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The Study of Angular Distribution of UV Radiation at various sites of Kathmandu Valley, Nepal

Bishowvijaya Pandey[1*] and Khem N. Poudyal[2]
[1]Department of Physics, Patan Multiple Campus, Patan Dhoka, Lalitpur, Tribhuvan University, Kathmandu, Nepal
[2]Department of Physics, Institute of Engineering, Tribhuvan University, Kathmandu, Nepal
bishowvijaya@gmail.com

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Abstract

Solar radiation hazard is a global problem in the world. Though the solar radiation falling on atmosphere is taken as constant but it varies widely due to local effects. This paper primarily focusses on measurement and comparative analysis of solar irradiance in different locations Kathmandu, Nepal using UV meter model 3D. Radiation is measured at different inclinations (0^0, 15^0, 30^0, 45^0, 60^0, 75^0 & 90^0) in different directions (East, West, North & South). Experimental result showed that amount of radiation incident at particular place is directly dependent on optical depth and fluctuations on results are caused by local parameters like pollution, daylight time, inclination, orientation and others. Maximum UV flux density was found at 45^0 on South at noon time at each locations. Also strong correlation between theoretical result and experimental result is found. Result of this research work is beneficial for the further identification, impact and analysis of radiation at different places, taking safety measures in priority basis thus improving life of flora & fauna and protecting the whole environment.

Keywords: Solar irradiance, Orientation, Direction, Altitude, UV flux density.

Introduction

Sun is the closest star from the Earth and hence solar energy is the fundamental as well as primary source of energy which governs Earth's climate and atmosphere. The Sun is at a distance of about $1.49X10^8$ km away from Earth and its temperature is about 5777 K on surface[1]. The irradiance at the surface of the Sun is roughly $63x10^6$ W/m^2 which varies inversely with the square of distance as we move away from the Sun. The thermal energy produced due to nuclear fusion at the Sun reaches to the Earth in the form of EM waves by radiation process. Since the orbit of Earth around the Sun is an elliptical path so once in a year it approaches relatively nearer to the Sun at perihelion and becomes farther at aphelion in opposite time. Due to this reason solar radiation at the top of the atmosphere fluctuates by approx. 3.5% throughout the year. The annual average solar irradiance is approximately 1366.1 W/m^2 at the top of the Earth's atmosphere[2]. This irradiance is known as Solar Constant since its variation is about ±1 W/m^2 around the average value during a typical Sun cycle of 11 years[3].

Also due to its spherical shape only half of the Earth's surface is lighten up. The axis of Earth is inclined to the plane of elliptic at an angle of 66.5^0 thus causing different seasons and varying length of day and night. On Summer Solstice (21st June), the Northern hemisphere is tilted towards the sun and the Southern hemisphere is away and vice-versa on Winter Solstice (21st Dec). During spring equinox and fall equinox (21st March and 23rd Sept) the Sun is vertically overhead so the entire world has equal duration of day and night. The total daily radiation decreases from equator to pole which is maximum at midday for a particular place. Since the Earth is not a perfectly black body so it reflects some part of radiation back to the space.

Figure-1
Earth-Sun configuration[4]

The albedo/reflectivity (ratio between the reflected and incoming energies) of Earth relies on climatic condition, geographical location, and surface properties. Earth's mean albedo is approx. 0.3 which means 0.3 part is reflected back and rest 0.7 part is absorbed by the Earth[5].

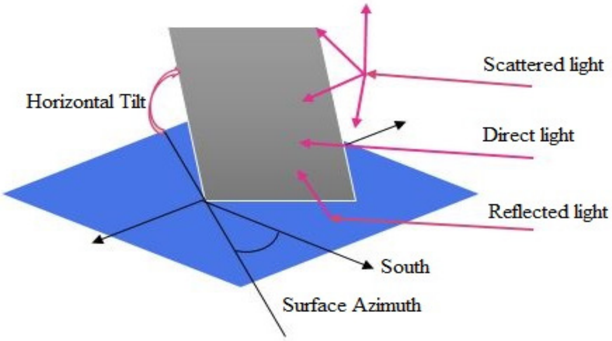

Figure-2
Radiation on tilted surface[6]

The Sun emits wide range of EM radiations categorized in two groups: ionizing and non-ionizing radiation. X-rays and gamma rays belong to ionizing radiation where as UV rays, visible rays, IR rays and radio waves are non-ionizing radiations. The interfering effect of UV radiation on biological process is wavelength specific. Higher wavelength band spectrums are substantive for the life on Earth where as short wavelength bands are harmful for them as these radiations can ionize atoms and molecules. The constituents of Earth's atmosphere like Nitrogen, Oxygen etc. prevent ionizing radiations by the process of absorption and scattering. Non-ionizing radiations are also absorbed by Ozone. However some part of UV radiations reaches to the Earth's surface. The part of the spectrum that reaches to us from the Sun is between 100 nm and 1 mm. The band within the range of 100-400 nm is ultraviolet radiation, 400-700 nm is called visible radiation and that of 700 nm to 1 mm is infrared radiation[7]. Taking an account of wavelength UV radiation can be categorized as UV-A, UV-B and UV-C[8]. 0.5% of all solar radiation falls under UV-C which is capable of harming living beings. Chiefly it is absorbed by Ozone, and trivial amount approaches to Earth's surface. UV-B is photo activating radiation and partially absorbed by stratosphere. UV-A is less energetic than B type. Even though Ozone present in atmosphere it does not absorb UV-A but cloud can obstruct its path. It has the ability to cause fluorescence.

