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Estimation of total solar radiation using RadEst 3.0 software at Dang, Nepal

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Abstract

The RadEst 3.0 version software estimates total solar radiation using meteorological parameters such as precipitation, temperatures and solar radiation of Dang (Lat.28.7°N, Lon.82.18°E, and Alt.659m). The annual average daily global solar radiation is about 16.7 MJ/m^2/day which is sufficient to generate the solar energy. Radiation is calculated as the product of the atmospheric transmissivity of radiation and radiation outside earth atmosphere. The model parameters are fitted in two years data. The values estimated by the models are compared with measured solar radiation data. The performance of the model was evaluated using root mean square error (RMSE), mean bias error (MBE), Coefficient of Residual Mass (CRM) and coefficient of determination (R^2). The RadEst 3.0 software which showed the better results using BC, CD, DB and DCBB, among them the DB model is the best model for this site. The values of RMSE, MBE, CRM and R^2 are 2.98, 1.27, 0.00 and 0.66 respectively. The finding coefficients of different models can be utilized for the estimation of solar radiation at the similar meteorological sites of Nepal. The result conformed that there is strong correlation of total solar radiation with altitude and local weather condition.

Keywords: Total solar radiation, Temperature, Atmospheric pollution, RadEst 3.00 software, Coefficients.

Introduction

Nepal is a land-locked mountainous beautiful country situated in between 26.37^0 - 30.45^0 N latitude and 80.07^0 - 88.2^0 E longitude within a span of 200 km from south to north and about 800 km from east to west[1]. It shares borders with India on three sides and China on one side.Inside this region, Nepal possesses climate variation and diversity in biosphere. The national average total solar energy is 3.6 to 6.2kwh/m^2 /day and about 300 sunny days in a year[1]. The increase of total solar energy with altitude is due to decrease of atmospheric pollution and clouds in the atmosphere.

It does not have its own fossil energy resources and has not access to the ocean. To break this dependency on fossil fuel, Nepal should need a clean energy revolution. The recent annual average solar insolation is about 4.23 kWh/m^2 /day[2,3] which is closer to 4.38 kWh/m^2/day (Lao Peoples of Democratic Republic PDR). Thus, this result supports that Nepal lies in a favorable insolation zone in the world map. Hence, solar energy is one of the best options in developing counties like Nepal[4,5]. The relative humidity is also lower to compare in eastern part of Nepal. This paper is used to estimate daily total solar energy from minimum and maximum air temperatures, precipitation and geographical location by using RadEst 3.0 software. The appropriate model is selected to study global solar radiation in similar geographical regions and for solar energy technology development in Nepal. Energy strategist planners utilize this work which will help the solar energy potential to solve the energy crisis of Nepal[6,7].

Models

Four models[8,9] calculate daily solar radiation at earth surface. These models determine the results in graphical form by using statistical tools which adopt the parameters given as follow:
tt_i = estimated transmissivity,
τ = clear skytransmissivity,
ΔT = monthly average temperature,
T_{max} = daily maximum air temperature,
T_{min} = daily minimum air temperature,
b = coefficient of temperature range
c = very sensitive empirical parameter,
T_{nc} = temperature factor,
c_1 = seasonal variation magnitude parameter,
c_2 = seasonal variation profile parameter,
i = day of the year,i= 1to 365 or 366
$f(T_{avg})$ = average temperature function,
$f(T_{min})$ = minimum temperature function.
$Es_t\,Rad_i$ = estimated radiation (MJ m^{-2} day^{-1})
$PotRad_i$ = Potential radiation outside atmosphere (MJ m^{-2} day^{-1})

These models which estimate the atmospheric transmissivity of solar radiation based on the difference between maximum and minimum air temperature. The estimated value of radiation ($EstRad_i$) is calculated as the product between the estimated transmissivity (tt_i) and the value of potential radiation ($Pot\,Rad_i$) outside the earth atmosphere:

$$Est\,Rad_i = tt_i\,Pot\,Rad_i$$

The potential radiation is estimated as

$$Pot\,Rad_{doy} = 117.5\,dd2\{h_s\,Sin(lat)\,Sin(dec) + Cos(lat)\,Sin(h_s)\}/\pi$$

In this equation lat means latitude of the monitoring site, measured in degree, dec is solar declination , dd2 is distance of sun, h_s is half day length.

