Patan Pragya *(Volume: 12, Number: 1, 2023)* *ISSN 2594-3278*

Received Date: April 2023 Revised: June 2023 Accepted: July 2023

Impact of Meteorological Parameters on Solar Radiation over Langtang National Park, Nepal

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Doi : https://doi.org/10.3126/pragya.v12i01.61477

Abstract

The main objective of this research is to study the impact of meteorological parameters on atmospheric turbidity index on Langtang National Park (28.2112^o N, 85.5663^o E, 3862 m asl) for a period of one year (2018). Daily data of Aerosol optical depth (AOD) and meteorological parameters are obtained from AERONET and NASA website respectively. The maximum and minimum values of direct solar radiation (I_B) during the study period are found 1286 ± 24 W/m^2 in January and 1123 ± 3 W/m^2 in August respectively. The maximum and minimum value of diffuse solar radiation (I_D) is found 119 ± 21 W/m^2 in April and 59 ± 2 W/m^2 in August respectively. The annual average of direct solar radiation and diffuse solar radiation are found 1202 ± 63 W/m^2 and 90 ± 20 W/m^2 respectively. There is a negative effect of maximum temperature, minimum temperature, dew point, relative humidity, water contend and rainfall on I_B, but no significant effect of those parameters on I_D. The result of this research work is beneficial for the further identification, impact and analysis of solar radiation at different places with same geographical and meteorological condition. The study of solar radiation is important for energy harvesting and agriculture.

Key Words: Aerosol, atmospheric transmittance, diffuse solar radiation, direct radiation and meteorological parameters

Introduction

The sun is the closes star from us. It contains large amount of Hydrogen in plasma state. During thermonuclear fusion reaction, the Sun radiates 4 x 10^{26} W energy in form of electromagnetic wave of wavelength range 0.3 µm to 3µm by [1]. Orbit of the Earth around the Sun is elliptical. So solar radiation incidents on the outer layer of the atmosphere of the Earth decreases with square of the distance between the Sun and the Earth [2]. About 1367 W (solar constant, I_{sc}) of the solar energy incidents on one square meter area of outer layer of the atmosphere when the Sun and the Earth is at distance of 1AU [3]. I_o solar radiation incident on specific point of outer layer of the atmosphere depends on day number of year (DOY, n_d) [4].

$$I_o = I_{sc}\left[1 + 0.033\cos\left(\frac{360}{365}n_d\right)\right] \quad (1)$$

The solar radiation (I_o) interacts with aerosol, gas molecules, water vapor etc. of the atmosphere. The solar radiation passing through the atmosphere is scattered and absorbed. According to Beer Lambert's law, the solar radiation decreases exponentially in the atmosphere [5]. The solar radiation incidents on ground on two ways, direct and diffuse [6]. The solar radiation incident on the ground depends on physical parameters (latitude, longitude, altitude, day number of year, solar zenith angle etc.) and meteorological parameters (temperature, humidity, rainfall, dew point, local weather condition etc.) [7].

Nepal (26.36^o N to 30.45^o N, 80.06^o E to 88.2^o E) is a land-locked South East Asian mountainous country along with complex landscape, is situated between big industrial countries, India and China. The elevation of Nepal ranges from 60 m to 8848 m within a span of 200 km from south to north and about 800 km from east to west [8]. In developing countries like Nepal, the most of energy consumption is wood, agriculture residue, cow dung, and coal and petroleum product. Petroleum fuel based vehicle emits huge amount of carbon dioxide and other harmful gases such as sulpher dioxide, nitrous oxide, methane, carbon mono oxide etc. Due to the huge number of vehicles increases air pollution. Industrial byproduct of China and India directly effect on the concentration of atmospheric components above Nepal. Therefore, detail study of the solar radiation is very important.

