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Estimation of Global Solar Radiation using Angstrom and Gopinathan Model on Sunshine Hour and Temperature in Highland, Nepal

Jay S. Saud[1], Prakash M. Shrestha[1], Usha Joshi[1], Babu R. Tiwari[2], Indra B. Karki[1] and Khem N. Poudyal[2]

[1]Department of Physics, Patan Multiple Campus, Tribhuvan University

[2]Department of Applied Sciences and Chemical Engineering, IOE Pulchok Campus

Tribhuvan University

Author Note

Mr. Jay Singh Saud completed his MSc in Physics, from Patan Multiple Campus, TU, Patan Dhoka. Mr. Prakash Man Shrestha is an Associate Professor of Physics in Patan Multiple Campus, TU, Patan Dhoka. Ms. Usha Joshi is an Assistant Professor of Physics in Patan Multiple Campus, TU, Patan Dhoka. Dr. Babu Ram Tiwari, is an Assistant Professor of Physics in Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus, TU. Professor Dr. Indra Bahadur Karki is a Professor of Physics in Patan Multiple Campus, TU. Professor Dr. Khem Narayan Poudyal is a Professor of Physics in Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk, TU.

Correspondence concerning this article should be addressed to Dr. Babu Ram Tiwari, Department of Applied Sciences and Chemical Engineering, IOE. Email: baburam.tiwari@pcampus.edu.np

Abstract

In developing countries like Nepal, the direct measurement of global solar radiation (GSR) is difficult. So, the estimation of GSR is carried out at Jumla (29° 16′ N, 82° 11′ E and about 2347 m altitude) for the year 2015 and 2017 using regression technique to the meteorological parameters on Angstrom model, Gopinathan and Olomiyesan- Oyedum models. Among three models, Olomiyesan and Oyedum model is better than other models. Its empirical constants $a = 0.38$, $b = 0.10$ and $c = 0.09$ are found. The values of statistical errors MBE, MPE and RMSE are smaller than other models. Similarly, the coefficient of determination (R^2=**0. 89**) is greater than other models. Finally, the finding empirical constants and meteorological parameters sunshine hour, and temperature are used to estimate the GSR for the year 2017. In addition to this, the annual average GSR for the year 2015 and 2017 are found to be 18.86 MJ/m^2/day and 17.50 MJ/m^2/day respectively. It is concluded that the finding empirical constants are used to estimate the GSR and solar energy at similar geographical location of Nepal.

*Keywords***:** global solar radiation, relative sunshine duration, clearness index, regression analysis

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With the evolution of mankind, the energy has been becoming an important part of life. In the ancient period of time there was no invention and use of energy resources in different forms. The only available energy source is solar energy originated from the sun. That's why sun is termed as the 'GOD' because it is the source of all kinds of energy in the earth necessary to survive living beings. Solar energy is clean and pollution less source freely available everywhere. So to promote the alternative energy source like solar energy, it is necessary to study about global solar radiation. Many empirical models have been formulated so far to estimate the GSR (Poudyal, 2015). The Global Solar Radiation is very important weather variable to study various environmental phenomenon as it plays vital role in the climate change. Nepal is situated in between 26˚22' - 30˚27' N latitude and 80˚ 4' - 88˚ 12 ' E longitude. So it receives the annual average global solar radiation of 3.6 - 6.2 kWh/m^2/day and sunshine hours for about 300 days in a year (Ahmad, 1989). The global solar radiation is important for most ecological model and input for different solar systems. Sunshine duration the main parameter to estimate global solar radiation. A study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries. Unfortunately, there are very few meteorological stations that measure global solar radiation in the developing countries. For such stations, the alternative approach is to estimate global solar radiation from other measured meteorological parameters (Poudyal et al., 2012).

