Empirical Modelling for Solar Ultraviolet Irradiance and Illuminance by Means of Solar Zenith Angles in Lashio, Myanmar

Kyaw Thiha[1], Swe Swe Thant[2]

Abstract

In this paper, empirical models are developed with regression equations to predict the solar ultraviolet radiation (I_{uv}) based on measured sun position values for Lashio, in Northern Shan state, Myanmar. These measurements are taken daily in an equinox. The value of the mean bias error (*MBE*), mean square error (*RMSE*) and mean percentage error root (*MPE*) were determined for the equation. The values of the correlation coefficient (r) and coefficient of determination (R^2) were also determined for each equation. The equation with the highest values of r, R^2 and at least values of *RMSE*, *MBE* and *MPE* is given as $I_{uv} = 22.49\, e^{-0.0152\, \theta_z} - 6.321$ named as a natural exponent model where θ_z is solar zenith angle. The results obtained show a remarkable agreement between the measured and the predicted values using our proposed models. This paper also examines the relationship between solar ultraviolet irradiance and illuminance received on the ground surface for Lashio. The relationships between solar ultraviolet irradiance and illuminance were found to be a linear equation which was sufficient, i.e. no significant improvement was obtained using a quadratic equation.

Key words: Regression coefficient, zenith angle, site specific models, Lashio.

Introduction

Human exposure to solar ultraviolet radiation has important public health implications. Evidence of harm associated with overexposure to UV has been demonstrated in many studies. Skin cancer and malignant melanoma are among the most severe health effects, but a series of other health effects have been identified. The information presented forms a knowledge base for the prevention of adverse effects of UV exposure that is achievable with known and accessible interventions. UV prevention focuses on protecting the skin and other organs from UV radiation. On the other hand, a moderate degree of UV exposure is necessary for the production of Vitamin D which is essential for bone health. Additionally, evidence emerges that low Vitamin D levels are likely to be associated with other chronic diseases. Thus, public health policy on ultraviolet radiation needs to aim at preventing the disease burden associated both with excessive and with insufficient UV exposure.

The extraterrestrial solar radiation spectrum contains UVC (spectral range 100–280 nm), UVB (spectral range 280–315 nm), and UVA (spectral range 315–400 nm). At various altitudes and blocking of different bands of ultraviolet radiation, essentially all UVC is blocked by dioxygen (from 100-200 nm) or by ozone (200-280 nm) in the atmosphere. The ozone layer then blocks most UVB. Meanwhile, UVA is hardly affected by ozone and most of it reaches the ground. Erythema is sunburn, the reddening of the skin when it is exposed to too much UV radiation (UVA and UVB both contribute to erythema). In many cases, the UV radiance is multiplied with the erythemal action spectrum and integrated over the UVA and UVB wavelengths. The result is called erythemal UV radiation. The erythemal action spectrum has been defined by the International Lighting Commission (CIE).

---

[1] Dr, Demonstrator, Physics Department, Lashio University

[2] Dr, Assistant lecturer, Physics Department, Lashio University

The growing evidence of global depletion of stratospheric ozone has emphasized the importance of monitoring terrestrial ultraviolet (UV) radiation. Reductions in stratospheric ozone result in increased amounts of solar UV radiation reaching the earth's lower atmosphere and surface. UV radiation affects many chemical and biological processes and any increase in the radiation intensity is of concern, because of the potential adverse affects on the biosphere, on tropospheric air quality and on material such as wood and polymers. Inverse relation is already known between the ozone density in the atmosphere and the amount of UV radiation reaching the earth surface. From this point of view, the amount of UV radiation is highly affected by the ozone destroy pollutants such as freo refrigerants, spry, and atomic bomb test.

