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# A comparative study of monthly mean daily clear sky radiation over India

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**Abstract**
An attempt has been made to analyze the three years measured data of different Indian cities and to develop a new set of equations to estimate the monthly mean daily clear sky radiation over India. The statistical analysis has been used for present study. The comparison of present estimates has been made with various earlier proposed models. The root mean square error (RMSE) and mean bias error (MBE) have also been computed to test the accuracy of the proposed equations. The percentage of MBE with new constant for all stations under consideration is varying from 0.22 to 2.09 % while RMSE is varies from 2.22 to 10.37%. It is found that in comparison to other models, the results with new proposed equations estimates better for the climate of India.


**Keywords:** Atmospheric transmittance, Clear sky radiation, Solar radiation, Sunshine hour.

## 1. Introduction

The total solar radiation reaching the earth's surface through atmosphere can be classified into two components, beam radiation and diffuse radiation. The total radiation is sometimes referred as global radiation. Beam radiation is the solar radiation propagating along the line joining the receiving surface and the sun. It is also referred to as direct radiation. Diffuse radiation is the solar radiation scattered by aerosols, dust and molecules and does not have any unique direction. When the amount of diffuse radiation reaching the earth surface is less than or equal to 25% of global radiation, the sky is termed as clear sky.

In order to predict the insolation for a given location, it is useful to define a standard "clear sky" and calculate the radiation that would be received on a horizontal surface under no-cloud conditions. Good prediction of the clear sky solar radiation for a given location requires, in principle, a long term average meteorological data, which are still scarce for many locations around the world. Therefore, it is not always possible to predict the value of clear sky solar radiation with a reasonable accuracy and hence a continuous study is going on for the improvement of theoretical models.

For estimating the clear sky beam radiation ($G_{cb}$) on the surface of a given location, Hottle [1] presented a method for standard atmosphere using a set of six equations for four different types of climate taking into account of zenith angle ($\theta_z$) and altitude (A). Liu and Jordan [2] developed an empirical relationship between transmission coefficients for beam radiation ($\tau_b$) and diffuse radiation ($\tau_d$) for clear days. The clear sky diffuse radiation ($G_{cd}$) estimated by Liu and Jordan, can be added to the $G_{cb}$, as predicted by Hottel [1], to obtain the total clear sky solar radiation (Gc). Mean time several correlations and models

[3-10] have been developed by various investigators for estimating monthly mean clear sky radiation. Some of those are either empirical and therefore are site dependent or semi-empirical of a more general nature. In order to improve the accuracy of model, some investigators also incorporated various parameters such as zenith angle and altitude. However, these models suffers with varying degrees of complications, may be because of less number of availability of measuring data, and hence could not show much accuracy in predicting the results.
Our aim for presenting this paper is to analyze the long range measured clear sky solar radiation data of some Indian cities and made a comparative study considering recent and more relevant theoretical models [3-5]. We also propose a new set of constants for each location to estimate the monthly mean daily clear sky radiation.

## 2. Data collection

The solar radiation data of three years (2003-2005) comprising of monthly average daily diffuse radiation, global radiation and bright sunshine hours for four Indian stations, viz. Jodhpur ($26.30^0$N & $73.03^0$E), Calcutta ($22.65^0$N, & $88.35^0$E), Bombay($19.12^0$N &$72.85^0$E) and Pune ($18.53^0$N & $73.91^0$E) have been collected from India Meteorology Department (IMD) Poona, India. Latest MATLAB software with proper computer programming was used for the present analysis. The monthly average daily extraterrestrial radiation ( $G_{on}$ ) and the maximum possible monthly average daily sunshine hours ($S_0$) are obtained using standard method [10]. The developed correlations are employed to calculate the monthly mean clear sky radiation for the four considered locations and then compared it with the measured as well as estimated data of Hourwitz [3], Kasten-czeplak [4] and Toğrul [5] correlations.

