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Estimation of Global Solar Radiation using Sunshine Duration in Himalaya Region

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Abstract

This research work proposes the coefficient equation of Angstrom type of model for the estimation of global solar radiation in Himalaya Region Kathmandu (Nepal) (Lat. 27.7º, Long. 85.5º and Alt. 1350m) using relative sunshine hour. The model regression coefficients a and b obtained in this research are 0.21 and 0.25 respectively. The performance parameters of the model are: Root Mean Square Error RMSE = 0.071, Mean Bias Error MBE= 0.055 Mean Percentage Error MPE= 0.047 and coefficient of determination R^2= 0.71.The solar energy can be utilized effectively throughout the year. The model could be employed in estimating the global solar radiation at the similar geographical location of the country.

Keywords: Global solar radiation, relative sunshine duration, clearness index, regression analysis.

Introduction

The utilization of solar energy, like any other natural resources, requires detailed information on availability. The study of solar radiation should incorporate solar radiation local weather condition. The global solar radiation potential will be milestone for designing and predicting the performance of solar energy equipment and solar energy potential[1]. It is known that the higher the altitude the greater the solar radiation under the clear and intermediate sky conditions, but under the overcast days the solar radiation is very low in comparison with sunny days[2]. Actually, the mapping of the solar radiant energy on the earth's surface is a requirement not only in the studies of climate change, environmental pollution but also in agriculture, hydrology, food industry and non conventional energy development programs[3].

Nepal is located in favorable latitude, receives ample solar radiation throughout the country. The average global solar radiation varies from 3.6–6.2 kWh/m2/day, and the sun shines for about 300 days in a year .The national average sunshine hours and solar energy are 6.8/day and 4.7 kWh/m2/day respectively[4].

Energy is accepted as intrinsically linked with environmental, social and economic dimensions of sustainable development. The demand of energy, the consumption of fossil fuels and pollution level are increasing with an alarming rate worldwide. Looking into the seriousness of problem, various stakeholders have now become aware of the urgent need for management of resources and energy conversion activities. The energy consumed in the household sector is perhaps the single largest consumer of energy in the nation's economy in developing countries in the world[5].

With the rapid depletion of fossil fuel reserves, it is feared that the world will soon run out of its energy resources. This is a matter of concern for the developing countries whose economy heavily depends on imported petroleum products. Under these circumstances it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the ever increasing energy demand. Among the non-conventional energy resources, solar energy, wind energy and biomass has emerged as most prospective option for the future[6]. In addition that, aggressive consumption rate of fossil fuels has created unacceptable environmental problems such as greenhouse effects, which may lead to disastrous climatic consequences. Thus, renewable and clean energy such as that obtained by using solar cells is required to maintain the quality of human life as well as the environment[7].

Detailed information about the availability of solar radiation on horizontal surface is essential for the optimum design and study of solar energy conversion system. The best way of knowing the amount of Global Solar Radiation (GSR) at any given site is to install solarimeter or other instrument at many locations in the given region and look after their day to day maintenance and recording which is a very costly exercise.

When solar radiation enters the atmosphere, a part of the incident energy is removed through the process of absorption, scattering and reflection. The absorption of global solar radiation is by ozone, water vapour, clouds and oxygen. The reflection of global solar radiation is mainly by clouds and this plays an overriding part in reducing energy of solar radiation reducing the surface of the earth[8]. The troposphere is the lower layer of the earth atmosphere. Most of the weather phenomena, systems, convection, turbulence and clouds occur in this layer, although some may extend into the lower portion of the stratosphere. The troposphere contains almost all the atmospheric water vapour, it contains about 70 to 80 percent of the total mass of the earth atmosphere and 99 percent of the water vapour. The resulting solar interaction on the atmosphere leads to changes in weather as well as so called climate change[9]. Clouds take leading role to the fluctuate the intensity of sunshine hours on the ground surface. The variation however is not due to the angle of incidence of the sun's rays with ground surface and its azimuth[10]. There is an urgent need for clean, pure drinking water in many countries. Often water sources are brackish and there are many costal locations where sea water is abundant but potable water is not abundant. Pure water is also needed in some industries, hospitals and schools. Distillation is one of the processes that can be used for water purification and solar radiation can be the source of heat energy[11].

