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Estimation of Global Solar Radiation Using Empirical Model on Meteorological Parameters at Simara Airport, Bara, Nepal

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Abstract: This research work purpose to estimate the daily global solar radiation (GSR) using CMP6 pyranometer at low altitude of Simara Airport (lat. $27^0$9'33" N and long. $84^0$58'48" E, Alt.137m respectively). The measured data is used to study the diurnal, monthly, and seasonal variation of GSR. The maximum and minimum value of GSR is found at the spring and winter season respectively. A number of multi linear regression equations were developed to predict the relationship between GSR with one or more combinations of meteorological parameters using the regression technique and calculate the empirical constants from Tiwari & Sangeeta model which is the best empirical model among other tested models. The empirical constants and sunshine hour are utilized to estimate the GSR for the years 2009 and 2010 in the Simara Airport. The annual average solar insolation 4.62 and 4.56 kWh/m^2/day is found at Simara Airport for years 2009 and 2010. The performance of each model was analyzed by calculating Root Mean Square Error (RMSE), Coefficient of Determination (R^2) Mean Bias Error (MBE), and Mean Percent Error (MPE). The finding empirical constants 0.30 and 0.52 can be utilized to estimate the GSR where there is no measured data of GSR at similar meteorological sites of Nepal.

Keywords: Global solar radiation, sunshine duration, empirical model, regression technique

1. Introduction

Solar energy is one of the major sources of energy which can be directly obtained from sun. Sun has ample of energy which helps for existence of human life as well as all living creatures on the earth. Solar radiation is considerably effected on passing through earth's atmosphere [17]. The radiation coming from the Sun which is in the form of energy is called solar energy. This energy is obtained by the process of thermonuclear reaction [6]. Nepal is situated in favorable latitude, so that there is about 300 sunny days and the annual average solar insolation varies from 3.6-6.2 kWh/m^2/day in a year. In addition that, there is about 6.8 sun shine duration per day [15]. Solar energy is not only used as alternative energy supply in remote areas but also equally use at urban areas of Nepal. The solar energy plays the vital role to utilize for water heating, water pumping, to make green house for modern agriculture, and to provide the solar PV for lighting [8, 3].

There was not continuous measurement of global solar radiation data and meteorological parameters in many parts of world. Even present time, there is no mechanism to monitor the meteorological parameters such as global solar radiation, sunshine duration, rainfall, relative humidity, temperature , wind direction and wind speed which are urgent for the study of solar energy potential climate change, global warming and other many more [9]. The solar radiation and meteorological data are useful to estimate the solar energy potential at the measuring sites which will be useful for the modern agriculture, hydrology and climate change [4]. The energy enhances the quality of human life style. In addition that, the energy consumption is also directly attached with socioeconomic activities as well as all over the development of the nation [11].

In the context of Nepal, there is about 80 percent of total of population live in rural areas. Many people have no access to modern forms of energy like hydroelectricity, petroleum product and renewable resources [12]. Even in 21^{st} century, about more than 83 percent of total energy consumption in Nepal is carried from traditional energy resources such as fuel wood, agriculture residue and cattle dung which are used for cooking and heating purposes in the rural areas of Nepal. So, the government should be focused to explore and implement solar energy as well as other renewable energy resources which are available different parts of the country [2]. The solar radiation which comes from the sun enters to our atmosphere and some parts of radiation is reflected, some is scattered and some are diffuse [13]. The sum of direct solar radiation, diffuse radiation and scattered radiation arriving at a particular point is called global solar radiation which is affected by clouds, water vapor, aerosols, ozone, and other gases. The cloud is one of the key affecting factor of solar radiation. The water vapor varies during day and seasonal variation [19]. Thus, there is more water vapor is found at summer than at dry season. These parameters are not only effects on solar radiation arriving at the earth surface but also the incident angle of solar radiation, season, geographical location, latitude, solar zenith angle, day length and local weather condition [1,16]. This paper is mainly focused on linear regression techniques to find the empirical constants for the prediction of global solar radiation at Simara.

2. Methods and Instrumentation

The daily global solar radiation on horizontal surface at Simara, Nepal (lat.$27^0$9’33” N, long. $84^0$58’48” E and alt.137m) was measured, using CMP6 pyranometer. It is shown in Fig. 1. The pyranometer needs small amount of power to operate. In this instrument, the black coated on the thermopile sensor absorbs the solar radiation. This radiation is converted to heat and the heat flows through the sensor to the pyranometer housing. Finally the thermopile sensor generates a voltage output signal that is proportional to the solar radiation. Finally the global solar radiation is directly found in the W/m^2/day at the data logger.

