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Evaluation of global solar radiation with single and multiple parameter models in midwestern region Jumla, Nepal

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Abstract

This study is focused on the performance of four single and multiple-parameters models for the estimation of global solar radiation in Midwestern, Jumla Nepal located at latitude of 29.27^{0}N, longitude of 82.19^{0}E and at an elevation of 2,347 m from mean sea level. The study is carried for year 2011 and 2012. The performance of models was evaluated on the basis of Root Mean Square Error RMSE, Mean Bias Error MBE, Mean Percentage error PME and coefficient of determination (R^2). Based on the statistical error indices obtained, Swarthman- Ogunide model was found to perform best in terms of accuracy with least RMSE value and highest coefficient of determination, R^2 value for the location. Thus, the Swarthman - Ogunide model is suitable for estimating global solar radiation in the Midwestern, Jumla Nepal and other locations with similar geographical and climatic conditions. Also, from regression technique and statistical analysis it is found that sunshine based modified Angstrom-Prescott model showed the best results in terms of empirical coefficients a and b are 0.41, 0.34 and 0.35, 0.46 respectively.

Keywords: Global Solar radiation, Clearness index, Empirical model, Statistical error, Regression analysis.

Introduction

In order to utilize solar energy in adequate amount, it is essential to know information about solar radiation and its components of a particular location. Solar radiation data are applicable in many sectors such as solar heating, cooking, internal illumination of buildings, drying etc and are largely used by agriculturist, hydrologist and solar engineers[1]. Global solar radiation (GSR) played considerable role in renewable energy source as an important economic parameter. Currently, it is matter of study due to its importance in delivering energy in Earth climate system. The climatic condition and geography such as longitude, latitude and altitude of particular site play crucial role to gather amount of solar radiation. The global solar radiation received at any site is not only useful for the local community rather it is equally beneficial for global community. In order to design and manufacture solar devices, it is necessary to know the information about distribution of solar radiation throughout the world[2].

The information of solar radiation for the specific area or location is crucial for many practical applications including, hydrology, modern agriculture, solar active energy, solar passive energy and climate change. It is unfortunately that, to a lot of people of developing countries like Nepal, solar radiation measurements are not accessible due to the heavy costs associated with purchase, maintenance and calibration necessities of the measuring equipment. Consequently, the use of easily accessible meteorological parameters model is essential to estimate the solar radiation.

There are many factors on which GSR depends such as, atmospheric effect, including absorption and scattering of radiation, local variation in the atmosphere such as water vapor, clouds and pollution, latitude of the location and season of the year and time of day. The geography of Nepal is in suitable latitude and gathers sufficient solar radiation all over the country. According to different research work, the variation of average GSR varies from 3.6-6.2 kWh/m^2/day and sun shines about 300 days in a year. The national average sunshine hours are 6.8/day and national average solar energy is 4.7kWh/m^2/day[3]**.** Energy can play a dynamic role to link environment, social, economic dimensions of prosperous development of nation. The energy consumption scenario is rapidly increasing in geometrical ratio day by day. The consumption of fossil fuel and its impact on environment degradation are increasing in roaring speed in world wide. For developing countries like Nepal, whose major portion of economy is dependent on imported petroleum products to run day to day life, it is the matter of concern and discussion. Under these critical circumstances it is essential to utilize an alternative energy source to maximum level to escape the alarming fear of fuel crisis. In the context of Nepal, alternative energy source like sun has multiple applications to mitigate the current fossil fuel consumption.

To determine average solar radiation as a function of measured climatic data, there are several empirical models. On the basis of different models many research paper have been published for the determination of monthly averaged GSR and some of regression constants obtained from these models are globally applicable, while others are place dependent[4]. Single and multiple parameter models for the determination of GSR can be assigned on the basis of number of input meteorological parameters employed. Consequence of this, the model can be codified as single and multiple meteorological parameter models.

Single meteorological parameter models: Empirical models in which single meteorological variable is employed as crucial input data for the evaluation of GSR. The generally used meteorological variables in this domain are air temperature, sunshine duration and cloud cover.

Multiple - meteorological parameter models: For multiple parameter models, it requires two or more than two category of input data for the evaluation of GSR. In these models, the taken in meteorological variable involves maximum and minimum temperature, sunshine hour, dew point temperature, relative humidity, evaporation, soil temperature, cloud cover, precipitation, pressure and wind speed.

In spite of the fact that, many empirical models have been progressed for the evaluation of GSR and investigation is still progressing on to develop new model and to ameliorate the efficiency of previously existing models. It is essential to verify the both existing and recently developed models in a given geographical location for the proper application of solar energy.

