Research Journal of Chemical Sciences ISSN 2231-606X
Vol. **8(1),** 23-29, January **(2018)** *Res. J. Chem. Sci.*

Prediction of global solar radiation using meteorological parameters on empirical model at mountain Region Jumla, Nepal

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Available online at: www.isca.in, www.isca.me
Received 23rd November 2017, revised 12th January 2018, accepted 17th January 2018

Abstract

In this study, sunshine based Angstrom-Prescott model along with multiple linear regression model based on three meteorological parameter (relative sunshine hours, maximum and minimum temperature, minimum relative humidity) were developed to predict the monthly average global solar radiation for the year 2011 of Jumla. The estimated solar radiation from these models were compared with the measured solar radiation which were found to be in close agreement with each other. The statistical test like mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE) and coefficient of determination (R^2) were performed to evaluate the model. The multiple linear regression model has a higher value of R^2 (0.95) and lower value of RMSE (0.3614) which indicate a better agreement between the measured and estimated global solar radiation. It is suggested that the multiple linear model can be employed for the estimation of monthly global solar radiation on horizontal surface for Jumla and other region with similar climatic condition where radiation data are inaccessible.

Keywords: Solar radiation, sunshine hours, angstrom-prescott model, regression model, statistical test.

Introduction

Nepal, a least developed country, has set a 14th national plan incorporating the sustainable development goal as endorsed by UN with a target of graduating to middle income nation by 2030 through high economic growth creating the foundation for sustainable economic prosperity. Nepalese economy is estimated to grow by 6.94% in current fiscal year[1]. Energy is the bedrock of transformation ambition to underpin an estimated growth, to increase the accessibility and availability of electricity, to fulfill the demand for greater mobility and to develop the infrastructure[2].

Traditional, commercial and renewable sources has 74.5%, 22%, 3.5% share on the current energy consumption of Nepal respectively. Firewood alone share 2/3 of total energy consumption which is a major cause of premature death in rural area of Nepal due to indoor air pollution and environmental degradation as a result of deforestation and biodiversity loss. The import and consumption of petroleum product especially LPG has increased rapidly because of urbanization .The current urban population comprising inhabitant of municipalities, sub metropolitan and metropolitan stands at 58.25% which has wide ranging effect on energy use, stimulating the switch to modern fuel and escalate the demand for electronic appliances, vehicles ownership as well as for steel, cement and other energy intensive material[1,2].

The electricity contribute 4.1% of the total energy consumption with 961.2MW connected to grid out of which hydroelectricity share 907.6MW, thermal plant generate 53.4MW and that of solar energy is 100KW. The deficit electricity of 482.9MW manifest as load shedding[1].

Electricity consumption per capita is 128KWh which is far below the Asia average of 918KWh.It is imperative to increase electricity consumption per capita to 2000KWh to achieve a HDI of 0.8 which is an indication of prosperity of nation[3].

It is high time that the concerned authorities and energy policy maker should initiate to address the immediate energy need either relying on fossil fuel or through renewable form of energy. It will be prudent step to embrace renewable energy as it not only deals with the problem of climate change but also laid foundation for sustainable economy on a low carbon trajectory[2].

The economically emerging nation, viz., India and china has pledge to reduce CO_2 emission by 33-35% and 60-65% respectively of 2005 level by 2030, by increasing a share of non-fossil fuel as well as increasing a forest cover area . At the same time china and India has set a target of adding 184GW and 100 GW of solar power by 2040 and 2022 respectively as a steps toward sustainable development through a promotion of renewable resources. This inclination to solar power results in reduction of cost of solar PV modules as well as reflects the truth that 21st century is the era of clean and green energy[4].

Wind, solar, hydroelectricity and biomass are the available form of renewable energy in Nepal[5]. However harnessing a solar power is the best alternative for Nepal, being located in a favorable latitude where sunshine for about 300 days a year and receive an average solar radiation for 3.6-6.2KWh/m^2/day with national intensity of about 4.23KWh/m^2/day[6]. Besides this solar is the best alternative for rural electrification in country like Nepal which has difficult topography and scattered settlement with low population density[7].

