Solar ultraviolet (UV) radiation as a potential health hazard in the Himalayas

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Abstract

This paper is an attempt to bring forth situations of UV radiation levels or UV index (UVI) and effects affecting different causes to concerned living beings and on environment in the Himalayas. It has analyzed solar radiation data observed at different locations, covering the elevation range of 2735 meters (m) above sea level (a.s.l.) to 4355 m a.s.l of the Nepal Himalayas. In addition, existing research results reported by other researchers on Himalayan UVI and UV guidelines of the World Health Organization (WHO) have been reviewed. The study has identified that mountaineers/ climbers are exposed to enhanced high levels of UV radiation due to the coupled effect of the altitude-related increase of UV radiation and the reflection from snow and ice-covered surfaces. Sun protection measures are essential to be applied according to the UVI range/ categories associated with existing weather conditions and seasons while out climbing or mountaineering, especially during high-intensity sun hours (09:00–13:30 local time (LT)) in the spring and autumn.

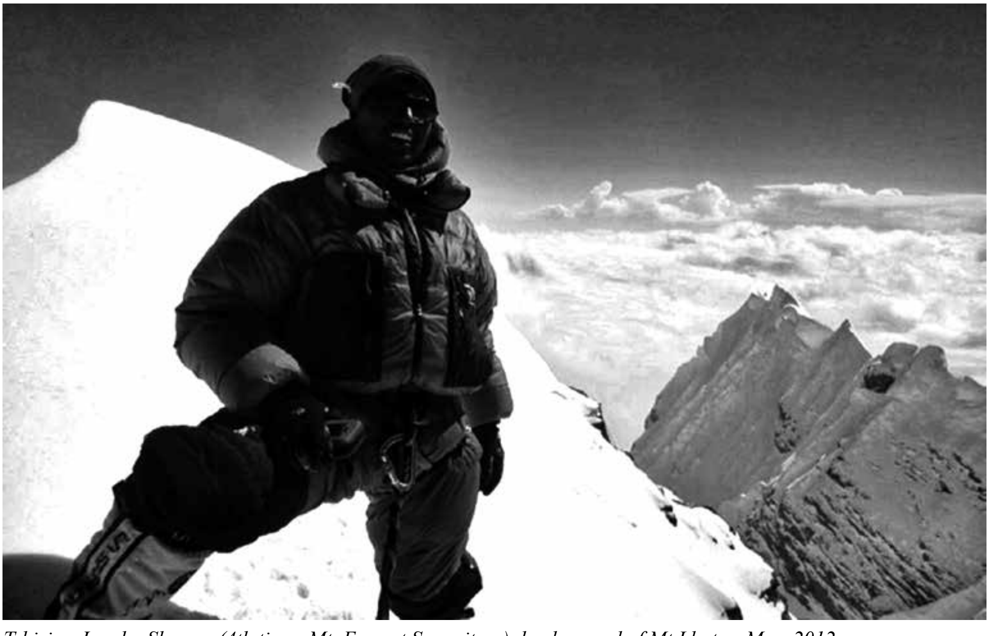
Keywords: *Solar UV radiation, UV Index, Himalayas, health hazard, Sun protection*

Introduction

The sun is the ultimate source of energy for the earth and sunlight is crucial for many processes on the earth, such as heat and production of oxygen through photosynthesis. Different life forms are possible only due to the availability of the right proportion of solar energy at or near the earth's surface. Sunlight (or in scientific terms: solar radiation or electromagnetic radiation) is transmitted in the form of waves with wavelengths in the range of about 0.2 to 2.6 micrometer. The solar spectrum consists of UV rays in the range of 200 to 400 nanometer.

A small amount of UV radiation is beneficial for humans and essential in the production of vitamin D (Holick, 1996; Lehmann, 2005). Also, UV radiation is widely used in industrial processes and in medical practices for a variety of purposes, such as killing bacteria and viruses, phototherapy, sun-tanning, etc. (CCOHS, 1997-2020). Despite being beneficial, prolonged exposure to solar UV radiation may result in sunbite to acute and chronic health effects on the skin (erythema and cancer), eyes and immune system (WHO, 2002; Moehrle et al., 2003). Regarding the multiple efffects on exposed human skin, a well-known mountain guide and climber- Mr. Tshiring Jangbu Sherpa narrates his experiences:

> "There are many risks to sunlight. When the sun rays fall on the white snow, its reflection burns the skin of the face and turns it very black, and the evening cold also affects the face. Use of UV cream on the whole face is mandatory. UV cream and protective goggles are thus very much essential for the high mountain trekkers and mountaineers. So I'd like to advise all the mountain aspirants to take precaution to protect toes, nose, hands, ears from the snow-bite and sun-bite."



