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Comparative study of UV index in the selected sites of Nepalese teritory

Isman Mainali , Prakash Khadka, Nurapati Pantha*

Central Department of Physics, Tribhuvan University, Kathmandu, Nepal

*Corresponding author. Email: `mrnurapati@gmail.com`

Abstract

Progression and development of many underwater and terrestrial life forms are influenced by many environmental factors, including the amount of ultraviolet radiation present at water and the Earth's surface. Spectral measure of solar UV radiation helps us to understand the causes of change in environment and also raise public awareness about potential threats when the index value goes higher. This paper presents the value of UV index over six different locations of Nepal which are situated at different latitude and at different altitude. The numeral values of UV index during solar noon, provided by POWER data sets from year 2001 AD to 2021 AD, was used which were then compared with standard value categories of UV index based on WHO guideline. The UV index value for these locations were compared on monthly and annual basis. Upon analysis, it was found that during solar noon average value of UV index above Dolpa was highest with the value 9.10. The maximum value of UV index above other locations were: 8.43(Birgunj), 8.13(Hetauda), 6.14(Rolpa) and 5.45(Tulsipur) respectively. During mid-summer the value of UV index in each of these locations fall into high or very high category as per the WHO guideline. Thus, people from these locations are vulnerable to the exposure of harmful UV radiation. This study reveals that special care should be taken during midday from June through August.

Keywords
UV index, UV radiation, Aerosols, Surface albedo, Altitude effect, Latitude effect.

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1 Introduction

UV radiation is a kind of electromagnetic radiation generated by sun and some artificial sources such as arc welders, tanning beds etc. It lies in between wave- lengths of about 400nm(boarder to visible-light region) and about 100nm(boarder to X-ray region). This kind of radiation is produced by extremely hot surfaces like sun and by excitation of atoms in a gaseous discharge tube. Most of the UV radiation present in sunlight is soaked up by Oxygen in Earth's atmosphere to form Ozone layer of lower stratosphere [1].

Depending upon the interaction of wavelength of ultraviolet radiation with biological materials, it is classified into three divisions: a)UV-A (400-315 nm) b)UV- B (315-280 nm) and c)UV-C (280-100 nm) [2]. Ninety nine percent of UV radiation that reaches Earth's surface is ultraviolet A radiation and remaining 1 percent is ultraviolet B radiation while UV-C does not reach Earth's surface due to screening of ozone layer. When Ozone layer depletes then more UV-B radiation reaches Earth's surface and causes many hazardous effects on organisms [3].

UV index is a tool used to measure the power of sun's ultraviolet radiation at a specific place and time. This scale was first developed in 1992 by Canadian scientists and then standardized adopted by the World Meterological Organization(WMO) and UN's World Health Organization(WHO). This is a linear scale and increases at constant rate. Higher value of UV index represents greater threat of sunburn due to UV exposure. During night time the index has value 0 which corresponds to zero UV radiation. When it was originally designed, an index of 10 corresponded roughly to noon time summer sunlight with clear sky. The index compress several factors into a single number that gives us concept of how cautious we need to be in sun. A score of 1 or 2 implies low UV concentration, 3 to 5 implies moderate, 6 or 7 implies high, 8 to 10 implies very high and 11 and above implies extreme condition [4].

There are several factors that affects the value of UV index over the specific locations. Some of the factors are as mentioned below:

A. *Altitude*

The altitude plays vital role in variations of UV index level at different geographical regions. With increase in altitude the value of UV index increases and vice versa. As altitude increases, atmosphere gets thinner due to which less amount of solar radiation is absorbed or scattered. In addition, direct sun's rays fall on the surface at higher altitude which increases the UV intensity. Also the effect of reflection by snow covered mountain at higher altitude contributes to increasing UV. As per WHO guideline, every 1000m increase in altitude causes 10% increase in UV index [5].

B. *Absorption and scattering by aerosols*

Aerosols are tiny particles that are suspended in air which are emitted either due to industrial processes or natural sources like volcanic eruption. The surface UV irradiance is affected by absorption and scattering process of atmospheric aerosols. Thus, aerosols are referred to as either absorbing or non-absorbing. The effect of these two processes are ascertained by values for aerosol optical depth(AOD) and single scattering albedo(SSD).