Despite of huge potential of hydroelectricity, hydropower construction has been delayed by technical or environmental problem and public opposition. Most of the proposed as well as under construction project are runoff river types so solar can be a complementary energy sources by maintaining a water level of reservoir based project like Kulekheni hydroelectricity project as well as enhancement of roof top solar can reduce or even replace costly diesel powered backup generation[2,5].

Actual knowledge and data of solar radiation of a pertaining location are required for the utilization of solar energy in agriculture, hydrology as well as in design and operation of solar plant and solar devices. However in developing country like Nepal solar radiation measuring station are few because of cost as well as difficulty in maintenance and calibration of the measuring instrument result into limited number of data of restricted location[8,9]. In absence of these measurement, theoretical model and empirical correlation have become the desired tools to estimate the global solar radiation of a place using some meteorological parameter such as temperature, sunshine hours, relative humidity, rainfall, wind speed which can be measured reliably by meteorological station located at different parts of country[10].

Several researchers has used modified version of AP model as well as linear and nonlinear multiple regression equation for the estimation of global solar radiation. However AP model ubiquitous because of its reliability simplicity and higher efficiency[8].

In Nepal Angstrom type as well as multiple linear regression equation have been used to estimate global solar radiation of limited location like Kathmandu, Pokhara, Lukla, Jumla. etc.[9,11]

This study aspire to develop a multiple linear regression equation based on sunshine hour's, temperature and relative humidity and assess its predictability over AP model for the estimation of global solar radiation in horizontal surface for Jumla, North West of Nepal[12,13].

Materials and methods

The raw data of daily solar radiation, sunshine hours, temperature and relative humidity of Jumla (latitude 29.28^0, longitude 82.17^0 and altitude 2300m above the sea level) for year 2011 were collected from archives of department of hydrology and meteorology, government of Nepal (DHM/ GON). The global solar radiation on horizontal surface were measured by using CMP6 Pyranometer. A CMP6 Pyranometer is designed for measuring short wave irradiance over a spectral range of 310µm to 2800µm on a plane surface incident from the hemisphere above the instrument[14]. It can operate within the temperature range of -40°C to 80°C. Microsoft excel has been used for the analysis of data.

Empirical method based on sunshine hours: Angstrom-Prescott model is convenient and widely used for predicting global solar radiation on the basis of sunshine hours is given as

$$\frac{\overline{H}_g}{\overline{H}_o} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) \quad (1)$$

Where: $\overline{H}_g$ is the monthly average of daily global solar radiation on a horizontal surface, $\overline{H}_o$ is the monthly average of extraterrestrial solar radiation on horizontal surface, $\overline{n}$ is the monthly average daily number of hours of sunshine and $\overline{N}$ is the maximum monthly average daily sunshine. The constant 'a' and 'b' are location specific empirical coefficient obtained from regression analysis of measured solar radiation with sunshine hours.

The monthly average daily extraterrestrial solar radiation $\overline{H}_o$ is estimated using

$$\overline{H}_o = \frac{1}{n_2 - n_1}\sum_{n_1}^{n_2} H_o \quad (2)$$

Where n_1 and n_2 are the day number at beginning and end of the month respectively and H_o is given by

$$H_o = \frac{24}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360}{365}n\right)\left(\omega\frac{\pi}{180}\sin\emptyset\sin\delta + \cos\emptyset\cos\delta\sin\omega\right) \quad (3)$$

$$\delta = 23.45\sin\left(\frac{360}{365}(284 + n)\right) \quad (4)$$

$$N = \frac{2}{15}\cos^{-1}(-\tan\emptyset\tan\delta) \quad (5)$$

$$\omega = \cos^{-1}(-\tan\emptyset\tan\delta) \quad (6)$$

Where: I_{sc} is the solar constant, φ is the latitude of the site, δ is the solar declination, ω is the hour angle, n is the Julian days starting from 1^{st} of January[15].