Langtang National Park (28.2112^o N, 85.5663^o E and altitude 3862 m asl) is Nepal's first Himalayan national park. The national park lies in the districts of Nuwakot, Sindhupalchowk and Rasuwa in the central Himalayan region of Nepal [9]. It is the fourth-largest national park in Nepal that spreads over 1.7 sq.km of land. The conservation area is recorded to have over 70 glaciers of different sizes and also have Ganesh Himal and Langtang mountain ranges. The place is known for lakes lying at very high altitudes like the Gosai kunda, Surya kunda, Dudh kunda, Bhairav kunda, and Parvati kunda. The National Parke has a wide variety of climatic zones ranging from subtropical to alpine. The days are warm and sunny during April, May, October, and November [10]. The annual average value of Angstrom exponential (α), Angstrom turbidity coefficient β) and Linke turbidity factor (L_T) are found 1.04 ± 0.29, 0.03± 0.02 and 2.5 ± 0.6 respectively on 2018[11].The National park is shown in figure 1.

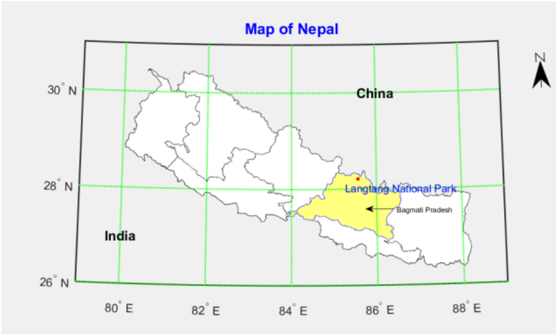


Figure.1: *Map of Langtan National Park*

Source: Survey Department, 2020

2. Materials and Methods

The solar radiation (I_o) incident on the outer layer of the atmosphere decreases exponentially due to absorption and scattering [5]. The atmospheric transmittance (τ) is ratio of the solar radiation incidents on ground (I) to that incident on outer surface of atmosphere (I_o). According to Beer's law, atmospheric transmittance is attenuated exponentially in atmosphere with extinction coefficient (k) and optical air mass (m) [12].

$$\tau = e^{-km}$$

Extinction coefficient (k) is due to ozone, water vapor, gas mixture, aerosol and Rayleigh scattering. The atmospheric transmittance is product of 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)[13]. Here τ_o depends on ozone column (l) and relative air mass (m_r). Relative air mass depends on zenith angle (θ_z), τ_w depends on water content (w) and relative air mass, τ_g and τ_r depends air mass (m_a) and these two also depend on atmospheric pressure (P), altitude and relative air mass. τ_a depends on Angstrom turbidity coefficient (β), Angstrom exponentialα) and air mass. Solar zenith angle (θ_z) depends on solar declination (δ), solar hour angle (ω) and latitude (φ) of the place. The Atmospheric transmittances are [14]

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

$$\tau_w = 1 - 2.4959\, u_1[(1 + 79.034\, u_1)^{0.682} + 6.385\, u_1]^{-1} \quad (3)$$

$$\tau_g = e^{[-0.0127\, m_a^{0.26}]} \quad (4)$$

$$\tau_a = (0.1244\, \alpha - 0.0162) + (1.003 - 0.125\, \alpha)e^{[-\beta\, m_a(1.089\,\alpha + 0.5123)]} \quad (5)$$

$$\tau_r = e^{[-0.0903\, m_a^{0.83}(1.01 + m_a - m_a^{1.01})]} \quad (6)$$

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 [15] Parameterization Model is used to predict direct solar radiation (I_B) and diffuse solar radiation (I_D). Solar radiation is

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

and

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

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

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

(9)

Here τ_{aa} is the atmospheric transmittance of aerosol absorption.

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

(10)

Here $\tau_{as} = \tau_a / \tau_{aa}$

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

(11)

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

Daily ground based data of aerosol optical depth (AOD) are collected from AERONET for Langtang National Park for 2018. Satellite based daily data of meteorological parameters (maximum temperature, minimum temperature, dew point, relative humidity and rainfall) are downloaded from NASA website. Open source software Python 3.7 is used to analysis and to plot graph. The quartiles (Q_1, Q_2, Q_3), skewness (γ_1) and kurtosis (γ_2) are used are used to analyzed distribution of data [16]. Standard error (SE) is used as error bar in graph. Data presented in forms of 'mean ($\bar{x}$) ± standard deviation (σ)'.

