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VERIFICATION OF THE ATMOSPHERIC TURBIDITY OVER OSOGBO BETWEEN THE YEARS 2009 TO 2019

[1]BABATOLA, BABATUNDE KEJI, [1]ADEBAYO, SAMUEL, [2*]ADEGBITE, ISMAILA OLAWALE; & [2]OMISORE, ADEDOTUN OLURIN

[1]*Department of Science Laboratory Technology, Physics Unit, Osun State Polytechnic, Iree.* [2]*Department of Statistics, Osun State Polytechnic, Iree, Nigeria*

Abstract

A Verification of atmospheric turbidity has been undertaken for Osogbo metropolis sky. Values of turbidity indices, namely, Linke factor (T_L), Angstrom coefficient (β) and Illuminance turbidity factor (T_{il}) are derived directly from measurements taken by pyrheliometer, Volz sunphotometer and beam illuminance meter. Monthly mean values and frequency of occurrence of the value of each turbidity index are used to characterize variations of atmospheric turbidity. Simple polynomial equations are developed for computing values of Linke factor and illuminance turbidity factor as functions of solar altitude angle. Using the values of Linke factor and illuminance turbidity factor obtained from the models developed, values of beam normal irradiance and illuminance can be calculated accurately under clear sky conditions. Values of daylight illuminance are useful for daylighting application that contributes to energy conservation for buildings. Knowledge of the size of beam normal irradiance is useful for calculation of cooling load in air-conditioning buildings in tropical climate.

Keywords: *Atmospheric turbidity; Linke factor; Angstrom coefficient; Illuminance turbidity factor, Solar, Water vapour.*

Introduction

Atmospheric turbidity can be defined as the reduction in the transparency of air resulting from the scattering of light by tiny suspended tiny particles in the air

(Water droplets, Ice crystals in the air, dust and smoke particles) and absorption of light by atmospheric constituents (Iqbal, 1983). Solar irradiance is attenuated spectrally when passing through the earth's atmosphere. Solar irradiance is subjected to scattering by air molecules and aerosols over the whole solar spectrum. It is also absorbed in selective spectral bands by various atmospheric constituents, mainly ozone, water vapor, oxygen and carbon dioxide. Both scattering and absorption processes modify considerably the spectral intensities of incoming extraterrestrial solar irradiance through the whole waveband (Chaiwiwatworakul & Chirarattananon, 2004). Attenuation of solar irradiance is strongly dependent on conditions of the sky, cleanliness of the atmosphere, and composition of gaseous constituents. In a clean and dry atmospheric condition, solar irradiance is attenuated by permanent atmospheric constituents of air molecules, gases and ozone, whose contents are nearly invariable. Two additional attenuation processes, which are the absorption by water vapor and scattering by aerosol particles, take place in a real atmosphere. The additional attenuation caused by these two processes is known as being due to the turbidity of the atmosphere (Bird, 1982).

Sun-Earth Distance r

The earth revolves around the sun in an elliptical orbit with the sun at one of the foci (Iqbal, 1983). The amount of solar radiation reaching the earth is inversely proportional to the square of its distance from the sun. The mean sun-earth distance r_o is called one astronomical unit which is give as : AU = 1.496 x 108 km eq. 1

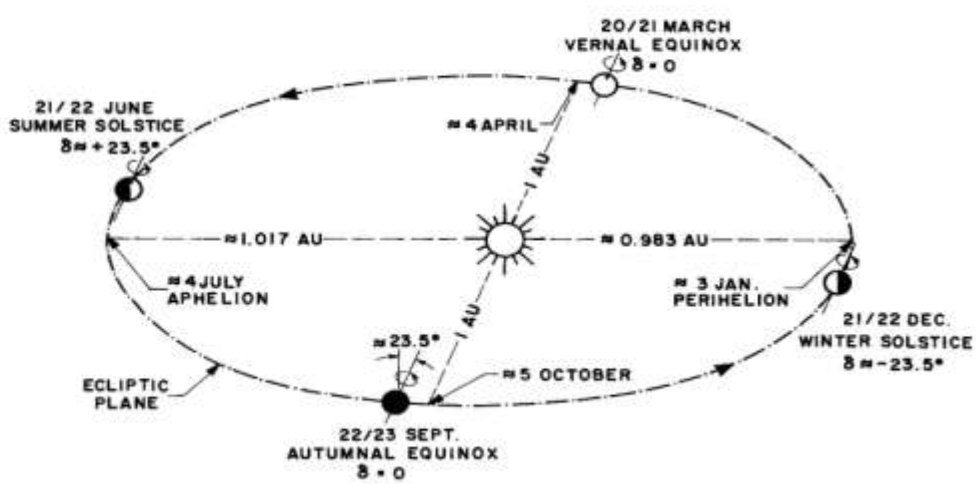

Figure 1: Position of the Earth round the year

The position and distance of the earth from the sun round the year is expressed diagrammatically in figure 1.1 below. The minimum sun-earth distance is about 0.983 AU, and the maximum approximately 1.017 AU. The earth is at its closest point to the sun (perihelion) on approximately 3^{rd} January and at its farthest point (aphelion) on approximately 4^{th} July. The earth is at its mean distance from the sun on approximately 4^{th} April and 5^{th} October. In long-term cycles.