The global solar radiation data were measured for each minute of a day and recorded using data logger for 24 hours for the month [7, 14]. The daily sunshine duration, relative humidity, temperature data for Simara were obtained from the Department of Hydrology and meteorology (DHM)/GoN. The bright sunshine duration is simply calculated from the measured global solar radiation and diffuse solar radiation. The time period is considered as bright sunshine if direct solar radiation is greater than or equal to 120 w/m^2 [5]. The Angstrom and Prescott empirical model is given as

$$\frac{H_g}{H_0} = a + b\frac{n}{N} \tag{1}$$

where constants a and b are empirical constants, N is the day length (hours), n is sunshine duration, H_g is measured GSR (MJ/m^2/Day) and H_0 is calculated extraterrestrial global solar radiation using equation (1). Finally we have

Fig. 1: CMP6 Pyranometer [10]

$$H_0 = \frac{24}{\pi} H_{sc}(1 + 0.033 Cos\frac{360n}{365})(Cos\phi Cos\delta Sin\omega_s + \omega_s \frac{\pi}{180} Sin\phi Sin\delta) \tag{2}$$

where φ is the latitude (rad) and δ is the solar declination angle (rad), ω is sunset hour angle for typical day and n is mean day of each months where, n is the day of the year. January first n=1 to 365 days

The declination can be determined from the equation

$$\delta = 23.45 Sin(\frac{360}{365}(284 + n)) \tag{3}$$

The relation of day length is

$$N = \frac{2}{15} Cos^{-1}(-Tan\phi Tan\delta) \tag{4}$$

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \quad (5)$$

where ω is the sunset hour angle

Tiwari & Sangeeta empirical model is also popular model to estimate the average global solar radiation on horizontal surface which is given as

$$a = -110 + 0.235\cos\phi + 0.323\left(\frac{n}{N}\right) \quad (6)$$

$$b = 1.449 - 0.553\cos\phi - 0.694\left(\frac{n}{N}\right) \quad (7)$$

where a and b are empirical constants

The Angstrom-Prescott model and Tiwari & Sangeeta empirical model both are used to estimate the daily global solar radiation on the horizontal surface at Simara [18].

3. Results and Discussion

The performance of the models are evaluated by using statistical parameters i.e. coefficient of determination (R^2), the root mean square error (RMSE), Mean bias error (MBE) and Mean percentage error (MPE). The lower value of RMSE and MPE is the more reliable and accurate. The empirical constants a= 0.30 and b= 0.52 are obtained from Angstrom equation.

The value of regression constants were estimated using Tiwari & Sangeeta model. The value of regression constants can be utilized to estimate the global solar radiation at identical geographical location in the Nepal.

Table.1. Statistical tools

Year	2009 (MJ/m^2/day)	2010 (MJ/m^2/day)
RMSE	0.01	0.06
MBE	0.02	0.02
MPE	8.28	10.20
R^2	0.97	0.82

The comparative study between predicted and measured GSR presented in Fig.1, could be used to estimate the GSR using sunshine hour at that location. Fig. 1(a), and (b) showed that there is remarkable agreement between the measured and predicted values of global solar radiation for the years 2009 and 2010.

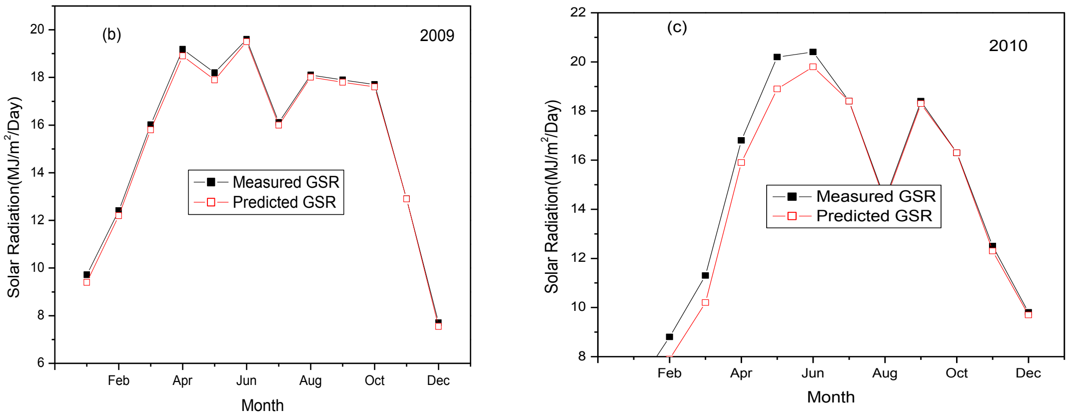

Fig. 1.a and b Comparative study between measured and predicted GSR at Simara Airport for the years 2009 and 2010.

