Estimation Of The Albedo Of The Earth's Atmosphere At Makurdi, Nigeria

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ABSTRACT: This work investigated the atmospheric conditions over Makurdi in order to access the availability of solar radiation, due to the fact that solar radiation reaching the Earth's surface depends on the climatic condition of the location. The monthly mean daily global solar radiation and air temperature data for Makurdi covering a period of 10 years (2000-2010) were obtained from Air Force Base, Makurdi. The model for shortwave solar energy balancing at the edge of the Earth atmosphere was adopted in this work. The results show that the global solar radiation and the albedo depict direct opposite relationship while the Earth's surface temperature varies directly with the global solar radiation since surface temperature is the reflection of both the duration and intensity of solar radiation. The highest albedo of 0.7 was obtained in August; the peak of cloud activity while the lowest albedo of 0.5 was recorded in November; when it was relatively cloudless and dustless. The albedo simulated corresponds with that obtained in other locations when compared.

Keywords: albedo, atmospheric condition, Earth's surface, Makurdi, reflected shortwave radiation,

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 being 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-direct by 180° after it strikes an atmospheric particles. 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], [3]. Most of the reflection in our atmosphere is mostly done by clouds and the reflectivity of a cloud can range from 40 to 90%. The fraction of the incident solar radiation that is reflected and scattered back into space is called albedo. Albedo is also known as reflectance or reflectivity of a surface. It is related to reflection of solar radiation at a surface and therefore defined in terms of it. Albedo or reflection co-efficient is the reflecting power of a surface. It is defined as the ratio of reflected radiation from the surface to incident radiation upon it. It is a dimensionless fraction and may be expressed as a percentage. Albedo is measured on a scale from 0 for no reflecting power of a perfectly black surface to 1 for perfect reflection of a white surface. The albedos of the individual surfaces on the Earth, such as water, vegetation, snow, sand, surfaces of buildings, dry soil, that of the atmosphere, etc, all constitute the surface or planetry albedo [21].

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Albedo varies diurnally and seasonally from place to place as well as from time to time in the same location due to the amount of cloud cover and particulate matter in the air plus the nature of the surface [13]. The angle of the Sun's ray also affect albeo because the lower the Sun's angle the higher the albedo [12], [15]. Like solar radiation, albedo values also vary across the globe with latitude. The average overall albedo of the Earth, its planetary albedo, is 30 to 35%, because of the covering by clouds, but varies widely locally across the surface depending on the geological and environmental features [21]. For surfaces between the tropics (23.5°N to 23.5°S) the average albedo is 19-38%. At the poles it can be as high as 80% in some areas. This is as a result of the lower Sun angle present at the poles but also the higher presence of fresh snow, ice, and smooth open water- all areas prone to high levels of reflectivity. Today, albedo is a major concern for humans worldwide. Albedo is very useful in the studies dealing with thermal balance in the atmosphere. It is an important input parameter or quantity in evaluating the total insolation on a building or a solar energy collector because, materials with high albedo and emittance attain low temperature when exposed to solar radiation, and therefore reduce transference of heat to their surroundings. It is commonly used in astronomy to describe the reflective properties of planets, satellites, and asteroids [4]. Albedo is an important concept in climatology and astronomy, as well as in calculating reflectivity of surfaces in LEED sustainable rating systems for buildings [12]. 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. Hence, it has a direct effect on Earth's energy budget and, therefore, global temperatures. If the Earth receives more energy from the Sun than it sends back to space, the Earth gets warmer. On the other hand, if the Earth reflects more of the Sun's energy than it absorbs, the Earth gets colder. Some research works on the albedo of the Earth's atmosphere for different location have been carried out. Some of the several reports on surface albedo estimation are from satellite data [17], [19], [20]. Most of the estimated short-wave broadband albedo from satellite data is often corrected for geometric, atmospheric, spectral, topographic, and anisotropic effects in order to obtain accurate results [18], [22]. Working on the solar radiation measurements in Maceio Brazil, [8] recorded the albedo in the rainy and dry seasons in Maceio, Brazil as 0.53 and 0.59 respectively. Babatunde *et al* [3], worked on the simulated reflected shortwave radiation and its characteristic variation at Ilorin, Nigeria. Their results showed among other things that the highest reflectance of 0.64 was recorded at the peak period of cloud activity in August, and the lowest reflectance of 0.36 was obtained in November when it was relatively cloudless and dustless. This work hopes to investigate the atmospheric condition over Makurdi and its effects in reflecting shortwave solar radiation, in order to determine the total solar radiation available in Makurdi. Makurdi, having an area of about 33.16 km^2 is located at latitude $7^0 41'$ N and longitude $8^0 37'$ E. Makurdi is noted for its hotness during the dry season and heavy rainfall during rainy season particularly in the month of August with an average air temperature and rainfall of about 33^oC and 200 mm respectively. This high temperature is attributed to the present of River Benue (the second largest river in Nigeria) which cuts across the middle of the city, and serves as heat reservoir. The high rainfall is equally due to the presence of the river. Also, presence in Makurdi is Dangote Cement Company which is one of the largest cement producing companies in Nigeria, located a few kilometers from the town. The atmospheric condition over Makurdi is largely influence by the cement dusts. The monthly mean daily global solar radiation and air temperature data used in this research were obtained from Nigeria Meteorological (NIMET) Agency, Air Force Based Makurdi, Benue State. The period under focus is from 2000-2010. Short wave solar energy balancing at the edge of the atmosphere can be computed using the relation given by [2] as:

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

Where H_m is the global solar radiation and H_o is the extraterrestrial radiation. $\frac{H_m}{H_o}$ is the ratio of the global to the extraterrestrial radiation and it is the fraction of the extraterrestrial radiation transmitted through the atmosphere to the ground surface. This fraction is called clearness index. H_a is the absorbed solar radiation and $\frac{H_a}{H_o}$ is the fraction absorbed, called the absorption coefficient or absorptance. $\frac{H_r}{H_o}$ is the ratio of the short wave reflected radiation, H_r towards the space to the extraterrestrial radiation, H_o incident on the surface of the Earth at the edge of the Earth's atmosphere. This fraction is called the reflection co-efficient or reflectance. $\frac{H_a}{H_o}$ has been found to be very small compared to the other ratios, hence negligible i.e. $\frac{H_a}{H_o} << 1$ [2]. Equation (1) then becomes:

$$\frac{H_m}{H_o} + \frac{H_r}{H_o} \approx 1 \qquad (2)$$

Therefore, the reflectivity or albedo can be estimated using:

$$\frac{H_r}{H_o} = 1 - \frac{H_m}{H_o} \qquad (3)$$

The extraterrestrial radiation, H_o is the solar radiation received at the top of the Earth's atmosphere from the Sun on a horizontal surface and it is considered as the incident solar radiation. The monthly mean daily extraterrestrial radiation, H_o on a horizontal surface was computed from the equation given by [7]:

$$H_o = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180} W_s \sin\phi \sin\delta + \cos\phi \cos\delta \cos W_s\right) \qquad (4)$$

where W_s is the sunrise, sunset hour angle given by [9] as:

$$W_s = \cos^{-1}(-\tan\phi \tan\delta) \qquad (5)$$

ϕ and δ are the latitude and declination angles respectively. The value of declination was computed from the equation of [6] as:

$$\delta = 23.45 \sin\left[360 \left(\frac{J+284}{365}\right)\right] \qquad (6)$$

where J is the day number of the year (known as the Julian day). E_o is the eccentricity correlation factor of the Earth's orbit given by [14]:

$$E_o = 1 + 0.0033 \left(\frac{360 J}{365}\right) \qquad (7)$$

I_{sc} is the solar constant in $MJm^{-2}day^{-1}$. The value of I_{sc} used in this work was $4.921 MJm^{-2}day^{-1}$.