Traditionally, the distance r is expressed in terms of a Fourier series type of expansion with a number of coefficients. With a maximum error of 0.0001. Spencer developed the following expression for the reciprocal of the square of the radius vector of the earth, called the eccentricity correction factor of the earth's orbit (E_o).

$E_o = (r_o/r)^2 = 1.000110 + 0.034221 \cos\Gamma + 0.001280 \sin\Gamma + 0.000719 \cos 2\Gamma + 0.000077 \sin 2\Gamma$. eq.2

Γ is measured in radians, and it is called the day angle. It is represented by $\Gamma = 2\pi(d_n - l)/365$ eq. 3

Where d_n is the series counting of the days of the year where January 1^{st} is 1 and December 31^{st} is 365.

For most engineering and technological applications, a very simple expression,

$E_o = (r_o/r)^2 = 1 + 0.033 \cos[(2\pi d_n/365)]$ eq. 4

Solar Declination δ

The plane of revolution of the earth around the sun is called the ecliptic plane. The earth itself rotates around an axis called the polar axis, which is inclined at approximately 23^o from the normal to the ecliptic plane. The earth's rotation around its axis causes the diurnal changes in radiation income (Aydinlis & Rattunde, 1982). The position of this axis relative to the sun causes seasonal changes in solar radiation. The angle between the polar axis and the normal to the ecliptic plane, remains unchanged. The same is true of the angle between the earth's equatorial plane and the ecliptic plane (Iqbal, 1983). This angle is called the solar declination δ. It is zero at the vernal and autumnal equinoxes.

The daily value of the solar declination can be calculated using equation 5 below:

$\delta = (0.006918 - 0.399912 \cos\Gamma + 0.070257 \sin\Gamma - 0.006758 \cos 2\Gamma + 0.000907 \sin 2\Gamma - 0.002697 \cos 3\Gamma + 0.00148 \sin 3\Gamma)(180/\pi)$. eq. 5

The solar declination can also be calculated using the equations equation 6 and 7 below

$\delta = \sin^{-1}\{0.4 \sin [(360/365)(d_n - 82)]\}$ in degrees eq. 6

Obtained from Perrin de Brichambaut and

$\delta = 23.45 \sin[(360/365)(d_n + 284)]$ in degrees eq. 7

Dry Air

The actual composition and concentration of the constituents of clean air vary with geographic location, elevation, and season. The "normal" composition of the U.S. Standard Atmosphere 1976 is given in Table 1.1 (Iqbal, 1983). The concentration of some gases such as carbon dioxide, ozone, carbon monoxide, and methane can be highly variable. These gases are not homogeneously distributed, in space or in time, throughout the atmosphere. These variations are a function of the industrial and agricultural activity of the place, its surroundings, and the general dynamic nature of the atmosphere. The dissociation of molecular oxygen (0_2) by solar ultraviolet radiation begins beyond about 90 km in the vertical direction. Consequently as altitude increases, concentration of 0_2 decreases and concentration of atomic oxygen (O) increases. Because molecular nitrogen is much more difficult to dissociate, concentration of atomic nitrogen (N) remains very small, even at high altitudes. Table 1.1 shows relative proportions of the three principal constituents up to a 500-km altitude. Beyond this elevation, however, there are further changes in the atmosphere: above 600 km, helium becomes a major constituent, and at about 2000 km, the principal constituents are ionized helium, ionized hydrogen, and electrons. (Iqbal, 1983).

