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Comparative study of solar radiation at four sites of Nepal: A case study

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Abstract

Solar radiation data are of great important for solar energy systems. This study aimed to compare solar radiation at Manang, Kathmandu Val-ley, Nepalgunj and Biratnagar. Daily data of global solar radiation (H_g) measured by CMP6 pyranometer are received from Department of Hydrology and Meteorology of Nepal. Coefficient of variance, skewness, kurtosis and Fourier series are used to analyze the solar radiation. Daily, monthly and seasonal analysis are done. Global solar radiation are found maximum (18.6 ± 6.7 MJ/m^2/day) at Manang and minimum (14.1 ± 4.1 MJ/m^2/day) at Biratnagar. Solar radiation is more deviated at Manang whereas less deviated at Kathmandu Valley. Solar radiation is maximum in spring and mini-mum in winter at four sites. H_g is mostly seasonally dependent at Nepalgunj but less dependent at Biratnagar. The present research will help to advance the state of knowledge of global solar radiation in energy harvesting and agriculture.

Keywords:

Coefficient of variance, Fourier series, kurtosis, quartile, skewness.

Introduction

The Sun is major source of energy for the Earth. The Sun is in plasma state. Energy of the Sun is due to thermonuclear fusion reaction. The Sun radiates 4×10^{26} W energy in form of electromagnetic wave of wave length ranging 100 to 4000 nm [1]. Out of that solar energy, 1367 W incidents on one square meter area of outer layer of the atmosphere when the Earth is at distance 1.49×10^{8} km from the Sun [2]. The Earth moves around the Sun in elliptical orbit. Extra terrestrial solar radiation (H_0) is solar energy incident on one square area of the outer most layer of the atmosphere at particular time. When that solar radiation enter in atmosphere, absorption and scattering occur due to interaction with components of the atmosphere [3]. The solar radiation reduces in the atmosphere [4]. Solar radiation incident on the ground is due to direct and diffusion of solar radiation. Global solar radiation (H_g) is sum of direct solar radiation and diffuse solar radiation [5].

Nepal (lat.: 26.36° N to 30.45° N, long.: 80.06° E to 88.2° E, altitude: 58 m to 8848 m a.s.l.) is a land locked south east mountainous Asian country with a large area of beautiful landscape. Within this small and beautiful setting it possesses diversity in biosphere and variation of climate. Nepal can be divided ecologically, into three main regions. Among the three regions, the lowland which represents the Terai, Chure and some parts of Mahabharat ranges (60 m to 610 m), the second region is midland, it includes the middle hills, complex terrain, valleys, doons and Mahabharat ranges (610 m to 2750 m) and the third one region is situated at highland, it covers the great Himalaya region above 2750 m [6]. Nepal lies in sun belt (latitude 15° to 35°). Annual solar isolation is 3.6 to 6.2 kWh/m^2/day and sunshine duration is 300 days in Nepal [7]. Nepal has a population of 27.16 millions as in 2021[8]. In terms of energy consumption, the country used about 64 % sourced from conventional resources like wood, animal dung, and agricultural residues [9]. 61 % energy is used in residential purpose i.e. cooking. We try to reduce that energy by promoting clean and green solar energy. It is essential to reduce import of petroleum product which spend large amount of hard earn foreign currency.

Materials and Method

Four research sites are selected on basis of altitude. Manang is highland, Kathmandu Valley is midland. Nepalgunj and Biratnagare is lowland.

Manang (28.64°N, 84.09°E, 3353 m a.s.l.) is high land in Gandaki Pradesh.The annual mean of maximum temperature and minimum temperature were -1.8 an 13.8°C respectively and the annual rainfall was 467.1 mm in 2018 [9]. Area, Population and population density of Manang district are 2246 sq.km, 5658 and 6 per square km. respectively in 2021 [8].

