Received Date: Oct. 2022 Revised: Nov. 2022 Accepted: Dec. 2022

Estimation of Global Solar Radiation at Mid Hill Region, Okhaldhunga

U. Joshi[1,2*],A.M.Karmacharya[3],P.M. Shrestha[1],N.P. Chapagain[4], I.B. Karki [1], K.N. Poudyal[5]
[1]Department of Physics, Patan Multiple Campus, TU, Patan, Nepal
[2]Central Department of Physics, TU, Kirtipur, Nepal
[3]Department of Electrical Engineering, Pulchowk Campus, IOE, TU, Patan, Nepal
[4]Department of Physics, Amrit Campus, TU, Kathmandu, Nepal
[5]Department of Applied Sciences, Pulchowk Campus, IOE, TU, Patan, Nepal
[*]Corresponding email: usha.joshi@pmc.tu.edu.np

Doi : https://doi.org/10.3126/ppj.v2i2.53127

Abstract

Global solar radiation knowledge canbe valuable in fulfilling energy demands and exploring numerous applications of solar technology. Since only a few meteorological stations are available and the installation of additional stations is complicated because the cost is very high, a comparative study of various models is essential for accurate global solar radiation prediction rather than measurement. In the present study, four modelsbased on sunshine hour, temperature, and relative humidity for estimating daily global solar radiation were compared using the regression technique for Okhaldhunga (Lat.27.3081^{0}N, Lon.86.5042^{0}E, Alt.1720m.a.s.l.). These models were evaluated and compared basedon four statistical error tests.The basis ofanalysis, model M4, which uses sunshine hour, maximum temperature, and relative humidity, wasused for estimating daily global solar radiation with acceptable accuracy. The empirical constants obtained for M4 models werea=0.62, b=0.47, c= -0.003, and d= -0.003. The site's annual average global solar radiation was 4.16 kWh/m^2/day. The results of this study help estimateglobal solar radiation for similar geographical locationsin Nepal.

Keywords: Global Solar Radiation, empirical constants, sunshine hours, regression technique & statistical error test

1. Introduction

The energy released by the sun reaches our planet in the form of light, namely solar radiation. This radiation reaching the earth supports the life of humans and all the living things existing there. But solar radiation is greatly affected as it passes through the earth’s atmosphere[1]. Sun produces energy through thermonuclear fusion that combines about 6.5 x 10^8metric tons of hydrogen atoms into helium every second, releasing massive energy[2]. Geographically, Nepal is located at the most suitable latitude (26-30 degrees), which enables her to harness solar energy to the maximum. The average value of global solar radiation(GSR) in Nepal varies from 3.6-6.2 kWh/m^2/day, while there are typically about 300 sunny days annually[3]. On an annual basis, the average solar energy in Nepal has a value of 4.23 kWh/m^2 with average sunshine hours of 6.8 hours/day, more significant than most European countries[4].As a result, solar energy can prove to be fundamental for the development of various sectors, such as agriculture, transport, commerce, etc., while functioning as an alternative to the power supplied from the grid in rural and urban areas of the country[5].

The suitability of the geographical location and the necessity for an alternative source make solar energy an ideal candidate. Additionally, proper measurement and probing of solar radiation are paramount. Global solar radiation can be directly measured by using CMP6 first-class pyranometer. Solar radiation and meteorological data can be used to estimate the solar energy potential at a particular site. Such research can be helpful in modern agriculture, climate studies, and environmental studies, ultimately serving to uplift the quality of life[6][7]. Further, the total energy consumption can be improved,directly tied up with socioeconomic activities anda country's overall development [8].

As global solar radiation is the sum of diffused and direct solar radiation, particles in the atmosphere affect global solar radiation. The radiation from the sun is diffused because of these particles. These particles may also be water vapor, clouds, aerosols, ozone, and other gases [9].Water vapor varies with the time of the year. Consequently, GSR differs as well. GSR varies with a place due to variations in position, latitude, altitude, solar zenith angle, and local weather conditions[2][10]. This paper aimsto study the impact of meteorological parameters on GSR using linear regression to develop a predictive model dependent on these parameters for estimating GSR inthe mid-hill region of Okhaldhunga.

