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Research Article

Estimation of Solar Insolation and Angstrom–Prescott Coefficients Using Sunshine Hours over Nepal

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The amount of solar insolation that reaches the Earth in one hour is sufficient to fulfill its annual energy budget. One of the challenges for harvesting this energy is due to a lack of relevant data. In the least developed countries like Nepal, the number of observation stations is insufficient. This data gap can be filled by employing credible empirical models to estimate solar insolation in regions where insolation measurements are not available. In this paper, Angstrom–Prescott model parameters are estimated for fifteen different locations of Nepal. Then, correlation is developed for the prediction of solar insolation using only sunshine hour data. The different statistical parameters such as root mean square error (RMSE = 1.958), mean bias error (MBE = −0.018), mean percentage error (MPE = 2.973), coefficient of residual mass (CRM = 0.001), and correlation coefficient (r = 0.909) were used to validate the developed coefficients. The resulting Angstrom–Prescott coefficients are a = 0.239 and b = 0.508. These coefficients can be utilized for the prediction of solar energy at different parts of the country in similar weather conditions.

1. Introduction

The knowledge of solar radiation is important for many applications such as solar power plants, engineering designs, building energy systems, irrigation system development, climatological studies, solar energy systems, evapotranspiration estimation, and regional crop growth modeling [1, 2]. In all these field studies, reliable solar radiation data is vital for a good result.

Nepal earns ample solar radiation from the sun throughout the country as it lies in the most favorable latitude (15°–35°) on the global map. The average global solar radiation in Nepal varies from 3.6 to 6.2 kWhr/m^2/day. Likewise, in 2003, there are about 300 sunny days [3] and the annual average sunshine hour and solar energy are about 6.8 hours per day and 4.7 kWh/m^2/day in Nepal, respectively [4]. Later in 2010, it was found that the annual average solar insolation is 4.23 kWhr/m^2 in Nepal [5] which is very high in comparison with many European countries [6]. This clean energy not only is used for rural electrification but also helps to improve the quality of education, public health, and small-scale cottage industries. That helps to reduce import in LPG gases and petroleum products. In the end, it supports the growth of the economy of the nation. In addition, solar energy is clean renewable energy which helps to decrease the effect of pollution due to the use of clean energy in place of a large amount of traditional energy. In recent years, more than 70 MW of solar PV electricity has been generated in different parts of the country. This solar energy has been utilized for rural electrification and also supply to national grid (30.14 MW) which helps to solve the energy crisis in the nation in a small step. The above mentioned data shows that there is a large amount of solar energy potential available to be produced at different parts of the country to solve the basic need for energy for the holistic development of the country [7, 8].

It is crucial to estimate global solar radiation (GSR) for development of the solar power projects. The information about the GSR can be acquired by installing the pyranometer at different locations. However, it is quite expensive and lengthy process. In Nepal, there are very few stations where a pyranometer is installed by the Department of Hydrology and Meteorology, Government of Nepal. Due to financial and technical constraints, there is an alternative way available to us, which is to use empirical models, RadEst-based model [9], ANN-based model [10, 11], machine learning [12, 13], etc. The best way is to use mathematical models to estimate solar insolation using sunshine hours [14]. Due to the lack of continuous data for a long time and the few meteorological stations that are available in Nepal, there is a lack of research interest. Even if few research activities are found, there is no continuity. This finding could fill a little hole in the realm of solar energy research.

The bright sunshine hour-based model provides better GSR estimation when compared to temperature and cloud-based model. This is because the amount of GSR reaching the Earth's surface is closely related to a bright sunshine hour [15]. The virtue of bright sunshine hour is that it is a function of latitude, solar declination, and cloudiness. Using the ratio of the bright sunshine hour to sunshine duration called relative sunshine hour data (n/N) has the advantages of eradicating the first two factors leaving the cloudiness as the only one to be considered. The relative sunshine hour follows the necessity of relative radiation, i.e., the ratio of GSR to extraterrestrial solar radiation [16]. This type of model is found in the Angstrom–Prescott model [17, 18]. Most of the long wavelength solar radiation reaching the Earth surface is absorbed and transmitted by the atmosphere and certain part is reflected to space. The GSR is the total amount of solar insolation reaching the Earth's surface and has less dependence on temperature [19].

Many authors estimated the value of "*a*" and "*b*" for different sites. Black et al. collected records of solar radiation and sunshine duration have been collected for 32 stations and obtained regression constants $a = 0.23$ and $b = 0.48$ [20]. Mabasa et al. estimated Angstrom–Prescott regression constants for six locations in South Africa [19]. Srivastava and Panday estimated Angstrom–Prescott regression constants for India using records of seven different locations [21]. Muzathik et al. estimated empirical constants based on the monthly average record for Terengganu state, Malaysia [22]. Similarly, Amorox et al. [23], Janjai and Tohong [24], Chegaar et al. [25], Junliang [26, 27], Ogleman et al. [28], Samuel [29], and Rivington et al. [30] estimated the values of "*a*" and "*b*" for different sites at different parts of the world. In the case of Nepal, Poudyal et al. [5] estimated Angstrom–Prescott coefficients ($a = 0.21$, $b = 0.25$) for Kathmandu using monthly mean daily GSR data for year 2009. Similarly, Adhikari et al. [31] did the same for four locations, Kathmandu, Biratnagar, Pokhara, and Jumla, from 2011 to 2012, and compared it with temperature and humidity dependent model. Joshi et al. [32] estimated solar insolation (4.16 kWh/m^2/day) and empirical constants ($a = 0.325$, and $b = 0.272$) for Kathmandu using the A-P model and other meteorological parameters dependent model on the basis of daily mean hourly data of GSR from 2010 through 2015.

The aim of this work is to develop empirical constants for the Angstrom–Prescott model for different locations of Nepal. Then, correlations are developed for the prediction of solar insolation using only sunshine hour. The obtained empirical constants can be used to predict GSR with radially available sunshine hour in coming years for given locations and similar geographical locations. The value of empirical constants obtained from plot can be used to predict GSR for all over the locations of Nepal. The estimated GSR for any location can promote clean and renewable energy technology consequently reducing pollution due to use of large amount of traditional energy resources. Again, it supports the growth of economy of nation by lowering import of LPG gas and petroleum products and reinforces rural electrification. However, this research does not cover other meteorological parameters such as temperature, relative humidity, rainfall, altitude, and dewpoints.

2. Materials and Methods

2.1. Site Selection. Nepal (Lat. 26°22′N–30°27′N and longitude of 80°04′E to 88°12′E) is situated at the complex terrain of the Trans-Himalaya region and is landlocked between India and China. It is about 800 km long and 200 km wide with an area of 147,516 km^2. Ecologically, Nepal is divided into three regions: Low-land, Mid-land, and High-land. The geographical locations of the fifteen measuring sites are presented in Figure 1 and Table 1.

The solar insolation and meteorological parameter data were obtained from local government authorities such as Alternate Energy Promotion Centre (AEPC), Government of Nepal, World Bank, and Department of Hydrology and Meteorology (DHM), Government of Nepal, for the year 2018–2020. For five stations (Dharan, Pulchowk, Lumle, Nepalgunj, and Jumla), the data of solar radiation were obtained from stations installed by AEPC in collaboration with World Bank. The data in these stations were logged every minute. For the remaining ten locations, the data of solar radiation were obtained for one hour-interval from Department of Hydrology and Meteorology (DHM), Government of Nepal. These data were converted into daily average global solar radiation using Simpson's one-third rule implemented using Python programming language. There were negligible missing or unknown data. Such missing and unknown data points were filled with the average of the adjacent values of the same variable. Same was done for the outliers [13]. Kipp and Zonen pyranometer is used to measure solar insolation. Campbell-Stock sunshine recorder is used to measure bright sunshine duration. Sunshine duration is the period during which direct solar irradiance exceeds a threshold value of 120 W/sq m [34].