Solar cooling is an attractive idea because cooling loads and availability of solar radiation are approximately in phase. As the refrigeration system operates – pump work neglected - without the need for mechanical or electrical power, it is independent of electrical grids and thus may prevent in remote rural regions the spoiling of agricultural products in storage due to the lack of refrigeration. That is why there is a high demand for application of solar cooling for decentralized cold storage of food in the countries of the sun belt of the earth[12].

There are several types of empirical formulae for estimating the monthly mean daily global solar radiation as a function of readily measured climatic data[3,13,14]. It is known that the simplest regression relation is Angstrom-Prescott, which relates the monthly mean daily global solar radiation to the number of hours of bright sunshine.

The global solar radiation varies from latitude to latitude. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the day length. The ratio is known as fraction of sunshine hours n/N. It is found to vary daily and seasonality[15,16]. The amount of global solar radiation H_0 is the extraterrestrial radiation which is found at the top of the atmosphere of the site. Similarly H_g is global solar radiation which is the fraction of the extraterrestrial radiation at the ground surface after scattering, reflection and absorption in the atmosphere. The ratio of H_g/H_0 is a possible measure of the transparency of the atmosphere to the solar radiation. It is also called clearness index or coefficient of transmission[17].

This paper focuses on linear regression techniques used to develop some predictive model classified as sunshine hours for the estimation of global solar radiation at this Himalaya region.

Material and Methods

The monthly mean and daily data of Global Solar Radiation (Hg) and sunshine hours were collected from the Tribhuvan International Airport Department of Hydrology and Meteorology Government of Nepal. The data were measured by using Environdata EASIDATA Mark 4. This EASIDATA Mark 4 is a modular weather station that supports any combination of up to 16 digital plug-in sensors. Its multiple-memory system ensures efficient use of memory and typically provides daily summaries, hourly and 10 minute data for periods of 1 - 3 months. It can store up to 216 data types, including real time calculations on sensor inputs. This weather station is extremely flexible and can generate customized calculations, making it ideal for specialized applications.

The operating temperature is from -20^{0}C to + 60.0°C and resolution is 0.1°C.This device is compact, robust, automatic weather station. Similarly, all the measuring data are recorded by data stored into 4 independent memory areas. 64 K battery backed RAM -stores 20,000 values, likewise the optional memory 256 K can be used for 80,000 values. It collects the data at real time for the needs of meteorology and slow signal analysis. Easy-Access is an integrated package that includes data collection, storage and display modules. The solar radiation sensor's cosine correction is achieved by shaping a teflon diffuser and accurately housing this inside an opaque cylinder. The accuracy of solar radiation of the device is about +/- 5 percent[18].

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface H using the sunshine duration data is due to Angstrom[19] and Prescott[20] have put the Angstrom correlation in more convenient form as

$$\frac{H_g}{H_0} = a + b\frac{n}{N} \quad (1)$$

where, constants *a* and *b* are estimated using regression coefficients. *N* is day length (hours), *n* is bright sunshine hours, Hg is measured GSR (MJ/m^2/day) and H_0 is extraterrestrial GSR (MJ/m^2/day). For, the value of H_0 is calculated using equation (1.10.3)[21].

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

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.

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

The relation of day length is,

$$Day\ length = \frac{2}{15}Cos^{-1}(-Tan\ \phi Tan\ \delta) \quad (4)$$

$$\omega = Cos^{-1}(-Tan\,\phi Tan\,\delta) \quad (5)$$

where I_{sc} is solar constant (W/m^2), 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 month.

