

Original Research Article
**INVESTIGATION OF THE EARTH'S ALBEDO
USING METEOROLOGICAL PARAMETERS
OVER MAIDUGURI, NIGERIA**

ABSTRACT

This study employed the shortwave solar energy balancing at the edge of the Earth's atmosphere to estimate and compare the variation of albedo for Maiduguri situated in the Sahelian region of Nigeria, using measured monthly mean daily meteorological parameter of global solar radiation obtained from the National Aeronautics and Space Administration (NASA) during the period of thirty-eight years (1984 – 2021). The variation of albedo with surface temperature, maximum wavelength, clearness index, global solar radiation, relative humidity and mean temperature for this location was investigated. The results in this study show that the estimated surface albedo depicts a direct opposite relationship with the clearness index, an inverse relationship with the emitting Earth's surface temperature and a direct relationship with the wavelength for the studied location. The highest and lowest values of albedo for the location was found in the months of August and November with 0.5125 and 0.3344 respectively. The emitting Earth surface temperature ranged between 232.8674 K in August and 251.7177 K in November. These values agreed closely to the standard emitting Earth surface temperature value (255.0000 K). The maximum emitting wavelength values were found to be > 4 indicating that the radiation is longwave and is found within the infrared region of the electromagnetic spectrum. The results in this study will be useful for the design of solar energy collectors, atmospheric radiative transfer and studies that relates to atmospheric thermal balance.

Keywords: Albedo, earth surface temperature, global solar radiation, maximum wavelength, Maiduguri

1. INTRODUCTION

The Sun provides a natural influence on the Earth's atmosphere and climate. Over the years, the amount of solar radiation reaching the Earth's surface has been modified, especially since the industrial revolution. Apart from scattering and absorption of solar radiation in the atmosphere, the other mechanism by which the amount of incoming solar radiation reaching the Earth's surface is modified is through reflection. Reflection is a process where sunlight is re-directed by 180° after it strikes an atmospheric particle. The shortwave reflected solar radiation include; the reflected radiation back to space by clouds, reflected radiation from the Earth's surface, and the scattered radiation back to space by atmospheric particles and clouds [1].

The solar radiation reaching the Earth's surface depends upon the climatic condition of the location, hence, the study of what happens to sunlight as it passes through the atmosphere is crucial to many aspects of science and general knowledge [2]. Over the years, the amount of solar radiation reaching the Earth's surface is being modified through reflection, scattering

and absorption in the atmosphere. The fraction of the incident solar radiation that is reflected and scattered back into space is called albedo [3].

Albedo is related to reflection of solar radiation at a surface and therefore defined in terms of it, as the ratio of the reflected solar radiation to the incident solar radiation at the surface, i.e., $\frac{H_r}{H_0}$. The extraterrestrial radiation, H_0 at the edge of the atmosphere, from the sun, is considered the incident solar radiation. Albedo or reflection coefficient is also known as reflectance or reflectivity of a surface; by this, the surface albedo of the Earth is regarded the same as planetary albedo by many scientists [4]. The average overall albedo of the Earth, its planetary albedo, is about 0.3. This fraction of incoming radiation is reflected back into space. The other 0.7 part of the incoming solar radiation is absorbed by our planet [5 - 6]. It is assumed however that the reflected radiation, H_r , is both diffuse and specular in nature, that is, it is diffuse if the reflected radiation is uniform or isotropic in all angular directions, and specular if the surface of reflection is smooth with respect to the wavelength of the incident radiation such that the laws of reflection are satisfied [3].

It was said by Gutman [7] that the observed albedo assumed that the radiation field is isotropic. Albedo, as a property of a surface, therefore, can be used to determine the brightness of a surface. According to Parado and Ferreira [8], materials with high albedo and emittance attain low temperature when exposed to solar radiation, and therefore reduce transference of heat to their surroundings. Thus, albedo is an important input parameter or quantity in evaluating the total insolation on a building or a solar energy collector. It is also important in the studies dealing with thermal balance in the atmosphere. The Earth's albedo affects the amount of Sun-light the planet absorbs. It plays a major role in the energy balance of the Earth's surface, as it defines the rate of the absorbed portion of the incident solar radiation [3].

The purpose of this present work is to (i) estimate the value of the earth's albedo at Maiduguri, Nigeria, (ii) compare the emitting earth surface temperature for the study area to the standard value of emitting surface temperature of the earth (iii) to investigate the type of radiation based on the values of the wavelength obtained for the study area (iv) investigate the variation of albedo with the meteorological parameters

2. METHODOLOGY

The monthly mean daily measured global solar radiation, minimum and maximum temperature and relative humidity data used in this study was obtained from the National Aeronautics and Space Administration (NASA). The period under focus was thirty-eight years (1984 – 2021). The mean temperature was obtained by taking the average of the minimum and maximum temperature. The location under study was Maiduguri situated in the Sahelian region of Nigeria.