2. Materials and Method

The data of global solar radiation and meteorological parameters such as daily temperature, sunshine duration, relative humidity, and rainfall of Okhaldhunga (Latitude:27.3081^{o}N, longitude:86.5042^{o}E and altitude:1720m.as.l.) were collected from the Department of Hydrology and Meteorology, Government of Nepal for the year 2019 and 2020. The daily GSR was measured on a horizontal surface at the site using a CMP6 pyranometer. The measuring site, Okhaldhunga, lies in Province 1, inthe mid-hill region. Figure1 shows the location onthe Map of Nepal. It has a subtropical highland climate with cool, dry winter and rainy summer. It has a maximum annual temperature of 28.8^o C and a minimum annual temperature of 11.5^{o}C.

A pyranometer is based on the principle of measuring the temperature difference between a radiation absorption element and an element shield from GSR. A transducer converts the temperature difference into a suitable voltage. The voltage is later converted into solar irradiance magnitude (W/m^2). GSR was measured per minute and stored in the LOGBOX SD data recorder. The operating range of the pyranometer varies from -40^{o}C to 80^{o}C, and the spectral range is 310nm to 2800nm. It includes infrared, visible, and ultravioletwavelength. The field of view and sensitivity of the apparatus are 180^o and 5212µV/W/m^2, respectively. Low noise, high resolution, and low power consumption are some of the salient features of this instrument[11].Bright sunshine duration is when direct solar radiation is at least 120 W/m^2 obtained from GSR and diffused solar radiation[12].

Figure 1: The measuring site in Map of Nepal [13]

A number of empirical formulas based on various parameters can be used to calculate the GSR. The following table lists four different empirical models used to estimate GSR at the measuring site in this study.

Table 1: List of models used for the determination of GSR

Model no.	Model	Symbol	Parameters	Relation
1	Angstrom-Prescott Model[14][15]	M1	n, N	$\frac{H_g}{H_o} = a + b\left(\frac{n}{N}\right)$
2	Swarthman-OguniadeModel[16]	M2	N, N, RH	$\frac{H_g}{H_o} = a + b\left(\frac{n}{N}\right) + c(RH)$
3	Modified Angstrom Model	M3	n, N, T_1	$\frac{H_g}{H_o} = a + b\left(\frac{n}{N}\right) + c(T_1)$
4	Abdalla model[16] [17]	M4	n, N, T_1, RH	$\frac{H_g}{H_o} = a + b\left(\frac{n}{N}\right) + c(T_1) + d(RH)$

where Hg is the measured GSR(MJ/m^2/day), Ho is the theoretical value of GSR (MJ/m^2/day), Hg/Ho=KT is the clearness index, n is the bright sunshine hour, n/N is the relative sunshine hour.

Ho can be calculated by following equation[18]:

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

Where $\varphi$is the latitude in radians, $\delta$is the solar declination angle in radians, $\omega$is the sunset hour angle for a typical day, and n_d is the day of the year. The value of n_d ranges from 1 to 365.

The declination angle is calculated by using the following equation:

$$\delta = 23.4\sin\left[\frac{360(284 + n_d)}{365}\right] \ldots .(2)$$

The sunset hour angle is,

$$\omega = \cos^{-1}(-\tan\varphi\tan\delta) \ldots (4)$$

And the relation of day length is,

$$N = \frac{2}{15}\omega \text{….(5)}$$

The value of daily average hourly extraterrestrial radiation and day length were evaluated using the aboveequations. Empirical constants for different models were assessed using regression analysis to estimate GSR. By comparing against the actual measured value, we evaluated this model using statistical tools such as Root Mean Square Error (RMSE), Mean Percentage Error (MPE), Mean Bias Error (MBE), andCorrelation Coefficient(CC)[19].

3. Results and Discussion:

The seasonal and monthly variation of GSR for Okhaldhunga is shown in Figures 2 and 3, respectively. In this location, the maximum GSR obtained in the Spring season is 17.75±5.45 MJ/m^2/day. The minimum value of GSR is 13.41±3.74 MJ/m^2/day during Winter. The values are similar to those obtained from Lumle and Kathmandu, with nearly theexact altitude locations.Butthe pattern of seasonal variation of GSR was slightly different in Okhaldhunga. GSR is less in the summer than in Autumn[20][21]. Due to the smaller zenith angle, lesser clouds and rainfall resulted in high GSR values during the spring.On the contrary, minimum GSR resulted due to high zenith angle and hazy sky. From figure 3, the maximum GSR was received for the months of March and April due to fewer clouds, no wind, and less rainfall. However, the trend deviates from May through July for the study area due to the onset of the rainy season. During May and April, the smaller values of GSR can be explained by the cloudy sky due to pre-monsoon. About 80% of the rainfall of the whole year occurs during monsoon[22]. The maximum value of GSR received in April was 18.81 ± 5.22 MJ/m^2/day, whereas the minimum value of GSR obtained in Septemberwas 10.54±4.10 MJ/m^2/day.