The Angstrom-Prescott regression equation has used to estimate the monthly average daily global solar radiation on a horizontal surface in Kathmandu. The solar radiation reaching the earth's surface can be estimated by empirical model when measured data are available. The simplest model commonly used to estimate the average global solar radiation on horizontal surface is the well known Angstrom, Prescott equation[19,20].

Results and Discussion

The input parameters are used for the estimation of monthly average daily global solar radiation at Himalaya Region. The main parameters are shown in table 1. In the given table, it is found that the sunshine duration is more than 6 hours except in July, August and September in 2009.

The regression coefficients, a and b obtained in this investigation were 0.21 and 0.25 respectively. Hence the first order polynomial equation is

$$\frac{H_g}{H_0} = 0.21 + 0.25\frac{n}{N} \quad (6)$$

The value of regression coefficients of a and b can be utilized to estimate the global solar radiation at similar geographical situation in the Nepal.

Table-1
Meteorological Data and Global Solar Radiation at Himalaya Region of Kathmandu, 2009

Months	n	N	n/N	Hg MJ/m^2/day)	H0 (MJ/m^2/day)	K_T=Hg/H0
Jan	6.12	11.3	0.5416	7.35	19.69	0.3733
Feb	7.80	11.05	0.7059	9.09	26.31	0.3455
Mar	6.77	11.83	0.5723	9.85	32.03	0.3075
Apr	7.79	12.67	0.6148	14.65	37.51	0.3906
May	6.39	13.38	0.4776	14.52	40.82	0.3557
Jun	7.11	13.73	0.5178	17.13	42.13	0.4066
Jul	4.85	13.53	0.3585	13.71	41.38	0.3313
Aug	4.00	12.89	0.3103	12.13	38.6	0.3142
Sep	5.89	12.07	0.4880	13.50	33.74	0.4001
Oct	7.26	11.2	0.6482	12.15	27.41	0.4433
Nov	7.40	10.52	0.7034	9.30	22.33	0.4165
Dec	6.53	10.27	0.6358	7.13	20.28	0.3516