Table-1
CIE Photobiological Spectral Bands[8, 9]

UV types	Wavelength range (nm)	Biological effects
UV-A	315-400	Deeper penetration, less absorption; Photochemical cataract, erythema, tanning of skin pigmentation, reduction in photosynthesis
UV-B	280-315	Penetration; skin erythema(sunburn), cataracts, skin malignancies, non-melanoma skin cancer, DNA mutation, change in Ozone concentration
UV-C	100-280	Superficial absorption in tissues; germicidal(kills bacteria, viruses and fungi)

Though solar radiation incident on the Earth's atmosphere is relatively constant but inside atmosphere it is highly affected by the mobile nature of atmosphere. Also the atmospheric alterations (absorption and scattering), local effects (presence of clouds, water vapour and pollution), Earth-Sun geometry (Earth's longitude, latitude, declination, zenith, azimuth angles, seasons, sunrise and sunset times), Earth's magnetic field, view factors, shadows, inclination of the surface, mountain slopes and time of the day cause the variation in solar radiation. Altitude is one of the major factors among them[10].

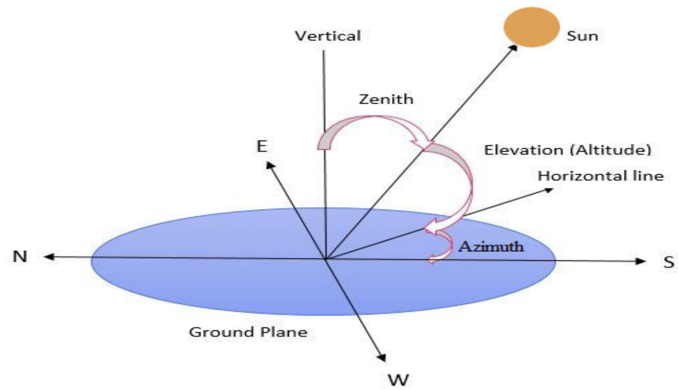

Figure-3
Elevation and Zenith of the Sun from Earth's surface

Methodology

The portable UV-meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) designed by Robertson-Berger (1969, 1976) consists of two probes viz. UV-A detector probe and minimal erythemal dose (MED) probes which are attached with the main unit[11]. It displays UV irradiance in milliwatts per square centimeter with uncertainty of the order of 10%. Its calibration was done using spectroradiometer on a lucid day[12]. The meter was inclined at different orientations viz. 0^0, 15^0, 30^0, 45^0, 60^0, 75^0 and 90^0 in different directions. By doing so the diurnal varieties of UV isolation data of different sites with different slopes of Kathmandu valley were recorded with an interval of one hour from morning to evening. During the measurements, the outside temperature ranged between min. 9.2^0C to max. 31^0C. Sites under observation were:

Site 1: Tribhuvan Intl Airport, Kathmandu ($27^0$42'24.9" N, $85^0$18'55.1" E)

Site 2: Siphal, Kathmandu ($27^0$42'40.6" N, $85^0$20'27" E)

Site 3: Ratna Park, Kathmandu ($27^0$42'3.5" N, $85^0$21'11.5" E)

Theory/Geometry of Atmosphere and Direct Solar Radiation: The solar radiation flux density normal to an arbitrarily oriented inclined surface is given by[13, 14].

$$S_{sl} = S_{\perp} \, Cos\, i \qquad (1)$$

$S_{\perp}$ is the solar radiation flux normal to sun rays with atmospheric mass 'm' near the Earth's surface, i is the incident angle of solar radiations to a given surface. The cosine of the angle of incidence on any given surface is given by the relation

$$Cos\, i = Cos\theta_i\, Cosh_0 + Sin\theta_i\, Cosh_0\, Cos\alpha ; \alpha = \alpha_0 - \alpha_n \quad (2)$$

θ_i is the angle of inclination of the surfaces relative to the horizontal plane, h_0 is the height of the Sun, α_0 is Sun's azimuth angle, α_n is the projection of the normal to the surface on the horizontal plane as counted from plane of meridian (the azimuths are taken positive when counted in clockwise direction).

Figure-4
3D UV meter

Also the solar height and azimuth can be calculated from following expressions as:

$$Cos\,\alpha = \frac{Sinh_0\, Sin\,\theta_l - Sin\,\theta_d}{Cosh_0 - Cos\,\alpha} \quad (3)$$

$$Sinh_0 = Sin\alpha\, Sin\theta_d + Cos\theta_l\, Cos\theta_d\, Cos\theta_h \quad (4)$$

$$Sin\alpha = \frac{Cos\,\theta_d\, Sin\,\theta_h}{Cosh_0} \quad (5)$$

Where: θ_l is the latitude, θ_d is the Sun's declination, θ_h is the horary angle of the Sun at a given moment counted from the moment of apparent noon.

By combining above relations

$$S_{sl} = S_{\perp}\begin{bmatrix} Cos\left(Sin\theta_l\, Sin\theta_d + Cos\theta_l\, Cos\theta_d\, Cos\theta_h\right) + Sin\theta_i \\ \left\{ \begin{matrix} Cos\alpha_n \left\{Tan\alpha\left(Sin\alpha Sin\theta_d + Cos\alpha Cos\theta_d\, Cos\theta_h\right) - Sin\theta_l\, Sin\theta_d\right\} \\ + Sin\theta_n\, Cos\theta_d\, Sin\theta_h \end{matrix} \right\} \end{bmatrix} \quad (6)$$

This is the general formula of dependence of incoming radiation on the slope of orientation determined by θ_i and θ_n for any latitude θ_l at different time of the day or year.

Results and Discussion

Optical Depth: The optical depth **t** is defined as the measure of the opacity of a medium to the transmission of electromagnetic radiation from a source to a point in the surface of the Earth. The optical depth depth along optical path dx is,

$$optical \quad depth\ (t) = \partial \int_0^x b_i\, dx \quad (7)$$

Where: b_i is the extinction coefficient corresponding to the atmospheric constituents[15].

