

Estimation of Global Solar Radiation using Modified Angstrom Empirical formula on the basis of Meteorological parameters in Himalaya Region Pokhara, Nepal

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Abstract: This research work proposes the coefficient equation of modified Angstrom model using sunshine hour and meteorological parameters for the estimation of global solar radiation in Himalaya Region Pokhara (28.22°N, 83.32° E), Nepal . This site is about 800.0 m above from the sea level lying just 20.0 km south of the Machhaputre Himalayas. The model coefficients a and b obtained in this research are 0.43 and 0.23 respectively. The performance parameters of the model are: Root Mean Square Error RMSE = 0.13 MJ/m²/day, Mean Bias Error MBE= 0.02 MJ/m²/day Mean Percentage MPE= 5 percent and coefficient of determination R²= 0.70.

Keywords: global solar radiation, sunshine hour, empirical formula, clearness index, regression analysis

1. Introduction

The global or total solar radiation is the fundamental input for design, optimization and performance evaluation of solar technologies and applications such as photovoltaic and solar thermal systems for any specific location. However, for many developing countries including Nepal, solar radiation measurements are not readily available lack of financial constraint associated with acquiring the solar radiation data. The national average sunshine duration and solar insolation are 6.8/day and 4.7 kWh/sq.m/day respectively. However the energy scenario of Nepal is alarming situation because of 6 to 16 hours loads shedding per day at rainy season and dry season respectively [1].

In this situation, it is only option to develop the best possible methods or select the appropriate models to find out the authentic data of global solar radiation [2]. There are several types of empirical formulae for estimating the monthly mean daily global solar radiation as a function of readily measured climatic data [3,4,5] . It is known that the simplest regression relation is Angstrom-Prescott, which relates the monthly mean daily global solar radiation to the number of hours of bright sunshine. This paper explains on modified Angstrom formula and linear regression techniques used to estimate the regression coefficients for the estimation of global solar radiation using sunshine duration.

2. Methods and Instrumentation

The global solar radiation on a horizontal surface was measured using Kipp and Zonen CMP6 Pyranometer at Pokhara. This instrument is installed near Pokhara Airport. The CMP6

Pyranometer is shown in figure 1.



Figure 1. CMP6 Pyranometer

This CMP6 Pyranometer is first class among the different Pyranometers. Its operating temperature ranges from -40°C to 80°C . It has wide spectral range of instrument from 310 nm to 2800 nm. The sensitivity of instrument and field of view are 5 to $15\ \mu\text{V}/\text{W}/\text{m}^2$ and 180° respectively. In this instrument, the measuring data is recorded by LOGBOX SD data logger within a minute resolution for 24 hours. Its special features are low noise, high resolution and low power consumption. It works in all weather conditions. It collects the data at real time for the needs of meteorology and slow signal analysis. We can insert the SD memory card for long term data storage. For the communication LOGBOX uses either RS232 or RS485 communication port [6].

The global solar radiation (H_g) is measured using CMP6 Pyranometer on the horizontal surface at Pokhara. The relation of extraterrestrial global solar radiation H_0 is calculated using equation (1.10.3) [7].

$$H_0 = \frac{24}{\pi} I_{sc} \left(1 + 0.033 \cos \frac{360}{365} n\right) \left(\omega \frac{\pi}{180} \sin \phi \sin \delta + \cos \phi \cos \delta \sin \omega\right) \quad (1)$$

where H_0 is monthly mean of daily global extraterrestrial solar radiation ($\text{MJ}/\text{m}^2/\text{day}$), H_g is monthly mean of daily global solar radiation ($\text{MJ}/\text{m}^2/\text{day}$), ϕ is the latitude (rad) and δ is the solar declination angle (rad). ω is sunset hour angle for typical day and n is mean day of each months

where, n is the day of the year. January first $n=1$ to 365 days.

$$\delta = 23.45 \sin \left(\frac{360}{365} (284 + n)\right) \quad (2)$$

The relation of day length is,
$$N = \frac{2}{15} \cos^{-1}(-\tan \phi \tan \delta) \quad (3)$$

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

where ω is the sunset hour angle

On the basis of R^2 , the H_g/H_0 can be found using the linear equation and after applying the equation (1) for the extraterrestrial global solar radiation is found. At the end H_g can be calculated which will be novel work where all types of measuring instruments could not be installed.