Figure 4 depicts the monthly variation of measured GSR with the sunshine hour. There is remarkable agreement between these two parameters. The measured GSR gradually increases with sunshine hours up to April. Afterward, both decreased sharply due to clouds and rain from the month's May through August. It might sometimes extend to September as well. Later in October and November, the sky is evident following the rainfall resulting in higher values of both GSR and sunshine hour. The maximum value of sunshine hours was observed in November (7.342hr), and the minimum value was observed in July(2.325hr).

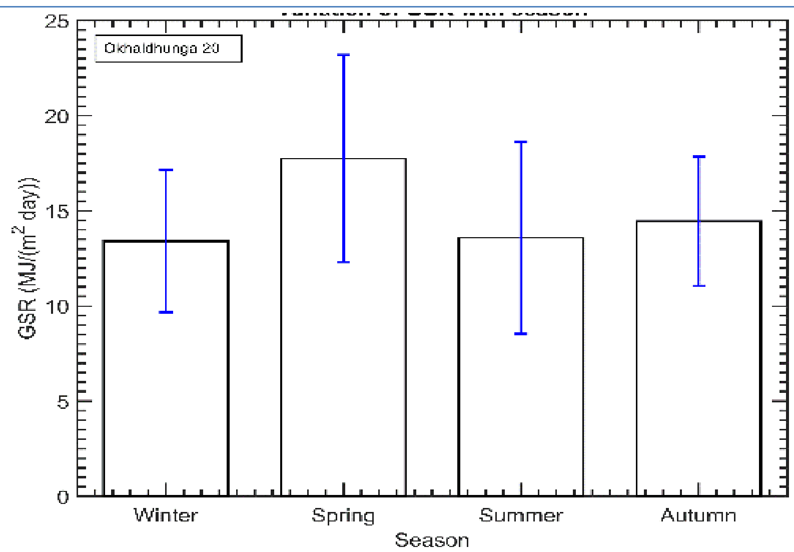


Figure 2: Seasonal variation of GSR in Okhaldhunga in (2019-2020)

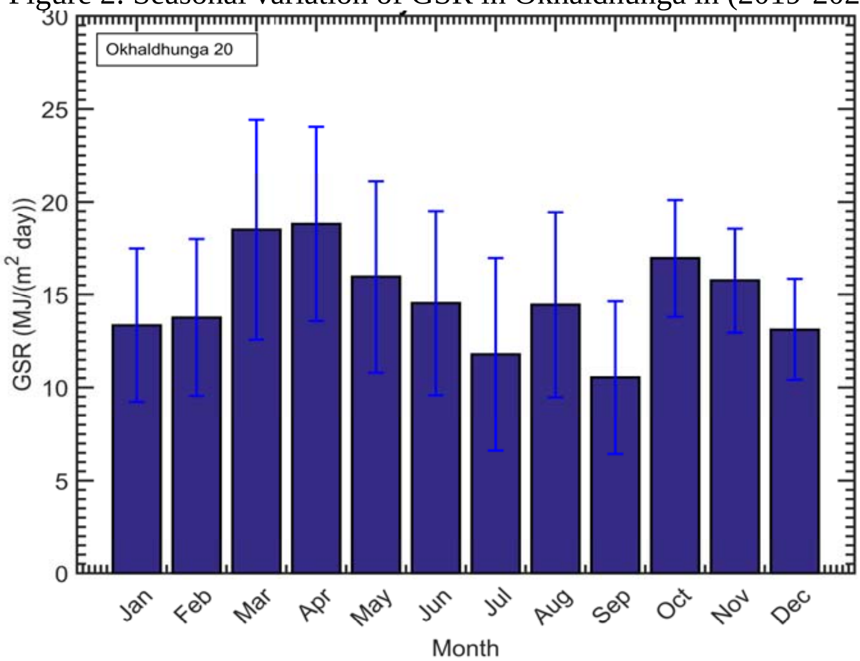


Figure 3:Monthly variation of GSR in Okhaldhunga in (2019-2020)