A correlation between the ultraviolet (UV) and the global solar radiation (G) over Egypt were carried out. Green *et al*. (1974) formulated a semi-empirical analytic approach for calculating the terrestrial direct, diffuse and global UV radiation in the 280–340 nm spectral range. Their formula includes the following parameters: wavelength, solar altitude, ozone thickness, aerosol thickness, ground albedo, ground altitude and cloudiness. Green *et al*. (1980) later developed an improved analytical characterization for the diffuse spectral global UV radiation. Frederick and Lubin (1988) developed a radiative transfer model to determine the spectral irradiance at each wavelength between 290 and 400 nm. The input to their model includes the following parameters: ozone field, atmospheric optical thickness, UV surface albedo, site location, day of the year and hour of day. An indication of the activity in this field is the recent publication of a comparison of 18 different radiative transfer models used for UV index calculations (Koepke *et al*., 1998). Webb and Steven (1986) used a much less rigorous approach, and developed empirical relationships between the daily integrated totals for UVB radiation as a function of those totals for global radiation on a monthly basis. The study of Kudish and Evsec (2000) has taken an approach similar to that of Webb and Steven (1986), but has utilized hourly radiation intensity values in order to develop empirical relationships between the hourly radiation intensity values for both UVB and UVA, as a function of the corresponding global radiation intensity values. The solar zenith angle (θ_z) influences the magnitude of the diffuse erythemal UV. The present work is devoted to develop a number of empirical site-specific models to estimate the global solar ultraviolet irradiance (both UVA and UVB) on horizontal surface empolying sun positon values for Lashio city, Myanmar and to select the most appropriate model for Lashio.

Material and Methods

Solar ultraviolet radiation can be obtained by predicting it using either a site-specific radiation model or a mechanistic prediction model. A site-specific model relies on empirical relationships of solar ultraviolet radiation with commonly recorded variables. Although a site-specific equation requires a data set with actual solar ultraviolet radiation data for determining appropriate coefficients, this approach is frequently simpler to compute and may be more accurate than complicated mechanistic models. These simple, site-specific equations, therefore, may be very useful to those interested in sites near to where these models are developed.

The intensity of the sun is highly dependent on the position of the sun in the sky relative to the observer on the Earth's surface. At higher zenith angles, the light goes through more atmosphere than when the sun is directly overhead. Thus all clear sky models require geometric inputs describing the solar zenith angle throughout the year.

The measurement of the ultraviolet component of solar radiation for March, 2014 (an equinox condition) are performed in Lashio University campus situated in Longitude 22°57' N and Latitude 97°44'W in the northern hemisphere. The general tool UV513AB digital UVAB Meter [Dimensions: 5.51 x 1.93 x 1.14 in. (140 x 49 x 29mm) Weight: 3.2 oz. (90g)] is employed to measure ultraviolet light in the range from 280 to 400 nanometers (UVAB). The illumination range of the meter allows us to conduct the most precise quantitative measurements of ultraviolet radiation for radiometry and laboratory requirements. Illuminance is measured using a lux meter (Model LT300 EXTECH instrument). Although the measuring method in it itself is accurate, lux readings are deceptive in regards to describing light sensitivity. Whereas a lux meter records the amount of visible light that hits, or illuminates, a given area (incident light).

Evaluation of the uncertainties associated with solar ultraviolet radiation measurements leads us to believe that the absolute accuracy of our data is ±3%. The contribution from the electronics to the above uncertainty is negligible. An important characteristic of correlation models is the standard deviation of the data from the regression fit. The standard deviations for these measurements steadily have from about 1.8 to 2.8. However, in all cases, the residuals that make up the standard deviation were not normally distributed, and this lends itself to some ambiguity in determining the best regression fit.

The performance of the models was evaluated on the basis of the following statistical error tests: the mean percentage error (*MPE*), root mean square error (*RMSE*), and mean bias error (*MBE*). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations. *MPE*, *MBE* and *RMSE* are defined as below: The mean percentage error is defined as

$$MPE(\%) = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{I_{i,c} - I_{i,m}}{I_{i,m}}\right)\times 100 \,. \qquad (1)$$

where $I_{i,m}$ is the i^{th} measured value, $I_{i,c}$ is the i^{th} calculated value of solar ultraviolet irradiance and N is the total number of observations. The *MPE* test gives long term performance of the examined regression equations. Positive values of *MPE* mean overestimation in the calculated values of the solar ultraviolet irradiance, while the negative values give underestimation. A low *MPE* is desirable. Because actual rather than absolute values of the forecast errors are used in the formula, positive and negative forecast errors can offset each other; as a result the formula can be used as a measure of the bias in the forecasts. A disadvantage of this measure is that it is undefined whenever a single actual value is zero. The root mean square error is defined as

$$RMSE(mWcm^{-2}) = \left[\frac{1}{N}\sum_{i=1}^{N}(I_{i,c} - I_{i,m})^2\right]^{1/2} . \qquad (2)$$

