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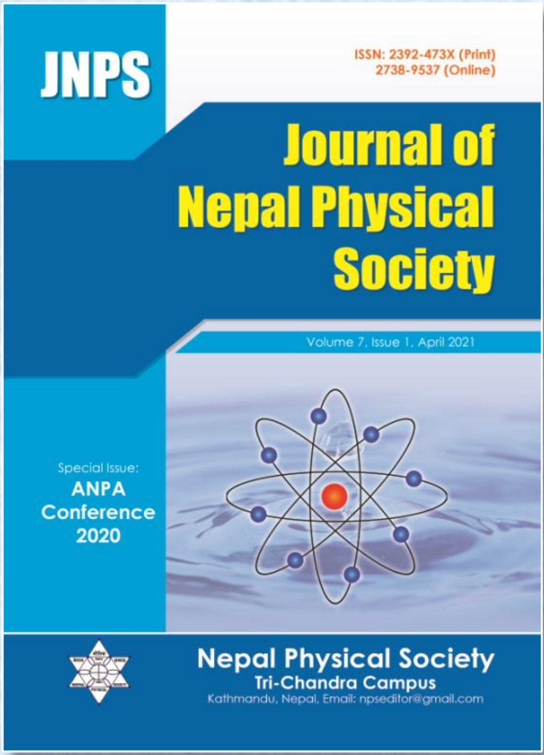

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Study of Variability of Atmospheric Ozone over Jumla in Half Period of 24 Solar Cycle

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ABSTRACT

This paper reports the variation of total ozone column (TOC) over Jumla (Lat.:-29.28^o N, Long.:-82.16^o E and Alt.:- 2300 m above sea level) from 2008 to 2014 derived from Total Ozone Mapping Spectrometer (TOMS) satellite observations. The monthly, seasonal, annual variations of TOC, solar insolation and clearness index have been analyzed. The result exemplifies that during the whole study period, the maximum value of monthly average TOC is 289.21 DU ± 10.75 DU in April, while the minimum value is 257.23 DU ± 11.25 DU in December. The results also show that TOC is highly seasonal dependent with larger TOC in spring 273.68 DU ± 14.92 DU and lower in the winter season (260.68 DU ± 15.25 DU). The average annual value of TOC exhibits slightly variable with a maximum in 2010 (277.52 DU ± 40.64 DU) and minimum in 2008 (267.19 DU ± 11.11 DU). The average values of solar insolation and clearness index for whole study the period are 5.10 86 kWh/m^2/day ± 0.86 kWh/m^2/day and 0.59 ± 0.12 respectively. The average value of TOC during the whole study period is 271.84 DU ± 14.19 DU, which indicates a good amount of stratospheric ozone content over Jumla.

Keywords: Clearness index, ozone, solar insolation, total ozone column, Transmittance.

1. INTRODUCTION

The atmospheric ozone is a form of the element oxygen with the chemical formula O_3. Average concentration is about 3 part per million by volume [1]. Approximately 90 percentages of the ozone in the atmosphere concentrates in the stratosphere, from 15 to 50 km above the Earth's surface [2]. Although the proportion of ozone in the atmosphere is low, it filters certain wavelengths of ultraviolet (UV) light from the Sun [3] and protects humans from UV. Sun emits electromagnetic wave of wavelength(λ) from 300 nm to 3000 nm[4] in which infrared(λ >700 nm) is 50 percentages, visible(400 nm< λ<700 nm) is 40 percentages and ultraviolet(λ <400 nm) is 10 percentages .The UV radiations are of shorter wavelengths ranging from 100 nm to 280 nm(UVC), 280 nm to 315 nm(UVB) and 315 nm to 400 nm(UVA). UVC is completely absorbed by the ozone layer and only 5 percentage of UVB reaches the Earth's surface, while nearly 95 percentage of UVA is able to penetrate the atmospheric layers as shown in figure 1. Sydney Chapman (1930) proposed that the ozone is formed in the atmosphere on absorption of certain radiations by the oxygen (photo chemical) [1], shown in Figure 1.

