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Modeling of Ultraviolet Radiation by Regression Analysis

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1. Introduction

In recent years interests of scientific community, general population and international organizations have shifted towards the field of environment safety. Solar UV radiation reaching the Earth's surface affects the biosphere. In view of the relationship between increased UV levels at the Earth's surface and depletion of ozone in the stratosphere, significant attention on the level of UV solar radiation on the Earth's surface has arisen. During the last two decades, there has been increasing interest and activity in the area of ultraviolet (UV) radiation research, evoked by stratospheric ozone depletion [Bais, A. F., and Lubin, D., (2007),]. All radiation from the sun travels in the form of electromagnetic waves. The types of solar radiation are characterized in terms of wavelengths. The shortest wavelength radiation (100–280 nm) is referred to as UV C radiation. Radiation at these wavelengths is almost entirely absorbed by atmospheric oxygen, nitrogen and ozone, preventing it from reaching the earth surface. Wavelengths between 280 and 315 nm comprise the UV-B portion of the spectrum. Ultraviolet-B radiation is absorbed mostly but not completely by atmospheric ozone. Wavelengths between 315 and 400 nm are referred to as UV-A radiation. Absorption of UV-A radiation by atmospheric ozone is comparatively small. Although the intensity of solar UV-B radiation is low, the energy per photon is high. Due to this higher energy level, UV-B radiation can have severe harmful impacts on human beings, on ecosystems, and on materials [Webb A.R., (1998)] [Adam M.E.N., and El Shazly S.M., (2007)].

Wavelengths shorter than those of light at the violet end of the visible spectrum are referred to as ultraviolet radiation. Ultraviolet (UV) radiation represents 3% to 5% of the total solar radiation that penetrates the earth's surface [Kane AB, Kumar V., (1999)].Therefore, at ground level, UV radiation represents about 5% of solar energy and the radiation spectrum is between 290 and 400 nm. [World Health Organization International Agency for Research on Cancer, (2005)]. Some researchers have employed the modified Angstrom type equations to correlate UV radiation with the corresponding sunshine duration in various locations. Jianhui et al.[Bai Jianhui, Wang Gengchen and Hu Fei,(2003)] developed an empirical formula for estimating UV radiation in overcast sky from sunshine hours and also found that the sunshine hours is a useful parameter to estimate UV radiation. Frederick et al. [Frederick J.K. and Snell H.E., (1990)] and Schafer [Schafer J., Saxena V.,Wenny B.,Barnard W. and Deluisi J.,(1996)] analyzed and found that change in the characteristics of cloud can lead to the variation of UVB reaching the ground. Using three years of data, Kerr and McElroy et al. [Kerr J. and McElroy C.T., (1993)] showed an increase in UV that agreed with the decrease in ozone level observed during the same time period.

2. Data and Methodology

Hourly Instantaneous values of UV radiation measured using UV Meter have been converted into hourly average daily values. UV radiations over Chennai for the period from August 2011 to July 2012 were recorded using UV meter. The model is UV light meter model: UV-340A. The instrument can measure low range of 1999 uw/cm^2 and high range of 19990 uw/cm^2 with accuracy of + or – 4%. Sunshine data were obtained from Regional Meteorological Department, Chennai.

2.1 Angstrom Regression Equation

The general equation for the ratio of the monthly-average daily radiation on a horizontal surface (U) to the monthly average daily extraterrestrial radiation on a horizontal surface (U_O) is dependent on sunshine duration given by Angstrom [Angstrom A., (1924)] to estimate the UV radiation on a horizontal surface.

$$\frac{U}{U_O} = a + b\frac{S}{S_O} \quad \textbf{(1)}$$

Where a and b are the regression coefficients obtained by fitting measured data. S is the monthly-average daily hours of bright sunshine (sunshine duration) and S_O is the monthly-average of the maximum possible daily hours of bright sunshine (i.e., day length). Coefficient "a" represents the overall atmospheric transmission for overcast sky condition i.e., when sunshine duration is zero. Coefficient "b" indicates the rate of increase of clearness index (U/U_O) with relative sunshine duration (ratio S/S_O).

