Research Article

Science Technology and Engineering Journal (STEJ) Vol.8, No.2 pages 58-66

Estimation of Ultraviolet Radiation Intensity under Cloudless Sky of Thailand

Sayan Phokate[1*], Apiwat Boonkhuang[1]

[1] *Department of Applied Physics, Faculty of Engineering, Rajamangala University of Technology Isan, Khon Kaen Campus, Nai Muang Sub-district, Muang District, Khon Kaen Province, Thailand, 40000*

[*] *Corresponding Author: syphokate@hotmail.com*

(**Received**: 16th June 2022, **Revised**: 26th September 2022, **Accepted**: 18th October 2022)

Abstract - The purpose of this research is to estimate ultraviolet radiation intensity values using mathematical models. Ultraviolet intensity data obtained at a wavelength of 290-390 nm, along with global solar radiation and climate data on cloudless days. The case study of Thailand where the four solar radiation monitoring stations from the North, Northeast, Central and South among them are Chiang Mai, Ubon Ratchathani, Bangkok, and Songkhla provinces respectively. The models were created using data during 2017 to 2019. Following that, the model was validated using 2020 data on a cloudless days. It was found that the intensity of ultraviolet radiation was related to the ratio of solar radiation intensity at the Earth's surface to extraterrestrial solar radiation intensity and the cosine of the zenith angle. In addition, the intensity of ultraviolet radiation is related to water vapor, ozone content, and visibility data. All of which can show mathematical relationships. The validation results of the model revealed reasonable agreement between the models with a positive correlation with one another. According to the results, all data are not significantly different at the 0.05 level.

Keywords: Estimation, ultraviolet radiation, solar radiation, water vapor, ozone

1. Introduction

Ultraviolet rays are electromagnetic waves with short wavelengths and high photon energy. There are three wavelengths of ultraviolet radiation: ultraviolet A (UVA) with a wavelength of 315-400 nm, ultraviolet B (UVB) with a wavelength of 280-315 nm, and ultraviolet C (UVC) with a wavelength of 280-100 nm. In general, ultraviolet radiation entering the earth consists of 96% UVA and 4% UVB, while UVC is absorbed by air molecules in the upper atmosphere so that it cannot pass through the earth (Chadyšiene & Girgždys, 2009). Most of the sun's ultraviolet radiation is absorbed from the stratosphere, which contains ozone gas. At present, the amount of ozone in the atmosphere is decreasing due to the use of chlorofluorocarbons and human industrial activities resulting in changes in the amount of ultraviolet radiation reaching the Earth's surface. Although they are very small compared to the intensity of solar radiation in the range of illumination, they have a significant impact on life and the environment on earth. This is harmful to the skin, sunburn, acute inflammation and genetic material abnormalities that promote cellular aging and carcinogenesis (Elwood & Jopson, 1997; Wei *et al.*, 2003; Krutmann *et al.*, 2012). The average person's skin cancer is increasing at a rate of 4-6% per year (Godar, 2005). Overexposure to UV rays and prolonged exposure is the main cause of blindness. The World Health Organization (WHO) estimates that 20% of blind people suffers from cataracts as a result of UV exposure. It also contributes to the deterioration of tissues caused by the generation of free radicals due to ultraviolet radiation (Yin & Jiang, 2013). Therefore, it is critical to monitor changes and systematically monitor them in order to provide inputs to prevent potential hazards to human health.

Ultraviolet radiation is related to the intensity of solar radiation because ultraviolet is part of the solar radiation (Iqbal, 1983; Pinazo *et al.*, 1995; Ineichen, 2006). They are absorbed and scattered by atmospheric elements such as ozone, air molecules, water vapor and aerosols as they pass through the atmosphere into the Earth's surface. The decrease in solar radiation was correlated in a mathematical model with precipitable water vapor and visibility data (Janjai *et al.*, 2003; Phokate, 2020). Therefore, the intensity of ultraviolet radiation reaching the earth changes according to the composition of the atmosphere and the meteorological changes of the atmosphere. To study the intensity of ultraviolet rays reaching the earth, long-term data collection is required to analyze the changes in order to make an estimate. Including studying the relationship with various meteorological data in the development of models to estimate the accurate data can be applied to solar energy, biotechnology, health and other fields.