$$O_2 + \text{photon } (h\upsilon) = 2\,(O)$$

$$O_2 + (O) + M = O_3 + M$$

where M is third atom or molecule. Ozone also destroyed on absorption of certain radiations (photo dissociation).

$$O_3 + \text{photon } (h\upsilon) = (O) + O_2$$

Ozone plays a critical role in regional and global climate change, human health, and environmental conditions.Chlorofluorocarbons (CFCs) and other chlorine-containing volatile gases have a potentially damaging effect on ozone in the stratosphere. Studies have shown that ozone depletion occurred not only in the Antarctic but also in other latitudes.11-year solar cycle of solar radio flux effects the stratosphere and troposphere ozone .The decrease of stratospheric ozone leads to the increase of UV radiation at the Earth's surface, resulting in the increased risk of several severe human diseases, such as skin cancer and eye cataracts. In addition to its effects on mankind, UV radiation can disturb the normal genetic activity of plants and has negative impacts on the growth of plants .Ozone is a strong greenhouse gas in the Earth's atmosphere, as it absorbs both ultraviolet and infrared radiation. Variations of atmospheric ozone effect global or regional climate change. Therefore, the study of variability of the total ozone column (TOC) at the regional or global scale has caught the attention of scientists and government officers .The total ozone column (TOC) is measured by Dobson unit (DU).One Dobson unit refers to a layer of 0.01 mm thick gas under standard temperature and pressure (STP) [5].

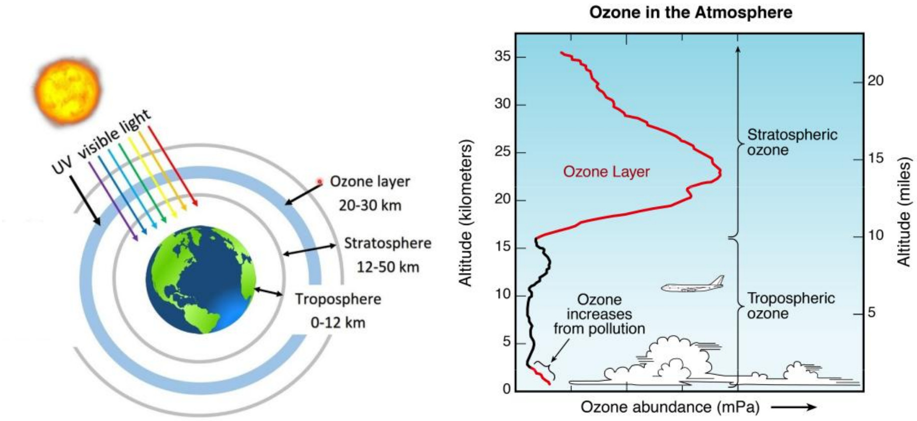


Fig. 1: Atmosphere [source: University Corporation for Atmospheric Research (UCAR)]

Sun is in plasma state. Different parts of the Sun rotates about own axis with different angular speed. So Sun has two magnetic field, poloidal field (10 gauss) and toroidal field (3 kgauss to 5 kgauss). Due to high magnetic field (10 gauss to100 gauss) and low temperature (4000 K), sun spot form. Formation of sun spot is cyclic, called as solar cycle [6].Solar cycle 24 starts from 4 January 2008 and reached maximum in 2014 .It ends between mid-2019 and late 2020.It effects ionosphere and geomagnetic field. Sun also emits radio wave of frequency 2.8 GHz, called as Solar radio flux (F10.7 cm).It is excellent indicator of solar activity. It correlates with the sunspot number, ultra violet (UV) and visible solar irradiance. Solar flux units (s.f.u.) is 10^{-22} Wm^{-2} Hz^{-1}.It affects the ionosphere and modifies the upper atmosphere.