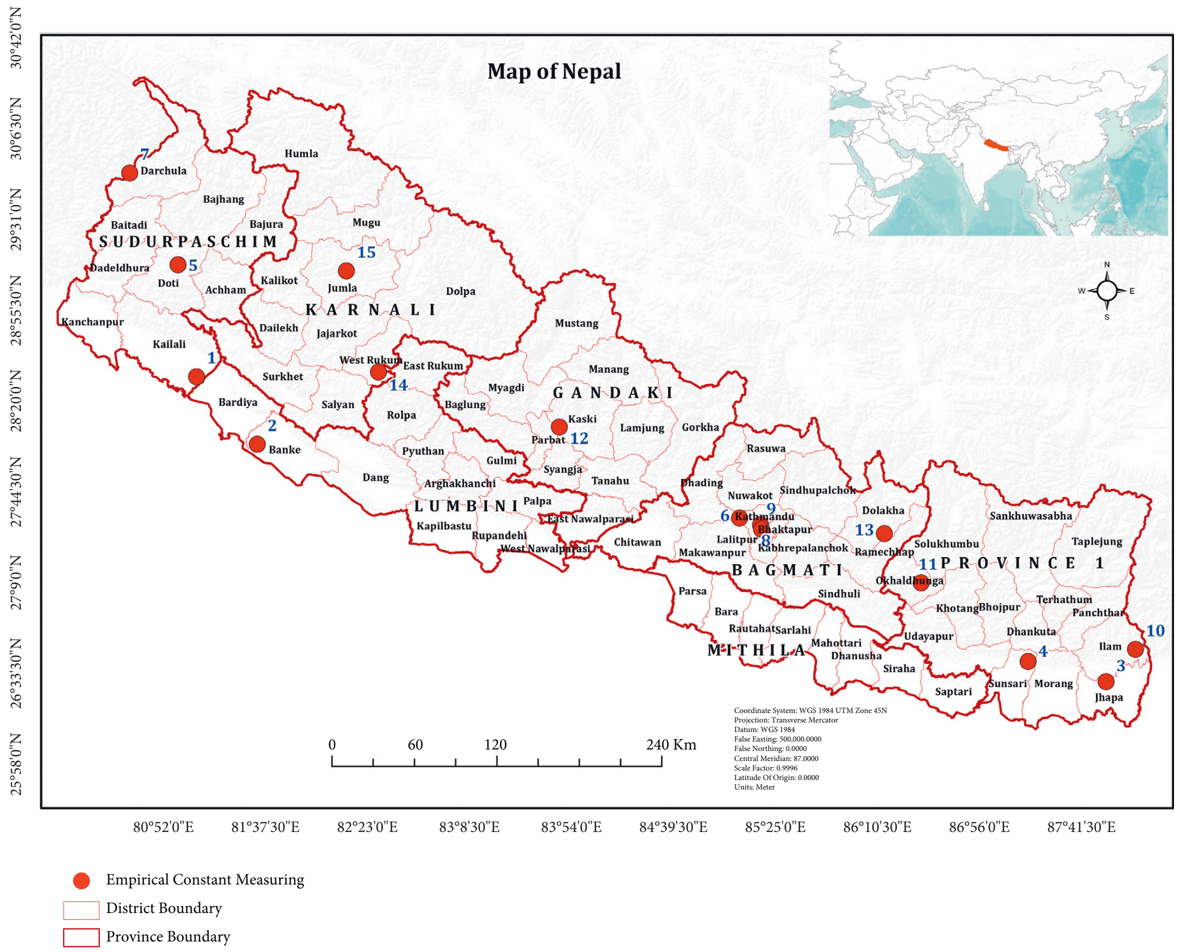


Figure 1: Map of Nepal with measuring site [33].

Table 1: Geographical locations and regression equations for measuring sites.

S. No.	Location	Latitude deg N	Longitude deg E	Altitude masl (meter above sea level)	Angstrom–Prescott model
1	Tikapur	28.5365	81.1151	149	Hg/Ho = 0.272 + 0.374 (n/N)
2	Nepalgunj	28.113	81.589	150	Hg/Ho = 0.255 + 0.451 (n/N)
3	Kankai	26.6583	87.8619	300	Hg/Ho = 0.004 + 0.654 (n/N)
4	Dharan	26.7929	87.2926	310	Hg/Ho = 0.291 + 0.407 (n/N)
5	Dipayal	29.2621	80.9369	662	Hg/Ho = 0.278 + 0.519 (n/N)
6	Dhunibesi	27.7229	85.1643	1085	Hg/Ho = 0.235 + 0.432 (n/N)
7	Darchula	29.8429	80.5388	1097	Hg/Ho = 0.234 + 0.592 (n/N)
8	Pulchowk	27.6816	85.3187	1320	Hg/Ho = 0.293 + 0.413 (n/N)
9	Khumaltar	27.6517	85.3257	1350	Hg/Ho = 0.271 + 0.448 (n/N)
10	Ilam	26.868	88.0783	1570	Hg/Ho = 0.198 + 0.543 (n/N)
11	Okhaldhunga	27.3081	86.5042	1720	Hg/Ho = 0.215 + 0.598 (n/N)
12	Lumle	28.2966	83.8179	1740	Hg/Ho = 0.261 + 0.541 (n/N)
13	Jiri	27.6304	86.2321	1877	Hg/Ho = 0.26 + 0.564 (n/N)
14	Musikot	28.619	82.4625	2100	Hg/Ho = 0.244 + 0.532 (n/N)
15	Jumla	29.2724	82.1935	2383	Hg/Ho = 0.28 + 0.553 (n/N)

2.2. Model. There exists linear relationship between GSR and sunshine duration was presented by Angstrom in 1924 [17, 35]. The equation is

$$\frac{\overline{H}_g}{\overline{H}_c} = a_1 + b_1\frac{\overline{n}}{\overline{N}}, \quad (1)$$

where $\overline{H}_g$ is monthly average daily global solar radiation measured on horizontal surface, $\overline{H}_c$ is monthly average clear sky daily global solar radiation measured on horizontal surface, $\overline{n}$ is monthly average daily bright sunshine hours, $\overline{N}$ is monthly average maximum possible sunshine hours, and a_1 and b_1 are empirical constants.

There is ambiguity in (1) as there is uncertainty in the definition of $\overline{H_c}$ and $\overline{n}/\overline{N}$ because there may be a problem in calculating clear sky radiation accurately. This model was modified by Prescott in 1940 [18] by replacing H_c by H_0, extraterrestrial solar radiation. The new model is known as Angstrom–Prescott model which is the most popular and commonly used model, given by

$$\frac{\overline{H_g}}{\overline{H_0}} = a_2 + b_2\frac{\overline{n}}{\overline{N}}, \tag{2}$$

where $\overline{H_0}$ is monthly average daily extraterrestrial solar insolation for the location and a_2 and b_2 are empirical constants.

The empirical constants a_2 and b_2 depend upon location. The coefficients a_2 and b_2 represent the fraction of extraterrestrial radiation on overcast days and average days, respectively. The ratio Hg/Ho is the clearness index and n/N is the cloudless index. It gives information about the atmospheric characteristics and conditions of the study area. In this way, the empirical relations can be used to generate solar radiation for the implementation of solar energy and solar thermal technologies where there are no alternative means of energy in all parts of the world [36].