2. METHOD OF ANALYSIS

The extraterrestrial radiation was calculated using equation (4). By inserting the values of I_{sc} and equations (5), (6) and (7) into equation (4), the monthly mean daily extraterrestrial radiation, H_o on a horizontal surface was computed. This was used as one of the input data in computing the reflection co-efficient using equation (3).

3. RESULTS

The monthly mean annual global solar radiation, clearness index, reflection co-efficient or reflectivity, and temperatures are presented in Table 1. The variation of monthly mean annual global solar radiation, maximum and minimum temperature and reflection co-efficient are presented in Figure 1. Figure 2 shows the comparison between the monthly mean annual clearness index with reflection co-efficient while the variation of monthly mean annual global solar radiation with reflection co-efficient is presented in Figure 3.

TABLE 1: MONTHLY MEAN ANNUAL SOLAR RADIATION, CLEARNESS INDEX, REFLECTION CO-EFFICIENT AND TEMPERATURES FROM 2000 TO 2010.

Months	H_m ($MJm^{-2}day^{-1}$)	H_r ($MJm^{-2}day^{-1}$)	H_O ($MJm^{-2}day^{-1}$)	$\frac{H_m}{H_O}$	Hr/Ho	$T_{max.}$ (°c)	$T_{min.}$ (°c
Jan	14.05455	19.2001	33.25465	0.42263	0.577366	35.08182	20.39091
Feb	15.61818	19.95391	35.57208	0.43906	0.560943	37.33636	23.00000
Mar	15.55455	21.89193	37.44649	0.41538	0.584619	38.04545	24.84545
Apr	14.79182	23.29302	38.08482	0.38839	0.611609	35.97273	25.58182
May	14.35455	22.91593	37.27047	0.38515	0.614855	33.33636	24.22727
Jun	13.65455	22.80787	36.46243	0.37448	0.625517	31.21818	23.13636
Jul	12.00909	25.33924	37.34833	0.32154	0.678457	30.54545	23.52727
Aug	11.35455	26.13541	37.48995	0.30287	0.697131	30.05455	23.14545
Sep	13.06364	24.50231	37.56594	0.34775	0.652248	30.83636	22.85455
Oct	14.86364	21.15124	36.01486	0.41271	0.587292	32.08182	23.00909
Nov	15.69091	17.97473	33.66565	0.46608	0.533919	34.12727	22.06364
Dec	15.26364	17.11538	32.37901	0.47141	0.528595	35.10909	17.46364

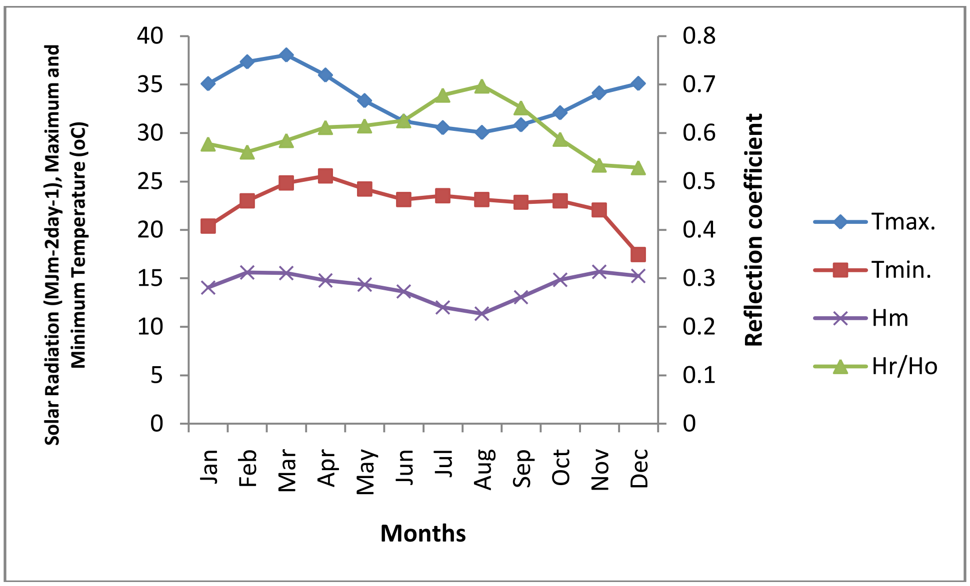

Fig. 1 Variation of monthly mean annual global solar radiation, maximum and minimum temperature and reflection co-efficient.