The monthly mean daily extraterrestrial radiation, H_0 on a horizontal surface was calculated from the expression given by [9 – 17].

$$H_0 = \left(\frac{24}{\pi}\right) I_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] \left[\cos\phi \cos\delta \sin\omega_s + \left(\frac{2\pi\omega_s}{360}\right) \sin\phi \sin\delta\right] \quad (1)$$

where I_{sc} is the solar constant ($=1367 \text{ Wm}^{-2}$), ϕ is the latitude of the site, δ is the solar declination and ω_s is the mean sunrise hour angle for the given month and n is the number of days of the year starting from 1st of January to 31st of December. The solar declination, δ and the mean sunrise hour angle, ω_s was calculated using the following equations [18] as reported in [19 – 26].

$$\delta = 23.45 \sin\left\{360 \left(\frac{284+n}{365}\right)\right\} \quad (2)$$

$$\omega_s = \cos^{-1}(-\tan\phi \tan\delta) \quad (3)$$

The shortwave solar energy balancing at the edge of the Earth's atmosphere was computed using the expression [27].

$$\frac{H_m}{H_o} + \frac{H_a}{H_o} + \frac{H_r}{H_o} = 1 \quad (4)$$

where H_m is the measured global solar radiation ($\text{MJm}^{-2}\text{day}^{-1}$), H_o is the extraterrestrial radiation ($\text{MJm}^{-2}\text{day}^{-1}$), the ratio $\frac{H_m}{H_o}$ is the fraction of the extraterrestrial radiation, H_o is transmitted through the atmosphere to the ground surface, is known as the clearness index [28 – 29]. H_a is the absorbed solar radiation, the ratio $\frac{H_a}{H_o}$ is the solar energy fraction absorbed, and is known as the absorption co-efficient or absorbance, and $\frac{H_r}{H_o}$ would be the solar energy fraction reflected back to space, and is known as the reflection co-efficient or reflectance [27] and H_r is the shortwave reflected radiation. According to Babatunde [27] the ratio $\frac{H_a}{H_o}$ is expected to be very small in value when compared with the other ratios given in equation (4) and therefore can be neglected, i.e., $\frac{H_a}{H_o} \ll 1$. Therefore equation (4) becomes

$$\frac{H_m}{H_o} + \frac{H_r}{H_o} \approx 1 \quad (5)$$

From this, an expression for estimating the reflectivity or albedo was obtained as

$$\frac{H_r}{H_o} = 1 - \frac{H_m}{H_o} \quad (6)$$

The flux density of longwave radiation emitted by the Earth, F_E , given by the Stefan-Boltzmann law [30] is expressed as

$$F_E = \sigma T_E^4 \quad (7)$$

where σ is the universal Stefan-Boltzmann constant, $\sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$, and T_E is the Earth's temperature, in Kelvin (K). F_E is also given [30] as

$$F_E = \frac{(1 - \frac{H_r}{H_o}) F_s}{4} \quad (8)$$

where $\frac{H_r}{H_o}$ is the planetary albedo of the Earth for the study area and F_s is the flux density of solar radiation incident upon the Earth (1368 Wm^{-2}). If equations (7) and (8) are combined together the following equation was obtained and that relates the surface temperature of the Earth, T_E to its albedo for the study locations [31] as

$$T_E = \left[\left(\frac{(1 - \frac{H_r}{H_o}) F_s}{4\sigma} \right) \right]^{1/4} \quad (9)$$

Equation (9) shows that the temperature T_E decreases as albedo increases. In atmospheric science the term "shortwave" ($\lambda < 4 \mu\text{m}$) refers to the wavelength band that carries most of the energy associated with solar radiation and "longwave" ($\lambda > 4 \mu\text{m}$) refers to the band that encompasses most of the terrestrial (Earth-emitted) radiation. In the radiative transfer literature, the spectrum is typically divided into the regions. Shown in figure 1. The relatively narrow visible region, which extends from wavelengths of 0.39 to 0.76 μm , is defined by the range of wavelengths that the human eye is capable of sensing [30]. The near infrared region, which extends from the boundary of the visible up to $\sim 4 \mu\text{m}$, which is dominated by solar radiation, whereas the remainder of the infrared region is dominated by terrestrial (i.e., Earth emitted) radiation [30]. Microwave radiation is not important in the Earth's energy balance but it is widely used in remote sensing because it is capable of penetrating through clouds [30]. The maximum wavelength of emission at temperature, T_E was obtained using the Wien's displacement law [30] as

$$\lambda_m = \frac{2897}{T_E} \quad (10)$$

λ_m = will be expressed in micrometers and T_E in degrees Kelvin.

