Study of Impact of Meteorological Parameters on Atmospheric Transmittance of Solar Radiation over Jumla

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CONFLICT OF INTEREST: None

ABSTRACT

This paper reports the variation of atmospheric transmittance with meteorological parameters over Jumla (Lat.29.28°N, Long.:82.16°E and Alt.: 2300 m above sea level) from 2011 to 2013 (three years) by using CMP6 pyranometer and satellite data. The trends of monthly and seasonal variations of atmospheric transmittance, solar insolation and clearness index have been analyzed. The result exemplifies that during the study period, average value of global solar radiation, solar insolation and clearness index are 19.26 ±3.88 MJ/m^2/day, 4.95±1.14 kWh/m^2/day and 0.59 ±0.12 respectively. The average value of atmospheric transmittance during the whole study period is 0.60± 0.11. The average value of atmospheric transmittance of ozone, Rayleigh scattering, gas mixture ,water vapor and aerosol are 0.9830±0.0007, 0.8999±0.0178, 0.9875± 0.0007, 0.8839±0.0101 and 0.7836±0.0909 respectively. There is positive correlation of relative sunshine hour and negative correlation of rain fall with atmospheric transmittance. Result of this research work is beneficial for the further analysis of solar radiation at different places improving life of flora and fauna and protecting the whole environment.

Keywords: Clearness index, Global solar radiation, Meteorological parameters, Solar insolation

1. INTRODUCTION

The Sun is the closest star from The Earth. The main source of energy of the Sun is thermonuclear fusion reaction. Four hydrogen nucleus combine and form helium nucleus on emission 26.7MeV energy in form of electromagnetic wave of wave length range 0.3 μm to 3 μm (Poudyal *et al.* 2011). The Sun radiates 4×1026J energy per second (Wallace & Hobbs 2006). Average solar radiation

1367W/m^2 (solar constant, Isc) (Duffie & Beckman 2013) incidents on outer layer of the atmosphere when the Earth is at mean distance 1.49×108km from the Sun. As orbit of the Earth around the Sun is elliptical, the solar energy incident on specific point of outer atmosphere (Ho) is inversely proportional to square of distance between the Sun and the Earth at specific time. The solar energy passing through the atmosphere is scattered and absorbed by molecules and particles. The solar energy interacts with large particle of the atmosphere such as water droplets, dust and aerosol. By Beer Lambert's law, solar radiation decreases exponentially with extinction coefficient (k) and optical air mass(m) in the atmosphere, the solar radiation on ground(Hg) is given by(Iqbal 1983;Liou 2002)

$$H_g=H_o\, e^{-Km}$$

Ratio of Hg to Ho is atmospheric transmittance (τ) or clearness index (K_T).

The solar energy is the fundamental as well as primary source of energy for the Earth. Study of atmospheric transmittance and its effect of different meteorological parameters are used in different area: Agriculture, Hydrology, Climate change and so on. The solar radiation on ground depends on different physical parameters (latitude, longitude, altitude, aerosol, cloud, absorption, ozone and albedo) and meteorological parameters (precipitation, ambient temperature, wind speed, humidity, local weather conditions and seasonal variation).

Nepal is a land-locked South East Asian mountainous country with area of beautiful landscape situated between latitudes of 26.36ºN to 30.45ºN and longitudes of 80.06ºE to 88.2º E. The elevation of the country ranges from 60m to 8848m within a span of less than 200 km from south to north and about 800km from east to west (Majupuria 1999). In fiscal year 2010/2011, 425TJ energy is consumed in Nepal (MoF 2010/011). Out of that energy, tradition fuel is 83.7 percentages, commercial fuel is 15.5 percentages and renewable energy is 0.8 percentage. Large amount of petroleum oil are used in vehicle and domestic fuel. Combustion of petroleum oil produces air pollution. Nepal is situated between two big industrial countries India and China and their industrial byproduct can directly affect the atmosphere above Nepal. Therefore, detail study of atmospheric transmittance is very important.

