SURVEY OF THE REFLECTIVITY OF THE EARTH'S ATMOSPHERE OVER SOME SELECTED CITIES IN NIGERIA

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ABSTRACT: *Solar radiation is rapidly gaining ground as a supplement to the non renewable sources of energy, which have a finite supply. But the amount of solar radiation reaching the Earth's surface depends on the climatic and atmospheric conditions of the locations. This work evaluates the temporal and spatial variability of the reflectivity of the Earth's atmosphere over Ibadan, Enugu, Sokoto and Kano, in order to access the effect of the atmospheric conditions on solar radiation in the areas. The data used for this study were obtained from the International Institute of Tropical Agriculture, Ibadan (1980-2010). The model for shortwave solar energy balance at the edge of the Earth's atmosphere was adopted in this work. The results show that seasonally, the reflectivity obtained in this work ranged from 0.52 - 0.64, 0.46-0.55, 0.38-0.53, and 0.41-0.57 for Oyo, Enugu, Sokoto and Kano respectively. Annually, the reflectivity obtained ranged from 0.48-0.65, 0.36-0.64, 0.22-0.50 and 0.36-0.60 for Ibadan, Enugu, Sokoto and Kano respectively. This result may be due to the influence of the dry, dusty tropical-continental air mass and the warm, tropical-maritime air mass which control the atmospheric conditions of Nigeria. The atmospheric conditions of the selected cities for the period under review vary from being cloudy, heavily laden with harmattan dust, cloudless (clear) to dustless (clean), hence there is high prospect of solar technology in the areas. This information is useful to solar energy technology, environmental engineers and for climatic modeling. The results obtained were compared with the results of other places having almost latitudinal location and co-ordinates similar to the selected cities.*

KEYWORDS: Reflectivity, Renewable energy, Earth's atmosphere, Solar radiation, Nigeria

INTRODUCTION

With the rapid depletion of fossil fuel reserves and its effects on the environment and climate, modern technologies have being developed towards renewable and environmentally friendly alternative energy resources to cope with the ever increasing energy demand. Among the renewable resources, only solar energy has the greatest potentiality, availability and is free from environmental hazard (Burari and Sambo, 2001).

The Sun provides a natural influence on the Earth's atmosphere and climate (Austin *et al.*, 1999). It is the dominant direct energy input into the terrestrial ecosystem; and it affects all physical, chemical, and biological processes. We can capture and convert solar radiation into useful forms of energy, such as heat and electricity, using a variety of technologies. Solar radiation is rapidly gaining ground as a supplement to the nonrenewable sources of energy, which have a finite supply. The technical feasibility and economical operation of these technologies at a specific location depend on the available solar radiation.

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

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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 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 (Babatunde and Aro, 1990; Babatunde *et al*., 2005). The fraction of the incident solar radiation that is reflected and scattered back into space is called albedo (reflectance or reflectivity of a surface). Albedo or reflection co-efficient is the reflecting power of a 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.

Like solar radiation which varies across the globe in intensity from one geographic location to another depending upon the latitude, season, time of day and atmospheric conditions, albedo also 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 (Liou, 1980). The angle of the Sun’s ray also affect albedo because the lower the Sun’s angle, the higher the albedo (Mathew, 1984).

The overall reflectance of sunlight from Earth and its atmosphere is a fundamental parameter for climate studies (Siti and Andy, 2014). 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 (Bond, 2010). 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.

Nigeria is located in western Africa on the Gulf of Guinea. It lies between latitudes 4^0 and 14^0N, and longitudes 2^0 and 15^0E. Like the rest of West Africa, the climate is controlled largely by the two dominant air masses. These are the dry, dusty, tropical-continental air mass (which originates from the Sahara region), and the warm, tropical-maritime air mass (which originates from the Atlantic Ocean). The influence of both air masses is determined largely by the movement of the Inter-Tropical Convergence Zone (ITCZ), a zone representing the surface demarcation between the two air masses. The interplay of these two air masses gives rise to two distinct seasons in Nigeria. The wet season is associated with the tropical maritime air mass, while the dry season is a product of the tropical continental air mass (Ekpoh and Ekpenyong, 2011).