2. Materials and methods

Ultraviolet intensity estimation uses data obtained from the meter in the wavelength range 290 nm to 390 nm, measurement resolution 0.01 mW/cm^2 in the range 1 $\mu W/cm^2$ - 40 mW/cm^2, relative sensitivity at wavelength 365 nm. Data on cloudless days were selected based on cloud cover data on the same day, where clouds on that day must be less than 1 part of the total 10 parts of the sky (Boland *et al.*, 2001; Ineichen, 2006). The solar radiation intensity and research data were obtained from four meteorological stations, namely Chiang Mai (18.77 °N, 98.96 °E), Ubon Ratchathani (15.25 °N, 104.86 °E), Songkhla (7.2 °N, 100.6 °E) and Bangkok Meteorological Department (13.73 °N, 100.56 °E) between 2017 and 2019 were used to create the model. The 2020 data are used to test the model. The ultraviolet radiation is related to the solar radiation intensity and the zenith angle of the sun (Khogali & Al-Bar, 1992; Barbero *et al.*, 2006).

$$I_{UV} = a + b(\cos Z) + c(G/G0) \quad (1)$$

where I_{UV} is the ultraviolet intensity (mW/m^2), G is the solar radiation intensity (W/m^2), G0 is the extraterrestrial solar radiation intensity (W/m^2), Z is the zenith angle of the sun, a b and c are constants.

The extraterrestrial solar radiation intensity (G_0) and the cosine of the zenith angle (cos Z) are obtained from the equation (Iqbal, 1983).

$$G_o = \frac{24}{\pi} I_{SC} E_o \cos\phi\cos\delta[\sin\omega_s - \frac{\pi}{180}\cos\omega_s] \quad (2)$$

$$\cos Z = \sin\delta\sin\phi + \cos\delta\cos\omega \quad (3)$$

where I_{SC} is the solar constant (1,367 W/m^2), ϕ is latitude (degrees), δ is the declination angle (degrees), ω_s is the hour angle at sunset (degrees) and E_0 is the orbit error correction value (-).

The amount of ozone in the atmosphere is usually reported as the total vertical ozone thickness in the atmosphere, assuming that the vertical amount of ozone of the atmosphere converges at the Earth's surface at standard temperature and pressure in centimeters, or Dobson unit (DU) (Fioletov, 2008; Dobson, 2005). For Thailand, the amount of ozone was measured using the Dobson Spectrophotometer at the Bangkok Meteorological Department. The researchers compared the ozone content obtained from climate data of Robinson (1966) at latitudes 10 °N and 20 °N with the ozone content of Bangkok Meteorological Department at latitudes 13.73 °N. It was found that the change in time of year was consistent and the ozone content was relatively small change in time and latitude. Therefore, Bangkok's ozone content was applied to other stations.

The amount of water vapor in the atmosphere is expressed in terms of the precipitable water vapor, assuming that the water vapor in the column of the atmosphere condenses into water (Iqbal, 1983; Garrison, 1992; Gueymard & Garrision, 1998). The amount of water vapor is related to the relative humidity and air temperature from the upper air data. For Thailand, there are 4 measurement stations, namely Chiang Mai, Ubon Ratchathani, Songkhla and Bangkok Meteorological Department. It can be calculated from the equation (Phokate, 2017).

$$w = 1.461407\exp(0.0451e) \quad (4)$$

where w is precipitable water vapor (cm). The e is the actual vapor pressure (mbar), which depends on the temperature and relative humidity at the surface.

The decrease in solar radiation intensity is due to the composition of the atmosphere, which is absorbed by ozone and water vapor in the air. It is also absorbed and scattered by aerosols, which is associated with visibility data. Therefore, ultraviolet radiation is associated with ozone content, visibility data, and precipitable water vapor in a mathematical model. Which can be used to estimate the ultraviolet intensity in other locations. The model was tested for accuracy using 2020 cloudless skies date data, which were not used for modeling. The performance of model was assessed based on some commonly used statistical indicators. The two statistical estimators of mean bias error (MBE) and root mean square error (RMSE) are used to evaluate the accuracy of the model (Iqbal, 1983; Nik *et al.*, 2012). It represents the mean deviation between the model data and the actual measurement data, with values approaching zero indicating the validity of the model which can be shown as the equations.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad (6)$$

where n is number of samples, P is the estimated or the forecasts and O is the observed values or the measured.