The prime goal of this investigation is to use single and multiple meteorological parameter models for the determination of monthly average daily global solar radiation on the horizontal surface of Mid-western region, Jumla, Nepal.

Studied Models: Angstrom-Prescott Model: The Angstrom-Prescott model used to determine monthly average global solar radiation on the horizontal surface is the modified form of the Angstrom model[5]. It is a single- parameter model based on the sunshine duration. It has been broadly employed for determining the monthly average daily global solar radiation.

The Angstrom-Prescott model is given as:

$$\frac{H_g}{H_o} = a + b\frac{s}{S} \qquad (1)$$

Where: Hg=monthly average daily global radiation on a horizontal surface (MJ/m^2day); Ho=monthly average daily extraterrestrial radiation (MJ/m^2 day); s=monthly average daily hours of bright sunshine; S = monthly average day length, a, b = empirical coefficients.

The ratio of $\frac{H_g}{H_o} = K_T$ is called clearness index or coefficient of transmission can be defined as the ratio of monthly average daily radiation on a horizontal surface to the monthly average daily extraterrestrial radiation[6].

The monthly average daily extraterrestrial radiation on a horizontal surface (Ho) can be enumerated from the following equation[5].

$$H_o = \frac{24}{\pi} I_{sc} \left[1 + 0.033 \text{ Cos } \frac{360\, n}{365}\right] \left[\text{Cos } \phi \text{ Cos } \partial \text{ Sin } \omega + \frac{\pi}{180} \omega \text{ Sin } \Phi \text{ Sin } \partial\right] \qquad (2)$$

Where: Isc = solar constant (=1367Wm^{-2}); ϕ = latitude of the location; ∂ = solar declination angle; ω = mean sunshine hour angle for the given month; n = number of days of the year starting from first January.

The solar declination angle (∂) and the mean sunshine hour (ω) for the measured site can be computed by relation (3) and (4) respectively[5].

$$\delta = 23.45 \text{ Sin } \left[\frac{360(284 + n)}{365}\right] \qquad (3)$$

$$\omega = \text{Cos}^{-1}(-\tan\phi \tan\partial) \qquad (4)$$

For the month of evaluation, the optimum feasible sunshine period (monthly average day length S) can be determined by using the following equation[5].

$$S = \frac{2}{15}\omega \qquad (5)$$

Garica Model: This model was suggested by Garica in 1994 and it is single parameter based model for the evaluation of GSR. This model is modified form of Angstrom-Prescott model with temperature as input parameter and expressed in the form[7].

$$\frac{Hg}{Ho} = a + b\frac{\Delta T}{S} \qquad (6)$$

Where a, b are regression constants which we determined in our study. ΔT = difference between maximum and minimum temperature values.

Swarthman-Oguniade Model: This is the multiple-parameter model for the determination of global solar radiation and demonstrated in the form[8].

$$\frac{Hg}{Ho} = a + b\, S_R + c\, R_H \qquad (7)$$

Where: regression constants a, b and c are determined in this study. S_R = ratio of monthly average daily number of bright sunshine hours to the monthly average day length. R_H = relative humidity.

Olomiyesan and Oyedum Model: It is a multiple meteorological parameter model used for the evaluation of GSR and developed in the year 2016. The model is of the form[9].

$$\frac{Hg}{Ho} = a + b\frac{s}{S} + c\frac{\Delta T}{S} \qquad (8)$$

The regression constants a, b and c are estimated for the site of study. Other symbols are previously interpreted.

Methodology

The meteorological parameters like sunshine duration, daily temperature, relative humidity and solar radiation of selected site were collected from Department of Hydrology and Meteorology Government of Nepal. The investigated location was at latitude of 29.270 N, longitude of 82.19^0 E and at an elevation of 2,347 m from mean sea level. The data were measured by using CMP6 Pyranometer. The word pyranometer is originated from Greek language. In Greek language "Pyr" meaning "fire" and "ano' meaning "sky" and meter meaning measurement. The device which measures the solar radiation which comes from the sun through the sky is called pyranometer.

The operating temperature of CMP6 Pyranometer has from -40^o C to 80^{o}C and wide spectral range of instrument from 310 nm to 2800 nm, lies in the region of Ultraviolet, Visible and Infrared wavelength. The field of view and sensitivity of the apparatus are 180^o and 5215 μ/V/W/m^2 respectively. The instrument has data recording capability within a minute resolution for 24 hours and recorded by LOGBOX SD data recorder. For data recording 128 KB of memory is accessible and for long time data storage requirements SD memory card be used. Important features of this instrument are low noise, high resolution and minimum power consumption. It has operating capacity in all weather conditions. It collects the data at real time for the needs of meteorology and slow signal analysis[10].