Nepal is a land-locked South East Asian mountainous country with a large area of beautiful landscape situated between latitudes of 26.36° N to 30.45° N and longitudes of 80.06° E to 88.2° E. The elevation of the country 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 [7].Nepal is situated between two giant industrial countries India and China and their industrial byproduct can directly effect the concentrations and depletion of ozone concentration .Therefore, detail study of atmospheric concentration is very important. Total ozone data obtained from Brewer instrument from February 2001 through February 2002 over Kathmandu are high in summer and spring seasons (up to 327 DU) and low (213 DU) during the winter season[8].TOC over Kathmandu for 10 years period from 1979 to1988 were derived from TOMS satellite, the average value of TOC is 277 DU [9]. Total ozone column (TOC) over Kathmandu, during the last 13 years(October 2004 to April 2016) of observations using remote sensing-derived data, the highest value of TOC is found to be 344 DU in March and the lowest value of TOC is 219 DU in December. The average TOC during the whole study period is found to be 268 DU [10].

Jumla (Lat.:29.28° N, Long.:82.16 ° E and Alt.:2300 m above sea level) lies in the Mid-Western region of Nepal, covers area 2,531 square km is shown in Figure:2 .Population and population density are 108,921 and 43 square km .respectively [11]. Rara Lake, the largest lake of Nepal, lies at an altitude of 2,990 m above sea level, has a water surface of 10.8 km^2, a maximum depth of 167 m, is 5.1 km long and 2.7 km wide. It situates in alpine climatic zone [12].The annual average measured value of global solar radiation (GSR) is 19.90 ± 0.66 $MJ/m^2/day$ in Jumla for 2011[13].

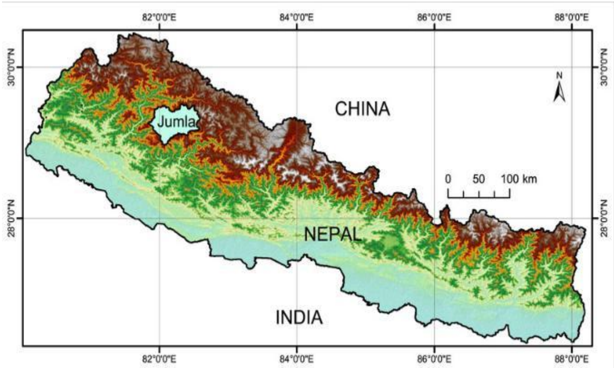


Fig. 2: Map of Jumla [source: researchgate]

2. MATERIALS AND METHODS

Total ozone column (TOC) data are collected from http:/data.ceda.ac.uk/badc/toms/data/omi/ for half period of 24 solar cycle (2008 to 2014). The Total Ozone Mapping Spectrometer (TOMS) is an instrument built and operated by the National Aeronautics and Space Administration (NASA). Out of five TOMS instruments which were built, four entered successful orbit.The Ozone Monitoring Instrument (OMI) has replaced Earth Probe TOMS since January 1, 2006.Sunspot numbers and Solar index F10.7 are collected from https://omniweb.gsfc.nasa.gov/.Solar insolation data and clearness index are collected from https://power.larc.nasa.gov/data-access-viewer/.MATLAB 2015 software are used to analysis data and plot graph. Mean, standard deviation, correlation coefficient are used as statistical tool. Standard error is used as error bar in graph. Data are presented in form mean ± standard deviation.

The spatial variability is quantified by calculating the coefficient of relative variation (CRV)[14]

$$CRV_i = \frac{TOC_i^{max} - TOC_i^{min}}{TOC_i^{mean}} 100 \qquad (1)$$

where TOC_i^{max} ,TOC_i^{min} and TOC_i^{mean} are denote the maximum, minimum, and monthly mean TOC value in i^{th} month respectively.

In order to quantify the long-term ozone trend, the annual cycle is estimated from the best fit of the monthly TOC time series [15]

$$D_p(t) = a_0 + a_1 cos\omega t + b_1 sin\omega t \qquad (2)$$

where t is the time in month ,a_0 (DU) is offset, $a_1 cos\omega t + b_1 sin\omega t$ is the seasonal component of the TOC variability, and ω is 2π/12. The amplitude seasonal component is $\sqrt{a_1^2 + b_1^2}$ DU.