Literature/Theoretical underpinning

According to Babatunde (2003), shortwave solar energy balancing at the edge of the Earth’s atmosphere can be computed using the relation:

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

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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 shortwave 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. $\frac{H_a}{H_o} << 1$ (Babatunde, 2003). 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 (Duffie and Beckman, 1991):

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

where W_s is the sunrise, sunset hour angle given by (Fayadh and Ghazi. 1983) as:

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

$\emptyset$ and δ are the latitude and declination angles respectively. The value of declination was computed from the equation of (Cooper, 1969) 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:

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

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

Several research works have been carried out on the estimation of albedo of the Earth's atmosphere (Palle´ *et al*., 2009; 2004; Babatunde, *et al*., 2005; Audu and Isikwue, 2014); and albedo of different objects on the Earth's surface (Siti and Andy, 2014). Most researchers used satellite data (Nunez, 2006; Robert and Catherine. 1973: Saunders. 1990) while others used data from meteorological stations (Babatunde, *et al*., 2005; Audu, *et al*., 2014). However, none

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of these works have investigated the albedo of the Earth's atmosphere over the selected cities considered in this work. Hence, this work hopes to survey the reflectivity of the Earth's atmosphere over Oyo, Enugu, Sokoto and Kano, due to the influence of tropical- maritime air mass and tropical-continental air mass on the climate and atmospheric conditions of Nigeria; making the sky to be cloudy and heavily laden with harmattan dust.

METHODOLOGY

The monthly mean daily global solar radiation data used in this research was obtained from International Institute of Tropical Agriculture Ibadan, Nigeria. The period under focus is from 1980-2010. 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).

Results/Finding

The variation of daily mean monthly reflectivity in Oyo, Enugu, Sokoto and Kano are presented in Figures 1 – 4 respectively, while the temporal variations of annual reflectivity in Ibadan, Enugu, Sokoto and Kano are presented in Figures 5 – 8 respectively. Table 1 shows the maximum and minimum values of reflectivity in these cities from 1980 – 2010.

