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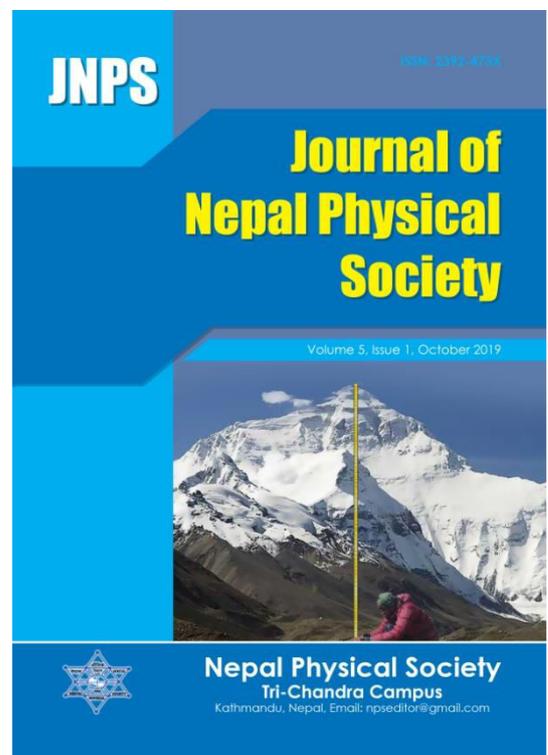
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EMPIRICAL MODELS FOR THE EVALUATION OF GLOBAL SOLAR RADIATION IN THE DIFFERENT SITES OF NEPAL

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ABSTRACT

To operate many phenomenon's on the earth surface such as physical, chemical and biological process solar radiation plays vital role. A common practice is to estimate average daily global solar radiation (GSR) using appropriate empirical models for the areas lacking the actual measured values. In this context several single and multiple meteorological parameters were selected to estimate the GSR for Jumla, Nepalgunj and Kathmandu. In order to validate the selected models various statistical test were employed. The selected models were compared on the basis of statistical errors. In the statistical analysis the value of root mean square error (RMSE) and coefficient of determination R^2 is found to 0.15, 0.23, 0.26 and 0.98, 0.96, 0.96 respectively for Jumla, Nepalgunj and Kathmandu in Samuel model. These values were comparatively better than other models. It is concluded that Samuel model (order three) is the best among the used models. The established result uncover that there is a good possibility of solar energy as a alternative energy source in Nepal.

Keywords: Empirical models, Global solar radiation, Regression constants, statistical error, Sunshine hour.

BACKGROUND

It is essential to have knowledge on global solar radiation of the study site in order to design and operate the solar energy devices. Solar engineers, agriculturists and hydrologists use the solar radiation data for various purposes such as solar heating, cooking, drying and interior illumination of buildings [1, 2]. Since it has a huge economic uses as a renewable energy, lots of studies have been done due to its importance in contributing energy for Earth's climate system. Several factors do play role in quantifying the solar radiation on earth's surface. Among them, the climatic condition and geography of the site affect the amount of the solar radiation received by earth's surface. The data or information obtained from the study of a particular site not only useful for the site but also forms a basis for estimating the global solar radiation for the wider world. So, the extraction of global solar radiation data requires the knowledge of the radiation data of various sites and for that proper worldwide marketing, the designers and manufacturers of solar equipment will be needed to

know the average GSR available in different and specific regions [3]. Since the GSR depends upon various parameters, so for a particular given sites, a proper solar radiation model can be useful for the study of global solar radiation. The availability of a solar radiation model, for the region, is very useful in estimating the amount of power that could be generated from a particular solar energy system [2]. For the application of solar energy in the context of Nepal, it is compulsory to develop data base in order to use it in active and passive energy form which could be a giant step for development of many sectors like communication, tourism, education, industry, community health and scientific agriculture. One of the practical possibilities of renewable energy for the electrification of rural area is photovoltaic [26].

The genuine and reliable information regarding the solar radiation for the particular site can be applied in various fields like hydrology, modern agriculture, solar active energy, solar passive energy, water storage reservoir, irrigation system and climate change. Further, specific understanding on GSR is

required in order to design solar energy system ([26]. Although we are aware of the importance of solar irradiance data, very few number of measuring equipment are available and due to lack of regular maintenance and calibrations of sensors, most of the stations have missing data [4, 5]. In addition, for the developing countries like Nepal, due to the cost and need of regular maintenance, calibrations of measuring equipment, solar radiations measurements are not accessible [6]. So, mostly we have to rely on several models/methods to estimate the solar radiation based on the easily available meteorological parameters.

