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New Multivariate Models for the Estimation of Earth's Albedo and Its Variation with Meteorological Parameters Over Kano, Nigeria

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Abstract

The study of what happens to sunlight as it goes through the atmosphere is vital to many fields of science because over time, reflection, scattering, and absorption in the atmosphere have changed the amount of solar radiation that reaches the Earth's surface. This study examined the variation in albedo over Kano, situated in the Sahelian climatic zone of Nigeria. The study's data, which covered the years 1984–2022, totaled thirty-nine, was obtained from the National Aeronautics and Space Administration (NASA). Utilizing monthly average daily measured meteorological data on global solar radiation, wind speed, mean temperature, surface pressure, and relative humidity, eleven models of three categories based on two, three, and four variable regression models were developed. Five validation indicators were used to verify the regression models: the t-test, coefficient of determination (R^2), mean percentage error (MPE), root mean square error (RMSE), and mean bias error (MBE). The developed models that were considered most appropriate for estimating surface albedo were ranked; the three-variable regression model ALB7, which included the wind speed, relative humidity, and mean temperature, outperformed the previously employed generalized method from literature in estimating surface albedo over Kano. The variation of measured albedo with meteorological parameters depicts a direct relationship for clearness index and wind speed; an inverse relationship was observed for surface pressure. Mean temperature and surface pressure exhibit an inverse relationship during the wet season and vice versa for the dry season.

Keywords: Albedo, global solar radiation, metrological parameters, maximum wavelength, NASA

INTRODUCTION

The Sun is the principal direct energy source for the terrestrial ecosystem, influencing every physical, chemical, and biological process (Madugu et al., 2010). Out of all the renewable energy sources, solar energy is the most promising, readily available, and environmentally safe (Audu *et al.*, 2014). Since the amount of solar radiation that reaches the Earth's surface varies on the local climate, understanding what happens to sunlight as it travels through the atmosphere is essential to many fields of study and general knowledge (Audu *et al.*, 2014). Because of atmospheric absorption, scattering, and reflection, the amount of solar energy that reaches the Earth's surface has changed over time. The fraction of incident solar energy reflected and scattered back into space is known as albedo (Akpootu and Iliyasu, 2017). The

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albedo, commonly known as the reflection co-efficient, is a surface's reflectance or reflectivity. The average overall albedo of the Earth, or planetary albedo, is approximately 0.3. This proportion of incoming radiation is reflected into space. Our earth absorbs the remaining 0.7 of the incoming solar radiation (Babatunde *et al.*, 2005).

The Earth's albedo influences the quantity of sunlight that the planet absorbs. It is critical to the Earth's surface energy balance because it determines the rate at which incident solar radiation is absorbed. As a result, it has a direct impact on the Earth's energy budget, and thus global temperatures. If the Earth receives more energy from the Sun than it emits back into space, it warms up. On the other hand, if the Earth reflects more solar radiation than it absorbs, it becomes colder (Audu *et al.*, 2014). Some studies on the albedo of the Earth's atmosphere have been conducted in various areas (Akpootu *et al.* 2023a, b; Akpootu *et al.* 2020; Akpootu and Iliyasu, 2017; Audu and Isikwue 2014; Audu *et al.*, 2014; Babatunde *et al.*, 2005; De sonsa *et al.*, 2005). The majority of short-wave broadband albedo estimates are based on satellite data and are frequently modified for geometric, atmospheric, spectral, topographic, and anisotropic factors to ensure reliable results (Zhao *et al.*, 2000; Pinty *et al.*, 2000). Although local weather patterns and prevailing atmospheric factors might occasionally inspire the development of new models or the modification of current ones, most models generally show reasonable accuracy (Psiloglou and Kambezidis, 2009).

However, some of these works has estimated albedo over the atmosphere of Kano, Nigeria, utilizing the generalize approach postulated by Babatunde (2003). Hence, this work hopes to investigate the following: (i) the variation of Earth's surface albedo with meteorological parameters (wind speed, surface pressure, relative humidity, mean temperature and global solar radiation); (ii) the correlation of the generalize approach from literature and the developed new multivariate regression models developed for this study, with the measured albedo for Kano; and (iii) to utilize five validation indices of Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-test and coefficient of determination (R^2) to examine the newly developed multivariate regression model and the calculated albedo (existing model from literature, previously used for the study location), so as to checkmate their accuracy level with the measured albedo values and present the best fit model for estimating Earth's surface albedo over Kano.