Tshiring Jangbu Sherpa, (4th times Mt. Everest Summiteer), background of Mt Lhotse, May, 2012

The depletion of the stratospheric (20-25 kilometres a.s.l.) ozone layer leads to an increase in ground-level UV radiation because ozone is an effective absorber of UV radiation. The depletion of the stratospheric ozone due to the release of chlorofluorocarbons and other atmospheric pollutants has been observed for several decades. The changes in the stratospheric ozone and climate over the past forty years have altered the solar UV radiation conditions at the earth's surface (Diffey, 2004; Barnes, 2019). Watanabe et al. (2011) reported that ground-level UV radiation does not return to its previous stage even after recovering stratospheric ozone (part of the ozone recovery was observed in the 1990s compared to the 1980s) due to various interacting processes.

At higher altitudes, a thinner atmosphere filters less UV radiation (Blumthaler et al., 1997; Pfeifer et al., 2006). High elevation areas such as the Himalayas receive more UV radiation mainly due to decreasing amounts of air molecules, aerosols, ozone and clouds in the atmosphere (Schmucki and Philipona, 2002; Sharma et al., 2015). In recent years, there has been growing concern about increasing levels of UV radiation in the sunlight, especially at high altitudes (Barnes, 2019).

In the Himalayan countries, including Nepal, the people reside at around 3000-4000 m a.s.l., and it is of great interest to evaluate irradiances at those altitudes in order to determine the erythemal (erythema: redness of the skin) UV radiation exposure of the inhabitants. In addition, visitors from within the countries and different parts of the world travel and trek to those areas in different seasons for different purposes, such as hiking, trekking, skiing, trade, mountaineering, research, etc. where the degree of UV radiation is almost unknown. Moreover, at high altitude, there is an elevated risk of UV radiation exposure for mountain guides and mountaineers due to the altitude-related increase of UV radiation and the reflection from snow and ice-covered surfaces (McKenzie et al., 1998; Cockell et al., 2001). Painful injuries of snow blindness and retinal burn from intense solar radiation (visible rays and invisible UV rays) reflected by snow or glaciers have been reported by many mountain climbers and recorded as one of the well-known medical emergencies (Moehrle et al., 2003; Isser et al., 2019; Sherpa, 2020). Following is the narrative of a highly experienced Rock and Alpine Guide regarding the effect of sunlight:

> “Over the two decades that I've been guiding, I've decided that the greatest enemy to the climber is not the rain, it's not the snow and it's not the wind. Instead, it is the sun. There is nothing more relenting and nothing that will have such dire long term effects as the sun."

Jason D. Martin, Executive Director, American Alpine Institute, AMGA Certified Rock and Alpine Guide

Very few sporadic and site-specific studies on UV radiation have been carried out in the Himalayas (Singh and Singh, 2004; Pokhrel and Bhattarai, 2011; Sharma et al., 2015). The studies are quite limited and inadequate to make the concerned stakeholders aware. To the best of our knowledge, no studies on UV radiation have been reported from above 2850 m a.s.l. in Nepal Himalayas. The main objective of this study is to present the results of solar UV radiation level or UVI (i.e. a measure of the intensity of UV radiation) at high altitude sites of the Nepal Himalayas. The global solar radiation data observed at the high altitude meteorological stations were used to calculate the UVI for the respective locations. Additionally, existing research results reported by other researchers on Himalayan UVI and UV guidelines of the WHO will be reviewed to complement the present study.

Materials and methods

Study area

Solar radiation data were collected from high altitude meteorological stations that cover an elevation range of 2735 m a.s.l. to 4355 m a.s.l. in the southern slope of Nepal Himalayas. The stations are scattered and extended approximately 450 km from east to west of the Nepal Himalayas. The details of the study area are given in Table 1.

Table 1: High-altitude (in descending order) meteorological stations in the Nepal Himalayas.

