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RESEARCH ARTICLE

Study of UV Index and Total Ozone Climatology Over Bhairahawa, Pokhara, and Lumle in Nepal

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Highlights

- This study aims to examine the UV Index and Total Ozone Climatology over three stations across the central region of Nepal
- The exploration of UVI and ozone data from the OMI/AURA satellite over specific locations in Nepal aims to enrich the existing knowledge ultraviolet radiation and its varying intensity, thereby its harmful implications on living beings.
- This study concludes that the solar UV index increases with an increase in altitude, among other influential factors.

Abstract

Recent studies on solar ultraviolet (UV) radiation have been pivotal in unveiling its detrimental impacts on humans and other living organisms on Earth. The Ultraviolet Index (UVI) is a crucial tool to ascertain the level of solar ultraviolet radiation at any given location, utilizing data from diverse sources. This study aims to examine the UV Index and Total Ozone Climatology over Bhairahawa (27.52°N, 83.43°E, 109m asl), Pokhara (28.22°N, 83.32°E, 850m asl), and Lumle (28.30°N, 83.80°E, 1740m asl), situated in the mid of Nepal, using OMI/Aura satellite data. The average minimum and maximum UV index recorded are 3.11±1.01 and 7.77±2.25 at Bhairahawa, 4.31±1.36 and 12.90±2.28 at Lumle, and 4.03±1.34 and 10.71±3.38 at Pokhara respectively. Additionally, the minimum Total Ozone Column (TOC) value is observed to be 251.4-288.5DU in December, with the maximum value reaching 291-285.3DU in April across all sites. This study concludes that the solar UV index increases with an increase in altitude, among other influential factors. The exploration of UVI and ozone data from the OMI/AURA satellite over specific locations in Nepal aims to enrich the existing pool of knowledge on solar ultraviolet radiation and its varying intensity, thereby contributing to the comprehension of its harmful implications on living entities.

Keywords: *Aura Satellite, Solar Ultraviolet Index, Solar UV Radiation, OMI, Total Ozone Column*

Introduction

Solar UV radiation, emitted by the sun, undergoes significant modifications while entering the Earth's atmosphere due to absorption and scattering processes by atmospheric particles and gases present there [1]. It is essential for life on Earth, the ecosystem, global biogeochemical cycles, and materials, although it encompasses a small fraction, <10%, of the solar electromagnetic spectrum, lying between 200nm-400nm [2]. While solar UV radiation plays a crucial role in processes like vitamin D synthesis and crop enhancement, its overexposure can lead to detrimental effects including skin burns, skin cancer, cataracts, premature aging of the skin, and material degradation [3,22]. Classified by wavelength, it is divided into three groups which are UV C (200-280nm),

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UV B (280-315nm), and UV A (315-400nm) [2]. Although UV C is the most energetic and harmful, it is fortunately completely absorbed by ozone and oxygen in the stratosphere. Approximately 10% of UV B reaches the Earth's surface, while most UV A experiences minimal absorption [3,4,19].

Some variables, such as cloud cover, ozone, aerosols, solar zenith angle, earth-sun distance, surface albedo, altitude, latitude, and topography of surface of earth, can affect the complex phenomena of solar ultraviolet (UV) radiation on its intensity and the UV Index [13]. Understanding the nature and effects of solar UV radiation on the biosphere has been a research focus since the mid-1980s when reports began to show the stratospheric ozone layer was being lost [21, 27]. The successful Montreal Protocol adopted in 1987 represented a major advancement in the preservation of the ozone layer by controlling ozone-depleting substances (ODs) and has contributed to a decrease in OD concentrations since the 1990s [8,29]. Recent data, however, indicates a significant slowdown, roughly 50%, in the rate of decline of the ozone-destructive trichlorofluoromethane (CFC-11) since 2012 [18,19]. This underscores the continued necessity of close observation and additional steps to protect the ozone layer and lessen the effects of solar UV radiation.