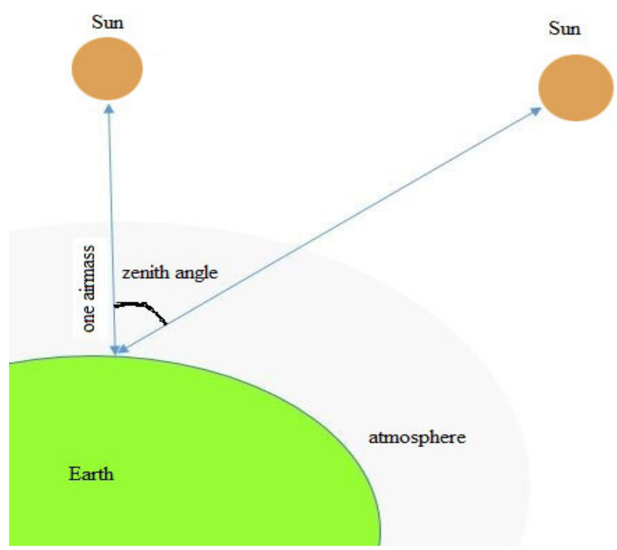

Figure-5
Variation in optical depth with position of the Sun

As light rays enter in Earth's atmosphere they suffer collision with atoms, molecules, water droplets, dusts and other constituents. As a result of this either photons may be absorbed or scattered causing dimming of light. Airmass traversed by a light in Earth's atmosphere before reaching to the ground determines annihilation of amount of light. An increase in zenith angle **Z** causes increase in airmass as given by the relation.

$$airmass \ = (one\ airmass\ ) \times Sec\ Z \quad (8)$$

where one airmass is amount of air directly above the atmosphere.

Taking Tribhuvan International airport, Gaucharan, Kathmandu as primary location UV flux density were measured in different direction with different orientations.

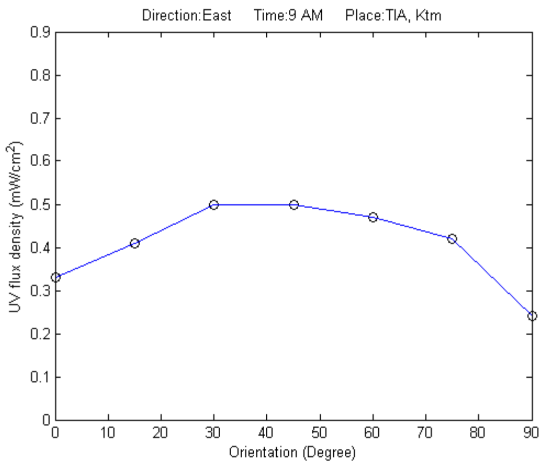

Figure-6
Variation of UV flux density in East direction with different orientations at 9 AM

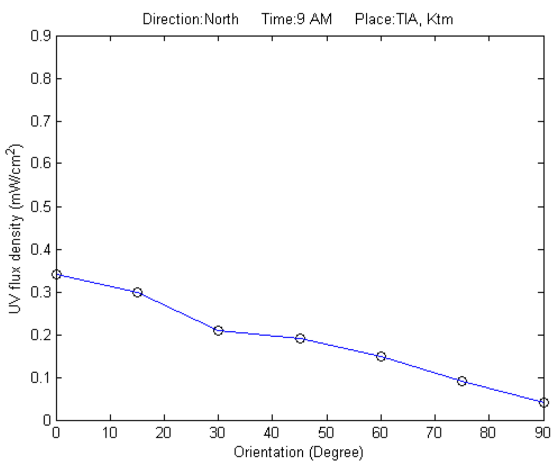

Figure-7
Variation of UV flux density in North direction with different orientations at 9 AM

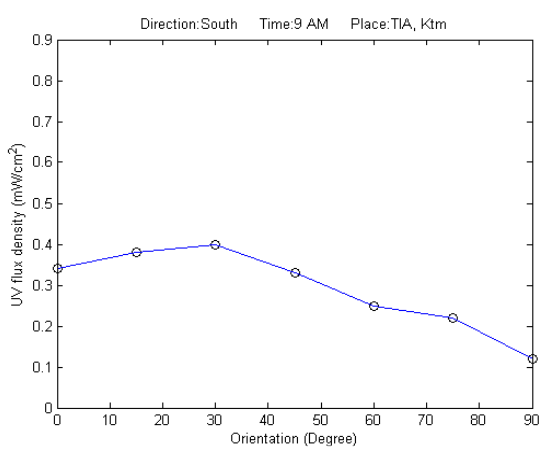

Figure-8
Variation of UV flux density in South direction with different orientations at 9 AM

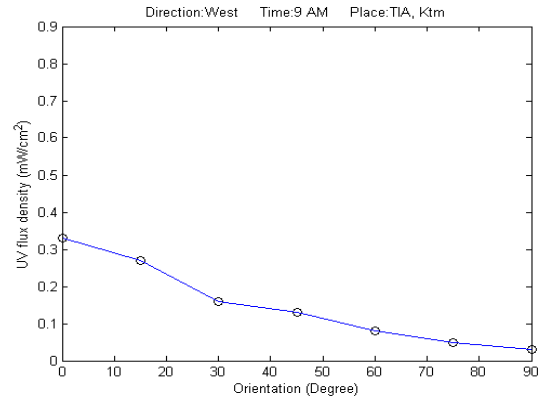

Figure-9
Variation of UV flux density in West direction with different orientations at 9 AM

At 9 AM it is observed that radiations from east and south were dominant in comparison with those from north and west as shown in figures above. Also the radiation was maximum at 30^0 to 45^0 orientation in these dominant directions.