SOURCES OF DATA AND METHOD OF ANALYSIS

This study used monthly average climatic data for thirty-nine (39) years, from 1984 to 2022, which included observations of surface pressure, relative humidity, global solar radiation, wind speed, mean temperatures, and measured albedo. The data for Kano were collected from the National Aeronautics and Space Administration (NASA) web site. Over the course of a month, the average daily data can be used to estimate the mean daily extraterrestrial radiation on a horizontal surface, denoted by H_o and expressed in $MJm^{-2}day^{-1}$. Every day of the month can have this done (Iqbal, 1983; Zekai, 2008; Saidur *et al.*, 2009). This analysis is based on equations by Iqbal (1983) and Zekai (2008), which were adopted by Akpootu and Abdullahi (2022).

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

where I_{SC} = 1367 Wm^{-2}

There are four parameters in the equation used to calculate H_o: I_{sc}, ϕ, δ, and ωs. These stand for the solar constant, solar declination, location latitude, and mean sunrise hour angle, in that order. n, or the total number of days in a year from January 1st to December 31st, is also considered in this computation. Iqbal (1983) and Zekai (2008) are the methods used by

Akpootu and Abdullahi (2022) to compute the solar declination and mean sunrise hour angle. This can be computed from:

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

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

The expression from Babatunde (2003), adapted by Akpootu *et al.* (2023a, b), would be used to calculate the shortwave solar energy balance at the edge of the Earth's atmosphere. It is as follows:

$$\frac{H_m}{H_o} + \frac{H_a}{H_o} + \frac{H_r}{H_o} = 1 \tag{4}$$

While H_o represents the clearness index, the ratio H_m/H_o indicates the percentage of extraterrestrial radiation that is transmitted from the atmosphere to the ground surface (Babatunde and Aro, 1995; Udo 2000). where H_o denotes extraterrestrial radiation ($MJm^{-2}day^{-1}$) and H_m denotes the measured global solar radiation ($MJm^{-2}day^{-1}$). Babatunde (2003) states that H_a represents solar energy that has been absorbed, $\frac{H_r}{H_o}$ is the percentage of solar radiation that has been reflected into space, and H_r represents shortwave reflected radiation. The ratio of $\frac{H_a}{H_o}$, which indicates the percentage of solar radiation absorbed, is the absorption co-efficient, also referred to as absorbance. Babatunde (2003) states that the ratio $\frac{H_a}{H_o}$ can be disregarded because it is negligible in relation to the other ratios in equation (4) ($\frac{H_a}{H_o} \geq 1$). Consequently, equation (4) becomes

$$\frac{H_m}{H_o} + \frac{H_r}{H_o} \approx 1 \tag{5}$$

The following expression from equation (5) was used to measure the reflectivity, or albedo (Babatunde, 2003).

$$\frac{H_r}{H_o} = 1 - \frac{H_m}{H_o} \tag{6}$$

Developed Albedo Models

In this work, regression models with two, three, and four variables were utilized as the approach for predicting Earth's surface albedo. Four meteorological factors (WS, T_{mean}, RH, and PS) were utilized as independent variables, and one dependent variable (observed albedo, or Alb_{mea}) was employed in multiple linear regression to make sure no important parameter was overlooked. Monthly average mean temperature (°C), monthly average relative humidity (%), monthly average daily air pressure (hPa), and monthly average wind speed (ms^{-1}) are the meteorological parameters.

The suggested multivariate regression models with two variables are:

$$Alb_{mea} = a + bWS + cRH \tag{7}$$

$$Alb_{mea} = a + bWS + cT_{mean} \tag{8}$$

$$Alb_{mea} = a + bWS + cPS \tag{9}$$

$$Alb_{mea} = a + bRH + cT_{mean} \tag{10}$$

$$Alb_{mea} = a + bRH + cPS \tag{11}$$

$$Alb_{mea} = a + bT_{mean} + cPS \tag{12}$$

The suggested three variables multivariate regression models are:

$$Alb_{mea} = a + bWS + cRH + dT_{mean} \tag{13}$$

$$Alb_{mea} = a + bWS + cT_{mean} + dPS \tag{14}$$

$$Alb_{mea} = a + bWS + cPS + dRH \tag{15}$$

$$Alb_{mea} = a + bRH + cT_{mean} + dPS \tag{16}$$

The suggested four variables multivariate regression model is:

$$Alb_{mea} = a + bWS + cRH + dT_{mean} + ePS \tag{17}$$

Where T_{mean} is the mean temperature, PS is the surface pressure, WS is the wind speed, Alb_{mea} is the measured albedo, RH is the relative humidity, a, b, c, d and e are empirical coefficients.