The daily extraterrestrial solar radiation on a horizontal surface (H_o) in MJ/m^2/day is computed from the following equations [35, 36]:

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360 n_d}{365}\right)\right] \left[\cos\varnothing\cos\delta\sin\omega + \frac{\pi}{180}\omega\sin\varnothing\sin\delta\right], \tag{3}$$

where I_{sc} is the solar constant (=1367 W m^{-2}), $\varnothing$ is the latitude of the site (rad), δ is the solar declination (rad), ω is the mean sunrise hour angle for the given month, and n_d is the number of days of the year starting from the 1st of January ($n_d = 1$) to 31st December ($n_d = 365$).

The solar declination (δ) and the mean sunrise hour angle (ω) can be computed by the following equations [35, 36]:

$$(\delta\ \text{degree}) = 23.45\sin\left[\frac{360}{365}(284 + n_d)\right], \tag{4}$$

$$\omega = \cos^{-1}(-\tan\varnothing\tan\delta). \tag{5}$$

The maximum possible sunshine duration (day length) in hours can be computed by [35, 36]

$$N = \frac{2}{15}\omega = \frac{2}{15}\cos^{-1}(-\tan\varnothing\tan\delta). \tag{6}$$

The clearness index (K_T) is the ratio of the measured horizontal solar insolation (H_g) to the extraterrestrial solar radiationH_o.

The daily extraterrestrial solar insolation H_o and day length N for 15 meteorological stations each are mentioned above using (3) and (6), respectively. The data of solar insolation and bright sunshine hour of each station over the period 2018–2020 are analyzed and prepared in the form of hourly averaged daily solar insolation. These data were used in (7) to estimate daily solar insolation (H_g) on the surface, using regression techniques.

$$\frac{H_g}{H_o} = a + b\frac{n}{N}. \tag{7}$$

H_g is the hourly average daily measured solar radiation; H_o is daily extraterrestrial solar insolation for the location; n is the daily bright sunshine hour. The regression coefficients a and b of the Angstrom–Prescott model are the intercept on H_g/H_o axes and slope of regression line, respectively. The validation of estimated solar insolation is done by comparing estimated annual solar insolation with measured solar radiation.

2.3. Statistical Analysis. The statistical tools used to validate estimated data are room mean square error (RMSE), mean bias error (MBE), mean percentage error (MPE), coefficient of residual mass (CRM), and correlation coefficient (r) [37]:

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum (H_c - H_m)^2}, \tag{8}$$

$$\text{MBE} = \frac{1}{N}\sum (H_c - H_m), \tag{9}$$

$$\text{MPE} = \frac{1}{N}\left[\sum\left(\frac{H_c - H_m}{H_m}\right) \times 100\right], \tag{10}$$

$$r = \frac{\sum (H_m - \overline{H_m})(H_c - \overline{H_c})}{\sqrt{\sum (H_m - \overline{H_m})^2 (H_c - \overline{H_c})^2}}, \tag{11}$$

$$\text{CRM} = \frac{\sum H_m - \sum H_c}{\sum H_m}, \tag{12}$$

where H_m is measured GSR, H_c is estimated GSR, and N is number of data points.

Then the yearly average of correlation between estimated and measured values of solar insolation is determined. The correlation between Angstrom–Prescott coefficients and sunshine duration ratio for all given places are determined using trend lines in the plot between them. With the help of a correlation equation, which uses only sunshine hour data, it will be possible to estimate solar insolation for the places where solar radiation data is not available. The proposed methodology is expressed as flow chart in Figure 2.

3. Results and Discussion

The extraterrestrial daily solar radiation and maximum day length are calculated by using (3) and (6), respectively, for all locations separately. The empirical constants also called model coefficients a and b are determined by linear regression analysis technique for different locations for the years 2018 and 2020 on average. The regression coefficient 'a'

