A Comparative Study of Various Models for the Estimation of Monthly Average Daily Global Solar Radiation on Horizontal Surface at Kathmandu

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Abstract: In this present study, various empirical regression based models used across various parts of the world to determine global solar radiation on horizontal surface are generalized into seven different models. The common dependent parameter is sunshine duration and others are maximum and minimum temperature along with relative humidity. The regression analysis has been carried out for Kathmandu with the help of data available for Tribhuvan International Airport for period of 2002 to 2010. The comparative performance of the models has been evaluated on the basis of statistical parameters – Root Mean Square Error , Mean Biased Error , Mean Percentage Error , Co-relation Coefficient and t-statistic. The results obtained in this study indicate that Iqbal model (with determining variables consisting of sunshine duration, average ambient temperature, maximum ambient temperature and relative humidity) is best suitable for the estimation of monthly average daily global radiation on horizontal surface for Kathmandu.

Keywords: RMSE; MBE; MPE; CC; t-stat; Monthly average daily global radiation

1. Introduction

1.1 Background

One of the key inputs for the accelerated economic growth is Power. Nepal is endowed with huge hydropower potential. Estimated theoretical power potential from its water resources is about 84,000 MW of which recent studies estimates 43,000 MW economically exploitable. But the installed hydropower generation capacity as of July 2013 is merely 746 MW, of which 704 MW is grid-connected. Predominance of run off the river type hydropower projects, resulted low available energy output in the dry season, when the system demand is high, which is nearly 40 to 45% of the installed capacity. It is to be noted that 80 percent of rainfall in this Himalayan country occurs in the wet season (or the monsoon months of July, August and September), while the dry season (October through June) rainfall contribution is limited to only 20%. This variation in the rainfall in monsoon and non-monsoon months, with a hydropower generation schemes based on run off the river types, has resulted in acute power shortages in dry months with wide ranging economic implications. The power cut/ load shedding in the peak dry season reaches upto 18 hours a day. For instances, in November 2012, early post monsoon month, shortfall of nearly 470MW was recorded. This gap between power supply and demand needs immediate attention with economically viable short term options. Since solar electricity generation systems are easy and quick to install, are very attractive option in many locations in the county (NEA, 2014).

According to SWERA report (AEPC, 2008), Nepal is one of the under developed countries in the world economy scenario but in terms of renewable energy, it is one of the richest countries. Nevertheless most of the energy demand is fulfilled from the forest products and fossil fuel with very few portions from the renewable energy. In addition solar and wind energy could be the milestone in the renewable sector after hydro electricity for harvesting the energy at the time that price of the fossil fuel is sky rocketing daily. Especially, Nepal having a weak economy definitely needs to substitute imported fossil fuels by implementing indigenous renewable energy resources to meet its energy demands as soon as possible. Nepal has great potential for the renewable energy and because of the difficult topography and scattered settlement, solar and wind energy can be one of the best alternative energy solutions for the remote area of Nepal.

Table 1: CSP Potentioal in Nepal (Source:AEPC, 2008)

S.N.	Solar Radiation Class (kWh/m^2/day)	Average Annual Radiation (kWh/m^2/day)	Area(km^2)
1	3.5-4.5	4.16	2174.49
2	4.5-5.5	5.22	32597
3	5.5-5.75	5.561	2729.53
		Total	37501.02

According to this analysis, Nepal has about 37,501 sq km area that falls under CSP(Concentrated Solar Power) potential which is 25% of the total area of Nepal. Considering high concentrating solar radiation required for power generation from the CSP, area under average annual irradiance >5.5 kWh/m²/day is about 2,729 sq.km. Typical solar trough technology produces 33.5 MW peak per sq.km of land area. If only 2% of the best solar irradiance is taken for the power generation, it can yield 1,829 MW

Table 2: Grid connected PV potential in Nepal (Source: AEPC, 2008)

S.N.	Solar Radiation Class (kWh/m²/day)	Average Annual Radiation (kWh/m²/day)	Area(km²)
1	5.0-5.5	5.28	1724.5
2	5.5-5.96	5.67	443.48
		Total	2167.98

In SWERA report, Grid connected integrated PV potential has been shown for the urban area. Considering power generation per sq. km considered as 50 MW and 2% of the land area as suitable land, then an area of 2,167 sq. km has been shown to yield 2,100 MW. So the exploitable area for grid integrated PV potential is significantly high in Nepal.

The annual peak power demand of the integrated Nepal Power System (INPS) in fiscal year 2012/2013 is estimated to be 1,094 MW. Out of 1,094 MW of peak demand, only 719 MW could be supplied and 375 MW was shed (NEA, 2013).