Sites (Name of station)	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)
Khumbu (Dingboche) (DHM)	27º 53' 40"	86º 50' 40"	4355
Makalu (Sipton-La) (DHM)	27º 40' 00"	87º 13' 00"	3980
Langtang (Kyangjing) (DHM)	28º 13' 00"	85º 37' 00"	3920
Khumbu (Syangboche) (GEN-AWS)	27º 48' 36"	86º 43' 12"	3833
Annapurna: Machapuchhare (Fish-tail) - Base Camp (DHM)	28º 32' 00"	83º 57' 00"	3470
Kanjiroba – Hurikot (DHM)	29º 07' 00"	82º 36' 00"	2735

Data

In this study, global solar radiation (direct plus diffused radiation) data from the stations were collected (DHM, 1993-1994; Adhikary, 2012), sorted out and analyzed. Absolute extreme values of instantaneous global solar radiation data recorded once a month (monthly maximum) around local noon (±1 hour) under clear-sky conditions in Makalu, Khumbu (Dingboche), Langtang, Annapurna and Kanjiroba were selected from the data set covered the period from January 1993 to December 1994. The monthly maximum data were used to calculate monthly maximum UVI and then maximum seasonal average UVI for clear-sky conditions. The data were extracted from the two-year data set in order to calculate maximum possible UVI around local noon under clear-sky conditions at the high altitude meteorological stations.

Similarly, the 30-minute averaged global solar radiation (under all existing weather conditions) data recorded at Syangboche (Khumbu) Glaciological Expedition in Nepal (GEN) - Automatic Weather Station (AWS) for the period from June 1996 to May 1997 (Ueno et al., 1996 & 2001) were processed to obtain monthly mean hourly values. The hourly solar radiation data were then used to calculate diurnal (06:00–18:00 LT) hourly UVI. The purpose of the GEN-AWS data is to illustrate diurnal patterns of UVI that may typically represent the Khumbu region and serve as a reference for other regions of Nepal Himalayas as well. The summer, autumn, winter and spring seasons correspond to the months of June-August, September-November, December-February, and March-May, respectively. The instrumentation details are given in Ueno et al. (1996), Ueno et al. (2001), and Adhikary (2012). Although the study period may seem quite older but the writers have not yet come to know any other such studies carried out until May 2020. Hence this study projects the data as the nearest reference so far.

Solar UV radiation and UVI

Ordinarily, solar radiation is divided into three major energy forms with varying wavelength ranges, namely UV radiation (100 – 400 nm), visible light (400 – 700 nm), and near-infrared radiation (700 – 3500 nm). UV radiation, visible light and near-infrared radiation represent 8.7 %, 38.3 % and 51.7 % of solar energy respectively (University of Calgary, 2020). The sun emits UV radiation in three bands, UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm) (Figure 1). All UVC and approximately 90% of UVB radiation are absorbed by atmospheric ozone, water vapor, oxygen and carbon dioxide, while UVA is less affected by the atmosphere (WHO, 2002; Dhakal, 2009; CCOHS, 1997-2020). Therefore, the UV radiation reaching the earth's surface is largely composed of UVA with a small UVB component. The release of certain industrial chemical pollutants, such as chlorofluorocarbons into the atmosphere, is gradually eroding the earth's protective shield (ozone layer) which stops the sun's harmful UV radiation from reaching the earth (Diffey, 2004; Kerr & Fioletov, 2008; Barnes, 2019).

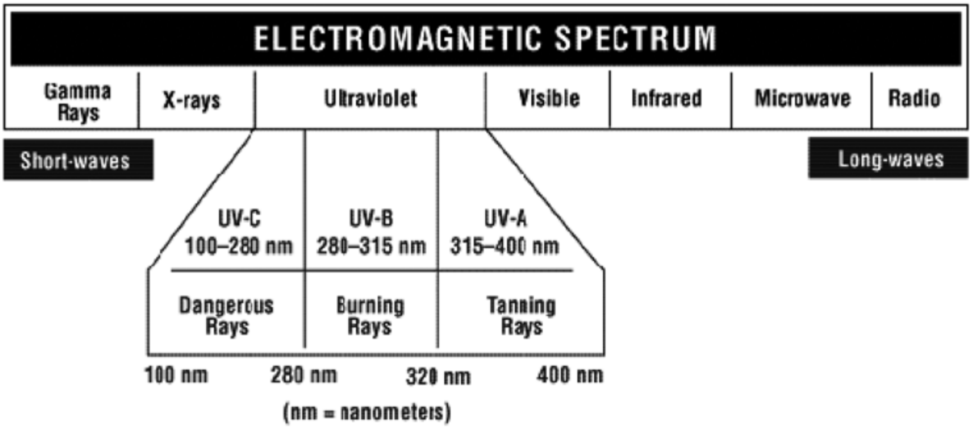


Figure 1: *Solar electromagnetic spectrum; shorter wavelengths (higher frequency) have higher energy, thus increasing the effect on chemical and biological systems (Adapted from CCOHS, 1997-2020).*