To analyze the short-term variability, MMV (month-to-month variability) is calculated by using Equation (3)

$$MMV_i = \frac{|TOC_{i+1} - TOC_i|}{TOC_i} 100 \qquad (3)$$

where TOC_i and TOC_{i+1} represent the TOC of i^{th} and $(i + 1)^{th}$ month, respectively.

The temporal autocorrelation coefficients (TAC) also are used to quantify the short-term variability Equation (4), which can indicate the persistence of the TOC series:

$$TAC = \frac{\sum_{i=1}^{11}(TOC_i - \overline{TOC})(TOC_{i+1} - \overline{TOC})}{\sum_{i=1}^{11}(TOC_i - \overline{TOC})^2 \sum_{i=1}^{11}(TOC_{i+1} - \overline{TOC})^2} \qquad (4)$$

where $\overline{TOC}$ is mean TOC.

Atmospheric transmittance by ozone (τ_{oz}) [16] is function of ozone column (l) in cm and relative air mass (m_r). Relative air mass depends on solar zenith angle (θ_z), solar declination (δ), solar hour angle (ω) ,day number of year (n_d) and latitude (ϕ) of the place.

$$\tau_{oz} = 1 - [0.1611\, U_3 (1 + 139.48\, U_3)^{-0.3035} - 0.002715\, U_3 (1 + 0.044\, U_3 + 0.0003\, U_3^2)^{-1}] \qquad (5)$$

Where

$$U_3 = l m_r$$

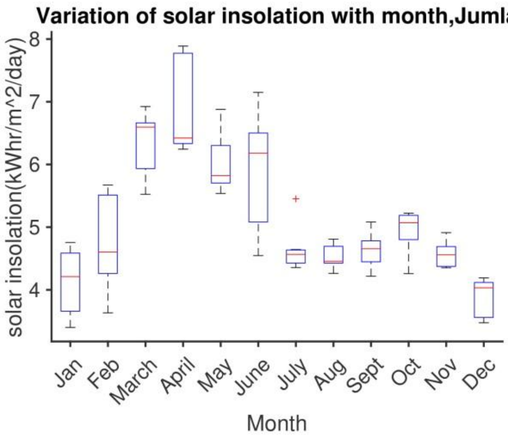
$$m_r = \frac{1}{\cos\theta_z + 0.15(93.885 - \theta_z)^{-1.253}}$$

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

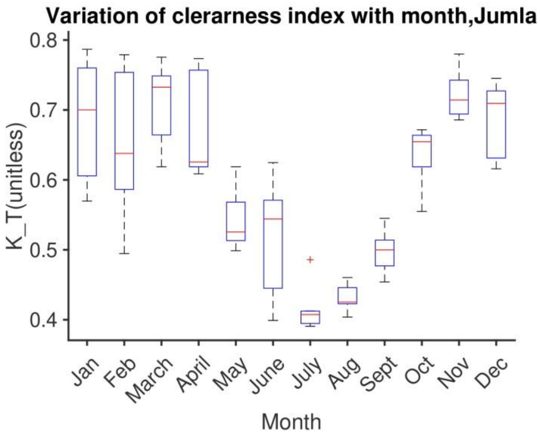
$$\delta = 23.45\sin\left(\frac{360}{365}(284 + n_d)\right)$$

3. RESULTS AND DISCUSSION

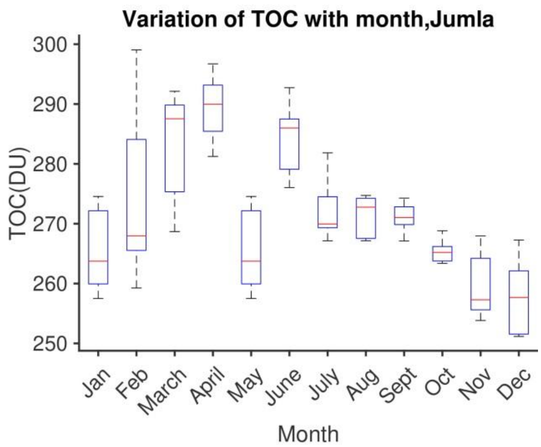
Figure 3 shows a monthly variation of solar insolation, clearness index, total ozone column and transmittance by ozone. Solar insolation is maximum 6.94 kWh/m^2/day ± 1.37 kWh/m^2/day in April due to long day length and less solar declination angle and minimum 3.88 kWh/m^2/day ± 0.73 kWh/m^2/day in December due to short day length and large solar declination angle.Clearness index is maximum 0.72 ± 0.09 in November due to clear sky and minimum 0.41 ± 0.09 in July due to rain. TOC is maximum 289.21 DU ±10.75 DU in April and minimum (257.23 DU ± 11.25 DU) in December. Transmittance by ozone is maximum 0.9861 ±0.0002 in July and minimum 0.9782 ± 0.0007 in December.