Incoming solar radiations affect the climatic factors. Solar radiation data are very important for the development and applications of solar energy technology. The study of global solar radiation includes various parameters like rainfall, sunshine hour, relative humidity and temperature. Among the various parameters sunshine hour is a good predictor of global solar radiation. The establishment of an empirical model may take a long period of global radiation and sunshine duration measured (Aryal, 2012). The green planet earth receives 1.76 x 10^{24} erg radiant energy per second which is the most by any luminous masses in solar system. The radiant energy is the only source that affects atmospheric motion and responsible for the various phenomena in the atmosphere. It affects the processes like air and soil heating, evapotranspiration and snow melting. Therefore, its knowledge is important in different fields as hydrology, climatology, biological processes agriculture and most applications concerning the utilization of renewable energy resources (Kunwar & Poudyal, 2017).

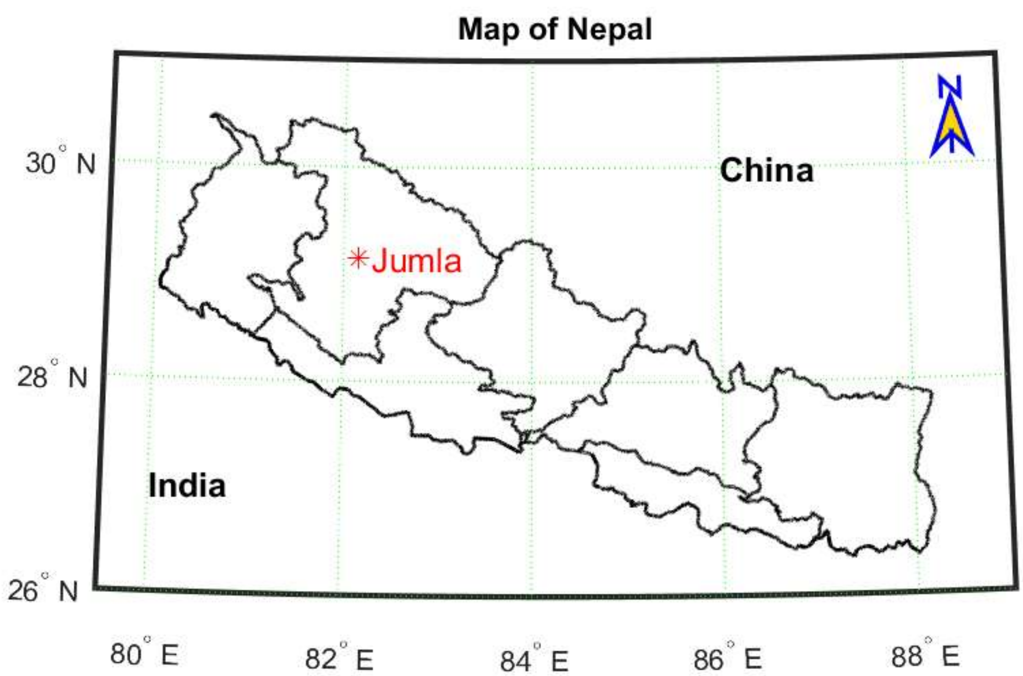
Sufficient amount of energy is one of the important factors of economic growth and development. Today's world is facing increasing energy consumption, giving rise to more use of fossil fuels that is responsible for the global warming phenomenon. Most countries in the world are introducing renewable energy projects to reduce dependence on the fossil fuels. Renewable energy sources are clean and widely available in different parts of the world (Yakuba & Medugu, 2012). The amount of energy emitted by the sun in one hour is sufficient to cover the world's energy need for one year. The sun discharges an enormous amount of energy but the earth intercepts an average of 1367 watts per square meter is called solar constant. The energy received by the earth depends upon the thickness of atmospheric layers (Janjai et al., 2011). With the rapid use and degradation of fossil fuel in the world, they create negative impact on economy and environment. The construction period for the new power generation projects takes long time and rapid improvement of energy supply cannot be expected. On the other hand, the biomass energy does not work well in cold high altitude region. Although in Nepal there is high probability of Hydroelectricity, it costs high and needs huge infrastructure to construct and operate. All above mentioned facts show that it's time to shift towards more clean and sufficient alternative form of energy i.e. solar energy (Kondratyev, 1969).