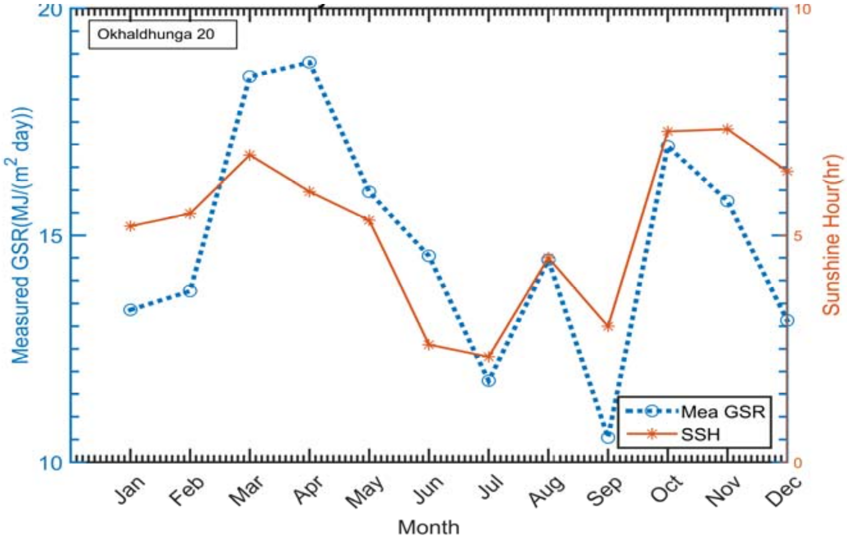


Figure 4: Monthly variation of the sunshine hour and measured GSR in Okhaldhunga in (2019-2020)

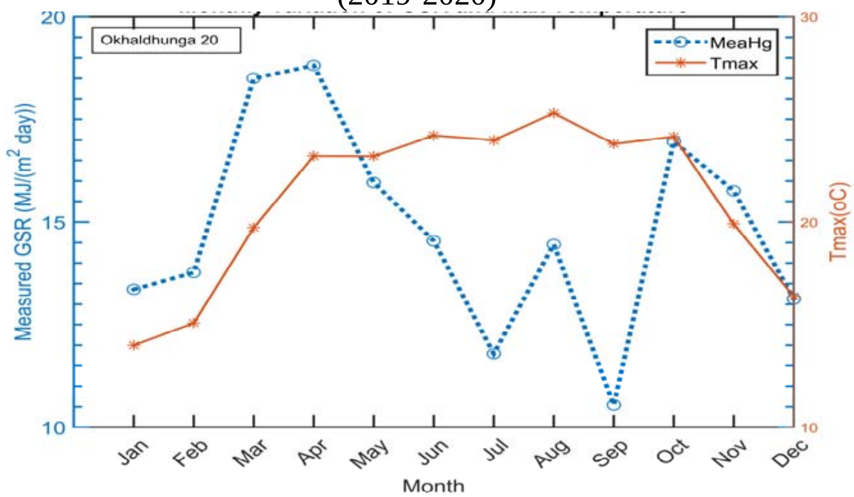
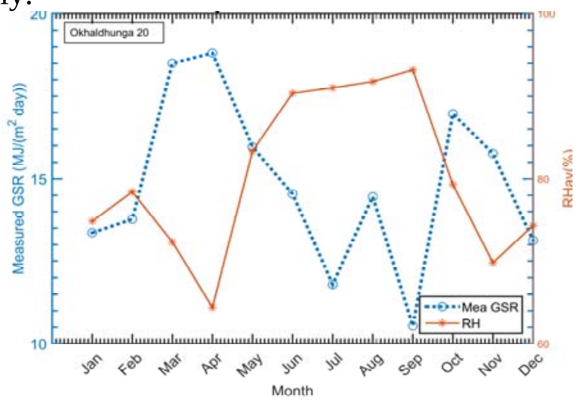


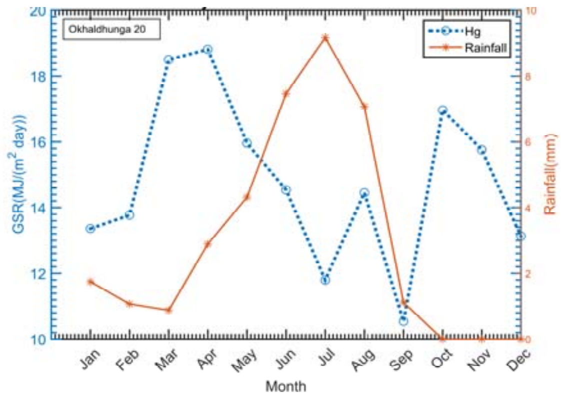
Figure 5: Monthly variation of maximum temperature and measured GSR in Okhaldhunga(2019-2020)