The solar UV Index (UVI) is a measure of the maximum erythemal effective UV radiation, induced by the sun on a specific day on a horizontal surface, a joint collaborative effort between the World Health Organization (WHO), World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), and International Commission on Non-Ionizing Radiation Protection (ICNIRP). The Ultraviolet Index (UVI) ranges from 0 at night to 20 during solar noon in tropical areas. It is used for public awareness campaigns and attempts to prevent skin cancer. UVI levels are higher near the equator, and they gradually decrease with increase in latitude. Values of UVI over 3 suggest taking preventative measures. We need to recognize and minimize the risks of solar UV radiation and take precautions when spending time outside.

Several studies on the measurement or comparison of UV irradiance (or UVI) have been carried out worldwide, using different ground-based instruments, satellite estimates, and models, to monitor UV products continuously for four decades [1,6]. However, the South Asian subcontinent still lacks comprehensive and sufficient researches in comparison to other continents [9, 10]. The research on solar UV radiation in Nepal is seems to be very less in comparison to other Asian countries such as Japan, India and China. After establishment of a project “Solar Radiation and Aerosols in the Himalayan Region” under collaboration Engineering campus, Pulchowk, Tribhuvan University, Nepal and Norway governmentusing ground-based measurements NILU-UV irradiance meter for the year 2009 to 2011 by at four measurement sites namely Kathmandu (KTM), Pokhara (PKR), Biratnagar (BRT) and Lukla (LUKL) in Nepal, some research has been performed in different areas related to UV radiation till now [8].

Because there are few ground-based UV measurements available, which results in patchy geographic coverage, satellite platforms become crucial resources because they provide a worldwide viewpoint [24, 26]. This emphasizes how important satellite-based methods are to closing the measurement gap and improving our knowledge of UV radiation, especially in areas with poor ground-based data.

Using information from the Ozone Monitoring Instrument (OMI) satellite, this study examines the climatology of the UV Index and its relationship to the Total Ozone Column (TOC) over Bhairahawa, Pokhara, and Lumle in Nepal. The upcoming parts will offer a comprehensive examination of the Data and Method utilized in the research, showcase the Results and Discussions that arise from the analysis, and conclude with a Conclusion that combines the patterns and discoveries that have been noted. By using satellite data to gain a complete picture of the climatological processes, the research seeks to provide important insights into the relationship between UV Index and TOC in the designated regions.

Sites, Data and Methodology

Study Sites

The study sites are located at Bhairahawa, Pokhara, and Lumle in Nepal, a mountainous landlocked nation tucked away on the southern flank of the Himalayas as shown in table and figure 1. Nepal's elevation ranges greatly, from lowlands in the southern plain at 60 meters above sea level (ASL) to high mountains rising to 8,848.86 meters, Mt. Everest, lie between latitudes around 26°22' N and 30°27' N and longitudes 80°40' E and 80°12' E with varied geography having many middle-striped mountains between China and India.

The selection of study sites is based on the assumption that meteorological and environmental circumstances stay largely consistent, taking into account closeness in longitude, regional resemblance, and near geographical adjacency. Furthermore, a particular season is picked to reduce elements like surface albedo, pollution, and cloud cover in the sky. Taking these considerations into account, a variety of heights are covered by the study sites that were selected. These include the high mountain valley of Pokhara, the lowland site of Bhairahawa, and the northern high mountain region of Lumle. Table 1 presents the planned placement of these sites geographically to encompass a range of climatic variables for a thorough investigation.