The absorption and scattering constituents of AOD depends on wavelength and is likely to be proportional to λ^α, where α is the Angstrom coefficient. The aerosols can have impact on cloud cover, cloud properties and precipitation which ultimately affect hydrological cycle [6]. Significant engrossment of aerosols has been monitored under forest fires or fume from burning animal waste or plant materials, and desert dust [7].

C. *Scattering by clouds*

Cloud cover is one of the compelling geophysical variate that affects surface emission at all wavelengths. Cloud bears several varieties and different variety of cloud have different impact on angular distribution and intensity of surface UV radiation. In cloudless days UV irradiance is higher. Generally, clouds depress the concentration of UV radiation through its absorption. But, thin clouds may even elevate the UV concentration due to dissemination from cloud particles [8]. It has been observed that short wavelength radiation is less influenced by existence of cloud compared to longer wavelength which shows the wavelength dependent effect of clouds on surface irradiance.

D. *Surface albedo*

Surface reflective power (Surface albedo) disperse radiation upward to the airspace which increases surface UV irradiance. The estimates of surface ultraviolet rays from satellite data is also affected by snow on the ground. Due to increased reflectivity from snow the estimated surface irradiance reduces. With mixture of cloud cover and snow the estimation of UV radiation becomes more complex.

E. *Latitude*

At the equator UV radiation from the sun is at its peak and it decreases gradually as it moves towards the pole. The main reason behind it is during solar noon, the sun is directly overhead above equator, causing radiation to travel shortest distance through the atmosphere before striking the ground. At higher latitude, the radiation takes lengthier route through the atmosphere.

F. *Molecular scattering*

Under the considerations of clean atmosphere with absence of absorption, particulate scattering and reflection from the ground (i.e. albedo = 0), the only scattering is molecular scattering or Rayleigh scattering. Molecules of Oxygen and Nitrogen are smaller than the wavelength of UV and visible emission and cause Rayleigh scattering. While molecules of water vapor, aerosols etc. are larger than UV visible radiation and cause Mie scattering [9]. The chief variable for evaluating surface UV in Rayleigh atmosphere are surface pressure and SZA.

G. *Solar Zenith angle*

With increase of solar zenith angle(SZA) the amount of radiation falling on a horizontal plane of surface of Earth decreases. There are two main reasons behind it:

a) The amount of solar radiation reaching the Earth's surface is proportional to the cosine of angle between normal to the surface direction of radiation.

b) The relative path length of direct radiation passing through the aerosphere increases as the sun descend in the sky.

The first fact states that both diffuse and direct component of surface ultraviolet rays are subjected to cosine effect. The second fact states that when SZA increases to 90 degree the departing of relative path length(μ) from secant of solar zenith angle deviates notably. Thus, with increase in SZA direct solar beam reduces due to scattering and absorption process in the atmosphere [8].

H. *Absorption by atmospheric gases*

Atmospheric gases like sulfur dioxide, ozone and nitrogen dioxide absorb UVB radiation. The diffused and direct component of surface UV emission are both absorbed by these gases. The diffused component is reduced due to absorption that occur in optical path both before and after the scattering of radiation. According to Beer's law, the direct component of surface UV radiation is inversely proportional to the secant of solar zenith angle times exponent of the coefficient of absorption at a specific wavelength. This explains the reduction of direct component.

I. *Depletion of ozone layer*

The ozone layer is region of Earth's stratosphere containing layers of ozone molecules that absorb almost all of the harmful ultraviolet light coming from the Sun. It is mainly present in the lower portion of earth's atmosphere and has ability to absorb around 99 % of the harmful affecting UV radiation coming from the sun which can have negative influence on life of earth. The over time thinning of the earth's ozone layer in the upper atmosphere due to release of chemical compounds consisting gaseous chlorine or bromine from industries or other human activities is called ozone layer depletion. One chlorine atom carries potentiality to destroy 100 ozone molecules per second [10].

Ozone is strong absorber of UVB radiation. So intensity of UVB radiation on Earth's surface depends upon the thickness of ozone layer [11].The depletion of ozone layer leads to direct exposure to harmful UV radiation of the sun. The optical path of UV radiation is plainly lengthened near the surface and is obviously reduced as ozone is destroyed. UVB radiation is known to be biologically damaging.