Fig. 2 shows that there is a remarkable agreement between the measured GSR and sunshine duration because of dependent factor to each other. The GSR increases with increase in sunshine and decreases with decrease in sunshine duration. However, in the month of July both sunshine duration and GRS decreases sharply due to cloudy as well as high frequency of rainfall for the year 2009. Likewise there is minimum amount of sunshine duration and GSR was found on August and September for 2010.

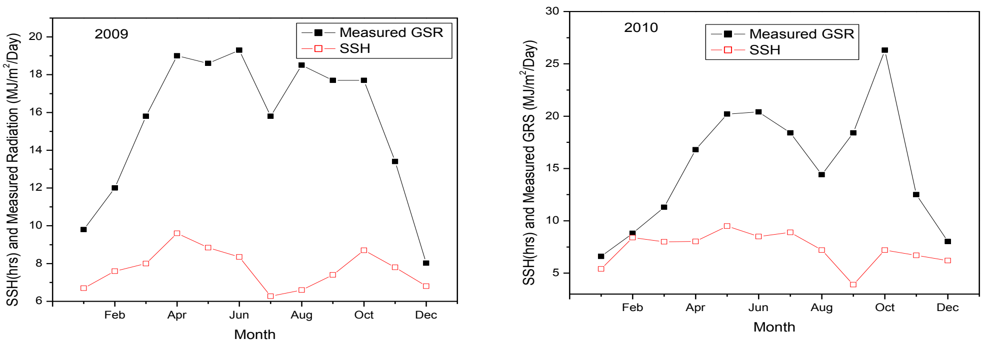

Fig. 2a & b: Comparative study of monthly average measured global solar radiation and sunshine duration in Simara Airport, for years 2009 and 2010

Fig. 3 shows that there is strong agreement in between temperature and measured GSR, it indicates that the temperature varies from season to season due to the rotation of the earth. The temperature is directly affects the results of global solar radiation. Fig.3 shows that the temperature gradually increases with increase in GSR up to from January to June after that both temperature and GSR decreases sharply due to high frequency of rain fall as well as cloudy days in July, August and still September. It was observed that the lowest value of monthly mean temperature and monthly mean global solar radiation in August was found in the years 2009 and 2010 at Simara Airport.

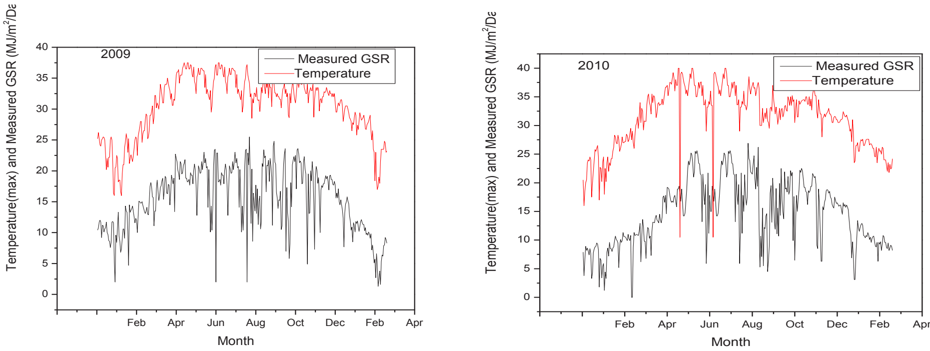

Fig. 3.a and b. Variation of GSR with Temperatures for the years 2009 and 2010

Monthly average measured value of GSR is shown in Fig. 4 for the years 2009 and 2010 in Simara Airport. A trend line is drawn to the monthly variation of GSR at Simara. The trend line of third degree polynomial is fitted with measured data of GSR for the years 2009 and 2010. It is shown in Fig. 4. The coefficient of determination and p-value 0.71, and <0. 0013 are found for the year 2009. It indicates that there is about 71 percent of data is closer to the best fit line. Similarly the p-value is also found within the range of permission limit. The maximum and minimum value of GSR and temperature was observed in May and June in 2009. However, the minimum amount of GSR found in December and January due to the high SZA, clouds, haze and cold wave.

Likewise, the coefficient of determination and p-value 0.74 and <0. 00032 are found for the year 2010. The coefficient of determination is about 74 percent means majority of data are closer to the best fit line and p-value is within the significant limit for the year 2010 which is shown in Fig. 4. In addition, the GSR gradually increases from January to June due to the clear sky less cloudy days and decreases in the month July, August and September because of the clouds and rainfall. In spites of this, the GSR becomes relatively high in October and then shrinks due to the high SZA in remaining months. The trend line of third degree polynomial is fitted with measured data of GSR in years 2009 and 2010 which is shown in Fig. 4.