Bristow and Campbell Model[10]: The first model Bristow and Campbell from which other models have been developed. To estimate the daily radiation flux of incoming solar radiation, this model exploits the relationship between diurnal air temperature range and global solar radiation load to estimate the daily radiation flux of incoming solar radiation. It assumes that daily maximum air temperature will decreases with reduction in transmissivity (increased cloud cover). Then, the minimum air temperature will be due to the cloud emissivity. Conversely, clear skies will increase maximum air temperature due to higher short wave radiation input and minimum air temperature due to higher transmissivity. This method has been used in different work and improvements also have been made for last many years.

Estimated transmissivity is $tt_i = \tau[1 - \exp(\frac{-b\,\Delta T_i^c}{month\,\Delta T})]$

Hence from equation estimated radiation provided by

$$Est\,Rad_i = \tau[1 - \exp(\frac{-b\Delta T_i^c}{month\Delta T})]Pot\,Rad_i$$

Where: $\Delta T_i = T_{\max i} - (T_{\min_i} + T_{\min(i+j)})/2$

Campbell and Donatelli Model[11]: From the modification of BC model, the Campbell and Donatelli is derived. The CD model uses correction factor for seasonality effects which occur in mid-latitude areas such as Nepal. An estimate for transmissivity is increased by a factor T_{nc} which is summer night temperature factor[12]. In this model transitivity is obtained as

$$tt_i = \tau[1 - \exp\{-b f(T_{avg})\Delta T_i^2 f(T_{\min}\}]$$

Thus,

$$Est\ Rad_i = \tau[1 - \exp\{-b f(T_{avg})\Delta T_i^2 f_1(T_{\min})Pot\ Rad_i\}]$$

$$T_{avg} = (T_{\max i} + T_{\min i})/2$$

Donatelli and Bellocchi Model[13]: The third model is Donatelli and Bellocchi. This model is used toestimate the total solar energy from air temperature. However, it differs from the previous models. In this model variation of clear sky transmissivity is taken into account. Temperature difference is estimated through additional parameters $c_1$and c_2, these are the seasonality factors. The transmissivity in DB model is obtained as,

$$tt_i = \tau[1 + f(i)][1 - \exp\{\frac{-b\Delta T^2}{\Delta T_{week}}\}]$$

Providing radiation estimate as

$$Est\,Rad_i = \tau[1 + f\ (i)][1 - \exp(\frac{-b\Delta T_i^2}{\Delta T_{week}})]Pot\,Rad_i$$

Where: $f(i) = c_1\{Sin(i\,c_2\frac{\pi}{180}) + Cos(i\,f(c_2)\frac{\pi}{180})\}$,

$f(c_2) = 1 - 1.90c_3 + 3.83c_3^2$, $c_3 = c_2 - \mathrm{integer}(c_2)$

Donatelli-Campbell-Bristow-Bellocchi Model[14,15]: This is fourth model which is based on fluctuation data of atmospheric air. It includes all the above three models allowing switching such features on/off. More specifically, for instance, setting parameter $c_1 = 0$. Unchecking T_{nc}, and selecting the option box average monthly ΔT, the DCBB model becomes BC model.

The estimated transmittivity is $tt_i = \tau[1 + f(i)][1 - \exp\{\frac{-b\Delta T^2 f(T_{\min})}{\Delta T_{avg}}\}]$

which provides radiation estimate as

$$Est\,Rad_i = \tau[1 + f\ (i)][1 - \exp(\frac{-b\Delta T_i^2 f(T_{\min})}{\Delta T_{avg}})]Pot\,Rad_i$$

Where: $f(i) = c_1\{Sin(i\,c_2\frac{\pi}{180}) + Cos(i\,f(c_2)\frac{\pi}{180})\}$

$$f(c_2) = 1 - 1.90c_3 + 3.83c_3^2$$

$$f(T_{avg}) = 0.017\exp\{\exp(-0.053xT_{avg})\}$$

Where: $T_{avg} = (T_{\max i} + T_{\min i})/2$ and $f(T_{\min}) = \exp(T_{\min}/T_{nc})$

$$c_3 = c_2 - \mathrm{integer}(c_2)$$

Instrumentation: Environmental data were collected by the CMP6 Pyranometer installed at Dang (Lat.28.7°N, Lon. 82.18°E, and Alt.659 m). The operating temperature of the CMP6 Pyranometer is from -40°C to 80°C. Sspectral range of this instrument is from 310nm to 2800nm. The field of view and sensitivity of instrument are 180° and 5 to 15 µV/W/m^2 respectively. The measuring data is recorded by LOGBOX SD data logger in the instrument within a minute resolution for 24 hours. Special features of this instrument are low noise, high resolution and low power consumption. This instrument can work in all weather conditions. It collects the data at real time for the needs of meteorology and slow signal analysis. The SD memory card can be inserted for long term data storage. For the communication LOGBOX uses either RS232 or RS485 communication port[16].