Material and Method

Jumla is located in Himalaya Region of Karnali Province, Nepal. It is shown in Figure 1. Its geographical coordinates are 29˚ 15' North, 82˚ 15' East and altitude is about 2514 m from the sea level. The total area of Jumla district is 2,531 km^2 the average lowest temperature varies from -7.8˚C in winter to 30.8˚C in summer.

Figure 1

Map of Nepal (Survey Department, GoN,2020)

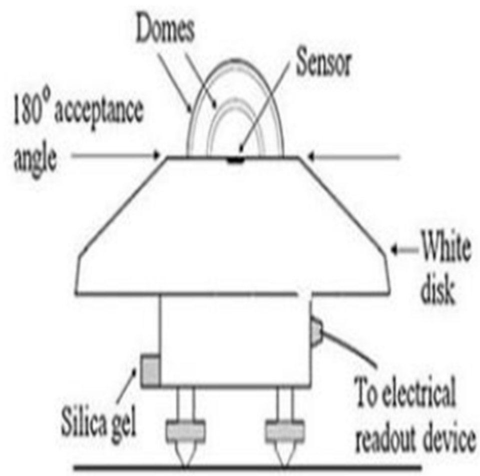


The annual average global solar radiation is 3.6 – 6.2 kWh/m^2/day and the sun shines for about 300 days in a year. It lies in between cold climate to alpines. This region is wet, cloudy with windy in summer and chilly cold and dry in winter. Its total precipitation is about 670 mm to 967 mm per year. The topography of Jumla is steep (Kipp & Zonen, 2008).

The CMP6 Pyranometer is used to measure global solar radiation as shown in Figure 2. It consists of thin blackened surface supported inside a well-polished case. The spectral range of this instrument is from 285 nm to 2800 nm. The operating temperature is from – 40ºC to 80ºC. The main components of Pyranometer are two glass domes, metal body, black sensor, radiation screen level and cable. There is a sensor that is designed to measure the GSR flux from a field of view of 180º (Poudyal, 2015).

Figure 2

CMP6 Pyranometer and its Internal Structure (Kipp & Zonen, 2008)



Working Principle: When solar radiation falls on this surface, the temperature rises until its rate of loss of heat is equal to the rate of gain of heat by radiation. The black coating on the thermopile sensor absorbs the solar radiation and is converted into heat. This rise in temperature sets up a thermal e.m.f. which is measured on recorder. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation. So we get the global solar radiation directly in W/m^2 (Kipp & Zonen, 2008).

Theory

Global solar radiation can be estimated using two different methodologies: empirical models and parametric models. Empirical models need a large database and they are best for local applications. Parametric models are of general use and need a large information on atmosphere composition (Tiwari & Tiwari, 2016).

Angstrom-Prescott Model

Various empirical models have been developed to calculate global solar radiation using different parameters. The equation postulated by (Angstrom, 1924) and modified by (Prescott, 1940) is given by

$$H = H_o[a + b\left(\frac{n}{N}\right)] \quad (1)$$

Where,

$H = Incoming\ daily\ terrestrial\ global\ solar\ radiation$ (MJ/m^2/day)
$H_o = Daily\ extraterrestrial\ radiation$ (MJ/m^2/day)

$n = \ Bright\ sunshine\ hours\ per\ day$ (hr.)

$N = Astronomical\ day\ length$ (hr.)

The astronomical day length N is calculated as

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

Where,

$\emptyset =$ latitude in degree

$\delta =$ Solar declination angle in degree

H_o is determined by using equation defined by Duffi and Beckman (1991)

$$H_o = \frac{24}{\pi} I_{sc} \left[1 + 0.33 \cos(\frac{360n}{365})\right] [\cos \emptyset \cos \delta \sin \omega_s + \frac{2\pi\omega_s}{360} \sin \emptyset \sin \delta] \quad (3)$$

Isc = Solar constant

ω_s = Sunset angle

Gopinathan Model

The empirical coefficient a and b can be estimated using Gopinathan (1988) model as follows,

$$a = 0.265 + 0.07z - 0.135 \frac{n}{N} \quad (4)$$

$$b = 0.401 - 0.108z + 0.325 \frac{n}{N} \quad (5)$$

Where, z is altitude of the site in kilometer. To compute the estimated values of global solar radiation, the values of a and b are used in Equation (1) given by Angstrom.