## 3. Mathematical models

*3.1 Hourwitz correlation*

Hourwitz correlation [3] has been developed and reported in literatures that calculate the clear sky solar radiation based on astronomical parameters i.e. Solar zenith angle $\theta_z$ and given as;

$$G_c = 1098\left[\cos\theta_z \exp\left(\frac{-0.057}{\cos\theta_z}\right)\right] \tag{1}$$

*3.2 Kasten –Czeplac model*

Kasten [4] correlation presented the clear sky global solar radiation in the following linear form

$$G_c = 910\cos\theta_z - 30 \tag{2}$$

*3.3 Toğrul model*

Toğrul et al. [5] have developed the following exponential correlations for the ratio of daily global solar radiation (G) to clear sky global solar radiation as a function of average sunshine duration ($\overline{S}$) for six cities in Turkey.

$$G = 0.596\exp^{0.5821\left(\frac{\bar{s}}{s_o}\right)} Gc \tag{3}$$

*3.4 Present correlations*

The analysis of three years data from January 2003 to December 2005 of above selected locations in India results the following first , second and third order equations;

$$\frac{\overline{G}}{G_c} = 0.4954 + 0.5939\left(\frac{\bar{s}}{s_o}\right) \tag{4}$$

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$$\frac{\overline{G}}{\overline{G_c}} = 0.4874 + 0.6147\left(\frac{\overline{s}}{\overline{s_o}}\right) - 0.0179\left(\frac{\overline{s}}{\overline{s_o}}\right)^2 \tag{5}$$

$$\frac{\overline{G}}{\overline{G_c}} = 0.8846 - 1.5236\left(\frac{\overline{s}}{\overline{s_o}}\right) + 3.6958\left(\frac{\overline{s}}{\overline{s_o}}\right)^2 - 2.0927\left(\frac{\overline{s}}{\overline{s_o}}\right)^3 \tag{6}$$

## 4. Statistical tests

The degree of accuracy of each considered correlation to fit the measured data of $\frac{\overline{G}}{\overline{G_c}}$ is evaluated by two statistical tests, root mean square error (RMSE) and mean bias error (MBE).

*4.1 Root mean square error*

The RMSE is defined as;

$$\%\,\mathrm{RMSE} = \frac{100}{\mathrm{G_{cm}}}\left\{\frac{1}{N}\sum\left(G_{pre} - G_{obs}\right)^2\right\}^{1/2} \tag{7}$$

where $G_{pre}$ is predicted value, $G_{obs}$ is observed value, N is total number of observations and $\mathrm{G_{cm}}$ is mean of N measured values in clear sky condition .The RMSE is always positive and a zero value is ideal. This test provides information on the short term performance of the models by allowing a term –by –term comparison of actual deviation between the calculated value and the measured value.

*4.2 Mean bias error*

The MBE is defined as:

$$\%MBE = \frac{100}{\mathrm{G_{cm}}}\left[\sum\left(G_{pre} - G_{obs}\right)\right]/\,N \tag{8}$$

This test provides information on the long term performance. A low MBE is desirable. Ideally a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated and negative underestimate.

## 5. Results and discussions

In the present study the monthly mean daily clear sky measured data of global radiation and sun-shine duration for Jodhpur, Calcutta, Bombay and Pune are analyzed using least square regression analysis. The present estimated values of the monthly mean clear sky solar fraction using Eqs. (4) to (6) are summarized in Table 1.

These calculated values for considered locations are well compared with the estimation of Hourwitz [3], Kasten and Czeplak [4] and Toğrul et al. [5] along with measured data and shown through Figures 1 to 4. On comparisons, we found similar types of variation for all the reported results which showing minimum values during June to August, the cloudiest season in India. Further, Kasten and Czeplak and Toğrul et al predict in general lower value than others particularly for Pune station having lowest latitude. Our all present first, second and third order correlation shows a very good agreement with experimental data, however the second order ( Eq. 5) is found better one.

For looking the accuracy of proposed correlations, percentage of RMSE and MBE are also calculated and shown in Table 2.

These percentage values are very low indicating fairly good agreement with measured data. The maximum variation of estimation does not exceed 10 percent over entire year except a slight increase of RMSE for Bombay. On looking the overall comparison through all Figures 1 to 4 and data reported in Table 2, the order of equation hardly makes any difference in predicting results for any season; however the close analysis recommends the second order equation to obtain high degree of accuracy for better estimations of monthly mean daily clear sky radiation for Indian locations.