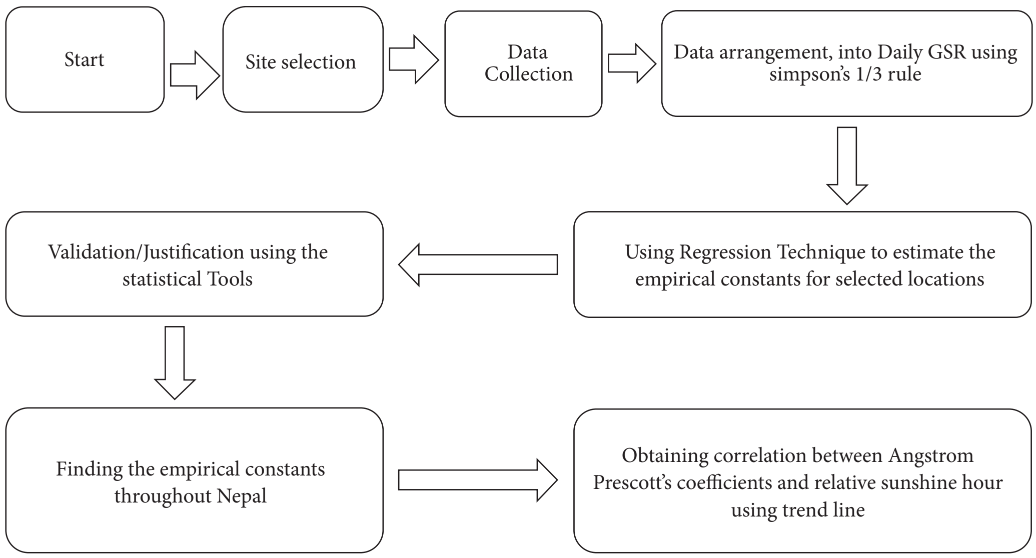


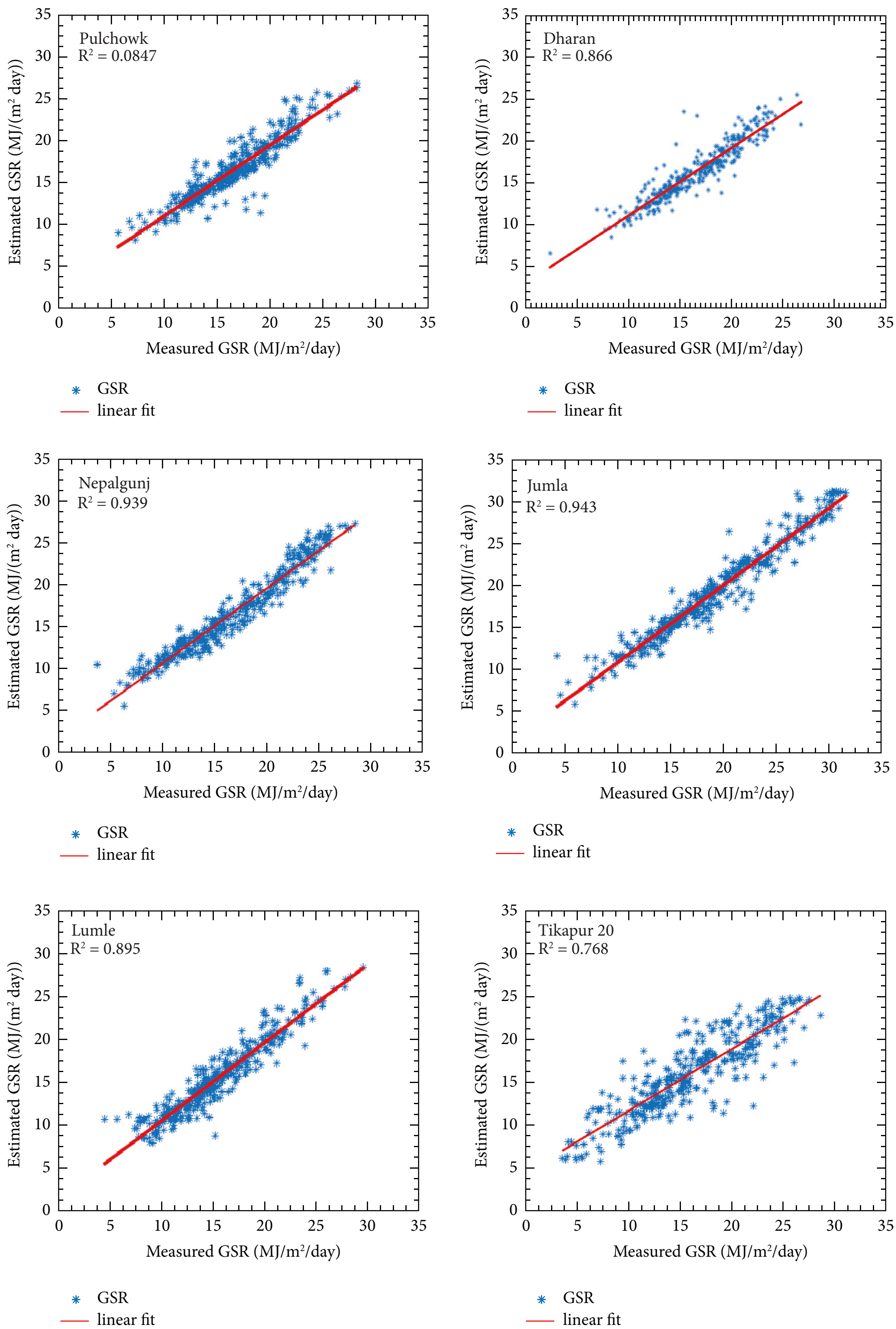
Figure 2: Flow chart of the proposed methodology.

is the intercept and b is the slope of the regression line. Regression equations obtained for different meteorological stations are listed in Table 1 for daily solar insolation and sunshine data. These equations are used for the estimation of daily GSR for different years at different geographical locations separately. The estimated GSR was compared with corresponding values of measured GSR. The validation of a model for different locations is performed by different statistical tests such as correlation coefficient, root mean square error (RMSE), mean bias error (MBE), and mean percentage error (MPE).

The linear variations of daily average hourly measured and estimated GSR for the model for all locations are shown in Figure 3. Similarly, daily variations of measured and estimated GSR for given locations for the models are shown in Figure 4. Figure 3 shows that there is remarkable agreement between daily average measured and estimated solar insolation with a highly acceptable coefficient of determination (R^2) greater than 0.705 except Okhaldhunga. Jumla has the highest R^2 equal to 0.906. Likewise, Figure 4 shows that there is good agreement between daily average measured and estimated GSR. The annual average highest value of GSR is 19.11 MJ/m^2/day for Jumla and that lowest value is 13.06 MJ/m^2/day for Ilam. This can also be observed in Figure 5 that gives the variation of GSR, clearness index, and relative sunshine hour. Generally, with the increase of clearness index and relative sunshine hour, GSR is increased following all stations except for Kankai. Here, even at large relative sunshine hour, clearness index is low since the sky is cloudy and dusty. In Figure 4, it is shown that at the time of monsoon season (June, July, August, and September) GSR decreases, due to increase in cloudy and rainy days. This effect occurs highest in Lumle, Pokhara, Ilam, and Jiri. However, this effect is lowest in Nepalgunj and Dharchula. From Figure 6, it is observed that Jumla has maximum clear days (189 days) (clearness index >0.65) and 25 cloudy (clearness index <0.34) days as there is less pollution and it is far from the urban areas [38]. Similarly, in eastern part of Nepal, Ilam has 141 (maximum) days, where 60 days are cloudy and clear days, respectively.

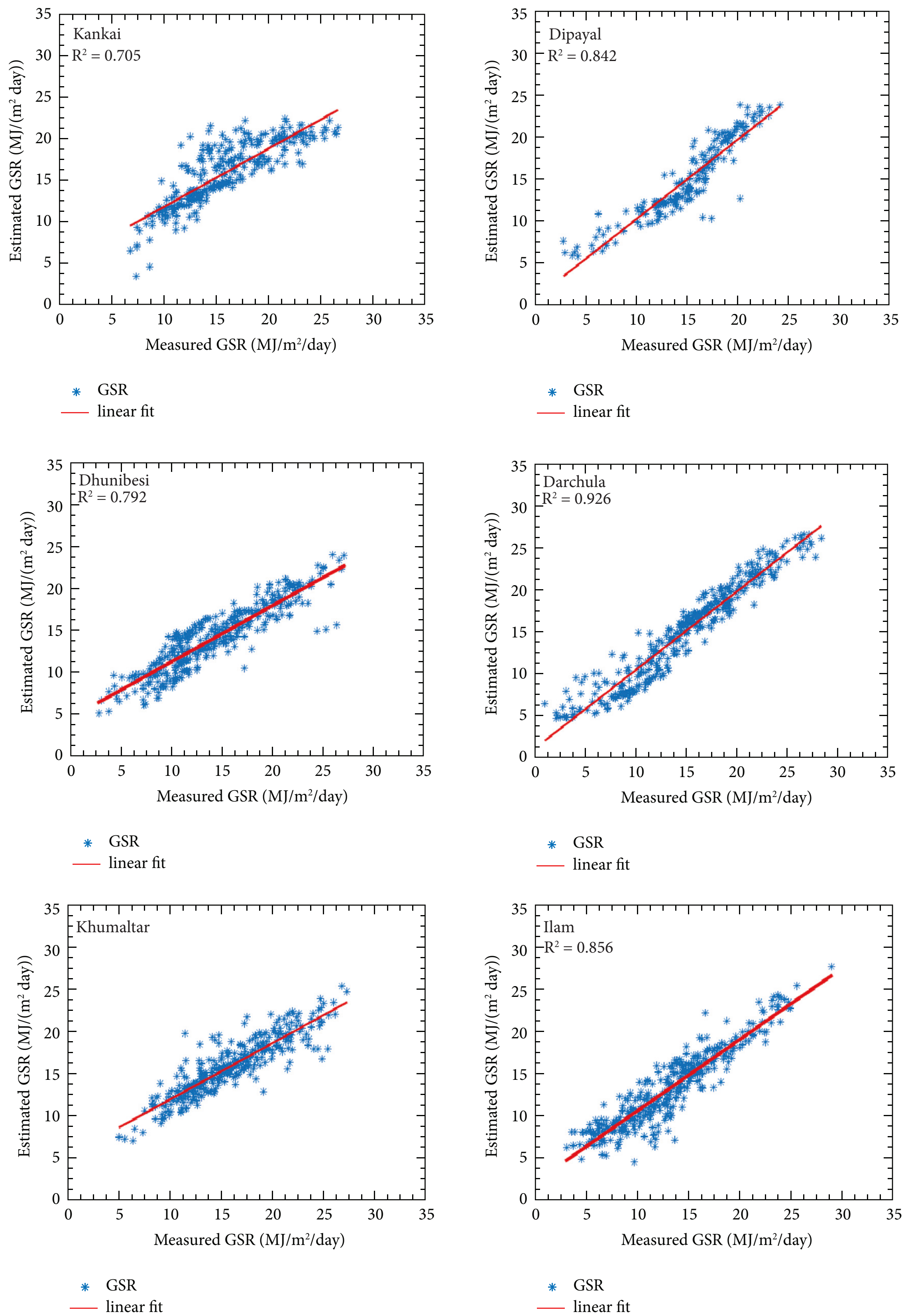
Furthermore, it is validated by comparing estimated annual GSR for the same meteorological locations and measure annual GSR for that location. Table 2 gives the estimates of annual solar insolation for selected meteorological stations in Nepal with measured annual solar insolation. It shows that there is good agreement between measured and estimated values. The relative percentage change between measured and estimated GSR varies numerically from 0.117% (Lumle) to 1.136% (Dhunibesi). This validation can be seen in Figure 7(a) and Figure 7(b). There is a slight increase in GSR with altitude except for Dhunibesi and Ilam due to local weather conditions.

