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Prediction of Solar Radiation using Empirical Models over Lowland Region Nepal

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ABSTRACT

Renewable energy sources are becoming more and more popular as a result of the world's rapidly rising energy needs and the depletion of fossil fuel stocks. Solar energy significantly increases the need for electricity. Due to high energy demands, solar energy most viable out among all of energy sources. Before choosing a location for a solar-powered power plant, it is necessary to predict or anticipate solar energy. For the estimation of the solar energy we use meteorological parameters such as sunshine hour, temperature and relative humidity on selected empirical models to find the empirical coefficients at the study site Biratnagar ($\text{Lat.}\,26^0 27' 15''$ E, $\text{Long.}\,87^0\ 16' 47''$N, and alt. 72 m) Nepal. Regression technique is utilized on meteorological parameters including global solar radiation at different models viz. Angstrom-Prescott (A-P) model, Ogunlade model, Gopinathan model and Hargreaves model. Among the four models, the A-P model is better than other models by analyzing the statistical tools. Finally, the empirical constants of A-P model $a = 0.40$ and $b = 0.11$ are found. The finding coefficients can be used to estimate the solar radiation and solar energy at similar geographical locations of Nepal.

Keywords: Meteorological parameters, Global solar radiation**,** Empirical model, Seasonal variation, Regression technique, Empirical coefficients.

1. INTRODUCTION

Solar energy is a vital source of sustenance for all living organisms on earth, and it originates from the sun through a process of thermonuclear fusion reaction at its core. This energy can be directly harnessed by Photo-voltaic cells or indirectly through wind, biomass, hydropower, and fossil biomass fuels [1]. The solar energy which is received on earth varies with latitude, cloud cover, aerosols, altitude, slope of the location and meteorological parameters. [2]. The study of solar radiation involves considering local weather conditions and meteorological parameters to design efficient solar energy devices.

Nepal is situated within the solar belt on the world map, specifically between the latitudes of 15 and 35^0 degrees. The country experiences around 300 days of sunshine annually, and the average amount of solar energy received per day is about 23 kwh/m^2/day. However, obtaining data on solar radiation is difficult and expensive due to limited advanced technology, skilled personnel, and instrumentation. As a result, only a few meteorological stations in developing countries like Nepal have access to this information. Solar energy system plays as a crucial role in diverse realms in Nepal; households' electricity & cook, irrigation as water pumping, grain draining and refrigeration, house heating system. Furthermore, it uses for traffic signal and street light [3,7]. There is about 25 % hard earn foreign currency is invested to import petroleum products. Solar energy cut off the cost of fossil fuel which helps to enhance the overall income of the country. Solar energy is environment friendly clean energy source and which helps to reduce the indoor and outdoor pollution of the nation. Government of Nepal (GoN) gives top priority to promote solar energy technology in Nepal. Recently Nepal Electricity Authority (GoN) has lunched the 25MW solar electric power project. There is about 10 MW of solar energy is produced and connected to the national grid and the remaining part will be completed within couple of year [8].

Rigorous literature review is over viewed and we found that there is no more enough measurement data on solar radiation so that the alternative way is urgent to predict the solar radiation for the promotion of solar energy technology in Nepal. Thus, empirical models are used to predict solar radiation based on physical and meteorological parameters [4].

The primary aim of this research work is to utilize regression analysis on meteorological factors in the lowland region of Biratnagar, Nepal, to determine the empirical constant. Many approaches and techniques exist for calculating horizontal Rs based on geophysical and atmospheric variables. For this study, the modified A-P model and Gopinathan Model, as well as the Hargreaves and Samani Model and Ogunlade and Swartman Model, were compared for the best fit [1,2,3]. The estimated values for total solar radiation were then evaluated by comparing them to measured values, using the Modified Angstrom and considering variables such as sunshine hours, rainfall, and temperature to determine the average daily total solar radiation at the study site [4, 5].