The geographical location of Nepal is in favorable latitude and receives sufficient and adequate amount of solar radiation throughout the country. From the various research works, the variation of average global solar radiation varies about 3.6- 6.2 kWh/m²/day and sun shines 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 [7].

Several types of empirical models can be used to estimate the daily average solar radiation as a function of readily measured climatic data. On the basis of different models many research paper have been published for the determination of monthly averaged global solar radiation and some of regression coefficients/constants obtained from these models are globally applicable, while others are place dependent [5]. Several studied model shown that the best performing models are those where sunshine duration are used and those utilize cloudiness and temperature are secondary model on basis of performance [8,9].

The prime focus of this investigation was to validate the performance of six temperatures and sunshine duration based empirical models.

Nomenclature:	
H _g	monthly average daily global solar radiation on the horizontal surface of selected location (MJm ⁻² day ⁻¹)
H _o	monthly average daily extraterrestrial

	global solar radiation for the selected location (MJm ⁻² day ⁻¹)
T _{max}	monthly average daily maximum temperature (°C)
T _{min}	monthly average daily minimum temperature (°C)
s	monthly average daily hours of bright sunshine (h)
S	monthly average day length (h)
I _{sc}	solar constant (= 1367 Wm ⁻²)
n	number of days starting from first January
z	altitude of site (m)
RMSE	root- mean square error (MJ/m ² / day)
MBE	mean bias error (MJ/m ² / day)
MPE	mean percentage error
MABE	mean absolute bias error (MJ/m ² / day)
MAPE	mean absolute percentage error
SD	standard deviation (MJ/m ² / day)
GSR	Global solar radiation
a-d	regression coefficients
Greek letters	
∂	solar declination angle (deg)
ω	mean sunshine hour angle for the given month (deg)
φ	latitude of the site (deg)

Description of sites and approach of data analysis

Due to the geographical location of Nepal in world map, it receives moderate solar radiation. In order to get reliable and better analytic performance of six empirical models of study sites of different geographical locations are introduced. Variation of altitude for the three regions namely Midwester and Central which contains three selected sites ranges from 150 m (Nepalgunj) to 2347 m (Jumla) from mean sea level and this study is focused on these sites. The geographical location of selected site is specified in table 1.

Table 1: Geographical locations of the studied sites.

Region	Site	Latitude (°N)	Longitude (°E)	Elevation (m)	Year
Mid-western	Jumla	29.27	82.19	2347	2011
Mid-western	Nepalgunj	28.05	81.61	165	2014
Central	Kathmandu	27.69	85.35	1338	2011

Selected models for the determination of GSR

Firstly Angstrom [10] and Prescott [11] formulated the relation for the determination of global solar radiation and various models based on the commonly available meteorological parameter are employed in the past for the same reason. In our study six different empirical models are applied in order to study the GSR for the study sites. Out of

these six empirical models two are based on the temperature and other four models are based on the sunshine hour as input parameter.

3.1. Estimation of extraterrestrial solar radiation (H_o): The monthly average daily extraterrestrial radiation on a horizontal surface of the studied location can be computed by using following relation [12]

$$H_o = \frac{24}{\pi} I_{sc} [1 + 0.033 \cos \frac{360n}{365}] [\cos \phi \cos \delta \sin \omega + \frac{\pi}{180} \omega \sin \phi \sin \delta] \dots\dots\dots (1)$$

Where I_{sc} is solar constant (= 1367 Wm⁻²)

The solar declination angle (δ) and the mean sunshine hour (ω) can be enumerated by using the equations (2) and (3) respectively [1, 12]

$$\delta = 23.45 \sin \left[\frac{360(284 + n)}{365} \right] \dots\dots\dots (2)$$

Where n is number of days starting from first January

$$\omega = \cos^{-1} (-\tan \phi \tan \delta) \dots\dots\dots (3)$$

φ is latitude of the site

The maximum feasible sunshine length for a given month can be obtained by employing the given equation [1, 12].

$$S = \frac{2}{15} \omega \dots\dots\dots (4)$$

Table 2: List of models used for the determination of global solar radiation.