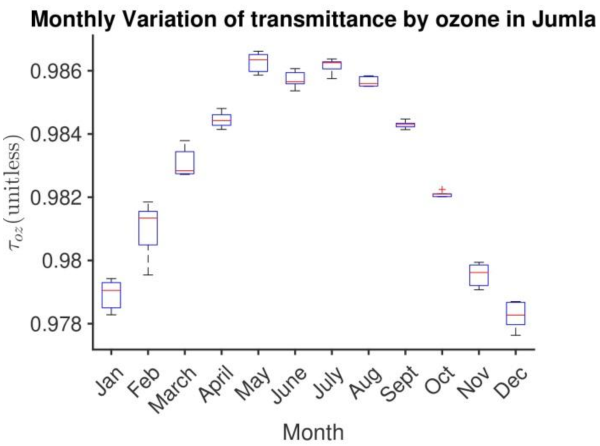
a)Solar insolation



b)Clearness index



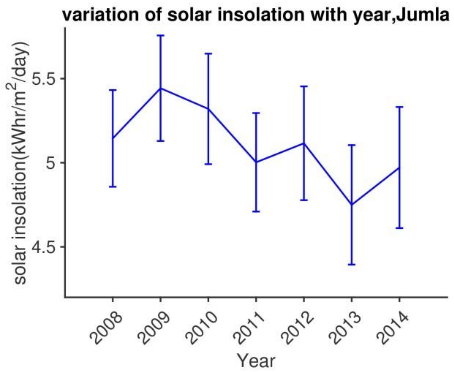
c)Total ozone column



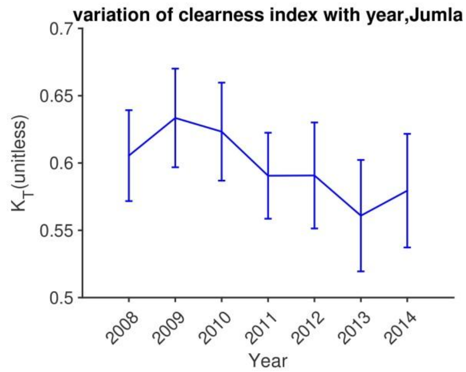
d)Transmittance by ozone

Fig. 3: Monthly variation of parameters

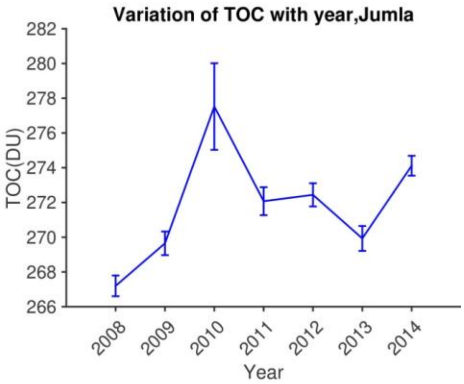
Figure 4 shows annual variation of solar insolation, clearness index, total ozone column and transmittance by ozone. Solar insolation is maximum 5.44 kWh/m^2/day ±1.08 kWh/m^2/day in 2009 and minimum (4.74 kWh/m^2/day ±1.23 kWh/m^2/day) in 2013.Clearness index is maximum 0.63 ± 0.12 in 2009 and minimum 0.56 ± 0.14 in 2013. TOC is maximum (277.52 DU ± 40.64 DU) in 2010 and minimum (267.19 DU ± 11.11 DU) in 2008.Transmittance by ozone is maximum (0.9831 ± 0.0006) in 2008 and minimum 0.9826 ± 0.0008 in 2010.