Figure 5 illustrates some correlation between temperature and measured value GSR. The temperature varies with the season due to the rotation of the earth and affects GSR. GSR gradually increases with an increase in temperature from January to May. But later on, the temperature remains almost constant. The GSR increases again when there is a spike in temperature in August. Starting from October, the values of GSR and temperature both have sharply decreased. The maximum monthly average temperature is 25.30 ± 1.46^{o}C in August, and the minimum monthly average temperature is 6.99 ± 1.5^{o} C in January. The period of discord between these two parameters indicates that GSR is dependent on temperature and other factors.

Figures 6a and 6b representthe monthly variation of GSR with relative humidity and rainfall, respectively. Both graphs indicate that the parameters are negatively correlated with measured GSR. The weather is relatively dry during the spring, with little rainfall and consequently less relative humidity. This results in higher values of GSR. During the summer, monsoon rainfall increases the relative humidity of the atmosphere. As a result, we have lower values of GSR. Although rainfall is minimal during Autumn(starting September), the relative humidity is relatively high, in fact, maximum, due to the cloudy sky. Therefore, GSR appears to be minimum in September and increases there onwards. The yearly rainfall in Okhalhunga was 1755mm, and the location received maximum rainfall in July.



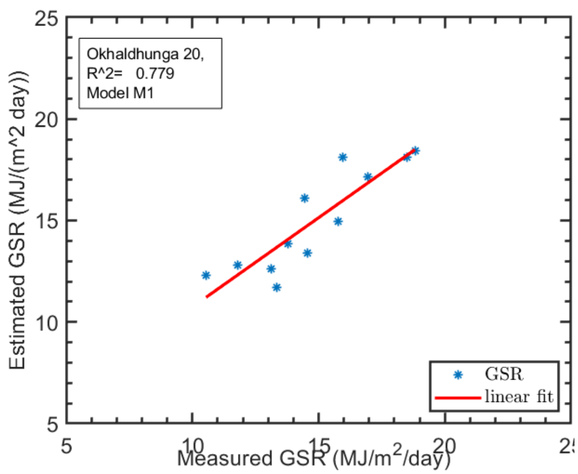
(6a)

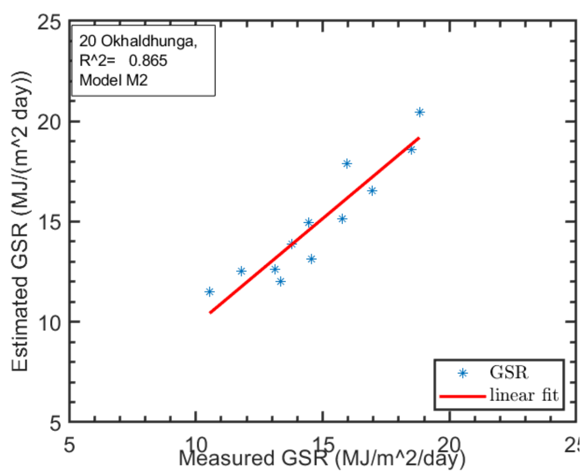


(6b)

Figure 6(a): Monthly variation of relative humidity and measured GSR in Okhaldhunga in (2019-2020)

Figure 6(b): Monthly variation of rainfall and measured GSR in Okhaldhunga in (2019-2020)