The UVI is a simple and informative index jointly developed by WHO, United Nations Environment Programme (UNEP), and the World Meteorological Organization (WMO) to measure the level of UV radiation exposure (WHO, 2002; CCOHS, 1997-2020). The UVI describes the level of solar UV radiation at the earth's surface that is relevant to effects on the human skin, and is dependent largely on UVA and partly on UVB radiation. UV radiation levels and therefore the values of the index vary throughout the days, months and seasons. The UVI can be measured directly with an instrument (e.g. UVS-E-T broadband radiometer, UVI sensor) or calculated by using empirical equations (Casale et al., 2003; Singh & Singh, 2004; Pokhrel & Bhattarai, 2011).

Methodology

UVI was calculated according to Pokhrel and Bhattarai (2011), who found an excellent quadratic relationship between observed UVI and global solar radiation at a station in Lukla. The equation is

$$Y = 8.6 \times 10^{-6} X^2 - 0.0021X + 0.22$$

Where, Y: UVI, and X: Global solar radiation

Although UV radiation at a place is affected by the atmospheric water vapor and concentration of the ozone layer in the stratosphere, these parameters were ignored in the equation. For this reason, hence the formula especially works in the high elevations, for instance, the Himalayas where the atmospheric effect is smaller. Scatter chart, and line and bar graphs were prepared in excel software.

Results

Figure 2 shows the monthly maximum instantaneous global solar radiation observed around solar noon (±1 hour) under clear-sky conditions at each high altitude meteorological station. The intensity of solar radiation (solar insolation) is found to be quite high; the parabolic trend clearly indicates that the monthly maximum solar radiation from the late spring to the early autumn was close to the solar constant (a yearly average value: 1367 W/m^2), solar radiation available at the top of the atmosphere where the effects of the atmosphere including the clouds are nil (Johnson, 1954).

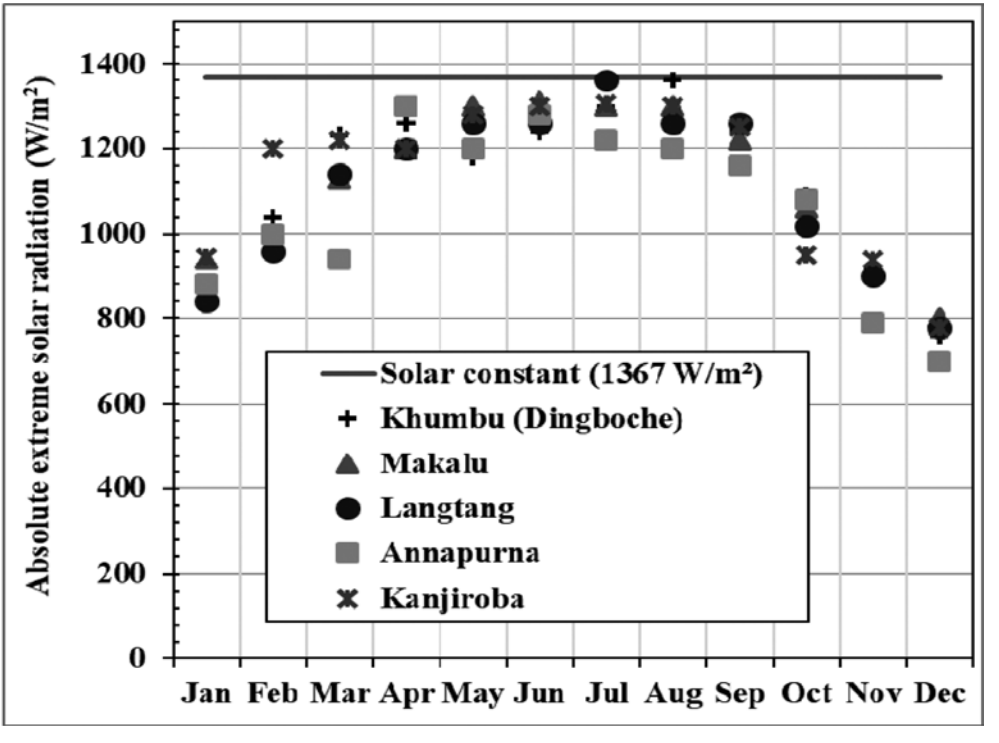


Figure 2: *Monthly maximum instantaneous global solar radiation observed around local noon (±1 hour) under clear-sky conditions at each meteorological station, evaluated from January, 1993 to December, 1994 data. The solar constant (a yearly average value: 1367 W/m^2) is plotted to illustrate how close the maximum values are to the solar energy available at the top of the atmosphere.*