Table1. The present ($G'/G_c$) estimated data using first, second and third order correlations for Jodhpur, Calcutta, Bombay and Pune

| Station | Jodhpur | | | Calcutta | | | Bombay | | | Pune | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | Eq.(4 | Eq.(5) | Eq.(6) | Eq.(4) | Eq.(5) | Eq.(6) | Eq.(4) | Eq.(5) | Eq.(6) | Eq.(4) | Eq.(5) | Eq.(6) |
| January | 0.9397 | 0.9392 | 0.9368 | 0.7971 | 0.797 | 0.7921 | 0.9428 | 0.9422 | 0.9411 | 0.9463 | 0.9458 | 0.9439 |
| February | 0.9664 | 0.9588 | 0.9558 | 0.866 | 0.8659 | 0.8666 | 0.9993 | 0.998 | 0.9749 | 1.0051 | 1.0037 | 0.9769 |
| March | 0.9416 | 0.9406 | 0.9107 | 0.846 | 0.8461 | 0.8448 | 0.9615 | 0.9607 | 0.9549 | 0.9682 | 0.9674 | 0.9594 |
| April | 0.9403 | 0.9395 | 0.9111 | 0.866 | 0.866 | 0.8667 | 0.9447 | 0.9441 | 0.942 | 0.9563 | 0.9556 | 0.9514 |
| May | 0.9302 | 0.931 | 0.9001 | 0.8639 | 0.8639 | 0.8644 | 0.9428 | 0.9423 | 0.9412 | 0.9631 | 0.9623 | 0.956 |
| June | 0.8635 | 0.8639 | 0.8537 | 0.7061 | 0.7052 | 0.7169 | 0.7733 | 0.7731 | 0.7684 | 0.7853 | 0.7852 | 0.78 |
| July | 0.8096 | 0.8052 | 0.7859 | 0.6915 | 0.6904 | 0.7099 | 0.6519 | 0.6501 | 0.7014 | 0.6814 | 0.6802 | 0.7069 |
| August | 0.8269 | 0.8239 | 0.8015 | 0.698 | 0.6970 | 0.7128 | 0.6765 | 0.6752 | 0.7048 | 0.6953 | 0.6943 | 0.7115 |
| September | 0.8982 | 0.9006 | 0.9054 | 0.7049 | 0.704 | 0.7162 | 0.7294 | 0.7289 | 0.7314 | 0.7679 | 0.7677 | 0.7633 |
| October | 0.9746 | 0.9637 | 0.9952 | 0.7853 | 0.7852 | 0.7801 | 0.9133 | 0.9131 | 0.9152 | 0.9004 | 0.9002 | 0.9026 |
| November | 1.006 | 0.9778 | 0.9889 | 0.9734 | 0.9725 | 0.9625 | 0.9635 | 0.9628 | 0.9563 | 0.9631 | 0.9623 | 0.956 |
| December | 0.9577 | 0.9529 | 0.9695 | 0.853 | 0.853 | 0.8525 | 0.9361 | 0.9357 | 0.9357 | 0.967 | 0.9662 | 0.9586 |

Table 2. Percentage root mean square error (RMSE) and percentage mean bias error (MBE) for four stations

| Station | Proposed equation (4) | | Proposed equation (5) | | Proposed equation (6) | |
|---|---|---|---|---|---|---|
| | %MBE | %RMSE | %MBE | %RMSE | %MBE | %RMSE |
| Jodhpur | 1.45 | 2.32 | 1.39 | 2.3 | 0.85 | 2.3 |
| Calcutta | -1.39 | 7.16 | -1.44 | 7.16 | -1.05 | 7.02 |
| Bombay | 2.09 | 10.37 | 1.98 | 10.37 | 2.03 | 10.16 |
| Pune | -0.22 | 2.22 | -0.33 | 2.25 | -0.56 | 2.34 |