Monthly mean daily maximum possible sunshine duration on a particular day can be calculated using the given equation [Cooper P.I., (1969)].

$$S_O = \frac{2}{15}\omega \quad (2)$$

Extraterrestrial radiation received on a horizontal surface during entire day is an important factor that affects solar radiation available at earth on a horizontal surface. Daily extraterrestrial radiation on a horizontal surface is calculated using the following equation [Firoz Ahmad, and Intikhab Ulfat, (2004)].

$$UV_O = \frac{24}{\pi} G_O \left[\cos\varphi\cos\delta\sin\omega + \frac{\pi}{180}\omega\sin\varphi\sin\delta\right] \quad (3)$$

$$\text{Where} G_O = G_{sc}\left(1 + 0.003\cos\frac{360n}{365}\right) \quad \textbf{(4)}$$

where UV_O is the daily extraterrestrial radiation on a horizontal surface on the nth day, G_O is the hourly extraterrestrial radiation, G_{sc} is the solar constant (=1,367 W/m^2), n is the day of the year (1 on January 1 st and 365 on December 31 st, February 29th has been ignored, ω is the sunrise hour angle on nth day, φ is the latitude of the area, δ is the solar declination on nth day. Solar declination is the angle made by the line joining the centre of the sun and the earth with its projection on the equatorial plane. It is zero at the autumnal and vernal equinoxes,23.45^0 at the summer solstice on June 21 and -23.45^0 at the winter solstice on December 21 in the northern hemisphere. Thus it has a range $23.45^0 \leq \delta \leq 23.45$, on nth day.

The values of sunrise hour angle, the solar declination and the maximum possible sunshine hours on a particular day can be computed from the following equations [Okundamiya M.S., and Nzeako A.N., (2010)]
According to Cooper,

$$\delta = 23.45 \sin\left[\frac{360(284+n)}{365}\right] \quad \textbf{(5)}$$

$$\omega = \cos^{-1}[-\tan\varphi\tan\delta] \quad \textbf{(6)}$$

2.2 Models Performance Tests

A Statistical Analysis was conducted in order to evaluate the performance of each single model. Four statistical instruments were used to quantify the performance of the models.

(i) Mean Bias Error (MBE)
It is derived as follows

$$MBE = \frac{1}{N}\sum_{i=1}^{N} P_{cal}^{i} - P_{obs}^{i} \quad \textbf{(7)}$$

N is the total number of observations, and P_{obs} and P_{cal} are the ith observed and measured values of p parameter. This test provides information on the long term performance. A low MBE is desired.

(ii) Root Mean Square Error (RMSE)
It is defined as:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(P_{cal}^{i} - P_{obs}^{i})\right]^{1/2} \quad \textbf{(8)}$$

The RMSE provides information on the short term performance of the correlation by allowing a term-by-term comparison of the deviation between the calculated and observed values. The smaller the values, better the model performance and RMSE is a non-systematic error.

(iii)Mean Absolute Percentage Error (MAPE)
It is defined as:

$$MAPE = \frac{100}{N}\sum_{i=1}^{N}\frac{P_{cal}^{i} - p_{obs}^{i}}{p_{obs}^{i}} \quad \textbf{(9)}$$

MAPE is an overall measure of forecast accuracy computed from the absolute differences between a series of forecasts and actual data observed, each absolute difference is expressed as a percentage of each actual data, then summed and averaged [Legates D.R., and McCabe G.J., (1999)].

(iv) Mean Absolute Error (MAE)
It is defined as

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|P_{cal}^{i} - P_{obs}^{i}\right| \quad \textbf{(10)}$$

It gives the absolute value of bias error and is a measure of the goodness of the correction.