Table 1: Constituent by volume

Constituent Gas	Content (% by volume)
Nitrogen	**78.084**
Oxygen	**20.948**
Argon (Ar)	**0.934**
Carbon dioxide (CO_2)	**0.333**
Neon (Ne)	**18.18×10^{-4}**
Helium (He)	**5.24×10^{-4}**

Krypton (Kr)	**1.14 x 10^{-4}**
Xenon (Xe)	**0.089 x 10^{-4}**
Hydrogen (H_2)	**0.5 x 10^{-4}**
Methane (CH_4)	**1.5 x 10^{-4}**
Nitrous oxide (N_2O)	**0.27 x 10^{-4}**
Ozone (O_3)	**0-12 x 10^{-4}**
Sulphur dioxide (SO_2)	**0.001 x 10^{-4}**
Nitrogen dioxide (NO_2)	**0.001 x 10^{-4}**
Ammonia (NH_3)	**0.004 x 10^{-4}**
Carbon monoxide (CO)	**0.19 x 10^{-4}**
Water vapor (H_2O)	**0-0.04 x 10^{-4}**
Nitric oxide (NO)	**0.0005 x 10^{-4}**
Hydrogen sulphide (H_2S)	**0.00005 x 10^{-4}**
Nitric acid vapor	**Traces**

All molecules of air deplete solar energy by scattering, which takes place at all wavelengths, and which therefore is called a continuum process. The most important of the dry air absorbers are ozone, carbon dioxide, oxygen, oxides of nitrogen, nitrogen, and hydrocarbon combinations.

Water Vapour

Water can exist in the atmosphere in three states, as gas, liquid, and ice. Water in gaseous state is called water vapour. The amount of water vapour present in the atmosphere can be defined in terms of; Mixing ratio (M_r) and Precipitable water (w'). The mixing ratio is the ratio of the mass of water vapor present to the mass of dry air present in a unit volume. Precipitable water is the total amount of water vapor in the zenith direction, between the surface of the earth and the top of the atmosphere. The precipitable water can be expressed mathematically by equation 8 below.

$$w^1 = \frac{1}{g}\int_0^{\alpha} M_r dz \qquad \text{eq. 8}$$

z = vertical height and g = acceleration due to gravity.

Aerosol

An aerosol is a small solid or liquid particle that remains suspended in the air and follows the motion of the air (Iqbal, 1983). Sources of aerosol include; Soil dust, Sea-Salt, Volcanic Aerosol, Biogenic Aerosol, Forest fire or Biomass burning, Sulphate and Nitrate Aerosol etc. Rain, snow, and hail are not aerosol particles. However, coagulated water vapor molecules that follow the motion of the air are considered aerosols. Natural aerosol particles range in radius from 10^{-3} to 10^{-2}μm, very small particles (called Aitken particles) from 10^{-3} to 10^{-1}μm and large particles from 0.1 to 1μm. Particles in the 1-100μm range are called giant particles. Rain reduces the number of aerosol particles but increases the size of those that remain. Consequently, turbidity (in the optical sense) remains unchanged immediately after rain. An atmosphere containing aerosols is also called turbid or hazy. A property of an aerosol-laden atmosphere that depletes direct solar radiation is called atmospheric turbidity.

Turbidity is an optical parameter of the atmosphere and can be roughly related to horizontal visibility, which in itself is subjective to measurement.

Aerosols in the atmosphere can be quantified by any one of the following three parameters:

(1) number of dust particles per cubic centimeter,

(2) atmospheric turbidity and

(3) visibility

Aerosol plays a major and vital role in the climate change and it also affects the human life. It is found that the tiny particles of dust, smoke and the various gases emitted by industrial activities goes into the atmosphere and they cause the asthmatic problems for the human life.

Relative Optical Path Length/Relative Optical Mass (m)

When monochromatic radiation traverses a medium, each molecule (or particle, in the case of aerosols) attenuates energy (Garge, 1982). Attenuation is a function of the type and the number of molecules in the path of a solar ray. The number of molecules a solar ray strikes before reaching the ground is related to the distance traversed by the ray. Calculation of this distance, called the path length or slant path. The density multiplied by the path length represents the mass of a substance in a column of unit cross section; this is also called the optical mass (Prescott, 1940). The actual optical mass can be written as:

$$m_{act} = \int_0^{\infty} \rho ds$$
eq. 9

Where

ds = Path length of the sun ray from the sun and ρ = Density of the path

The integration is along a path s (called the slant path) traversed by the beam of radiation from the upper limits of the atmosphere to the ground.

Effects of atmospheric aerosols on air quality and human health

Besides its effect on the incoming solar radiation, aerosols also have environmental issue such as degradation of air quality and implying health hazardous (Gruter, 1986). If the soot particles are very large in the atmosphere, then it causes considerable risks to public health and for agriculture.

Scattering of Direct Solar Radiation

When an electromagnetic wave strikes a particle, a part of the incident energy is scattered in all directions (Pinazo,1995). This scattered energy is called diffuse radiation. All particles in nature, whether the size of an electron or a planet, scatters radiation. A particularly simple solution is obtained when the particle is spherical and is much smaller than the wavelength of incident radiation. This solution was derived late in the nineteenth century by Lord Rayleigh and in his honor is called Rayleigh's theory. This theory is particularly useful in studying scattering of solar radiation by air molecules
(Iqbal, 1983).