Jumla (Lat.:29.28º N, Long.: 82.16º E and Alt.: 2300 m a.s.l.) situates in Himalayan mountainous region in the Mid-Western region of Nepal, covers area 2,531 sq. km is shown in Fig.1.Population and population density are 108,921 and 43 per sq.km respectively (CBS 2011). Rara Lake, largest of lake of Nepal lies in this region at an altitude of 2,990 m above sea level. t lies in alpine climatic zone (Adhikari *et al.* 2013). The annual average measured value of global solar radiation(GSR) is 19.90±0.66 MJ/m^2/day in Jumla for 2011 (KC *et al.* 2016).

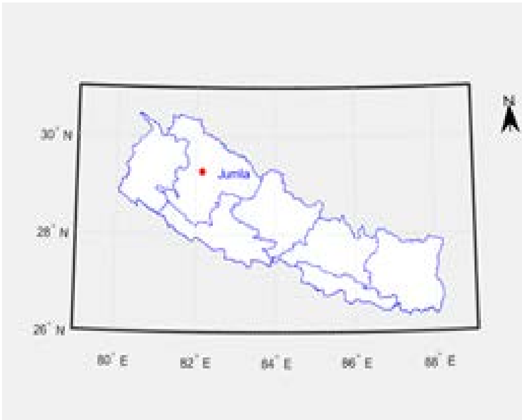


Fig.1:Map of Jumla [source: Department of Survey, 2020]

2. MATERIALS AND METHODS

Extinction of solar radiation (k) is sum of extinction due to gas mixture, water vapor, ozone, aerosol and Rayleigh scattering. So atmospheric transmittance is transmittance due to ozone(τ_{oz}), water vapor (τ_w), gas mixture (τ_g), aerosols (τ_a) and Rayleigh scattering (τ_r) (Iqba l1983).

$$\tau = \tau_{oz}\tau_w\tau_g\tau_a\,\tau_r$$

τ_{oz} 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. Water content relates relative humidity (RH) and air temperature T). τ_g and τ_r depend air mass(m_a) which depends on atmospheric pressure(P), altitude and relative air mass. τ_a depends on Angstrom turbidity coefficient (β), Angstrom exponential (α) and air mass.

$$\tau_{oz} = 1 \left[.0\,1611\,u_3 \left(1+139\,48\,u_3\right)^{-0.3035} \quad .0\,002715\,u_3 \left(1+.0.044\,u_3 + 0.0003\,u_3^2\right)^{-1} \right]$$

$$\tau_w = 1 - 2.4959\,w\,m_r \left[\left(1+79\,034\,w\,m_r\right)^{0.682} + 6.385\,w\,m_r \right]^{-1}$$

$$\tau_g = e^{-0.0127 m_a^{0.26}}$$

$$\tau_a = \left(0.1244\,\alpha \quad .0\,0162\right) + \left(1.003 \quad .0\,125\,\alpha\right) e^{-\beta\, m_a (1\,089\,\alpha + .0\,5123)}$$

$$\tau_r = e^{-0.0903\, m_a^{0.83} \left(1.01 + m_a \quad m_a^{1.01}\right)}$$

$$u_3 = l\, m_r$$

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

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

$$w = .0\,493 \left(\frac{RH}{T}\right) e^{\left(26.23 \quad \frac{5416}{T}\right)}$$

The Global solar radiation(GSR) is sum of direct solar radiation and diffused solar radiation. Daily GSR and meteorological data are collected from Department of Hydrology and Meteorology (DHM), Government of Nepal for three year 2011, 2012 and 2013 for Jumla. First class CMP6 pyranometeris used by DHM to measured GSR in W/m^2. It has thermopile sensor with spectral range of 285nm to 2800nm as shown in fig.2 (Kippand Zonen 2008). Total ozone column data are collected from website.

http://data.ceda.ac.uk/badc/toms/data/omi/.Clearness index and solar insolation data are collected from website https://power.larc.nasa.gov/data-access-viewer/.