3. Results and Discussion

3.1 Daily Variation of Global Solar Radiation in Pokhara

The diurnal variation of global solar radiation varies due to inclination, solar zenith angle, altitude, change in season and local weather condition. Figure 3.2 shows the daily variation of global solar radiation at the measurement site Pokhara. The maximum solar radiation is found to be 28.86 MJ/m²/day on 4th of June. The given figure shows that there is comparatively less amount of global solar radiation is found at the summer season due the excess clouds and rain at that time.

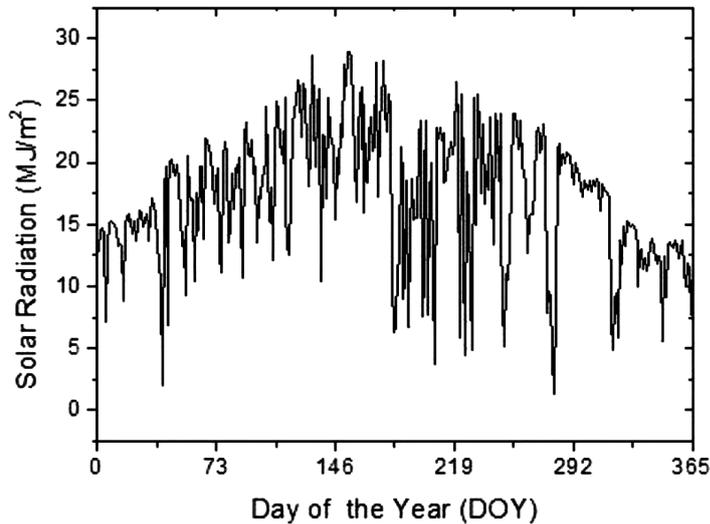


Figure 2 Daily Variation of Global Solar Radiation in 2009-2010

3.2. Monthly Variation of Global Solar Radiation

Figure 2 show the trend of measured and extra terrestrial global solar radiation is very much similar. However there was maximum solar radiation 23.21 MJ/m²/day is found in the month of June. The monthly obtained data indicates that the measured data are relevant as well as sufficient to explore the solar energy even in December when GSR is 12.04 MJ/m²/day.

Monthly mean measured radiation, global extraterrestrial solar radiation, clearness index are presented in given Table 3.1

Table 3.1: Meteorological Parameters for Pokhara, 2009-2010

Month	n (hours)	N (hours)	n/N	H _g MJ/m ² /day	H ₀ (MJ/m ² /day)	Clearness Index K _r =H _g /H ₀
Jan	7.7774	10.4315	0.7453	14.2977	21.6470	0.6613
Feb	7.3000	11.0263	0.6622	15.6855	26.0600	0.6023
Mar	6.9968	11.8292	0.5917	17.8546	31.8485	0.5632
Apr	7.3433	12.6893	0.5802	19.4620	37.4304	0.5216
May	6.9806	13.4076	0.5199	22.3728	40.8376	0.5492
Jun	7.2333	13.7666	0.5255	23.2134	42.2038	0.5501
Jul	4.8226	13.6034	0.3545	15.3787	41.6992	0.3703
Aug	3.5867	12.9994	0.2745	18.4421	38.9382	0.4742
Sep	4.6065	12.1714	0.3807	18.2363	34.2082	0.5368
Oct	7.6733	11.3119	0.6798	17.0272	28.1934	0.6111
Nov	6.1290	10.5969	0.5774	13.9031	22.8391	0.6067
Dec	8.0903	10.2442	0.7896	12.0415	20.3490	0.5920

3.3 Estimation of global solar radiation using sunshine duration

Global solar radiation is backbone for existence of life on the earth. Its measurement is too expensive, time consuming, risk of maintenance and calibration of the instruments. Therefore, it has been great importance to propose an efficient option to be used as a solar estimator based on other more readily available meteorological data. Several empirical models for calculating GSR are recommended in literature. Some of these models use variables like sunshine durations, air temperatures, relative humidity and cloudiness [8, 9, 10].