3. Results

The data on cloudless days from 2017 to 2019 were selected from 177 sets for regression analysis. It was found that the ultraviolet intensity (I_{UV}) was related to the ratio of the solar radiation intensity at the Earth's surface (G) to the extraterrestrial solar radiation intensity (G0) and the cosine of the zenith angle (cosZ).

That is, the low G/G0, the higher the I_{UV}. The I_{UV} is directly proportional to the cosine of the zenith angle (Figure 1). The correlation coefficient (R^2) is 0.873 and the standard error is 1.505. The mathematical relationship can be written as the equation.

$$I_{UV} = 64.425 - 9.933(\cos Z) - 193.475(G/G0) \quad (7)$$

where I_{UV} is the ultraviolet intensity (mW/m^2), G is the solar radiation intensity (W/m^2), G0 is the extraterrestrial solar radiation intensity (W/m^2) and Z is the zenith angle of the sun.

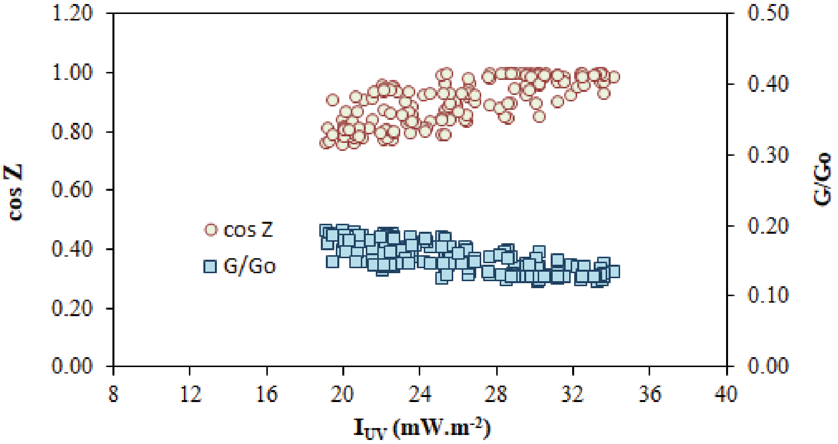

Figure 1. Illustrate of ultraviolet intensity and the ratio of terrestrial solar radiation intensity to the extraterrestrial solar radiation intensity and cosine of the zenith angle on a cloudless day of the year from 2017 to 2019.

The ultraviolet intensity data obtained from the measurements were used to correlate the ozone content, precipitable water vapor and the visibility data for climate data on cloudless days between 2017 and 2019. It can be shown as shown in Figure 2. The correlation coefficient (R^2) is 0.827 and the standard error is 1.732. The relationship can be written as follows:

$$I_{UV} = -2.79032 + 1.511924(w) + 0.08722(Oz) + 0.208231(Vis) \quad (8)$$

where I_{UV} is the ultraviolet intensity (mW/m^2), w is the precipitable water vapor (cm), Vis is the visibility data (km) and Oz is the ozone content (DU).

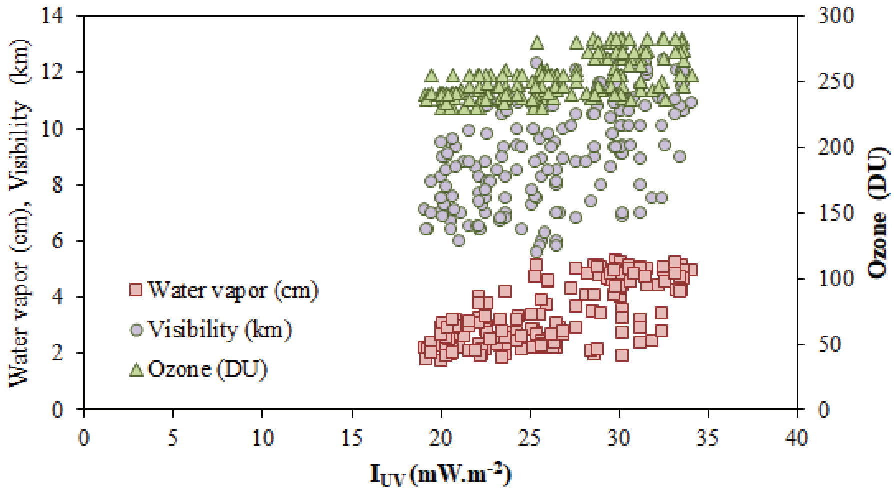

Figure 2. The illustrate shows the distribution of ultraviolet radiation intensity and water vapor content in the air, visibility data and ozone content on cloudless days of 2017 to 2019.