2 Effects of High UV Index

UV radiation has low penetrating power compared to X-rays. So its effects on the human body are limited to the surface skin. Melanin is a chemical pigment present in skin which absorbs UV radiation and limits its penetration into tissues. When these pigments in cells are activated by UV radiation they migrate to the surface of the skin causing suntan. Persons with fair skin are more prone to harmful effects of UV radiation as they have less melanin pigment [12]. Some of the effects of over exposure to UV radiations are discussed below:

A. *Effects on aquatic animals*

Numerous aquatic animals, with an emphasis on fish, corals, amphibians, zooplankton, and other aquatic organisms have shown the significant role that UV radiation plays as an environmental stressor. According to a recent metaanalysis that revealed negative effects of ambient UV-B radiation on the growth and survival of a wide range of aquatic organisms (not just animals). Reduced survival rates of copepods from Antarctic waters and UV-exposed larval kill are two direct effects of UV on marine zooplankton. In marine copepods fed UV-exposed versus unexposed diatoms, the indirect effects of UV include reduced egg production and more deformed larvae. In juvenile Atlantic salmon, increased UV-B radiation can lower growth rates and immune function; in juvenile rainbow trout, it can increase trematodes, or parasitic flatworms that cause cataracts [13].

B. *Effects on Human Health*

Continuous exposure to the sun causes premature aging, which progressively can make skin become bulky, creased, and leathery [14]. Many researches have revealed that UV radiation is likely to increase certain cataracts. UV radiation can also cause skin cancer around the eyes and degeneration of macula [15]. Besides these effects, excessive exposure to ultraviolet radiation can abolish skin's natural defense and proper functioning of the body's immune system. Unprotected exposure to UV radiation is the major cause of skin cancer. Skin cancers like Melanoma, and types of non-melanoma skin cancers like Basal cell carcinomas and squamous cell carcinomas are immediate consequences of exposure to higher amount of UV radiation [16].

3 Methods

A. *Measurement Ideology*

NASA has been disseminating crucial data for the study of climate and climatic processes through its Earth Science research program. The NASA Global Energy and Water Exchange-Surface Radiation Budget project (GEWEX SRB) and CERES SYN1deg Edition 4.1 provide surface shortwave radiation or solar insolation, along with superior valuations of the Earth's top-of-atmosphere (TOA). The solar-related data from these sources are presented on a comprehensive 1^0 latitude longitude grid. The POWER data sets simultaneously integrate these data sets.

The POWER data sets furnish both low-energy and high-energy solar fluxes to individuals. The GEWEX shortwave algorithm employs a remodeled method by Laszlo and Pinker (1992) to solve the radiative transfer equation. It involves the use of a radiative transfer model, alongside temperature and moisture profiles taken from ISCCP nnHIRS and cloud parameters deduced from the International Satellite Cloud Climatology Project (ISCCP), with supplements from 4-D data assimilation products produced with MERRA-2 and distributed by NASA Goddard Space Flight Center (GSFC). Additionally, ozone column amounts are obtained from satellite measurements [17]. As raw data, three satellite visible radiances are utilized: the sky composite radiance, instantaneous clear-sky radiance, and the instantaneous cloud-sky radiance. These are then converted into broadband shortwave TOA albedos using the Angular Distribution Models (ADM) from the Earth Radiation Budget experiment. To find the absolute value of surface reflective power and produce a TOA skyward flux, a radiative transfer model is applied. POWER provides the ultraviolet irradiance at all temporal levels from 2001 to the months of Near Real Time (NRT) directly from CERES SYN1deg, which is available only in all-sky conditions.