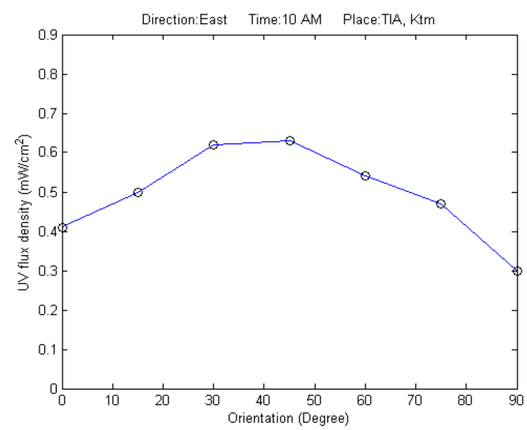

Figure-10
Variation of UV flux density in East direction with different orientations at 10 AM

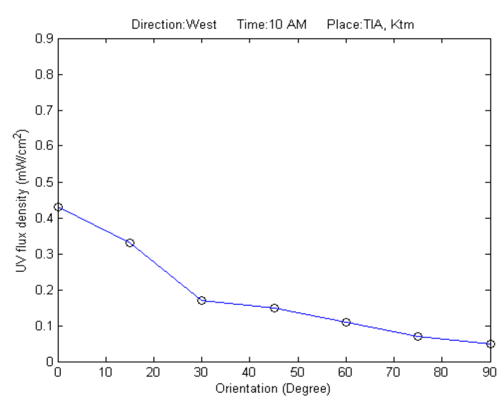

Figure-11
Variation of UV flux density in West direction with different orientations at 10 AM

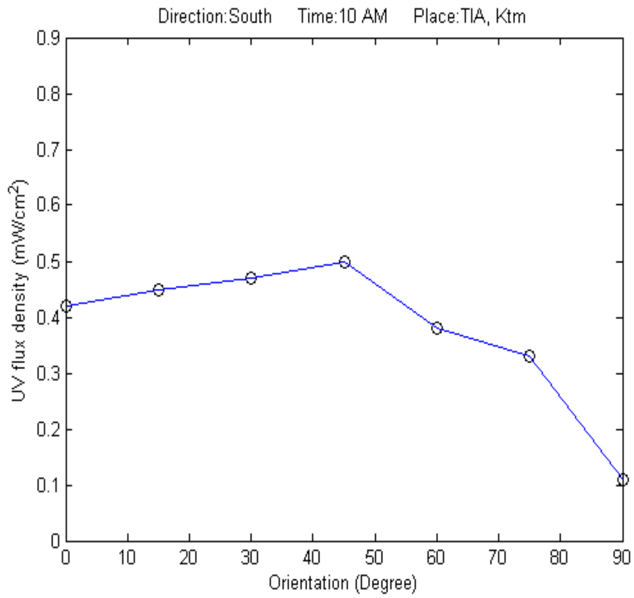

Figure-12
Variation of UV flux density in South direction with different orientations at 10 AM

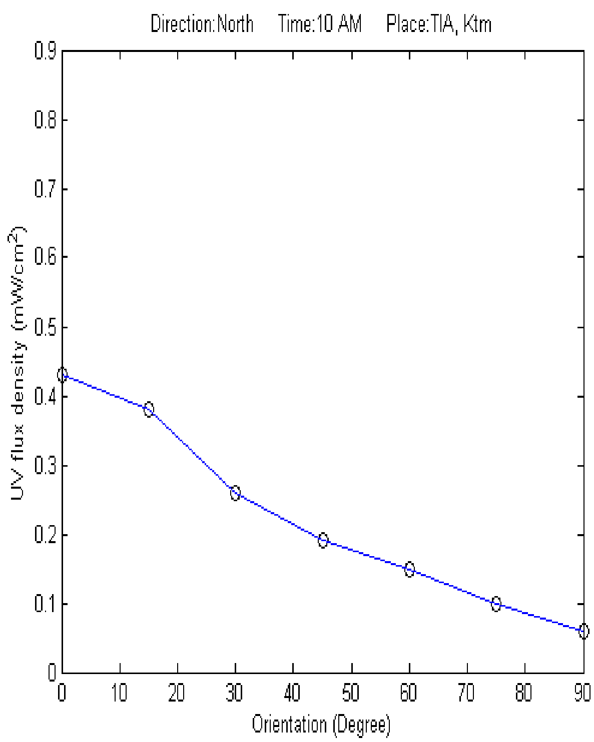

Figure-13
Variation of UV flux density in North direction with different orientations at 10 AM

Same measurement was taken at 10 AM and nature of graphical results were found similar with previous results as shown above. But values of UV flux density were more than previous values.

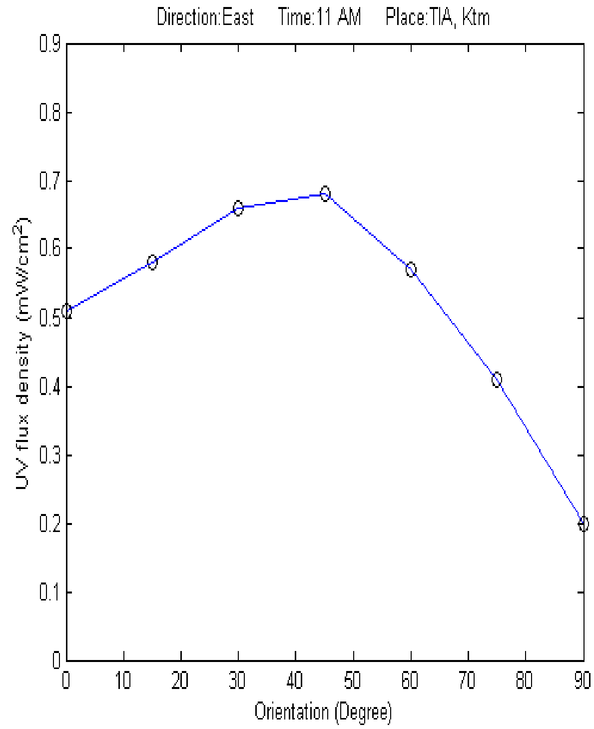

Figure-14
Variation of UV flux density in East direction with different orientations at 11 AM