2. METHODS AND INSTRUMENTATION

The location of Biratnagar is at $\mathbf{26^0 27'15''}$ **E** North latitude and longitude $\mathbf{87^0\ 16'47''}$**N** East longitude, with an elevation of 72 meters above sea level. It is situated in the lowland region of the Morang district within Koshi Province. The climate in this area is characterized as warm and temperate, with ample rainfall in the summers and relatively low in the winter. The average annual temperature is 24.3^0C, and the average annual rainfall is approximately 1898 mm. The research site for this study is illustrated in Figure 1. In Biratnagar, sunshine hours, relative humidity, and temperatures are utilized to forecast global solar radiation and its components. The primary data sources for this study were daily solar radiation measurements on a horizontal surface, along with sunshine hours, temperature, and relative humidity data for the Biratnagar area, obtained from the Department of Hydrology and Meteorology, government of Nepal (DHM/GON). Those data is measured by CMP6 pyranometer.

Fig. 1: Map of Nepal with Measuring Site.

2.1. Theory and Models

Solar energy scientists have developed various empirical models on the basis of different meteorological parameters to predict the solar energy potential at the different part of the globe. The value of extraterrestrial solar radiation (H0) is determined by the solar constant and other physical parameters. The solar constant value varies due to the rotation of earth and solar cycles [12,13,18]. The global solar radiation (H_g) on the horizontal surface at Biratnagar is measured using a CMP6 Pyranometer. The relationship between extraterrestrial global solar radiation H_0 is calculated using equation 5 [9], and the variation in this relationship can be up to ± 3 percent. The expression for extraterrestrial radiation (H_0) is given by

$$H_0 = H_{sc}(1 + 0.033\cos\frac{360n}{365}) \quad \text{..................(1)}$$

where 'n' is the number of days.

Global solar radiation incident on a horizontal plane normal to radiation is given as

$$H_0 = H_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)\cos\theta_z \quad \text{......(2)}$$

H_0 is for horizontal surface at any time between sun shine and sunrise. From above these two equations,

$$H_0 = H_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)(\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta) \quad \text{......(3)}$$

On integrating,

$$H_0 = \frac{24}{\pi}H_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)\int_{-\omega}^{\omega}(\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta)d\omega \quad \text{......(4)}$$

Finally,

$$H_0 = \frac{24}{\pi}H_{SC}\left(1 + 0.033\cos\frac{360n}{365}\right)(\cos\phi\cos\delta\sin\omega + \omega\frac{\pi}{180}\sin\phi\sin\delta) \quad \text{......(5)}$$

where, ω is the hour angle and n are the day of the year. January first n=1 to 365 days.

2.2. The list of models used for study

2.2.1 Sunshine Based Model

Angstrom first proposed an empirical correlation that used sunshine hours to estimate global solar radiation. Later on, Prescott modified this correlation, which is now known as the Angstrom-Prescott model [7]. Equation 6 represents this model.

$$\frac{H_g}{H_0} = a + b\left(\frac{n}{N}\right) \quad \text{......(6)}$$

Angstrom's equations in research as well;

$$\frac{H_g}{H_0} = a + b\left(\frac{n}{N}\right) + cT_{max} \quad \text{......(7)}$$

$$\frac{H_g}{H_0} = a + b\log(R_H) \quad \text{......(8)}$$

The coefficients b and c imply the rate of increase of $\frac{H_g}{H_0}$ and $\frac{H_g}{H_0}$ is called as clearness index.

2.2.2 Gopinathan Model

Gopinathan model has given by the following correlations

$$\frac{H_g}{H_0} = a + b\left(\frac{n}{N}\right) \quad \text{......(9)}$$

Where, a = 0.265+0.07z-0.135 ($\frac{n}{N}$), b = 0.401-0.108z+0.325($\frac{n}{N}$), Z is altitude in kilometers.