Figure 3 shows the maximum seasonal average UVI at each station, calculated from the data shown in Figure 2. The seasonal and spatial variations of UVI are clearly seen. The magnitude of spatial variation, however, is relatively small; the altitude effect is weaker. In the Himalayan stations, the maximum seasonal average UVI around the local noon under clear-sky conditions were alarmingly high in summer (11–12) followed by spring (9–11), autumn (7–9) and

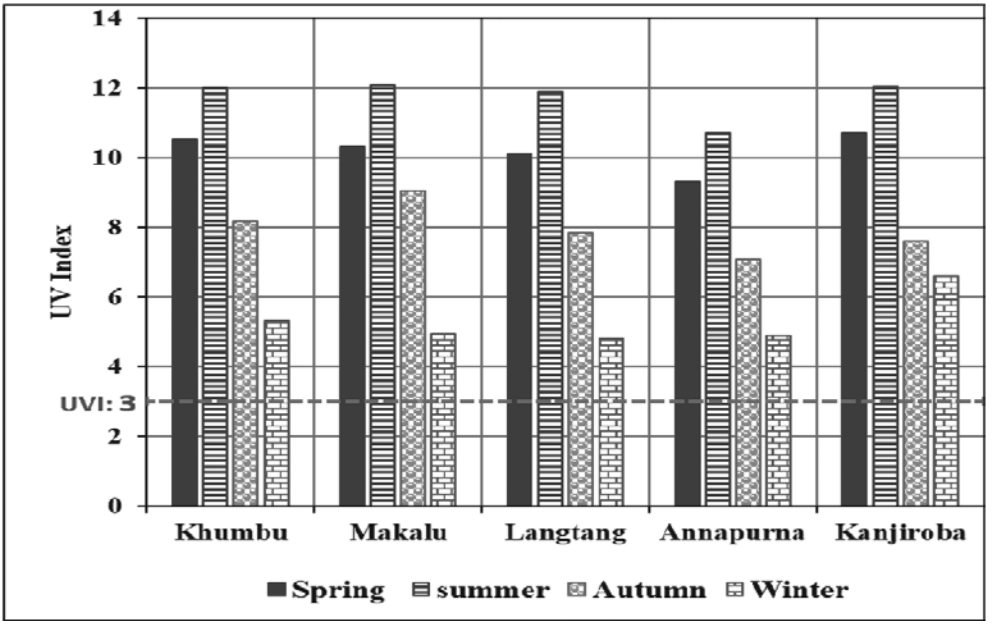


Figure 3: *Maximum seasonal average UVI calculated from the data shown in Figure 2 for each meteorological station under clear-sky conditions. The broken horizontal line indicates, based on the WHO guidelines, the level (UVI: 3) above which UV protection is required for outdoor activities.*

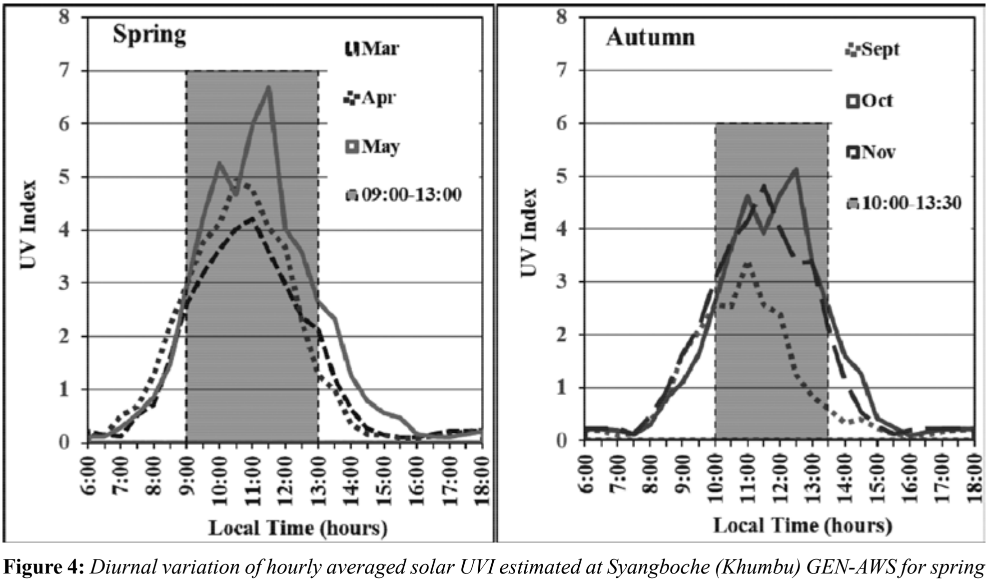


Figure 4: *Diurnal variation of hourly averaged solar UVI estimated at Syangboche (Khumbu) GEN-AWS for spring (March-May 1997) and autumn (September-November 1996). The shaded areas indicate time durations during which UV protection measures are required for outdoor activities.*