3. Models

3.1 Model based on Relative sunshine duration

These models were developed using the data points of 334 and validated using data points of 31. From the observed values of UV radiation and the computed values of extraterrestrial radiation, the value U/U_O on a horizontal surface was obtained. From the results of performance test conducted on the models based on sunshine duration and relative sunshine duration [Nouby Adam M.EL.,(2012)]. Model used by sunshine duration had least error than relative sunshine duration. The models giving the regression equation (11 to13) were developed using least square method.

$$\frac{U}{U_O} = 0.0043\left(\frac{S}{S_O}\right) + 0.0193 \quad \textbf{(11)}$$

$$\frac{U}{U_O} = 0.0048\left(\frac{S}{S_O}\right)^2 - 0.0001\left(\frac{S}{S_O}\right) + 0.0199 \quad \textbf{(12)}$$

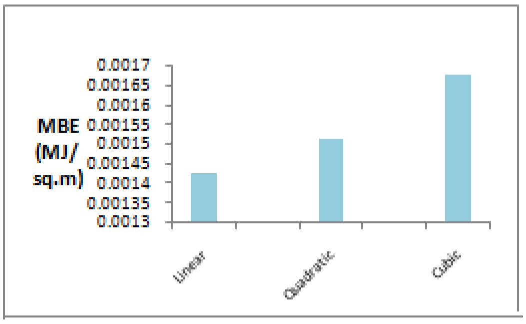
$$\frac{U}{U_O} = 0.006\left(\frac{S}{S_O}\right)^3 - 0.0035\left(\frac{S}{S_O}\right)^2 + 0.0029\,S + 0.0197 \quad \textbf{(13)}$$

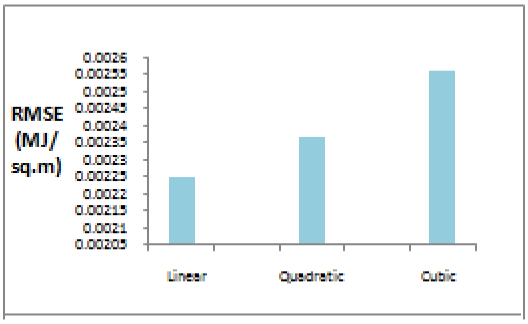
Table1 gives the performance of linear, quadratic and cubic regression models developed between relative sunshine duration and UV radiation

Table 1: Performance of models using U/U_O and S/S_O

Model	MBE (MJ/m^2)	RMSE (MJ/m^2)	MAPE (%)	MAP (MJ/m^2)
Linear	0.001429	0.002246	9.787170	0.001787
Quadratic	0.001514	0.002361	10.59613	0.001946
Cubic	0.001675	0.00256	11.45806	0.002093

From the table, it is observed that Linear equation has least values of error among the three models developed between relative sunshine duration and UV radiation. The results are also depicted in the figure 1.





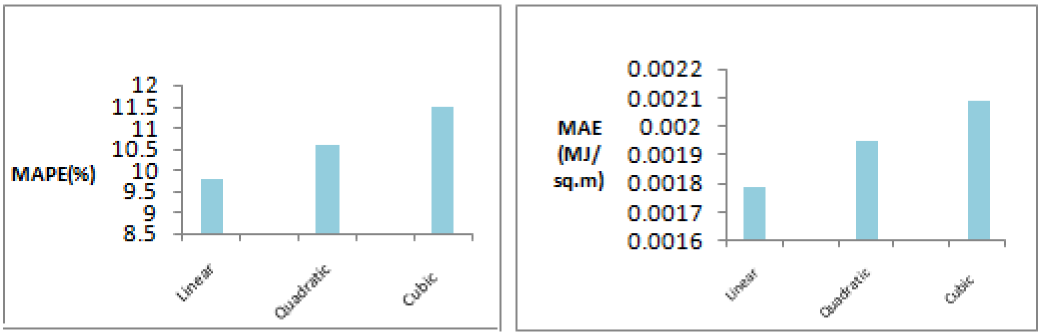


Figure 1: Performance evaluation of models based relative sunshine duration

3.2 Models based on Sunshine duration

These models were developed using the data points of 334 and validated using data points of 31. Linear, Quadratic and cubic models were developed using Sunshine duration and are given in the regression equation (14 to 16).