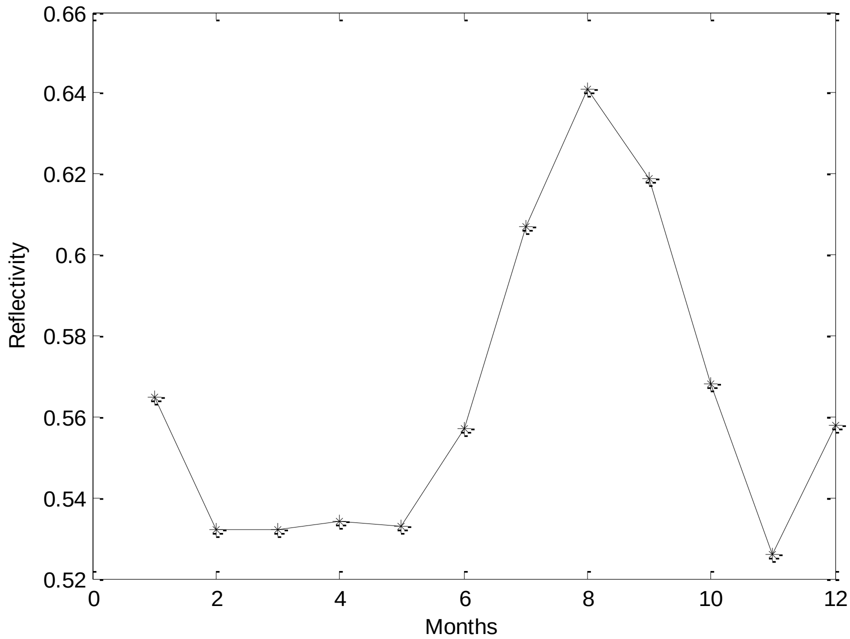

Figure 1: Variation of daily mean monthly reflectivity in Ibadan

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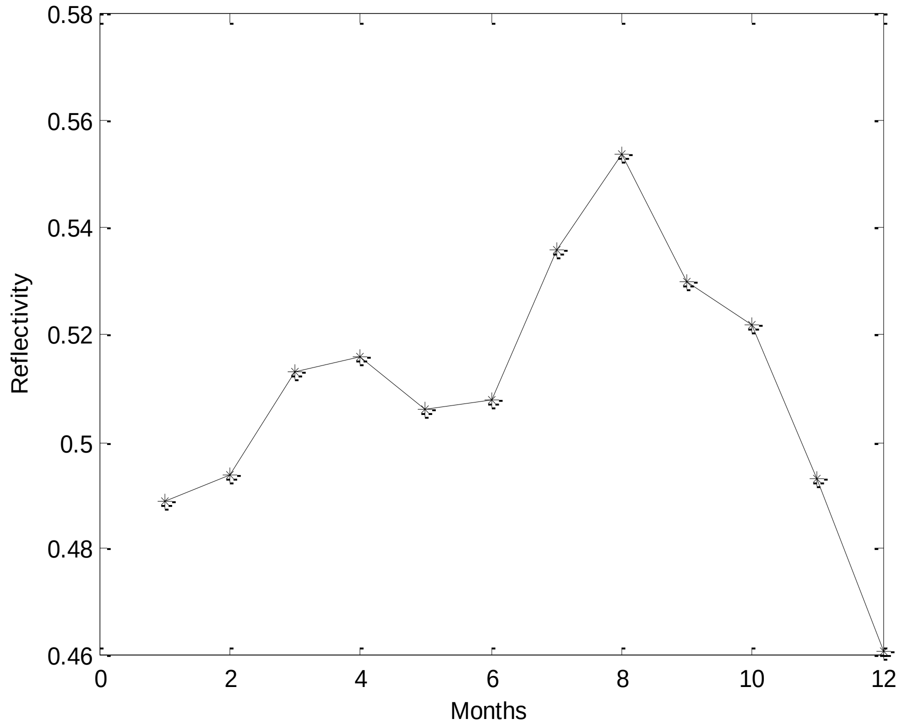

