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Estimation of Direct and Diffuse Solar Radiation on Bode, Bhaktapur

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ABSTRACT

The main objective of the study is to estimate direct solar radiation (I_B) and diffuse solar radiation (I_D) on Bode, Bhaktapur (27.68^o N, 85.39^o E, 1297 m a. s. l.) for a period of one year (2013). Daily data of Aerosol optical depth (AOD), total ozone column are derived from NASA website. The maximum and minimum monthly average of diffuse solar radiation values were found 318±95 W/m2 in April and 108 ± 20 W/m2 in August respectively. The maximum and minimum monthly average of direct solar radiation values were found 975±74 W/m^2 in February and 748 ± 126 W/m^2 in March respectively. The annual average of diffuse solar radiation and direct solar radiation are found 216 ± 88 W/m^2 and 864 ± 125 W/m^2 respectively. Result of this research work is beneficial for the further identification, impact and analysis of direct solar radiation diffuse solar radiation at different places.

Keywords: Aerosol, Atmospheric transmittance, Gas mixture, Rayleigh scattering, Ozone, Water content.

INTRODUCTION

The solar energy arriving in the earth's surface is in the form of electromagnetic radiation of wavelength from 300 nm to 3000 nm [1]. The solar radiation decreases as square of distance from The Sun to the Earth due to elliptic orbit. 1367 W/m^2 (I_{sc}, solar constant) [2] of the solar radiation incidents of outer surface of Earth's atmosphere when distance between Sun and Earth as 1.49×10^8 km. Normal solar radiation (I_0) incident on specific point of outer surface of the atmosphere at specific time depends on day number of year (DOY, n_d) [3].

$$I_0 = I_{sc}\left[1 + 0.033\cos\left(\frac{2\pi}{365}n_d\right)\right] \quad \text{.......................(1)}$$

When the solar radiation enters in the earth's atmosphere, scattering, reflection, and absorption by the atmospheric particles like gas molecules, aerosols, water vapor, ozone and clouds occur. The solar radiation is attenuated in atmosphere with attenuation coefficient (k) and optical air mass (m) [4]. The solar radiation incident on ground (I) is sum of direct solar radiation (I_B) and diffuse solar radiation (I_D) [5]. The Sun is the closest star from the Earth and hence solar energy is the primary source of energy. Solar energy is the largest renewable resources on earth. Study of direct solar radiation and diffuse solar radiation and its effect of different meteorological parameters are used in Agriculture, Climate change and energy harvesting.

Nepal is a mountainous land locked country located in the south east of Asia. It possesses diversity in biosphere [6]. Nepal lies on Solar belt having latitude range from 15^o N to 35^o N. The annual solar isolation is 3.6 kWh/m^2 /day to 6.2 kWh/m^2 /day in Nepal [7]. Out of the total energy consumed in Nepal, renewable energy consumption is 2.1% [8]. Large amount of foreign currency is wasted on importing petroleum product. So, energy harvesting from solar is required.

Bode (27.68°N, 85.39°E, 1297 m a. s. l.) lies in Madhyapur Thimi Municipality of Bhaktapur district in Bagamati Pradesh. It is an ancient Newar city. It covers area 0.41 km^2. It has population 6,364 with population density 16,000 km^{-2} [9].

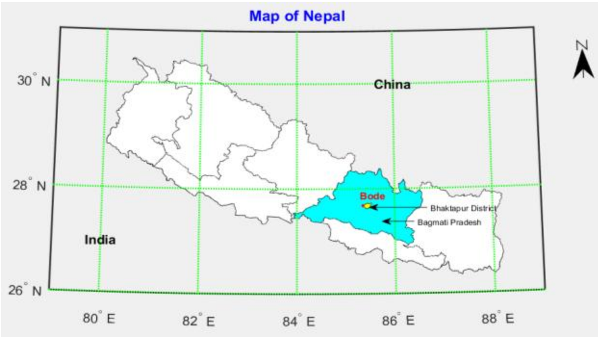


Fig. 1: Map of Bode, Bhaktpur
[source:Survey department, 2020]

Map of Bode is shown in figure 1. An average daily high temperature above 28^o C and average daily low temperature above 3 ^{o}C. The annual mean of solar radiation, Angstrom exponential (α) and Angstrom turbidity coefficient (β) were found 4.70 ± 1.10 kWh/m^2 /day, 1.13 ± 0.21 and 0.18 ± 0.14 respectively on Bode for 2013 [10]. Pyranometer is used to measured global solar radiation which is sum of direct solar radiation and diffuse solar radiation. Solar tracker and diffuse Pyranometer are not available to measure direct solar radiation and diffuse solar radiation on Bhaktpur. So estimation of direct solar radiation and diffuse solar radiation are required for Bode.