Olomiyesen and Oyedum Model

A two parameter – based empirical model is developed by Olomiyesan and Oyedum (Olomiyesan et al, 2017) to estimate global solar radiation and is given by,

$$\frac{H}{H_0} = a + b \frac{n}{N} + c \frac{\Delta T}{N} \quad (6)$$

where,

$\Delta T = T_{max} - T_{min}$ is the temperature difference and a, b and c are empirical constants which are to be determined.

Results and Discussion

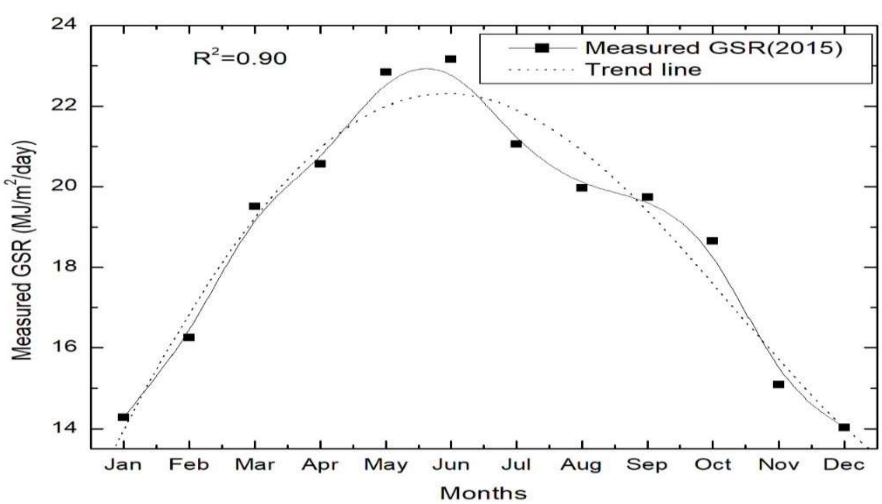
The measurement and estimation of Global Solar Radiation of Jumla has been carried out in this thesis work. Data are measured with CMP6 Pyranometer and necessary meteorological parameters are available from Department of Hydrology and meteorology (DHM). There are so many empirical models for the estimation however three different linear models are selected based on sunshine hour, relative humidity, altitude and temperature to predict the GSR for the year 2015 and 2017.

Monthly Mean Variation of Global Solar Radiation

The variation of monthly average GSR for the years 2015 in Jumla is shown in Figure 3 below.

Figure 3

Monthly Mean Variation of Global Solar Radiation



Maximum and minimum value of measured GSR is observed to be 23.17 MJ/m^2/day and 14.02 MJ/m^2/day in June and December respectively in Jumla.

Similarly, the annual average measured value of GSR is 18.76 MJ/m^2/day. The coefficient of determination (R^2) is 0.90 which signifies that 90 percent of the data are closer to best fit.

Seasonal Variation of GSR

Figure 4 and 5 show the seasonal variation of measured solar radiation and predicted solar radiation in Jumla for the year 2015 and 2017 respectively. The obtained values of GSR in winter, spring, summer and autumn are 14.84, 20.97, 21.39 and 17.91 MJ/m^2/day respectively for the year 2015. The maximum value of GSR is found in summer than in spring because of cloudy and rainy days.
In 2017, the average GSR in spring is greater than summer because of spring in no more cloud and rain in comparison to summer season.