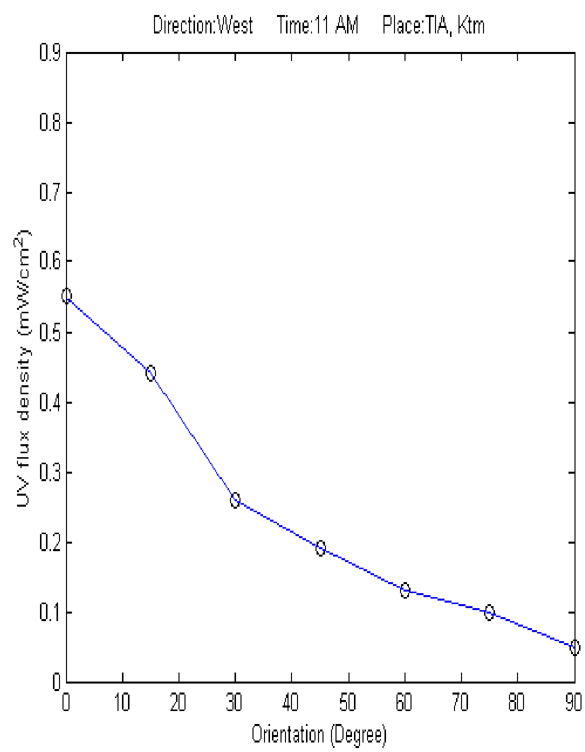

Figure-15
Variation of UV flux density in West direction with different orientations at 11 AM

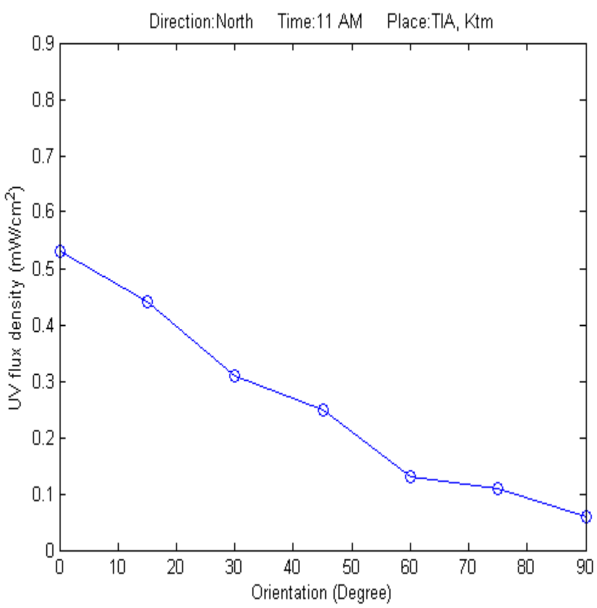

Figure-16
Variation of UV flux density in North direction with different orientations at 11 AM

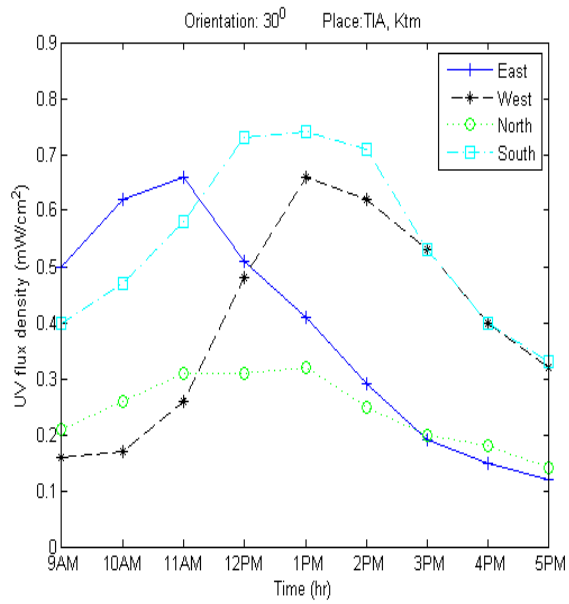

Figure-18
Variation of UV flux density with time at an orientation of 300

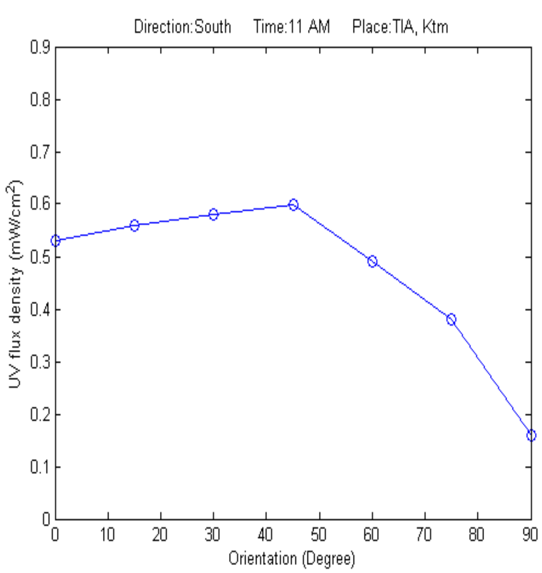

Figure-17
Variation of UV flux density in South direction with different orientations at 11 AM

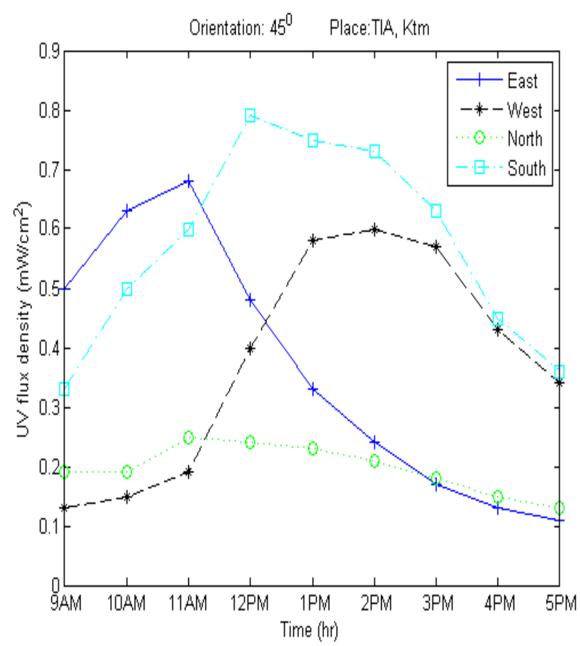

Figure-19
Variation of UV flux density with time at an orientation of 450

Measurements taken at 11 AM too followed similar pattern. This shows that radiation from east and south direction is generally more specially from 30^0 to 45^0 and it goes on increasing from the beginning of the day.