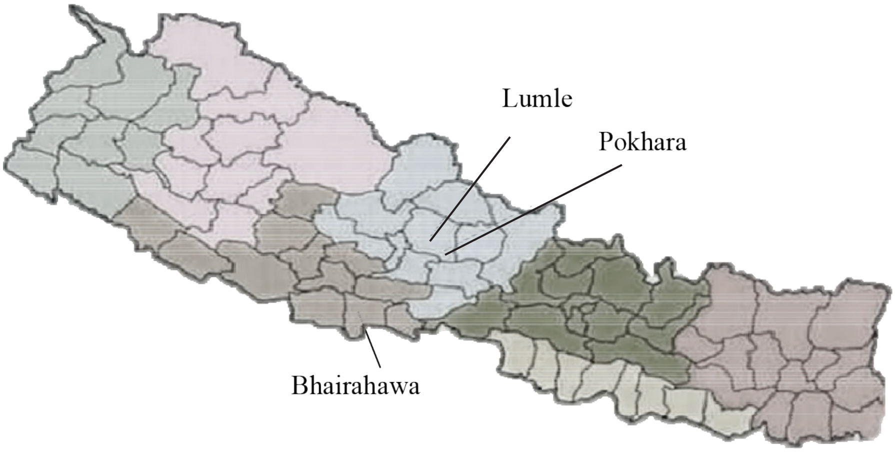

Fig 1. Location of Study Sites

Bhairahawa is located in the middle, southern, and plain regions of Nepal with geographic coordinates between latitude 26.72°N and longitude 83.43°E and an elevation of 109 meters above sea level. Bhairahawa has a tropical climate with summer temperatures that can reach as high as 40°C and high levels of humidity. Bhairahawa experiences extremely chilly and hazy winters, with lows of about 10°C. The Department of Hydrology and Meteorology (DHM) of the Government of Nepal reports that the region receives an annual precipitation that varies from year to year and ranges from roughly 1300 mm to 2780 mm.

Table 1: Location of Study Sites

Sites	District	Altitude(m)	Latitude	Longitude
Bhairahawa	Rupandehi	109	27.52°N	83.43° E
Pokhara	Kaski	850	28.22° N	83.32° E
Lumle	Kaski	1740	28.30° N	83.80° E

Pokhara is a valley with an urban atmosphere that is known for its regular afternoon rains, situated 850 meters above sea level WITH latitude 28.22°N and longitude 83.32°E. it is covered with a rural, mountainous terrain. Summertime temperatures range from 14°C to 25°C, while wintertime temperatures range from 3°C to 16°C in Pokhara. Pokhara has a diversified environmental profile due in part to its unique geographical features and climate.

Lumle is known for being an agricultural hub perched on a slope above the settlement between latitudes 28.30°N and 83.80°E having a population, according to the 1991 Nepal census, 4,685 people living in 955 houses. Lumle is a village located 32 kilometres from the popular tourist attraction of Pokhara. The weather in Lumle is mild all year round, with much less precipitation in the winter than in the summer.

OMI/Aura Satellite

An essential component of NASA's Earth Observing System (EOS) Aura satellite is the Ozone Monitoring Instrument (OMI). Although it was launched in July 2004, OMI has been continuously gathering data, and as of August 9, 2004, it has contributed vital data for atmospheric observations. As part of the EOS Aura mission, the Finnish Meteorology Institute (FMI) in Helsinki, Finland, and the Netherlands Institute for Air and Space Development (NIVR) in Delft collaborated to create this instrument, a nadir-viewing near-UV/Visible CCD spectrometer [28]. OMI measures solar-reflected and backscattered radiation with a spectral resolution that varies from 0.42 nm in the ultraviolet to 0.63 nm in the visible spectrum, covering a wavelength range of 264 nm to 504 nm. The ground footprint at the nadir is 13 × 24 km², including a 2600 km wide swath. OMI allows for daily continuous global mapping, differentiating between different types of aerosols, including dust, smoke, and sulphate's. It is noteworthy because it can map UV-B radiation trends and distribution worldwide. With an orbital period of roughly 98 minutes and an equatorial crossing local time of 13:42 hours, the Aura satellite, which houses OMI, offers global coverage and all-weather observational capability. OMI data are used in this study for thorough analysis and insights.