Figure 4

Seasonal Variation of GSR in Jumla for 2015

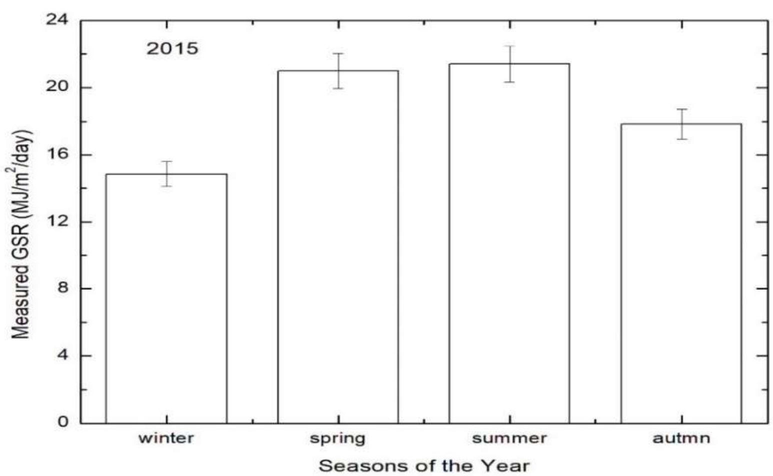
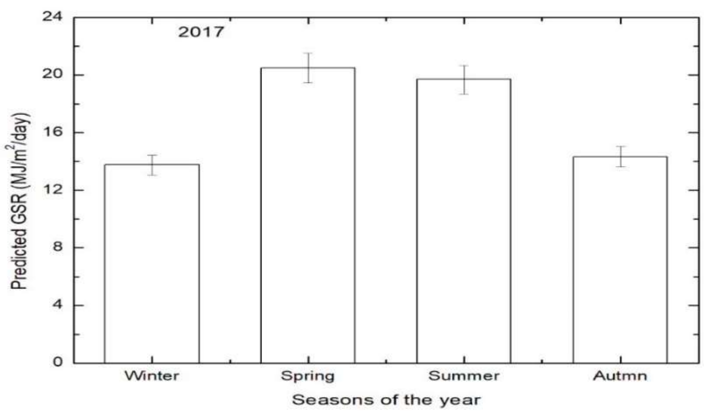


Figure 5

Seasonal Variation of GSR in Jumla for 2017



The predicted *and measured global* solar radiation using Angstrom*, Gopinathan* and *Olomiyesan and Oyedum Model* for the year 2015 is shown in the *Figure 6, 7 and 8 respectively. Among three models the Olomiyesan and Oyedum Model* is better than other models.