The values of statistical errors, RMSE, MBE, MPE, CRM, and r, for fifteen meteorological stations are listed in Table 3. These errors give performance of the Angstrom–Prescott model in different locations [12]. The correlation coefficient lies between 0.755 and 0.972 and highest values occurred for station at Jumla and lowest at Okhaldhunga. Similarly, the coefficients of determination (R^2) are also highest at Jumla as shown in Figure 3. The lower values of RMSE, MBE, MPE, and CRM are preferred as they indicated differences between estimated and measured value of solar radiation. The lowest value of RMSE is 1.344 MJ/m^2/day for the station at Nepalgunj. Similarly, the lowest values of MBE and MPE are 0.005 MJ/m^2/day and 0.645% for the stations at Kankai and Musikot, respectively. Lower values of MBE and MPE indicate goodness of fit between clearness index and relative sunshine hour. Also, the value of MPE is less than 7.746% at any stations considered. The CRM ranges from 0 to 0.01 which indicates perfect estimation. This suggested that the Angstrom–Prescott correlation model is good model to estimate the solar radiation in Nepal.



(a)

Figure 3: Continued.



(b)

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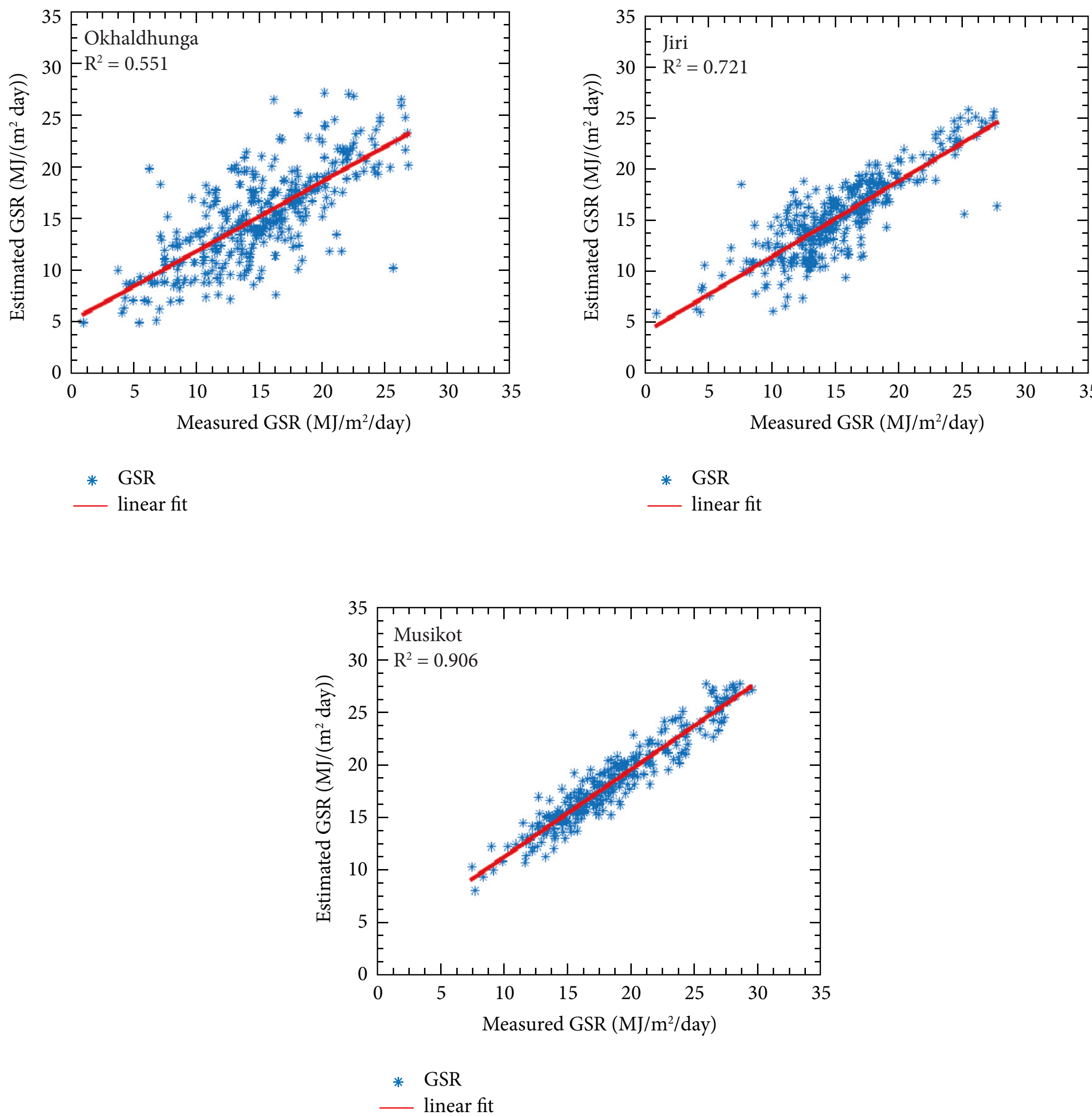


(c)

Figure 3: Linear variation of daily average measured and estimated GSR for A-P models for different locations.