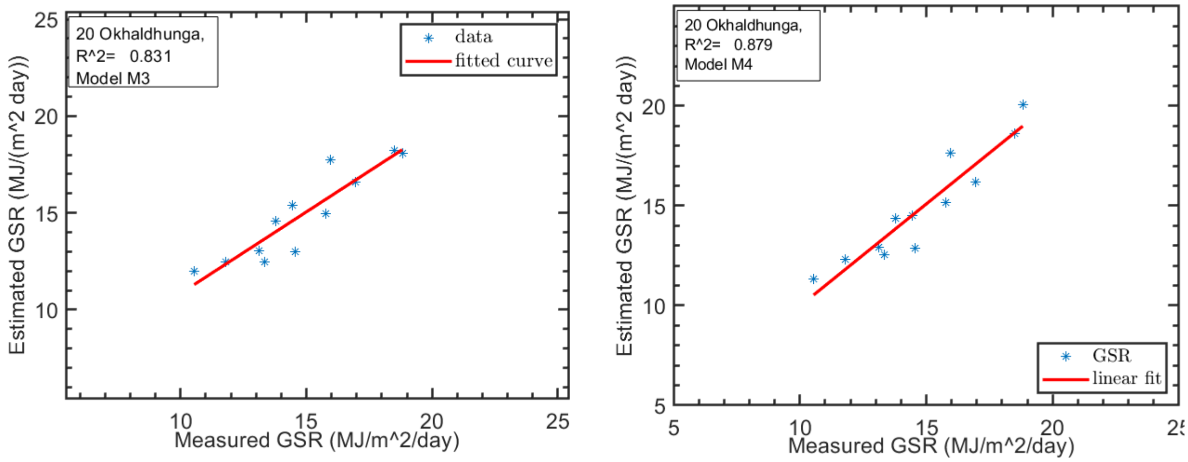


Figure 7: Linear variation between measured and estimated monthly average GSR at Okhaldhunga for given models.

Now, the empirical constants were determined using regression techniques for each model from 2019 to 2020. Four statistical tools were used to evaluate model performance, namely RMSE, MBE, MPE, and correlation coefficient. RMSE provides information on the short-term comparison of the actual deviation between estimated and measured GSR values. MBE provides the long-term performance of the examined regression. Lower values of RMSE, MBE, and MPE are favorable. In contrast, higher correlation coefficients and coefficient of determination values are desirable. These values indicate the prediction accuracy of the model. The evaluated values of statistical errors and empirical constants for the models are shown in Table 1.

Table 1: The empirical constants and statistical errors for Okhaldhunga

Models	**a**	**b**	**c**	**d**	**MBE**(MJ/m^2/day)	**RMSE**(MJ/m^2/day)	**MPE(%)**	**Correlation coefficient (cc)**
M1	0.215	0.598			0.165	3.417	7.745	0.755
M2	0.564	0.478	-0.004		0.138	3.139	7.003	0.796
M3	0.325	0.578	-0.005		0.080	3.370	7.736	0.756
M4	0.622	0.470	-0.003	-0.003	0.080	3.113	7.038	0.796

According to the statistical error data in Table 1, the correlation coefficient is highest for models M4 and M2. RMSE is the minimum for model M4. MBE is minimum both for models M3 and M4. The correlation coefficient and coefficient of determination are the highest for model M4. Overall performance of the models, the model M4, Abdalla model is better than other models.

The linear variation of measured and estimated monthly average GSR is shown in figure 7. It is shown that there is excellent correspondence between these values. All the models have a coefficient of determination more significant than 77%. Model M4 has the highest value among these four models 87.9% indicates the better model. The annual average solar energy potential is 14.97 ± 0.26MJ/m^2/day, and the total yearly solar energy is 5404.33 MJ/m^2/day.

4. Conclusion

This study analyzed seasonal and monthly variations of GSR potential and the effect of meteorological parameters on GSR.The maximum and minimum GSR are found in Spring and Winter, respectively, similar to Kathmandu. Estimating global solar radiation is obtained using four models: Angstrom - Prescott model, Swarthman- Oguniade Model,the modified Angstrom model, and the Abdalla model. Among these four models, the Abdalla model is better than other models because the statistical errors (RMSE=3.11, MBE=0.08, MPE=7.03)are comparatively lesser than other models. Similarly, the coefficient of determination (R^2 = 0.62) is higher than in other models. The annual average value of GSR is 4.16 kWh/m^2/day, which is found in Okhaldhunga, avery high amount to promote solar energy technology. In the end, the predicted empirical constants(a = 0.62, b = 0.47, c = -0.003, and d = -0.003) for the Abdalla model can be utilized for the estimation of global solar radiation at a similar geographical location in Nepal.

Acknowledgment

The authors sincerely thank the Department of Hydrology and Meteorology, Ministry of Energy, Water Resources and Irrigation, Government of Nepal, for providing pertinent meteorological data. The authors would like to thank faculty members and staff of the Department of Physics, Patan Multiple Campus, TU, Nepal, and the Department of Applied Sciences, Chemical Engineering IOE, Pulchowk Campus, TU, for their support.