MATERIALS AND METHODS

Atmospheric transmittance(τ)is ratio of solar radiation incidents on ground (I_N) to that incident on outer surface of atmosphere (I_o). According to Beer's law ($\tau = e^{-km}$) [5], atmospheric transmittance is attenuated exponentially in atmosphere with attenuation coefficient(k) and optical air mass(m) [11]. Attenuation coefficient (k) is sum of attenuation coefficient due to ozone(k_o), water vapor (k_w), gas mixture (k_g), aerosol (k_a) and Rayleigh scattering (k_r). So atmospheric transmittance (τ) is due to atmospheric transmittance of ozone (τ_o), atmospheric transmittance of water vapor (τ_w), atmospheric transmittance of gas mixture(τ_g), atmospheric transmittance of aerosol(τ_a) and atmospheric transmittance of Rayleigh scattering (τ_r) [12]. τ_o is function of ozone column (l) in cm and relative air mass (m_r). Relative air mass depends on solar zenith angle(θ_z). τ_w is function of water content (w) in cm and relative air mass. τ_g and τ_r is function of air mass (m_a) which depends on atmospheric pressure (P), altitude of the place(z) and relative air mass. τ_a is function of Angstrom turbidity coefficient (β), Angstrom exponential (α) and air mass. Atmospheric transmittances are [13]

$$\tau_o = 1 - [0.1611\, u_3 (1 + 139.48\, u_3)^{-0.3035} - 0.002715\, u_3 (1 + 0.044\, u_3 + 0.0003\, u_3^2)^{-1}] \quad (3)$$

$$\tau_w = 1 - 2.4959\; u_1 [(1 + 79.034\, u_1)^{0.682} + 6.385\, u_1]^{-1} \quad (4)$$

$$\tau_g = e^{[-0.0127 m_a^{0.26}]} \quad (5)$$

$$\tau_a = (0.1244\,\alpha - 0.0162) + (1.003 - 0.125\,\alpha) e^{[-\beta\, m_a (1.089\,\alpha + 0.5123)]} \quad (6)$$

$$\tau_r = e^{[-0.0903\, m_a^{0.83} (1.01 + m_a - m_a^{1.01})]} \quad (7)$$

Where

$$u_3 = l\, m_r$$

$$u_1 = w\, m_r$$

$$m_a = \frac{P}{101325} m_r$$

$$m_r = \frac{1}{cos\theta_z + 0.15(93.885 - \theta_z)^{-1.253}}$$

Bird and Hulstrom [14] developed Parameterization Model C. This model is used to estimate direct solar radiation (I_B) and diffuse solar radiation (I_D). Those are

$$I_B = 0.9751 I_o (\tau_o\, \tau_w\, \tau_g\, \tau_a\, \tau_r + B(z)) \quad (7)$$

Here B(z) is correction due to altitude z in meter.

And

$$I_D = I_{dr} + I_{da} + I_{dm} \quad (8)$$

Here I_{dr} is diffuse solar radiation produced by Rayleigh scattering, I_{da} is diffuse solar radiation produced by aerosols and I_{dm} is diffuse solar radiation produced by multiple reflections.

$$I_{dr} = 0.79 I_o \cos\theta_z\, \tau_o\, \tau_g\, \tau_w\, \tau_{aa} \frac{0.5(1-\tau_r)}{1 - m_a + m_a^{1.02}} \quad (9)$$

Here τ_{aa} is the atmospheric transmittance of aerosol absorptance. Solar zenith angle (θ_z) depends on solar declination (δ), solar hour angle (ω) and latitude (φ) of the place.