The Linke Turbidity Factor

The Linke turbidity factor (T_L) is an index that represents the depth of clean and dry atmosphere that would be necessary to produce attenuation of the extraterrestrial irradiance that is produced by real atmosphere. Note that, in a pure Rayleigh atmosphere the turbidity factor T_L = 1. The value closest to this ideal is achieved in extremely clear, cold air at high latitudes, T_L = 2. For a polluted atmosphere the turbidity factor can increase to 8 (Robinso, 1995).
The calculation of the Link turbidity factor is based on the approach proposed by Kasten in 1980

$$T_L = T_{LK}\left[\frac{\delta_{RK}}{\delta_{Ra}}\right] \quad \text{eq. 10}$$

Where T_{LK} = Linke Turbidity Factor under clear sky, δ_{RK} = Rayleigh Integral, δ_{Ra} =Integral optical thickness

T_{LK} = $(0.9 + 9.4\sin(h).\ln(\varepsilon I_o/I_n)$ eq. 11

T_{LK} = $(0.9 + 9.4\sin(h).\ln[(r_o/r)^2 I_o/I_n]$ eq. 12

δ_{RK} = $(9.4+0.9m_A)^{-1}$ eq. 13

δ_{Ra} = $(6.5567+1.75m_A - 0.1202m_A^2 + 0.0065m_A^3 - 0.00013m_A^4)^{-1}$ eq. 14

Where h = Sun elevation angle in degrees, ε =Sun-Earth correction distance = $(r_o/r)^2$

r_o = Average sun earth distance = 1.497×10^{11}m

r = Daily sun earth distance, I_o = Solar constant = 1367Wm^{-2} I_n =Direct normal solar radiation

m_A =Atmospheric air mass (Depends on the sun elevation angle and local air pressure P)

m_A = $(P/101325)[\sin(h) + 0.15(h+3.885)^{-1.253}]^{-1}$

P = Local air pressure = $10325e^{-0.0001184z}$

z = Altitude in meter

Angstrom Turbidity Factor (β)

This is the measure of presence of aerosols in the atmosphere. It characterizes the amount of aerosol content in the vertical column of air with transversal unitary (Gueymard and Garrison 1998). The typical values of this parameter varies between 0.0 to 0.5 (Gueymard and Garrison 1998). The minimum value which zero is an ideally dust free atmosphere while values higher than 1 refers to an extremely turbid atmosphere. It was introduced by Angstrom by equation 15 below

$\tau_a(\lambda) = \beta \times \lambda^{-\alpha}$ eq. 15

Where $\lambda^{-\alpha}$ = Aerosol optical thickness at wavelength λ

β = Angstrom turbidity coefficient at 1μm and α wavelength exponent.

Planck's Radiation Law

In order to understand the properties of the solar radiation reaching Earth, it is useful to review some concepts of electromagnetic radiation and the properties of black-bodies. Electromagnetic radiation can be regarded as a wave, characterized by its wavelength λ. All electromagnetic radiation travels at the speed of light c (2.998×108 m/s) in a vacuum (or c/n in a material with refractive index n) and has a frequency ν such that c = λν. By quantum mechanics, electromagnetic radiation can also be regarded as a flux of photons, where the energy content in each photon depends on the frequency. In electromagnetic radiation with a certain wavelength λ a photon has the energy

$E\ hf = \frac{hc}{\lambda}$ where h is Planck's constant (6.626×10^{-34} Js). eq. 16

The radiation emitted from a hot object like the Sun, or any object for that matter, is distributed over a range of wavelengths and, consequently, consists of a flux of photons with different energy content (Gueyman & Vignola, 1998). The distribution of radiated energy over wavelengths, as well as the total energy flux, depends on the temperature of the object. This can be approximated with a black-body, which is an idealized state of an object in a thermodynamic equilibrium, where the object is a perfect absorber and emitter of radiation (Katz, Baille & Mermier, 1982). Based on both quantum mechanics and thermodynamics a black-body can be described by Planck's radiation law, where the wavelength distribution of radiation emitted from a black-body with temperature T is given by:

$$G_{b\lambda} = \frac{2\pi hc^2}{\lambda^5 (e^{\frac{hc}{\lambda kT}} - 1)} \qquad \text{eq.17}$$

where k is Boltzmann's constant (1.380×10−23 JK−1). Gbλ is often given in units of Wm−2μm−1 . We can also express this distribution in terms of photon flux by dividing the emitted power at each wavelength by the corresponding photon energy:

$$\Phi_{b\lambda} = \frac{\lambda}{hc} G_{b\lambda} \qquad \text{eq.18}$$

in units of s^{-1}m−2μm^{-1}. By differentiating the distribution in equation 18 with respect to wavelength and equating to zero, the wavelength corresponding to the maximum of the distribution can be found. The relation between this wavelength and the black-body temperature is

$$\lambda_{max}T = 2897.8\ \mu mK \qquad \text{eq. 19}$$

which is known as Wien's displacement law and states that the maximum wavelength is inversely proportional to the temperature. Another useful relation, which can be obtained by integrating Planck's law Tover all wavelengths, is the Stefan-Boltzmann equation. It expresses the total emitted black-body radiation:

$$G_b = \int_0^\infty G_{b\lambda} d\lambda = \sigma T^4 \quad \text{eq. 20}$$

Where σ is the Stefan-Boltzmann constant (5.670 × 10−8 Wm−2K−4). G_b is in units of Wm^{-2}. Note that this is also the unit most often used for incident solar radiation. The latter two equations tell us something fundamental and familiar about heated objects: the Stefan-Boltzmann equation shows that the total radiated power increases with the temperature of the object and Wien's displacement law shows that the peak wavelength decreases with increasing temperature, which, for example, causes metals to glow brighter as they get hotter.

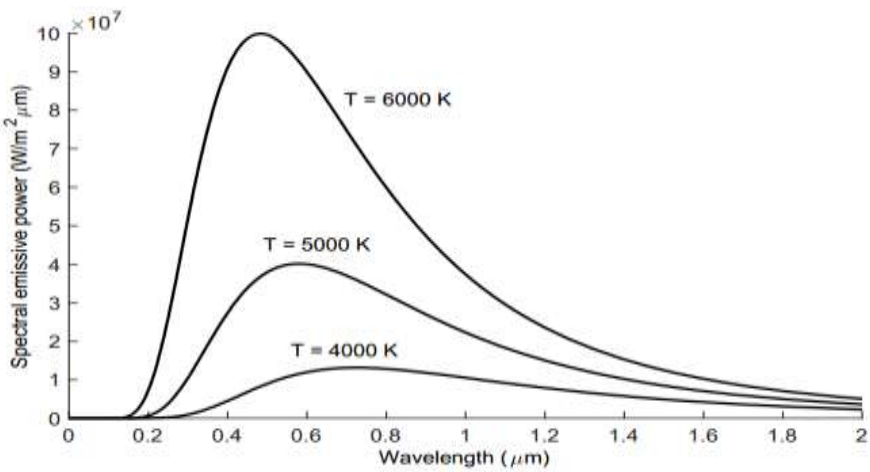

Figure 2 Stefan-Boltzmann

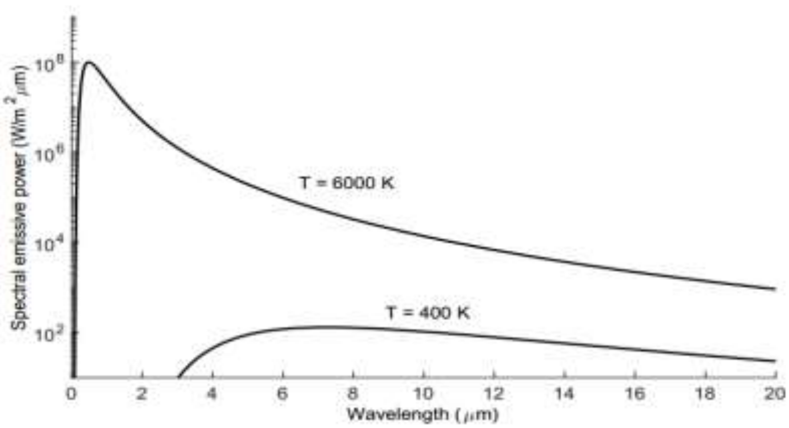

Figure 3: Wien

The Solar Constant

Let us now turn to the actual solar radiation that reaches Earth's atmosphere. How much radiation is there and how is it distributed over the wavelengths? To start with, we note that solar radiation levels in the solar system drop with the square of the distance to the Sun. To realize this, assume that the Sun's radius is r and its surface temperature T. The surface area of the Sun is then $4\pi r^2$ and the total radiative flux from the Sun is, using the Stefan-Boltzmann equation, σT4×$4\pi r^2$. Now, the surface of a larger imaginary sphere with radius l with the Sun at its center will receive the same amount of radiation, but over the larger area $4\pi l^2$ (Gueymard, 1994). Consequently, the energy flux per unit area at the distance l from the Sun is

$$G_l = \frac{\sigma T^4 \, X \, 4\pi r^2}{4\pi l^2} = \sigma T^4 (\frac{r}{l})^2 \qquad \text{eq . 21}$$

If you use the black-body temperature of the Sun (5777 K), the radius of the Sun (6.957 × 108 m) and the distance between the Sun and Earth (1.495 × 1011 m), you will get the average radiative flux just outside Earth's atmosphere, per unit area facing the Sun: 1367 W/m^2. This will be denoted by Gsc and is called the solar constant, or the air mass zero (AM0) radiation.