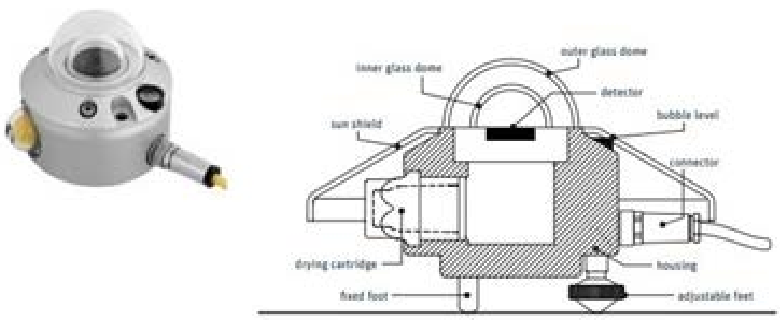


Fig.2: CMP6 pyranometer[source:www.kippzonen.com]

MATLAB 2015 software is used to analysis data and open source software Python 3.7 is used to plot graph. Mean ($\bar{x}$), standard deviation (σ), correlation coefficient (r) are used as Statistical tool. Standard error (SE) is used as error bar in graph. Data is presented in form mean ± standard deviation.

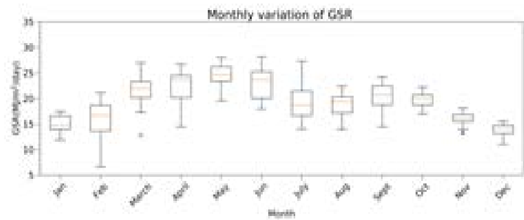
$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

$$SE = \frac{\sigma}{\sqrt{n}}$$

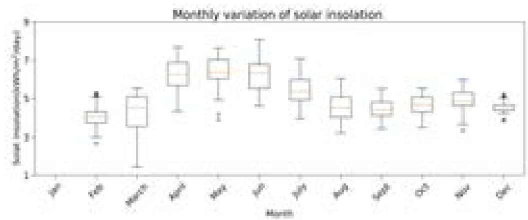
$$r = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

3. RESULTS AND DISCUSSION

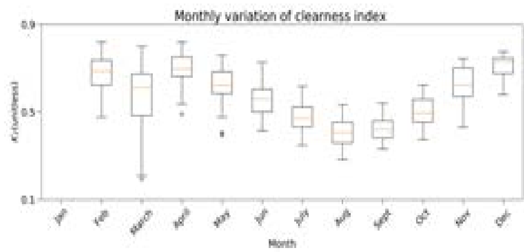
Monthly variation of GSR is shown in Fig.3(a). The maximum and the minimum values of GSR are 20.44±4.47 MJ/m^2/day in September and 13.90±2.03 MJ/m^2/day in December respectively. Variation is large in July and less in October. Fig.3(b) shows monthly variation of solar insolation. The maximum and the minimum values of solar insolation are 6.31±1.37 kWh/m^2/day in April and 3.93±0.61 kWh/m^2/day in December respectively due to solar declination .Variation is large in June and less in November. Fig.3(c) shows monthly variation of clearness index. The maximum and the minimum values of clearness index are 0.66±0.09 in October and 0.40±0.09 in July respectively due to local weather and aerosols. Variation is large in February and less in November. Fig.3(d) shows monthly variation of atmospheric transmittance. The maximum and the minimum values of transmittance are 0.70±0.06 in November and 0.44±0.12 in July respectively. Variation is seen to be large in February due to solar declination and less in October due to day length.