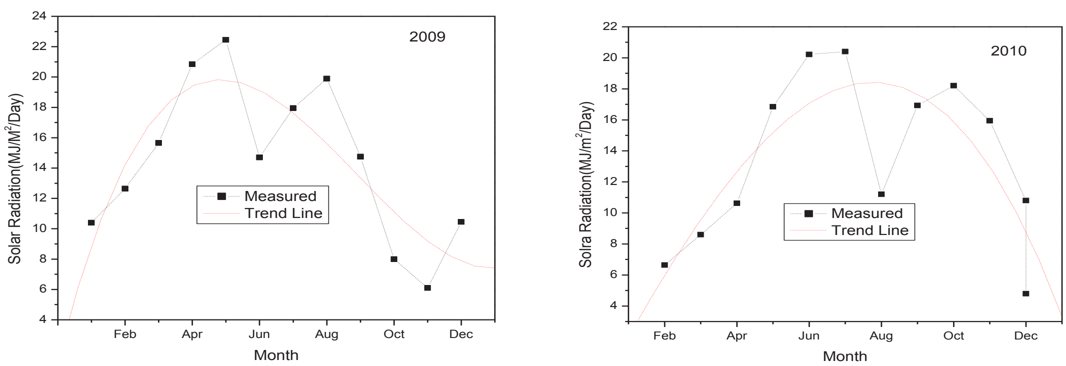

Fig. 4.a and b. Monthly mean variation of GSR in Simara Airport for years 2009 and 2010

The seasonal variation of GSR is shown in Fig.5 for the two years 2009 and 2010 of Simara Airport. The maximum and minimum GSR is found in Spring and Autumn season for the year 2009 mainly due local weather conditions. Similarly the maximum and minimum GSR is found in Spring and Winter season for the year 2010. The annual average GSR 15.32 MJ/m^2/Day, and 13.8MJ/m^2/Day are found in the years 2009 and 2010. These values are very much significant to generate the electricity. High value of GSR is attributed in spring due to less solar zenith angle, less cloud and less rainfall whereas there is large solar zenith, more fog in winter and provides lower values.

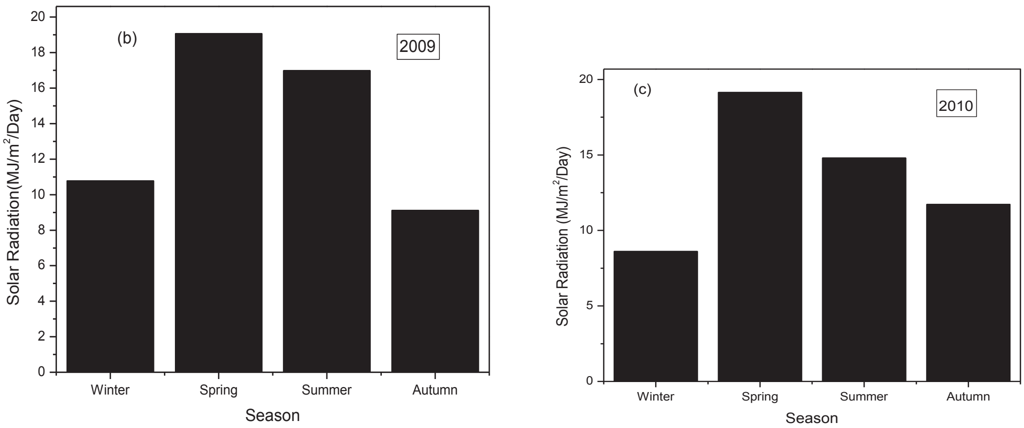

Fig. 5. a and b Seasonal Variation of GSR in Simara Airport for years 2009, and 2010

4. Conclusion

The global solar radiation was measured by using CMP6 pyranometer at Simara Airport. In this study, monthly, seasonal variation of global solar radiation potential was analyzed by using advanced statistical tools. It is concluded that the trend of global solar radiation is maximum on March, April and May due to clear and sunny weather at that time. Likewise, there is less amount of GSR is found on summer season because of wind blow , clouds and rainfall however, at the winter season the fog, cold wave and clouds covered the sky and the sunshine hour was also very small to compare in other seasons. Finally the overall performance of Tiwari & Sangeeta model was the best fit on the basis of the validation of data through the statistical tools. The annual average solar isolation 4.62 and 4.56 kWh/m^2/day are found at Simara Airport for the years 2009 and 2010 respectively. The obtained empirical constants and sunshine duration could be utilized to predict the GSR for the years to come at similar geographical locations where there is no measured solar radiation data.

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