Due to Earth's elliptic orbit around the Sun the actual solar radiation outside the atmosphere at a given time (the extraterrestrial radiation) will differ from Gsc. Over the year, it varies from 1412 W/m2 at the beginning of July to 1322 W/m^2 at the turn of the year; a 3.3% variation from the mean value. This can be expressed mathematically as

$$G_{on} = G_{sc}(1 + 0.033 \, X \cos\left(360X \frac{d}{365}\right)) \qquad \text{eq. 22}$$

where *d* is the day of the year. The subscript 0 denotes zero air mass (AM0) and the subscript *n* indicates that the radiation is on a plane normal to the Sun-Earth axis.

Methodology

The turbidity indices, namely, Linke factor, Angstrom coefficient, and illuminance turbidity factor have been derived from the record of two and half-year measurement at the solar and daylight monitoring station. The mean values and frequency of occurrence of each index have been used to characterize the atmospheric turbidity of Osogbos sky.

The turbidity indices, namely, Linke factor, Angstrom coefficient, and Illuminance turbidity factor
are to be derived and estimated using the followings.

Linke factor: $\boldsymbol{T_L = T_{LK}[\frac{\delta_{RK}}{\delta_{Ra}}]}$ **(**eq. 10)

Where T_{LK} = Linke Turbidity Factor under clear sky, δ_{RK} = Rayleigh Integral, δ_{Ra} =Integral optical thickness

Angstrom coefficient,: $\tau_a (\lambda) = \beta \text{ x } \lambda^{-\alpha}$ (eq. 15)

Where $\lambda^{-\alpha}$ = Aerosol optical thickness at wavelength λ

β = Angstrom turbidity coefficient at 1μm and α wavelength exponent.

Illuminance turbidity factor: $G_l = \frac{\sigma T^4 \ X \ 4\pi r^2}{4\pi l^2} = \sigma T^4 (\frac{r}{l})^2$ (eq . 2)1

Linear function has been used to correlate the index of Angstrom coefficient with the other two indices which are Linke factor and illuminance turbidity factor.

Table 2 : ATMOSPHERIC CLEARNESS AVERAGE GRAPH BETWEEN 2009 - 2019

	Month	**Air Clearness for 2009**	**Air Clearness for 2010**	**Air Clearness for 2011**	**Air Clearness for 2012**	**Air Clearness for 2013**	**Air Clearness for 2014**	**Air Clearness for 2015**	**Air Clearness for 2016**	**Air Clearness for 2017**	**Air Clearness for 2018**	**Air Clearness for 2019**
1	JAN	0.3069839	0.28525646	0.33358602	0.3314	0.32684658	0.2997232	0.3138322	0.35881921	0.2995729	0.2989892	0.30662179
2	FEB	0.311607	0.31293394	0.31442544	0.3145805	0.31574815	0.3134198	0.315849	0.31802839	0.3161592	0.3145961	0.31614086
3	MAR	0.3064646	0.29423237	0.29998268	0.2998416	0.30286015	0.2947517	0.2971947	0.30419858	0.30646	0.3090095	0.30679485
4	APR	0.2981867	0.28921823	0.29441528	0.2913124	0.28923404	0.289987	0.2879384	0.30129209	0.2788382	0.2798643	0.28257242
5	MAY	0.2764207	0.25536449	0.26183847	0.2586528	0.26569767	0.2692087	0.2603931	0.26860301	0.2566804	0.2571896	0.25711447
6	JUN	0.2574893	0.22968034	0.22784868	0.2303569	0.22674449	0.2354434	0.2305094	0.2490609	0.2329191	0.2345879	0.23066831
7	JUL	0.2307887	0.22131213	0.22197361	0.221906	0.20494871	0.2169691	0.2267156	0.24105886	0.2066883	0.2119685	0.20474676
8	AUG	0.2451564	0.2186693	0.23840169	0.2322114	0.24765249	0.2321427	0.2292252	0.23066672	0.2250281	0.224121	0.22708279
9	SEP	0.272322	0.25512495	0.26561188	0.2594108	0.2464774	0.2460651	0.2485534	0.24578922	0.2579106	0.2576415	0.25140568
10	OCT	0.2723344	0.28137417	0.28482066	0.2821683	0.2799575	0.2863045	0.2817582	0.27589139	0.2720641	0.2716375	0.27038809
11	NOV	0.2991303	0.29755174	0.2959725	0.2802787	0.28768402	0.3086914	0.3469805	0.34276517	0.2787151	0.2805061	0.28240061
12	DEC	0.303437	0.29936209	0.3379494	0.3100393	0.29905985	0.3506049	0.3684799	0.33216722	0.2898833	0.2895211	0.29235424