Thus, it is obvious that the exploitation of only solar energy through Grid connected integrated PV can curb our perennial problem of load shedding in very short time.

1.2 Rationale

In the present scenario of rapid depletion of various sources, solar energy proves to be a good alternative renewable energy source. For the best utilization of solar energy, solar energy conversion systems should work with maximum efficiency. The design of a solar energy conversion system requires precise knowledge of the availability of solar radiation and its components at the location of our interest (Sivamadhavi & Selvaraj, 2010).

According to Gadiawala et al., 2013, solar radiation and sunshine duration are two of the most important variables in the energy budget of the earth and play an important role in the performance evaluation of renewable energy systems and in many other applications like health, agriculture, construction, etc.

The solar radiation has temporal and spatial variations. To collect this information, a network of solar monitoring stations equipped with pyranometers and data acquisition systems are generally established in the desired locations. However, the number of such stations in the network is usually not sufficient to provide solar radiation data of the desired areas, especially in developing countries. This is mainly because high cost is involved with the measuring equipment and techniques. Therefore, it is necessary to develop methods to estimate the solar radiation on the basis of the more readily available meteorological data (Husaein, 2012).

Sunshine hours are measured at many locations around the world while global radiation is measured at selected locations only. In order to overcome this defectiveness, scientists have developed many empirical equations to estimate monthly average daily global radiation (Jamil & Tiwari, 2010)

In developing countries like Nepal, the facility of ground-based measurement of solar radiation is available only at selected sites whereas meteorological and hydrological data are available at different parts of the country (Adhikari et al., 2013); obviously the best way of knowing the amount of global solar radiation at the site of consideration is to install pyranometer at many locations in the given region and look after their day-to-day maintenance and recording, which is a very expensive venture.

The alternative approach could be to predict the global radiation with the help of some model incorporating the easily available meteorological parameters as input. The resultant correlation may then be used for locations of similar meteorological characteristics.

As per the information retrieved from the web page (http//www.dhm.gov.np), there are 282 meteorological stations across various parts of our country. These include 76 stations of climatology type which are significantly valuable in view of different parameters required for estimations of global radiation. Most of them are situated in rural areas. Moreover, SWERA report (AEPC, 2008) mentions that solar radiation higher than 6 kW/m²/day lies in rural area. It shows that harnessing of solar energy could be desirable option for sustainable rural development.

Thus, developing the empirical model to estimate the monthly average daily global solar radiation using easily available parameters such as sun- shine duration, maximum and minimum ambient temperature, relative humidity, rainfall and geographical location, etc., is an essential assignment for countries like Nepal where solar insolation data are not available at most of the places.

1.3 Problem Statement

Available literature reveals that the study in Nepal for the estimation of monthly average daily global radiation is very meager. One research (Poudyal et al., 2012) employs regression model using clearness index and cloud transmittance at Lukla(Latitude 26.69^{0}N, Longitude 86.73^{0}E, Altitude 2850 m) presents monthly and seasonal variations of global solar radiation as well as correlation between clearness index and cloud transmittance factor.

As per the study (Poudyal et al., 2012) the annual average daily global solar radiation is about 3.83 kWh/sq·m/day; the maximum and minimum global solar radiation of 5.33 and 2.08 kWh/sq·m/day is recorded in April and September 2010 respectively; the seasonal variation of solar energy is about 2.87 kWh/sq·m/day and 4.83 kWh/sq·m/day in summer and spring respectively which is not in line with the general trend; the coefficient of correlation (R^2) between cloud transmittance factor (cf) and clearness factor (K) is found to be 0.97; this novel result can be utilized to estimate the global solar radiation at the horizontal surface where K and cf are available.

Another research (Adhikari et al., 2013) employs regression model based on sunshine hours, temperature and relative humidity for Biratnagar, Kathmandu, Pokhara and Jumla. It has computed the global solar radiation for these locations. The values of global solar radiation estimated by the model are found to be in close agreement with measured values of respective sites. The estimated values were compared with Angstrom-Prescott model on the basis of RMSE, MBE, MPE, CC.

These are, undoubtedly, great work. However, there is no study as to which model as suggested by the two researches is more suitable. Moreover, the literature review (Jamil & Tiwari, 2010) suggests that there can be a number of other models which, upon study, can lead to better result than the earlier studied model. Thus, a comprehensive study on various models is needed to perform precise simulation which results in optimum solar design in the places where no direct measured data is available.

1.4 Objective of the Study

The main objectives of this study are given below:

i. To study various models pertinent to the estimation of monthly average daily global radiation.

ii. To set up the models using regression and analyze their performance with the help of statistical test.

2. Methodology

The detail methodology adopted for this study is shown in figure 1.