The *RMSE* is always positive, 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 the actual deviation between the calculated value and the measured value. However a few large errors in the sum can produce a significant increase in *RMSE*. The mean bias error is defined as

$$MBE(mWcm^{-2}) = \frac{1}{N}\sum_{i=1}^{N}(I_{i,c} - I_{i,m}) \,. \qquad (3)$$

This test provides information on the long-term performance. A low *MBE* is desired. Ideally a zero value of *MBE* should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation. The values of the correlation coefficient (*r*) and coefficient of determination (R^2) were also determined for correlation analysis of each regression equation.

These terms are defined by the:

$$r = \frac{\sum_{i=1}^{N}(I_{i,c} - \bar{I}_c)(I_{i,m} - \bar{I}_m)}{\left[\sum_{i=1}^{N}(I_{i,c} - \bar{I}_c)^2 \sum_{i=1}^{N}(I_{i,m} - \bar{I}_m)^2\right]^{1/2}}, \tag{4}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(I_{i,m} - I_{i,c})^2}{\sum_{i=1}^{N}(I_{i,m} - \bar{I}_m)}, \tag{5}$$

and $\bar{I}_c$ and $\bar{I}_m$ are, respectively, the average of the calculated and measured values.

Results and Discussion

Empirical models to estimate solar ultraviolet radiation are a suitable tool. The seven models listed were applied to the actual solar ultraviolet radiation data at Lashio. The calculated and measured valued of solar ultraviolet radiation on the clear days were compared, to find the best correlation that will fit the measured solar ultraviolet radiation. The empirical coefficients of the equations can be determined using available solar ultraviolet radiation data. The regression coefficient associated with meteorological data changes with latitude and atmospheric conditions. The results are as shown in Table.1.

The *RMSE* values, which are a measure of the accuracy of estimation, have been found to be the largest for linear model, as shown in Table.1 (in Figure. 1) and values of *RMSE* from most of the models are smaller than 0.9 which is good. It was observed that the lower the *RMSE,* the more accurate the equation used.

The *MBE* test gives long term performance of the examined regression equations. From Table 1, the *MBE* values obtained from the majority of proposed models are negative which shows that these models are under estimation in the calculated values. However, values of *MBE* from the Base 10 exponent model indicates an over estimation as shown in Figure.1. The *MPE* of all models are in the range of acceptable values between 5.218 % and 13.5 % as shown in Table.1.

Figure 2 summaries various regression analysis, obtained from the application of equations to the monthly mean value for the three variables on the study area. It is obvious that the correlation coefficient *r*, coefficient of determination R^2, *MBE* (mWcm^{-2}), *RMSE* (mWcm^{-2}) and *MPE* (%) vary from one variable to another variable. For instance, the correlation of coefficient of 1.056 for linear model exists between the solar ultraviolet irradiance data and zenith angles, also coefficient of determination of 0.688 implies 68.8% of solar ultraviolet irradiance data can be accounted using zenith angles. Similarly, the other proposed models are interpreted as the same way.

As may be seen from Figure 3, agreement between the values obtained from all models and the measured data are very good. Obtained results show that estimation of solar radiation using zenith angle data explained the highest portion of the solar ultraviolet radiation variance out of all the tested models. In general, sun position based models were less accurate in contrast to the meteorological based model. The sun position based models could be improved by adding other variables.

Table.1 Statistical test results of proposed models applied for Lashio.