Model	Symbol	Parameter required	Relation
Hargeaves and Samani [13]	M1	Ho, Tmax, Tmin	$\frac{H_g}{H_o} = a (T_{max} - T_{min})^{0.5}$
Annandale et al. [14]	M2	Ho, Tmax, Tmin, Z	$\frac{H_g}{H_o} = [a (1 + 2.7 \times 10^{-5} Z) (T_{max} - T_{min})^{0.5}]$
Ampratwum and Dorvlo model [15]	M3	Ho, s,S	$\frac{H_g}{H_o} = a + b \log \left(\frac{s}{S} \right)$
Newland model [16]	M4	Ho, s,S	$\frac{H_g}{H_o} = a + b \left(\frac{s}{S} \right) + c \log \left(\frac{s}{S} \right)$
Akinoglu and Ecevit model [17]	M5	Ho, s,S	$\frac{H_g}{H_o} = a + b \left(\frac{s}{S} \right) + c \left(\frac{s}{S} \right)^2$
Samuel model [18]	M6	Ho, s,S	$\frac{H_g}{H_o} = a + b \left(\frac{s}{S} \right) + c \left(\frac{s}{S} \right)^2 + d \left(\frac{s}{S} \right)^3$

Methodology, Comparison techniques of used model and their validation

The value of global solar radiation on the horizontal site of the studied location was measured by CMP6 pyranometer and estimated value of GSR obtained from the implementation of models M1 to M6 for three different sites were compared with the ground

measured data. In order to validate the performance of individual used model various statistical indicator were used. The statistical parameter includes; mean percentage error (MPE), mean absolute percentage error (MAPE), root mean square error (RMSE), mean absolute bias error (MABE), mean bias error (MBE), standard deviation (SD) and coefficient of

determination (R^2). To compare solar radiation models performance, these statistical tests are generally implemented and provide reasonable norms for the validation of model [19,20] MPE, MAPE, MABE, MBE, RMSE, SD, R^2 and r are interpreted as below [1,2,13,20]

$$MPE = \frac{1}{N} \sum_{i=1}^N \left(\frac{H_c - H_m}{H_m} \right) \times 100 \dots\dots\dots (5)$$

$$MAPE = \frac{1}{N} \sum_{i=1}^N \left| \frac{H_c - H_m}{H_m} \right| \times 100\% \dots\dots\dots (6)$$

$$MABE = \frac{1}{N} \sum_{i=1}^N |H_c - H_m| \text{ MJ/m}^2/\text{day} \dots\dots\dots (7)$$

$$MBE = \frac{1}{N} \sum_{i=1}^N (H_c - H_m) \text{ MJ/m}^2/\text{day} \dots\dots\dots (8)$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (H_c - H_m)^2 \right]^{\frac{1}{2}} \text{ MJ/m}^2/\text{day} \dots\dots (9)$$

$$SD = \sqrt{\frac{\sum_{i=1}^N (H_i - \bar{H})^2}{N}} \text{ MJ/m}^2/\text{day} \dots\dots\dots (10)$$

$$R^2 = \frac{\left[\sum_{i=1}^N (H_c - H_{c,avg})(H_m - H_{m,avg}) \right]^2}{\sum_{i=1}^N (H_c - H_{c,avg})^2 \left(\sum_{i=1}^N H_m - H_{m,avg} \right)^2} \dots\dots\dots (11)$$

Where H_m is the measured value, H_c is the calculated value of solar radiation and n is the number of comparisons, $H_{m,avg}$ is average of measured value of solar radiation, $H_{c,avg}$ is the average of calculated value of solar radiation, \bar{H} is mean value of radiation, The units of radiation are $\text{MJ/m}^2/\text{day}$.

The statistical result of various single-multiple parameters models used in the study is mentioned in the table 3.

Table 3: Statistical indicators for empirical models employed in the research for three different sites of Nepal.

