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Preliminary Assessment of Aerosol Optical Loading in the Atmosphere over Makurdi, Nigeria

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ABSTRACT

In this work, aerosol optical loading in the atmosphere over Majurdi was assessed using global solar radiation data from Gunn-Bellani Radiation Integrator for a period of ten years (2004 – 2013). Angstrom's turbidity model was employed in this study. The results reveal that aerosol optical loading ranges from 0.280 to 0.571, while the turbidity coefficient ranges from 0.114 to 0.232. The highest and lowest aerosol optical loading over Makurdi were recorded in August (0.57) and December (0.28) during rainy and dry seasons respectively. This seasonal variation may probably be due to the effect of aerosol as condensation nuclei for cloud droplets. The Angstrom exponent value of 1.3 indicates that the coarse mode particles exist in Makurdi.

Keywords: Aerosol Optical Loading, turbidity coefficient, solar radiation, Makurdi.

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1. INTRODUCTION

It is a known fact that the earth atmosphere is an envelope of gases. However, small particles of solid and liquid called aerosols from natural source (condensation, volcanoes, dust storm, forest and grass land fires) and human activities (burning of fossil fuels, ploughing or digging up soil) are also found in the atmosphere (Onyeuwaoma *et al*., 2015).

The different types of aerosols exert a strong influence on solar, cloud formation, meteorological variables, and chemistry of the atmosphere (Ramanathan and Carmichael, 2008). On earth's atmosphere, aerosols are regarded as pollutants because they influence the earth's climatic system. Both solar and terrestrial radiation budget impair visibility by absorbing and indirectly by providing the condensation nuclei for cloud droplets, as well as influencing tropospheric photochemistry. The presence of aerosols in the atmosphere also affects photosynthesis and agricultural production due to the reduction in solar energy (Bates *et al*., 2008).

Aerosols greater than 1 μm in diameter (coarse particles) are derived from soil dust and sea salt, while those with diameters less than 1 μm (fine particles) are formed mainly by combustion or chemical conversion of gaseous precursors into liquid or solid products [gas-to-particles conversion]. Aerosol size is the most important parameter used in characterizing the physical properties of aerosols. The fine particles have primary influences in terms of radiative forcing, having low impaction efficiencies and sedimentation velocities and a high scattering efficiency. They can travel long distances and be taken up to higher altitudes, where they are able to interact with clouds (Isikwue *et al*., 2012).

The particles in the atmosphere create a global dimming effect, where less of the radiation gets to the Earth. Besides global dimming, other impact of aerosol includes destruction of stratospheric ozone, radiative forcing and climate change. The most obvious effect of aerosol loading is the reduction in visibility and air quality. The monitoring of aerosol loading is of high environmental priority, particularly in industrialized cities and urban environment. Concentrated aerosols from substances such as silica, asbestos, and diesel particulate matter are sometimes found in the workplace and has been shown to result in a number of diseases, including respiratory failures, black lung, and ecological stress. Presence of Lead particles in the air may be due to human activities such as burning of fossil fuel, waste incineration, and metal processing industries. Small amount of lead can be harmful to infants and young children. They can cause impaired mental function and neurological damage in children (Chineke *et al*., 2007; Oyem and Igbafe, 2010).

The combined effect of scattering and absorption of solar radiation by aerosol is referred to as atmospheric turbidity. The angstrom's turbidity formula gives an alpha, a function of aerosol size. Low value of the alpha corresponds to high ratio of large to small particles (Canada et al., 1993; Alnaser and Awadalla, 1995). Aerosol Optical Thickness (AOT), also called Aerosol optical loading (AOL) or attenuation coefficient (τ) is a measure of loading in the atmosphere. Generally, an increased AOT value suggests large number of aerosols in the atmosphere, which lead to light scattering, thereby resulting in low visibility (Emetere et al., 2015). Therefore, there is need for continuous studies, in order to assess the presence of aerosol in the atmosphere.

Makurdi, the capital of Benue State, Nigeria, covers an area of about 33.16 km^2 and is located at latitude $7^0 41'$ N and longitude $8^0 37'$ E. It has a population of about 297,398 people. Makurdi is noted for its hotness during the dry season, with an average air temperature of about 33 ^{0}C. This high temperature is attributed to the presence of River Benue (the second-largest river in Nigeria) which cuts across the middle of the city and serves as a heat reservoir (Ibe *et al*., 2024).