No.	Models	Regression equations	*RMSE* *(mWcm^{-2})*	*MBE* *(mWcm^{-2})*	*MPE* *(%)*
1	Linear	$I_{uv} = -0.1215\theta_z + 10.22$	1.120	-0.283	6.431
2	Quadratic	$I_{uv} = 0.001287\ \theta_z^2 - 0.291\ \theta_z - 6.321$	0.906	-0.006	5.750
3	Natural exponent	$I_{uv} = 22.49\ e^{-0.0152\ \theta z} - 6.321$	0.909	-0.004	5.555
4	Natural Logarithm	$I_{uv} = -7.726\ Ln\ (0.01175\ \theta_z)$	0.914	-0.007	6.497
5	Base 10 Logarithm	$I_{uv} = -17.79\ Log\ (0.01175\ \theta_z)$	0.914	-0.007	6.498
6	Base 10 exponent	$I_{uv} = 24.89\ 10^{(-0.01607\ \theta z)}$	0.959	0.031	13.510
7	Inverse exponent	$I_{uv} = -\ 22.49\ [1 - e^{(-0.0152\ \theta z)}] + 16.16$	0.909	-0.013	5.218

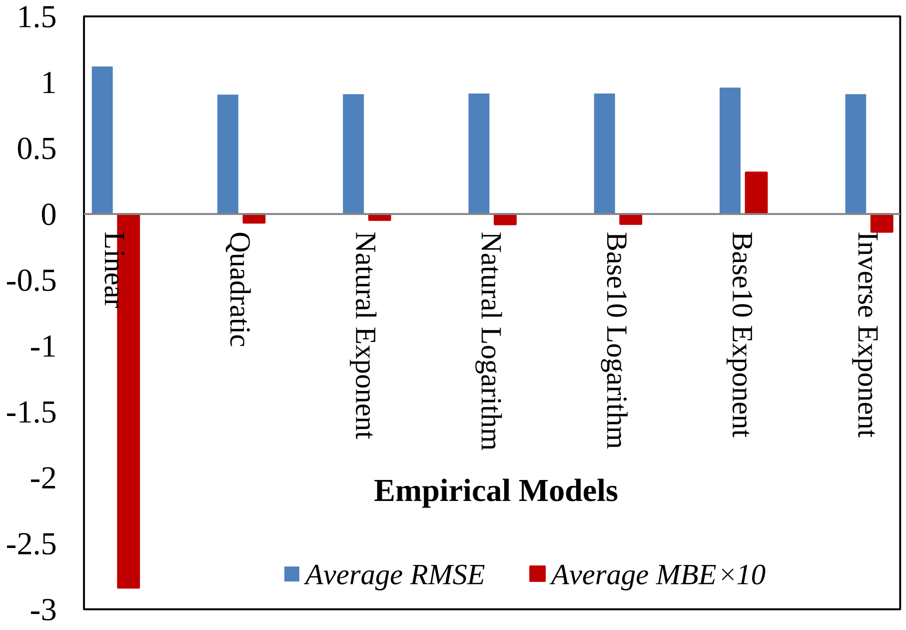

Fig. 1 Average *RMSE* and *MBE* in mWcm^{-2} as a statistical criterion for each proposed model