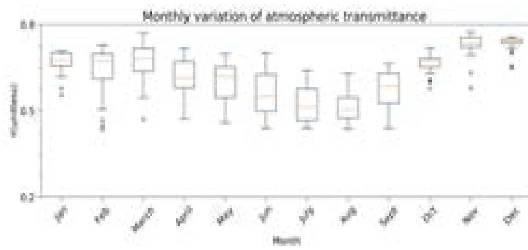
a) GSR



b) Solar insolation



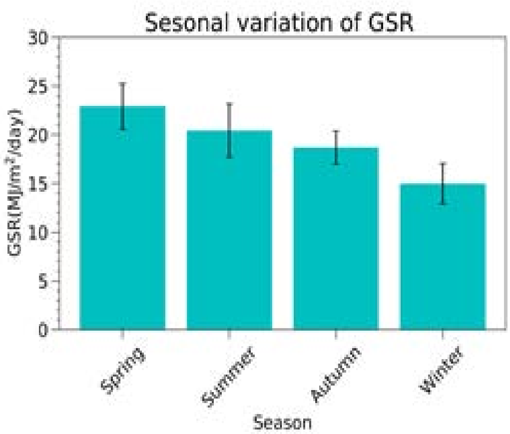
c) Clearness index



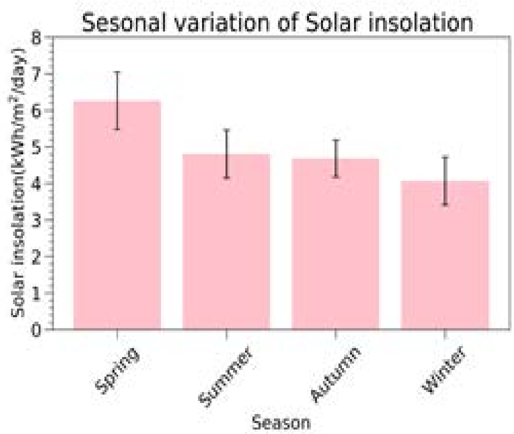
d) Atmospheric transmittance

Fig. 3:Monthly variation of parameters(GSR, solar insolation, clearness index, atmospheric transmittance)

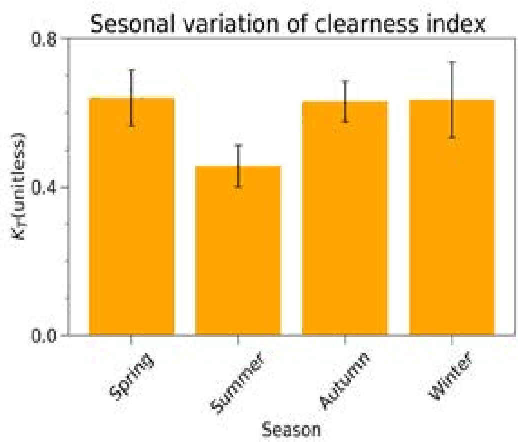
Fig.4(a) shows seasonal variation of GSR. The maximum and minimum values of GSR are 22.92 ±4.04 MJ/m²/day in spring and 14.99±3.57 MJ/m²/day in winter respectively. GSR varies large in summer whereas less in in winter. Fig.4(b) shows seasonal variation of solar insolation. The maximum and the minimum value of solar insolation are 6.26±1.35 kWh/m²/day in spring and 4.06±1.13 kWh/m²/day in winter respectively. Solar insolation varies large in spring and less in autumn.Fig.4(c) shows seasonal variation of clearness index. The maximum and minimum values of clearness index are 0.64±0.13 in spring and 0.45±0.09 in summer respectively. Clearness index varies large in winter and less in autumn. Fig.4(d) shows seasonal variation of atmospheric transmittance. The maximum and the minimum values of transmittance are 0.66±0.09 in autumn and 0.48±0.11 in summer respectively. Variation of transmittance is large in summer due to large day length and less in autumn due to solar declination.



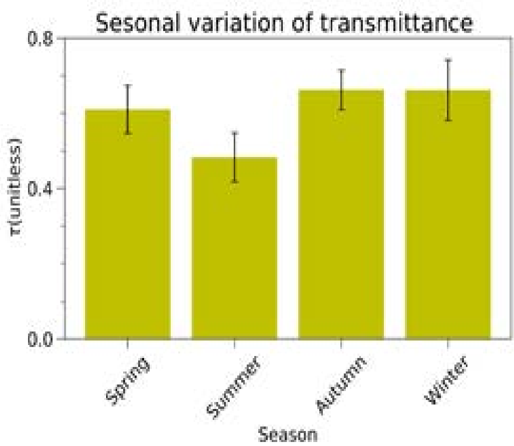
a) GSR



b) Solar insolation



c) Clearness index



d) Atmospheric transmittance

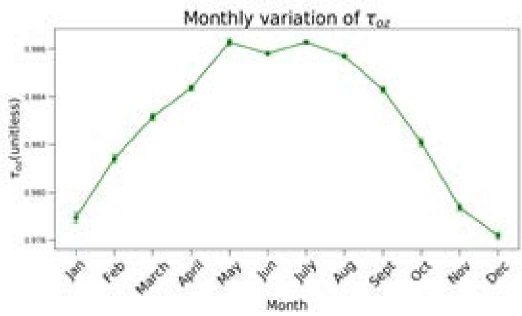
Fig. 3: Monthly variation of parameters(GSR, solar insolation, clearness index, atmospheric transmittance)

Table 1 shows statistics of maximum temperature, minimum temperature, relative humidity, water content, air mass and ozone.