2.1 Proposed Models

Followings are some of the generalized regression based empirical models (Gairaa & Bakelli, 2013) that have been used across various parts of the world. The common parameter among them is sunshine duration which is very commonly available in meteorological station. Similarly, some of them (5-7) employ parameters like temperature and relative humidity which are also easily available.

1. Linear Model (Angstrom-Prescott Model)

$$\frac{H}{H_0} = a + b\left(\frac{SS}{SS_0}\right) \quad \text{..........(1)}$$

2. Quadratic Model (Ogelman et. al. model)

$$\frac{H}{H_0} = a + b\left(\frac{SS}{SS_0}\right) + c\left(\frac{SS}{SS_0}\right)^2 \quad \text{..........(2)}$$

3. Logarithmic Model (Ampratwum et. al. model)

$$\frac{H}{H_0} = a + b\ ln\left(\frac{SS}{SS_0}\right) \quad \text{..........(3)}$$

4. Exponential Model (Almorox et. al. model)

$$\frac{H}{H_0} = a + b\ e^{\left(\frac{SS}{SS_0}\right)} \quad \text{..........(4)}$$

5. Abdalla Model

$$\frac{H}{H_0} = a + b\left(\frac{SS}{SS_0}\right) + c(T_{max}) + d\ (RH) \quad \text{..........(5)}$$

6. Hargreaves et. al. Model

$$\frac{H}{H_0} = a + b(T_{max} - T_{min})^{0.5} \quad \text{..........(6)}$$

7. Iqbal model

$$\frac{H}{H_0} = a + b\left(\frac{SS}{SS_0}\right) + c\left(\frac{T_{av}}{T_{max}}\right) + d\ ln(RH) \quad \text{..........(7)}$$

Where, H is the measured monthly average daily global radiation, H_0 is the extraterrestrial monthly mean daily global radiation, SS is the monthly mean daily sunshine hours, SS_0 is the monthly mean maximum possible daily sunshine hours, T_{max} and T_{min} are the monthly mean daily maximum and minimum air temperature, RH is the monthly mean daily relative humidity, RH_{max} and RH_{min} are monthly average daily maximum and minimum relative humidity. a, b, c and d are regression co-efficient.

2.2 Calculation of H_0

H_0 is extraterrestrial radiation and SS_0 is maximum possible sunshine hour obtained respectively by using equation 8 through 12 and equation 13 (Garg & Prakash, 2010), (Sukhatme, 2012) & (Tiwari, 2013).

$$H_0 = \frac{24}{\pi} I_{sc} E_0 \left[\frac{\pi}{180}\omega_s sin\varphi sin\delta + cos\varphi cos\delta sin\omega_s\right] ......(8)$$

I_{sc} is solar constant given by

$$I_{sc} = \frac{1367x3600}{1000000}\frac{MJ}{m^2h} ....(9)$$

E_O is eccentricity correction given by

$$E_0 = 1 + 0.33cos\frac{360N}{365} ....(10)$$

(Gairaa & Bakelli, 2013)

δ is solar declination given by

$$\delta = 23.45sin\left[\frac{360}{365}(N+284)\right] ....(11)$$

ω_s is sunrise hour angle given by

$$\omega_s = cos^{-1}(-tan\varphi\ tan\delta) ....(12)$$

SS_O is maximum possible sunshine hour given by

$$SS_0 = \frac{2}{15}\omega_s ....(13)$$

Where N is the day number considering N=1 from 1st January.

2.3 Statistical Test

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,e} - H_{i,m}\right)^2\right]^{\frac{1}{2}} ....(14)$$

$$MBE = \frac{1}{n}\left[\sum_{i=1}^{n}\left(H_{i,e} - H_{i,m}\right)\right] ....(15)$$

$$MPE = \left[\frac{1}{n}\left(\sum_{i=1}^{n}\frac{H_{i,e}-H_{i,m}}{H_{i,m}}\right)\right] x\ 100\% ....(16)$$

$$CC = \frac{\sum(H_{i,e}-\overline{H_e})(H_{i,m}-\overline{H_m})}{\sqrt{\left[\left\{\sum(H_{i,e}-\overline{H_e})^2\right\}\left\{\sum(H_{i,m}-\overline{H_m})^2\right\}\right]}} ....(17)$$

$$t = \sqrt{\frac{(n-1)MBE^2}{RMSE^2-MBE^2}} \text{ with d.f.=(n-1)} ....(18)$$

Where RMSE, MBE, MPE, R^2 and t are respectively the root mean square error, Mean bias error, Mean percentage error, Correlation co-efficient, and t-value. N is the number of observation, $H_{i,e}$, $H_{i,m}$, $\overline{H_e}$ and $\overline{H_m}$ are the estimated value, measured value, mean of the estimated value and mean of the measured value.