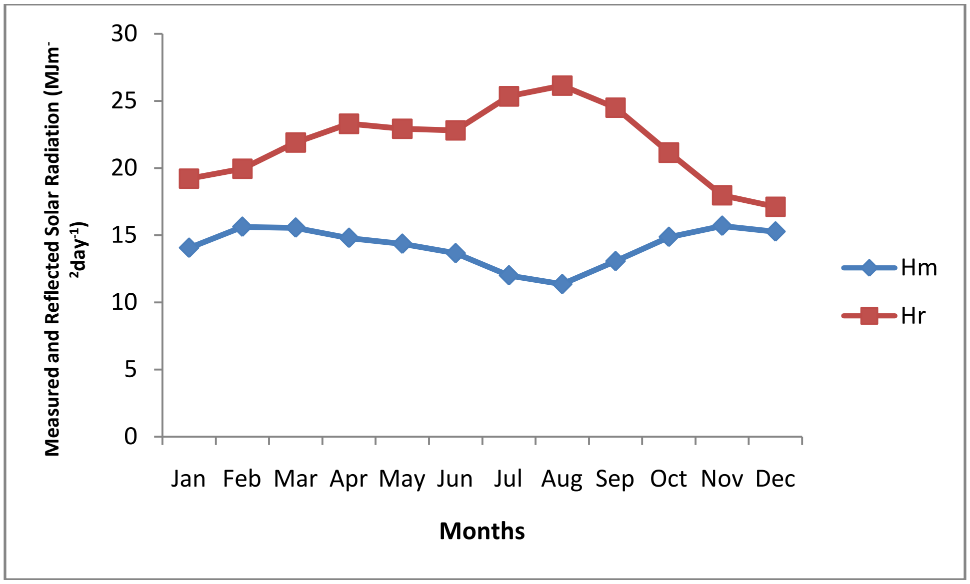

Fig. 2 Comparison between monthly mean annual clearness index with reflection co-efficient

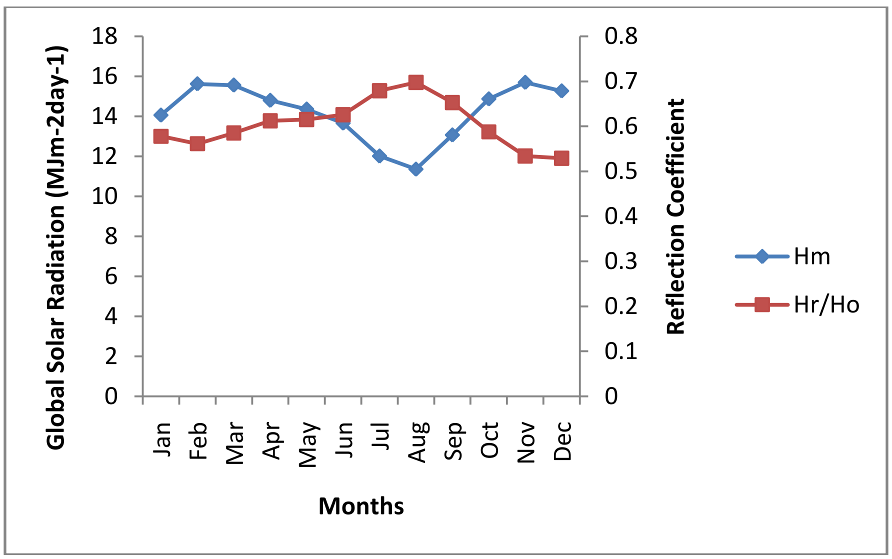

Fig. 3 Variation of monthly mean annual global solar radiation with reflection co-efficient