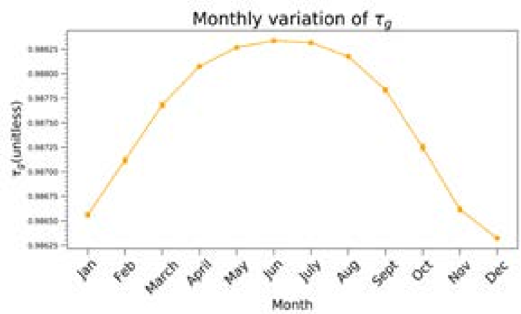
Table 1: Statistics of parameters

Parameters	maximum	minimum	mean	standard deviation
Maximum temperature(^{o}C)	26.0 (June)	13.2 (Jan.)	21.3	4.3
Minimum temperature(^{o}C)	16.1 (July)	-6.2 (Jan.)	5.0	8.3
Relative Humidity(%)	79.4 (Aug.)	46.4(Nov.)	59.9	11.3
Water content(cm)	3.1 (July)	0.7 (Jan.)	1.7	0.9
Relative air mass(unitless)	2.2 (Dec.)	1.2(June)	1.5	0.3
Optical air mass(unitless)	1.6 (Dec.)	0.9 (June)	1.2	0.2
Total ozone column(DU)	291.4(April)	258.9 (Dec.)	270.9	9.4

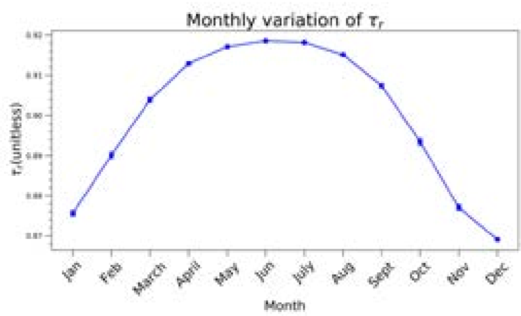
Fig.5(a) shows monthly variation of transmittance due to ozone(τ_{oz}).The maximum and the minimum value of τ_{oz} are 0.9862 in May and 0.9781 in December respectively due to TOC. Fig.5(b) shows monthly variation of transmittance due to gas mixture(τ_g). The maximum and the minimum value of τ g are 0.9883 in June and 0.9863 in December respectively due to optical air mass.Fig.5(c) shows monthly variation of transmittance due to Rayleigh scattering(τ_r).The maximum and the minimum value of τ_r is 0.9185 in June and 0.8690 in December respectively due to air mass. Fig.5(d) shows monthly variation of transmittance due to water vapor(τ_w).The maximum and minimum value of τ_w are 0.8953 in March and 0.8694 in August respectively due to water content.Fig.5(e) shows monthly variation of transmittance due to aerosol(τ_a).The maximum and the minimum value of τ_a are 0.9376 in November and 0.5855 in July respectively due to aerosols.