Data analysis techniques and methods of comparison: The solar radiation data which we analyze to check the performance of above used model consists of monthly mean daily global solar radiation for Jumla, Nepal (latitude of 29.27^{0}N, longitude of 82.19^{0}E and at an elevation of 2,347 m from mean sea level) have been collected for the period of 2011 and 2012 from Department of Hydrology and Meteorology Government of Nepal. The regression constants for the models used were obtained using Microsoft excel software data analysis tool and graph are obtained with the help of Origin software. We perform statistical error such as the mean percentage error (MPE), root mean square error (RMSE), mean bias error (MBE), correlation coefficient (r) and coefficient of determination (R^2) to evaluate the efficiency of used model. To estimate GSR by using different models, these are the statistical test generally implied. The tests are explained as below[1]:

The Mean percentage error is defined as;

$$MPE = \left[\sum \left(\frac{H_m - H_c}{H_m} \right) \times 100 \right] / N \quad (9)$$

Where: H_m is measured value, $H_{,c}$ is calculated value of solar radiation and N is the total number of observations.
The root mean square error is defined as;

$$RMSE = \left[\sum \left(\frac{H_c - H_m}{N} \right)^2 \right]^{\frac{1}{2}} \quad (10)$$

The mean bias error is defined as;

$$MBE = \left[\sum \left(H_c - H_m \right) \right] / N \quad (11)$$

To compute the model of solar radiation prediction the commonly used statistical error are RMSE and MBE. RMSE is always positive, a zero value is ideal, but few errors in the sum can produce a significant increase in the indicator. This test provides information on the short-term comparison of the actual deviation between the calculated value and measured value. Low values of MBE are desirable but overestimation of an individual data element will cancel underestimation in a separate observation. It is possible to have large RMSE value at the same time a small MBE or vice versa.

The estimation of radiation by the use of different models on the basis of statistical errors such as RMSE and MBE is not sufficient to check to performance of models. In order to validate the applied models it is equally essential to use PME error, which gives more reliable result.

The statistical error which gives long term performance of examined regression equation is MPE, the average amount of overestimation and underestimation in the calculated value are given by positive and negative value of PME. A low value of MPE is sensible[11].

Results and discussion

Determination of empirical constants: In equations 1, 6, 7 and 8 we employed the value of emprirical constants determined by linear regression analysis technique. The acquired equations for the year 2011 are given below.

$$\frac{H_g}{H_o} = 0.41 + 0.34 \frac{s}{S} \quad (12)$$

$$\frac{Hg}{Ho} = 0.43 + 0.13 \frac{\Delta T}{S} \quad (13)$$

$$\frac{Hg}{Ho} = 0.63 + 0.25\, S_R - 0.0023\, R_H \quad (14)$$

$$\frac{Hg}{Ho} = 0.42 + 0.11 \frac{s}{S} + 0.09 \frac{\Delta T}{S} \quad (15)$$

Similarly obtained equations for the year 2012 is given below.

$$\frac{H_g}{H_o} = 0.35 + 0.46 \frac{s}{S} \quad (16)$$

$$\frac{Hg}{Ho} = 0.27 + 0.26 \frac{\Delta T}{S} \quad (17)$$

$$\frac{Hg}{Ho} = 0.29 + 0.25\, S_R - 0.00034\, R_H \quad (18)$$

$$\frac{Hg}{Ho} = 0.20 + 0.11\,\frac{s}{S} + 0.09\,\frac{\Delta T}{S} \qquad (19)$$

For the determination of GSR of the specified place for the year 2011 and 2012 was done by employing modified equations of four different models as mentioned in equations 9 to 16.

A correlation of monthly average value of estimated GSR from four models (Angstrom-Prescott, Garica, Swarthman-Ogunide and Olomiyesan and Oyedum) with measured value GSR for Jumla in the year 2011 and 2012 are respectively shown in Table-1 and 2.

Table-1: Meteorological parameters and global solar radiation of Jumla for the year 2011.