The meteorological parameters and measured data of solar radiation are utilized in the RadEst 3.0 version Software. Its explanation is given above. In all these models minimum and maximum temperature, daily precipitation and total solar radiation data of each year are used, the daily values of total solar radiation have been estimated by using input data of Dang for two years (2009 and 2011).

Input Format: The latitude, longitude and altitude of monitoring sides are necessary for RadEst 3.0 version software. In this case range of clear sky transmissivity should be from 0.6 – 0.8. In each model clear sky transmissivity is used in the expression of transmissivity coefficient of atmospheric radiation and the latitude is used in the expression of potential radiation.

Analysis: In this process at least two years data should be required for the estimation and comparison of global solar radiation. Auto optimization is less accurate method in comparison to parameter fitting. Parameter fitting is more convenient because of the parameters related to affecting factors of global solar radiation. Different parameters are varied to obtain closer value of measured and estimated radiation.Value of root mean square error (RMSE), mean bias error (MBE), coefficient of residual mass (CRM) and coefficient of determination (R^2) are obtained by the analysis of different models. Themodel estimated and measured value of radiation are justified by these tools.

Results and discussion

Four models of RadEst 3.0 software were calibrated using parameter fitting by minimizing RMSE, CRM and MBE on the basis of 2009 data of Dang. But the value of coefficient of determination should be greater as far as possible. By PF in 2009 equal values of model estimated and measured radiation are found. The finding value of measured and model estimated solar radiation value 16.0 MJ/m^2 is found. Table-1 consists measured and model estimated average value, maximum value and yearly total value of global solar radiation of Dang. From this table it is concluded that, in comparison to BC, CD and MDCBB models there is nearly closer value in DB model. Hence DB model is better model to estimate the global solar radiation at selected sites of Nepal in 2011.

To estimate the total radiation for the year 2011 data, the parameters from 2009 are used .By auto optimization process, these four models are tested. Then total solar radiation is estimated by parameter fitting method. Then measured value of total solar radiation and estimated value of total solar radiation are very close. In Table-2, the parameter fitting based testing values are given.

Table-1: Average value of MEA, Model estimated, maximum value and yearly total value of global solar radiation of Dang 2009

Models	Average value (MJ/m^2)		Maximum Value (MJ/m^2)		Yearly total (MJ/m^2)	
	MEA	EST	MEA	EST	MEA	EST
BC	16.0	16.0	27.4	26.5	5837	5846
CD	16.0	16.0	27.4	26.5	5837	5855
DB	16.0	16.0	27.4	25.8	5837	5840
MDCBB	16.0	16.0	27.4	26.9	5837	5846

Table-2: Average value of MEA, Model estimated, maximum value and yearly total value of global solar radiation of Dang 2011.

Models	Average Value (MJ/m^2)		Maximum value (MJ/m^2)		Yearly total (MJ/m^2)	
	MEA	EST	MEA	EST	MEA	EST
BC	13.6	15.8	24.8	26.9	4972	5782
CD	13.6	15.7	24.8	26.2	4972	5741
DB	13.6	15.8	24.8	26.7	4972	5772
MDCBB	13.6	15.8	24.8	27.8	4972	5781

Analysis of error for years 2009 and 2011 data: Table-3 shows the error analysis between measured and model estimated value of global solar radiation in 2009. Value of the RMSE is lower in DB model than BC, CD and DCBB models in 2009. MBE is lower in BC model in comparison to other three models. The value of R^2 is greater in DB model in comparison to BC, CD and DCBB models. Thus, it is confirmed that the DB is the better model among the four models in terms of statistical analysis.

The error analysis in between measured and estimated values of global solar radiation of 2011 is given in Table-4. Values of RMSE and MBE are comparatively smaller in DB than BC, CD and DCBB models. The value of R^2 is higher in DB model than BC and CD models. Hence, it is found thatthe DB model is the best model than other three models.