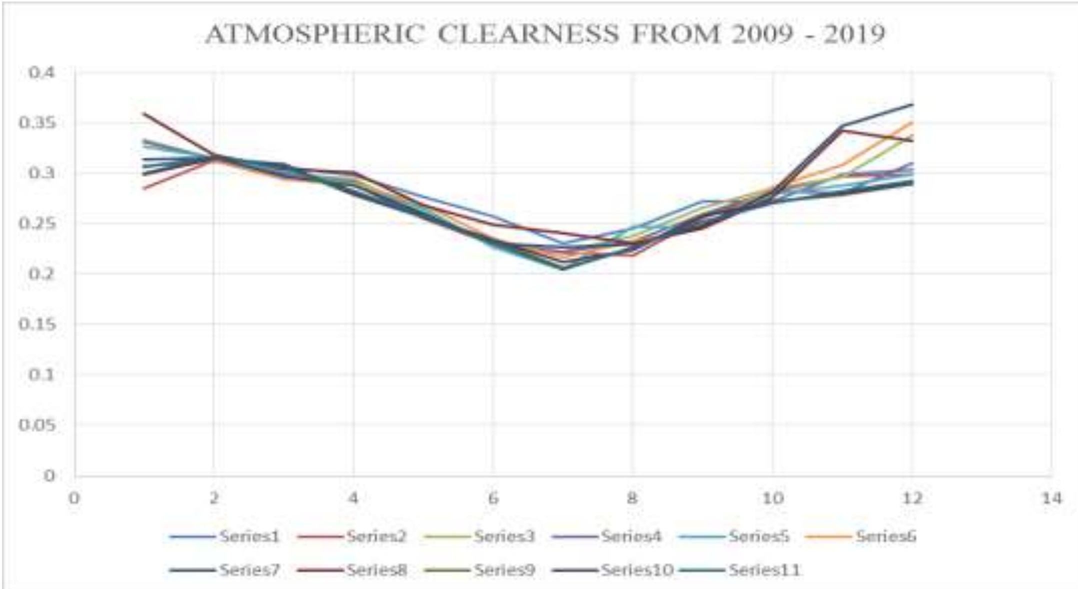

Figure 4: Atmospheric clearness

Table 3: AVERAGE LINKE TURBIDITY

	Month	Linke Turbidity (TL) 2009	Linke Turbidity (TL) 2010	Linke Turbidity (TL) 2011	Linke Turbidity (TL) 2012	Linke Turbidity (TL) 2013	Linke Turbidity (TL) 2014	Linke Turbidity (TL) 2015	Linke Turbidity (TL) 2016	Linke Turbidity (TL) 2017	Linke Turbidity (TL) 2018	Linke Turbidity (TL) 2019
1	JAN	2.89556	3.001463	2.756617	2.767955	2.793696	2.916202	2.849569	2.640599	2.914974	2.917358	2.878559
2	FEB	2.926139	2.905282	2.84167	2.873523	2.767151	2.900413	2.872818	2.786688	2.80473	2.83537	2.82121
3	MAR	2.890294	2.911634	2.878253	2.886169	2.870609	2.918571	2.894727	2.881773	2.846702	2.833926	2.843089
4	APR	2.935525	2.913094	2.884466	2.90074	2.92721	2.910804	2.918264	2.849249	2.969188	2.961132	2.944588
5	MAY	3.065259	3.081081	3.062434	3.095323	3.023324	2.997621	3.05363	3.018129	3.070547	3.065134	3.066413
6	JUN	3.172698	3.236569	3.273821	3.244808	3.260144	3.210713	3.224872	3.121376	3.20585	3.197731	3.226978
7	JUL	3.336454	3.309579	3.288238	3.293138	3.418344	3.328705	3.263292	3.150593	3.393271	3.348606	3.401916
8	AUG	3.237952	3.328699	3.195227	3.22831	3.12642	3.239714	3.244295	3.233948	3.272663	3.280385	3.25857
9	SEP	3.075623	3.110515	3.045832	3.088509	3.160479	3.163132	3.147117	3.159547	3.080823	3.083066	3.125371
10	OCT	3.079976	2.978916	2.965444	2.980225	2.990229	2.948328	2.976178	3.014161	3.024981	3.028931	3.035773