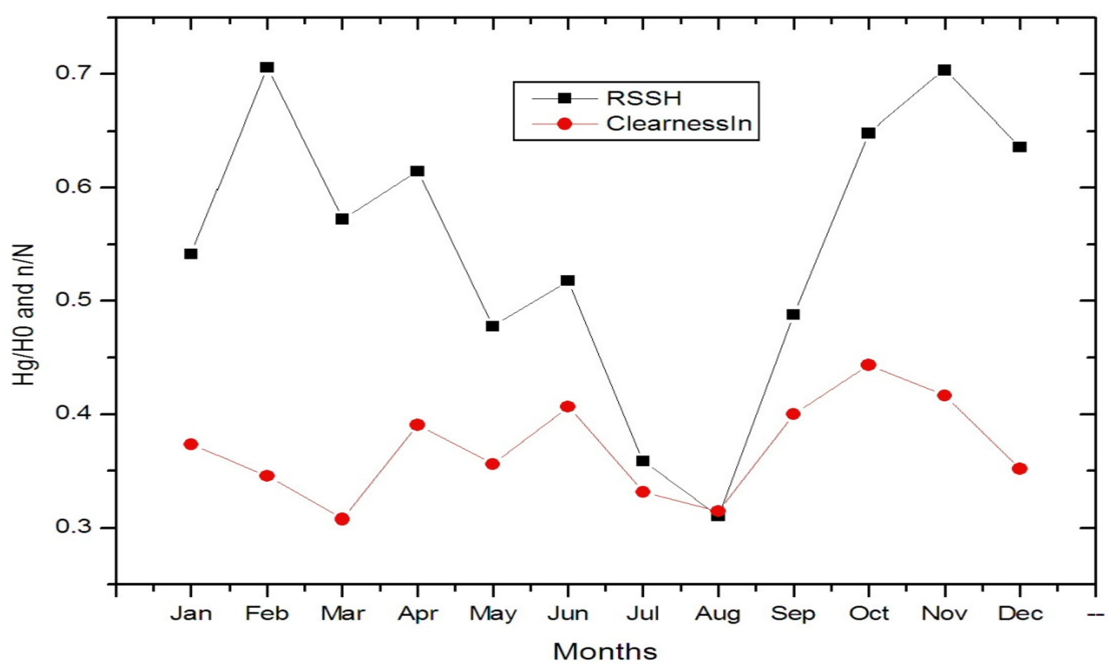

Figure-1
Comparative Study of Monthly Average Clearness Index and Relative Sunshine hour Sunshine Hour in Kathmandu, 2009

The relationship between the relative sunshine duration, n/N and clearness index ($K_T = H_g/H_0$) is presented in figure 1. The value of K_T = 0.3142 corresponding to the relative sunshine hour (RSSH) is about 0.3103 and measured global solar radiation is 12.13 MJ/m^2/day in the month of August. It indicates that the relative sunshine duration and clearness index values are the lowest in month of August. It is happened due high frequency rainfall in monsoon season.

Figure 2 also shows that there is strong agreement in between sunshine hour and measured GSR, it indicates that the sunshine duration varies from season to season due to the rotation of earth. The sunshine hour is directly affects the result of global solar radiation. The figure 2 shows that the sunshine duration gradually increases with increase in GSR up to from December to May after that both sunshine hour and GSR decreases sharply due to high frequency of rainfall as well as cloudy days in June, July, August and still September. It is noted that the lowest value of monthly mean sunshine duration and monthly mean daily global solar radiation in August are 4.0 hours and 12.31 J/m^2/day respectively.

Figure 3 shows that there is a remarkable agreement between the measured and predicted values of global solar radiation during the year 2009. Hence the coefficient of determination in between predicted values and measured values of global solar radiation is about 0.85.

Figure 4 shows that there is frequently changing the sunshine hours because of changing the local weather condition. The June, July and August lie in summer season. This summer season is monsoon season. There is about 70 to 90 percent rainfall takes place in summer season in Nepal[22]. Hence the sunshine duration is minimum in August where as the global solar radiation is 12.13 MJ/m^2/day comparatively lower in comparison of other months. It is occurred due to monsoon season which is our rainy season in this region. In other hands, the sunshine hour is the lowest in August due to the high frequency rainfall in monsoon season.