B. *Research area*

The research areas are located at different latitude, lon- gitude and altitude. Shey Phoksundo Rural Municipality lies within an elevation range of 2300 meters and 7425 meters, with a longitude 83.0900^0 E and latitude 29.4200^0 N [17, 18]. Manang is located at latitude of 28^0 $4^{'}$N and longitude of 84^0 $1^{'}$E with an altitude ranging from 2000 to 6000 meters [19]. Hetauda is positioned at a latitude of 27^0 $25^{'}$N and longitude of 85^0 $2^{'}$E respectively, and at an altitude of 345m from sea level [20]. Paribartan rural municipality is situated at longitude 82.5700^0 E and latitude 28.5000^0 N, within an elevation range of 1400- 1600 m from the sea level [21]. Birgunj is located at a latitude of $27^0 1^{'}$N and longitude of 84052 E respectively, and the elevation of city from sea level is 91m [22]. Tulsipur Municipality is situated at longitude 82.2983^0 E and latitude 28.1311^0 N, and at an altitude of 725 m from the sea level [23]. Furthermore, the research area are classified into three categories depending upon their altitude from sea level as: a) Low altitude (Birgunj and Hetauda) b) Moderate altitude (Tulsipur and Paribartan RM) and c) High altitude (Shey Phoksundo RM and Manang).

C. *Data Analysis*

For a comparative study of the UV Index above Birgunj, Dang, Hetauda, Rolpa, Dolpa, and Manang from 2001 AD to 2021 AD, data were obtained from power.larc.nasa.gov. The UV Index values were derived from mean solar day measurements taken hourly and averaged to obtain monthly averages. Subsequently, these monthly averages were further averaged to determine the annual average UV Index value. A standard deviation test was conducted to assess the dispersion of the data points.

4 Results and Discussion

A. *Annual variation and monthly variation of UV index above different locations*

At low altitude

The average value of UV index for every month from year 2001 AD to 2021 AD is presented in Table 1 below:

Table 1: Average UVI above Birgunj and Hetauda, and calculated Standard Deviation

Months	**Birgunj UV Index**	**S.D.**	**Hetauda UV Index**	**S.D.**
January	4.16	0.41	4.37	0.42
February	5.48	0.58	5.42	0.62
March	7.17	0.50	6.89	0.42
April	8.43	0.45	8.13	0.51
May	8.06	0.71	7.65	0.67
June	8.12	0.60	7.58	0.38
July	7.61	0.68	7.22	0.52
August	7.87	0.61	7.43	0.50
September	7.81	0.45	6.80	0.39
October	7.03	0.35	6.37	0.33
November	5.12	0.39	4.93	0.33
December	4.13	0.34	4.03	0.36

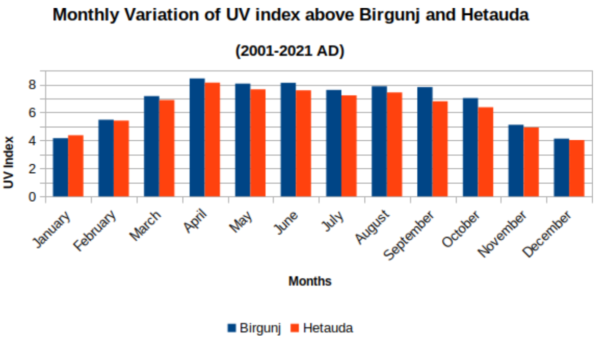

Figure 1 (a): Average Monthly Variation of UV index above Birgunj and Hetauda.

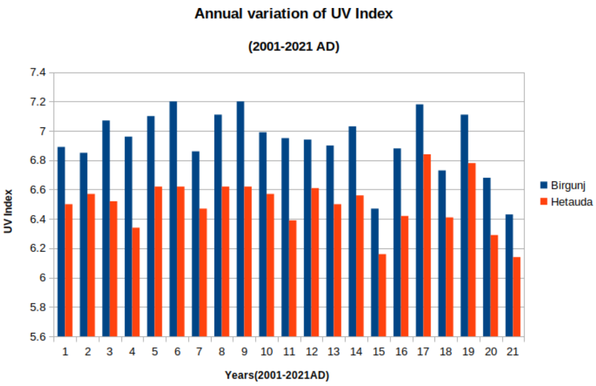

Figure 1(b): Average annual Variation of UV index above Birgunj and Hetauda.