Now in order to find the maximum radiation throughout the day measurement was carried out in different directions at 30^0 and 45^0 respectively and results were obtained as shown in graphs below.

From these observations maximum solar irradiation was recorded at 45^0 south facing slope at noon time. Same procedure was applied to other two sites viz. Ratna Park and Siphal. The values of UV flux density were found different for different locations but the maximum solar irradiation was found at 45^0 South facing slope at noon as shown below.

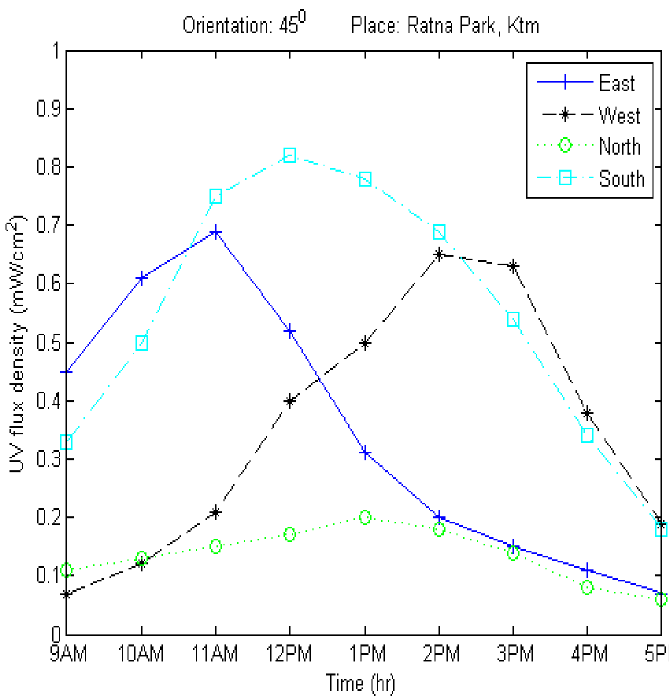

Figure-20
Variation of UV flux density with time at 450 orientation in Ratna Park

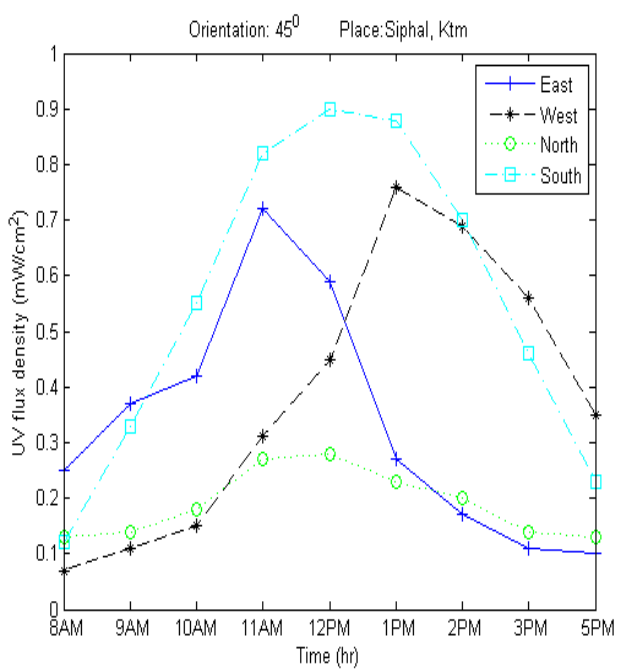

Figure-21
Variation of UV flux density with time at 450 orientation in Siphal

It is known that there is a strong relationship between optical path and direct solar irradiation so that the optical depth is minimum at the noon time where as the direct solar irradiation is maximum. Graphs below show relation between radiation and time of the day in TIA, Siphal and Ratna Park respectively at 45^0 orientation.