Empirical model based on sunshine hours, temperature and relative humidity: The proposed linear regression relation to predict global solar radiation based on sunshine hours, temperature and relative humidity is

$$\frac{\overline{H}_g}{\overline{H}_o} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) + c\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right) + d\overline{RH}_{min} \quad (7)$$

Where: a, b, c and d are regression constants, $\overline{T}_{min}$ and $\overline{T}_{max}$ are monthly average maximum and minimum temperature in ^{0}C and $\overline{RH}_{min}$ in monthly average minimum relative humidity.

Result and discussion

Data necessary for the analysis are depicted in Table-1.

The regression analysis was carried out to determine the regression constant, correlation coefficients(R) and coefficient of determination (R^2). The accuracy of empirical model has been examined by using statistical test like mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE). The empirical model along with constant, R, R^2, MBE, RMSE and MPE are summarized in Table-2.

Figure-1 shows the variation of $\bar{n}/\bar{N}$ and $\bar{H}_g/\bar{H}_o$, (K_T) the clearness index for Jumla. The poor sky condition due to high relative humidity and rainfall cause depression[16] in the month of July and August. Where $\bar{n}/\bar{N}$ goes as low as 0.27 and K_T reaches a minimum value of 0.54 for August and 0.55 for July.

Figure-2 show the monthly variation of measured solar radiation and extraterrestrial solar radiation with their respective error bars. The maximum variation in measured solar radiation occur at June because of fluctuating weather of study area where as variation in extraterrestrial radiation, attributed to variation in declination angle, is high at march and October. The maximum value of measured solar radiation is 25.36MJ/m^2/day at May and at of extraterrestrial radiation is 41.02 MJ/m^2/day at June.

Table-1: Input parameter for the estimation of regression constant.

Month	$\bar{H}_g/\bar{H}_o$	$\bar{n}/\bar{N}$	$\bar{T}_{min}/\bar{T}_{max}$	$\overline{RH}_{min}$(%)
Jan	0.67	0.81	-0.45	38.41
Feb	0.65	0.69	-0.23	44.20
Mar	0.69	0.74	0.02	36.49
Apr	0.64	0.57	0.18	44.19
May	0.63	0.53	0.34	51.62
Jun	0.60	0.40	0.53	61.55
Jul	0.55	0.28	0.65	72.57
Aug	0.54	0.28	0.63	77.37
Sep	0.59	0.52	0.51	68.33
Oct	0.68	0.82	0.19	44.86
Nov	0.74	0.83	-0.01	40.21
Dec	0.73	0.82	-0.31	30.64

Table-2: Summary of empirical models with statistical parameter.

Empirical Models	R	R^2	MBE	MPE (%)	RMSE
$\bar{H}_g/\bar{H}_o = 0.47 + 0.29(\bar{n}/\bar{N})$	0.94	0.89	-0.0141	0.0910	0.5564
$\bar{H}_g/\bar{H}_o = 0.663 + 0.185(\bar{n}/\bar{N}) + 0.055(\bar{T}_{min}/\bar{T}_{max}) - 0.003\overline{RH}_{min}$	0.97	0.95	0.0218	0.2438	0.3614