Methodology

The research entailed a methodical calculation of the Ultraviolet Index (UVI) monthly mean values, standard deviations, and box plots for the three locations—Bhairahawa, Pokhara, and Lumle. The UV index was then thoroughly examined, emphasizing the frequency distribution of UVI thresholds divided into classifications that were low, moderate, high, very high, and extreme. This investigation used high-resolution satellite data to cover the long study period from 2004 to September 23. Simultaneously, a comprehensive analysis of the monthly mean total ozone column, box diagrams, and standard deviation was conducted for the designated locations, Bhairahawa, Pokhara, and Lumle. The objective of this scientific-methodical approach was to identify subtle trends, time fluctuations, and statistical features in the metrics of UVI and total ozone column to provide a thorough grasp of the atmospheric dynamics that are predominant in the area under investigation.

Results and Discussion

UV Index Climatology

This section presents a thorough analysis of the climatology of the Ultraviolet Index (UVI). The monthly mean UVI values, standard deviations, and box diagram generation were calculated for the Bhairahawa, Pokhara, and Lumle locales. The investigation also included evaluating the altitude effect at these sites and looking into seasonal fluctuations. During the extensive 10-year study period, the UV radiation intensity was examined in more detail by investigating the UVI threshold frequency, which was divided into various levels such as low, moderate, high, very high, and extreme. This thorough analysis aims to identify the complex relationships, statistical traits, and environmental factors influencing the UV Index dynamics at the designated sites.

1) Monthly Variation of UVI at Bhairahawa, Pokhara, and Lumle:

Figure 2 shows the average monthly change in the solar Ultraviolet Index (UVI) for the localities of Bhairahawa, Pokhara, and Lumle based on AURA satellite Ozone Monitoring Instrument (OMI) data collected from 2004 to September 23, 2023, with error bars. At Bhairahawa (A), Pokhara (B), and Lumle (C), the UVI shows a noticeable seasonal pattern, with a minimum recorded in December, a peak around noon in July, and a subsequent decrease to minimal values by the following December. For Bhairahawa, Pokhara, and Lumle, respectively, the UVI values range from winter minimum of 3.11-3.32, 4.03-4.57, and 4.31-4.97 to summer maxima of 7.8, 10.4, and 13.

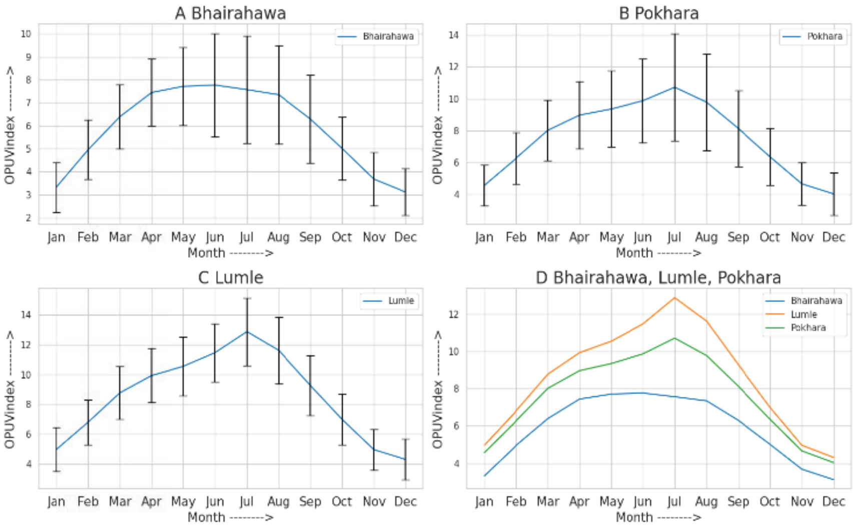

Fig 2. Monthly variation of UVI at Bhairahawa(A), Pokhara(B), Lumle(C) and altitude effect (D) during from 2004 to 2023-09-23

These fluctuations can be attributed to variances in altitude and latitude. According to standards published by the World Meteorological Organization (WMO) in 2010, these values correspond to exposure classifications that range from moderate to excessive. In summer, UVI levels are over 80% of all observations when they are over the "Extreme" threshold; in winter, UVI frequencies fall between the "Moderate" and "High" categories [2]. The results of this investigation are supported by comparisons with ground-based devices like the NILU UV radiometer, which show comparable minimum and maximum UVI values (3–4 and 9–11.5, respectively) for different locations in Nepal [4]. The credibility of the given data is further supported by the study's agreement with previous research on UVI, which frequently shows that satellite estimations exceed ground-based measurements by 15–45% [6].