Kathmandu Valley (27.72° N, 85.37° E, 1337 m a.s.l.) is combination of Kathmandu, Lalitpur and Bhaktpur district in Bagamati Pradesh. It covers an area of 893 square kilometers and is bowl-shaped. The central lower part of the Kathmandu Valley sits at an elevation of 1,425 m above sea level. The valley is encircled by four mountain ranges: Shivapuri Nagarjun National Park to the north (elevation 2,732 m), Phulchowki to the south (2,695 m), Nagarjun Hill to the northwest (2,095 m), and Chandragiri to the west (2,551 m). The average maximum temperature and minimum temperature were 26.0 an 12.5°C respectively and the annual rainfall was 1517.1 mm on 2020 [10]. Area, population and population density of Kathmandu valley are 899 sq.km, 3025386 and 337 per square km. respectively in 2021 [8].

Nepalgunj (28.10°N, 81.67°E, 165 m a.s.l.) is sub-metropolitan city in Banke district of Lumbini Pradesh.The annual mean of maximum temperature and minimum temperature were 19 an 30.2°C respectively and the annual rainfall was 1126.8 mm in 2018 [10]. Area, Population and population density of Banke district are 2337 sq.km, 603194 and 258 per square km. respectively in 2021 [8]. Nepalgunj recorded an annual average of global solar radiation 12.9 MJ/m^2/day [11] at 2011.

Biratnagar (26.48°N, 87.27°E, 72 m a.s.l.) is Eastern metropolitan city of the country, the capital of Koshi Pradesh. It lies in Morang district. The city lies in subtropic climate zone. The annual mean of maximum temperature and minimum temperature were 30.4 an 19.2°C respectively and the annual rainfall was 2580.1 mm in 2020 [10]. Area, Population and population density of Morang district are 1855 sq.km, 1148156 and 6197 per square km. respectively in 2021 [8]. Biratnagar receive annual average of solar energy 4.95 kWh/m^2/day [12] at 2011.

Research sites are shown in Figure 1.

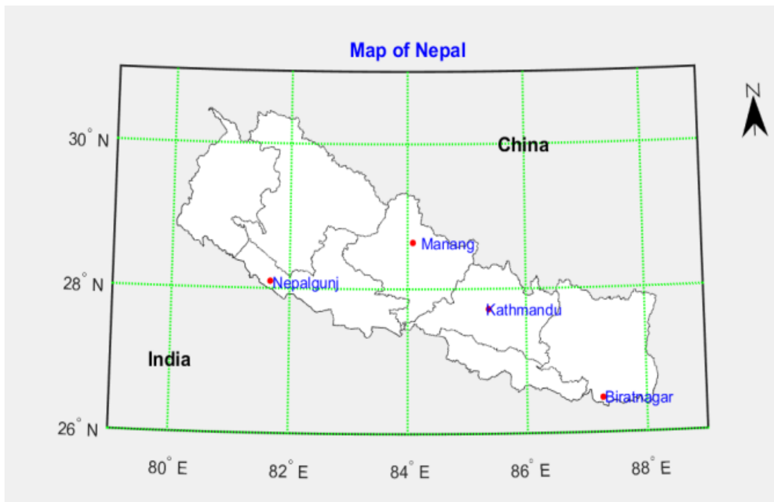


Figure 1: *Map* of research sites [source: survey department, Gov, 2020]

The daily data of global solar radiation (H_g) is received from Department of Hydrology and meteorology (DHM), Government of Nepal for a period of one year 2018. The global solar radiation on a horizontal surface was measured by using first class CMP6 pyranometer in W/m^2 with field of view 180°. It has thermocouple as sensor. It works on principle of Seebeck effect. When solar radiation incidents on sensor, temperature different is developed across the thermocouple. The temperature different develop the potential different across the thermocouple [13]. The diagram of CMP6 pyranometer is given in Figure 2