The values of sunshine duration including day length, fraction of sunshine hours, GSR, extraterrestrial solar radiation and clearness index are used to estimate regression coefficients “a” and “b”. On the basis of the regression coefficients and sunshine duration we could estimate the GSR for the years 2011 and 2012 at the same location.

Among the many empirical equations, the most widely used one is modified Angstrom empirical equation [11,12]. It is selected for the estimation of GSR in, Pokhara. Finally, using the linear regression method we found regression coefficients “a” and “b” which is shown in Table 3.1

Table 3.2: Regression coefficients at Pokhara of Nepal

Location /Coefficients	a	b
Pokhara	0.43	0.23

Hence the first order polynomial equation for Pokhara as explained by the given equation

$$\frac{H_g}{H_0} = 0.43 + 0.23\left(\frac{n}{N}\right) \quad (5)$$

The equation (5) used to estimate the GSR using the regression coefficients obtained in this study and sunshine duration measured at that particular location [13]. Figure 3.3 gives the comparison between measured values of GSR with predicted values of GSR in these three locations. The given Figure 3.3 showed that there is remarkable agreement between the measured and predicted values of GSR in Pokhara..However there is small variation during the time of rainy season.

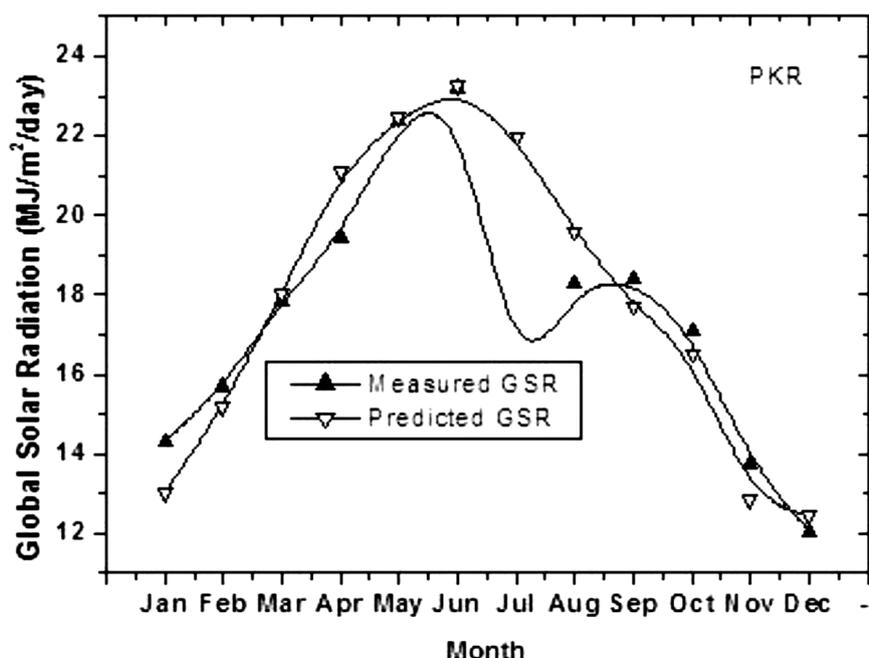


Figure 3: The comparison of measured GSR with predicted GSR At Pokhara (2009-2010)

The regression coefficients “a” and “b” are also called empirical constants and as earlier pointed out their values depend on latitude, relative sunshine hours, altitude, relative humidity, maximum air temperature and so on. The physical significance of the regression constants is that “a” represents the case of overall atmospheric transmission for an overcast sky condition i.e. $n/N=0$, while the coefficient “b” is the rate of increase of H_g/H_0 with n/N . The sum of two correlation coefficient $a+b$ significantly represents the overall transmission under clear sky condition or clear sky index suggested by [14]. The performance of the predicted GSR was statistically compared with measured GSR data. The values of root mean square error (RMSE) mean bias error (MBE) and mean percentage error (MPE) and coefficient of determination (R^2) are 0.13 MJ/m²/day, 0.02 MJ/m²/day, 6 percent, and 0.70 respectively. All the values are significant range. The values of MBE and MPE are very small and their values are closer to zero and they are highly significant up to the long term performance.