2.4 Process Flow Chart

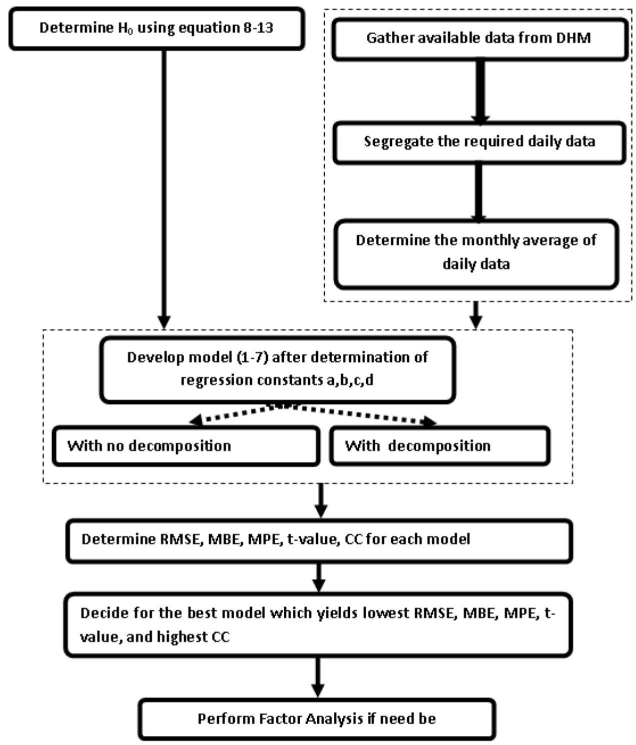

Figure 1: Flow chart showing various activities

First of all, the longitude & latitude of Kathmandu airport is taken. Then using equation 11, solar declination is calculated for each day. Then sunshine hour angle is calculated for each day using equation 12. Correspondingly maximum possible sunshine hour SS_0 is calculated by equation 13. Extraterrestrial radiation H_0 is calculated using equation 8, 9 & 10.

Monthly average value of actual measured radiation H, H_0 , SS, SS_0, T_{max} , T_{min} , RH are taken. Using these values, regression is carried out for determination of regression constants a, b, c & d pertinent to the models (1-7). On substitution of a, b, c & d yields to different models for the selected place.

Monthly average daily solar radiation is estimated using the model (1-7) thus set up. Using the actual value and estimated value, RMSE, MBE, MPE, CC, t-stat are computed corresponding to each of the seven model established. Models are evaluated on the basis of these statistical parameters. Lower value of RMSE, MBE,MPE, t-stat are desired where as higher value of co-relation co-efficient is desirable.

3. Data Analysis

The required data for global solar radiation, humidity, sunshine duration, temperature have been collected from the Department of Hydrology and Meteorology, Government of Nepal, Babarmahal, Kathmandu. The available data are for the period 2002 to 2010 AD .

The relevant data have been analyzed using Microsoft Excel-2007 with its data analysis tool. The analysis has been done for 9-year data (2002-2010), 6- year data(2002,2003, 2005, 2006,2007,2008) and for single year (2002) in order to see the trend of the result.

3.1 Result

Table 3: Comparison based on 9-year data analysis

Model	RMSE	MBE	MPE	CC	t-stat
Model 1	3.1995	0.1164	11.7608	0.3387	0.3765
Model 2	3.1933	0.1156	11.7613	0.3381	0.3749
Model 3	3.2239	0.1292	11.8670	0.3348	0.4148
Model 4	3.1941	0.1152	11.7497	0.3391	0.3735
Model 5	3.1283	0.0230	11.2542	0.3306	0.0760
Model 6	3.3339	0.1726	13.3703	0.2708	0.5362
Model 7	3.1263	0.0205	11.1326	0.3318	0.0677

Table 4: Comparison based on 6-year data analysis

Model	RMSE	MBE	MPE	CC	t-stat
Model 1	3.276081	0.117555	8.89875	0.357382	0.302548
Model 2	3.275995	0.117485	8.983806	0.351588	0.302377
Model 3	3.300764	0.132347	8.970664	0.355523	0.338125
Model 4	3.27339	0.116274	8.925861	0.355327	0.299493
Model 5	3.209804	0.051542	8.744725	0.351739	0.135322
Model 6	3.395348	0.141076	10.00433	0.296207	0.350407
Model 7	3.210188	0.011955	8.87885	0.337413	0.031381