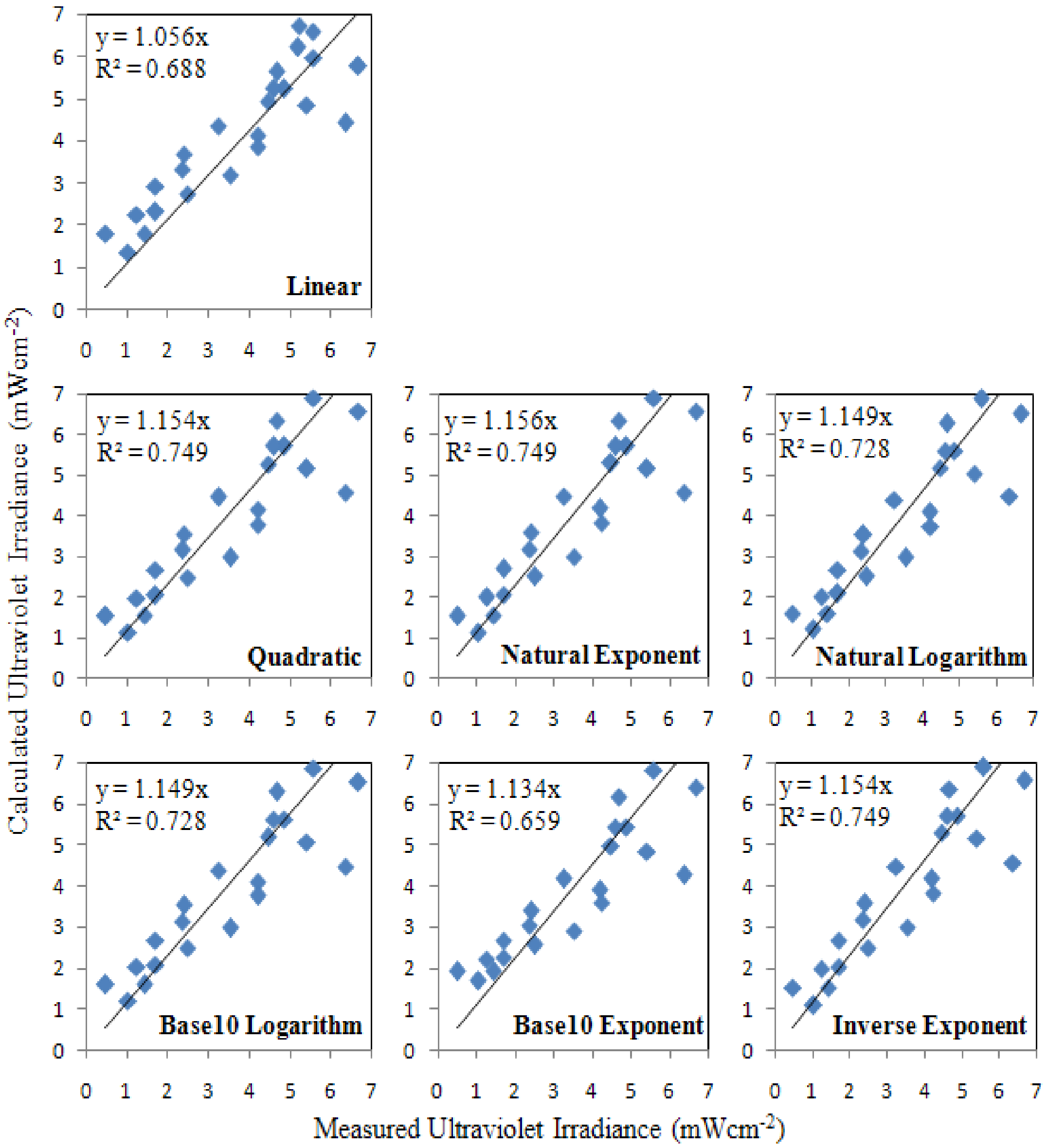

Fig. 2 The proposed models were validated by comparing calculated and measured solar radiation in Lashio.

The regression analysis shows that in the models based on data of zenith angles, the natural exponent model gives consistently a good estimate when applied to daily data. The natural exponent model had the best overall results for the R^2 and in general, it produced small residuals compared to the other models with overall *RMSE* of 0.909 mWcm^{-2}. The quadratic model performed better than the other model, considering the simplicity of the model and relative ease of deriving the coefficient compared to the other models, it has a finding root problem. Therefore, we did not choose as an excellent model.

The results demonstrated that most of the tested models used were able to adequately estimate solar ultraviolet radiation from daily zenith angles and/or elevation angles. Using meteorological variables and saturation deficit to estimate the solar ultraviolet radiation could get good results at most conditions. The new proposed models in this work to estimate solar ultraviolet radiation from more commonly and reliably measured meteorological data can be useful to provide the data which would otherwise be unavailable.

Many types of correlations were tried to find out the best fit between solar ultraviolet irradiance (I_{uv}) and illuminance (G) data. It was found that the data is going towards the best linear fit in the form:

$$I_{uv} = a\,G \pm b \tag{6}$$

where a and b are regression coefficients which depend on the weather parameters of the location. The data have been processed by a computer program and the obtained values for a and b were found to be 6.869 and +11.38 respectively. The obtained value for the correlation coefficient was $R^2 = 0.901$ and the standard deviation of the observed data was 2.633.