$$SE = \frac{\sigma}{\sqrt{n}} \quad (12)$$

Here n is the number of data. Correlation coefficient (r) is used to find relation between two variable x and y. Its value lies between -1 to +1.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (13)$$

3. Results and Discussion

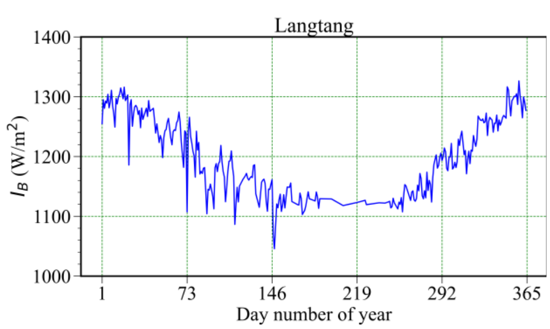
Daily data of aerosol optical depths (AOD) are downloaded from AERONET website for Langtang Nationa Park for year 2018. The available aerosol optical depth (AOD) for wavelength (λ) 675, 500, 440, 380 and 340 nm was consider for the investigation. We calculated important parameters Angstrom exponential (α) and Angstrom coefficient of turbidity (β) by using linear regression method under Angstrom model [17], given as

$$AOD = \beta\lambda^{-\alpha}$$

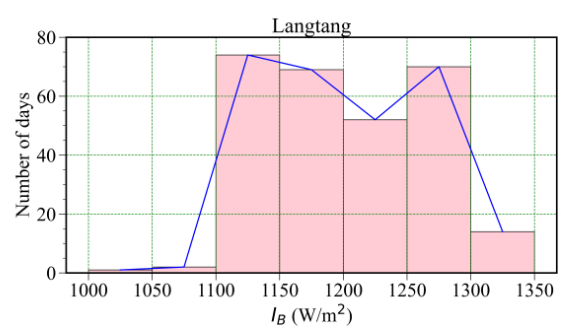
The daily direct solar radiation (I_B) and diffuse solar radiation (I_D) are calculated by using equations (1) to (11). Correlation coefficient of direct and diffuse solar radiation with meteorological parameters is calculated by using equation (13).

Variation of direct solar radiation

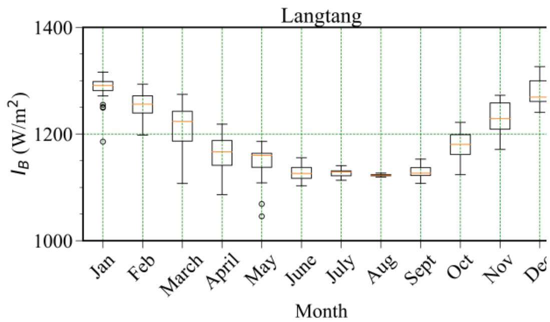
The figure 2(a) shows daily variation of direct solar radiation (I_B) and figure 2(b) shows corresponding histogram. The maximum and minimum value of I_B during study period of 2018 are found 1326 W/m^2 on 359th day of year due to clear day and 1046 W/m^2 on 149th day of year due to cloudy day respectively. The annual mean and standard deviation are found 1202 W/m^2 and 63 W/m^2 respectively. The solar radiation values in first quartile (Q_1), second quartile (Q_2, median) and third quartile (Q_3) are found 1145 W/m^2, 1197W/m^2 and 1260 W/m^2 respectively. Skewness (γ_1) and kurtosis (γ_2) are found 0.06 and -1.18 respectively. The distribution of I_B is slightly symmetric with low value peak. Out of 282 days of study period, 70 days has direct solar radiation between 1250 W/m^2 to 1300 W/m^2. The figure 2(c) shows monthly variation of direct solar radiation (I_B). The maximum and minimum value of I_B during the study period is found 1286 ± 24 W/m^2 in January and 1123 ± 3 W/m^2 in August respectively. Variation direct solar radiation is large in March due to large value of standard deviation 37 W/m^2 and less in August due less value in standard deviation 3 W/m^2. Figure 2(d) shows seasonal variation of direct solar radiation (I_B). The maximum and minimum value of I_B during the study period are found 1274 ± 22 W/m^2 in winter and 1126 ± 12 W/m^2 in summer respectively. Variation is large in spring due to large value of standard deviation 345 W/m^2 and less in summer due less value in standard deviation 12 W/m^2.