Where,

$\theta_z = \cos^{-1}(\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos\omega)$

$\delta = 23.45 \sin(\frac{360}{365}(284 + n_d))$

$\tau_{aa} = 1 - (1 - w_o)(1 - m_a + m_a^{1.06})(1 - \tau_a)$

Here w_o is 0.9.

$$I_{da} = 0.79 I_o \cos\theta_z \tau_o \tau_g \tau_w \tau_{aa} F_c \frac{0.5(1-\tau_{as})}{1 - m_a + m_a^{1.02}} \quad (10)$$

Here $\tau_{as} = \tau_a / \tau_{aa}$ and $F_c = 0.84$

$$I_{dm} = \frac{(I_B \cos\theta_z + I_{dr} + I_{da})\alpha_g \alpha_a}{(1 - \alpha_g \alpha_a)} \quad \text{.........................(11)}$$

Here α_g is albedo of ground (= 0.4). α_a is atmospheric albedo.

$\alpha_a = 0.0685 + (1.0 - F_c c)(1.0 + \tau_{as})$

Daily data of aerosol optical depth (AOD) of Bode for year 2013 are derived from the AERONET homepage of NASA. Daily data of Total ozone column (TOC) are derived from NASA web site. Angstrom turbidity coefficient (β) and Angstrom exponential (α)are calculated by using linear regression method in Angstrom model for wavelength (λ) 675, 500, 440, 380 and 340 nm [15].

$$AOD = \beta \lambda^{\alpha} \quad \text{..(12)}$$

Open source software Python 3.7 software is used to analysis data and to plot graph. Mean ($\bar{x}$) standard deviation (σ), quartiles (Q_1, Q_2, Q_3), skewness(γ_1) and kurtosis(γ_2) are used as Statistical tool. Standard error (SE) is used as error bar in graph. Data are presented in form of ' $\bar{x} \pm \sigma$'.

RESULTS AND DISCUSSION

The daily atmospheric transmittance of ozone (τ_o), atmospheric transmittance of water vapor (τ_w), atmospheric transmittance of gas mixture (τ_g), atmospheric transmittance of aerosol (τ_a) and atmospheric transmittance of Rayleigh scattering (τ_r) are calculated by using equations (2), (3), (4), (5) and (6). Figure 2 shows daily variation of atmospheric transmittances. The atmospheric transmittance of gas mixture (τ_g) is found maximum 0.9885 in March 25 whereas minimum 0.9871 in September 22. The annual average is found 0.9880 ± 0.0004. The atmospheric transmittance of water vapor (τ_w) is observed maximum 0.9292 in January