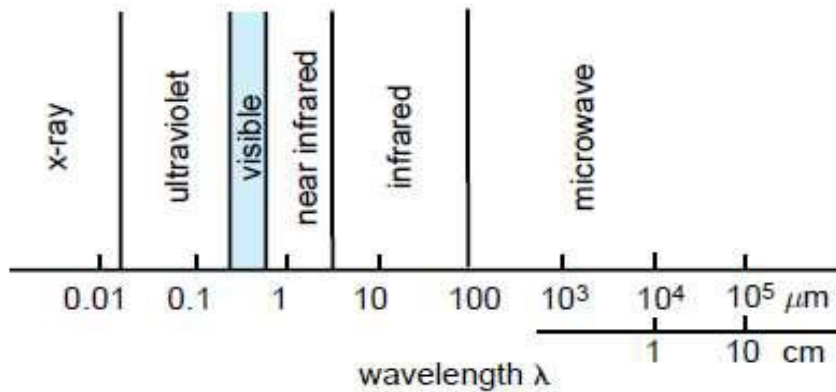


Fig. 1. The electromagnetic spectrum [30]

3. RESULTS AND DISCUSSION

Table 1. Monthly average daily albedo, clearness index, short wave reflected radiation, surface temperature and wavelength for Maiduguri (1984-2021)

Month	H_r/H_o	H_m/H_o	H_r ($MJm^{-2} d^{-1}$)	T(k)	Wavelength (μm)
Jan	0.3495	0.6505	20.2415	250.2792	11.5751
Feb	0.3511	0.6489	21.9221	250.1251	11.5822
Mar	0.3556	0.6444	23.5307	249.6900	11.6024
Apr	0.3901	0.6099	23.1499	246.2812	11.7630
May	0.4119	0.5881	22.3020	244.0421	11.8709
Jun	0.4453	0.5547	20.8165	240.5109	12.0452
Jul	0.4862	0.5134	19.3026	235.9413	12.2785
Aug	0.5125	0.4875	18.3808	232.8674	12.4406
Sep	0.4466	0.5534	20.3732	240.3638	12.0526
Oct	0.3747	0.6253	21.5318	247.8155	11.6901
Nov	0.3344	0.6656	21.0382	251.7177	11.5089
Dec	0.3626	0.6374	19.2155	249.0100	11.6341

Table 1 above shows the variation of the monthly average daily albedo, clearness index, short wave reflected radiation, surface temperature and wavelength for Maiduguri study area. The monthly average daily albedo increases from the months of January to August and decreases from the months of September to November. Then slightly increases in the month of December. The clearness index decreases from the months of January to August, increases from the months of September to November, then slightly decreases in the month of December. Solar radiation increases from months of January to April, decreases from months of May to August but slightly increases in the month of September and decreases from the months of October to December. Indicating that the surface temperature and maximum wavelength show opposite relationship for Maiduguri.

3.1 Analysis of the variation of albedo, surface temperature and maximum wavelength for Maiduguri

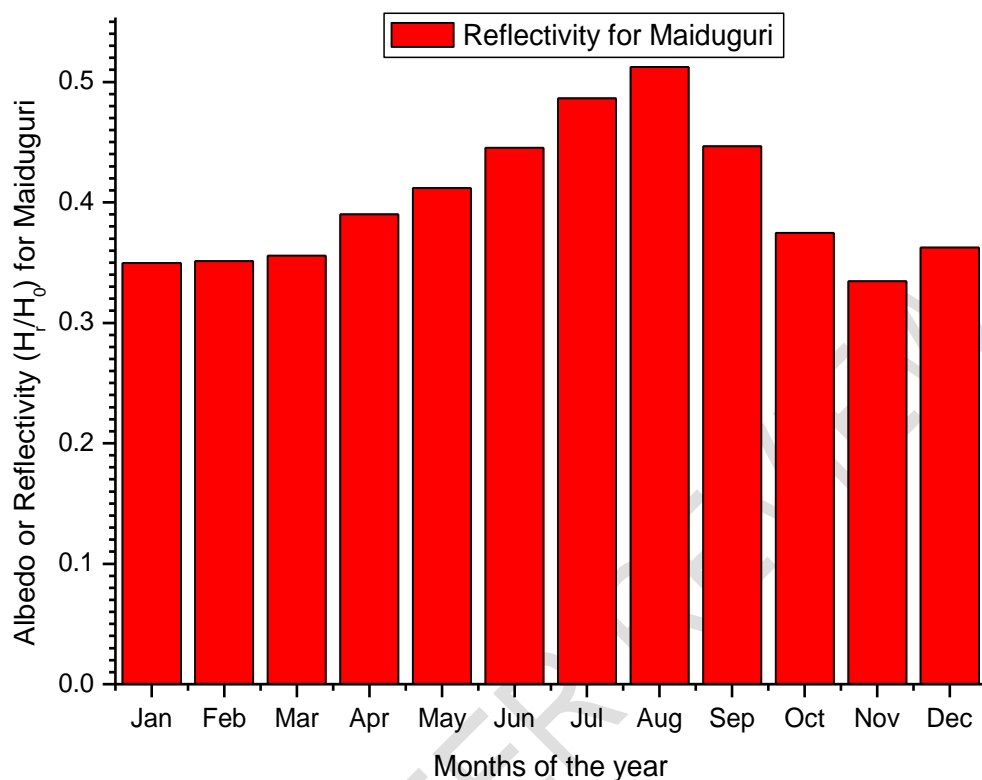


Fig. 2. Monthly average daily reflectivity (H_r/H_0) for Maiduguri (1984-2021)