4. Discussion and conclusion

The correlation in the mathematical model was tested by comparing the ultraviolet intensity obtained from the model with the measured ultraviolet intensity. The data on the cloudless days of 2020 were used for 39 datasets of the four stations, which were data on the same date, time and location that were not used in the modeling.

The model eq. (7) was obtained by correlating the measured ultraviolet intensity with the ratio of the solar radiation intensity to the extraterrestrial solar radiation intensity and cosine of the zenith angle. It was found that the ultraviolet radiation intensity obtained from the measurements was close and consistent with the values calculated from the model. The distribution during the year was consistent. The model had an error of 5.55% of the measured value (Figure 2 and Figure 4). The RMSE was 2.180 mW/m^2, the MBE was -0.097 mW/m^2, and the Pearson correlation coefficient was 0.921. This is consistent with Habte *et al.* (2019), ultraviolet radiation was calculated from solar radiation and air mass data, which correlated with the zenith angle. When testing the model it was shown that the resulting ultraviolet radiation were in good agreement with the actual measured values. In addition, Khogali & Al-Bar (1992) found a relatively high correlation between ultraviolet radiation with solar radiation at the Earth's surface, the extraterrestrial solar radiation intensity and the zenith angle.

The model eq. (8) was obtained by correlating the measured ultraviolet intensity with the precipitable water vapor, ozone content and visibility data. It was found that the correlation was quite high. The model had an error of 7.82% from the measured value (Figure 3 and Figure 4). The RMSE was 2.749 mW/m^2, the MBE was 0.293 mW/m^2, and the Pearson correlation coefficient was 0.853. Consistent with research by Habte *et al.* (2019), ultraviolet radiation is associated with atmospheric components such as aerosols, precipitable water vapor, ozone content and local surface characteristics. El-Hadidy *et al.*, (1990) found that ultraviolet radiation was associated with aerosols. which is related to visibility data. Nunez *et al.*, (1994), who found that incoming ultraviolet radiation decreased depending on the amount of ozone in the stratosphere and also differed by date, time, latitude, amount clouds and aerosols.

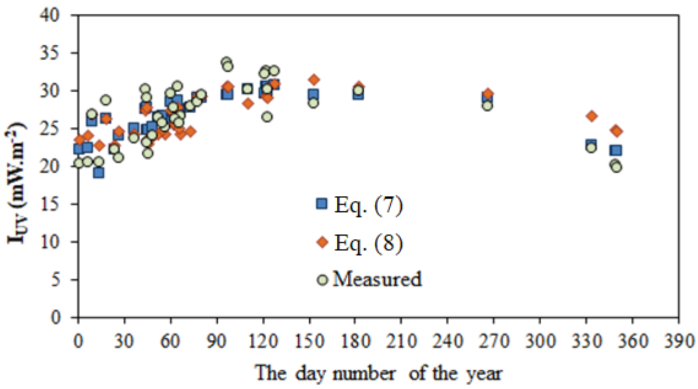

Figure 3. The ultraviolet intensity obtained from the models and measured using 39 datasets of the 2020 cloudless sky on the same date, time and location.

The dependent t-test from both models was compared with the measured values. It was found that the data from the models were not different from the data obtained at the 95% confidence level. These two equations are highly correlated. It shows that the model is accurate within acceptable criteria.