11	**NOV**	2.926219	2.911491	2.920284	3.042338	2.966285	2.862916	2.678074	2.694784	3.009295	2.999682	2.989851
12	**DEC**	2.900625	2.919693	2.731551	2.865051	2.928805	2.687254	2.605847	2.772114	2.967145	2.966837	2.951883

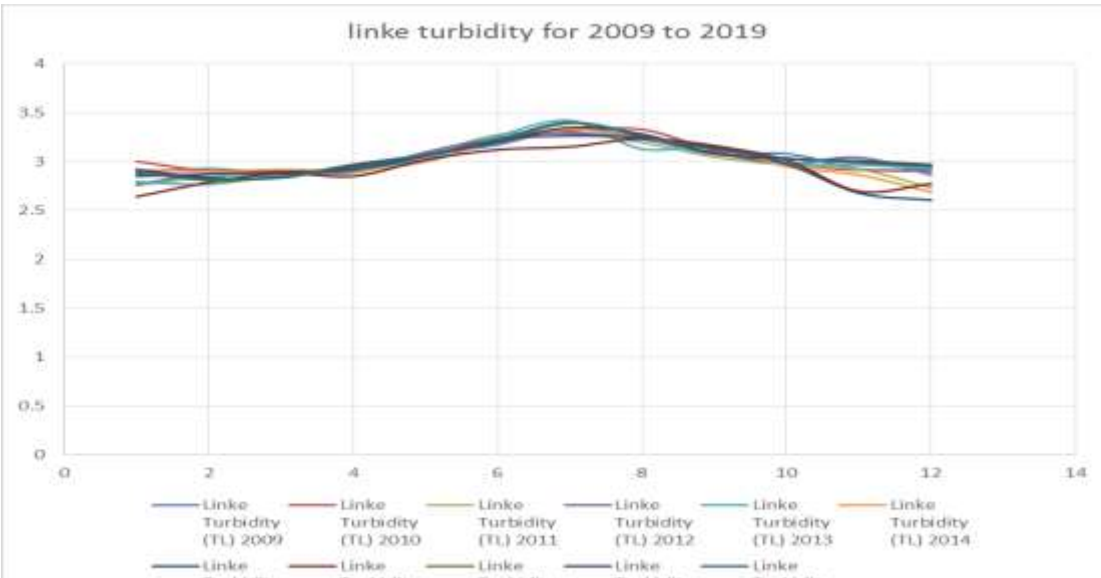

Figure 5: Hourly variations of atmospheric turbidity

Variations of Angstrom coefficient, Linke factor and illuminance turbidity factor are also investigated for hourly variation. The figure above exhibits the variations of Linke factor and illuminance turbidity factor during the time of a day. From the figure the mean value of Linke factor continuously increases with time from morning to noontime and then decreases in the afternoon. Similar pattern of variation to that of Linke factor is also observed for illuminance turbidity factor. It should be noted that the values of illuminance turbidity factor are more stable when compared to that of Linke factor.

Conclusion

The turbidity indices, namely, Linke factor, Angstrom coefficient, and illuminance turbidity factor have been derived from the record of two and half-year measurement at the solar and daylight monitoring station. The mean values and frequency of occurrence of each index have been used to characterize the atmospheric turbidity of Osogbos sky. Values of the turbidity of the atmosphere are found to vary with seasons, months and hours. The results show that the skies on cloudless days are clean and clear. Atmospheric turbidity is low and quite stable during dryer months and increases in wet season from March to August. The turbidity of the sky also varies with time of day. The turbidity increases from morning to noontime and then decreases in the afternoon. The annual mean values of Angstrom coefficient, wavelength exponent, Linke factor and illuminance turbidity factor are 2.90074, 2.92721, 2.92376 and 2.98718, respectively.

Linear function has been used to correlate the index of Angstrom coefficient with the other two indices which are Linke factor and illuminance turbidity factor. Illuminance turbidity factor strongly correlates with Angstrom coefficient. The results also demonstrate that illuminance turbidity factor is insensitive to the amount of water vapour in the atmosphere.

Recommendations

i. Values of daylight illuminance can be useful for daylighting application that contributes to energy conservation for buildings as well as meteorologist.
ii. Engineers and builders can employ this discoveries knowledge of the size of beam normal irradiance for calculating cooling load in air-conditioning buildings in tropical climate.

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