Fig. 2 shows that the surface albedo for the study area (Maiduguri) ranged between 0.3344 and 0.5125 although this value is higher than the albedo of the earth Atmosphere (0.30) but is within the range of surface albedo which varies from 0 for no reflection to 1 for complete reflection of light striking the surface. The figure indicates that high value of an albedo was recorded in the months of July, August and September with the highest value of (0.5125) in August which corresponds to the lowest clearness index value of 0.4875 and relatively low values of an albedo was in the months of November, December and January with the lowest value of (0.3344) in November which corresponds to the highest clearness index value of (0.6656). The highest value of albedo observed in the month of August specifies that this is the month where there is peak of rainy season in the study area and a predominantly cloudy month, this is to confirm that reflection of solar radiation by the planet earth in this region are mostly due to clouds, aerosols and air molecules of which cloud is the peak. The surface albedo obtained for the study area ranged between 0.3344 and 0.5125 with the highest value in the month of August (0.5125) during the peak period of rainy season and the lowest in November (0.3344) during the beginning of dry season when it was relatively cloudless and dustless. The result in this study is in line with that reported by Audu et al. [2] for Kano and Akpootu and Iliyasu [3] for Sokoto.

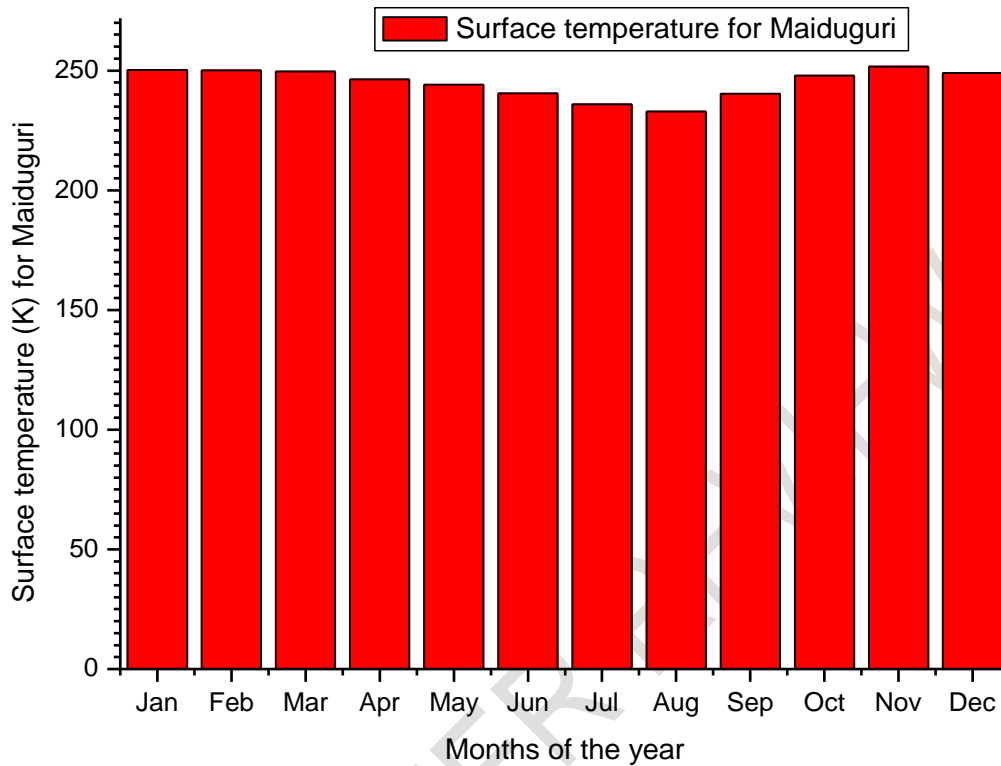


Fig. 3. Monthly average daily surface temperature (K) for Maiduguri (1984-2021)

Fig. 3 shows the variation of the radiated temperature by the earth for the study area (Maiduguri). It could be observed from the figure that the highest surface temperature was found in the month of January (250.2792 K) during the dry season period as this is anticipated because the albedo is low during this period, thereby allowing more radiation into the earth which accordingly increases the temperature. The lowest temperature occurred during rainy season in the month of August (232.8674 K) when the sky is cloudy. This corresponds to the highest reflectivity (albedo) with value of 0.5125, this is the cloudiest month for this region, where the rainy season is at its peak; the low temperature is expected, due to high reflection of solar radiation. In this present study, the surface temperature ranged between the values of 232.8674 K – 250.2792 K which compares constructively well with standard value for the emitting surface temperature of the earth (255.0000 K). The results revealed that there is an inverse relationship between the earth emitting surface temperature and the planetary albedo.