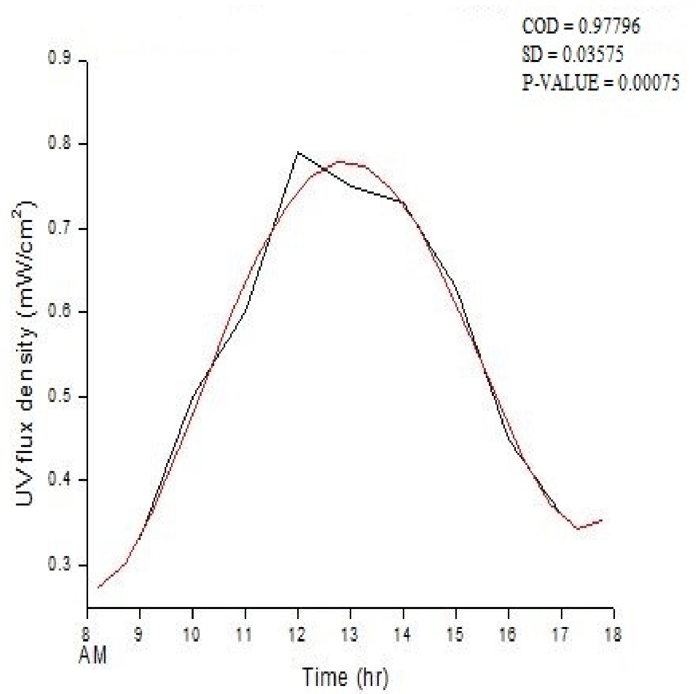

Figure-22
Radiation vs. Time of the day at 450 in TIA

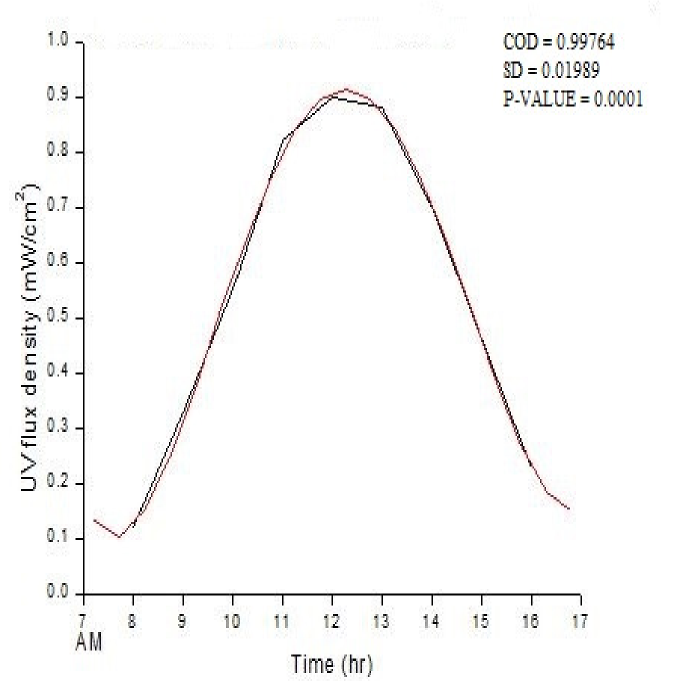

Figure-23
Radiation vs. Time of the day at 450 in Siphal

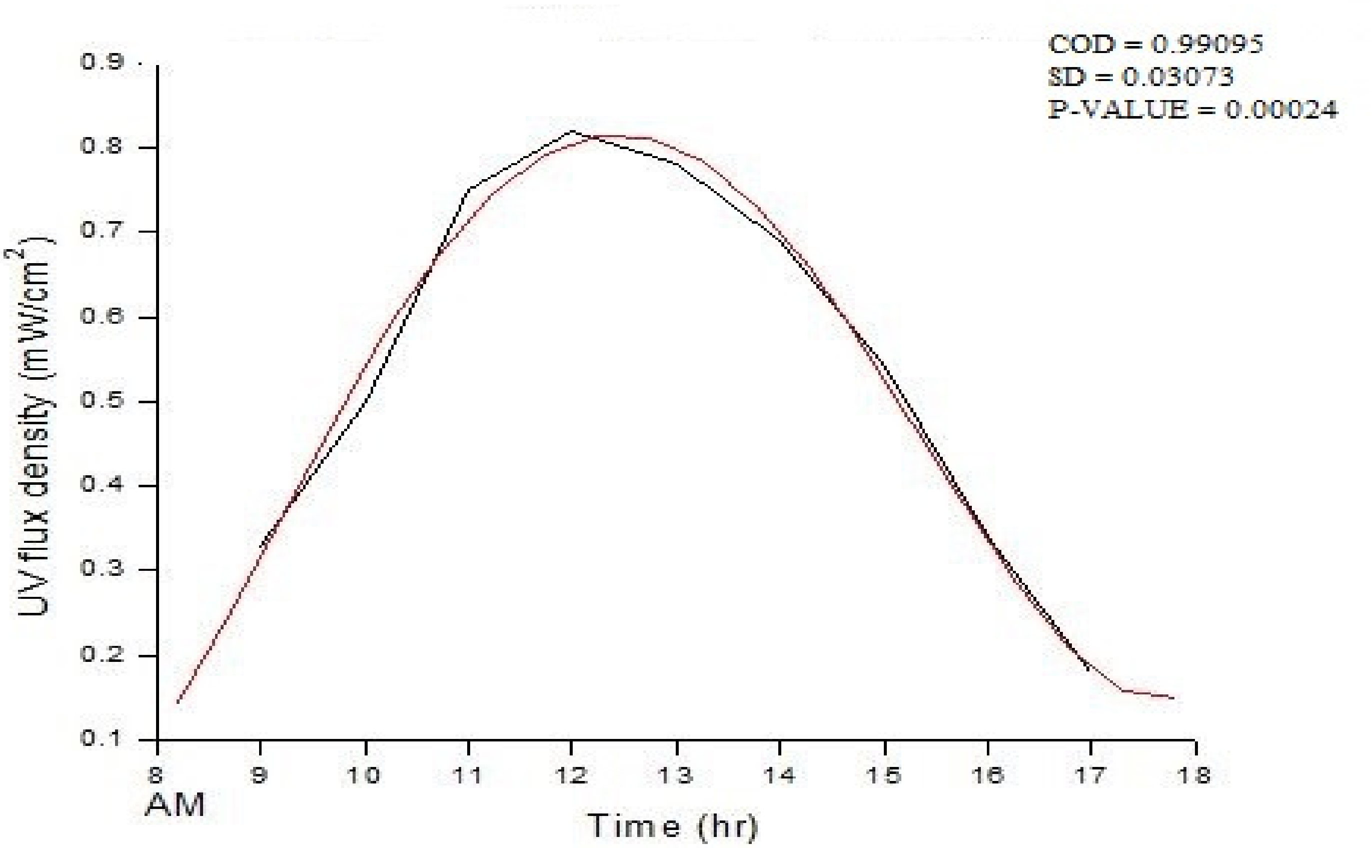

Figure-24
Radiation vs. Time of the day at 450 in Ratna Park

For different sites at 45^0 orientation the relationships are:

Tribhuvan Intl Airport, Kathmandu

$$y = 19.92768 - 7.10716x + 0.9197x^2 - 0.05013x^3 + 9.7902\times10^{-4}x^4 \quad (9)$$

Siphal, Kathmandu

$$y = 29.11322 - 11.06687x + 1.50796x^2 - 0.08632x^3 + 0.00177x^4 \quad (10)$$

Ratna Park, Kathmandu

$$y = 12.47078 - 5.08789x + 0.72469x^2 - 0.04209x^3 + 8.56643\times10^{-4}x^4 \quad (11)$$

Where: x is time of the day in 24 hour format and y is UV flux density measured at respective sites. A bi-quadratic polynomial is used to give the best fit with R^2-value (coefficient of determination) 0.97796, 0.99764 and 0.99095 for 1st, 2nd and 3rd equations respectively. Also the respective P-values are 0.00075, 0.0001 and 0.00024, and standard deviations are 0.03575, 0.01989 and 0.03073. The measured maximum UV-A flux densities at TIA, Siphal and Ratna Park are 0.79 mW/cm^2, 0.9 mW/cm^2 and 0.82 mW/cm^2 respectively. Though all sites are nearly in same altitude i.e. 14600 ft. but the values are different for different sites due to variation of concentration of pollution level. TIA is very close to ring road so vehicles and aircraft both are responsible for pollution. Ratna Park is the mini station for vehicles. Siphal, being a residential area, is least polluted than other sites. As pollutants obstruct the path of solar irradiation thus causing several impacts like variation in total power reception, the spectral density, and the incident angle of light on the surface. This is the reason why solar irradiation is maximum at Siphal in comparison to other sites.