Makurdi lies in the North-Central region of Nigeria. This implies that it is prone to the northeast trade wind, which carries harmattan dust into Nigeria. Secondly, the soil constituents of some parts of Makurdi, especially the North Bank of the River Benue comprises mainly of laterite and loose sand. Most of the roads in Makurdi town are not tarred hence, during the dry season (harmattan period), the atmosphere in Makurdi is filled with dust particles which have some detrimental effects on climates, the objects, and living beings in the environment. In addition, Benue State is the food basket of the nation, with Makurdi metropolis having many rice mills, cassava mills, and other grain mills, which could serve as sources of aerosols in the atmosphere over Makurdi and its environs. This suggests the need for continuous assessment of AOL in the area. Thus, this research is aimed at investigating AOL over Makurdi. The insight from this study could be used to predict the climatic condition over Makurdi, as well as provides information for existing industries to plan on how to control the emission of aerosols.

2. SOURCES OF DATA AND METHOD OF DATA ANALYSIS

Monthly mean daily global solar radiation from Gunn-Bellani Radiation Integrator provided by the Nigeria Meteorological Agency, Tactical Air Command Headquarters Makurdi Airport, Benue State, was used in this study. The global solar radiation (I_G) is one of the input data in the analysis. This study spanned for ten years (2004 – 2013). The data were analysed as follow.

- Monthly mean daily extraterrestrial radiation on a horizontal surface (I_o) was computed using equation 1 (Ranjan *et al*., 2007; Ndilemeni *et al*., 2013).

$$(1) \quad I_o = \frac{24}{\pi} I_{SC} = \left[1 + 0.0033\left(\frac{360J}{365}\right)\left(\frac{\pi}{180w_s}\sin\theta\sin\delta c + \cos\theta\cos\delta\cos w_s\right)\right]$$

where I_{SC} is the solar constant in $MJm^{-2}day^{-1}$; δ is the solar declination angle and ω_s is the sunrise sunset hour angle.

- The sunrise sunset hour angle and solar declination can be calculated using equation 2 and 3 respectively (Gana and Akpootu, 2013; Audu *et al*., 2014).

$$(2) \quad w_s = cos^{-1}(-tan\theta\ tan\delta)$$

$$(3) \quad \delta = 23.45\left[360\left(\frac{J+284}{365}\right)\right]$$

where θ is the latitude of the site, J is the day number of the year. Usually, the solar radiation is calculated on the 15^{th} of each month.

- An empirically estimated diffuse fraction of solar radiation was first computed using equations 4 and 5 given as (Khatrip *et al*., 2009; Onyeuwaoma *et al*., 2018):

$$(4) \qquad \frac{I_d}{I_G} = 1.0 - 1.13\frac{I_G}{I_o}$$

$$(5) \qquad \frac{I_d}{I_G} = 1.39 - 4.40\left(\frac{I_G}{I_o}\right) + 5.531\left(\frac{I_G}{I_o}\right)^2 + 3.108\left(\frac{I_G}{I_o}\right)^3$$

where I_G is the measured global solar radiation,, I_0 is the monthly mean extraterrestrial radiation and I_d is the diffuse solar radiation.

- The empirically estimated diffuse solar radiation, the global solar radiation and the extraterrestrial radiation were used to obtain the regression constant using SPSS Software.
- Subsequently, the regression constants (a-f), the global solar radiation, and extraterrestrial radiation were used to obtain the diffuse solar radiation using equation (6) and (7)

$$(6) \qquad \frac{I_d}{I_G} = a - b\frac{I_G}{I_o}$$

$$(7) \qquad \frac{I_d}{I_G} = c - d\left(\frac{I_G}{I_o}\right) + e\left(\frac{I_G}{I_o}\right)^2 + f\left(\frac{I_G}{I_o}\right)^3$$

- The direct solar radiation, I was then computed using equation 8.

$$(8) \qquad I = I_G - I_d$$

- Aerosol optical loading, also called aerosol optical thickness or attenuation coefficient (τ) for Makurdi was evaluated using equation 9. The average air mass, m was computed for a day from 8 am to 5 pm.

$$(9) \qquad \tau = \frac{InI_0 - In\,I}{m} \quad 96$$

where I is direct solar radiation

- Turbidity coefficients, β was determined using equation 10.

$$(10) \quad \ln\beta = \ln\alpha - \alpha\ln 2$$

3. RESULTS AND DISCUSSIONS

It could be observed from (Figure 1a) that the highest global radiation was recorded in March with a value of 19.09 $MJm^{-2}day^{-1}$ and the least is in August with an average value of 13.43 $MJm^{-2}day^{-1}$. This is within the range of solar radiation reported by Isikwue *et al*. (2012) that the average solar radiation in Nigeria per day is as high as 20 MJm^{-2}.

On the contrary, the diffuse solar radiation was highest in August with a value of 0.489 $MJm^{-2}day^{-1}$ (Figure 1c). This implies that in the month of August, more solar radiation were scattered as it penetrated the atmosphere. The month of December has the least diffuse radiation of 0.199 $MJm^{-2}day^{-1}$. The direct solar radiation over Makurdi has its lowest value of 12.94 $MJm^{-2}day^{-1}$ in August, which could be as a result of more solar radiation being scattered or absorbed (Figure 1d). From Figure 1e, the clearness index has a low value of 0.351 in the month of August, which implies that the availability of global solar radiation is low in the month of August.