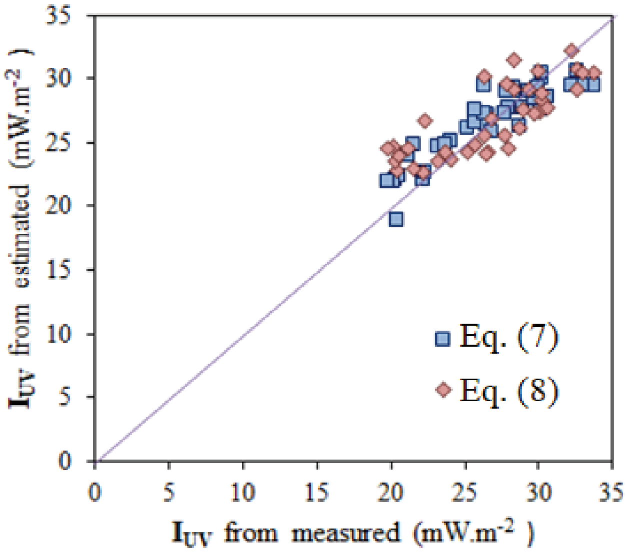

Figure 4. Comparison of ultraviolet intensity from measurements and ultraviolet intensity obtained from models (Eq. 7 and Eq. 8) under cloudless sky conditions in 2020.

In this research, ultraviolet intensity data in the wavelength range of 290-390 nm were used from measurements on cloud-free days at four measurement stations, namely Chiang Mai Station, Ubon Ratchathani station, Bangkok Meteorological Station and Songkhla Station during the years 2017-2019, there were 177 data sets find the relationship in a mathematical model. It was found that the measured ultraviolet intensity was correlated with the ratio of the solar radiation intensity at the Earth's surface to the extraterrestrial solar radiation intensity and the cosine of the zenith angle, with a correlation coefficient of 0.873. When ultraviolet radiation intensity from the measurements was taken to correlate with precipitable water vapor, ozone content and visibility data, it was found to be highly correlated with a correlation coefficient of 0.827. The model was tested by comparing the ultraviolet intensity obtained from the model with the ultraviolet intensity measured using 39 datasets of the 2020 cloudless day sky on the same day number. This data set is independent of the UV data that has been used for the relationship finding. It was found that the ultraviolet intensity calculated from the two models was close to and consistent with the measured values with a positive path correlation. The distribution during the year was consistent. The data from the model were not significantly different at the 0.05 level, with a relatively high correlation coefficient. Indicates that the model has acceptable accuracy.

5. Acknowledgement

The researchers would like to thank Rajamangala University of Technology Isan for supporting the research. The Meteorological Department for providing valuable information on the research was also acknowledged.

6. References

Barbero, F.J., Lopez, G., & Batlles, F.J. (2006). Determination of daily solar ultraviolet radiation using statistical models and artificial neural networks. *Ann. Geophys., 24*(8), 2105-2114. https://doi.org/10.5194/angeo-24-2105-2006.

Boland, J., McArthur, L.C., & Luther, M. (2001). Modelling the diffuse fraction of global solar radiation on a horizontal surface. *Environmetrics, 12*, 103-116. https://doi.org /10.1002/1099-095X(200103)12:2 <103::AID-ENV447>3.0.CO;2-2.

Chadyšiene, R. & Girgždys, A. (2009). Assessment of ultraviolet (UV) radiation from technical Sources. *Journal of Environmental Engineering and Landscape Management, 17*(3), 164-170. https://doi.org/10.3846/1648-6897.2009.17.164-170

Habte, A., Sengupta, M., Gueymard, C.A., Narasappa, R., Rosseler, O. & David, M.B. (2019). Estimating ultraviolet radiation from global horizontal irradiance. *IEEE Journal of Photovoltaics, 9*(1), 139-146. doi: 10.1109/JPHOTOV.2018.2871780.

Dobson, R. (2005). Ozone depletion will bring big rise in number of cataracts. *BMJ, 331*(7528), 1292-1295. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1298891/

El-Hadidy, M.A., Abdel-Nabe, D.Y., & Kross, P.D. (1990). Ultraviolet solar radiation at Dhahram, Saudi Arabia. *Solar Energy, 44*(6), 315-319. doi: 10.1016/0038-092x(90)90135-y. https://europepmc.org/article/AGR/IND90030455.

Elwood, J.M., & Jopson, J. (1997). Melanoma and sun exposure: an overview of published studies. *Journal international du cancer, 73*(2), 198-203.