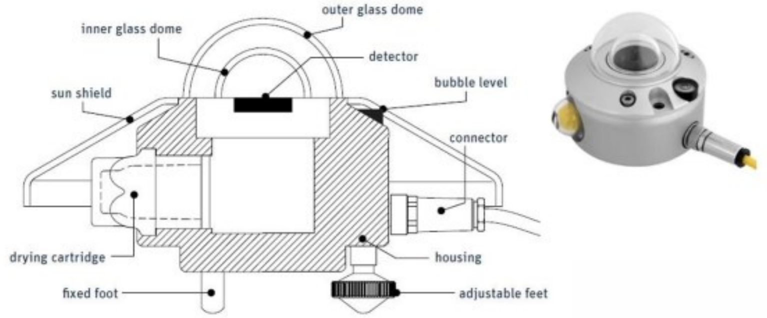


Figure 2: *CMP6 pyranometer[13]*

Open source software python 3.7 is used on Jupyter note of Anaconda plate form to analysis data and to plot graph [14]. Data presented in forms of '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 [15]. Q_1, Q_2, Q_3 give 25, 50 and 75 % of global solar radiation.

$$\gamma 1 = \sqrt{\frac{\mu_3^2}{\mu_2^3}} \quad (1)$$

$$\gamma 2 = \frac{\mu_4}{\mu_2^2} - 3 \quad (2)$$

where μ_2, μ_3 and μ_4 are second, third and forth moment about mean respectively. Skewness and kurtosis give nature of distribution of global solar radiation. If γ_1 is negative, distribution of H_g is negatively tailed and $\gamma 1$ is positive, distribution of H_g is positively tailed. If γ_2 is negative, distribution of H_g has low value peak (platykurtic), γ_2 is positive, distribution of H_g has high value peak (leptokurtic) and γ_2 is zero, distribution of H_g is Gaussian (mesokurtic). Coefficient of variance (CV) is used to check variability of global solar radiation.

$$CV = \frac{\sigma}{\bar{x}} x100 \quad (3)$$

If CV is greater than 20 %, distribution of H_g is highly scattered. Standard error (SE) is used as error bar in graph.

$$SE = \frac{\sigma}{\sqrt{n}} \quad (4)$$

Here n is number of data. Fourier series is used to analysis seasonal variation of time series data [16].

$$H_{gs} = a_0 + a_1 \cos\left(\frac{2\pi}{365} n_d\right) + b_1 \sin\left(\frac{2\pi}{365} n_d\right) \quad (5)$$

a_0 and $\sqrt{a_1^2 + b_1^2}$ are offset and amplitude of seasonal component respectively.

Results and Discussion

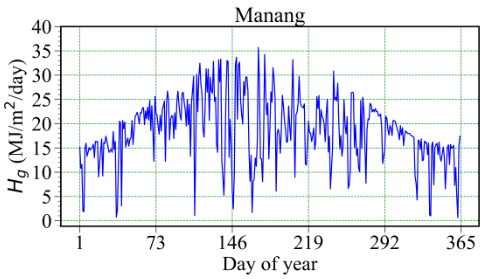
The daily ground based data of global solar radiation (H_g) is received from Department of Hydrology and meteorology (DHM), Government of Nepal for a period of one year 2018. The skewness (γ_1) and kurtosis (γ_2) are calculated by using equation (1) and (2). Figure 3(a) and 4(a) show daily variation and histogram of global solar radiation (H_g) at Manang. The maximum and minimum value of H_g are 35.7 and 0.6 MJ/m^2/day in 21 May and 29 December 2018 respectively. Mean ($\bar{x}$) and standard deviation (σ) are 18.6 and 6.7 MJ/m^2/day respectively. Coefficient of variance (CV) is 36 %. First quartile (Q_1), second quartile (Q_2) and third quartile (Q_3) are found 14.8, 18.5 and 23.1 MJ/m^2/day respectively. The skewness (γ_1) and kurtosis (γ_2) are found -0.16 and 0.20 respectively. Distribution of H_g at Manang is negatively tailed and has slightly high value peak. As $\gamma 2$ is nearly equal to zero, χ^2 test is done by using formula given below.