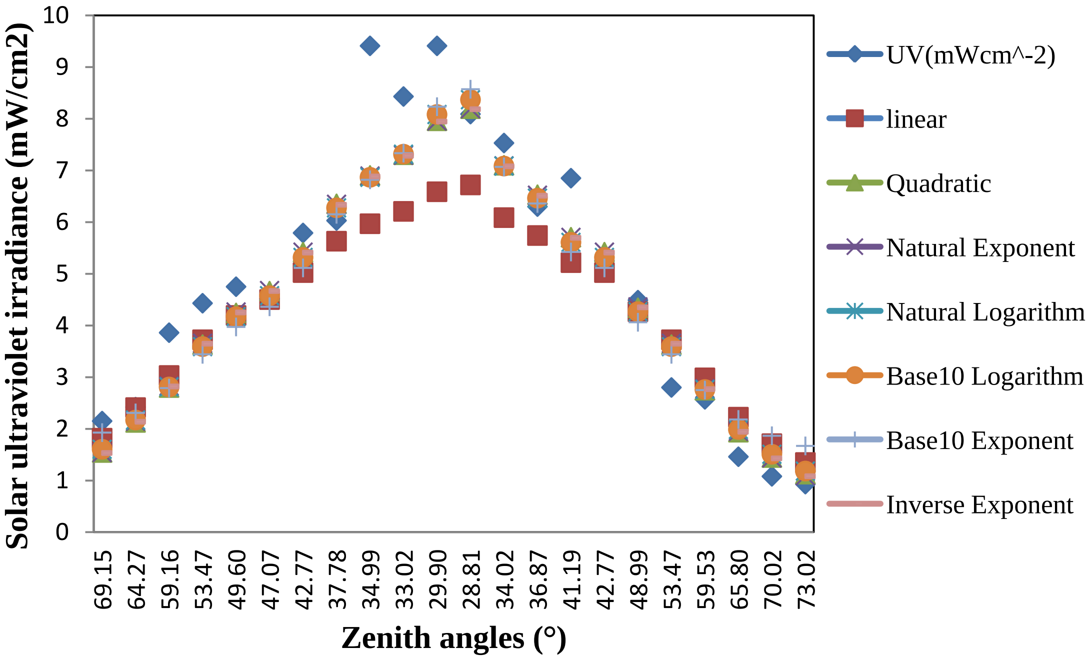

Fig. 3 Comparison between measured and calculated values of solar ultraviolet radiation as a function of zenith angles using empirical models for Lashio.

Conclusion

The main objective of this study is to evaluate the applicability of our proposed models for the estimation of the solar ultraviolet irradiance on a horizontal surface using sun position (especially zenith angle) data and to select the most appropriate model for Lashio city, Myanmar. According to the statistical results, all models show good estimation of the solar ultraviolet irradiation on a horizontal surface for Lashio. It is concluded that the natural exponent model is more accurate than the other models based on the zenith angles data. The conclusion is that the estimation of solar ultraviolet radiation can be performed with an acceptable accuracy using all the tested calibrated models. The relationships between solar ultraviolet irradiance and illuminance were found to be a linear equation which was sufficient, i.e. no significant improvement was obtained using a quadratic equation.

Acknowledgement

We would like to express thanks to Rector, Dr Maung Maung, Lashio University, for his encouragement to do this research. Thanks are also due to Dr. Htun Hlaing, Pro-Rector of Lashio University for constant encouragement to do the research on every meeting.

References

Agustine, C. and Nnabuchi, M. N. (2009) Inte. J. phy. Sci, **4**, 182.

Ahpabio, L.E. and Eluk, C.E (2003) Turk J Phys. **27**, 161.

Almorox, A.I. (2011) Turk. J. Phys. **35**, 53.

Dumas, A. et al., (2014) aXiv:physics, ao-ph, 1401.7837v**1.**

Feulner, G. (2012) arXiv:astr-ph.E, 1209.0602v**2.**

Fioletov, V.E. et al., (2002) Opt. Eng. **41** (12), 3051.

Ibeh, G.F. et al., (2012) J. Chem. Bio. Phy. Sci, Sec. C, **2**, No. 4, 2028.

Kudish, A.I. and Evsec, E. (2000) Int. J. Climatol. **20**, 759.

Lefevre, M. et al., (2013) Atmos. Meas. Tech, **6**, 2403.

Olmo, F.J. et al., (1999) Atmos. Envir., **33**, 4589.

Trabea, A.A. and Salem, I. (2001) Egypt. J. Sol., **24**, No.1, 123.