Months	s	S	s/S	ΔT	ΔT /S	R_H	Measured (H_g) ($MJ/m^2/day$)	Hg Est1	Hg Est2	Hg Est3	Hg Est4
Jan	8.39	10.35	0.81	20.27	1.96	66.53	14.56	14.90	14.88	14.77	14.89
Feb	7.59	10.98	0.69	18.70	1.70	66.81	16.90	16.99	17.16	17.10	17.10
Mar	8.71	11.82	0.74	19.35	1.64	59.98	21.87	21.51	20.93	22.02	21.11
Apr	6.77	12.72	0.53	16.73	1.32	66.03	23.77	22.72	23.11	23.50	22.95
May	7.19	13.47	0.53	15.73	1.17	68.83	25.36	25.00	24.60	25.58	24.68
Jun	5.50	13.84	0.40	11.79	0.85	73.88	24.58	23.87	23.68	24.49	23.66
Jul	3.77	13.67	0.28	8.54	0.62	84.76	22.31	21.72	22.04	21.73	21.84
Aug	3.62	13.02	0.28	9.22	0.71	86.13	20.48	20.23	20.93	20.10	20.62
Sep	6.33	12.15	0.52	12.42	1.02	81.52	19.83	20.46	19.62	19.96	19.84
Oct	9.19	11.25	0.82	18.69	1.66	66.39	18.87	19.52	18.33	19.34	18.71
Nov	8.73	10.51	0.83	20.69	1.97	61.07	16.71	15.82	15.67	15.93	15.73
Dec	8.33	10.16	0.82	23.37	2.30	64.41	14.91	14.00	14.82	13.96	14.58

Table-2: Meteorological parameters and global solar radiation of Jumla for the year 2012.

Months	s	S	s/S	ΔT	ΔT /S	R_H	Measured (H_g) ($MJ/m^2/day$)	Hg Est1	Hg Est2	Hg Est3	Hg Est4
Jan	8.75	10.35	0.84	17.21	1.66	71.72	15.58	16.05	15.26	15.43	15.84
Feb	7.17	10.99	0.65	18.39	1.67	66.63	16.30	17.19	18.64	15.45	17.42
Mar	8.99	11.85	0.76	19.69	1.66	55.33	22.89	22.91	23.01	22.18	22.84
Apr	7.37	12.75	0.58	16.69	1.31	63.78	21.84	23.79	23.57	21.04	22.56
May	8.73	13.49	0.65	18.26	1.35	59.27	25.05	27.44	26.35	25.39	26.07
Jun	9.28	13.85	0.67	14.90	1.08	63.44	25.36	28.83	24.08	25.20	25.74
Jul	3.85	13.65	0.28	8.92	0.65	82.83	17.67	24.65	18.94	17.45	16.76
Aug	4.60	12.99	0.35	9.41	0.72	82.14	17.97	22.86	18.32	18.00	16.99
Sep	7.04	12.12	0.58	12.22	1.01	80.23	21.14	21.39	18.44	22.25	18.92
Oct	9.82	11.22	0.88	18.69	1.67	63.75	21.40	21.20	19.81	20.80	20.86
Nov	9.33	10.49	0.89	20.80	1.98	56.95	19.63	17.24	17.84	19.25	17.87
Dec	8.01	10.15	0.79	23.20	2.28	70.04	16.85	14.48	17.54	16.47	16.02

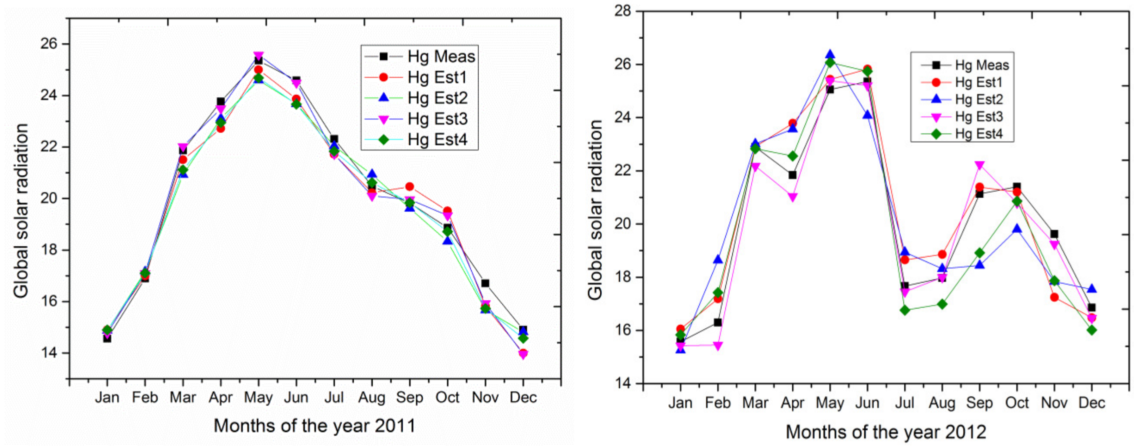

Figure-1: comparative study of estimated and measured global solar radiation for the year 2011 and 2012.