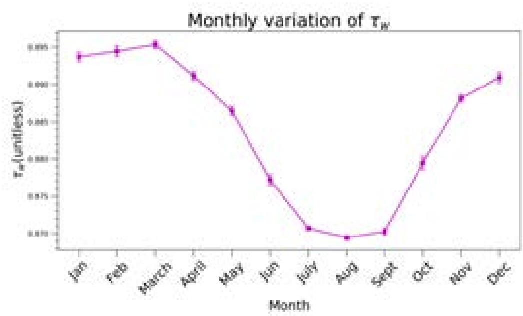
a) Ozone



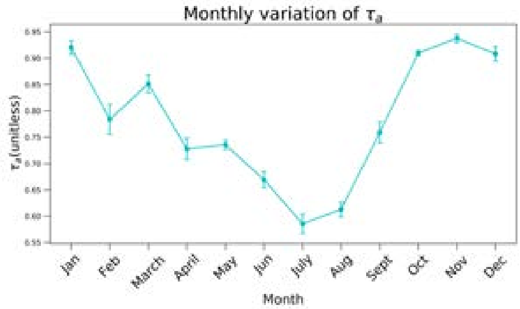
b) Gas mixture



c) Rayleigh scattering



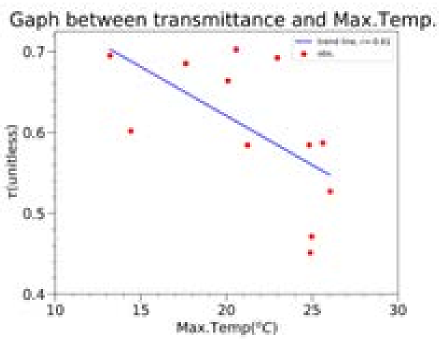
d) Water vapor



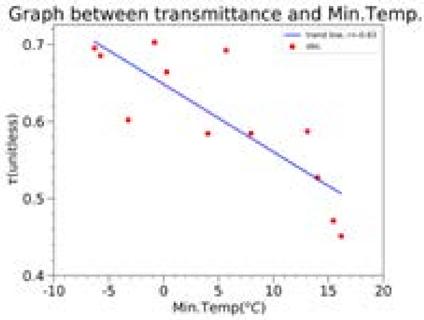
e)Aerosol

Fig.5: Monthly variation of various atmospheric transmittances due to ozone, gas mixture, Rayleigh Scattering, water vapor and aerosol)

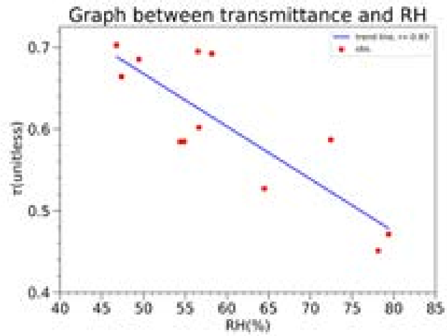
Fig.6(a) shows variation of atmospheric transmittance with the maximum temperature. Correlation coefficient is -0.61. Fig.6(b) shows variation of atmospheric transmittance with the minimum temperature. Correlation coefficient is -0.83. Fig.6(c) shows variation of atmospheric transmittance with relative humidity. Correlation coefficient is -0.83. Fig.6(d) shows variation of atmospheric transmittance with rainfall. Correlation coefficient is -0.85. Fig.6(e) shows variation of atmospheric transmittance with water contend. Correlation coefficient is -0.85. Fig.6(f) shows variation of atmospheric transmittance with relative sunshine hour(n/N).Correlation coefficient is 0.98. Here n is sunshine hour and N is day length. Fig.6(g) shows variation of atmospheric transmittance with total ozone column(TOC).Correlation coefficient is -0.32. There is positive relation of transmittance with relative sunshine hour whereas other parameters has negative relation.



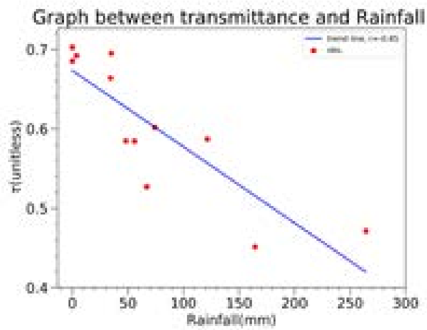
a) Maximum temperature



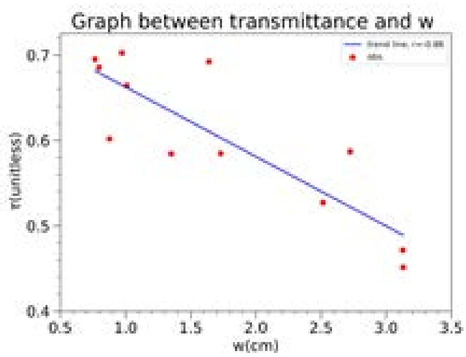
b) Minimum temperature



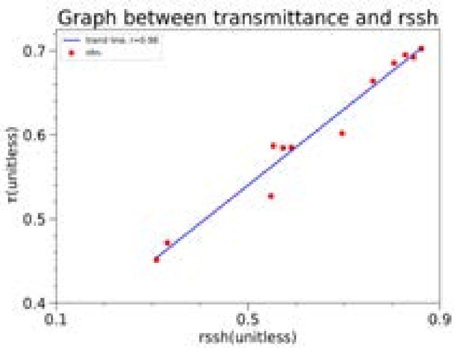
c) Relative humidity



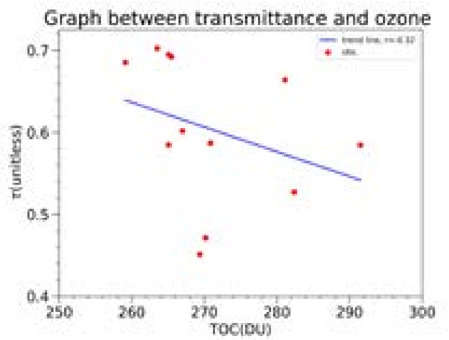
d) Rainfall



e) Water content



f) Relative sunshine hour



g) Total ozone column(TOC)