2) Seasonal Variation of UVI at Bhairahawa, Pokhara, and Lumle

The Ultraviolet Index (UVI) seasonal change at Bhairahawa, Pokhara, and Lumle is depicted in Figure 3. The pattern that is shown indicates that UVI values are lowest in the winter and increase as the temperatures rise in the spring and summer. Then, in the fall, when the temperature drops and precipitation increases atmospheric clarity, the UVI decreases, however, the strength of the altitude effect may vary slightly. Notably, the inverse square law is activated and the solar UV radiation is maximum in the summer when the distance between the sun and Earth is at its lowest. This idea applies to other seasons as well. In addition, solar zenith angles are lower than those of other seasons. Smaller sun zenith angles are associated with more solar UV radiation on Earth, according to the documented inverse relationship. As a result, summertime has the maximum UV radiation levels, and the other seasons follow the same guidelines.

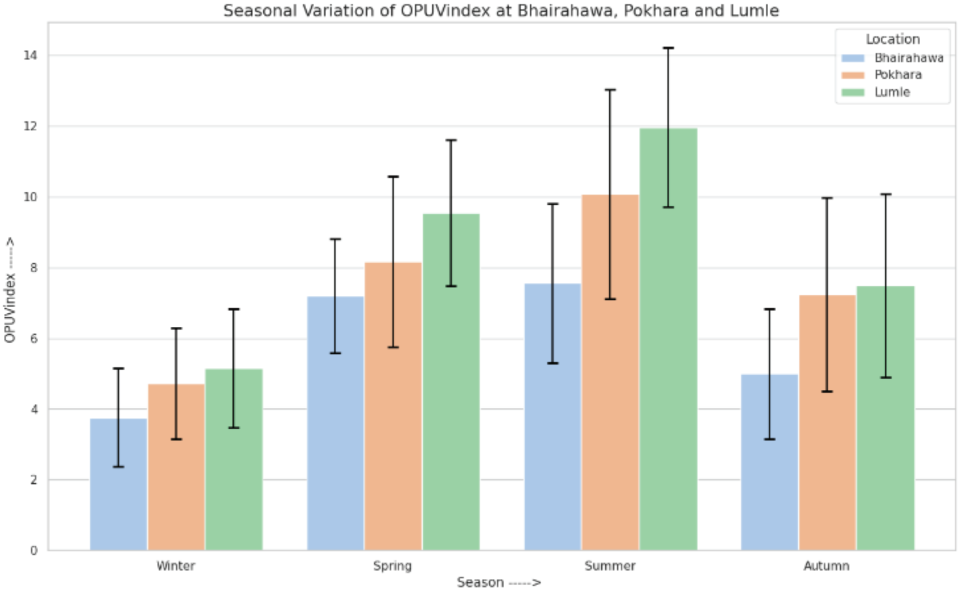

Fig 3. Seasonal Variation of UVI at Bhairahawa, Pokhara, and Lumle

3) Altitude effect

The Ultraviolet Index (UVI), as shown in Figures 2(D) and 3, shows a clear upward trend as altitude increases, peaking in July, the summer season. On the other hand, the winter months of December, January, and February are when they reach their lowest point. The UVI oscillates between its maximum and minimum levels, maintaining a fairly steady profile during the spring and fall seasons. The daily fluctuations in UVI at each location are shown by the observed zig-zag peaks in the plot. These variations are caused by localized weather conditions, which include aerosols, clouds, ozone levels, sun zenith angle (SZA), surface albedo, and altitude. Notably, Lumle has the highest UVI whereas Bhairahawa and Pokhara get the lowest UVI among the analysed areas. This observation is consistent with the well-established theory that UVI tends to increase with altitude [18, 24].