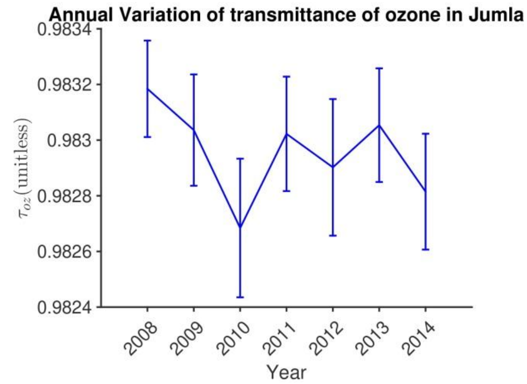
a)Solar insolation



b)Clearness index



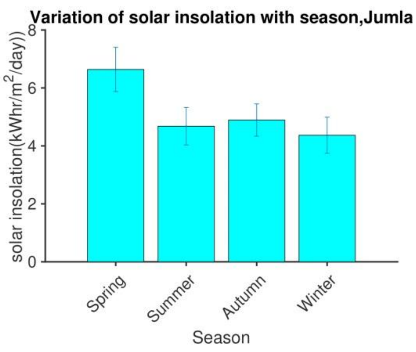
c)Total ozone column



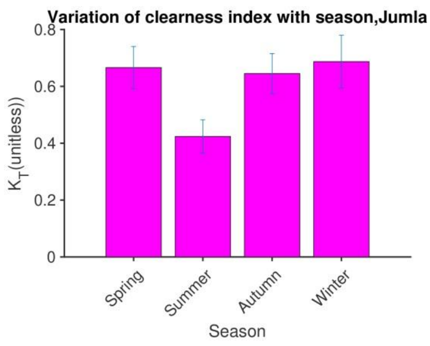
d)Transmittance by ozone

Fig. 4: Annual variation of parameters

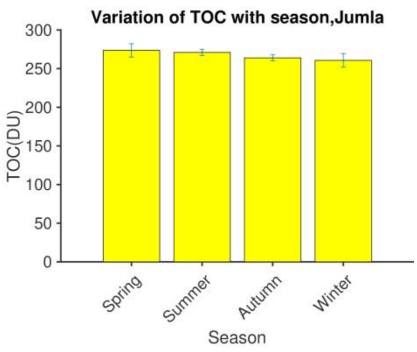
Figure 5 shows seasonal variation of solar insolation, clearness index and total ozone column. Solar insolation is maximum 6.63 kWh/m^2/day ± 1.32 kWh/m^2/day in spring and minimum 4.36 kWh/m^2/day ± 1.07 kWh/m^2/day in winter. Clearness index is maximum 0.68 ± 0.16 in winter and minimum 0.42 ± 0.10 in summer. TOC is maximum 273.68 DU ± 14.92 DU in spring and minimum 260.68 DU ± 15.25 DU in winter.



a)Solar insolation



b) Clearness index



c)Total ozone column

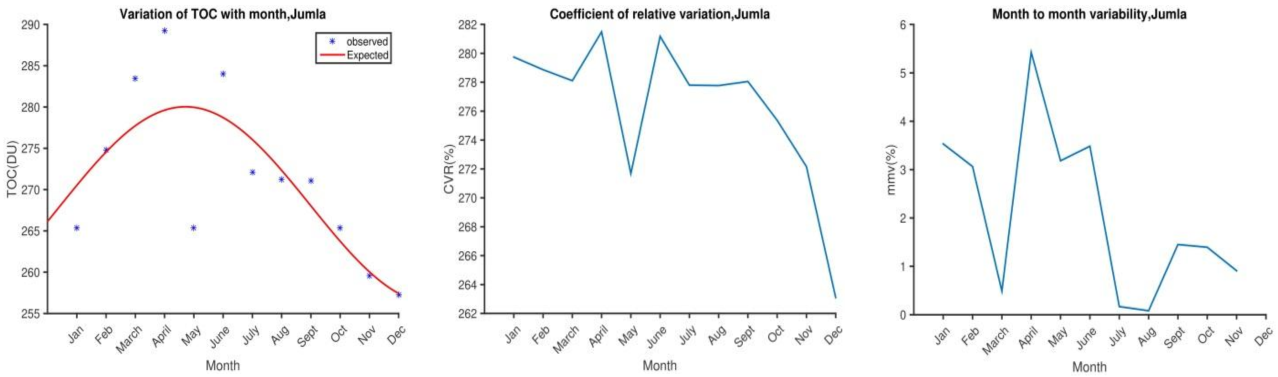
Fig. 5: Seasonal variation of parameters