4. CONCLUSION

During the study period of 2011 to 2013 in Jumla, annual value on of GSR, solar insolation and clearness index(KT) are 19.26±3.88 MJ/m^2/day, 4.95 ±1.14 kWh/m^2/day and 0.59±0.12 respectively. Annual average of atmospheric transmittance (τ) is 0.60±0.11.This shows that in Jumla about 60% of solar radiation is transmitted through the atmosphere. Annual mean of atmospheric transmittance due to gas (τ_g), ozone(τ_{oz}), Rayleigh scattering (τ_r), water vapor (τ_w) and aerosols (τ_a) are 0.9875±0.0007, 0.9830±0.0007, 0.8999 ±0.0178, 0.8839±0.0101 and 0.7836±0.0909 respectively. There is positive correlation of atmospheric transmittance with relative of sunshine hour and negative correlation with rain fall.

The yearly mean of atmospheric transmittance due to Rayleigh scattering followed by ozone, water vapor, gas mixture and aerosols are found 0.889, 0.983,0.881,0.987 and 0.698 respectively for 2012 on Kathmandu Valley ((Lat.:27.72°N, Long.: 85.32°E and alt.: 1337 m a.s.l.) (Shrestha *et al.* 2020). Atmospheric transmittance due to aerosol in Jumla is larger than that in Kathmandu Valley according to study of Shrestha *et al.*

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REFERENCES

1. Adam, M.N. and E.F.El-Nobi. 2017. Correlation between air temperature and atmospheric turbidity at a subtropical location. *World Environment,* 7(1):1–9.
2. Adhikari, K.R., B.K.Bhattarai andS.Gurung. 2013. Solar energy potential in Nepal and global context. *Journal of the Institute of Engineering*, 9(1):96 – 106.
3. Bed,K.C., K.N. Poudyal and S.Gurung.2016. Variation of global solar radiation at different altitudes of Mid -western region , Nepal. Research *Journal of Chemical Science,* 6(8):24–28.
4. CBS,2011.National population and housing census 2011.National planning commission, Government of Nepal 2011.
5. Duffie,J.A. andW.A. Beckman.2013.Solar engineering of thermal processes. JohnWiley and Sons.
6. Iqbal, M. 1983.*An introduction to solar radiation.* New York: Academic Press.
7. Iqbal, M. 2012. *An introduction to solar radiation.* Elsevier.
8. Kipp and Zonen. 2008. Instruction manual CMP6 pyranometer.
9. Liou,K.N. 2002.An introduction to atmospheric radiation, 84. Elsevier.
10. Majupuria, R.K. and T.C. Majupuria. 1999. Nepal nature's paradise: insight into diverse

facets oftopography, flora and ecology. M Devi, Gwalior, India.

11. MoF.2011. Economic Survey 2010/011, Ministry of Finance, Government of Nepal.
12. Poudyal, K.N.,B.K.Bhattarai,S.Sapkota and B.Kjeldstad.2011. Solarradiation potential at four sites of *Nepal. Journal of the Institute of Engineering*, 8(3):189–197.
13. Shrestha, P.M., N.P. Chapagain, I.B. Karki and K.N. Poudyal. 2020. Variation on atmospheric transmittance solar radiation at Kathmandu valley. *Journal of Nepal Physical Society,* 6(1):105–112.
14. Wallace, J.N. and P.V. Hobbs. 2006. Atmospheric science: an introductory survey,92. Elsevier.
15. Wang,L.,Y.Chen,Y.Niu,G.A.SalazarandW. Gong. 2017. Analysis of atmospheric turbidity in clear skies atWuhan, Central China. *Journal of Earth Science,* 28(4):729–738.