2.2.3 Temperature -Based Model

According to the temperature-based model, the difference between the maximum and minimum temperatures is directly related to the amount of extraterrestrial radiation received at the ground level [11]. Hargreaves and Samani proposed an equation to estimate global solar radiation using only the maximum and minimum temperature, which is referred to as the Hargreaves and Samani model.

$$\frac{H}{H_0} = a\,(T_{max} - T_{min})^{0.5} \quad \text{......(10)}$$

where a=0.16 for interior region and 0.19 for coastal region.

2.2.4 Ogunlade and Swartman model

Several studies have attempted to utilize various meteorological parameters, such as rainfall, relative humidity, temperature, evaporation, in conjunction with traditional estimators like sunshine, air temperature, and cloudiness, to forecast solar energy potential and Swartman proposed that the global solar radiation can be expressed as a function of the ratio of actual sunshine duration to potential sunshine duration and mean relative humidity [6,8].

$$\frac{H}{H_O} = a + b\,\frac{n}{N} + c\,R_H \quad \text{......(11)}$$

2.3. Tools used for Measurement

In the present study, we examined the solar energy potential on a horizontal surface in the lowland region of Biratnagar using meteorological parameters. The solar radiation was measured using CMP6 Pyranometer, which were positioned in unobstructed areas and equipped with data loggers. Figure 2 displays the CMP6 Pyranometer used in this study.

Fig. 2: CMP6 Pyranometer [4].

The data are taken from Department of hydrology and meteorology, Kathmandu and arranged and analysis by using excel 2010. Graphical Analysis has been performed using Origin. Scatter plot, error bar has been used to compare the results.

3. RESULTS AND DISCUSSION

In this study we utilize the four different models such as Modified Angstrom-Prescott, Swartman and Ogunlade, Gopinathan, and Hargreaves to predict the best value of solar energy potential using regression analysis for the year 2015. For the validation of the models we use four different statistical indicators i.e., mean bias error (MBE), root mean square error (RMSE), correlation coefficient (R^2) and mean percentage error (MPE) respectively.

3.1. Variation in Solar Energy across Seasons

In 2015, seasonal variation of global solar radiation (GSR) for Winter (December, January, February), Spring (March, April, May), Summer (June, July, August), and Autumn (September, October, November) which is shown in Fig. 3.1. The seasonal variation error is plotted in Fig. 3.2. The average yearly value of GSR for 2015 is 15.05 $MJ/m^2/day$, and the average values for Winter, Spring, Summer, and Autumn are 10.67, 19.09, 15.75, and 14.54 $MJ/m^2/day$ respectively. The comparison between the measured and predicted GSR using model 1, 2, and 3 for Biratnagar in 2015 is shown in Fig. 3.3 (a, b, and c). The analysis of errors in the seasonal variation of GSR at Biratnagar (2015) is presented in Table 3.1.

The seasonal variation of GSR for Winter seasons (December, January, February), spring seasons (March, April, May), summer seasons (June, July, August) and autumn seasons (September, October, November) respectively were observed in 2015 year is shown in Fig. 3.1 and error in the seasonal variation is plotted in Fig. 3.2 respectively. The yearly average value of GSR for the year 2015 is 15.05 $MJ/m^2/day$ and the average values for Winter, Spring, Summer, Autumn respectively is found to be 10.67, 19.09, 15.75 and 14.54 $MJ/m^2/day$. The comparison between the monthly mean measured and predicted Global Solar Radiation in Biratnagar 2015 by using model 1, 2 and 3 models are shown in Fig. 3.3 (a, b and c). The error analysis on seasonal variation of Global Solar Radiation at Biratnagar (2015) is presented in Table 3.1.