The graphs (**Fig:1(a)**& **(b)**) and Table 1 reveal that the UV index in Birgunj reached its maximum in the year 2009 AD with the value of 7.19 and its minimum in 2021 AD with the value of 6.43. In contrast, Hetauda shows slight variations in the UV index annually, with a minimum of 6.16 in 2015 and a maximum of 6.84 in 2017. Both locations experience the highest UV index in April, reaching 8.43 in Birgunj and 8.13 in Hetauda. Conversely, December records the lowest UV index values in both places. Notably, the peak UV index values observed in April classify as 'Very High' according to WHO guide- lines. The difference in local weather conditions or the accumulation of more aerosols in the atmosphere may be reasons for the lower UV index in Hetauda compared to Birgunj. Additionally, the higher air pressure in Birgunj, due to its lower altitude, implies greater global solar radiation (GSR) there than in Hetauda as air pressure increases the global solar radiation [24].

At Moderate altitude

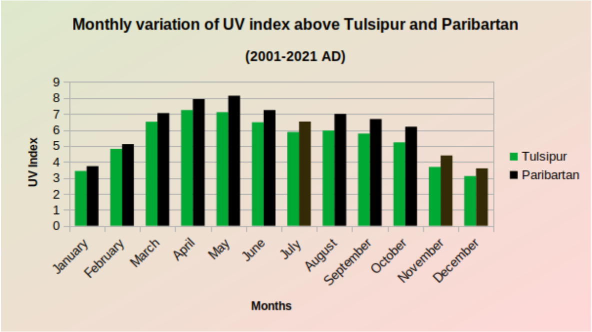

Figure 2(a): Average Monthly Variation of UV index above Tulsipur Sub- metropolitan and Paribartan Rural Municipality.

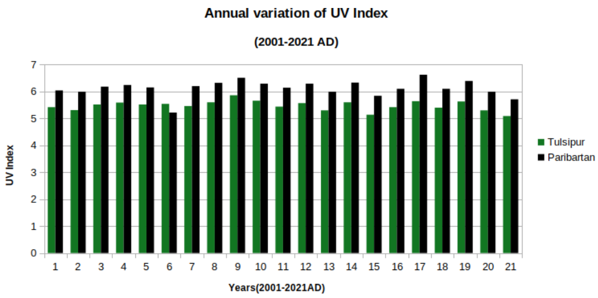

Figure 2(b): Average Annual Variation of UV index above Tulsipur Sub- metropolitan and Paribartan Rural Municipality.

Table 2: Average UVI above Tulsipur and Paribartan, and calculated Standard Deviation.

Months	**Tulsipur UV Index**	**S.D.**	**Paribartan UV Index**	**S.D.**
January	3.43	0.37	3.73	0.41
February	4.81	0.55	5.11	0.56
March	6.51	0.45	7.05	0.47
April	7.24	0.56	7.93	0.60
May	7.11	0.74	8.14	0.77
June	6.48	0.67	7.24	0.77
July	5.87	0.45	6.52	0.55
August	5.96	0.50	7.00	0.63
September	5.77	0.32	6.68	0.41
October	5.22	0.34	6.20	0.40
November	3.68	0.24	4.40	0.29
December	3.11	0.26	3.59	0.32

Based on the graphs (**Fig:2(a)** & **(b)**) and table(II) , it can be concluded that the UV index values above Tulsipur and Paribartan RM were highest in the year 2009 AD and lowest in 2021 AD. Upon analyzing the monthly data, it is evident that the UV index peaks in April for Tulsipur and in May for Paribartan, while reaching its minimum in December. The maximum UV index values observed in April classify as 'High' and in May as 'Very High' according to WHO guidelines. Additionally, due to its higher elevation, Paribartan RM experiences a higher UV index compared to Tulsipur Sub metropolitan.