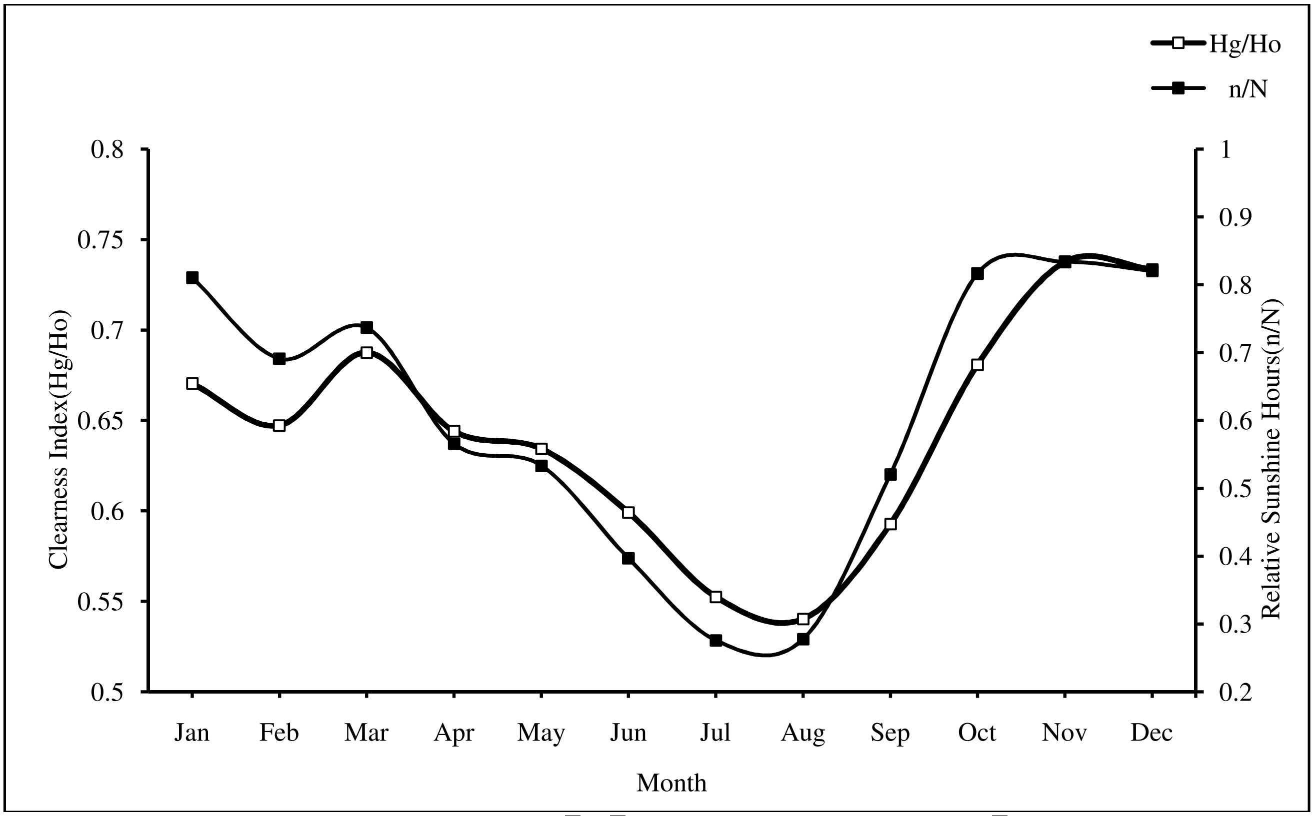

Figure-1: Monthly variation of clearness index ($\overline{H}_g/\overline{H}_o$) and relative sunshine hours ($\bar{n}/\overline{N}$) for year 2011 of jumla.