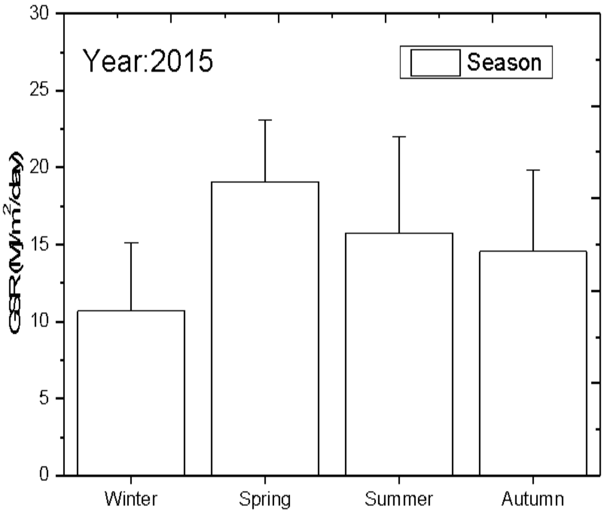


Fig 3.1: Seasonal variation of TSR in Biratnagar for year 2015.

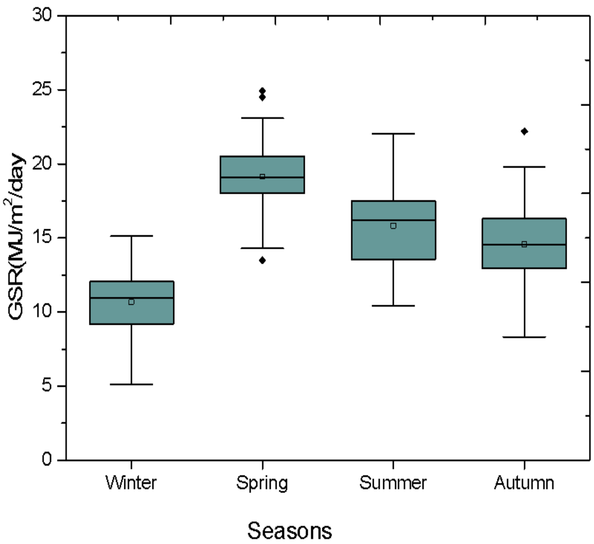
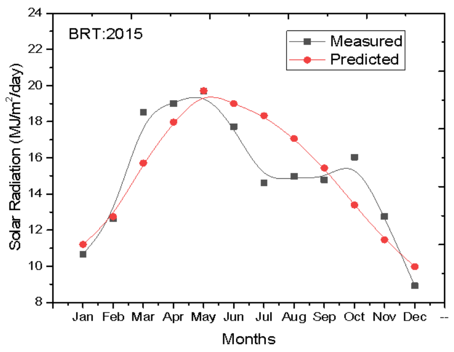
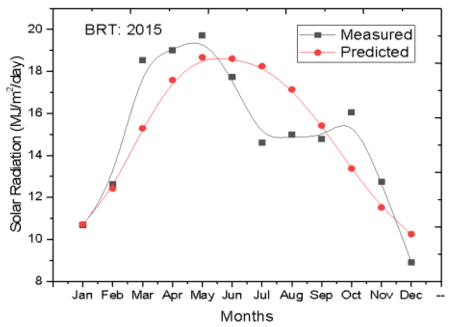


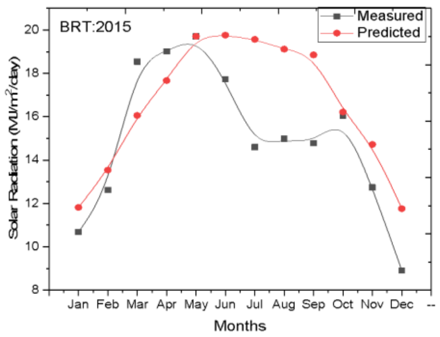
Fig.3.2: Error box plot of seasonal variation of year 2015 in Biratnagar.



(a)



(b)



(c)

Fig. 3.3: Comparison between the monthly mean measured and predicted Global Solar Radiation in Biratnagar 2015 by using model 1, 2 and 3 by a, b and c.