winter (5–7). The seasonal variation of solar UVI is due to the difference in solar zenith angle (solar zenith angle increases from summer to winter) that influences the attenuation of solar UV radiation reaching the earth's surface. The similarities and differences of UVI at the stations may have been influenced by similarities and differences of topography (altitude and aspect) and microclimates.

Figures 4 and 5 show the diurnal patterns and the values of the hourly averaged UVI from June 1996 to May 1997 at the Syangboche (Khumbu) GEN-AWS as an example. The graphs grouped into different seasons shed some light on diurnal scenarios of UVI for different months and seasons at the sites. As shown in Figure 4, the diurnal patterns and trends of the two seasons (spring and autumn) are similar except that the magnitudes of the UVI were slightly lower during the autumn (October: maximum 5.1 at 12:30 LT) than the spring (May: maximum 6.7 at 11:30 LT). On the other hand, the diurnal patterns and trends of summer and winter (Figure 5) are not similar, however, their magnitudes were similar; for example, maximum UVI for August (summer) and December (winter) were found to be 3.7 (at 9:30 LT) and 3.8 (at 12:00 LT) respectively. The implications of the UVI are summarized in Table 2.

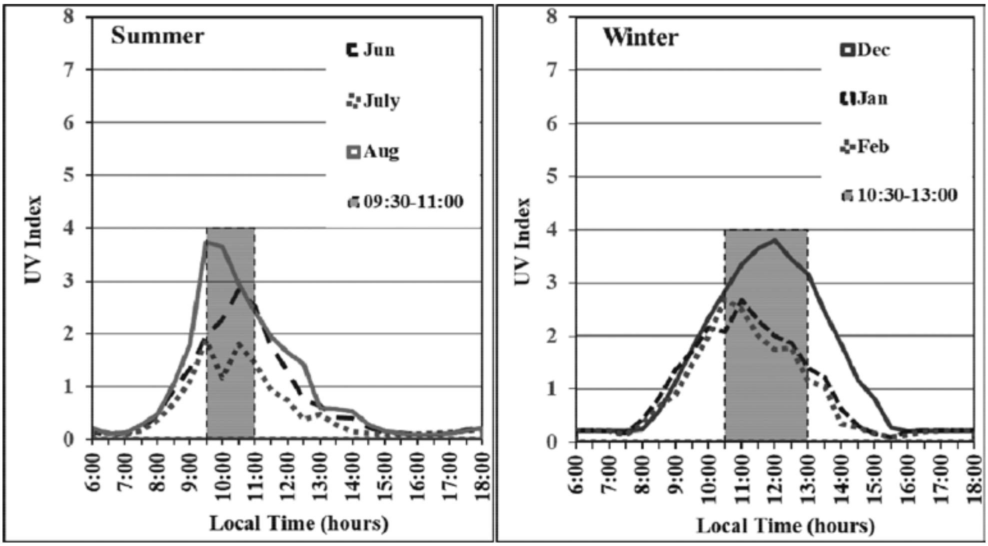


Figure 5: *Diurnal variation of hourly averaged solar UVI estimated at Syangboche (Khumbu) GEN-AWS for summer (June-August 1996) and winter (December 1996-February 1997). The shaded areas indicate time durations during which UV protection measures are required for outdoor activities.*

Discussion

In the Nepal Himalayas, the solar radiation and its corresponding UVI (11–12) around the solar noon under clear-sky conditions were extremely high in summer (June-August) (Figures 2 & 3) owing to the stronger solar radiation at the top of the atmosphere with shorter path-length of the sun's ray and the negligible effect of thinning atmosphere at higher altitudes. Also, strong UV irradiance in the fine days is due to less atmospheric water vapor with cold climate in the high elevations of the Himalayas (Blumthaler et al., 1997; Schmucki and Philipona, 2002; Sharma et al., 2015). However, in the Himalayas, fine days are quite rare in summer because of the high amount of atmospheric water vapor and a large amount of prevailing clouds associated with the monsoon (Ueno et al., 1993; Bollasina et al., 2002). As a result, the average UVI should be much lower in summer than spring and autumn with generally clear-sky conditions. The relatively lower UVI in the winter season is due to the shorter winter days with reduced light caused by higher zenith angle in winter, and occasional rain/snow characteristics in the Himalayas (Srivastava et al., 2006). This is supported by the UVI results obtained from the Syangboche (Khumbu) GEN-AWS (Figure 5).