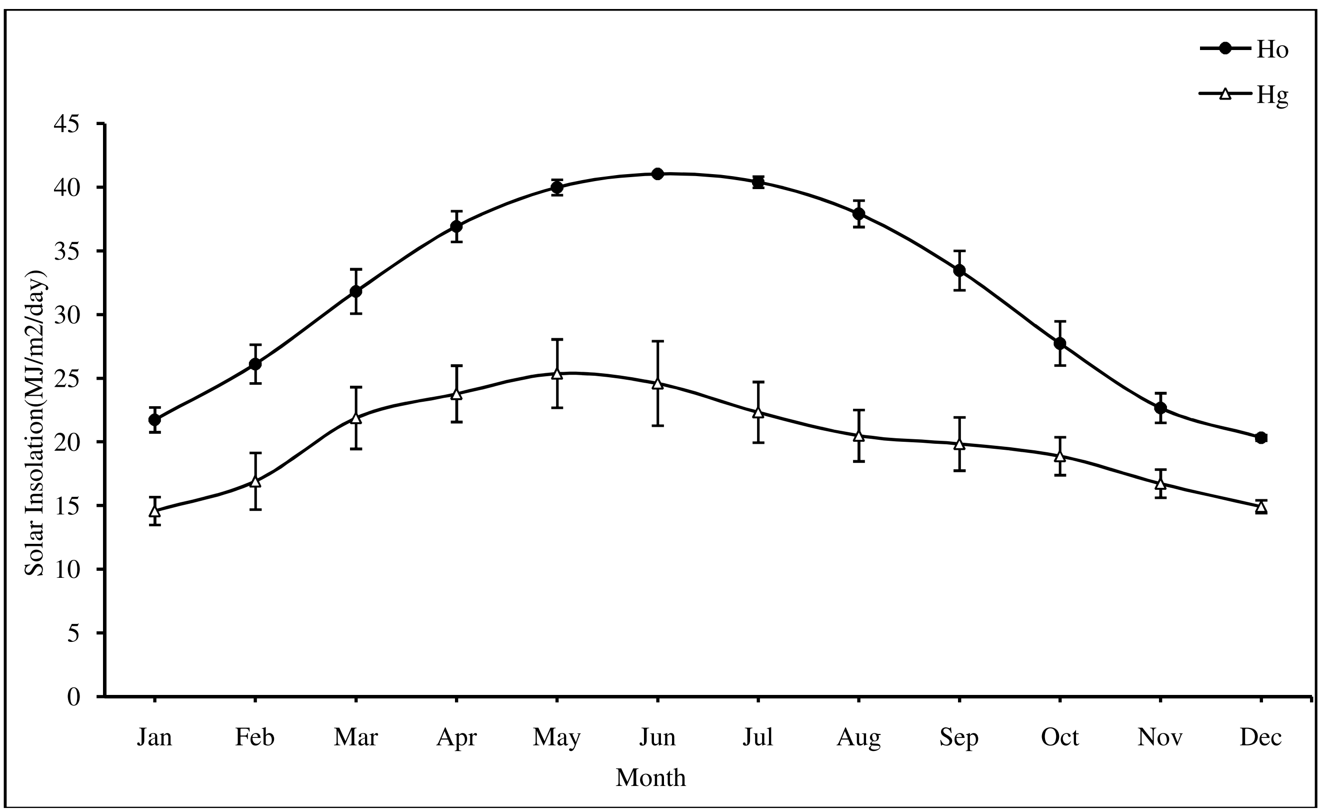

Figure-2: Variation of monthly average extraterrestrial solar radiation and global solar radiation.

