of daily average global solar radiation on the horizontal surface. Hence the multi parameter based Abdalla model is recommended for this location. This proposed model is able to predict the global solar radiation in any location as our results show that percentage error between measured and estimated GSR exhibit low values during the most of the months with maximum value in a single month (February) around 18%. The proposed model for Nepalgunj can be used for an estimation of global solar radiation for many similar geographical locations of Nepal. Again, the annual average global solar radiation is about 3.54 ± 0.25 MJ/m^2/day which is a significant amount to operate many more energy based devices.

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REFERENCES

[1] Poudyal, K. N., Bhattarai, B.K., Kjeldstad, B. and Sapkota, B.K. Solar Radiation Potential at Four Sites of Nepal, *Journal of the Institute of Engineering*, NUTA/IOE PCU/SAHR, **8**(3),189-197 (2011).

[2] Adhikari, K., Gurung, S. and Bhattarai, B. K. Empirical model based on meteorological parameters to estimate the global solar radiation in Nepal, *Bibechana* **11**(1), 25-33 (2014).

[3] Poudyal, K. N. Estimation of Global Solar Radiation Potential in Nepal, Doctoral Thesis at IOE, Tribhuvan University (2015).

[4] WECS, Water and Energy Commission Secretariat, "Energy Synopsis Report", Government of Nepal (2010).

[5] El-Sebaii, A. A. and Trabea, A. A. Estimation of Global Solar Radiation on Horizontal Surfaces Over Egypt, *Egypt. J. Solids*, **28**(1), 163-175 (2005).

[6] El-Sebaii, A. A., Al-Ghamdi, F.S., Al-Hazmi, Adel S. Faidah Estimation of Global Solar Radiation on horizontal surfaces in Jeddah, *Saudi Arabia Energy Policy*, **37**, 3645-3649 (2009).

[7] Iqbal, M. An Introduction to Solar Radiation, Academic Press New York (1983).

[8] Besharat Fariba, Dehghan Ali, A. and Faghih Ahmad, R. Empirical models for estimating global solar radiation: A review and case study. *Renewable and Sustainable Energy Reviews*, **21**, 798-821 (2013).

[9] Sayigh, A. A.M. Estimation of Total Radiation Intensity - A Universal Formula. In Mancini, N.A. and Quercia, I.F. (Eds.) 4th Course on Solar Energy Conversion, Vol. II; ICTP, Trieste, Italy (1977).

[10] Ahmad, M. J. and Tiwari, G. N. Solar radiation models–review. *International journal of energy and environment*, 1(3), 513-532 (2010).

[11] Angstrom, A. Solar and terrestrial radiation, *Quarterly Journal of Royal Meteorological Society*, **50** (210), 121–126 (1924).

[12] Prescott, J. A. Evaporation from water surface in relation to solar radiation, *Transactions of the Royal Society of Australia*, **64**, 114–118 (1940).

[13] Gopinathan, K. K. A simple method for predicting global solar radiation on a horizontal surface. *Solar and Wind Technology*, **5**, 581–583 (1988).

[14] Duffie, J. A. and Beckman, W. A. Solar Engineering of Thermal Processes, 2nd Edition, *John Wiley and Sons*, New York. NY (1991).

[15] Hinrichsen, K. The angstrom formula with coefficients having a physical meaning, *Solar Energy*, **52** (6), 491 (1994).

[16] Ogolo, E. O. "Evaluating the performance of some predictive models for estimating global solar radiation across varying climate condition in Nigeria, *Indian Journal of radio and space Physics*, **39**, 121-131 (2010).

[17] Wikipedia contributors, "Nepalgunj — Wikipedia, the free encyclopedia," (2020), [Online; accessed 26-March-2020].

[18] Kipp and Zonen, Manual CMA and CMP series, Instruction Manual, Version: 0806. Kipp and Zonen, B.V. Deiftechpark 36, 2628 XH Delft, The Netherlands (2006).

[19] Falayi, E. O., Adepitan, J. O. and Rabiu, A. B. Empirical models for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria.International Journal of Physical Sciences, **3**(9), 210-216 (2008).

[20] Swartman, R. K., & Ogunlade, O. Solar radiation estimates from common parameters. Solar Energy, **11**, 170–172 (1967).