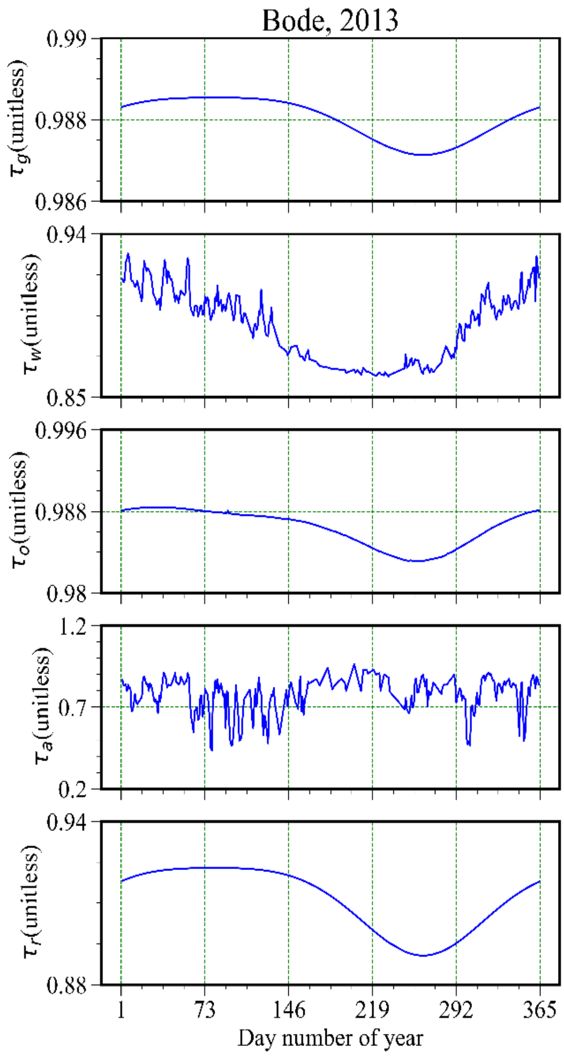


Fig. 2: Daily Variation of atmospheric transmittances

8 whereas minimum 0.8614 in August 23. The annual average is found 0.8614 pm 0.0017. The atmospheric transmittance of ozone (τ_o) is observed maximum 0.9884 in February 8 whereas minimum 0.9831 in September 21. The annual average is found 0.9867 ± 0.0017. The atmospheric transmittance of aerosol (τ_a) is found maximum 0.9636 in July 24 whereas minimum 0.4340 in March 25. The annual average is found 0.7738 pm 0.1113. The atmospheric transmittance of Rayleigh scattering (τ_r) is found maximum 0.9229 in March 15 whereas minimum 0.8906 in September 22. The annual average is found 0.9125 ± 0.0112. The average value of atmospheric transmittance of ozone, Rayleigh scattering, gas mixture, water vapor and aerosol are found 0.9830 ±0.0007, 0.8999 ± 0.0178, 0.9875 ± 0.0007, 0.8839 ± 0.0101 and 0.7836 ± 0.0909 respectively over Jumla from 2011 to 2013 [16]. The annual average of atmospheric transmittances of ozone, of water

vapor, of gas mixture, of aerosol and of Rayleigh scattering were found 0.983, 0.881, 0.987, 0.698 and 0.889 respectively in Kathmandu valley for 2012 [17]. The atmospheric transmittances of those places are comparable to that of Bode.