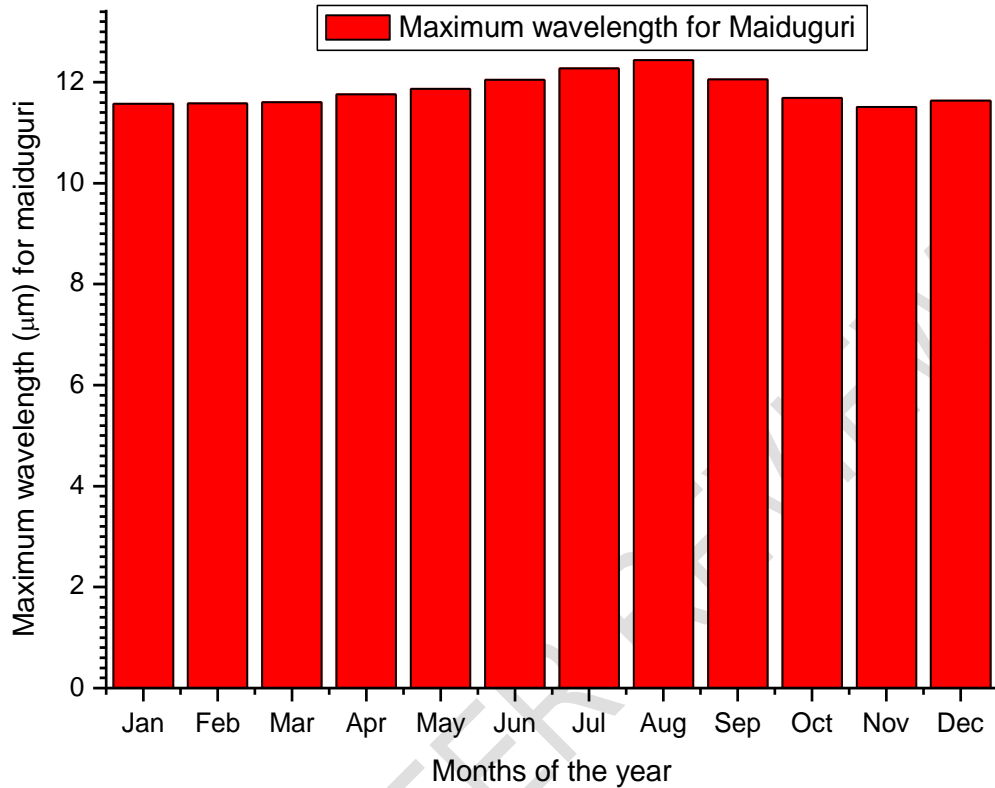


Fig. 4. Monthly average daily wavelength (μm) for Maiduguri (1984-2021)

Fig. 4 shows the variation of monthly average daily maximum emitting wavelength for the study area (Maiduguri). The highest peak wavelength was estimated in the month of August ($12.4406\mu m$) and the lowest was in the month of December ($11.5089\mu m$). The peak wavelength ranged in the values between $11.5089\mu m - 12.4406\mu m$ these values agree with that reported in radiative transfer literatures as contained in [30] that for longwave radiation ($\lambda > 4\mu m$) of [14]. This shows that the radiation is terrestrial (Earth emitted), and therefore within the infrared region.