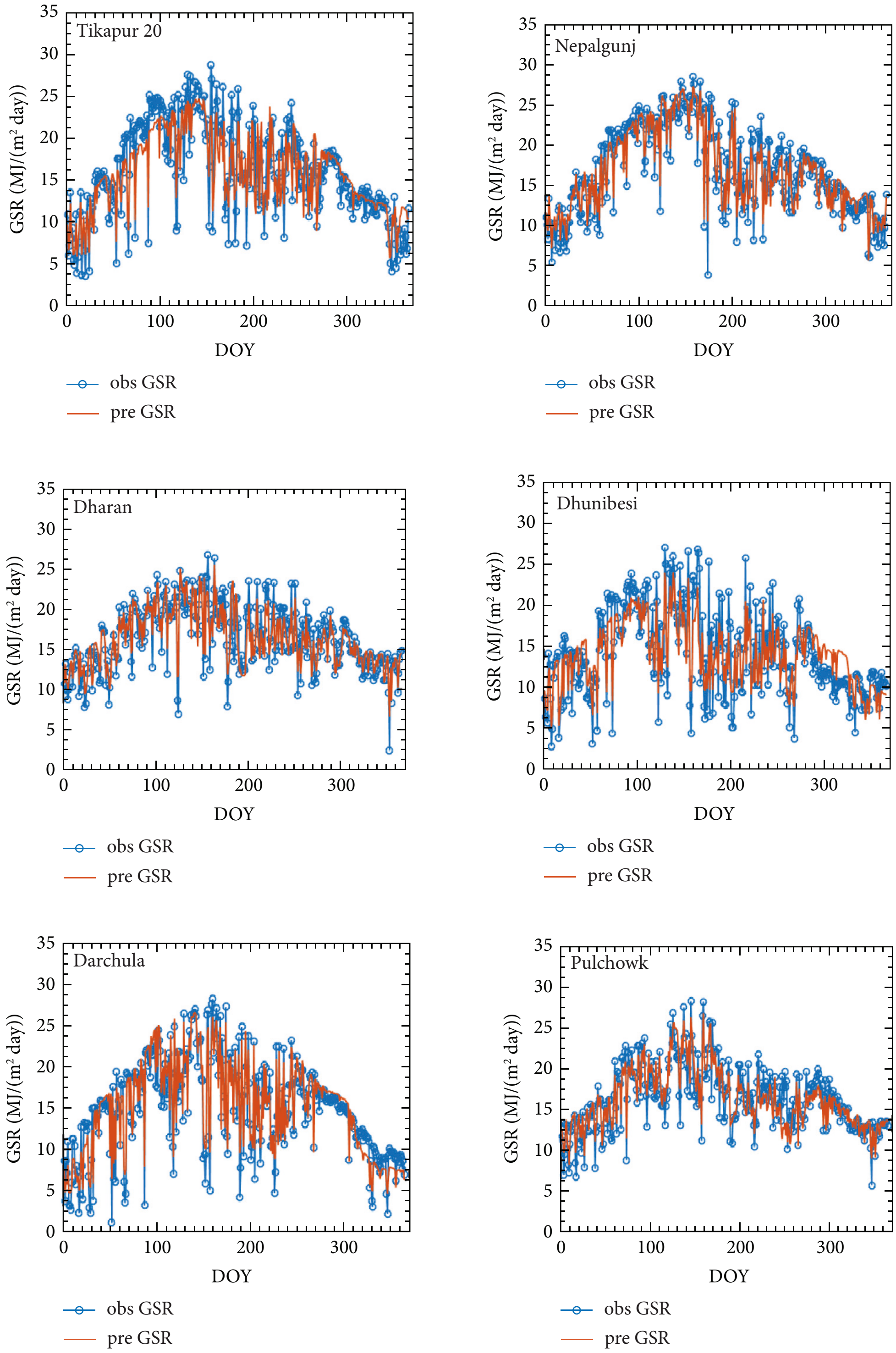
Now from table, the sum of regression coefficients $(a+b)$ is the transmissivity of the atmosphere for solar insolation under perfectly clear sky condition. The clear sky (day) means $n/N = 1$; then equation (7) becomes

$$\frac{H_g}{H_0} = a + b. \tag{13}$$

For complete overcast day, $n/N = 0$, then (7) is

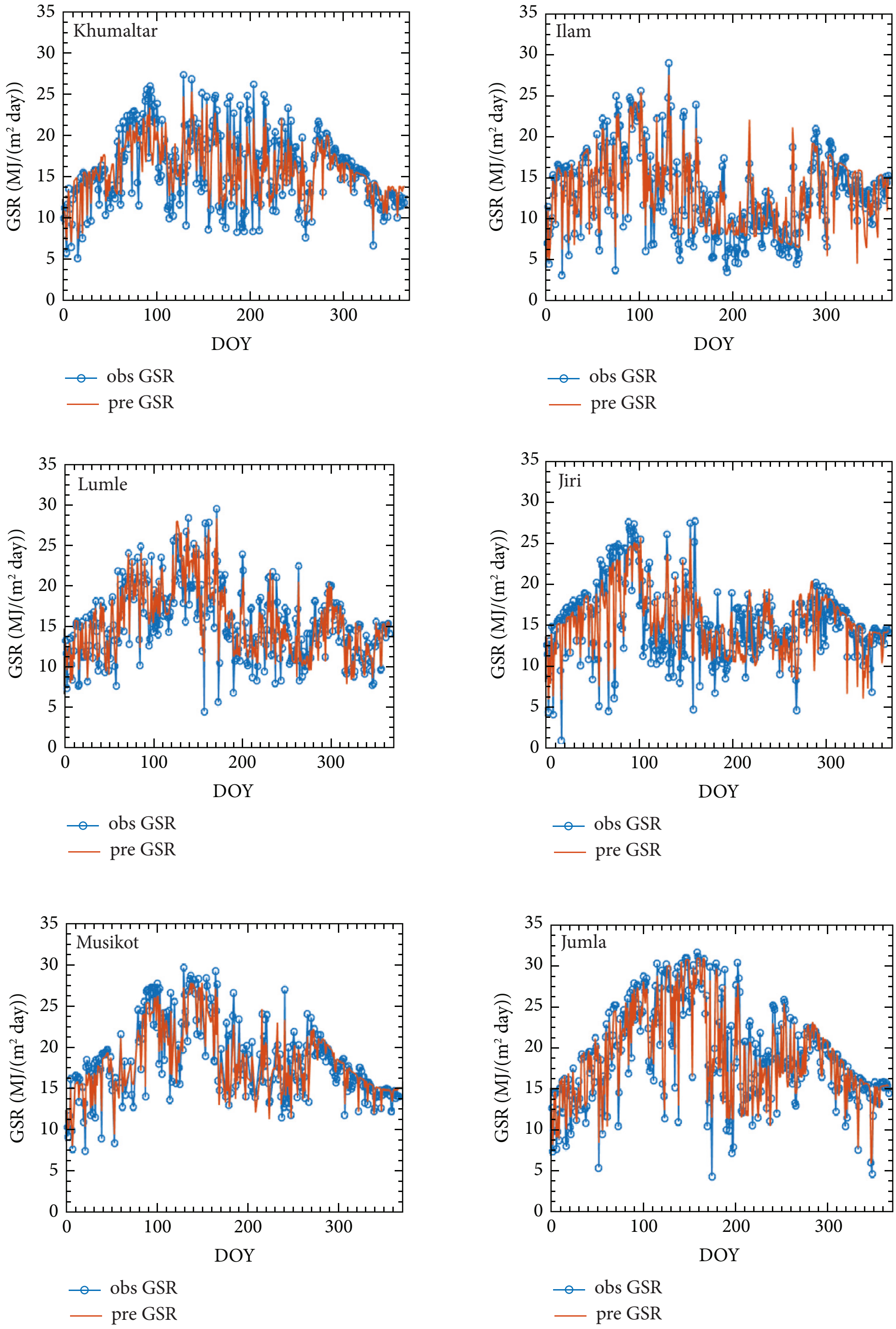
$$\frac{H_g}{H_0} = a. \tag{14}$$

Thus, the empirical constant "a" can be interpreted as transmissivity of an overcast (day) atmosphere [39]. At this time insolation is due to different components. The values of the sum of the empirical constants $(a+b)$ representing the max clearness index (for $n/N = 1$) are found to be almost equal for all stations. The average value of $(a+b)$ is 0.747. The highest value of $(a+b)$ is 0.833 found at Jumla. For Darchula, Okaldhunga, Lumle, Jiri, and Jumla, the value of $(a+b)$ is greater than 0.802 indicating clear sky due to less pollution at those places. In the paper of Martinez-Lozano, they found parameters "a" and "b" ranging from (0.016 to 0.44) and (0.19 to 0.87), respectively, for 101 locations using monthly average data. Similarly, they found parameters "a" and "b" ranging from (0.19 to 0.36) and (0.43 to 0.62), respectively, for 57 stations using daily data. Thus, the obtained values of regression coefficients are in close agreement with this paper [16]. The observed empirical constant a is in close agreement with value observed in paper of



(a)

FIGURE 4: Continued.



(b)

Figure 4: Variation of daily average measured and estimated GSR for A-P models for different locations.