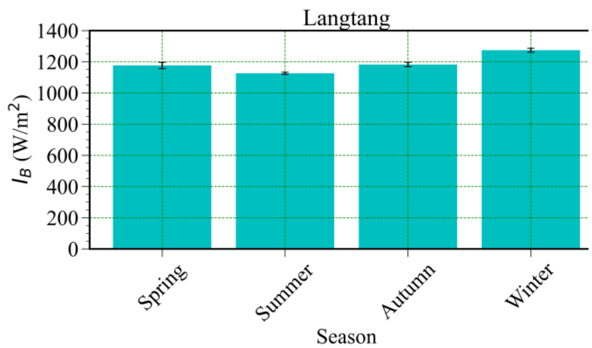
a)Daily variation



b)Histogram



c)Monthly

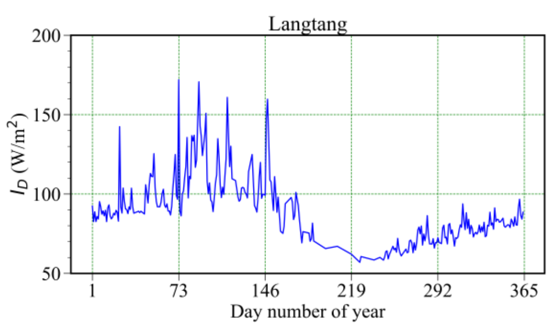


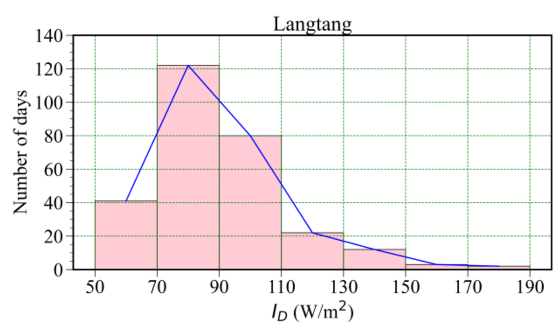
d)Seasonal

Figure.2: *Variation of direct solar radiation (I_B)*

Variation of diffuse solar radiation

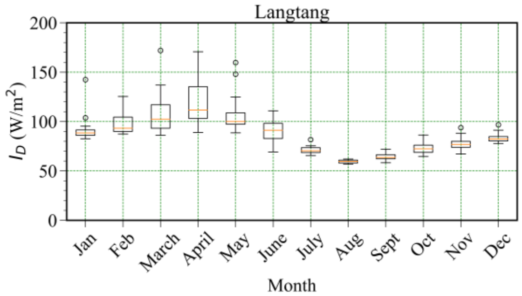
The figure 3(a) shows daily variation of diffuse solar radiation (I_D) and figure 3(b) shows corresponding histogram. The maximum and minimum value of I_D during study period of 2018 are found 172 W/m^2 on 74th day of year due to cloud and 57 W/m^2 on 227th day of year due to clear day respectively. The annual mean and standard deviation are found 90 W/m^2 and 20 W/m^2 respectively. The solar radiation value in the first quartile (Q_1), second quartile (Q_2) and third quartile (Q_3) are found 76 W/m^2, 88 W/m^2 and 100 W/m^2 respectively. Skewness (γ_1) and kurtosis (γ_2) are found 1.22 and 2.04.18 respectively. The distribution of I_D is positively tailed with low value peak. The distribution is not normal. Out of 282 days of study period, 122 days has diffuse solar radiation between 70 W/m^2 to 90 W/m^2. Figure 3(c) shows monthly variation of diffuse solar radiation (I_D). The maximum and minimum value of I_D during the study period is found 119 ± 21 W/m^2 in April and 59 ± 2 W/m^2 in August respectively. Variation is large in April due to large value of standard deviation 21 W/m^2 and is less in August due less value in standard deviation 2 W/m^2. Figure 3(d) shows seasonal variation of diffuse solar radiation (I_D). The maximum and minimum value of I_D during the study period is found 301 ± 99 W/m^2 in spring and 147 ± 43 W/m^2 in summer respectively. Variation of I_D is large in spring due to large value of standard deviation 99 W/m^2 and less in summer due less value in standard deviation 43 ± W/m^2.