Figure 6(a) shows monthly variation of TOC. Fitting equation (2) is

D_p (t) = 268.1 - 1.949 cos(0.368 t) + 11.771 sin(0.368 t)

Offset is 268.1 DU and amplitude of seasonal component is 11.93 DU.

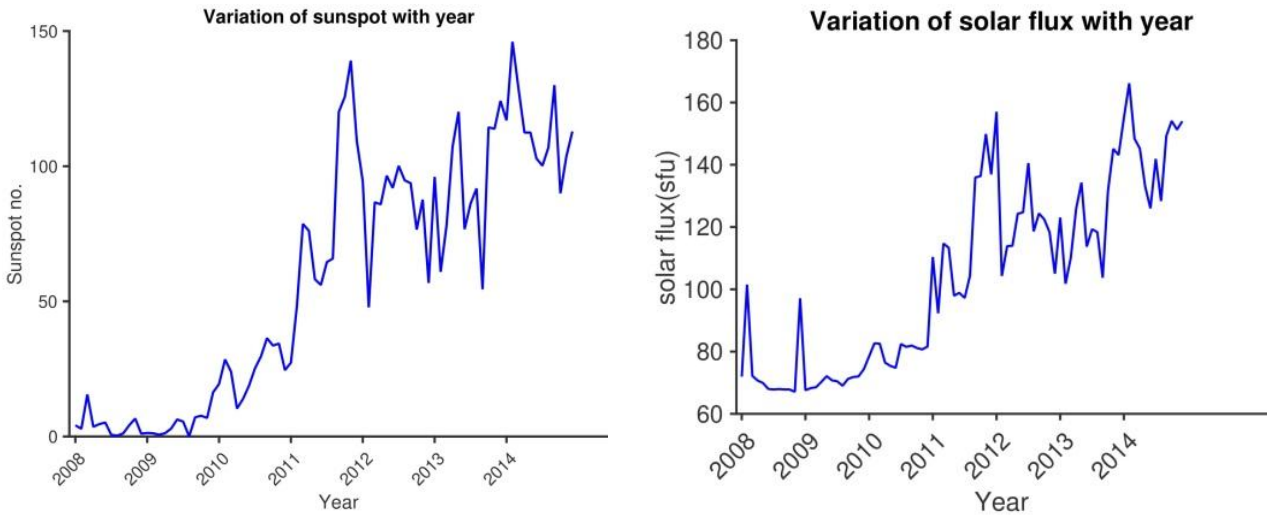
Figure 6(b) shows coefficient of relative variation (CRV) for month. CRV is maximum 281.48 percentages in April that means range of TOC is large. CRV is minimum 263.09 percentages in December that means range of TOC is small. Figure 6(c) shows month to month variability (MMV). MMV is maximum 5.42 percentages in April. It indicates that variation of TOC of January and February is large. MMV is minimum 0.08 percentages in August. It indicates variation of TOC in August and September is small. Temporal auto correlation coefficient (TAC) is 0.53. TOC correlates month to month average values.