$$\chi^2 = \sum_{1=1}^{n} \frac{(O_i - E_i)^2}{E_i} \qquad (6)$$

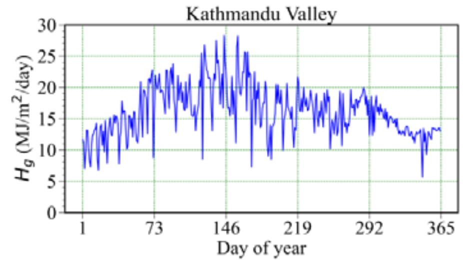
Here O_i and E_i are observed and expected frequency in i^{th} day respectively. The calculated value of χ^2 is 15.2 whereas table value of χ^2 for 95 % confident level at 7 degree of freedom is 2.1. As calculated value is greater than table value, distribution of Hg is not Gaussian (normal). Out of 365 days, 118 days has H_g between 15 to 20 MJ/m^2/day. Figure 3(b) and 4(b) show daily variation and histogram of H_g at Kathmandu Valley. The maximum and minimum value of H_g are 28.3 and 5.7 MJ/m^2/day in 25 May and 15 December 2018 respectively. Mean and standard deviation are 16.2 and 4.0 MJ/m^2/day respectively. Coefficient of variance is 25 %. First quartile (Q_1), second quartile (Q_2) and third quartile (Q_3) are found 13.1, 16.1 and 18.7 MJ/m^2/day respectively. γ_1 and γ_2 are found 0.28 and 0.02 respectively. Distribution of H_g at Kathmandu Valley is positively tailed and has slightly high value peak. As γ_2 is nearly equal to zero, χ^2 test is done by using equation (6). Calculated value of χ^2 is 106 whereas table value of χ^2 for 95 % confident level at 7 degree of freedom is 2.1. As calculated value is greater than table value, distribution of H_g at Kathmandu Valley is not Gaussian (normal). Out of 365 days, 157 days has H_g between 15 to 20 MJ/m^2/day.

Figure 3(c) and 4(c) show daily variation and histogram of H_g at Nepalgunj. Maximum and minimum value of Hg are 27.9 and 3.2 MJ/m^2/day in 15 June and 25 June 2018 respectively. Mean and standard deviation are 16.6 and 5.4 MJ/m^2/day respectively. CV is 33 %. Q_1, Q_2 and Q_3 are found 12.4, 16.0 and 21.3 MJ/m^2/day respectively. γ_1 and γ_2 are found 0.02 and -0.87 respectively. Distribution of H_g at Nepalgunj is positively tailed and has slightly low value peak. Out of 365 days, 116 days has H_g between 10 to 15 MJ/m^2/day.

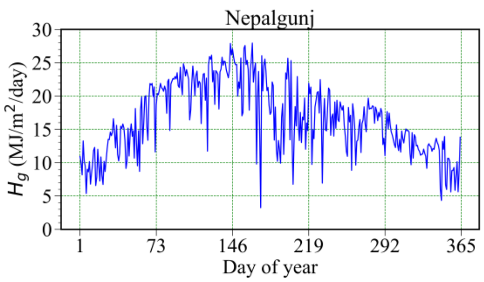
Figure 3(d) and 4(d) show daily variation and histogram of H_g at Biratnagar. Maximum and minimum value of H_g are 25.8 and 3.5 MJ/m^2/day in 10 June and 25 January 2018 respectively. Mean and standard deviation are 14.1 and 4.1 MJ/m^2/day respectively. CV is 29 %. Q_1, Q_2 and Q_3 are found 11.1, 14.2 and 17.2 MJ/m^2/day respectively. $\gamma 1$ and γ_2 are found -0.07 and -0.59 respectively. Distribution of H_g at Biratnagar is negatively tailed and has slightly low value peak. Out of 365 days, 139 days has H_g between 15 to 20 MJ/m^2/day. Statistical value of global solar radiation is shown in Table 1.