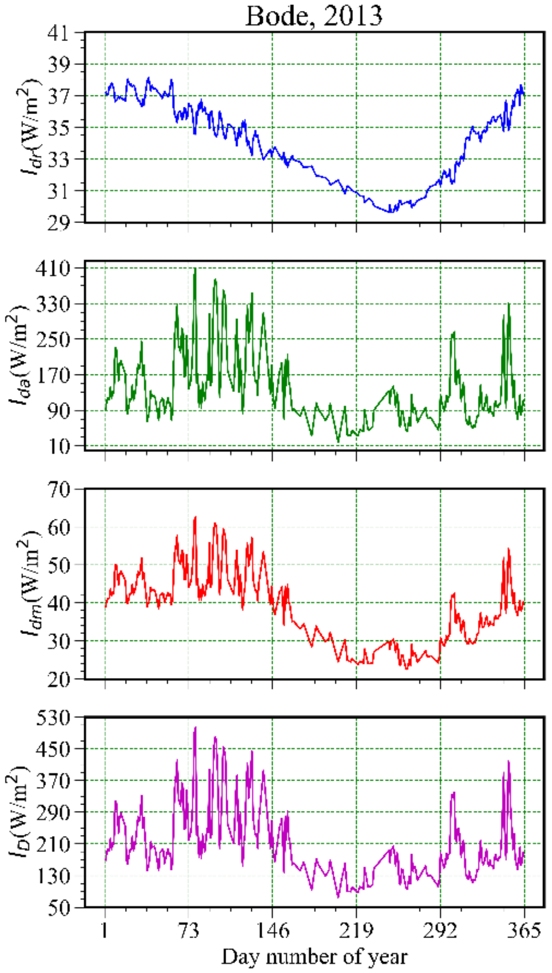


Fig. 3: Daily Variation of diffuse radiation

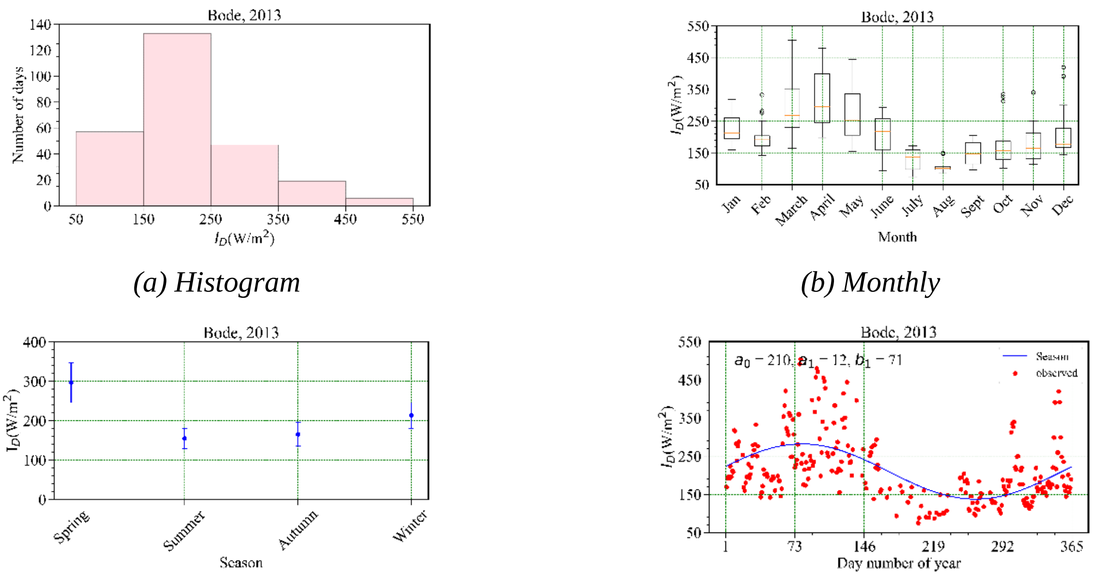
Diffuse solar radiation produced by Rayleigh scattering (I_{dr}), diffuse solar radiation produced by aerosols (I_{da}), diffuse solar radiation produced by multiple reflections (I_{dm}) and total diffuse radiation (I_D) are calculated by using equations (9), (10), (11) and (8). Figure 3 shows daily variation of the diffuse solar radiations. The diffuse solar radiation produced by Rayleigh scattering (I_{dr}) is found maximum 38 W/m^2 in February 8 whereas minimum 29 W/m^2 in September 11. The annual average is calculated 34 ± 3 W/m^2 . The diffuse solar radiation produced by aerosols (I_{da}) is found maximum 407 W/m^2 in March 22 whereas minimum 18 W/m^2 in July 24. The annual average is calculated 143 ± 79 W/m^2 . The diffuse solar radiation produced by multiple reflections (I_{dm}) is found maximum 62 W/m^2 in March 22 whereas minimum 22 W/m^2 in September 22. The annual average of diffuse solar radiation is found 39 W/m2 ± 9 W/m^2 . The diffuse solar radiation (I_D) is found maximum 504 W/m^2 in March 22 whereas minimum 75 W/m^2 in July 24. The annual average is observed 216 ± 88 W/m^2 . The annual average diffuse solar radiation was observed to be 7.92 MJ/m^2 /day in Aligarh (27.89° N,78.08° E) of India in September, 2013 to August [18].

Figure 4(a) shows histogram of diffuse solar radiation (I_D). First quartile (Q_1), second quartile (median, Q_2) and third quartile (Q_3) are found 156, 195 and 258 W/m^2 respectively. Skewness and kurtosis are found 1.04 and 0.4 respectively. The distribution of diffuse solar radiation is positively tailed and is not Gaussian. 133 days has diffuse radiation between 150 to 250 W/m^2 . Figure 4(b) shows monthly variation of diffuse solar radiation (I_D). I_D is found maximum 318 ± 95 W/m^2 in April due to dust particle in atmosphere whereas minimum 108 ± 20 W/m^2 in August due to rainy day. Figure 4(c) shows seasonal variation of diffuse solar radiation (I_D). I_D is found 44 W/m^2 in summer. The seasonal variation also can be analyzed by using Fourier series.

$$I_{Ds} = a_0 + a_1 \cos(\frac{2\pi}{365} n_d) + b_1 \sin(\frac{2\pi}{365} n_d)$$

It is shown in Figure 4(d). Offset (a_0) is 210 W/m^2 and seasonal component of amplitude ($\sqrt{a_1^2 + b_1^2}$) is calculated 72 W/m^2.