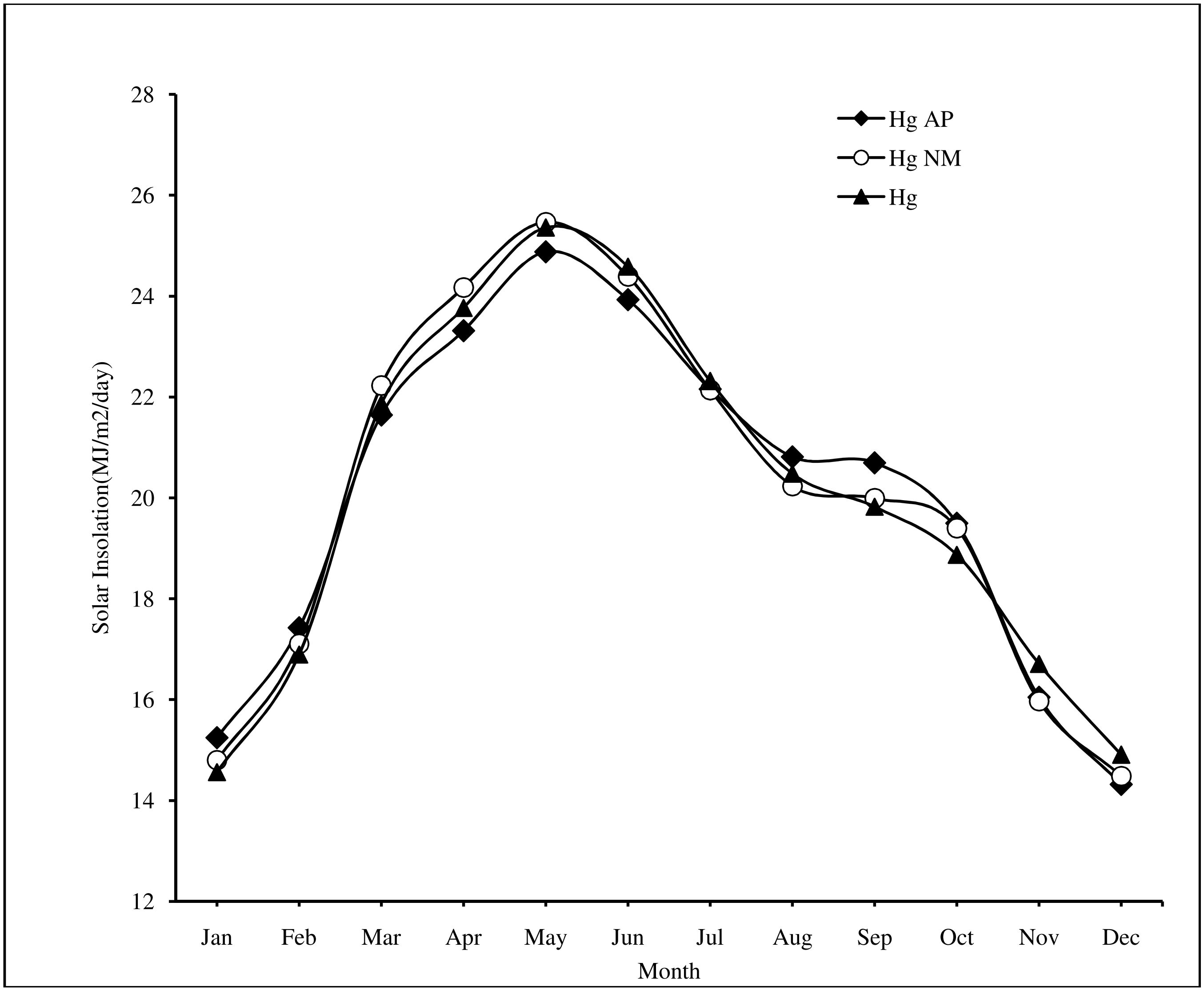

Figure-3: Comparison of measured monthly average solar radiation with estimated solar radiation from AP model and the proposed new model (NM).

Angstrom model gives that clearness index was related to the relative sunshine hours by the constant a= 0.47 and b= 0.29. The value of correlation coefficient is 0.94 and that of coefficient of determination is 0.89 which implies 89% of variation in clearness index can be explained by the relative sunshine hours, which is also indicated by a similar pattern of monthly variation as shown in Figure-1.

Similarly, the value of a, b, c, d for modified AP model are 0.663, 0.185, 0.055, -0.003 respectively.

Positive value of a, b, c signifies that clearness index increases with increase in relative sunshine hours and temperature ratio whereas negative coefficient d indicate a reverse behavior of relative humidity. The correlation coefficient and coefficient of determination for proposed model are 0.97 and 0.95 respectively which implies 95% of variation in clearness index can be explained by this model. The clearness index is generally low in June, July, and august despite of summer solstice in northern hemisphere because of high relative humidity as well as rainfall around study area. It is found that $\frac{\bar{H}_o}{\bar{H}_g}$ <0.75, normally absorption , scattering and reflection as well as presence of visible haze on more populated area created by burning of biomass for cooking and heating purpose reduce the intensity of solar radiation[11,17]. The least value of MBE, MPE and RMSE as shown in Table-2 indicate that both model are statistically significant however R^2 and RMSE signifies the superiority of modified model over AP model. The positive and negative MBE for modified model and AP model implies overestimation and underestimation of solar radiation respectively[18]. The plots of measured and estimated global solar radiation shown in Figure-4 and 5 depicts that modified model has greater predictability over AP model.