Sharma et al. (2015) reported similar results from Lukla (2850 m a.s.l.); UVI reached up to 9–11.5 during summer months (May-August) under clear-sky conditions, and maximum instantaneous UV value of more than 16 was observed at local noon in a typical clear-sky day of 28 July 2010. Singh and Singh (2004) also observed extremely high UVI values of 15 and 13 on cloud-free clear-sky days (at local noon in July) from western Himalayas (India) at Hanle (4517 m a.s.l.) and Leh (3441 m a.s.l.) respectively. An early study from the Tibet region at Lhasa (3648 m a.s.l.), by Ren et al. (1997) has shown that the UVI at local noon reached as high as 16, with an average value of 9.

The diurnal patterns of the hourly averaged UVI were investigated for each month (season) at the Syangboche (Khumbu) GEN-AWS (Figures 4 & 5). In contrast with the UVI results presented in Figure 3 (under clear-sky conditions), the solar radiation data recorded at the Syangboche (Khumbu) GEN-AWS that have been used to calculate UVI represent all types of prevailing weather conditions. The high values of UVI around midday (local noon) for all seasons are due to higher solar insolation caused by higher solar elevations. The diurnal variability of UVI and hourly maximum value depend also on different factors, such as solar zenith angle, atmospheric ozone, cloud cover and aerosols present in the atmosphere (Sharma et al., 2015; Sharma, 2016). The significantly low UVI in summer compared to other seasons was attributed to the attenuating effects of the high amount of cloudiness, increase in relative humidity and precipitable water molecules in the atmosphere on the incoming solar radiation in Nepal Himalayas (Ueno et al., 2001; Ueno and Pokarel 2002; Bollasina et al., 2002; Pokhrel and Bhattarai, 2011; Sharma et al., 2015). The sudden drop and rise of the UV values around noon, particularly in May and October indicate the attenuating effects of boundary layer clouds intruding to the Himalayas (visual and photographic observation by K. Ueno, 1991) on the incoming solar radiation. Clouds generally reduce solar UV radiation by absorption of sunlight; however, light or thin clouds have little effect and may even enhance UV radiation levels because of scattering from cloud particles (Schmucki & Philipona, 2002; Sharma, 2016).

The WHO (2002) has categorized degree of UV radiation exposure in terms of UVI and has given a color code for each category; less than 2 as low (green), 3 to 5 as moderate (yellow), 6 to 7 as high (orange), 8 to 10 as very high (red) and 11+ as extreme (purple) (Table 2). The WHO advises that the UVI should be presented as a single value rounded to the nearest whole number, and some sort of protection is required when the UVI is 3 or more. The present results from the Nepal Himalayas strongly suggest that extra UV safety precautions are needed, especially around local noon under clear-sky conditions. Similarly, as the UVI of 3 or more were observed during midday sun (spring: 09:00-13:00; autumn: 10:00-13:30; summer: 09:30-11:00; and winter: 10:30-13:00) (the shaded areas in Figures 4 & 5) under prevailing weather conditions UV protection actions must be taken accordingly (Table 2). The higher amount of UVI during spring and autumn (target seasons for mountaineering or tourism) suggests that mountaineers or tourists are vulnerable to the exposure of UV radiation.

Table 2: UV radiation exposure categories and practical sun protection measures for mountain dwellers/mountaineers focusing in the Himalayas (based on WHO, 2002; CCOHS, 1997-2020, and the present research)