2.2 Accuracy of the Models

The following measures were employed to statistically test each model's performance: t-test, coefficient of determination (R^2), mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE). El-Sebaii and Trabea's (2005) method, as reported by Akpootu and Mustapha (2015) and Olomiyesan *et al.* (2021), was used to compute MBE, RMSE, and MPE. The following equations are therefore presented:

$$RMSE = \left(\frac{1}{n}\sum_{i=1}^{n}\left(Alb_{i,cal} - Alb_{i,mea}\right)^2\right)^{\frac{1}{2}} \tag{18}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(Alb_{i,cal} - Alb_{i,mea}\right) \tag{19}$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Alb_{i,mea} - A_{i,cal}}{Alb_{i,mea}}\right) \times 100 \tag{20}$$

According to Bevington (1969), mean values can be assessed using the t-test and a random variable with t and $n-1$ degrees of freedom. The t-test is a non-dimensional parameter that is deemed significant at 95% if its value is < 2.20 and at 99% if it is < 3.12, according to Akpootu *et al.* (2019a, b), Akpootu *et al.* (2023a, b). It is articulable as follows:

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2}\right]^{\frac{1}{2}} \tag{21}$$

The albedo's ith value is denoted by the subscript 'i' in equations 22, 23, and 24, whereas the entire amount of albedo data is denoted by 'n', "cal" and "mea" subscripts stand for the calculated and measured albedo values, respectively. Almorox *et al.* (2005) and Chen *et al.* (2004) suggest that a mean percentage error (MPE) and root mean square error (RMSE) of ±10% be kept to a minimum, and that a mean bias error (MBE) of zero is acceptable. Consequently, the model's performance improves when the values of MBE, RMSE, MPE, and t-test drop; positive values for MBE and MPE indicate an average degree of overestimation in the computed values, while negative values indicate underestimate. According to Akpootu and Iliyasu (2015a, b); Akpootu *et al.* (2019c, d), the coefficient of determination (R^2) should be closer to a value of 1, preferably approaching 100%, in order to produce a more precise and reliable data modeling outcome. The presence of a substantial regression between the observed/measured and anticipated/predicted values suggests that the model is reliable and suitable.

Variation of Albedo with Clearness Index and Meteorological Parameters

The variation of albedo and clearness index with meteorological parameters (i.e wind speed, surface pressure, mean temperature, relative humidity and global solar radiation) was investigated for the study area and their corresponding outcomes are presented in section 3.2.

RESULTS

The variation of monthly average daily measured albedo, clearness index (H_m/H_o) and measured albedo; and variation of measured albedo with global solar radiation are presented in Figure 1a to 1c. The trend in variation of monthly mean meteorological parameters with the measured albedo are shown in figure 2a to 2d; The variations of monthly averaged daily measured albedo with the developed two-variable, three-variable and four variable models are presented in figure 3a to 3c; The variation of Monthly averaged daily measured albedo with the generalize equation (Calculated Albedo) is presented in Figure 4; The comparison between the measured albedo, calculated albedo (existing model), best ranked developed two, three and four multivariate regression models are presented in Figure 4. The results for the statistical analysis and ranking for the two, three, four variables and the calculated albedo were presented in Table 1 to Table 5.