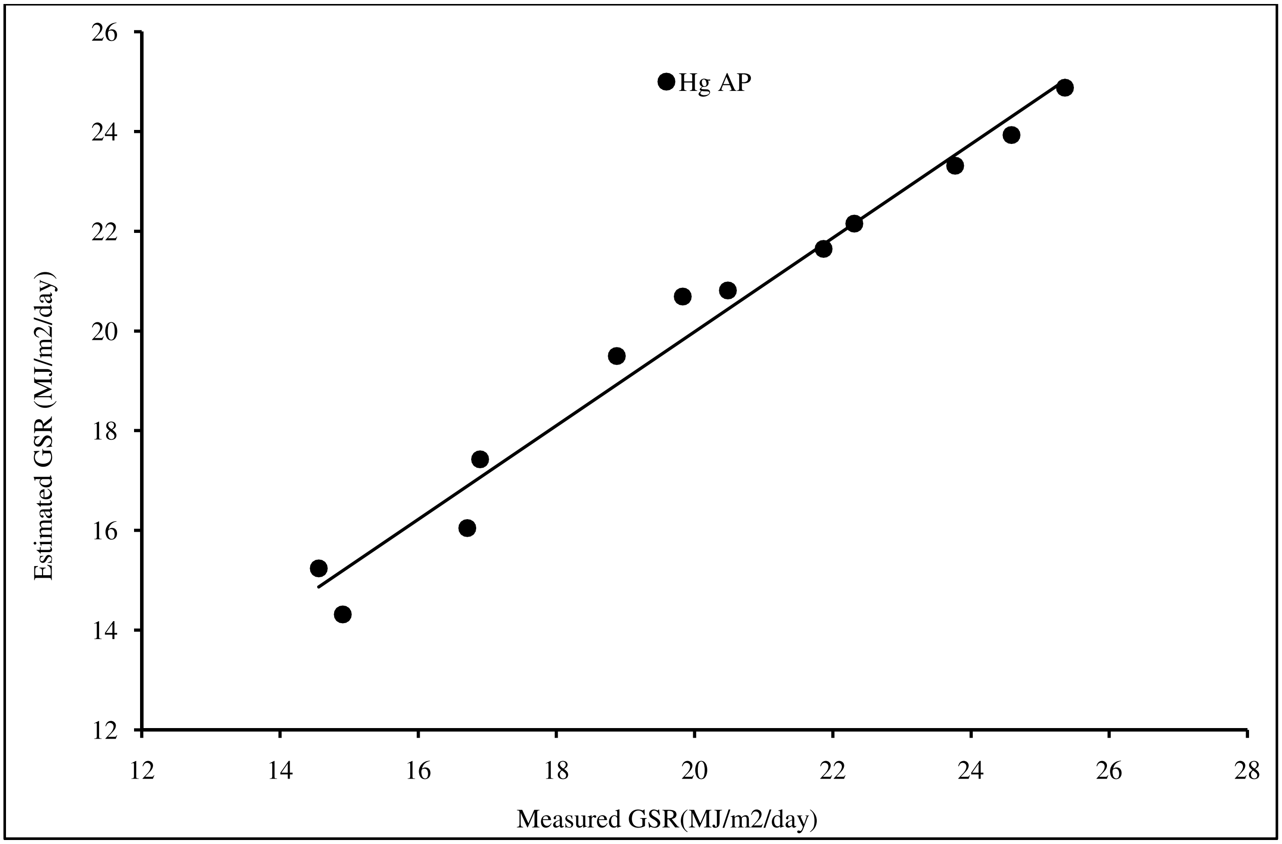

Figure-4: Plot of measured versus estimated GSR from AP model with trend line.