$$\frac{U}{U_O} = 1E - 05(S) + 0.0193 \quad (14)$$

$$\frac{U}{U_O} = -5E - 08(S)^2 + 3E - 05\,(S) + 0.0183 \quad (15)$$

$$\frac{U}{U_O} = -2E - 09S^3 + 7E - 07(S)^2 \text{-7E-05}(S) + 0.0213 \quad (16)$$

Results of performance evaluation tests conducted on the models based on sunshine duration are given in Table 2.The results are also depicted in the graph.2

Table 2 Performance of models using U/U_O and S

Model	*MBE (MJ/m^2)*	*RMSE (MJ/m^2)*	*MAPE (%)*	*MAP (MJ/m^2)*
Linear	3.95E-05	0.001846	8.265815	0.001563
Quadratic	-0.00086	0.002021	8.454835	0.001674
Cubic	0.001657	0.002543	11.38888	0.002044

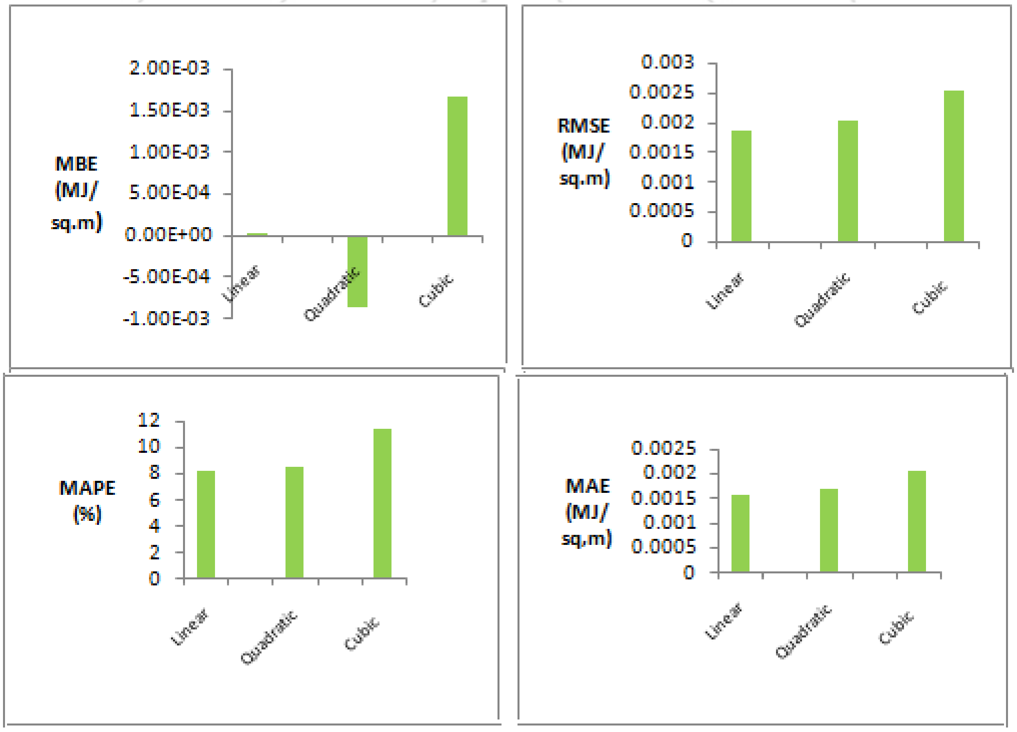


Figure 2: Performance evaluation of models based sunshine duration

4. Results and Conclusion

In this paper measured UV data for the period August 2011 to July 2012 were used and sunshine hours data for the same period were collected from RMD, Chennai. Regression models were developed using Relative sunshine hours and Sunshine duration with UV radiation data. When we compared sunshine duration regression model and relative sunshine hours regression model, sunshine hours regression model came out with less error. This was found out by employing some statistical parameters like MBE, RMSE and MAPE, MAP. The respective error values are 3.95E-05, 0.001846, 8.265815 and 0.001563.. All these values were in the acceptable range. Hence we recommend that our regression model relating UV radiation data and sunshine hours could be used to estimate the values of daily UV radiation.

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