3.4 Estimation of GSR using regression coefficients and sunshine duration

The modified Angstrom relation is used to estimate the GSR and regression coefficients. The obtained regression coefficients from the year 2009-2010 are used to estimate the GSR for the years 2011 and 2012. The model estimated values of GSR of Pokhara is comparatively higher than the measured values. So that the estimated value is over estimated. The statistical parameters RMSE, MBE, MPE and R^2 are 3.41 MJ/m²/day, 2.61 MJ/m²/day, 4 percent, 0.96, and -5.48 MJ/m²/day, 3.84 MJ/m²/day, 11 percent, 0.83, in 2011 and 2012 respectively. It concluded that the adopted

model gives the best estimated values of GSR. The measured value of GSR versus estimated value of graphs is shown in figures 3.3 and 3.4.

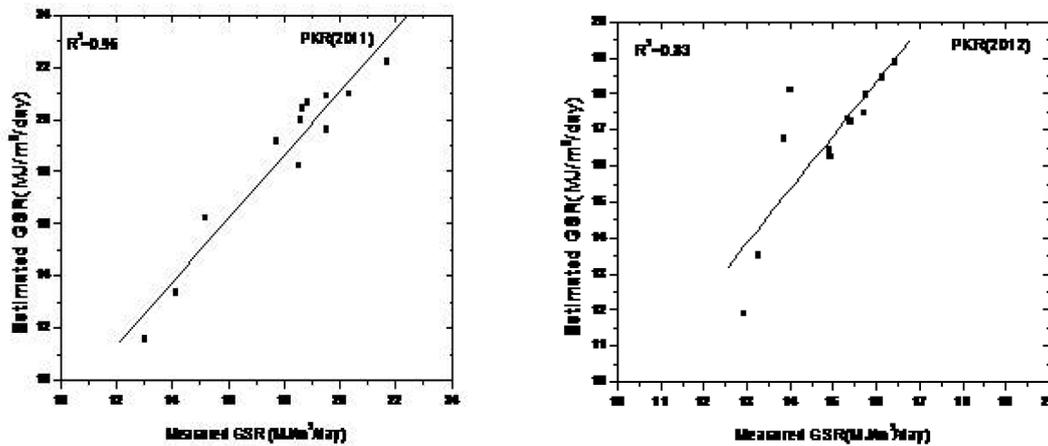


Figure 4 and 5: Comparison between measured and estimated GSR in Pokhara in 2011 and 2012

4. Conclusion

The prediction model is developed using monthly average daily values of clearness index, relative sunshine hour, and measured global solar radiation. The maximum and minimum values of monthly average global solar radiation are found 23.21 MJ/m²/day and 12.04 MJ/m²/day on June and December respectively. The overall performance of parameters RMSE, MBE, MPE and R^2 are found 0.13 MJ/m²/day, 0.02 MJ/m²/day, 5 percent, and 0.70 respectively. The above results showed that the estimated values of global solar radiation can be very efficiently used to compensate for the energy deficit. At the end, the obtained regression coefficients from the equation and sunshine duration could be employed for the estimation of global solar radiation in the year to come at the same location.

Acknowledgement: Authors are grateful to express thanks to Solar Radiation and Aerosol in Himalaya Region (SAHR) project of IOE Pulchowk (Nepal) for providing the data of Pyranometer. The support provided by the Prof. Balkrishna Sapkota, Prof. Binod K Bhattarai, Prof. B. P. Pokharel, Prof. R.K. Sharma, Asso. Prof. N.P. Sharma, faculty members and staffs of Department of Engineering Science and Humanities, Pulchowk Campus is highly acknowledged.

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