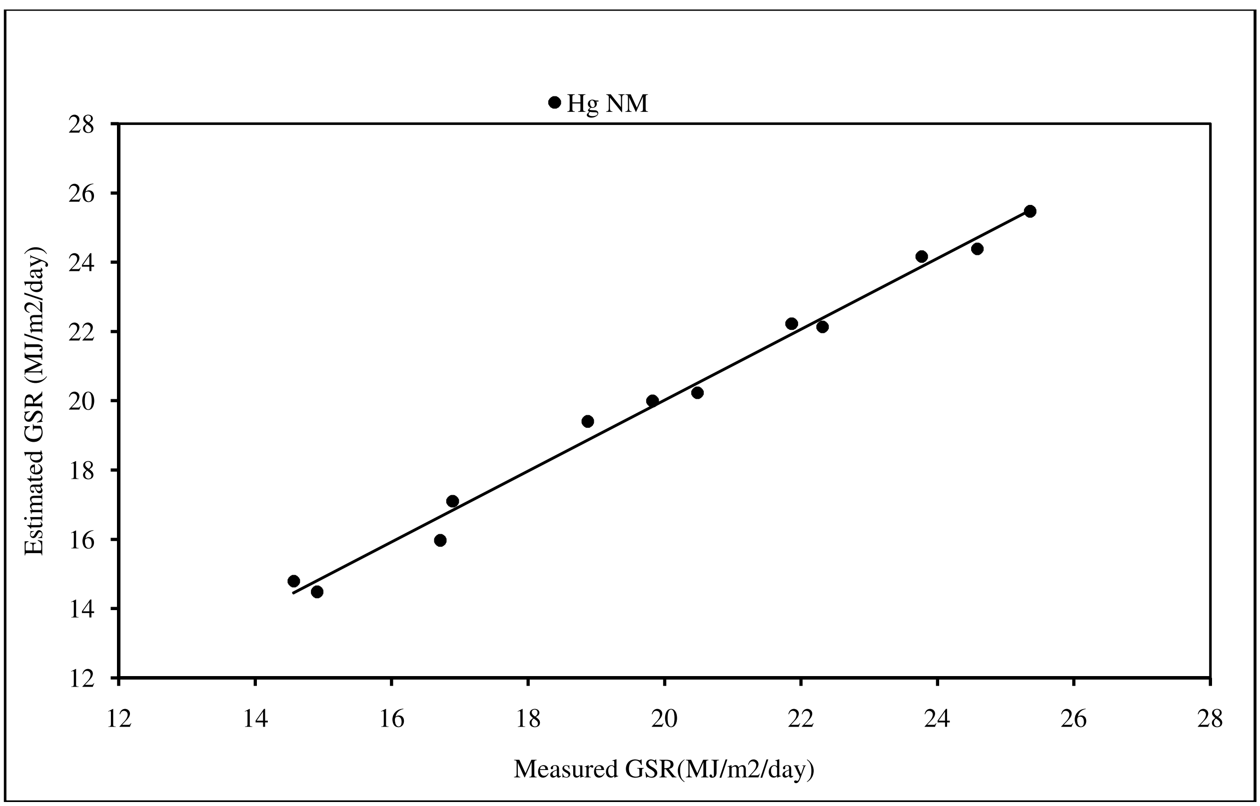

Figure-5: Plot of measured versus estimated GSR from modified model with trend line.

Conclusion

This study develops a single variable as well as multiple variable based linear model. It also shows that model based on multiple variable given as $\frac{\overline{H}_g}{\overline{H}_o} = 0.663 + 0.185\left(\frac{\overline{n}}{\overline{N}}\right) + 0.055\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right) - 0.003\overline{RH}_{min}$ have better performance over sunshine based AP model. It has been found that maximum value of solar radiation is 25.47MJ/m^2/day at May and minimum is 14.48 MJ/m^2/day at December. The MBE MPE, RMSE and R^2 of this model are 0.02177, 0.24382, 0.3614 and 0.95 respectively. The multiple variable based linear model fit well with the measured data, which signify its potentiality to estimate the missing data of solar radiation for the respective site as well as for the estimation of global solar radiation of geographically and climatically similar location as Jumla. Since the knowledge on solar radiation of a particular location is a stepping stone toward utilization of solar energy so these study helps in formulation of plans and policies for development of energy sector. In north-western part of Nepal which is sparsely populated with large unused land with difficult topography, solar energy can be a best alternative for rural electrification.

Acknowledgement

The authors would like to sincerely thank the department of hydrology and meteorology /Government of Nepal (DHM/ GON) for providing meteorological parameters and are grateful to Department of Engineering Science and Humanities Pulchowk Campus, Pulchowk Tribhuvan University, Kathmandu Nepal.

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