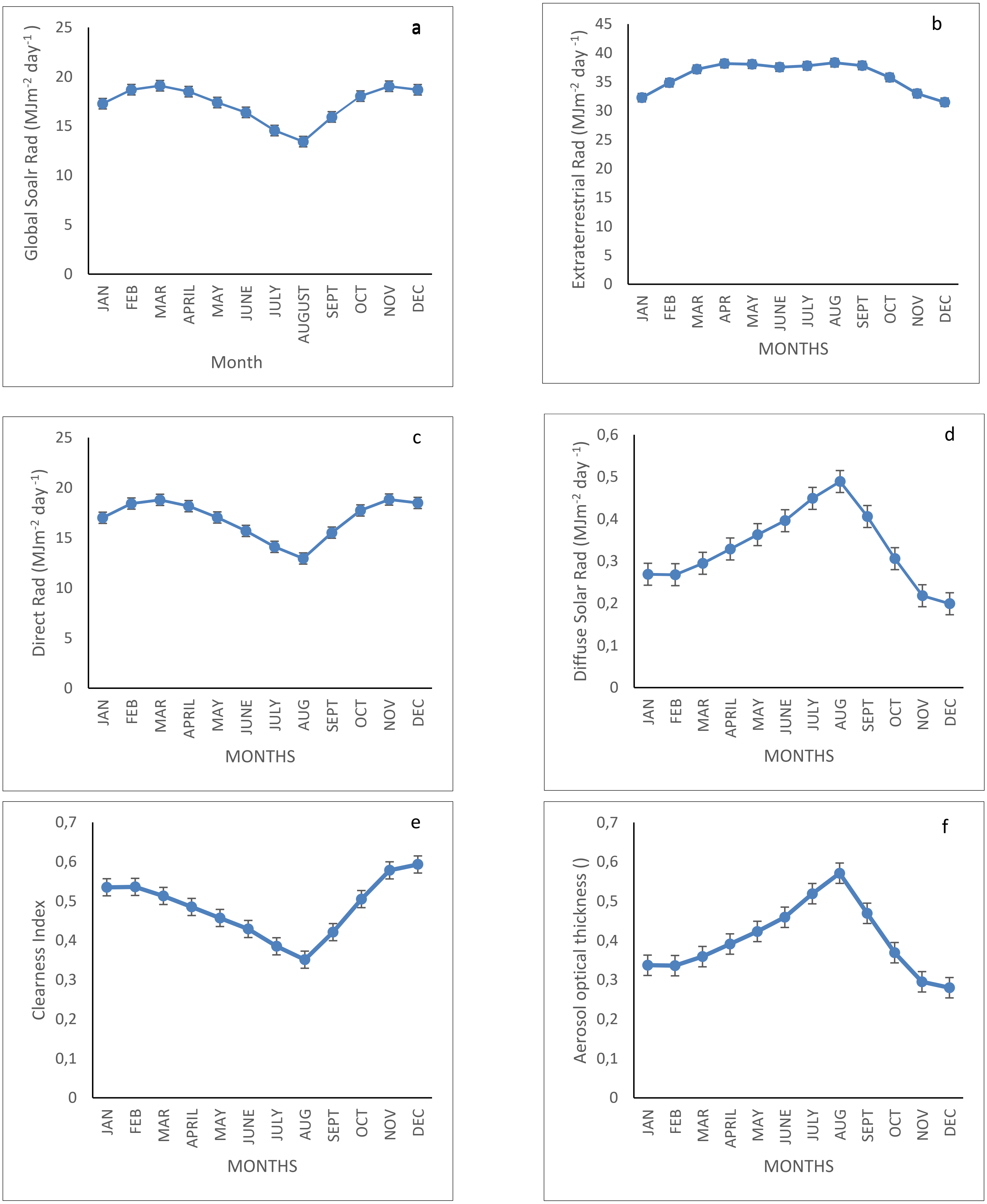
The AOT has its least value in the month of December with a value of 0.280 and highest value of 0.571 in the month of August (Figure 1f). The high AOT value in summer and low AOT in winter could be is could be attributed to the high wind speed producing larger amounts of wind-driven dust particles and changes in the direction of wind, respectively (Olayinka, 2011). This implies that the attenuation of aerosols, cloud or gases in the atmosphere is highest in the month of August. The turbidity coefficient has its highest value in August and least value in December (Figure 1g). This means that the turbidity coefficient is directly proportional to the AOT.