Table 5: Comparison based on 1-year data analysis

Model	RMSE	MBE	MPE	CC	t-stat
Model 1	0.5203	0.0290	0.2409	0.9525	0.18501
Model 2	0.5182	0.0291	0.2455	0.9526	0.186819
Model 3	0.6303	0.0375	0.2481	0.9385	0.197893
Model 4	0.5192	0.0312	0.2777	0.9515	0.199741
Model 5	0.4806	0.0208	0.2403	0.9562	0.143996
Model 6	1.0060	0.0626	0.8193	0.8233	0.206634
Model 7	0.3658	-0.0099	0.1413	0.9760	0.090186

Table 6: Comparison between model1 and model7
(Source: Journal of Power and Energy Engineering, 2013)

SN	Location	Regression constants				RMSE		MBE		MPE		CC	
		a	b	c	d	Ang	New	Ang	New	Ang	New	Ang	New
1	Kathmandu	-1.00E-04	0.324	-0.09	0.08	4.15	1.197	-2.32	0.866	11.52	0.34	0.44	0.93

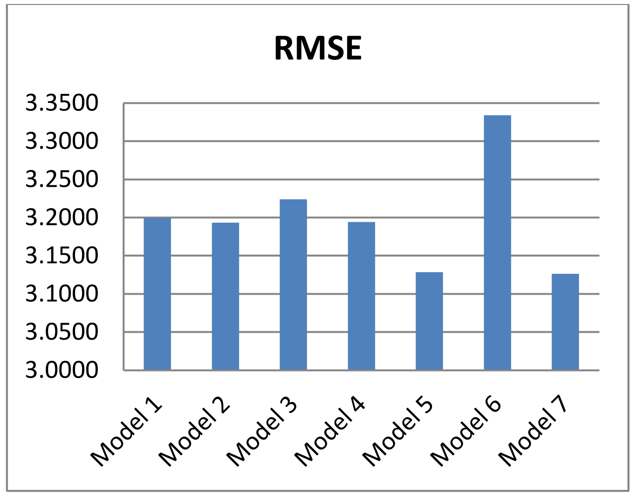

Figure 2: RMSE based on 9-year data analysis

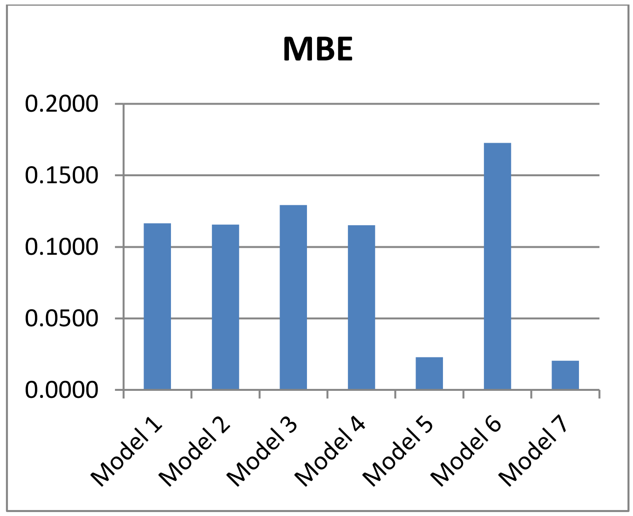

Figure 3: MBE based on 9-year data analysis

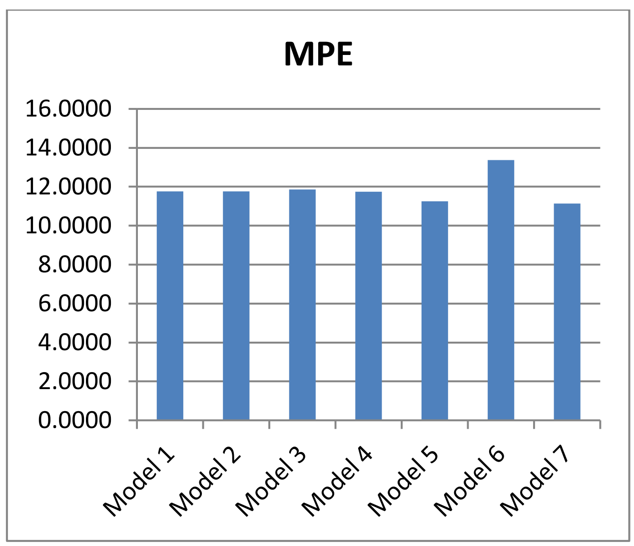

Figure 4: MPE based on 9-year data analysis

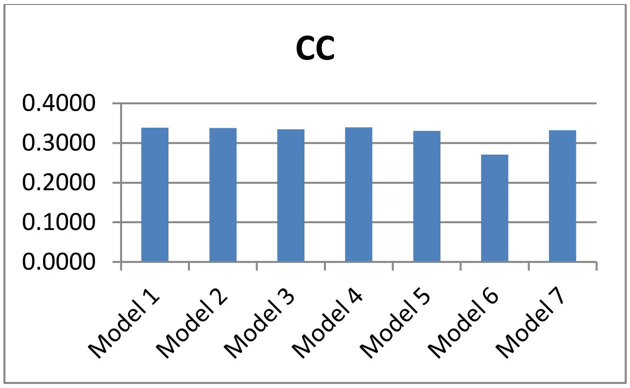

Figure 5: CC based on 9-year data analysis

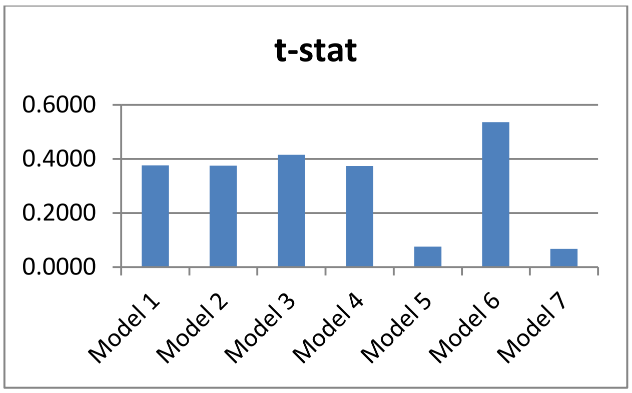

Figure 6: t-stat based on 9-year data analysis

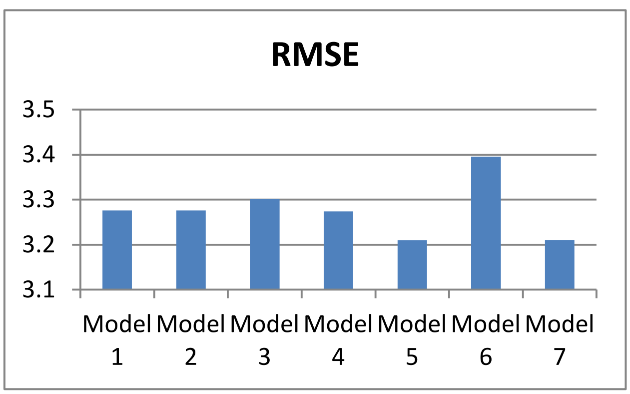

Figure 7: RMSE based on 6-rear data analysis

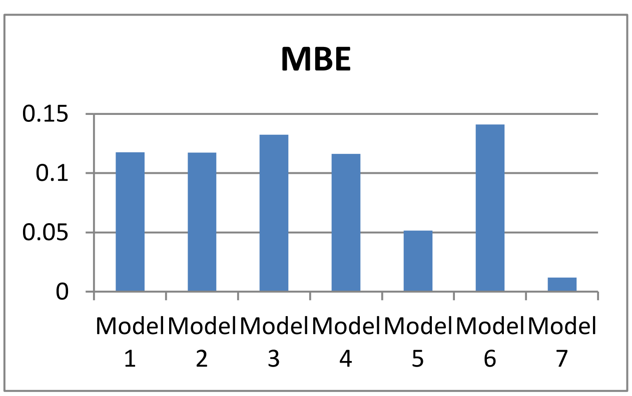

Figure 8: MBE based on 6-year data analysis

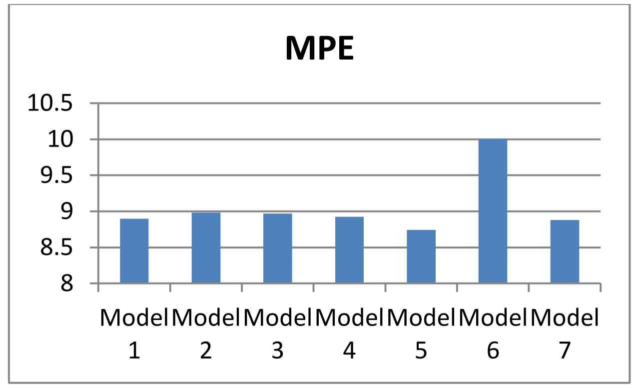

Figure 9: MPE based on 6-year data analysis

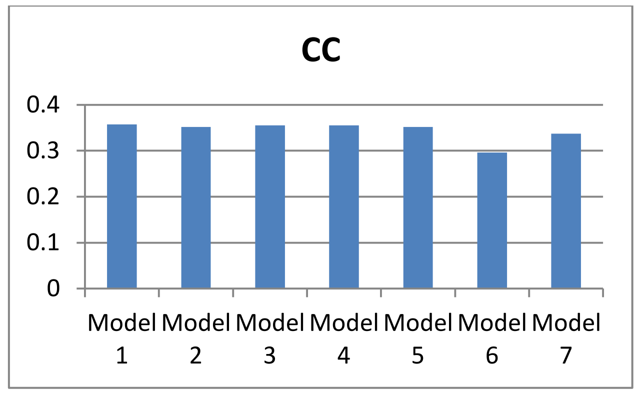