Fioletov, V.E. (2008). Ozone climatology, trends, and substances that control ozone. *Atmosphere-Ocean, 46*(1), 39-67. https://doi.org/10.3137 / ao.460103.

Garrison, J.D. (1992). Estimation of precipitable water over Australia for application to the division of solar radiation into its direct and diffuse components. *Solar Energy, 48*(2), 89-96.

Godar, D.E. (2005). UV doses worldwide. *Photochem Photobol, 81*(4), 736-749. doi: 10.1562/2004-09-07-ir-308r.1. https://pubmed.ncbi. nlm.nih.gov/15819599/.

Gueymard, C.A., & Garrision, J.D. (1998). Critical evaluation of precipitable water and atmospheric turbidity in Canada using measured hourly solar irradiance. *Solar Energy, 62*(4), 291-307. https://doi.org/ 10.1016/S0038-092X(98)00005-X.

Ineichen, P. (2006). Comperison of eight clear sky broadband models against 16 independent data banks. *Solar Energy, 80*(4), 468-478. https://doi.org/10.1016/j.solener.2005.04.018.

Iqbal, M. (1983). *An introduction to solar radiation*. Academic Press.

Janjai, S., Kumharn, W. & Laksanaboonsong, J. (2003). Determination of angstrom's turbidity coefficient over Thailand. *Renewable Energy, 28*, 1685-1700. https://doi.org/10.1016/S0960-1481(03)00010-7.

Khogali, A., & Al-Bar, O.F. (1992). A study of solar ultraviolet radiation at Makkah solar station. *Solar Energy, 48*(2), 79-87. https://doi.org/ 10.1016/0038-092X(92)90036-A.

Krutmann, J., Morita, A., & Chung, J.H. (2012). Sun exposure: what molecular photo dermatology tells us about its good and bad sides. *The Journal of Investigative Dermatology, 132*(3), 976-984. doi: 10.1038/jid.2011.394. https:// pubmed.ncbi.nlm.nih.gov/22170486/

Nik, W.B., Ibrahim, M.Z., Samo, K.B., & Muzathik, A.M. (2012). Monthly mean hourly global solar radiation estimation. *Solar Energy, 86*(1), 379-387. https://doi.org/10.1016/j.solener.2011.10.008.

Nunez, M., Forgan, B., & Roy, C. (1994). Estimating ultraviolet radiation at the earth's surface. *International Journal of Biometeorology, 38*(1), 5-17. doi:10.1007/BF01241798 https://www.researchgate.net/publication/226388033.

Pinazo, J.M., Canada, J., & Bosca, V. (1995). A new method to determine Angstrom's turbidity coefficient: Its application for Valencia. *Solar Energy, 54*(4), 219-226. https://doi.org/ 10.1016/0038-092X(94)00117-V.

Phokate, S. (2020). Estimation of extinction coefficient of solar radiation under cloudless sky in the atmosphere of Thailand. *Burapha Science Journal, 25*(3), 1083-1093.http://science.buu .ac.th/ojs246/index.php/sci/article/ view/2996.

Phokate, S. (2017). Atmospheric water vapor: Distribution and empirical estimation in the atmosphere of Thailand. *Journal of Physics: Conference Series, 901*, 1-6. https://iopscience.iop.org/issue/1742-6596/901/1.

Robinson, N. (1966). *Solar radiation*. Elsevier Publishing Company.

Wei, Q., Lee J.E., Gershenwald J.E., Ross M.I., Mansfield P.F., Strom S.S., Wang L.E., Guo Z, Qiao Y, Amos C.I., Spitz M.R., & Duvic M. (2003). Repair of UV light-induced DNA damage and risk of cutaneous malignant melanoma. *Journal of the National Cancer Institute, l95*(4), 308-315. doi:10.1093/jnci/95.4.308. https://pubmed.ncbi.nlm.nih.gov/12591987/.

Yin, B., & Jiang, X. (2013). Telomere shortening in cultured human dermal fibroblasts is associated with acute photodamage induced by UVA irradiation. *Postepy Dermatologii Alergologii, 30*(1), 13-18. doi: 10.5114/pdia.2013.33374. https://pubmed.ncbi.nlm.nih.gov/24278041/