Table 2 presents a detailed summary of the mean monthly change in the Ultraviolet Index (UVI), indicated by the symbol μ (mean), and the standard deviation, marked by the symbol σ, for the Nepalese cities of Lumle, Bhairahawa, and Pokhara. The table illustrates a clear trend in which the average monthly UVI (μ) and standard deviation are lowest in December, increasing progressively until July, then decreasing progressively until the following December. The observed variance in standard deviation can be explained by the major influences that various causes have on the atmospheric conditions after December. These influences lead to expected oscillations in UVI and its associated products. The dynamic character of UVI and the complex interactions between atmospheric components throughout the year are highlighted by this temporal analysis.

Solar Zenith Angle (SZA), surface albedo, altitude, and a variety of other local meteorological variables, such as clouds, aerosols, and ozone column levels, are all strongly correlated with the daily variations in the solar Ultraviolet Index (UVI) measured at each location. Higher UVI levels during the summer months are expected because of the lower solar zenith angle at lower latitudes relative to higher latitudes. However, other contributing factors also have an impact on these differences, therefore latitude is not the only determinant [8,15]. The intricate interactions between these factors emphasize the diverse ways that atmospheric dynamics affect UV radiation and contribute to the subtle daily trends in solar UVI.

Summertime brings with it increased environmental clarity because of the purifying power of rains, which removes pollutants and aerosols, resulting in higher UVI levels. There is then an accumulation of aerosols that absorb solar UV rays in the autumn months after the rainy season, which lowers UVI. This build-up continues through the winter and spring, resulting in a more gradual increase in solar UV radiation before summer and a slightly faster fall in radiation after the rainy season in the autumn. Because of its high altitude and rugged topography, Lumle retains a shallower atmosphere, which helps to create clearer conditions.

Ozone Climatology

Since the discovery of the ozone hole, multiple worldwide stations have been the subject of extensive research and comparisons between ultraviolet (UV) radiation and ozone columns at high latitudes. These studies have revealed a range of values in the troposphere and stratosphere, which have provided important new information about the intricate dynamics of ozone distribution and how it affects UV radiation [5,21].

1) Monthly Variation of Total ozone column (TOC) at Bhairahawa, Pokhara, and Lumle:

The Ozone Monitoring Instrument (OMI) aboard the AURA satellite estimates where the monthly average Total Ozone Column (TOC) quantities, expressed in Dobson units (DU), are extracted. As shown in Figure 4, the data is derived directly from the OMTO3_O3 product and spans the long period from 2004 to 2023-09-23. This analysis offers important insights into the temporal dynamics of ozone dispersion across the study period by providing a thorough portrayal of the monthly changes in the Total Ozone Column at the designated locations of Bhairahawa, Pokhara, and Lumle.

The results of the investigation show that April and December regularly have the highest and lowest average monthly ozone concentrations, respectively. The lowest values for Bhairahawa (A), Pokhara (B), and Lumle (C) are 258.5 DU, 251.4 DU, and 252 DU in December; the highest values for these same locations are 291 DU, 285.3 DU, and 283.3 DU in April. This pattern confirms previous studies by highlighting a decrease in the Total Ozone Column (TOC) with increasing altitude above sea level. The highest recorded monthly TOC values in the south and middle of India, which reach as high as 290 DU in April, May, and June, are significantly linked to longer days, higher temperatures, and lower relative humidity [20].