a) TOC *b)CRV* *c)MMV*

Fig. 6: Monthly variation of parameters

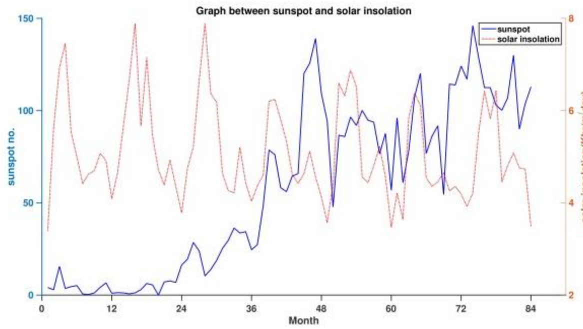
Figure 7(a) and 7(b) show monthly variation of sunspot number and solar radio flux. Sunspot become minimum (4.15 ± 4.10) in 2008 and maximum (113.59 ± 15.26) in 2014. Sun radio flux is minimum (70.53 sfu ±1.94 sfu) in 2009 and maximum (146.06 sfu ± 11.89 sfu) in 2014.



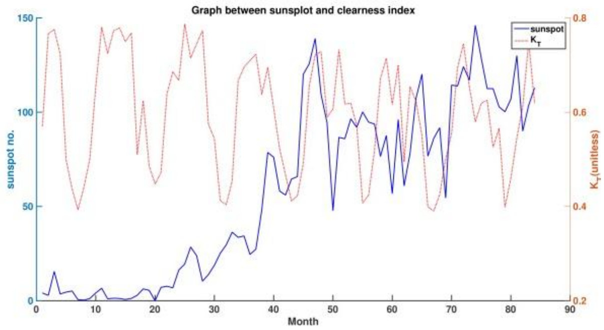
a) Sunspot *b) Solar flux*

Fig. 7: Variation of sunspot no. and solar flux

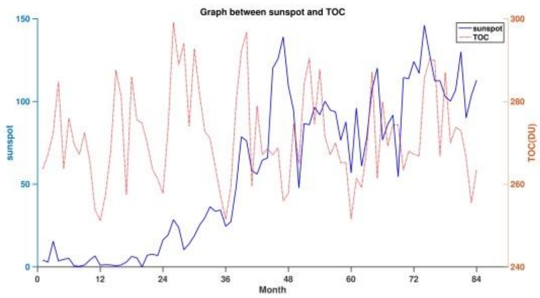
Figure 8 show variation of sunspot number with solar insolation, clearness index and TOC. Correlation coefficient of sunspot with those parameters is shown Table 1. There is positive correlation of sunspot with TOC but not significant. There is negative correlation of sunspot with solar insolation and clearness index.



a)Solar insolation



b) Clearness index



c) TOC

Fig. 8: Variation of sunspot no. with parameters

Table 1: Relation of sunspot with parameters

Parameters	Correlation coefficient
Solar insolation	-0.10
Clearness index	- 0.15
TOC	0.05

4. CONCLUSIONS

This paper presents the variation of total ozone column (TOC) over Jumla for seven years from January 2008 to December 2014 by using the ozone data derived from Total Ozone Mapping Spectrometer (TOMS). The trends of monthly, seasonal as well as annual variations of TOC have been analyzed. The result exemplifies that during the whole study period, 289.21 DU ± 10.75 DU in April and minimum 257.23 DU ± 11.25 DU in December. The results also show that TOC is highly seasonal dependent on the larger TOC in summer (276.58 DU ± 4.74 DU) compared to lower in winter 250.50 DU ± 5.99 DU. The average annual value of TOC exhibits slightly variable with a maximum 277.52 DU ± 40.64 DU in 2010 and minimum 267.19 DU ± 11.11 DU in 2008. The average value of solar insolation and clearness index are 5.10 kWh/m^2/day ± 0.86 kWh/m^2/day and 0.59 0.12 respectively. The average value of TOC during the whole study period is 271.84 DU ± 14.19 DU. Annual atmospheric transmittance by ozone is 0.9830 ± 0.0007.

AUTHOR CONTRIBUTIONS

Methodology, original draft preparation, visualization, writing, review and editing are done by first author (PhD Scholar). Other authors (supervisors) supervise. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

EDITOR'S NOTE

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NOTE

Clearness index and transmittance by ozone have no unit. So unit are not mentioned.