The high AOT values in the month of July and August could also be due to high condensation created when aerosol particles act as condensation nuclei. When this occurs, thick clouds are formed and they prevent solar radiation from reaching the Earth's surface.

The average value for the aerosol optical loading from April to October is 0.457 and an average of 0.322 from November to March. The result of seasonal variation, with higher value in rainy season, is in line with the result of previous work by (Olayinka, 2011)in Borno and Sokoto States, where the average AOT value in the rainy and dry season were 0.52 and 0.39 respectively for Borno State. For Sokoto State, the average AOT values for rainy and dry season were 0.45 and 0.24 respectively.

It is pertinent to note that the turbidity coefficient increases with increase in AOT and decreased with decrease in AOT. The turbidity coefficient values ranged from 0.114 to 0.232. The Angstrom exponent value of 1.3 indicates that coarse particles mostly exist in the atmosphere over Makurdi.

According to Hamasha et al. 2012) visibility is high when AOT is low, thus within the months of October – March, solar energy utilization and airplanes flight operations are highly encouraged. Moreover, October and March are months of transition from rainy to harmattan and harmattan to rainy season respectively. In these months of October – March, conditions are dry with little or no rain, and soil aerosols are easily transported by the prevailing North Easterly winds.


a
Global Soalr Rad (MJm^{-2} day^{-1})
0
5
10
15
20
25
JAN FEB MAR APRIL MAY JUNE JULY AUGUST SEPT OCT NOV DEC
Month
b
Extraterrestrial Rad (MJm^{-2} day $^{-1}$)
0
5
10
15
20
25
30
35
40
45
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS
c
Direct Rad (MJm^{-2} day^{-1})
0
5
10
15
20
25
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS
d
Diffuse Solar Rad (MJm^{-2} day $^{-1}$)
0
0,1
0,2
0,3
0,4
0,5
0,6
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS
e
Clearness Index
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS
f
Aerosol optical thickness ()
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS

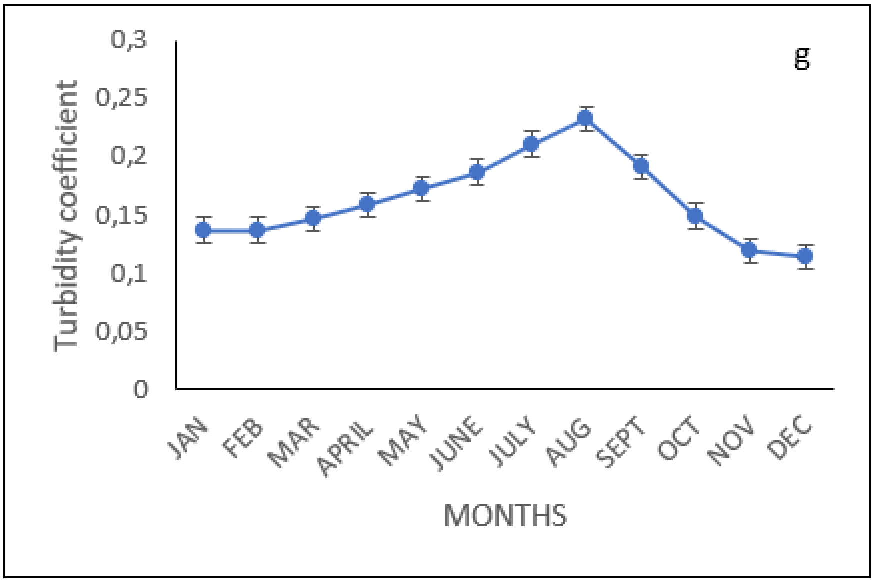


Figure 1. Variation of monthly mean **(a)** global solar radiation **(b)** extraterrestrial solar radiation **(c)** direct solar radiation **(d)** diffuse solar radiation **(e)** clearness index **(f)** aerosol optical thickness and **(g)** turbidity coefficient over Makurdi.

4. CONCLUSIONS

The aerosol optical loading has an average value of 0.457 for the rainy season and 0.322 for dry season. The aerosol optical loading and turbidity coefficient obtained in this work showed slightly higher value in the month of July and August probably due to thick cloud formed when aerosol acts as condensation nuclei for cloud droplet and secondly, it could be due to aerosol particles present in the atmosphere from anthropogenic sources such as burning of fossil fuel, biomass, dust from grain mills and soil excavation for construction and agricultural purposes. The aerosol optical loading has the same trend of variation with that of the turbidity coefficient. The volume size distribution of aerosol particles indicates a higher concentration of coarse mode particles. The unavailability of equipment to carry out measurement of direct and diffuse solar radiation is a big challenge to this work. We hereby recommend further studies on aerosol optical loading using in-situ measurement and the effect of atmospheric parameters such as rainfall and wind on aerosol optical thickness.

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