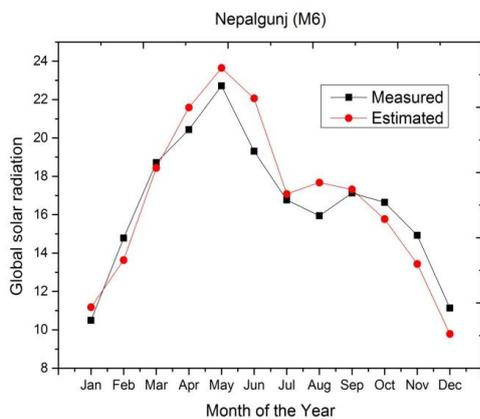
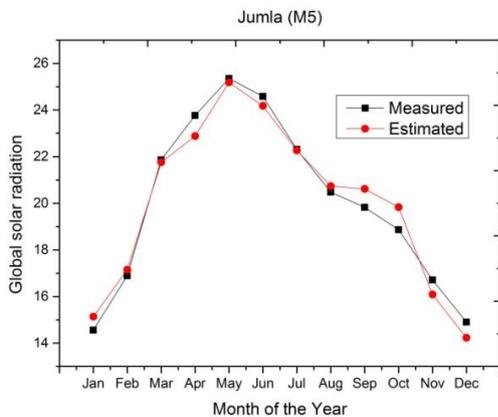
Location/ Model	MPE (%)	MAPE (%)	MBE ($\text{MJ/m}^2/\text{day}$)	MABE ($\text{MJ/m}^2/\text{day}$)	RMSE ($\text{MJ/m}^2/\text{day}$)	SD ($\text{MJ/m}^2/\text{day}$)	R^2
Jumla							
M1	0.95	4.34	-0.25	0.89	0.32	3.43	0.91
M2	0.95	4.34	0.24	0.89	0.32	3.43	0.91
M3	0.10	2.73	0.01	0.50	0.18	3.51	0.97
M4	0.15	2.91	-0.06	0.56	0.17	3.36	0.97
M5	0.06	2.56	-0.01	0.48	0.16	3.44	0.97
M6	0.97	2.73	-0.21	0.53	0.15	3.43	0.98
Nepalgunj							
M1	0.30	9.11	0.14	1.57	0.54	4.67	0.89
M2	0.30	9.11	0.14	1.57	0.54	4.67	0.89
M3	-0.63	6.59	0.21	1.04	0.37	4.08	0.92
M4	-0.63	6.68	0.22	1.06	0.37	4.13	0.93
M5	-0.63	6.69	0.22	1.06	0.37	4.13	0.93
M6	-0.63	6.74	0.22	1.07	0.23	4.13	0.96
Kathmandu							
M1	-3.35	11.44	0.38	1.54	0.54	2.75	0.59
M2	-3.35	11.44	0.38	1.54	0.54	2.75	0.59
M3	-0.63	6.92	0.12	0.97	0.34	3.06	0.86
M4	-0.64	6.66	0.11	0.93	0.33	2.99	0.86
M5	-0.62	6.67	0.11	0.94	0.33	3.02	0.86
M6	-0.58	6.17	0.12	0.90	0.26	3.10	0.96

RESULTS AND DISCUSSION

Easily available meteorological parameters based six on empirical models are used in this study for the estimation of global solar radiation at three different sites of Nepal. The monthly averaged daily global solar radiation estimated by employing above models three studied sites were compared with corresponding value of measured radiation. To analyze the soundness of used models we perform diverse statistical test. The statistical indices employed in all applied models are MPE, MAPE, MBE, MABE, RMSE, SD and R². The outcomes of these statistical indicators are mentioned in table 3. Also, empirical coefficients obtained by data analysis regression technique for all implemented models are condensed in table 4.

Table 4: Empirical coefficients for the selected model.

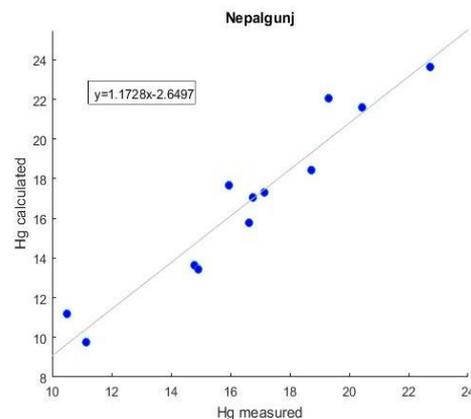
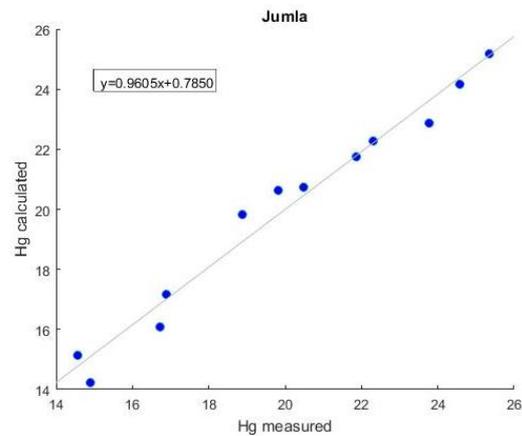
Location	a	b	c	d
Jumla				
M1	0.16			
M2	0.15			
M3	0.73	0.33		
M4	0.50	0.25	0.03	



M5	0.45	0.22	0.11	
M6	0.27	1.34	2.10	1.34
Nepalgunj				
M1	0.14			
M2	0.14			
M3	0.63	0.52		
M4	0.35	0.31		
M5	0.27	0.43	0.03	
M6	0.14	2.62	3.82	2.12
Kathmandu				
M1	0.13			
M2	0.13			
M3	0.68	0.65		
M4	0.38	0.38	0.30	
M5	0.04	1.13	0.50	
M6	0.42	1.21	3.02	5.15

Study area and selected models

The sunshine hour based model perform well in estimating GSR (Table 3) for the studied sites. The best performance of model for the given site is represented in fig 1.