3.2 Analysis of the variation of reflectivity with clearness index for Maiduguri

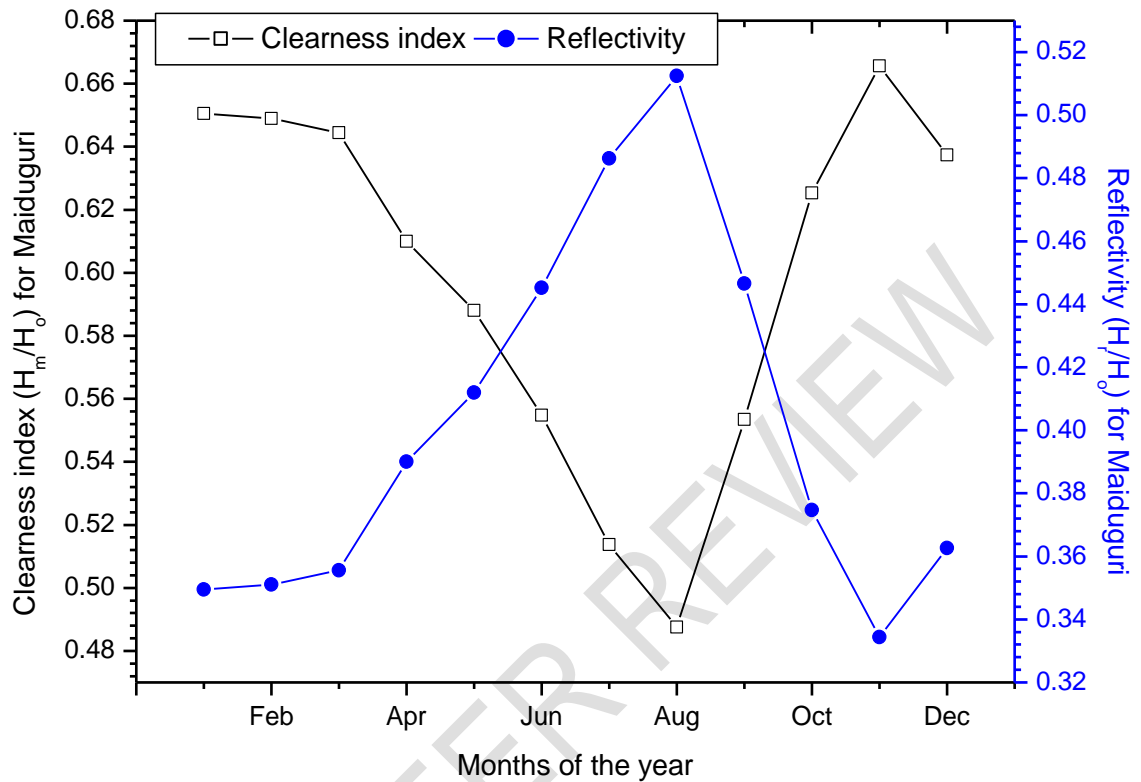


Fig. 5. Comparison between reflectivity (H_r/H_o) and clearness index (H_m/H_o) for Maiduguri (1984-2021)

Fig. 5 compares the variation of the reflectance/reflectivity and the clearness index for Maiduguri during the study period. It could be observed that the lowest value (0.4875) of clearness index corresponds to the highest value (0.5125) of reflectance in the month of August. Again, in the month of November, a very higher value (0.6656) of clearness index corresponds to a very low value (0.3344) of reflectance. The overall results show direct opposite relationship between the clearness index and reflectance, especially in the months between May and September. It implies that apart from the rainy season period the sky is clear almost through the year. The magnitude of the reflectance or albedo shows the notch of the surface brightness and the amount of the global solar radiation reflected back to space. Thus, when the sky is relatively cloudless, albedo or reflection coefficient would be relatively small, therefore, more radiation would be available to solar energy devices on the Earth. The measured global solar radiation (H_m) and the shortwave reflected radiation (H_r) are fractions of the extraterrestrial radiation (H_o), therefore, the clearness index and reflectance can be compared. The values of the clearness index are more than those of the reflectance, throughout the months for the period under investigation for Maiduguri except the month of August, the implication of this, is that, since the global solar radiation is towards the ground surface and the shortwave reflected radiation is towards the space, therefore, the global solar radiation received on the Earth's surface is more than the reflected radiation lost to space throughout the months in the location; signifying the availability of abundant solar radiation in the region.

3.3 Variation of reflectivity with meteorological parameters for Maiduguri

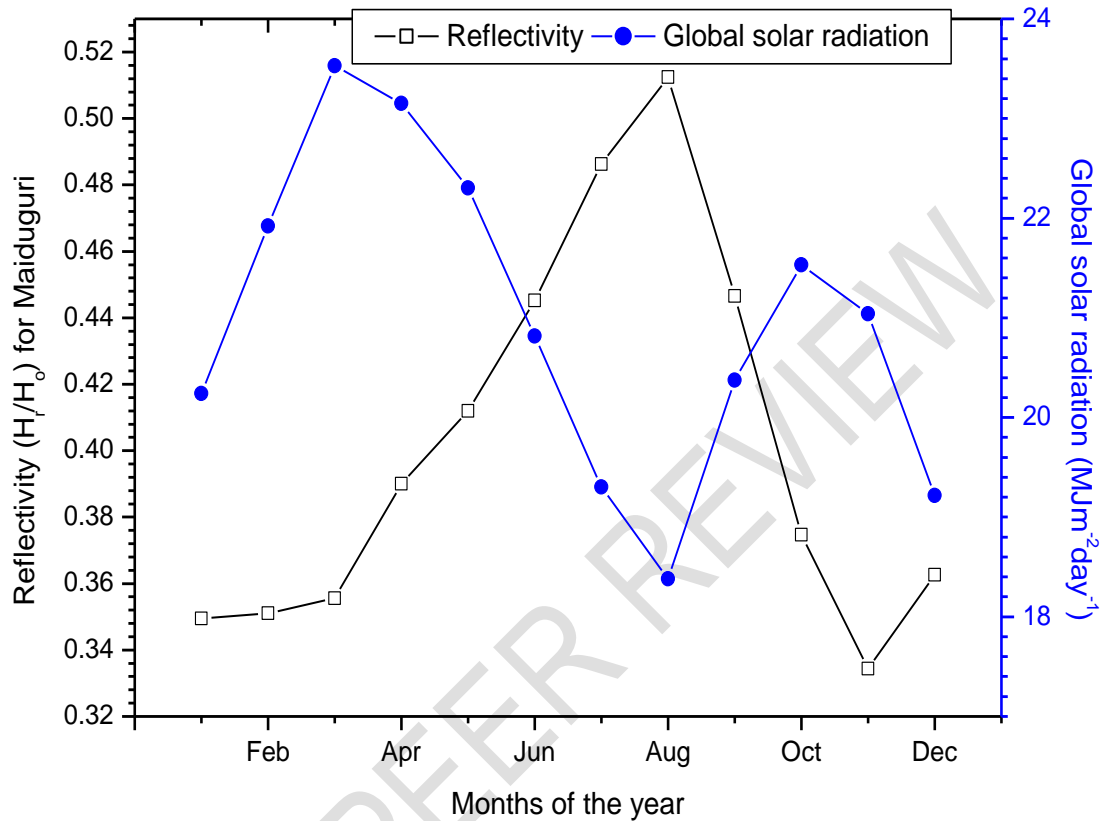


Fig. 6. Variation of monthly mean global solar radiation with reflectivity for Maiduguri (1984 - 2021)