Figure 6

Measured and Predicted GSR in Jumla for 2015 by Angstrom Model

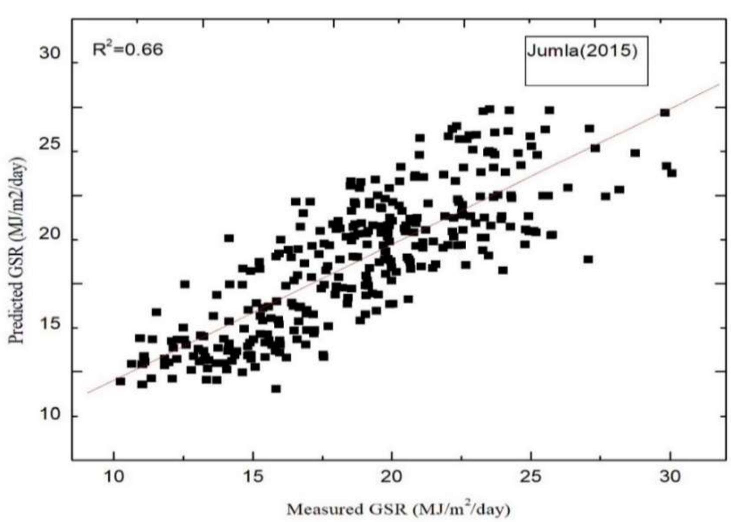


Figure 7

Measured and Predicted GSR in Jumla for 2015 by Gopinathan Model

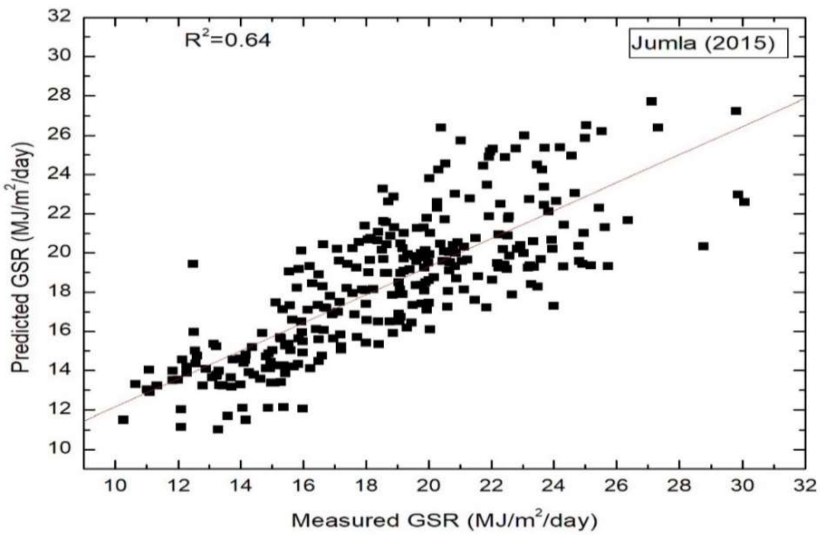


Figure 8

Measured and Predicted GSR in Jumla for 2015 by Olomiyesan and Oyedum Model

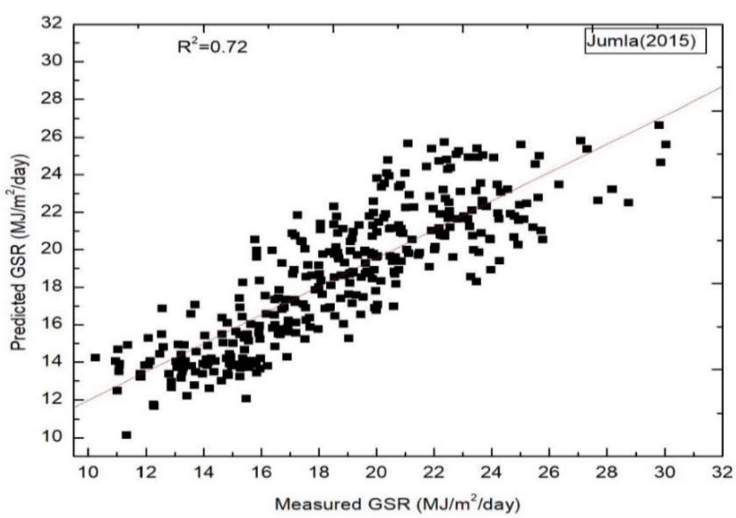


Table 1

Validation of the Models Using Different Meteorological Parameters Under Statistical Tests in the Year 2015

S. No.	Statistical Parameters	Angstrom – Prescott model	Gopinathan model	Olomiyesan and Oyedum model
1.	MBE ($MJ/m^2/day$)	0.17	0.16	0.08
2.	MPE (%)	1.98	2.12	1.77
3.	RMSE ($MJ/m^2/day$)	2.96	3.19	2.55
4.	R^2	0.66	0.64	0.72

The three linear models have been used to estimate the GSR and the regression coefficient. Thus, obtained regression coefficients from the year 2015 are used to estimate the GSR for the year 2017. Analyzing the errors as given in previous table, we conclude that these linear models can estimate the GSR with some errors. From the above finding empirical coefficients are compared with the result obtained by Adhikari et al. (2013), Shrestha et al. (2021), and KC et al. (2020). These finding results are very much closer to the results obtained the from present study. Thus, it is confirmed that there is sufficient amount of solar energy available in our research site.

Conclusion

The values of regression coefficient 'a', 'b' and 'c' are calculated using the data for the year 2015 for all three models. For model 1, a=0.39 and b= 0.29 and for model 2 we have a=0.34 and b=0.35 whereas for model 3 we have a=0.38, b= 0.10 and c=0.09. The obtained values of regression coefficients were used to estimate the values of GSR for one year. The trend of estimated GSR with measured GSR as given by the scatter plots suggests that the models can well predict the GSR values. The presented three models were compared on the basis of statistical tools such as RMSE, MBE, MPE and R^2.

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