Taking Siphal as site we have estimated optical depth at 45^0 inclination towards south as[13]

$$t = \ln Cos\,S_m + \ln Cos\,i - \ln S_{slant} \quad (12)$$

which also showed that optical depth is less at noon. Theoretical value of UV flux density are compared with measured values.

Table-2
Measurement of UV-A Solar Irradiation at different Hours of a day

S.N.	Time	Experimental Result (mW/cm^2)	Theoritical Result (mW/cm^2)
1	08:00 AM	0.12	0.15
2	09:00 AM	0.33	0.41
3	10:00 AM	0.55	0.63
4	11:00 AM	0.82	0.75
5	12:00 PM	0.90	0.93
6	01:00 PM	0.88	0.85
7	02:00 PM	0.70	0.67
8	03:00 PM	0.46	0.47
9	04:00 PM	0.23	0.26

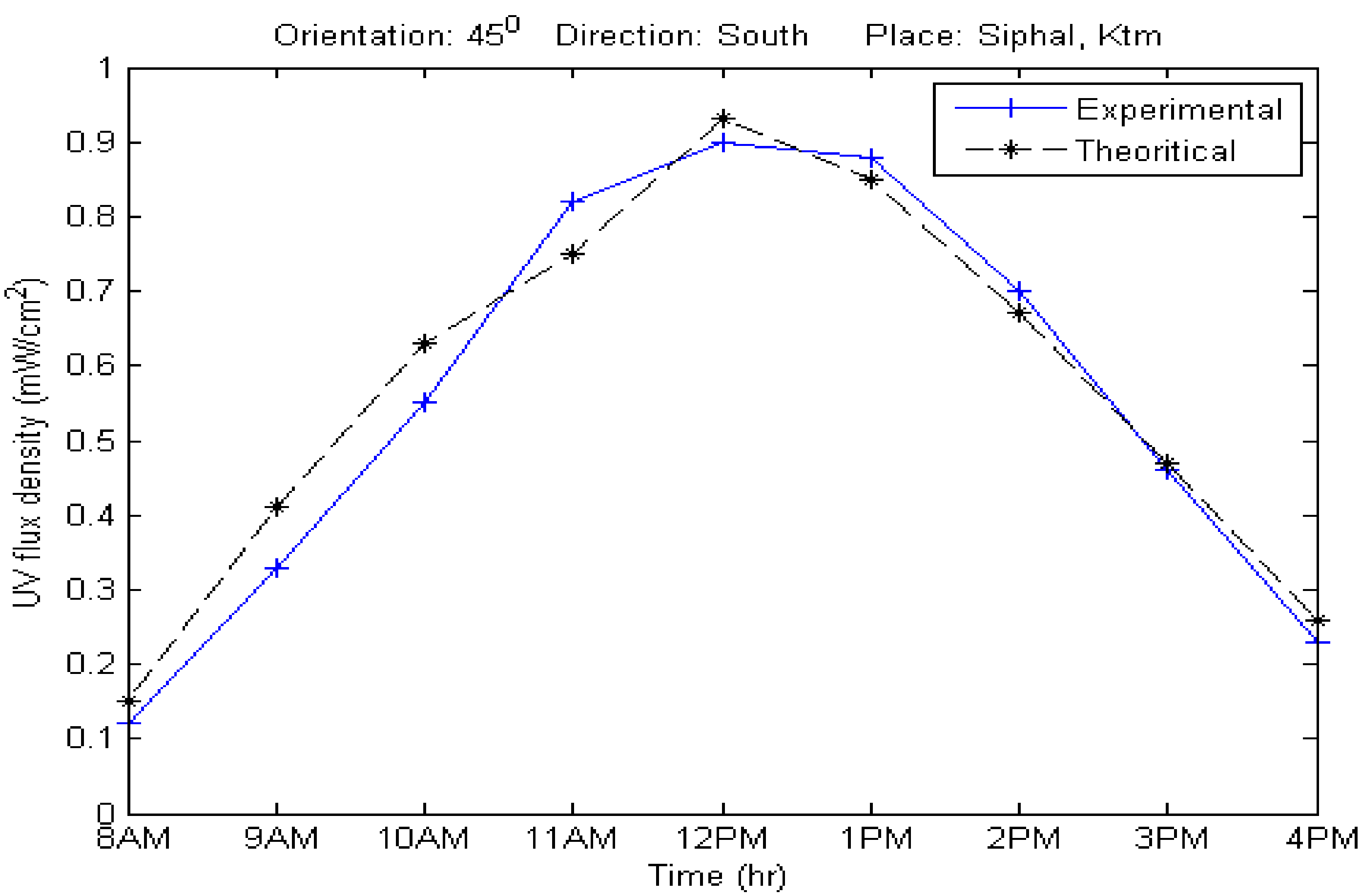

Figure-25
Comparative study of Experimental and Theoretical value of UV flux density

The measured value is found very much closer to the theoretical value with the correlation coefficient 0.98. Hence the experimental value is very much similar as that measured by Robinsion and Kondratyev[13].

Conclusion

As solar radiation and air pollution both are environmental problems but there is reciprocal relation between them. So while measuring the radiation at different locations of a common area the low amount of radiation at a place indicates the increment in pollution level. As Nepal being in a high altitude and affected by local as well as global air pollution so there is the necessity of minimization of pollution level and implication of radiation safety processes.

Abberviations: EM = Electromagnetic, IR = Infrared, UV = Ultraviolet, MED = Minimal Erythemal Dose, TIA = Tribhuvan International Airport.

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