Figure 2: Variation of daily mean monthly reflectivity in Enugu

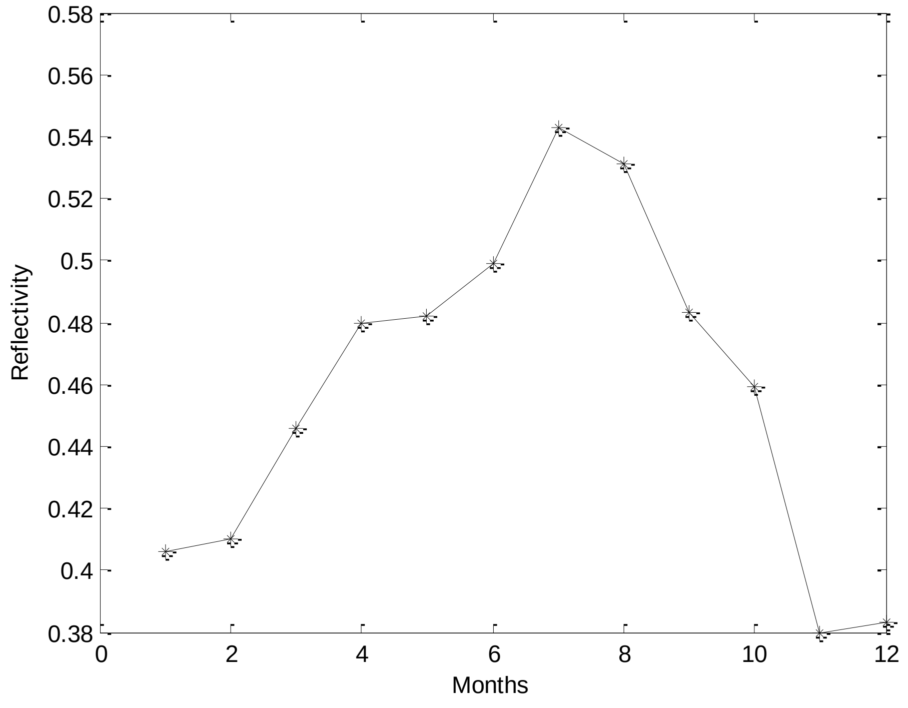

Figure 3: Variation of daily mean monthly reflectivity in Sokoto

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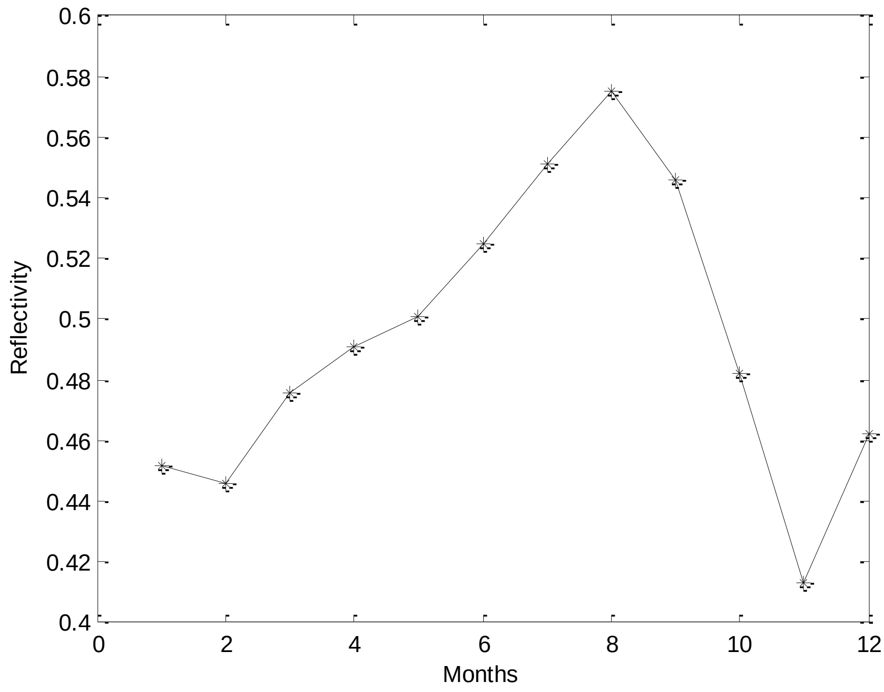