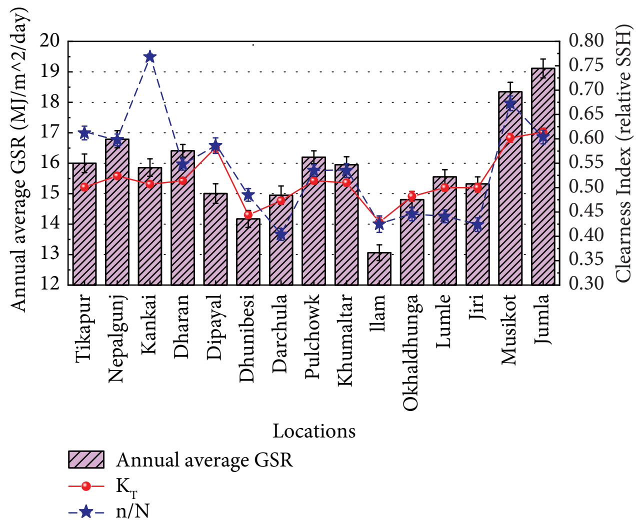


Figure 5: Annual variation of GSR, clearness index, and relative sunshine hour.

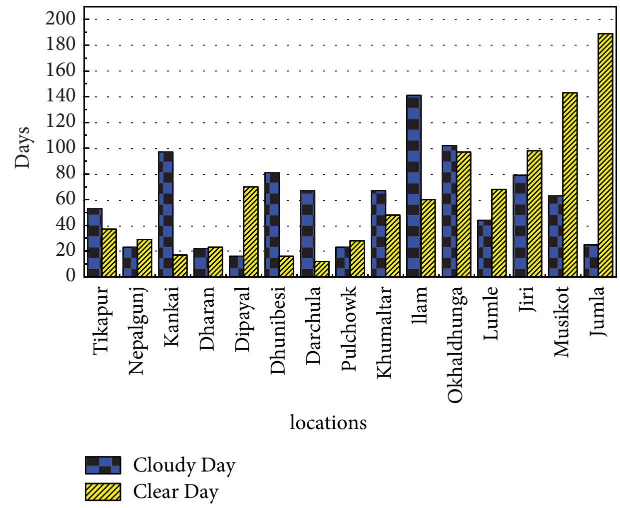


Figure 6: Clear and cloudy days in different locations.

Table 2: The annual average measured and estimated solar insolation and Angstrom–Prescott parameters for selected meteorological locations.

Location	Altitude masl	Annual average n/N	Annual mea. GSR (MJ/m^2/day)	Annual est GSR (MJ/m^2/day)	PE (%)	Empirical constant (a)	Empirical constant (b)	$a+b$
Tikapur	149	0.612	15.998	15.865	0.831	0.272	0.374	0.646
Nepalgunj	150	0.598	16.788	16.691	0.578	0.255	0.451	0.706
Kankai	300	0.768	15.856	15.861	−0.032	0.004	0.654	0.658
Dharan	310	0.548	16.407	16.337	0.427	0.291	0.407	0.698
Dipayal	662	0.586	15.006	15.076	−0.466	0.278	0.519	0.797
Dhunibesi	1085	0.485	14.17	14.009	1.136	0.235	0.432	0.667
Darchula	1097	0.404	14.95	15.058	−0.722	0.234	0.592	0.826
Pulchowk	1320	0.535	16.198	16.164	0.210	0.293	0.413	0.706
Khumaltar	1350	0.535	15.95	15.841	0.683	0.271	0.448	0.719
Ilam	1570	0.425	13.064	13.128	−0.490	0.198	0.543	0.741
Okhaldhunga	1720	0.446	14.806	14.971	−1.114	0.215	0.598	0.813
Lumle	1740	0.441	15.553	15.574	−0.135	0.261	0.541	0.802
Jiri	1877	0.424	15.321	15.367	−0.300	0.26	0.564	0.824
Musikot	2100	0.673	18.343	18.258	0.463	0.244	0.532	0.776
Jumla	2383	0.604	19.113	19.045	0.356	0.28	0.553	0.833
Average		0.539	15.835	15.816	0.117	0.239	0.508	0.747

Poudyal ($a = 0.21$, $b = 0.26$) for Kathmandu on the basis of data of 2010 [6] but second constant is different. Table 4 lists the empirical constants of different locations to compare with literature obtained values. It is observed that the empirical constant a is almost same for all mentioned and literature locations. There are fluctuations of value of b for Indian cities.

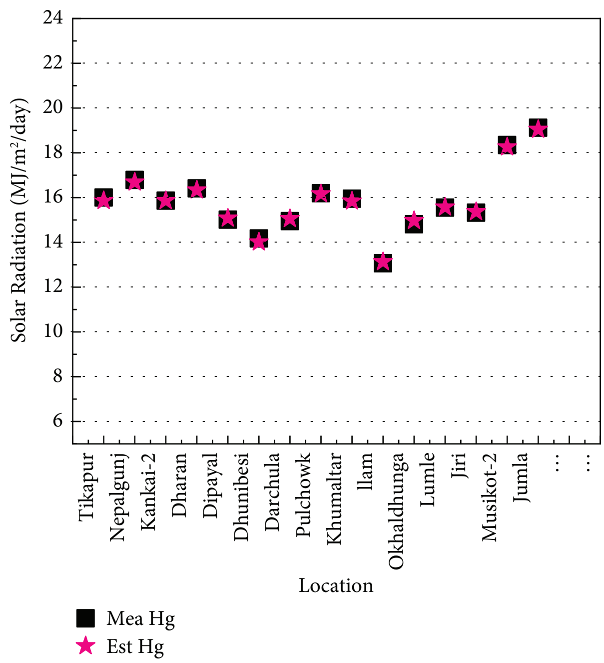
Now the averages of the correlation obtained in Table 3 for all meteorological locations are $a = 0.239$ and $b = 0.508$. Then, we get Angstrom–Prescott model for Nepal:

$$\frac{H_g}{H_0} = 0.239 + 0.508\left(\frac{n}{N}\right). \quad (15)$$

From this relation, solar insolation can be found if sunshine duration is known at any part of Nepal. Also, the new correlation between "a" and "n/N" and "b" and "n/N" is shown in Figure 8 and Figure 9. On fitting curve, the empirical constants "a" and "b" fit into second-order polynomials with the values of R^2 greater than 64%. Obtained values of coefficient of determination were considerably high and thus fitted quadratic equation for calculating the values of empirical constants for a given location can be justified. These values of empirical constants are extensively used for convenient calculation of solar insolation.

$$a = -4.881\left(\frac{n}{N}\right)^2 + 5.244\left(\frac{n}{N}\right) - 1.1198\left(R^2 = 0.862\right), \quad (16a)$$

$$b = 5.462\left(\frac{n}{N}\right)^2 - 6.195\left(\frac{n}{N}\right) + 2.205\left(R^2 = 0.643\right). \quad (16b)$$



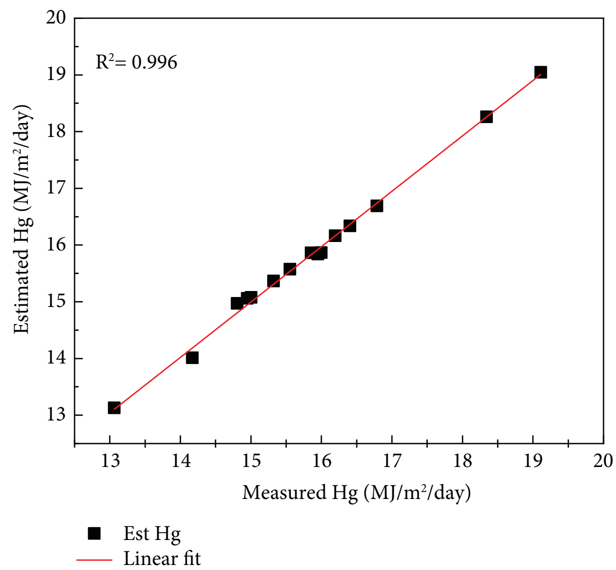


FIGURE 7: (a) Comparison between measured and estimated GSR. (b) Linear fit between measured and estimated GSR.