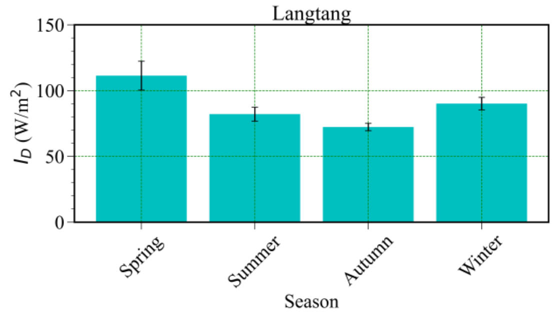




a)Daily variation

b)Histogram





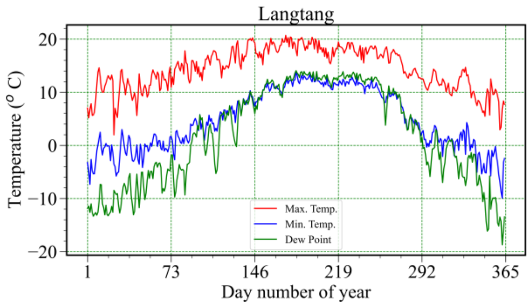
c)Monthly variation

d)Seasonal variation

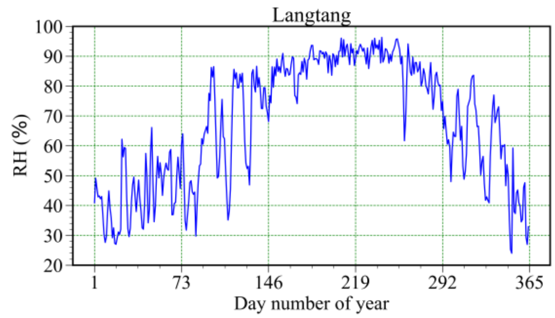
Figure 3: *Variation of diffuse solar radiation (I_D)*

Variation of solar radiation with meteorological parameters

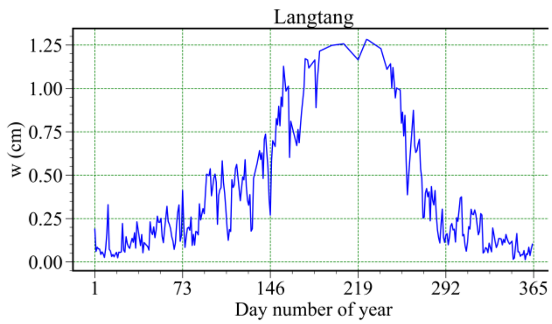
The figure 4(a) demonstrates daily variation of maximum temperature, minimum temperature and dew point. The highest value of maximum temperature is 20.7^o C on June 23, hottest day of the year. The annual average of maximum temperature is 14.4 ± 3.9^o C. The lowest value of minimum temperature is -9.9^o C on December 29, coldest day of the year. The annual average of minimum temperature is 4.7 ± 5.6^o C. The annual average of dew point is 1.8 ± 9.1^o C. Figure 5(a) shows correlation coefficient (r) of solar radiation with numerological parameters. The correlation coefficient of maximum temperature, minimum temperature and dew point with I_B are -0.74, -0.85 and -0.89 respectively. There is negative correlation of maximum temperature, minimum temperature and dew point with I_B. The correlation coefficient of maximum and minimum temperature and dew point with I_D are -0.01, -0.14 and -0.17 respectively. No significant effect of temperature and dew point on I_D. Figure 4(b) shows daily variation of relative humidity (RH). The annual average of RH is 67.7 ± 20.8 %. The correlation coefficient of RH with I_B and I_D are -0.78 and -0.26 respectively. There is negative effect of RH on I_B but no significant effect of RH on I_D. Figure 4(c) shows daily variation of water content (w). The annual average of w is 0.35 ± 0.32 cm. The correlation coefficient of w with I_B and I_D and is -0.81 and -0.13 respectively. There is negative effect of w on I_B but no significant effect of w on I_D. Figure 4(d) shows monthly variation of rainfall. The annual rainfall is 831.4 mm. The correlation coefficient of rainfall with I_B and I_D are -0.73 and -0.32 respectively. There is negative effect of rainfall on I_B but no significant effect of rainfall on I_D.