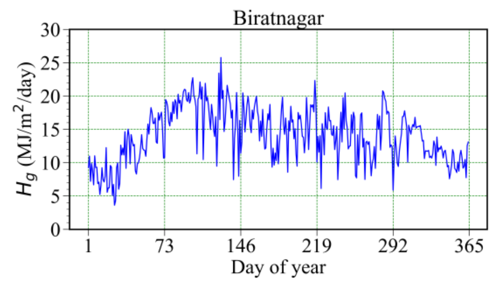
a) Manang



b)Kathmandu Valley



c) Nepalgunj

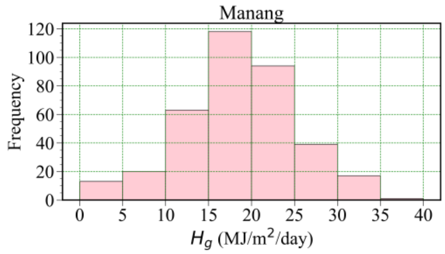


d)Biratnagar

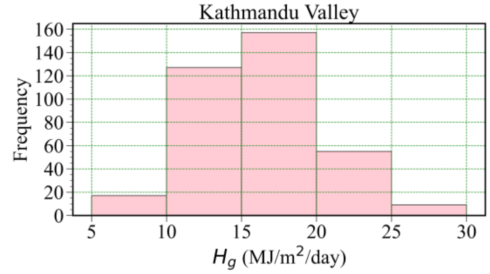
Figure 3: *Daily variation of global solar radiation (H_g)*

Table 1: *Statistical value of solar radiation*

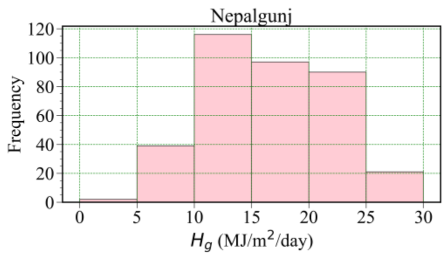
Parameter	Manang	Kathmandu Valley	Nepalgunj	Biratnagar
$\bar{x}$ (MJ/m^2/day)	18.6	16.2	16.6	14.1
σ (MJ/m^2/day)	6.7	4.0	5.4	4.136
CV (%)	36	25	33	29
Q_1 (MJ/m^2/day)	14.8	13.1	12.4	11.1
Q_2 (MJ/m^2/day)	18.5	16.1	16.0	14.2
Q_3 (MJ/m^2/day)	23.1	18.7	21.3	17.2
$\gamma 1$ (unitless)	-0.16	0.28	0.02	-0.07
γ_2 (unitless)	0.20	0.02	-0.86	-0.59