Figure 4: Variation of daily mean monthly reflectivity in Kano

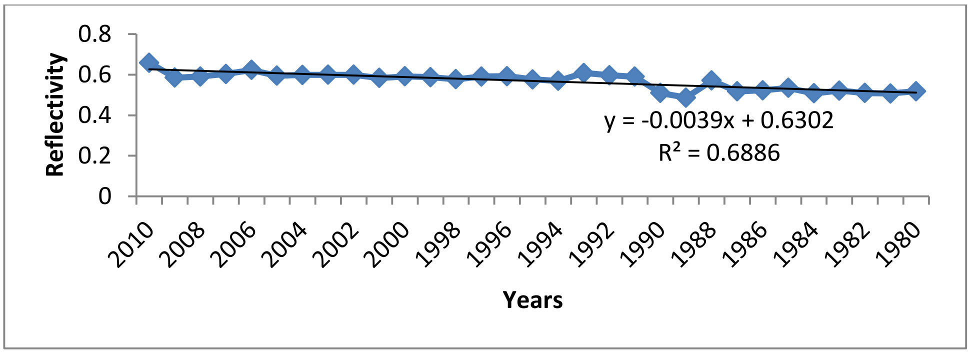

Figure 5: Temporal variation of monthly mean annual reflectivity in Ibadan

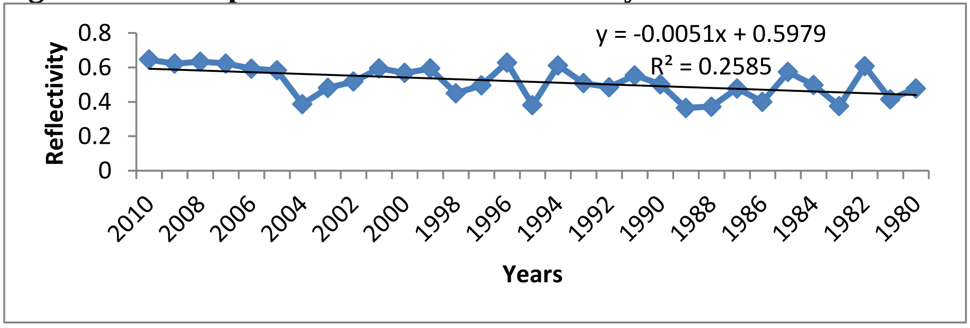

Figure 6: Temporal variation of monthly mean annual reflectivity in Enugu

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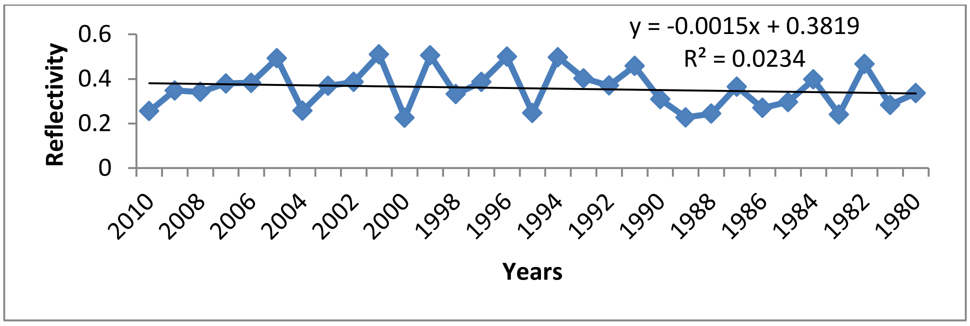

Figure 7: Temporal variation of monthly mean annual reflectivity in Sokoto

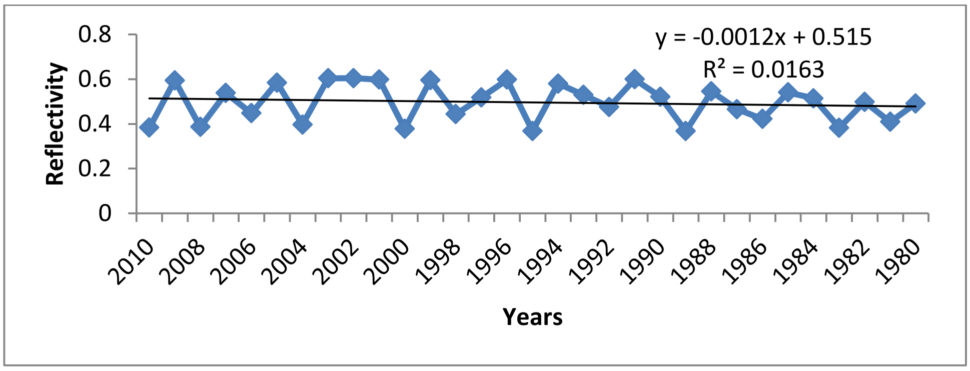

Figure 8: Temporal variation of monthly mean annual reflectivity in Kano

Table 1: Maximum and minimum values of reflectivity from 1980 – 2010

Location	Reflectivity (or albedo)(%)								
	Monthly				Annually				
	Max.	Month	Min.	Month	Max.	Year	Min.	Year	Average
Ibadan	64.10	Aug.	52.6	Nov.	65.8	2010	48.6	1989	56.8
Enugu	55.4	Aug.	46.1	Dec.	64.5	2010	36.4	1989	52.8
Sokoto	53.1	Aug.	38.0	Nov.	50.9	2001	22.6	2000	35.7
Kano	57.5	Aug.	41.3	Nov.	60.4	2002	36.7	1987	49.6

DISCUSSION

It could be observed from Fig. 1, that the reflectivity decreases from January to February and was relatively constant until May. It then increases rapidly to its peak (0.641) in August; the peak of cloud activities and decreases steadily again to the minimum value (0.526) in November; the onset of dry season, and thereafter increase to December. The variations of

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albedo observed from February to May (the transition period from dry to rainy seasons and the onset of rainy season when the sky is less cloudy), may be due to its location in the tropical rain forest, with dry season lasting for few months, thereby making the sky to be relatively clear with little harmattan dust.

The high values of Hr/Ho in rainy season particularly in August (the wettest month), were probably due to the rain bearing clouds which pervaded the sky. It implies that more solar radiation will be 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, the low values of Hr/Ho in dry season particularly at the onset of dry season may be due to the fact that the sky was cloudless with little hamarttan dust, hence low albedo. It implies that the global solar radiation received on the Earth's surface will be 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.

From Figure 2, the reflectivity increases steadily from January until April and then decreases to May. It was relatively constant from May to June, which is the transition period from dry to rainy seasons when the atmosphere is free from harmattan dust. It then increases rapidly to its peak (0.554) in August and decreases steadily again to the minimum value (0.461) in December.

It could be observed from Figure 3, that the reflectivity increases steadily from January until May and was relatively constant from May to June; the transition period from dry to rainy seasons. It then increases rapidly to its peak (0.531) in August; the wettest months, and decreases steadily again to the minimum value (0.380) in November; the onset of dry season, and thereafter increase to December.