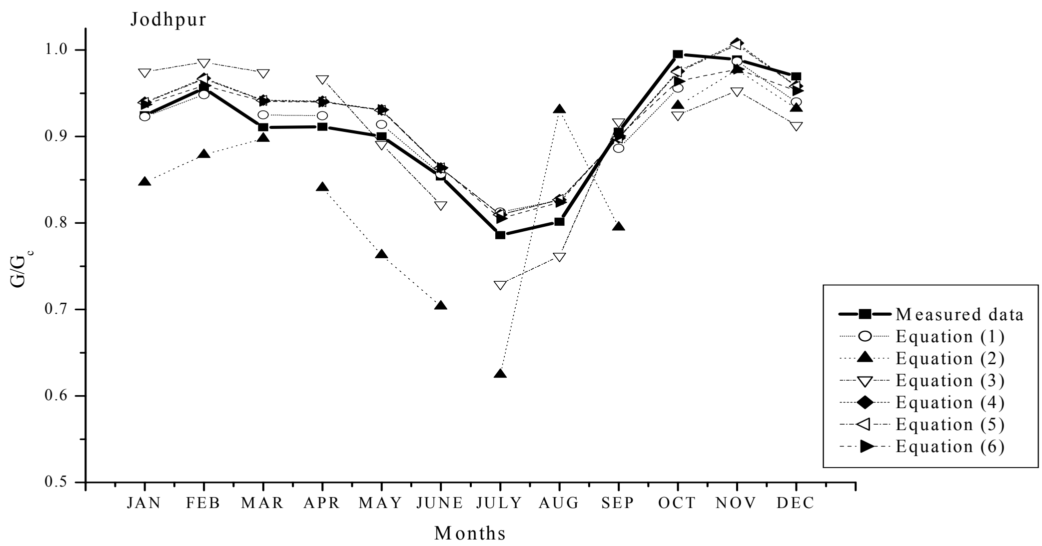


Figure 1. Comparison of the measured monthly mean daily clear sky solar radiation for Jodhpur with that computed by equations 1 to 6 respectively

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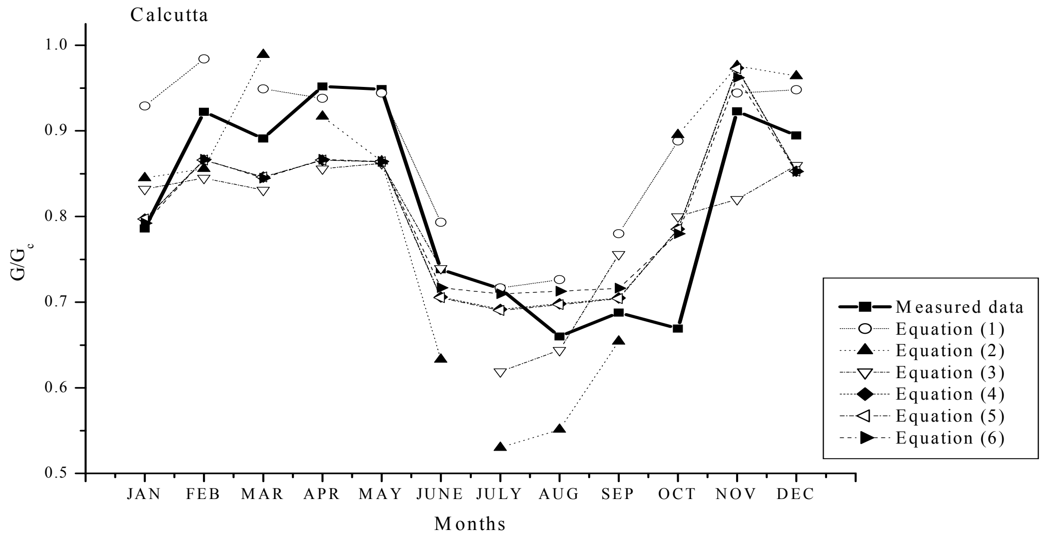


Figure 2. Comparison of the measured monthly mean daily clear sky solar radiation for Calcutta with that computed by equations 1 to 6 respectively