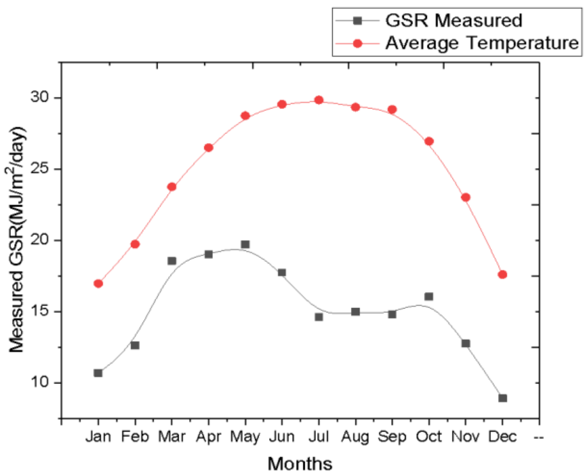


Fig. 3.4: Monthly mean variation Global Solar Radiation and Average temperature 2015 in Biratnagar.

Table 3.1. Error Analysis on seasonal Variation of Global Solar Radiation, Biratnagar (2015)

Seasons	GSR(MJ/m^2/day)
Spring	0.62
Summer	0.48
Autumn	0.34
Winter	0.24

The error bar above table shows that there is greater amount of fluctuation of global solar radiation is found in spring because of less solar zenith angle, less cloud, less rainfall and less precipitation. In this season's greater amount of total solar radiation reaches on the earth surface which is followed by summer, autumn and winter respectively. The monthly mean variation global solar radiation and average temperature in 2015 in Biratnagar is shown in Fig. 3.4. The statistical test and empirical constant result of models applied for Biratnagar, Nepal is tabulated in Table 3.2.

3.2. Monthly mean variation of radiation

The average values of solar radiation exhibit a seasonal variation, with May having the highest average value of 19.71 MJ/m^2/day and December having the lowest average value of 8.91 MJ/m^2/day. The yearly average measured value of solar radiation is significant at 15.05 ±2.19 MJ/m^2/day for generating solar energy. The coefficients of determination and p-values obtained are 0.59 and $<$ 0.01946, respectively, indicating higher radiation during spring and lower radiation during winter. Around 79% of the data closely aligns with the best fit line. A third-degree polynomial trend line is fitted with the measured data of solar radiation, and the monthly mean variation of solar energy in Biratnagar for 2015 with the third-degree polynomial fitting is depicted in Fig. 3.5.

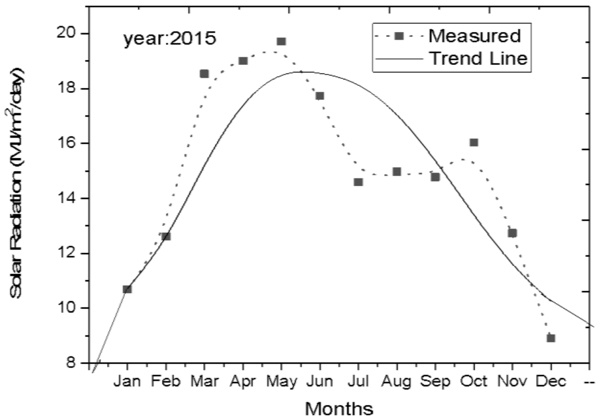


Fig.3.5: Monthly mean variation of Solar Radiation in Biratnagar for year 2015.

Table 3.2: Statistical test and Empirical Constant result of Models applied for Biratnagar, Nepal

Model	Statistical tools				Empirical Constant		
	MBE	RMSE	MPE (%)	R^2	a	b	c
Sunshine Based Model	-0.089	0.0046	6.3	0.89	0.4	0.1	
Gopinathan Model	0.08	0.0056	14.43	0.56	0.8	0.3	
Hargreaves and Samani Model	0.005	0.0103	18.68	0.76	0.16		
Ogunlade and Swartman Model	0.003	0.756	16.17	0.66	0.6	0.1	(-)0.002

3.3. Estimation of Global Solar Radiation using Regression coefficient

The estimation of global solar radiation using the regression coefficient technique in three different models which we used here are given in the figures 3.6, 3.7 and 3.8 respectively.