The daily direct solar radiation (I_B) are calculated by using equation (6). Figure 5(a) shows daily variation of direct solar radiation (I_B). The direct solar radiation (I_B) is maximum 1073 W/m^2 in February 8 whereas minimum 504 W/m^2 in March 22. The annual average is 864 ± 125 W/m^2. Figure 5(b) shows histogram of direct solar radiation (I_B). First quartile (Q_1), second quartile (median, Q_2) and third quartile (Q_3) are 797, 888 and 960 W/m^2 respectively. Skewness and kurtosis are calculated -0.83 and 0.28 respectively. Distribution of direct solar radiation is negatively tailed and is slightly Gaussian. 85 days has diffuse radiation between 800 to 900 W/m2. Figure 5(c) shows monthly variation of direct solar radiation (I_B). I_B is found maximum 975 ± 74 W/m^2 in February due to clear day whereas minimum 748 ± 126 W/m^2 in April. Figure 5(d) shows seasonal variation of direct solar radiation (I_B). I_B is found maximum 944 ± 91 W/m^2 in winter whereas minimum 856 ± 105 W/m^2 in autumn. The seasonal variation also can be analyzed by using Fourier series.



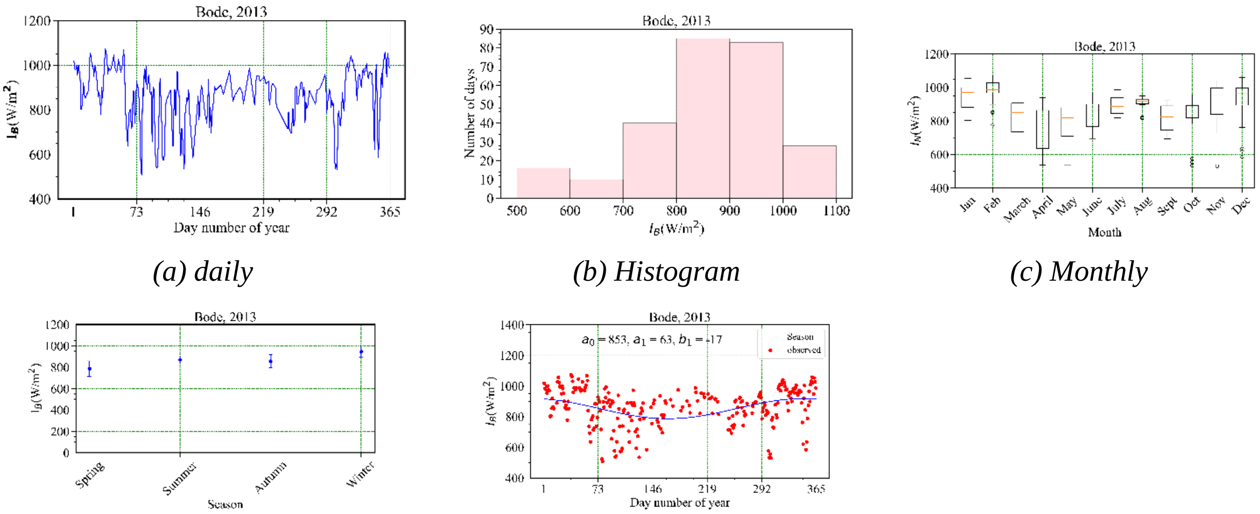
(a) Histogram *(b) Monthly*

(c) Seasonal *(d) Fourier analysis*

Fig. 4: Variation of diffuse solar radiation

$$I_{Bs} = a_0 + a_1 \cos(\frac{2\pi}{365} n_d) + b_1 \sin(\frac{2\pi}{365} n_d)$$

It is shown in Figure 5(e). Offset (a_0) is 63 W/m^2 and seasonal component of amplitude ($\sqrt{a_1^2 + b_1^2}$) is calculated 66 W/m^2.



(a) daily *(b) Histogram* *(c) Monthly*

(d) Seasonal *(e) Fourier analysis*

Fig. 5: *Variation of direct solar radiation*

CONCLUSION

Datasets on solar radiation is of great importance to the detection of global dimming and brightening. Direct solar radiation and diffuse solar radiation estimation using easily available satellite data on basis of atmospheric transmittance is therefore important to propose solar radiation potential of the location, the sustainable development of ecological environments and agriculture based productivity. In study period of one year (2013), the annual average of direct solar radiation and diffuse solar radiation are found 216 ± 88 W/m^2 and 864± 125 W/m^2 respectively. The annual average of diffuse solar radiation on Beijing (116.283° E, 39.933° N, 54 m a.s.l.) and Lasa (91.133^o E, 29.667^o N, 3649 m a.s.l.) of China were to be 6.6 MJ/m^2 /day and 6.1 MJ/m^2 /day respectively from 1993 to 2015 [19]. Diffuse solar radiation is large on Bode than big city of China and India. The Annual average of direct solar radiation is found 1106 ± 70 W/m2 in Jomsom (28.47^o N, 83.83^o E, 2,700 m a. s. l.) of Nepal for a year 2012 [20]. Direct solar radiation is less on Bode due to air pollution having Linke turbidity 5.70 ± 2.46 [10].