Figure 10: CC based on 6-year data analysis

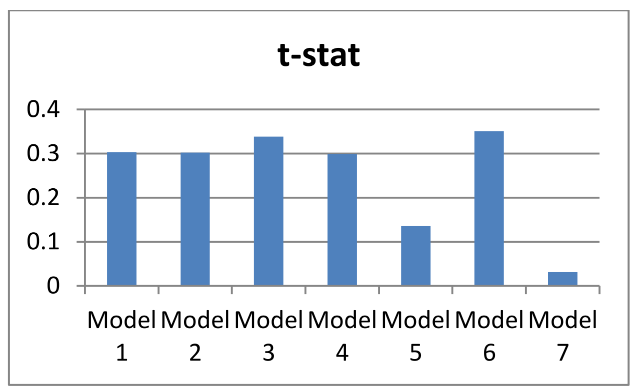

Figure 11: t-stat based on 6-year data analysis

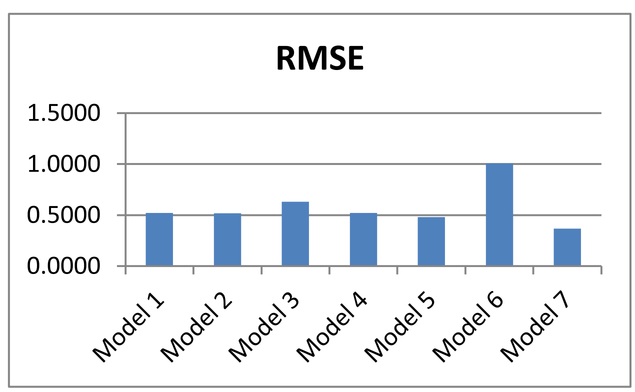

Figure 12: RMSE based on 1-year data analysis

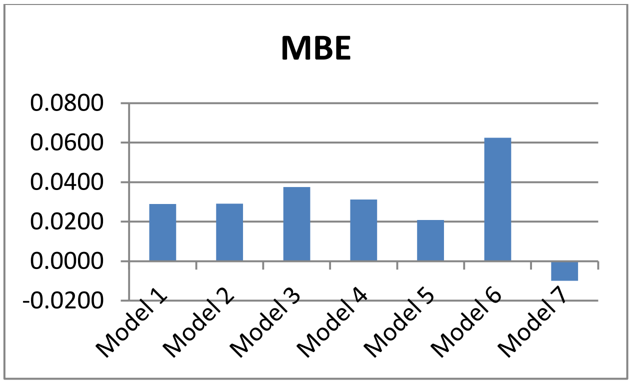

Figure 13: MBE based on 1-year data analysis

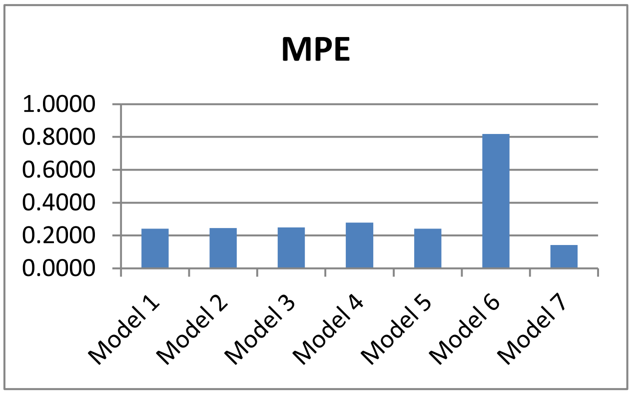

Figure 14: MPE based on 1-year data analysis

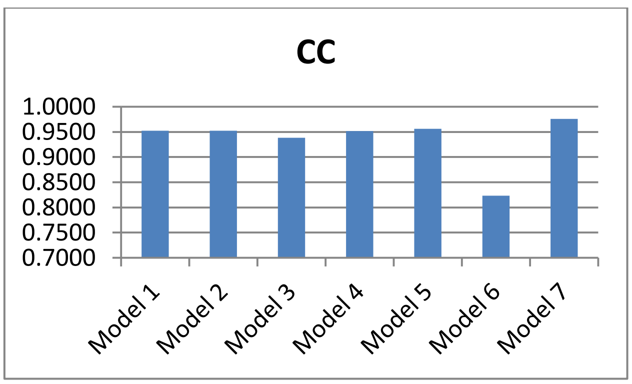

Figure 15: CC based on 1-year data analysis

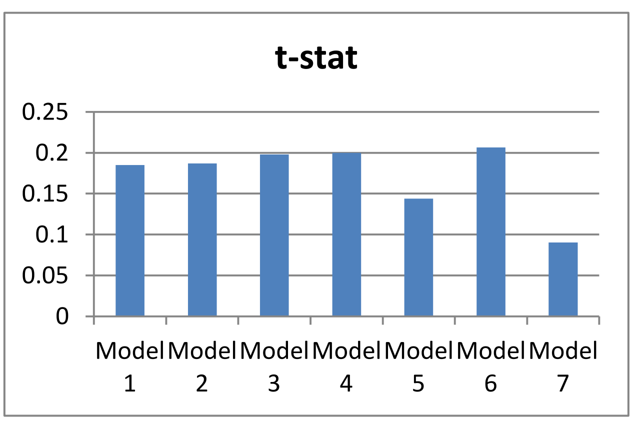

Figure 16: t-stat based on 1-year data analysis

3.2 Discussion

1. From the analysis result based on 9-yr data (2002-2010) as shown in table-3, we observe that Model-7 exhibits the minimum RMSE (3.1263), MBE(0.0205), MPE(11.1326%) & t-stat(0.0677) which is desirable whereas Model-4 shows maximum co-relation co-efficient (CC) of 0.3391 between the actual and the measured value of global solar radiation.

2. Similarly, the analysis result based on 6-yr data (2002, 2003, 2005, 2006, 2007, 2008) as shown in table 4 shows that Model 5, despite yielding minimum RMSE(3.2098), is equivalent to Model-7 in this respect; Model-7 has RMSE of 3.2101. Moreover, Model-7 yields minimum MBE(0.011955) and t-stat(0.031381) along with maximum CC(0.3374). However, Model-5 exhibits minimum MPE(8.7447%). But, MPE shown by Model-7, which is 8.87885 can be closely approximated as that of Model-5.