At High Altitude

Table 3: Average UVI above Manang and Shey Phoksundo, and calculated Standard Deviation

Months	**Manang UV Index**	**S.D.**	**Shey Phoksundo UV Index**	**S.D.**
January	4.48	0.62	4.89	0.62
February	5.86	0.72	6.70	0.93
March	7.28	0.49	8.99	0.93
April	8.05	0.57	10.89	0.88
May	8.47	0.67	12.06	0.92
June	8.34	0.61	12.56	0.80
July	7.94	0.51	11.54	0.66
August	8.18	0.44	11.02	0.48
September	7.90	0.35	10.29	0.54
October	7.13	0.52	8.83	0.52
November	5.21	0.46	6.44	0.33
December	4.37	0.38	4.98	0.50

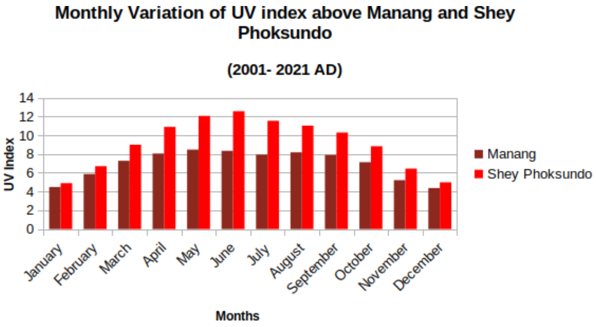

Figure 3(a): Average Monthly Variation of UV index above Manang and Shey Phoksundo Rural municipality.

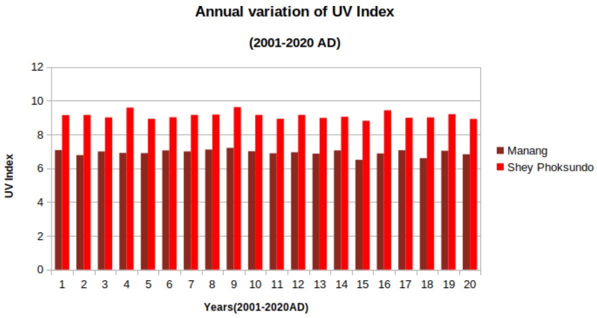

Figure 3(b): Average Annual Variation of UV index above Manang and Shey Phoksundo Rural municipality.

From the Table 3 and graphs (**Fig:3(a)** & **(b)**) above, it can be concluded that the UV index values above Manang and Shey Phoksundo, between the years 2001 and 2020 AD, reached their maximum in 2009 AD and minimum in 2015 AD. Analysis of the monthly UV index values reveals, peaks in May for Manang, and June for Shey Phoksundo, with minimum values occurring in December for Manang and January for Shey Phoksundo. The higher UV index above Shey Phoksundo, compared to Manang, can be attributed to its greater altitude.

The highest UV index value in Shey Phoksundo illustrates the influence of altitude on UV exposure, as this region has the highest elevation among the six territories. The increase in UV concentration with altitude is due to factors such as a decrease in air molecules, aerosols, high reflectivity of the ground and clouds in the atmosphere [25]. Additionally, the path length of the sun's rays shortens with increasing altitude. There is a decrease in the UV index values between June and August, coinciding with the period of maximum precipitation and cloud covers [26]. Thick cloud cover during this time lowers the amount of UV exposure. There is a slight rise in the UV index value after July. This could be attributed to a decrease in pollutants, which are flushed out due to rainfall, resulting in clearer skies [6]. Despite its higher altitude, Hetauda exhibits a lower UV index compared to Birgunj. This difference can be attributed to the increasing aerosol content in the atmosphere and the regional-scale transport of polluted air masses [27]. A similar UV index trend was observed in Kathmandu as well. Despite its higher altitude, the peak UV index value recorded was 6 to 7 [28]. Since both regions are industrial areas, the increasing aerosol concentration in the atmosphere has reduced the UV index due to which the effect of altitude became less dominant.

Upon analyzing yearly data, it is evident that the UV index peaked in the year 2009 AD, likely due to the heightened activation of factors influencing the UV index. However, there was a significant decline in the value around 2015 AD. This decline could be attributed to the arrival of primarily diffuse UV radiation caused by the accumulation of a large number of dust particles in the upper atmosphere following a devastating earthquake, which obstructed direct UV radiation. Also, different parts of Nepal received heavy rainfall in the same year which could also have reduced the over UV exposure [29]. Furthermore, the UV index appears to have declined in all six locations after 2019. The COVID-19 pandemic is undoubtedly responsible for this decline. With lockdown measures in place and no vehicular emissions, there was a significant reduction in airborne emissions of various oxides, which support the ozone layers thickening and help prevent significant amounts of incoming UV radiation.