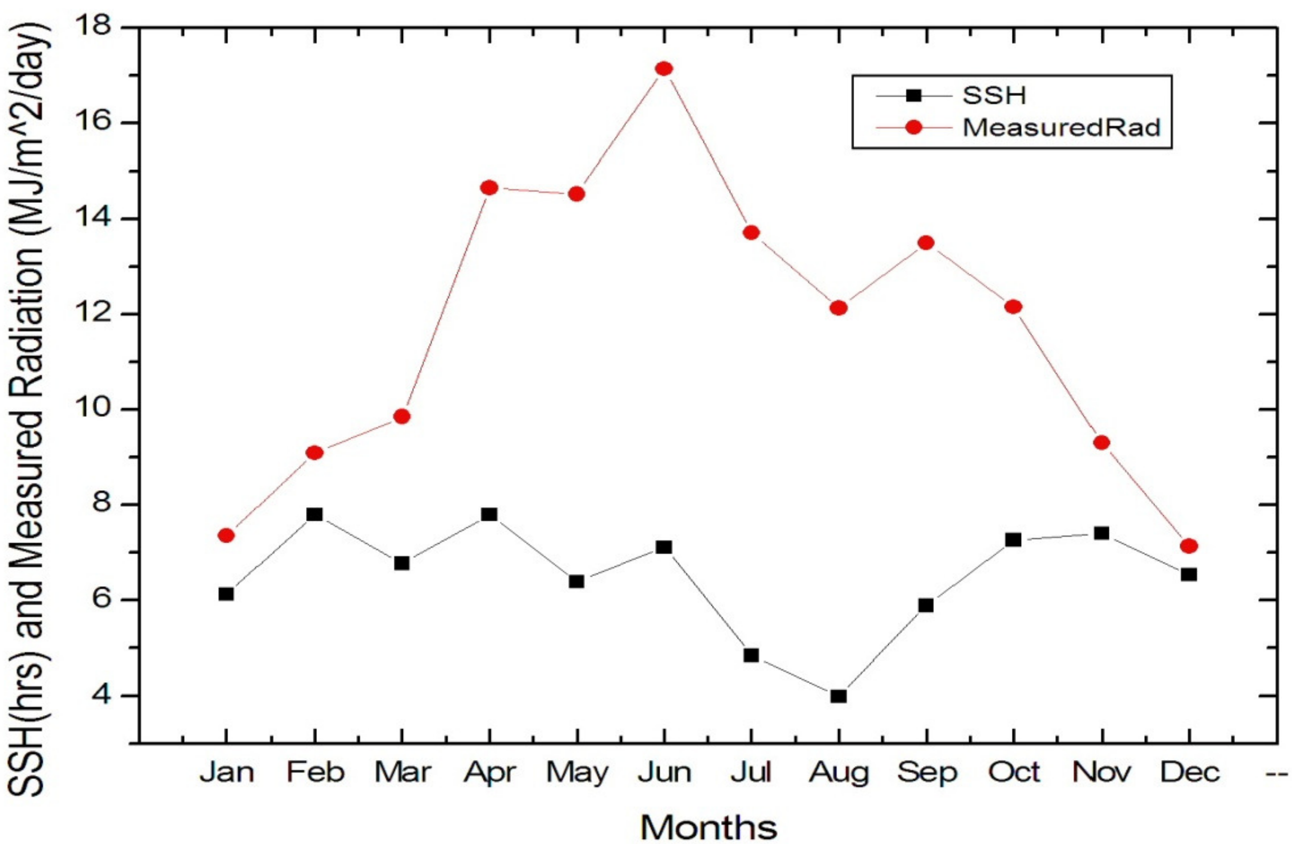

Figure-2
Comparative Study of Monthly Average Sunshine Hour and Monthly average Measured Global Solar Radiation in Kathmandu, 2009