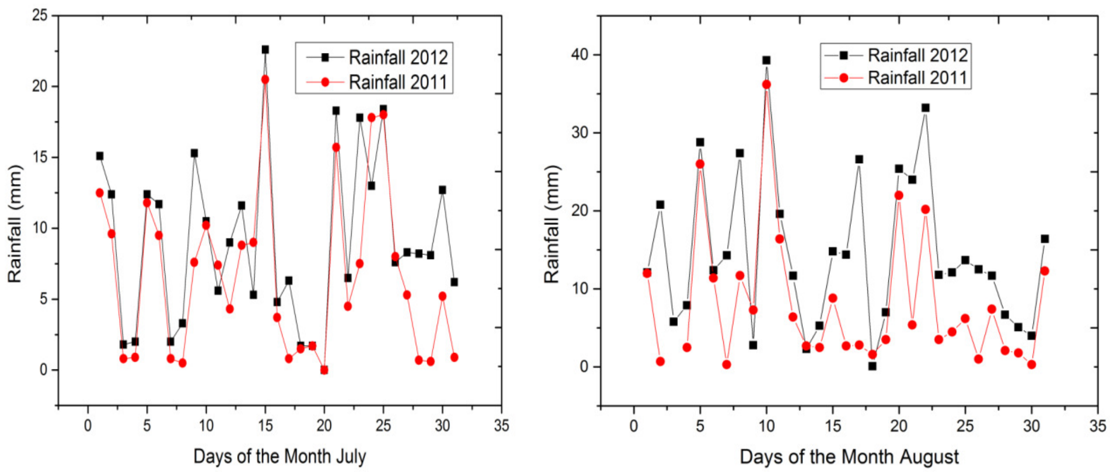

Figure-2: shows the variation of rainfall in the month of July and August for the year 2011 and 2012.

Figure-1 shows the comparative study of estimated and measured global solar radiation for the year 2011 and 2012 by employing four different models. From figure it has been noticed that the estimated global solar radiation by using all four models are in close agreement with the measured value of radiation for the year 2011 and 2012. For the year 2012 the global solar radiation has minimum value in the month of July and August as compared to previous year. The reason for the variation of GSR in these months is due to more amount of rainfall which is shown in Figure-2.

Figure-2 shows the variation of rainfall in the month of July and August for the year 2011 and 2012. The graph revealed that the amount of rainfall is higher in the month of July and August for the year 2012.

Statistical fallacy Indices of the employed Models: The preciseness of single and multiple parameter models employed was determined on the basis of statistical indices (MBE, MPE, RMSE and R^2). The evaluated values of fallacy indices of investigated models for the place are summarized in Table-3.

Table-3: Statistical Error Indicator of the Studied Models.

Jumla Midwestern Nepal	Model	MBE	MPE(%)	RMSE	R^2
Year 2011	Model 1	-0.28	1.34	0.63	0.97
	Model 2	-0.37	1.64	0.61	0.98
	Model 3	-0.14	0.80	0.45	0.99
	Model 4	-0.37	1.67	0.57	0.98
Year 2012	Model 1	1.36	1.76	2.98	0.93
	Model 2	0.41	-0.56	1.50	0.79
	Model 3	0.23	1.26	0.57	0.98
	Model 4	-0.32	1.70	1.37	0.91

Statistical Error Test: A lower value of RMSE signifies a good performance of studied model. Swarthman-oguniade model (model 3) shows the lowest RMSE values among all models used. On the basis of coefficient of determination (R^2) model 3 shows best result.

Conclusion

Single and multiple-parameter models have been employed in this study for the determination of global solar radiation. The statistical error indicator values showed that Swarthman-Ogunide model have least value of RMSE and signifies highest accuracy of the model for the selected location. Further, coefficient of determination, R^2 for the model 3 has maximum values. Hence, the inclusion of sunshine duration and relative humidity as input parameter improves the performance of global solar radiation model in the location. Also, based on RMSE value and coefficient of determination the Olomiyesan and Oyedum model have equally applicable for the location. The air temperature is also important parameter for the measurement of global solar radiation on the earth surface[12].

The regression technique and statistical analysis concluded that the sunshine based modified Angstrom-Prescott model (model 1) showed the best result in terms of empirical coefficients a and b are 0.41, 0.34 and 0.35, 0.46 respectively[13]. This research work is significant for the estimation of global solar radiation on the basis of sunshine hour and relative humidity.

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