Table 2 : Average monthly variation of UVI(μ) and standard deviation(σ) for Bhairahawa, Pokhara, and Lumle of Nepal

Locations	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhairahawa	μ	3.32	4.95	6.39	7.44	7.71	7.77	7.57	7.35	6.29	5.01	3.68	3.11
	σ	1.09	1.29	1.39	1.46	1.69	2.25	2.32	2.14	1.90	1.37	1.16	1.01
Lumle	μ	4.97	6.80	8.78	9.93	10.54	11.47	12.89	11.62	9.28	7.00	4.96	4.31
	σ	1.47	1.51	1.76	1.81	1.96	1.96	2.28	2.23	2.02	1.72	1.35	1.36
Pokhara	μ	4.57	6.27	8.01	8.97	9.36	9.87	10.71	9.78	8.12	6.36	4.67	4.03
	σ	1.28	1.61	1.91	2.12	2.39	2.64	3.38	3.03	2.40	1.78	1.34	1.34

The TOC levels at any particular site are determined by several factors that work together, including variations in the dynamical structure of the stratosphere, air circulation from the troposphere to the stratosphere, changes in anthropogenic ozone-depleting compounds, and solar flux [20]. Even though Lumle is much higher than Bhairahawa, it is still very close to Pokhara—only 32 km away—and has similar weather and atmospheric conditions.

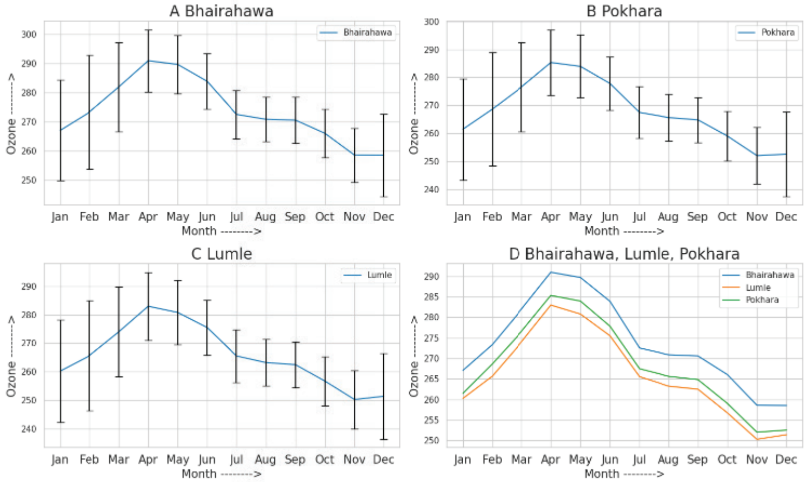

Fig 4. Monthly variation of mean total ozone column for Bhairahawa (A), Pokhara (B), Lumle (C), and altitude effect (D) using OMI data from 2004-2022.

Additionally, Table 3 gives a thorough summary of the monthly mean Total Ozone Column (TOC), which is indicated by the symbols µ (mean) and σ (standard deviation), for each station. According to Figure 5, there is an increase in the overall amount of ozone column along with its oscillations between January and March. This rise is related to higher aerosol levels and pollution at local stations. Remarkably, increased UV radiation reaching the Earth's surface can occur from even a slight decrease in atmospheric ozone content [22, 23]. Together, Figures 2 and 4 show that the solar ultraviolet index (UVI) and total ozone column (TOC) have an inverse relationship; that is, as solar UVI rises, the amount of total ozone column falls. This finding emphasizes how solar UVI and TOC dynamics are interdependent and affect atmospheric conditions.

2) Seasonal Variation of Ozone at Bhairahawa, Pokhara, and Lumle

Figure 5 shows the extremely consistent minimum and maximum values of the Total Ozone Column (TCO) over Bhairahawa, Pokhara, and Lumle, which are roughly 7 DU, across all seasons. The figure illustrates a clear seasonal trend in which summer is the season of maximum TCO and winter and fall are the seasons of minimum TCO. This variance that has been observed fits in with accepted climatological assumptions. The chart is intriguing because it highlights the narrow range of seasonal variation in TCO and highlights its comparatively steady behaviours all year long.