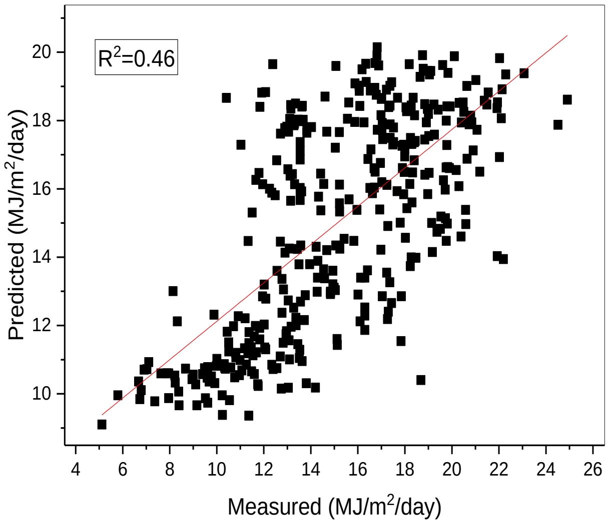


Fig. 3.6: Measured and predicted value of global solar radiation in Biratnagar (2015) using, Angstrom-Prescott.

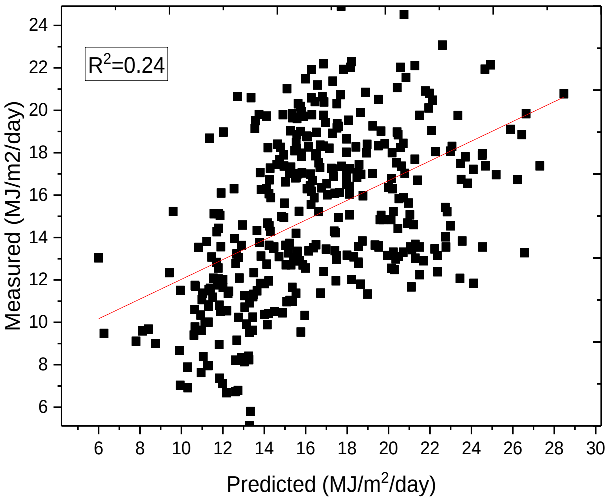


Fig. 3.7: Measured and predicted value of global solar radiation in Biratnagar (2015) using Ogunlade Model.

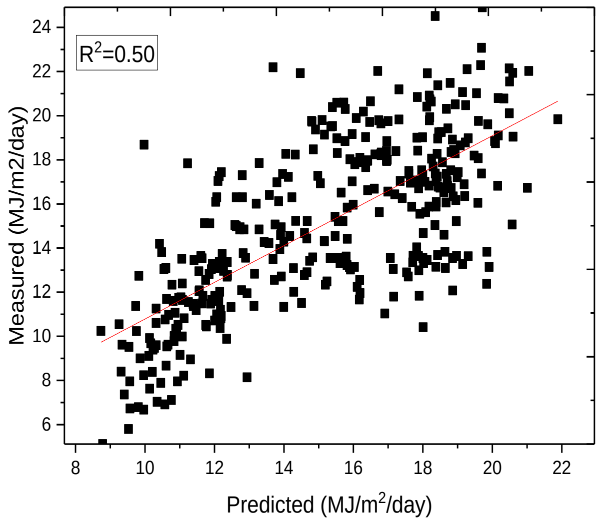


Fig. 3.8: Measured and predicted value of global solar radiation in Biratnagar (2015) using (Hargreaves Model).

4. CONCLUSION

The yearly average global solar radiation was found to be 15 ±2.19 MJ/m^2/day, which is significant for utilizing solar energy for various purposes. The seasonal variation study revealed that higher and lower values of solar radiation were observed in spring and winter, respectively, due to the meteorological parameters and rotation of earth. This paper focuses to estimate empirical constants using regression techniques to utilize four different empirical models for estimating the solar energy. Among the four linear empirical models, the Modified Angstrom-Prescott Model is better than others models and its empirical constants a=0.40 and b=0.11 will be used to predict solar energy in similar geographic locations of Nepal in coming years.

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