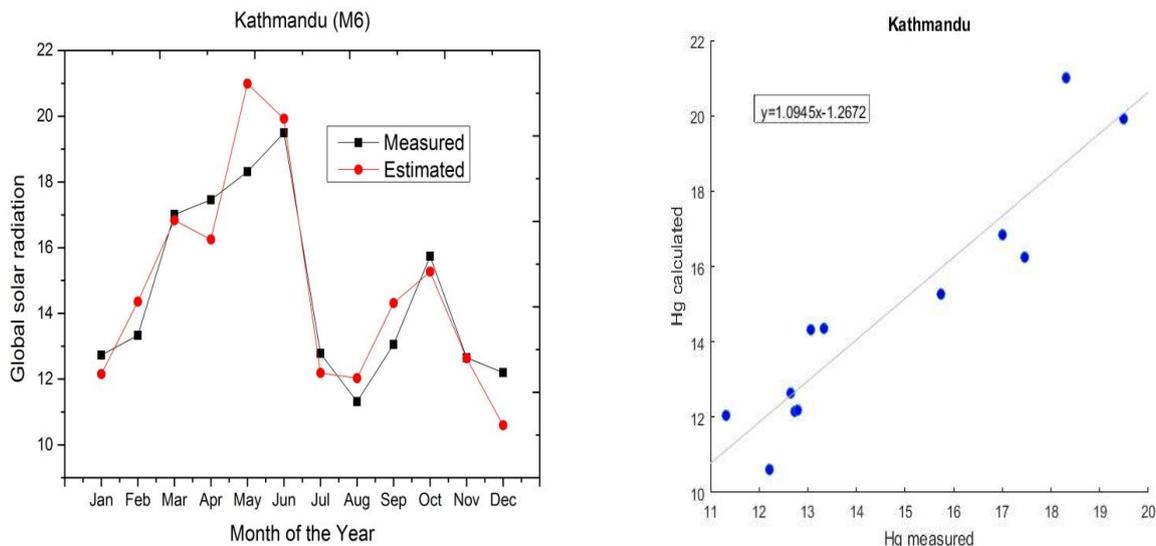


Fig. 1: Graph showing the relation between measured and estimated value of GSR (MJ/m²/ day) and scatter plot for the selected model for the given location.

In the study for the determination of global solar radiation, we have taken various single-multiple meteorological parameter models. Among those model, Annandale et al. (M2) is the multiple parameter model based on the model M1 in addition with the site altitude and rest of the models M1, M3-M6 are parameterized by single meteorological parameter temperature (T) and sunshine duration (s) respectively. From the statistical indicators (table 3) it has been found that Samuel model performs best among the used models indicating least value of RMSE and highest value of coefficient of determination.

The duration of radiation and intensity also play the vital role for the radiation received by the particular location. Above graph shows the value of global solar radiation received is maximum in the month of April and May it is mainly due to less cloud, slow wind, less rainfall and less solar zenith angle. However, the normal trend deviates for the months of June, July and August for all the studied sites due to the fact that they are rainy reasons for the country and maximum rainfall of the year occurs in these months. In the summer or monsoon season the average rainfall is about 70 to 90 percent of whole year and remaining month's remains almost dry [22]. In rainy season sky over the particular place is covered by cloud and this reduces the solar radiation reaching to the ground surface.

The meteorological factors such as rainfall, sunshine duration and temperature not only effect the global solar radiation but there are many other factors which effect on it. Astronomical factors

such as solar declination angle and hour angle varies over the year and so the amount of radiation. Geometrical factor such as solar zenith angle also effect the radiation received by the particular location. In addition to that, physical factors such as scattering of air molecules, water vapor content, scattering of dust, cold wave and location level atmospheric pollution has effect on radiation acquired by particular location.

CONCLUSION

The validation of different models is evaluated on the basis of various statistical parameters such as; MPE, MAPE, MABE, MBE, RMSE, SD and R². Based on the statistical interpretation, the obtained result reveals that sunshine duration related Samuel model shows better correlation with the measured result for the studied sites. In this study, the range of monthly averaged daily values of minimum and maximum global solar radiation is 14.56 - 25.35, 10.49 -22.71, 11.31 - 19.49MJ/m²/day respectively for jumla, Nepalgunj and Kathmandu.

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