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REFERENCES

[1] Poudyal, K. N.; Bhattarai, B. K.; Sapkota, B. and Kjeldstad, B. "Solar radiation potential at four sites of nepal," *Journal of the Institute of Engineering*, **8**: 189–197 (2011).

[2] Duffie, J. A. and Beckman, W. A. *Solar engineering of thermal processes* (John Wiley & Sons, 2013).

[3.] Iqbal, M. *An introduction to solar radiation* (New York: Academic Press, 1983).

[4] Poudyal, K. N.; Bhattarai, B. K.; Sapkota, B.; Kjeldstad, B. and Daponte, P. "Estimation of the daily global solar radiation; nepal experience," *Measurement*, **46**: 1807–1817 (2013).

[5] Wallace, J. M. and Hobbs, P. V. *Atmospheric science: an introductory survey*, **92** (Elsevier, 2006).

[6] Majupuria, M. R. K. T C, *Nepal nature's paradise: insight into diverse facets of topography, flora and ecology* (M Devi ,Gwalior, India, 1999).

[7] Shrestha, J.; Bajracharya, T.; Shakya, S. and Giri, B. "Renewable energy in nepal-progress at a glance from 1998 to 2003," in Proceedings of the *International Conference on Renewable Energy Technology for rural Development (RETRUD-03)*, pp. 12–14 (2003).

[8] MoF, "*Economic survey 2018/019*," (2018).

[9] CBS, "*National population and housing census 2011*," (2011).

[10] Shrestha, P.; Chapagain, N.; Karki, I. and Poudyal, K. "Study of linke turbidity factor over bode, bhaktapur," *Journal of Nepal Physical Society*, **6**: 66–73 (2020).

[11] Lothian, G. "Beer's law and its use in analysis. a review," *Analyst*, **88**: 678–685 (1963).

[12] Wang, L.; Chen, Y.; Niu, Y.; Salazar, G. A. and Gong, W. "Analysis of atmospheric turbidity in clear skies at wuhan, central china," *Journal of Earth Science*, **28**: 729–738 (2017).

[13] Bird, R. and Hulstrom, R. L. "Direct insolation models," *Tech. Rep.* (Solar Energy Research Inst., Golden, CO (USA), 1980.

[14] Bird, R. E. and Hulstrom, R. L. "Simplified clear sky model for direct and diffuse insolation on horizontal surfaces," Tech. Rep. (Solar Energy Research Inst., Golden, CO (USA), 1981).

[15] Angstrom, A. "Techniques of determinig the turbidity of the atmosphere," *Tellus*, **13**: 214–223 (1961).

[16] Shrestha, P.; Chapagain, N.; Karki, I. and Poudyal, K. "Study of impact of meteorological parameters on atmospheric transmittance of solar radiation over jumla," *Nepal Journal of Science and technology*, **20**: 104–112 (2021).

[17] Shrestha, P.; Chapagain, N.; Karki, I. and Poudyal, K. "Variation on atmospheric transmittance solar radiation at kathmandu valley," *Journal of Nepal Physical Society*, **6**: 105–112 (2020).

[18] Jamil, B. and Akhtar, N. "Empirical models for estimation of diffuse solar radiation based on measured data for humid-subtropical climatic region of india," *Journal of Renewable and Sustainable Energy*, **9**: 033702 (2017).

[19] Wang, L.; Lu, Y.; Zou, L.; Feng, L.; Wei, J.; Qin, W. and Niu, Z. "Prediction of diffuse solar radiation based on multiple variables in china," *Renewable and Sustainable Energy Reviews*, **103**: 151–216 (2019).

[20] Shrestha, P. M.; Gupta, S. P.; Joshi, U.; Chapagain, N. P.; Karki, I. B. and Poudyal, K. N. "Estimation of direct solar radiation on high mountain region, Jomson, nepal," *Patan Prospective Journal*, **2**: 221– 231 (2022).