4. DISCUSSION

From Figure 1, it could be observed that the global solar radiation and the minimum and maximum temperature exhibit the same trends, but varies in opposite direction with the reflectance. This implies that the Earth's surface temperature increases as the global solar radiation reaching the Earth's surface increases. This is because air temperature is the reflection of both the duration and intensity of the solar radiation incident on a given location [5] cited in [11]. This variation of global solar radiation with the air surface temperature was equally observed by [10], [11]. On the other hand, Earth's surface temperature decreases as the albedo increases because most of the solar radiations are reflected back into space. This inverse variation of Earth's surface temperature with albedo is given in the expression of [16] cited in [3] as:

$$T = \left[(1-a)\, {}^{S}\!/_{4Q}\right]^{1/4} \qquad (8)$$

Where a is the albedo, S is the solar radiation constant and Q is the universal Stefan-Boltzman constant. It indicates that temperature, T decreases as albedo increases. From the graph of the comparison between monthly mean annual clearness index, H_m/H_o with the reflection co-efficient, H_r/H_o (Figure 2), It could be observed that the lowest value (0.302) of H_m/H_o corresponds to the highest value (0.697) of H_r/H_o in the month of August. Again, in the month of December, a very high value (0.471) of H_m/H_o corresponds to a very low value (0.528) of H_r/H_o. The overall results depict direct opposite relationship between the clearness index and reflectance, especially in the months between June and October. It implies that apart from the rainy season period, the sky is clear almost through the year. A high value of reflectance was observed in February, though a relatively cloudless month. This indicates that reflection of radiation at that period was by the dust particles in the atmosphere. Hence, the atmosphere in February during the period under study was heavily laden with harmattan dusts. Figure 3 is the variation of monthly mean annual global solar radiation with reflection co-efficient. It is interesting to note that high reflection co-efficient was observed from July to September with the highest (0.697) in August. This corresponds to the low solar radiation observed in the same period with the lowest (11.35 $MJm^{-2}day^{-1}$) in the month of August. The highest reflection co-efficient with the corresponding lowest solar radiation observed in August was probably due to the rain bearing clouds which pervaded the sky in the rainy season. It implies that more radiation was reflected back into space than received on the Earth's surface, hence, high brightness of the Earth's surface toward the space and low surface temperature of the Earth. On the other hand, low reflection co-efficient was observed between October-December and February-March with the lowest in December (0.5). High solar radiation was observed in this period with the highest solar radiation (15.69 $MJm^{-2}day^{-1}$) in November (probably due to hamarttan dust which scattered the solar radiation at that time). It implies that the global solar radiation received on the Earth's surface was more than the reflected radiation lost into space. It also shows that the sky was relatively cloudless, albedo was relatively low and more radiation was available to the solar energy devices. April-June is a transition period from dry to rainy seasons and the variation of H_r/H_o with H_m/H_o were very small. The albedo value obtained in this work ranged between 0.5 and 0.7. This value is very close to the albedo (0.4 and 0.6) obtained using the same equation by [3] in Ilorin (8^0 30′ N, 4^0 34′ E) which is in almost the same latitudinal location with Makurdi. The result also corresponds to the albedo of 0.47 and 0.41 obtained by [8] in Maceio, Brazil (9^0 40′ S, 35^0 42′ W) of coordinates almost similar to that of Makurdi (7^0 41′ N, 8^0 37′ E).

5. CONCLUSION

The surface albedo for Makurdi simulated from this work for the period under study ranged between 0.5 and 0.7. 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 result is also within the range of albedo values obtained for different locations by other researchers. The atmospheric conditions at Makurdi for the period under review vary from being cloudy, heavily laden with harmattan dust, cloudless (clear) to dustless (clean). Hence, the atmospheric factors influencing the reflection and scattering of solar radiation are clouds and particles with clouds being the most. The highest albedo was observed in August while the lowest was recorded in November. It shows that solar radiation is available almost through the year in Makurdi. Therefore, Practitioner of solar energy technology can use these abundant natural resources as alternative energy resources in the state.

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