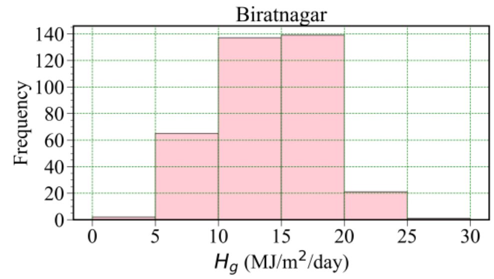
a) Manang



b)Kathmandu Valley



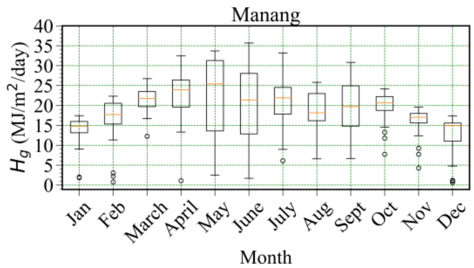
c) Nepalgunj



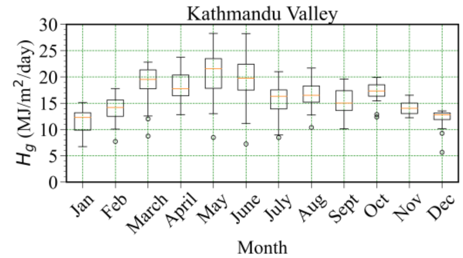
d)Biratnagar

Figure 4: *Histogram of global solar radiation (H_g)*

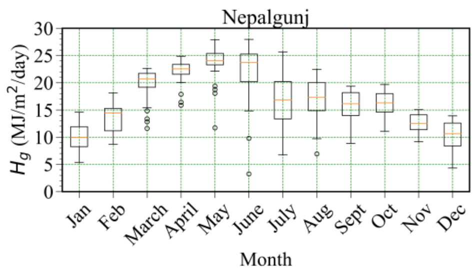
Figure 5(a) indicates monthly variation of global solar radiation (H_g) at Manang. Maximum and minimum monthly average of H_g are 22.1 ± 6.1 MJ/m^2/day and 12.2 ± 4.8 MJ/m^2/day in April and December respectively. CV is maximum 45 % in June and minimum 16 % in March. Figure 5(b) indicates monthly variation of global solar radiation (H_g) at Kathmandu Valley. Maximum and minimum monthly average of H_g are 20.9 ± 4.2 MJ/m^2/day and 11.5 ± 2.4 MJ/m^2/day in May and January respectively. CV is maximum 22 % in June and minimum 11 % in October. Figure 5(c) indicates monthly variation of H_g at Nepalgunj. Maximum and minimum monthly average of H_g are 23.6 ± 3.1 MJ/m^2/day and 10.0 ± 2.4 MJ/m^2/day in May and January respectively. CV is maximum 28 % in July and minimum 10 % in March. Figure 5(d) indicates monthly variation of H_g at Biratnagar. Maximum and minimum monthly average of H_g are 19.0 ± 2.7 MJ/m^2/day and 7.8 ± 2.1 MJ/m^2/day in April and January respectively. CV is maximum 25 % in October and minimum 14 % in March.



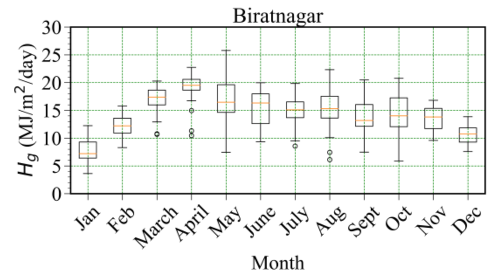
a) Manang



b) Kathmandu Valley



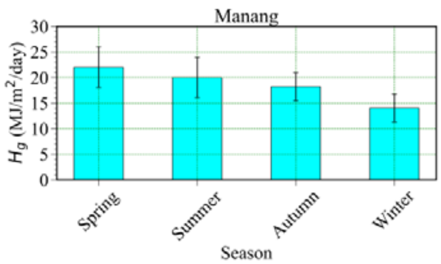
c) Nepalgunj



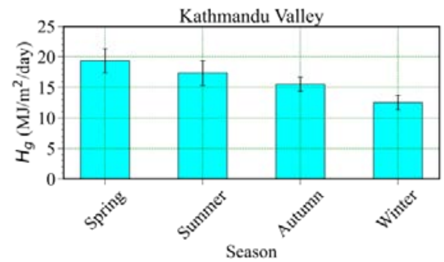
d)Biratnagar

Figure 5: *Monthly variation of global solar radiation (H_g)*

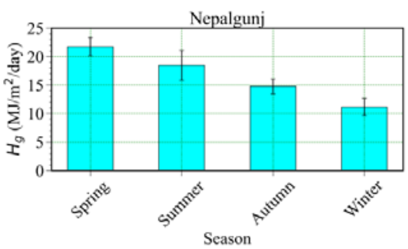
Figure 6(a) indicates seasonal variation of global solar radiation (H_g) at Manang. Maximum and minimum seasonal average of H_g are 22.0 ± 6.8 MJ/m^2/day and 14.0 ± 4.7 MJ/m^2/day in spring and winter respectively. CV is maximum 34 % in summer and minimum 26 % in autumn. Figure 6(b) indicates seasonal variation of global solar radiation (H_g) at Kathmandu Valley. Maximum and minimum seasonal average of H_g are 19.3 ± 3.5 MJ/m^2/day and 12.5 ± 2.1 MJ/m^2/day in spring and winter respectively. CV is maximum 20 % in summer and minimum 13 % in autumn. Figure 6(c) indicates seasonal variation of H_g at Nepalgunj. Maximum and minimum seasonal average of H_g are 21.7 ± 2.1 MJ/m^2/day and 11.1 ± 2.6 MJ/m^2/day in spring and winter respectively. CV is maximum 25 % in summer and minimum 15 % in autumn. Figure 6(d) indicates seasonal variation of H_g at Biratnagar. Maximum and minimum seasonal average of H_g are 17.5 ± 3.2 MJ/m^2/day and 10.1 ± 1.8 MJ/m^2/day in spring and winter respectively. CV is maximum 22 % in autumn and minimum 18 % in spring.