Variation of Albedo with Clearness Index and Meteorological Parameters

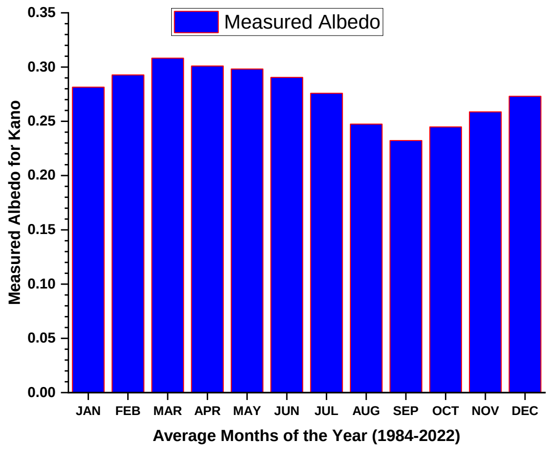

Figure 1a: Monthly average daily measured albedo for Kano

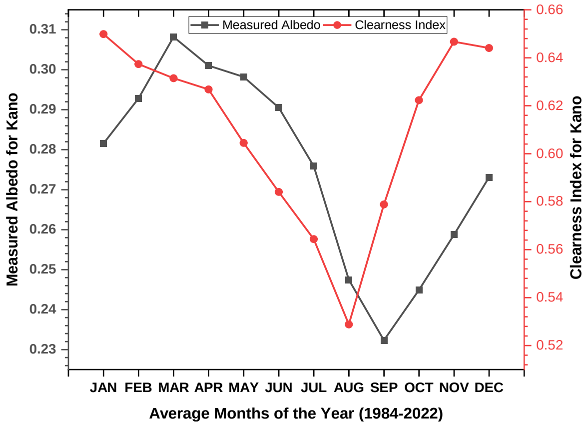

Figure1b: Analysis of the variation of measured albedo and clearness index (H_m/H_o) for Kano

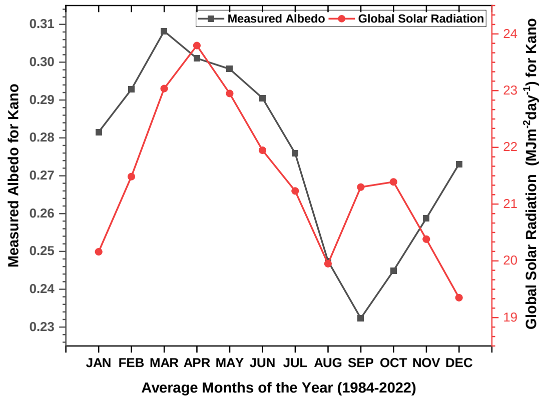

Figure 1c: Analysis of the variation of measured albedo with global solar radiation ($MJm^{-2}day^{-1}$) for Kano

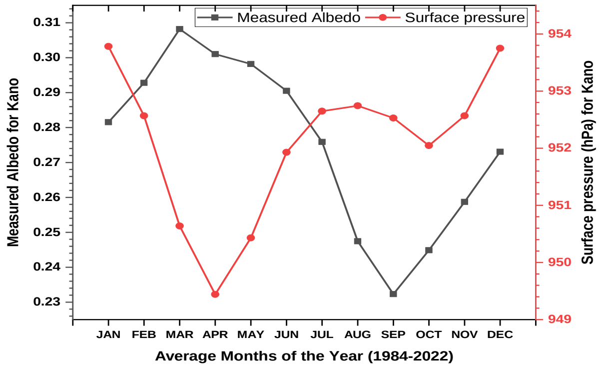

Figure 2a: Variation of monthly mean surface pressure (hPa) with measured albedo for Kano