It could be observed from Figure 4 that the reflectivity decreases from January to February and then increases steadily to its peak (0.575) in August and decreases steadily again to the minimum value (0.413) in November and thereafter increase to December. It is interesting to note that transition period was not well pronounced in Kano as observed in other cities. This may be due to the fact that the sky was heavily laden with harmattan dusts because of its location in the Sahel savannah zone about 840 kilometers from the edge of the Sahara desert.

From Figure 5, the general mean of Hr/Ho in Oyo within the period under investigation is 0.568. The values of Hr/Ho in some years are closer to this tri-decadal mean value, while they were anomalous values of Hr/Ho in other years which were either higher or lower than the mean. The highest (0.658) and lowest (0.486) Hr/Ho in the period under study were obtained in 2010 and 1989 respectively.

It could be observed from the variational trend of annual mean reflectivity (Fig. 6) that the gradient of the variation is negative, implying a decrease in the variation of Hr/Ho in the area within the period under study. However, the percentage of this variation is small (R^2=25.8%). These variations may be due to the location of Ibadan in the Tropical rain forest. The general mean obtained for Hr/Ho is 0.528, with the maximum and minimum values of 0.645 and 0.364 occurring in 2010 and 1989 respectively.

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The temporal variation of monthly mean annual reflectivity in Sokoto as presented in Fig. 7, shows that the gradient of the variation is negative, implying a decrease in the variation of Hr/Ho in the area within the period under study. However, the percentage of this variation is small (R^2=2.3%). The general mean obtained for Hr/Ho is 0.357, while the highest (0.509) and the lowest (0.226) Hr/Ho were obtained in 2001 and 2000 respectively (Table 1).

From the variational trend of annual mean Hr/Ho (Fig. 8), it could be observed that the gradient of this variation is negative, implying a decrease in the variation of Hr/Ho in the area within the period under study. The highest and lowest values of 0.604 and 0.367 of Hr/Ho were obtained in 2002 and 1989 respectively while the general mean obtained was 0.496.

The general observation from the variation of daily mean monthly reflectivity in Ibadan, Enugu, Sokoto and Kano (Figs. 1- 4 respectively), shows that Hr/Ho is very high in the rainy season with its highest value in August and low in the dry season with its lowest value at the onset of dry season and relatively low at the transition from dry to rainy seasons.

It is interesting to note that in the period under study, about 52% - 64%, 46%-55%, 38%-53% and 41%-57% of solar radiations in Ibadan, Enugu, Sokoto and Kano are reflected into space during dry and rainy seasons respectively. This may be due to the influence of the dry, dusty, tropical-continental air mass and the warm, tropical-maritime air mass which control the atmospheric conditions of Nigeria.

The albedo value obtained in this work ranged from 0.52 - 0.64, 0.46-0.55, 0.38-0.53, and 0.41-0.57 for Ibadan, Enugu, Sokoto and Kano repectively. These values are not too far from the values of 0.64-0.36 obtained by Babatunde *et al.*, (2005) in Ilorin (8^0 30′ N, 4^0 34′ E), 0.41-0.47 obtained by De sonsa *et al.*, (2005) in Maceio, Brazil (9^0 40′ S, 35^0 42′ W), 0.5-0.7 obtained by Audu and Isikwue (2014) for Makurdi (7^0 41′ N, 8^0 37′ E). However, the little differences in the values may be due to latitudinal and physiological differences.

CONCLUSION

- Seasonally, the reflectivity values obtained in this work ranged from 0.52-0.64, 0.46-0.55, 0.38-0.53, and 0.41-0.57 for Ibadan, Enugu, Sokoto and Kano repectively.
- Annually, the reflectivity obtained ranged from 48-65%, 36-64%, 22-50% and 36-60% for Ibadan, Enugu, Sokoto and Kano repectively.
- This may be due to the influence of the dry, dusty tropical- continental air mass and the warm, tropical- maritime air mass which control the atmospheric conditions of Nigeria.
- The results obtained were compared with the results of other places having almost latitudinal location and co-ordinates similar to the selected cities.
- The atmospheric conditions of the cities for the period under review vary from being cloudy, heavily laden with harmattan dust, cloudless (clear) to dustless (clean).
- This information is useful to solar energy technology, environmental engineers and for climatic modeling.

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