TABLE 3: Statistical errors for fifteen meteorological stations.

Location	Altitude masl	r	RMSE (MJ/m^2/day)	MBE (MJ/m^2/day)	MPE (%)	CRM
Tikapur	149	0.879	2.697	−0.133	3.964	0.008
Nepalgunj	150	0.969	1.344	−0.096	1.272	0.006
Kankai	300	0.840	2.413	0.005	2.053	0.000
Dharan	310	0.933	1.464	−0.070	1.278	0.004
Dipayal	662	0.923	1.758	0.071	3.344	0.005
Dhunibesi	1085	0.906	2.363	−0.161	4.291	0.011
Darchula	1097	0.962	1.583	0.108	5.179	0.007
Pulchowk	1320	0.921	1.577	−0.034	1.236	0.002
Khumaltar	1350	0.891	2.109	−0.109	2.068	0.007
Ilam	1570	0.926	1.872	0.064	4.405	0.005
Okhaldhunga	1720	0.755	3.418	0.165	7.746	0.011
Lumle	1740	0.946	1.454	0.021	1.403	0.001
Jiri	1877	0.850	2.343	0.046	4.565	0.003
Musikot	2100	0.956	1.411	−0.085	0.645	0.005
Jumla	2383	0.972	1.410	−0.068	1.146	0.004
Average		0.909	1.948	−0.018	2.973	0.001

The solar insolation may thus be estimated for any site in Nepal using (16a), (16b), and (7), even when solar radiation measurements are not available. Sunshine hour data suffices for the calculation of coefficients of the Angstrom–Prescott model.

The solar insolation is highest in the months of May, June, July, and August (about 140 days). Jumla, Lumle, Nepalgunj, Kathmandu, and Ilam have a high effect of rainfall during monsoon causing a reduction in solar insolation. However, at Dharan and Tikapur, this effect is comparatively less. The average yearly solar insolation is maximum (19.113 MJ/m^2/day) at Jumla and minimum (13.064 MJ/m^2/day) at Ilam. At Jumla, the total solar radiation was 6976.32 MJ/m^2/day and at Ilam was 4768 MJ/m^2/day. Furthermore, solar insolation in western Nepal represented by Jumla was 5.309 kWh/m^2, in mid-Nepal represented by Pulchowk was 4.499 kWh/m^2, and in eastern Nepal represented by Ilam was 3.63 kWh/m^2 [4]. It happened due to precipitation trends and local weather conditions. At the same time, it is noted that there is gradually lesser precipitation from the eastern part to the western part of Nepal, except in Pokhara. The annual average solar insolation of 4.31 kWh/m^2/day is found which is slightly higher than Poudyal, 2015, due to the lockdown effect of COVID-19 [6, 42].

Table 4: Comparison of empirical constants.

Location	Altitude masl	Empirical constant (a)	Empirical constant (b)	$a+b$	Remark
Tikapur, Nepalgunj	>300	0.263	0.412	0.675	
Kankai, Dharan, Dipayal	300–500	0.191	0.527	0.718	
Dhunibesi, Darchula, Pulchowk, Khumaltar	1001–1400	0.258	0.417	0.675	Nepal
Ilam, Okhaldhunga, Lumle	1401–1800	0.224	0.561	0.785	
Jiri, Musikot, Jumla	1801–3000	0.261	0.549	0.81	
South China (Guangzhou)		0.171	0.555	0.726	[15]
South-west China (Lhasa)		0.214	0.552	0.766	
Jodhpur	224	0.228	0.511	0.739	
Mumbai	14	0.223	0.512	0.735	[40]
Pune	560	0.229	0.531	0.76	
Delhi	216	0.222	0.372	0.594	
Shillong	1600	0.229	0.295	0.524	
Nagpur	310	0.235	0.279	0.514	[41]
Kodaikanal	2339	0.244	0.137	0.381	
Bangalore	921	0.243	0.173	0.416	
Nandi Hills	1474	0.242	0.178	0.42	
Bangkok		0.29	0.378	0.668	[24]
Songkhala		0.264	0.491	0.755	

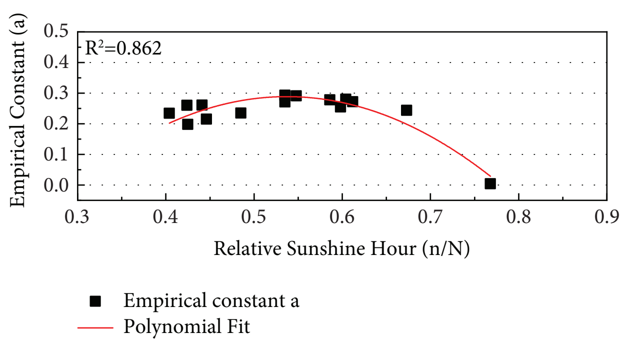


Figure 8: Correlation between empirical constant a and relative sunshine hour.

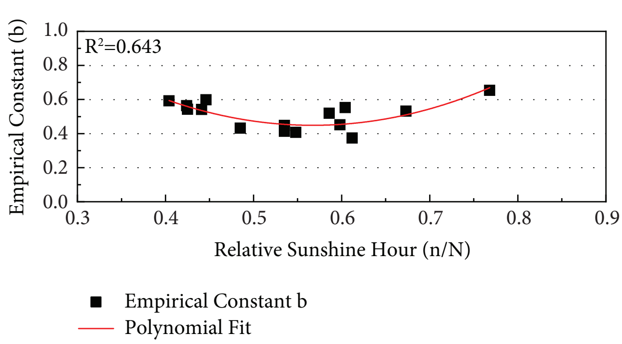


Figure 9: Correlation between empirical constant b and relative sunshine hour.

At the end, this type of research work of prediction of empirical constants to find the solar energy is novel work in our complex terrain of Himalaya. This location is not only vulnerable in terms of climate change, landslide, floods, fast rate of snow melt, and changes at biodiversity but also geographically very young mountain and still rising. So, this type of study is essential not only to promote carbon zero emission energy resources but also to solve the energy crisis at a local as well global scale [43].

4. Conclusion

Solar energy is one of the most effective and economical alternative energy sources. Estimation of solar insolation is essential for designing and sizing the solar energy system. In this study, regression technique was used to calculate annual average Angstrom–Prescott coefficients. The empirical constants were found to be $a = 0.230$ and $b = 0.508$, respectively, for Nepal and the annual solar insolation was 4.31 kWh/m^2/day. The statistical analysis confirmed that there is a good harmony between measured and estimated solar insolation. In this result, second-order polynomial equations based on the relative sunshine hour had been obtained for each of the empirical constants. The empirical constants and equations developed in this study might be used to calculate solar insolation where sunshine duration values are readily available. The outcome of this research is supportive to make plans, policies, and programs to promote clean and renewable energy technology in Nepal. Lastly, the sunshine-based model is best for majority of the study sites and in order to account for complexity of terrain further meteorological parameters might need to be included in some cases.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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