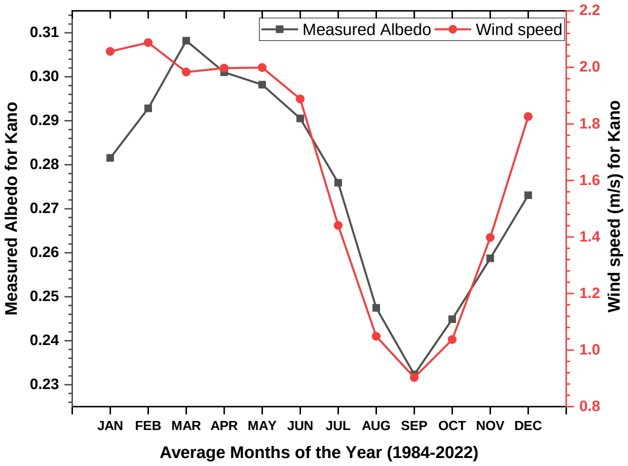

Figure 2b: Variation of monthly wind speed (m/s) with measured albedo for Kano

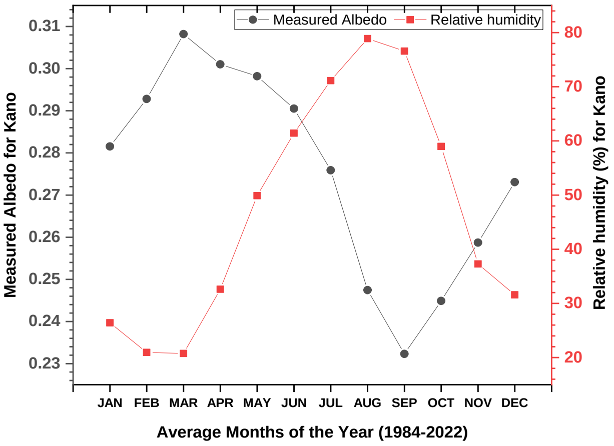

Figure 2c: Variation of monthly relative humidity (%) with measured albedo for Kano

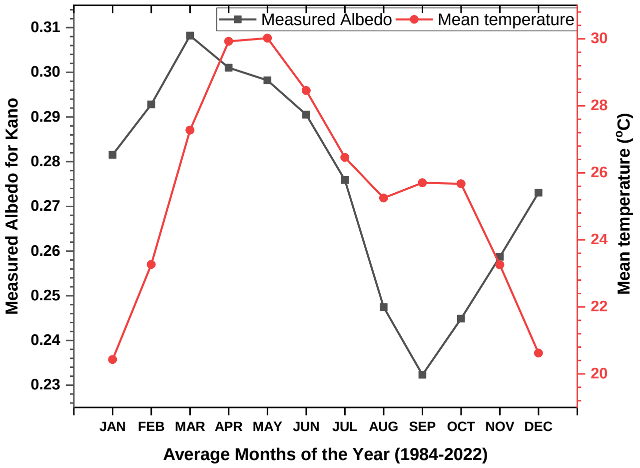

Figure 2di: Variation of monthly measured mean temperature (°C) with measured albedo for Kano

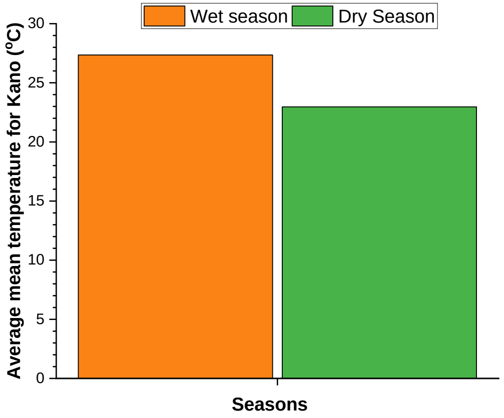

Figure 2dii: Variation of average mean temperature for wet and dry season for Kano

3.3 Correlation of Measured Albedo with Multivariate Models and Generalized Equation

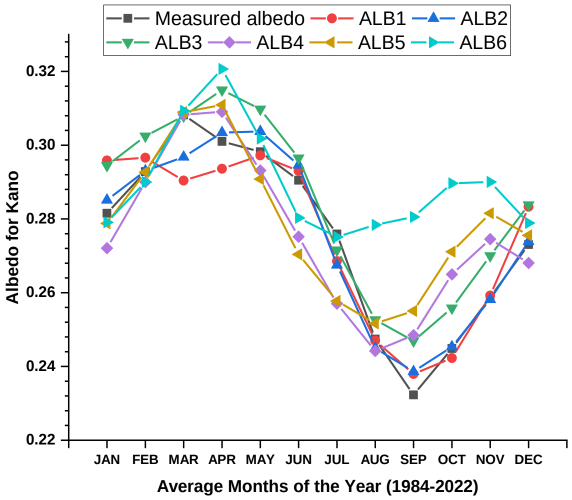

Figure 3a: Comparison between the measured and the developed two variable multivariate regression models for Kano.