UVI	Description	Sun (UV) protection measures
0 - 2	Low	• Minimal sun protection required for normal activity. • If outside for more than one hour, wear sunglasses and sunscreen.
3 - 5	Moderate	• UVI 4 around midday is common in summer and winter, while UVI 5 is common in autumn. • Take precautions — cover up, wear a broad-brimmed hat, sunglasses and sunscreen especially if you will be outside for 30 minutes or more. • Look for shade near midday when the sun is strongest.
6 - 7	High	• UVI 6 and 7 around midday are common in winter (clear-sky condition) and spring respectively. • Protection is required as UV radiation damages the skin and can cause sunburn. Avoid the sun at midday and take full precautions. • Seek shade, cover up, and wear a broad-brimmed hat, sunglasses and sunscreen.
8 - 10	Very High	• UVI 8-10 around midday are common in spring and autumn (clear-sky condition). • Extra precautions are required as unprotected skin can be damaged and can burn quickly. • Avoid the sun between 09:00 LT and 13:30 LT or take full precautions in the sun. Seek shade, cover up, and wear a broad-brimmed hat, sunglasses and sunscreen.
11 +	Extreme	• UVI 11 or more around midday are common in summer (clear-sky condition). • Unprotected skin will be damaged and can burn in minutes. • Avoid the sun between 09:00 LT and 13:30 LT or take full precautions in the sun. Cover up, and wear a broad-brimmed hat, sunglasses and sunscreen.
Note: *Avoiding the sun and seeking shade may not be applied to mountaineers/climbers. Also, the reflection of snow and glaciers can nearly double UV strength, so it is advisable to wear 100% UV protection sunglasses and apply a broad-spectrum waterproof sunscreen of sun protection factor (SPF) 30+ on exposed body parts.*		

At high altitudes where snow and ice are abundant, the degree of UV exposure would be much higher because of reflection from snow and ice-covered surfaces. For example, McKenzie et al. (1998) and Henderson et al. (2010) reported that clean fresh snow can reflect up to 90% of UV radiation on a sunny day. This means that one can be exposed to almost a double dose of UV – directly from the sun and reflected of snow-covered surfaces. Also, according to Blumthaler et al. (1997), Schmucki and Philipona (2002), Pfeifer et al. (2006), Sharma et al. (2015) and Barnes (2019), erythemal UV radiation levels increase by as much as 10-35 % per 1000 m increase in altitude, and the altitude effect in winter is higher (about 20% per 1000 m) than that in summer (about 15% per 1000 m). Hence mountaineers/climbers are exposed to extremely high levels of UV radiation due to the coupled effect of the altitude-related increase of UV radiation and the reflection from snow and ice-covered surfaces.

The UVI results from different locations of the Nepal Himalayas, western Himalayas (India) and Tibet revealed an extremely high intensity of UV radiation during clear-sky conditions followed by moderate to high intensity during prevailing weather conditions. The results and the UV radiation exposure categories together with respective sun protection measures (WHO, 2002; CCOHS, 1997-2020) (Table 2) suggest that the inhabitants and mountaineers visiting the high altitudes, such as the Himalayas, are considerably at high risk to UV radiation health hazard and serious protection measures should apply, particularly during spring and autumn when the weather is relatively fine and mountaineering activities are favorable.

Conclusion and recommendation

In this study, global solar radiation data observed at different locations, covering the elevation range of 2735 m a.s.l. to 4355 m a.s.l. that are scattered and extended approximately 450 km from east to west of the Nepal Himalayas were analyzed. The data then used to calculate the UV radiation level (UVI) for the respective locations that are popular for mountaineering activities. Additionally, a few existing research results on UVI reported by other researchers from the Indian Himalayas and Tibet, and WHO UV guidelines were reviewed.

The main results and recommendations are briefly summarized below.

- The maximum seasonal average UVI around midday under clear-sky conditions at the high altitude meteorological stations were alarmingly high in summer (11–12: very high/extreme) followed by spring (9–11: very high), autumn (7–9: high/very high) and winter (5–7: moderate/high). However, in the Himalayas, fine days are quite rare in summer because of a large amount of prevailing clouds associated with the monsoon that result in a much lower average UVI level than that of other months/seasons.
- In Khumbu, UVI around midday under prevailing weather conditions were minimum during summer (4: moderate) and winter (4: moderate), compared to spring (7: High) and autumn (5: moderate). The UV protection actions should be taken during midday; spring: 09:00-13:00 LT, summer: 09:30-11:00 LT, autumn: 10:00-13:30 LT, and winter: 10:30-13:00 LT.
- Sun protection measures should be applied according to the UVI range/categories associated with existing weather conditions and seasons (see Table 2) while out climbing or mountaineering, especially during high-intensity sun hours (09:00–13:30 LT).
- Mountaineers/climbers are exposed to extremely high levels of UV radiation - one of the potential mountaineering health hazards due to the coupled effect of the altitude-related increase of UV radiation and the reflection from snow and ice-covered surfaces.
- In order to gain a greater level of understanding of the distribution of UV irradiance in the Himalayas, more simultaneous measurements of solar radiation and erythemal UV radiation at various spatial/altitudinal locations in different seasons are needed.

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