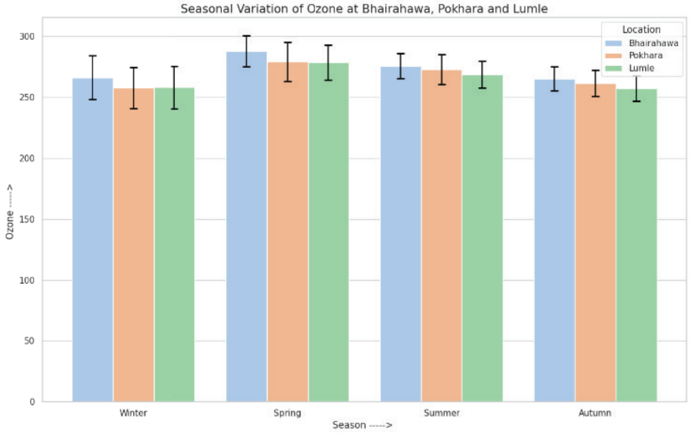

Fig 5. Seasonal variation of mean total ozone column for Bhairahawa, Pokhara, and Lumle using OMI data from 2004-2022.

In addition, the seasonal variations in TCO shown here offer an invaluable framework for comprehending its possible impact on solar ultraviolet (UV) radiation. A model states that at the peak of a solar cycle, a 1% increase in UV radiation is equivalent to a 2% rise in ozone concentration [20]. The narrow range of TCO fluctuations seen in this study, however, suggests that ozone's effect on solar UV radiation is minimal in comparison to the effects of other variables. Aerosols, cloud cover, surface albedo, altitude effects, and other atmospheric parameters are some of the elements that jointly affect the complex dynamics of UV light that reaches the Earth's surface.

Table 3. Monthly variation of mean total ozone column for Bhairahawa, Pokhara, and Lumle,

Location	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhairahawa	μ	267.1	273.3	281.9	291.0	289.7	283.9	272.5	270.9	270.6	266.0	258.6	258.5
	σ	17.3	19.6	15.3	10.7	10.1	9.5	8.3	7.7	7.9	8.3	9.3	14.2
Lumle	μ	260.2	265.7	274.0	283.0	280.8	275.5	265.5	263.2	262.5	256.7	250.3	251.4
	σ	17.9	19.4	15.7	11.9	11.3	9.6	9.2	8.2	8.0	8.6	10.2	15.1
Pokhara	μ	261.5	268.6	276.5	285.3	283.9	277.8	267.5	265.6	264.8	259.0	252.0	252.5
	σ	18.1	20.3	15.9	11.8	11.2	9.6	9.2	8.3	8.1	8.8	10.1	15.2

Conclusions

Using data from the Ozone Monitoring Instrument (OMI) on board the AURA satellite, this study aims to monitor the climatology of the Ultraviolet (UV) Index and the total amount of ozone for Bhairahawa, Pokhara, and Lumle in Nepal. The results show that the UV Index follows a seasonal pattern, with minimum values in the winter ranging from 3.32 to 4.97 and maximum values in the summer ranging from 7.8 to 13. Simultaneously, all research locations show seasonal fluctuations in the Total Ozone Column (TOC), with minimum values ranging from 251.4 to 288.5 Dobson Units (DU) in December and maximum values ranging from 285.3 to 291 DU in April, during overpass time.

One of the study's main findings is that altitude and the solar UV Index have an inverse relationship, whereas altitude and the total ozone column have a direct link. In particular, the total ozone column tends to decrease as altitude rises, whereas the solar UV Index continues to climb. This finding emphasizes the significance of taking height into account as a critical element impacting UV radiation and ozone distribution, and it is consistent with accepted concepts in atmospheric science.

To sum up, the study highlights the complex interactions between many elements that affect UV radiation and total ozone concentration, offering important information about the climatological dynamics of these parameters in the areas under investigation. Utilizing cutting-edge satellite data advances our understanding of these atmospheric processes, which is crucial for creating efficient plans for managing UV exposure and environmental monitoring.

Acknowledgements

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