Daily variation of total solar radiation with day of the year is shown in the Figures-1 and 2. Due to local weather condition there is significant variation of total solar radiation. At Dang in 2009 and 2011, the average measured values of total solar radiation are 16.0MJ/m^2/day and 13.6MJ/m^2/day respectively. Tables-3 and 4 show Values of RMSE and MBE which are more in 2011 than 2009 data.

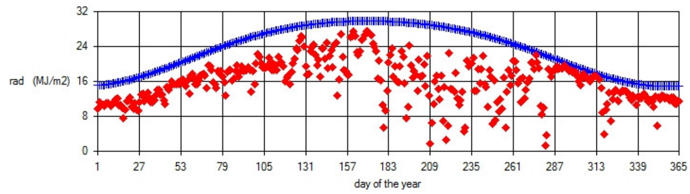
Coefficient determination between measured and model estimated value of total solar radiation is shown in Figures-3 and 4. The DB model is the best among other models because value of$R^2$is higher in comparison to other models.

Table-3: Error analysis f or year 2009.

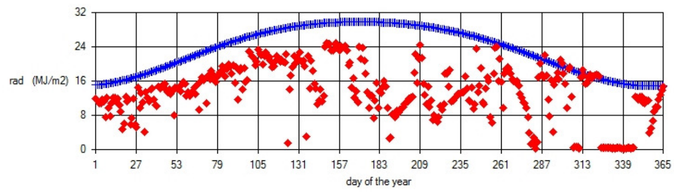
Models	RMSE (MJ/m^2)	MBE (MJ/m^2)	CRM (Unitless)	R^2 (Unitless)
BC	3.07	1.65	0.00	0.64
CD	3.79	2.02	0.00	0.52
DB	2.98	1.67	0.00	0.66
MDCBB	3.09	1.86	0.00	0.65

Table-4: Error analysis f or year 2011.

Models	RMSE (MJ/m^2)	MBE (MJ/m^2)	CRM (No Unit)	R^2 (No Unit)
BC	6.52	4.12	-0.16	0.16
CD	6.7	4.24	-0.15	0.15
DB	6.4	4.13	-0.14	0.17
MDCBB	6.44	4.39	-0.16	0.19



Figures-1: The variation of daily total solar radiation in 2009 and 2011.



Figures-2: The variation of daily total solar radiation in 2009 and 2011.

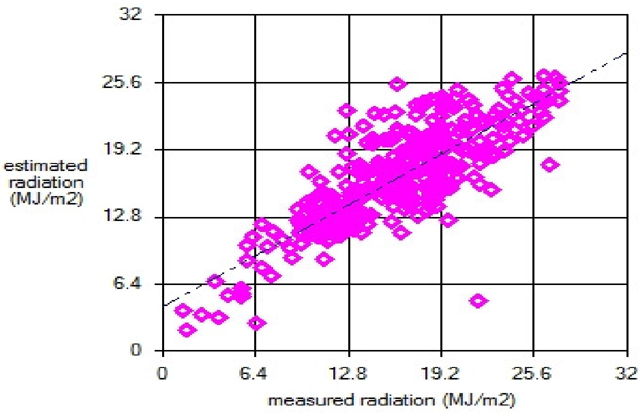


Figure-3: The coefficient of the determination in between measured and estimated value of total solar radiation in 2009 and 2011 of DB model.

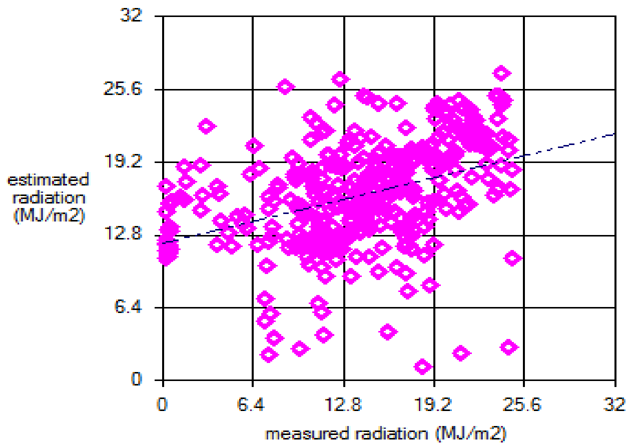


Figure-4: The coefficient of the determination in between measured and estimated value of total solar radiation in 2009 and 2011 of DB model.