References

[1] Olomiyesan B, Oyedum O, Ugwuoke P, Abolarin M. Evaluation of Some Global Solar Radiation Models in Selected Locations in Northwest, Nigeria. Open Access Journal of Photo energy. 2017;1(1):1-6.
[2] Iqbal M. An introduction to solar radiation. Academic Press, New York, NY; 1983.
[3] Shrestha JN, Bajracharya TR, Shakya SR, Giri B. Renewable Energy in Nepal-Progress at a glance from 1998 to 2003. In: Proceedings of the International Conference on Renewable Energy Technology for rural Development (RETRUD-03); 2003. p. 12-4.
[4] Poudyal KN. Estimation of global solar radiation potential in Nepal [Ph.D. thesis]. Kathmandu, Nepal: IOE, Tribhuvan University; 2015.
[5] Water and Energy Commission Secretariat (WECS). Energy Commission Secretariat. Energy Sector Synopsis Report, Nepal Government of Nepal. 2010.
[6] Babatunde E, Aro T. Characteristics variation of Total (Global) solar radiation at Ilorin. Nigeria Nig J of Solar Energy. 1990;9:157-73.
[7] Janjai S. Solar Radiation Maps from Satellite Data for Thailand. Solar Energy Research Laboratory, Department of Physics, Silpakron University. 2010.
[8] Bhattarai B. Factors affecting solar ultraviolet radiation, based on some case studies in Norway and Nepal. Doctoral Theses at NTNU. 2007:26-7.
[9] Tarpley J. Estimating incident solar radiation at the surface from geostationary satellite data. Journal of Applied Meteorology and Climatology. 1979;18(9):1172-81.
[10] Liou KN. An introduction to atmospheric radiation. Elsevier; 2002.

[11] Manual CMA and CMP series, Instruction Manual,Version:0806. Delftechpark 36, 2628 XH Delft, The Netherlands; 2008. http://www.kippzonen.com.

[12] Jarraud M. Guide to meteorological instruments and methods of observation (WMO-No. 8). World Meteorological Organisation: Geneva, Switzerland. 2008;29.

[13] Survey Department, Government of Nepal. Map of Nepal; 2020. [Online; accessed 04-June-2021]. Available from: http://www.dos.gov.np/download/news-events/shapefilegis-data-for-political-and-administrative-map-of-nepal.

[14] Angstrom A. Solar and terrestrial radiation. Report to the international commission for solar research on actinometric investigations of solar and atmospheric radiation. Quarterly Journal of the Royal Meteorological Society. 1924;50(210):121-6.

[15] Prescott JA. Evaporation from a water surface in relation to solar radiation. Trans Roy Soc S Aust. 1940;46:114-8.

[16] Swartman R, Ogunlade O. Solar radiation estimates from common parameters. Solar energy. 1967;11(3-4):170-2.

[17] Joshi U, Poudyal KN, Karki IB, Chapagain NP. Evaluation of Global Solar Radiation using Sunshine Hour, Temperature and Relative Humidity at Low Land Region of Nepal. Journal of Nepal Physical Society. 2020 Aug;6(1):16-24. Available from: https://www.nepjol.info/-index.php/JNPhysSoc/article/view/30429.

[18] Duffie JA, Beckman WA. Solar Engineering of Thermal Processes. 2nd edition. John Wiley and Sons, NewYork NY; 1991.

[19] Okundamiya MS, Emagbetere JO, Ogujor EA. Evaluation of various global solar radiation models for Nigeria. International Journal of Green Energy. 2016;13(5):505-12.

[20] Joshi U, Karki IB, Chapagain NP, Poudyal KN. Prediction of daily global solar radiation using different empirical models on the basis of meteorological parameters at Trans Himalaya Region, Nepal. BIBECHANA. 2021;18(1):159-69.

[21] Joshi U, Shrestha P, Maharjan S, Maharjan B, Chapagain N, Karki I, et al. Estimation of Solar Energy Using Different Empirical Models at Mid Hill, Nepal. Journal of Nepal Physical Society. 2021 Aug-6;7(2):42-8. Available from: https://www.nepjol.info/-index.php/JNPhysSoc/article/view/38621.

[22] Nayava JL, Singh R, Bhatta MR. Impact of climate, climate change and modern technology on wheat production in Nepal: A case study at Bhairahawa. Journal of Hydrology and Meteorology. 2009;6(1):1-14.