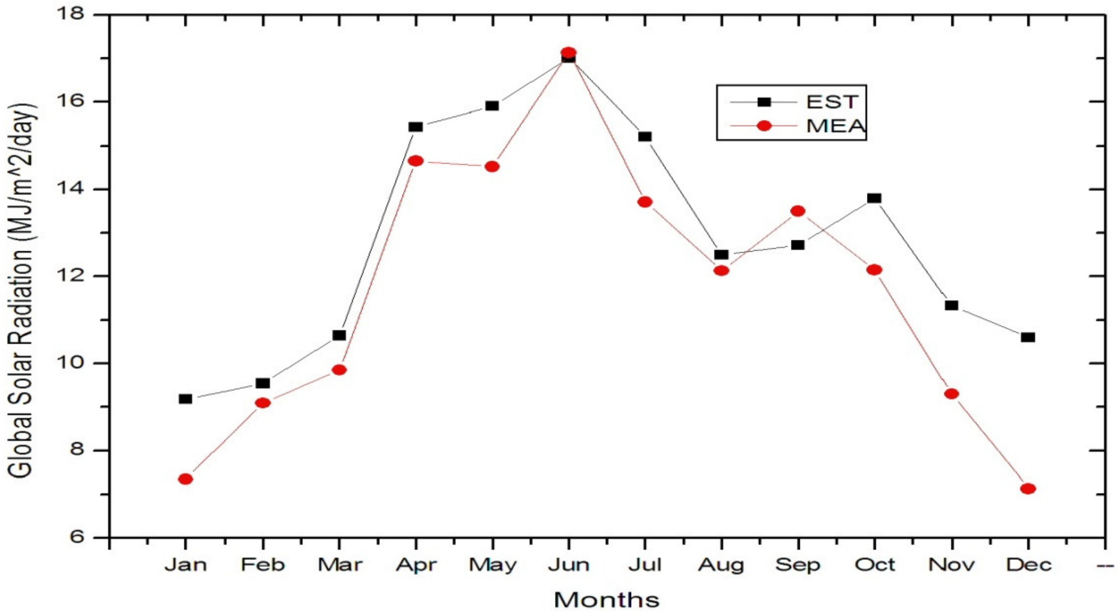

Figure-3
The comparison between measured values of global solar radiation with predicted solar radiation in Kathmandu, 2009

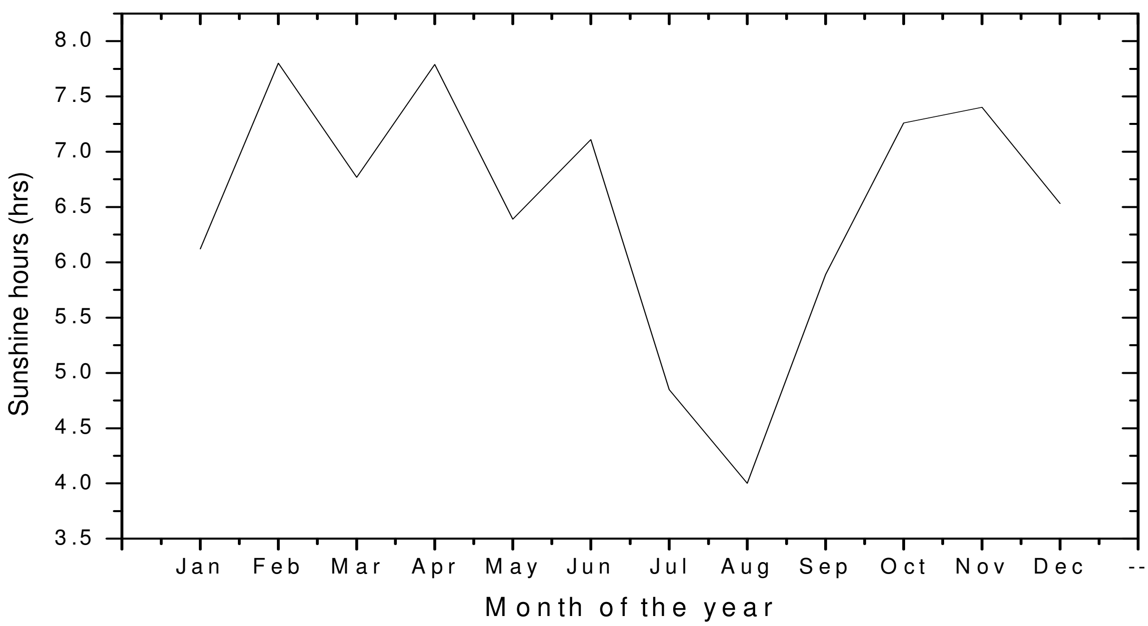

Figure-4
Monthly variation of Sunshine Hours in Kathmandu, 2009

Conclusion

The prediction model is developed using monthly average daily values of clearness index, relative sunshine hour, and measured global solar radiation. The maximum and minimum values of monthly average global solar radiation are found 17.13 MJ/m^2/day and 7.13 MJ/m^2/day in June and December respectively. The overall performance of parameters RMSE, MBE, MPE and R^2 are found 0.071, 0.055, 0.047, and 0.71 respectively. These statistical indices value showed that this research work is meaningful for the estimation of global solar radiation on the basis of sunshine hour.

It indicates that the estimated values of global solar radiation can be very efficiently used to compensate for the energy deficit. It concluded that the availability of global solar radiation is very encouraging from application point of view. At the end, the predicting regression equation could be employed for the estimation of global solar radiation in the similar climatic locations.

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