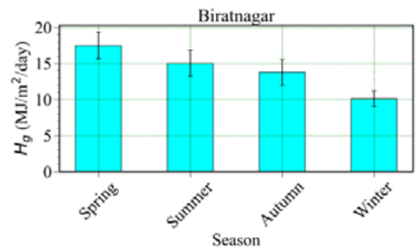
a) Manang



b)Kathmandu Valley



c) Nepalgunj

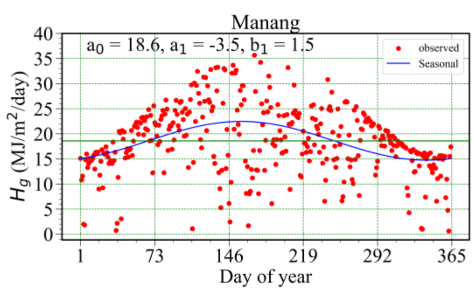


d)Biratnagar

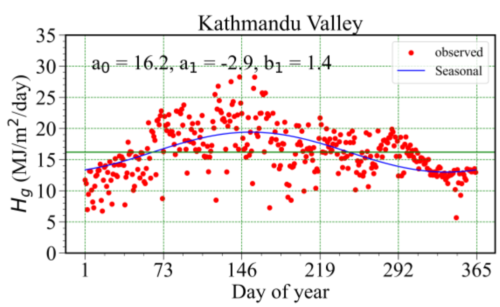
Figure 6: Seasonal *variation of global solar radiation (H_g)*

H_g is fitted in Fourier series by using Equation (5) to analyze seasonal. Figure 7(a) shows Fourier series in Manang. Offset (a_0) and amplitude of seasonal component ($\sqrt{a_1^2 + b_1^2}$) are found 18.6 and 3.8 MJ/m^2/day respectively. Figure 7(b) shows Fourier series in Kathmandu Valley. Offset (a_0) and amplitude of seasonal component are found 16.2 and 3.2 MJ/m^2/day respectively. Figure 7(c) shows Fourier series in Nepalgunj. Offset and amplitude of seasonal component are found 16.6 and 5.5 MJ/m^2/day respectively. Figure 7(d) shows Fourier series in Biratnagar. Offset and amplitude of seasonal component are found 14.1 and 3.0 MJ/m^2/day respectively. The offset (a_0) and amplitude of seasonal

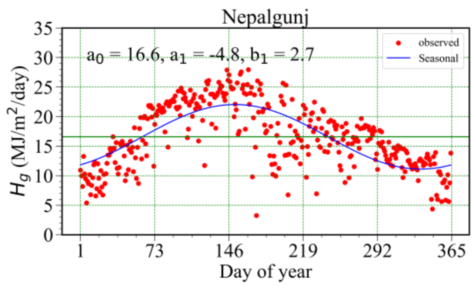
component ($\sqrt{a_1^2 + b_1^2}$)of H_g at four sites are shown in Table 2.