From Fig. 6 it was observed that the monthly global solar radiation is not uniform throughout the period of study. Peak solar radiation was observed in the months of March, April and May with values of $23.5307 MJm^{-2}day^{-1}$, $23.1499 MJm^{-2}day^{-1}$, and $22.3020 MJm^{-2}day^{-1}$ respectively. The highest global solar radiation value of $23.5307 MJm^{-2}day^{-1}$ was recorded in the month of March in the period under study. On the other hand, the months of August and December recorded the least amount of solar radiation average values of $18.3808 MJm^{-2}day^{-1}$ and $19.2155 MJm^{-2}day^{-1}$ respectively. The lowest global solar radiation value of $18.3808 MJm^{-2}day^{-1}$ was recorded in the month of December in the period under study. In general, highest value of solar radiation was obtained in dry season.

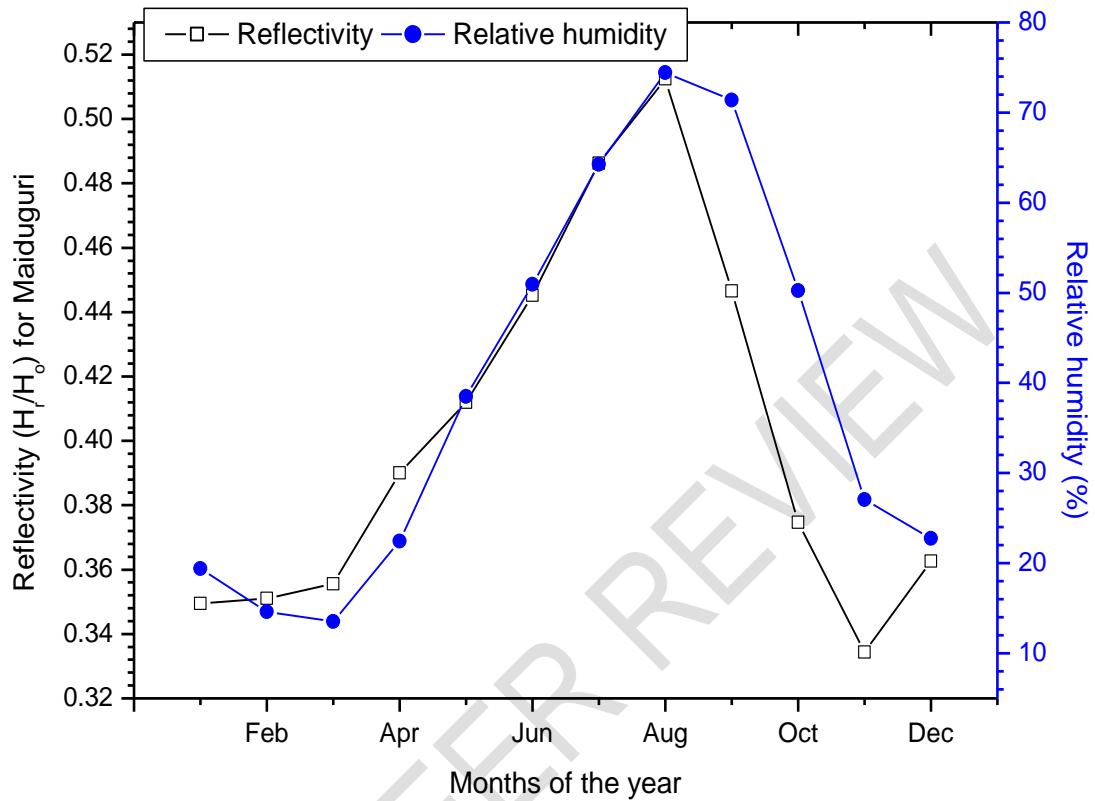


Fig. 7. Variation of monthly mean relative humidity (%) with reflectivity (H_r/H_o) for Maiduguri (1984-2021)

Fig. 7 shows the monthly variation of relative humidity with reflectivity for Maiduguri during the period under investigation. The figure showed the pattern of variation of relative humidity with albedo has almost similar trend. This is an indication that the moisture content in the atmosphere may reliably predict the values of albedo as a direct variation. The maximum and minimum values of 74.4387 % and 13.5187 % of relative humidity was observed in the months of August and March respectively. The relative humidity and albedo increase subsequently from March until both attained their maximum values of 74.4387 % and 0.5125 in August respectively. The implication is that the highest relative humidity in August corresponds to the highest albedo in the same month. The relative humidity and albedo decrease from September to December.