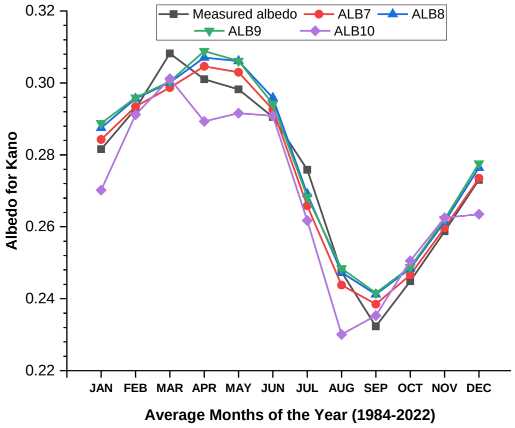

Figure 3b: Comparison between measured albedo and three variable regression model for Kano

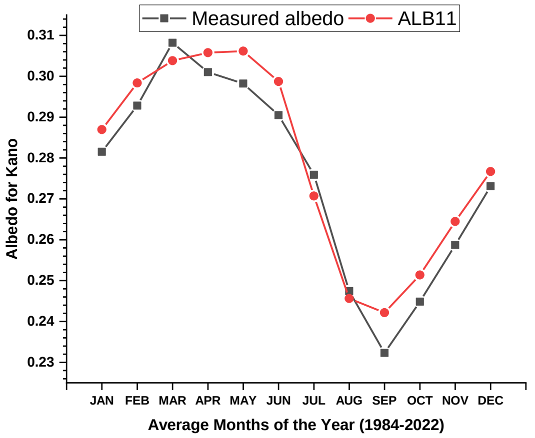

Figure 3c: Analysis of four variable regression model for Kano

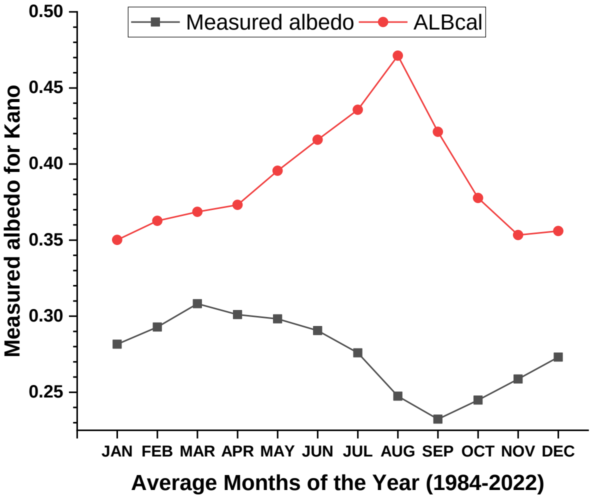

Figure 4: variation of Monthly averaged daily measured albedo with the generalize equation (Calculated Albedo).

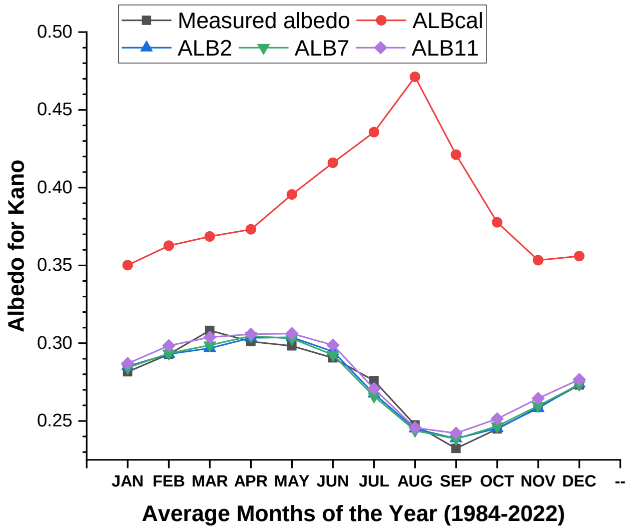

Figure 5. Comparison between the measured albedo, calculated albedo (existing model), best ranked developed two, three and four multivariate regression models for Kano