3. One year data analysis result (table 5) shows that Model-7 yields optimum value of RMSE, MBE, MPE and t-stat as 0.3658, -0.0099, 0.1413, 0.9760 and 0.090186 respectively.

4. In Table 4, which has been taken from Journal of Power and Energy Engineering, (Adhikari et al.,2013),the result associated with RMSE, MPE, CC , MBE of Model-7 has been compared with that of Model-1. It has been shown that MPE improves from 11.52% to 0.34% and CC improves from 0.44 to 0.93. This is not in conformance with the result shown in Table 1, Table 2 and Table 3. In the tables 3, 4 & 5, we see that the results shown by both the models(viz,1&7) are nearly equal. For example, in table 1, the value of MPE by model-1 and model-7 are 11.7608 and 11.1326; the respective value of value of CC are 0.3387 and 0.3318. Similarly, in table 2, the value of MPE by model-1 and model-7 are 8.8987 and 8.8788; the respective value of value of CC are 0.3573 and 0.3374. In case of table-3, the value of MPE by model-1 and model-7 are 0.2409 and 0.1413; the respective value of value of CC are 0.9525 and 0.9760.

5. The statistical parameters viz, RMSE, MPE, CC exhibit significant change as the input data have been increased; it is obvious from the table 3, 4 , 5 & charts. Moreover, MPE does not seem to be convergent in particular.

4. Conclusion

Error between estimated and actual value should be as low as possible, be it RMSE, MBE or MPE. Similarly, CC should be as high as possible. t-stat, which shows any significant difference between actual and estimated by the model, should be as low as possible. With this perspective, the desirable parameters have been highlighted in table 3, 4 and 5. Most of the highlighted cells are shown by model-7. Hence, model-7 can be taken as best suitable model for the prediction of monthly average daily global radiation.

The result of this present study does not comply with the comparative result presented by Adhikari et al., 2013. The abrupt change in RMSE, CC, MPE as shown in this report seems fallacious and so further suitable study like Factor Analysis need be carried out to find the actual dependence of sunshine duration on the outcome of the model.

Average solar radiation varies from 3.6 to 6.2 kWh/m^2/day while total sun shine days are about 300 per year (NEA, 2014). As per SWERA report (AEPC, 2008), high solar radiation(>6.0 kWh/m^2/day) location are not in urban areas. This shows the need of rural electrification. Study of such model which uses sunshine hour as prime element can contribute to the accurate and economic design for rural electrification. Moreover, the most suitable model identified for Kathmandu in this study can be used for other places having similar climactic conditions.

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