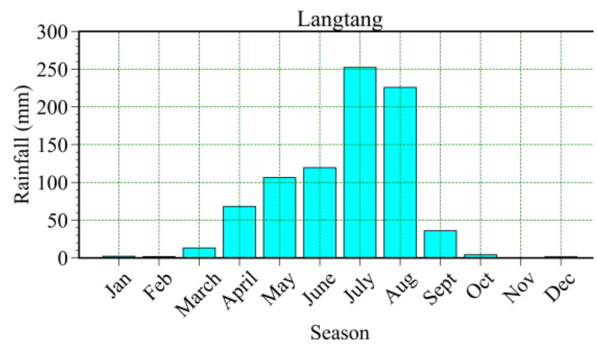
a)Maximum temperature, minimum temperature, dew point



b)Relative humidity



c) Water contend (w)



d)rainfall

Figure 4: *Variation of meteorological parameters*

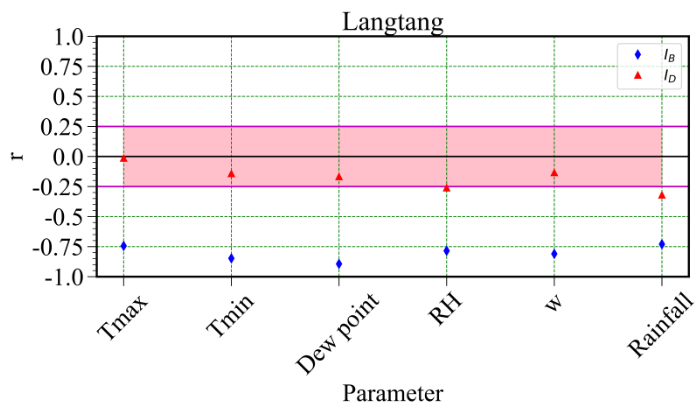


Figure 5: *Correlation coefficient of meteorological parameters with solar radiation*

Conclusion

Datasets on solar radiation are of great importance to the detection of global dimming and brightening. Direct solar radiation and diffuse solar radiation predicted using easily available satellite data on basis of atmospheric transmittance. They are therefore important to propose solar energy potential of the location, the sustainable development of ecological environments and agriculture based productivity. In study period of one year (2018) for Langtang National Park, the annual average of direct solar radiation and diffuse solar radiation are found 1202 ± 63 W/m^2 and 90 ± 20 W/m^2 respectively. The Annual average of direct solar radiation is compared with Jomsomof 2012 and Pokhara mof 2017. The value of Jomsom was found 1106 ± 70 W/m^2 [18] and Pokhara was found 808.1± 133.7 W/m^2 [19] respectively. Also the annual average of diffuse solar radiation on Beijing and Lasa of China were found 6.6 MJ/m^2/day (7.6 W/m^2) and 6.1 MJ/m^2/day (7.1 W/m^2) respectively from 1993 to 2015[20]. The diffuse solar radiation is large on Langtang National Park than that on big city, Beijing and Lasa, China but less than on Pokhara.

In the case of Langtang National Park, we observed that the maximum and minimum temperature, dew point, relative humidity, water contend and rainfall affect negatively on direct solar radiation but no effect of any meteorological parameters on diffuse solar radiation.

Acknowledgment

We the authors would like to convey our gratitude to faculty of CDP, Patan Multiple Campus, IoST for this opportunity as well as NASA and AERONET for the data. We sincerely appreciate NAST for the PhD fellowship. We also like to acknowledge Nepal Physical Society (NPS) and Association of Nepali Physicists in America (ANPA) for educational workshop of Python.

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