In 2009 and 2011 coefficient of determination found is 0.66 and 0.17 which is shown in Figures-3 and 4. This value is maximum in DB model in than other three BC, CD and DCBB models.

Monthly variation of Total Solar radiation: Monthly mean measured value of GSR is shown in Figure-5 for the years 2011 in Dang. The maximum and minimum value of GSR is observed to be 22.7 and 10.08 MJ/m^2/day in June and January respectively. The annual average measured value of GSR (16.7 ±1.3) MJ/m^2/day which is sufficient to generate the solar energy. The coefficient of determination and p-values are obtained as 0.92, and <0.0028. The value of coefficient of determination is about 92 percent which is the lowest among the three sites. It may be due to frequently changing local weather condition in this site. The p-value is also found within permissible range of acceptance. The trend line of fifth degree polynomial is fitted with measured data of GSR in Dang which is shown in Figure-5.

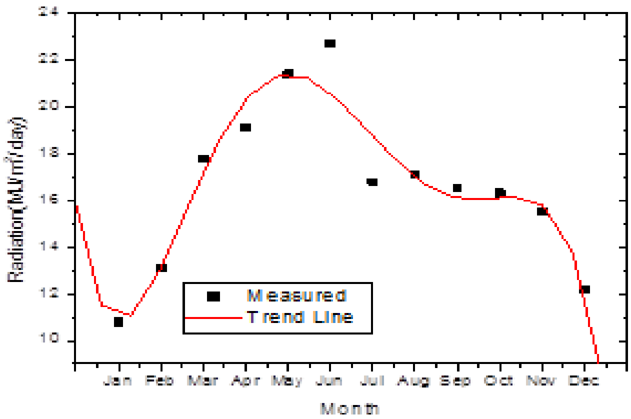


Figure-5: Monthly variation of total solar radiation in Dang, 2011.

Seasonal variation of total solar radiation in Dang, 2011: Figure-6 shows the seasonal variation of GSR in Dang in the year 2011. The GSR of 13.9, 21.1, 16.8 and 14.7 MJ/m^2/ day were found in winter, spring, summer and autumn seasons respectively. In this region, the maximum and minimum amount of GSR are obtained in winter and Autumn which is similar as in Nepalgunj. High value of GSR in spring is attributed due to less solar zenith angle, less cloud and less rainfall. The annual average GSR of 16.7MJ/m^2/day is obtained in Dang.

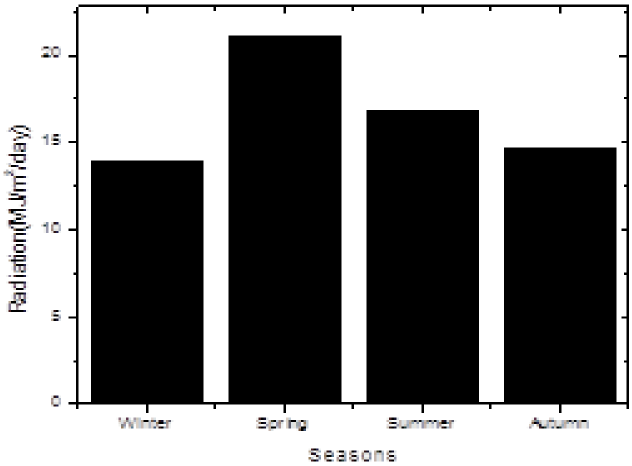


Figure-6: Seasonal variation of Solar radiation in Dang, 2011.

Conclusion

It is concluded that these four models BC, CD,DB and MDCBB are used to estimate the total solar radiation with variation of parameters and testing bystatistical and graphical tools and on 2009 and 2011 at Dang. By using statistical tools such as root mean square error (RMSE), mean bias error (MBE), coefficient of residual mass (CRM) and coefficient of determination (r^2), the performance of the model was evaluated for selected sites. By above result, it is concluded that DB is the best model for estimation of global solar radiation at Dang and other similar geographical altitudes of Nepal. For the design and estimation of performance of solar systems at the similar meteorological sites of Nepal, the findings of model coefficients can be used.

The annual average measured value of GSR (19.9 ±0.66) $MJ/m^2/day$ which is sufficient to generate the total solar energy in mid- western part of Nepal.

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