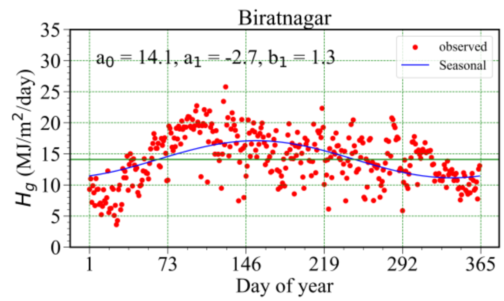
a) Manang



b)Kathmandu Valley



c) Nepalgunj



d)Biratnagar

Figure 7: *Fourier series of global solar radiation (H_g)*

Table 2: *Fourier coefficient of solar radiation*

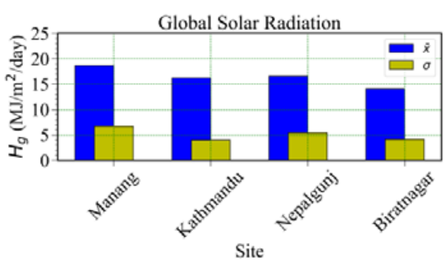
Site	a_0 (MJ/m^2/day)	$\sqrt{a_1^2 + b_1^2}$ (MJ/m^2/day)
Manang	18.6	3.8
Kathmandu Valley	16.2	3.2
Nepalgunj	16.6	5.5
Biratnagar	14.1	3.0

Annual mean ($\bar{x}$) and standard deviation (σ) of global solar radiation at four research site is shown in Figure 8(a). The annual mean is maximum at Manang where as minimum at Biratnagar. Standard deviation is maximum at Manang and minimum at Kathmandu valley. CV is maximum at Manang and minimum at Kathmandu Valley. Pokhara and Lukla receive annual average solar energy of 5.44 and 4.61 kWh/m^2/day respectively [12]. The solar radiation of 4.7 ± 1.6 kWh/m^2/day is found at Simikot from 2012 to 2015[17].

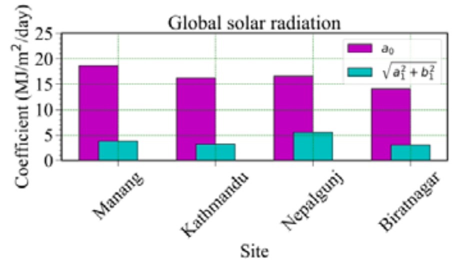
Fourier coefficient is shown in Figure 8(b). According to Fourier analysis, offset (a_0) is maximum at Manang whereas minimum at Biratnagar. Amplitude of seasonal component ($\sqrt{a_1^2 + b_1^2}$) is maximum at Nepalgunj and minimum at Biratnagar. Correlation coefficient (r) of global solar radiation with, latitude, longitude and altitude of four research sites are calculated by using formula given below.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (7)$$

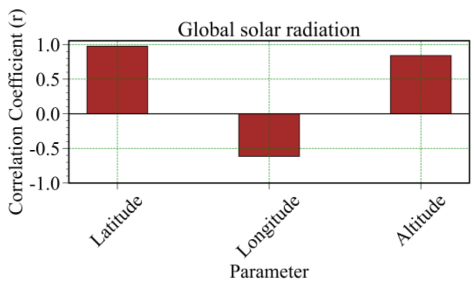
Correlation coefficient of H_g with latitude, longitude and altitude are found 0.97, -0.61 and 0.85 respectively. Global solar radiation increases with increase in latitude and altitude but decreases with longitude.



a) Mean and standard deviation of H_g



b) Fourier coefficient of H_g



c) Correlation coefficient of H_g

Figure 8: *Global solar radiation (H_g)*

Conclusions

During study period of 2018, annual average of global solar radiation are found 18.6 ± 6.7, 16.2 ± 4.0, 16.6 ± 5.4 and 14.1 ± 4.1 MJ/m^2/day at Manang, Kathmandu Valley, Nepalgunj and Biratnagar respectively. Solar radiation is more deviated at Manang due to high mountain whereas less deviated at Kathmandu Valley due to Valley structure. Among four research sites, solar radiation is maximum in spring and minimum in winter. It is mostly seasonally dependent at Nepalgunj but less dependent at Biratnagar.

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