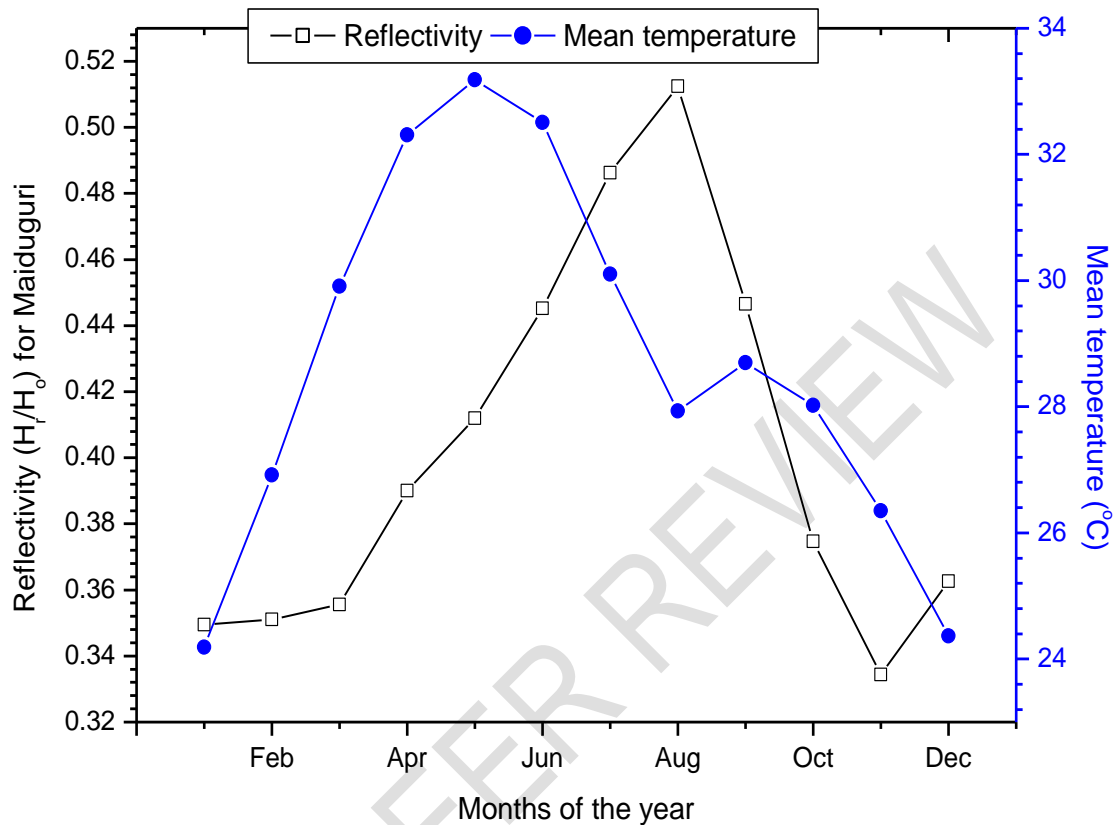


Fig. 8. Variation of monthly mean temperature (°C) with reflectivity (H_r/H_0) for Maiduguri (1984 - 2021)

Fig. 8 shows the variation of temperature with albedo for Maiduguri. The lowest and the highest temperature values of 24.1867 °C and 33.1845 °C were observed in the months of January and May respectively, the albedo increases from the months of January with lowest value of 0.3495 to its highest value of 0.5125 in August and decreases from the months of September to November and increases in the month of December. It could be seen that; the highest albedo was observed in month of August. The decrease in temperature from the months of June to August is an indication of rainy season. However, the rainfall in Maiduguri last until October. Since the rainfall for this region is very erratic and unpredictable the season sometimes is from June to October. The result shows that the temperature decreases from the months of June to August, then slightly increases in September and decreases further to December.

4. CONCLUSION

In this study, the shortwave solar energy balancing at the edge of the Earth's atmosphere was employed to estimate and compare the variation of albedo for Maiduguri (Latitude 11.85°N, Longitude 13.08°E and altitude 414.8 m above sea level) situated in Sahelian region of Nigeria, using measured monthly daily meteorological parameters of global solar radiation obtained from the National Aeronautics and Space Administration (NASA) during

the period of thirty-eight years (1984-2021). The highest and lowest values of albedo estimated for Maiduguri was found in the months of August and November with 0.5125 and 0.3344 respectively. The variation of clearness index with albedo revealed that the clearness index is higher than the albedo throughout the months for Maiduguri suggesting abundant global solar radiation throughout the years in Maiduguri. The emitting Earth surface temperature for Maiduguri ranged between 238.5837 K in August and 251.1607 K in January. The maximum emitting wavelength for Maiduguri ranged between 11.5089 μm in November and 12.4406 μm in August; these values shows that the radiation in this region is longwave radiation ($\lambda > 4 \mu\text{m}$) as expected and fall within the infrared region of the electromagnetic spectrum.

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