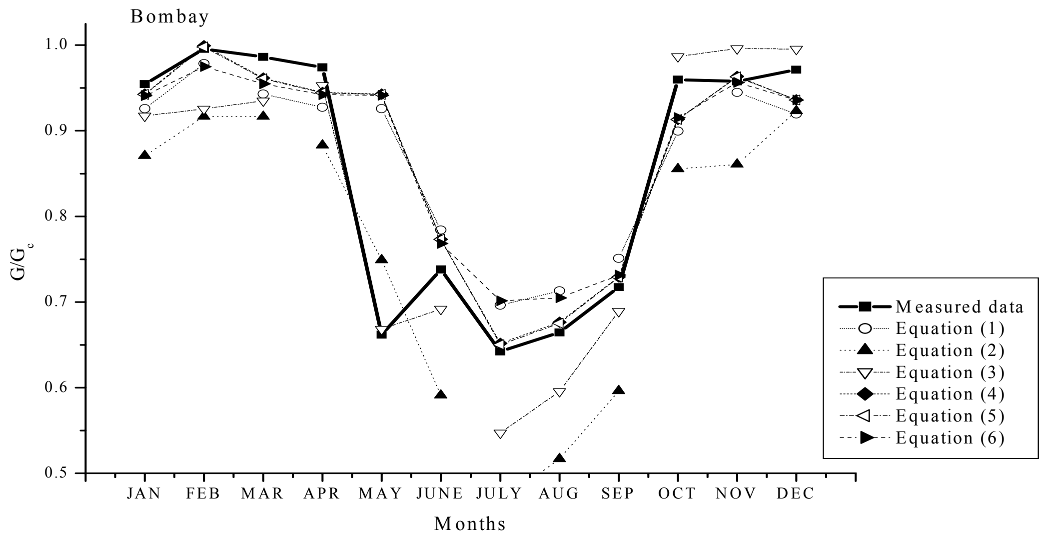


Figure 3. Comparison of the measured monthly mean daily clear sky solar radiation for Bombay with that computed by equations 1 to 6 respectively

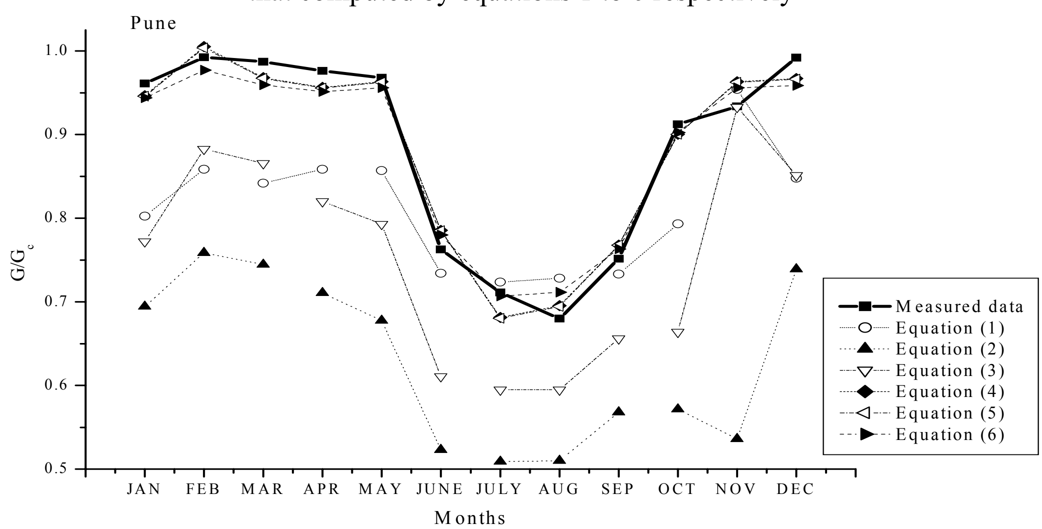


Figure 4. Comparison of the measured monthly mean daily clear sky solar radiation for Pune with that computed by equations 1 to 6 respectively

## 6. Conclusion

From the present analysis one can conclude that the linear equations particularly second order are more suitable than exponential equations to predict the monthly mean daily clear sky radiation on horizontal surface over Indian locations. The maximum percentage of MBE with new constants goes up to 2.09 % while maximum RMSE is 10.37 %.The equations (4-6) can further be tested for other locations as well.

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