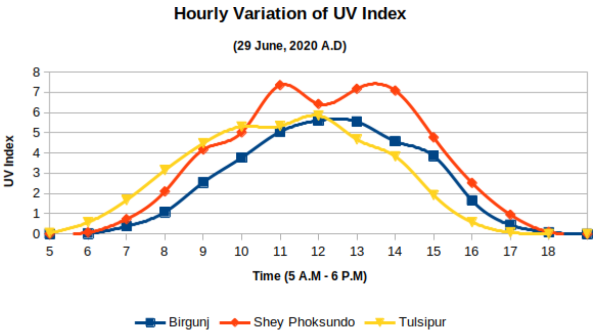

Figure 4: Hourly Variation of UV index above Birgunj, Tulsipur and Shey Phoksundo Rural municipality.

The monthly variation plot clearly indicates that the minimum UV index values are observed in December or January, while the values become dominant during the summer months. There is a clear upward trend in the first half of the year and a downward trend in the second half. Overall, the data analysis suggests that the UV index values in this region vary between 3 and 13. The maximum UV index values fall into the category of high and very high when compared with the standard values mentioned by the WHO [30].

Figure 4 represents the UV index trend during the day- time. From the graph, it is evident that the UV index rises after sunrise, peaks around solar noon, and then gradu- ally decreases, reaching zero at night. Additionally, the UV index remains at zero both before sunrise and after sunset. Figures 1a), 2a), and 3a) clearly illustrate that the UV Index value is low during the winter season (December and January) and increases with rising temperatures in the spring and summer. The study of the UV index in various locations across Nepal, conducted at different altitudes, reveals that the UV index becomes higher during April, May and June, and drops significantly in December. Additionally, UV index values increase with altitude. However, in industrial areas, despite the higher altitudes, there is no significant rise in UV index levels. From a global perspective, studies of the UV index con- ducted at various sites across Africa have shown that UV levels are higher near the equator and at higher altitudes. This highlights the impact of latitude and altitude on UV index levels at specific locations. Additionally, it was observed that UV index values increase during the summer and in areas with low industrial activity, while they decrease in winter, indicating the influence of seasonal changes and aerosol levels on UV index readings [30]. All these observations suggest that the UV index rises with increasing altitude, while a higher aerosol optical depth results in a significant reduction in UV index levels [31]. Furthermore, clouds usually decreases the concentration of UV radiation from reaching the earth but dispersion from thin cloud may sometime increase it [32]. The higher value of UV during summer suggests that special care should be taken to protect oneself from overexposure to UV radiation during peak hours in the summer season.

After closely analysing the data, it is recommended that people in all six locations adopt measures to protect themself from the possible threats posed by excessive UV exposure between the months of March and October. By adhering to simple yet crucial practices, such as wearing protective clothing, applying broad-spectrum sunscreen, and seeking shade during peak sunlight hours, individuals in the selected area alongside most of the territories of Nepal can significantly reduce the risk of sunburn, premature aging, and skin cancer [33]. Additionally, staying hydrated and using moisturizer can help prevent sunburn. Mountaineers are advised to wear sunglasses to protect their eyes. Hikers should consider using UV-blocking filters for their gear. It's also important to check the UV index of a location before planning outdoor activities. Promoting these habits within communities can foster a culture of sun safety, ensuring that people of all ages prioritize their health while enjoying outdoor activities.

5 Conclusion

Upon analyzing the UV index values above Birgunj, Hetauda, Tulsipur, Shey Phoksundo, Paribartan R.M., and Manang, it is evident that during solar noon, the UV index above Shey Phoksundo reaches the highest levels among all locations. The maximum average UV index above Shey Phoksundo is 12.56, indicating an extreme risk from unprotected solar exposure, observed typically in June, while the minimum value is 4.89, recorded in December.

Furthermore, the maximum average UV index values above Birgunj, Tulsipur, Paribartan, Manang, and Het- auda are classified as 'Very High' according to WHO guidelines, typically occurring in April and May. In contrast, the minimum average UV index values, classified as 'Moderate' according to WHO guidelines, are noted in December.

In conclusion, safeguarding ourselves against the detrimental effects of overexposure to UV radiation demands a proactive commitment to safety habits.

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