Multivariate Regression Models for Kano

The multivariate regression models based on equations 7 to 17 for two, three, and four variables yield the following results:

$$ALB1 = 0.1692 + 0.0590\,WS + 0.000202\,RH \tag{22}$$

$$ALB2 = 0.1353 + 0.05057\,WS + 0.002243\,T_{mean} \tag{23}$$

$$ALB3 = 5.31 + 0.04705\,WS - 0.00536\,PS \tag{24}$$

$$ALB4 = 0.2049 - 0.000945\,RH + 0.00451\,T_{mean} \tag{25}$$

$$ALB5 = 8.28 - 0.000683\,RH - 0.00837\,PS \tag{26}$$

$$ALB6 = 18.2 - 0.00417\,T_{mean} - 0.0187\,PS \tag{27}$$

$$ALB7 = 0.1412 + 0.04615\,WS - 0.000115\,RH + 0.002506\,T_{mean} \tag{28}$$

$$ALB8 = 1.36 + 0.04971\,WS + 0.00179\,T_{mean} - 0.00127\,PS \tag{29}$$

$$ALB9 = 5.09 + 0.05217\,WS - 0.00515\,PS + 0.000131\,RH \tag{30}$$

$$ALB10 = -29.73 - 0.001745\,RH + 0.01738\,T_{mean} + 0.03113\,PS \tag{31}$$

$$ALB11 = -7.18 + 0.0384\,WS - 0.000451\,RH + 0.00600\,T_{mean} + 0.00763\,PS \tag{32}$$

Table 1: Statistical error indicators for two-variable multivariant regression model for Kano

Models	MBE	RMSE	MPE	t-test	R^2
ALB1	0.000037	0.008139	-0.096380	0.015097	88.090000
ALB2	0.000045	0.005115	-0.053095	0.028868	95.300000
ALB3	0.008520	0.010191	-3.163171	5.054909	94.380000
ALB4	0.000033	0.012006	-0.224172	0.008984	74.090000
ALB5	0.003386	0.014843	-1.539629	0.777172	62.470000
ALB6	0.014100	0.023850	-5.688357	2.430973	33.500000

Table 1b: Ranking of-two variable multivariant regression model for Kano

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB1	2	2	2	2	3	11
ALB2	3	1	1	3	1	9
ALB3	5	3	5	6	2	21
ALB4	1	4	3	1	4	13
ALB5	4	5	4	4	5	22
ALB6	6	6	6	5	6	29

Table 2a: Statistical error values of the Modeled three-variable models for kano

Models	MBE	RMSE	MPE	t-test	R^2
ALB 7	-0.00001	0.00496	-0.03061	0.00932	95.58000
ALB 8	0.00262	0.00571	-0.99486	1.71193	95.38000
ALB 9	0.00303	0.00613	-1.15081	1.88801	94.90000
ALB 10	-0.00556	0.00918	1.95693	2.52383	90.40000

Table 2b: Ranking of three-variable multivariant model for Kano

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB 7	1	1	1	1	1	5
ALB 8	2	2	2	2	2	10
ALB 9	3	3	3	3	3	15
ALB 10	4	4	4	4	4	20

Table 3: Statistical error indicators for Four variable model for Kano

Models	MBE	RMSE	MPE	t-test	R^2
ALB 11	0.0039	0.0061	-1.4434	2.6941	95.9500

Table 4: Statistical Error indicators for calculated albedo (existing model-ALBcal) for Ikeja

Models	MBE	RMSE	MPE	t-test	R^2
ALBcal	0.1147	0.1253	-43.1967	7.5469	13.8863

Table 5a: Statistical overview of the top-performing models across each category for Kano

Models	MBE	RMSE	MPE	t-test	R^2
ALB2	0.000045	0.005115	-0.053095	0.028868	95.300000
ALB 7	-0.00001	0.004960	-0.030610	0.00932	95.580000
ALB 11	0.003900	0.006100	-1.443400	2.69410	95.950000
ALBcal	0.114700	0.125300	-43.19670	7.54690	13.886300

Table 5b: Ranks obtained for the best-performed models across each category for Kano

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB2	2	2	2	2	3	11
ALB 7	1	1	1	1	2	6
ALB 11	3	3	3	3	1	13
ALBcal	4	4	4	4	4	20

DISCUSSION

Figure 1a displays Kano's monthly average daily measured albedo. The figure shows that the highest values of albedo were recorded in March (0.3082), despite being a relatively cloudless month, indicating that albedo or radiation reflection at this time was caused by dust particles present in the atmosphere, indicating that the atmosphere was heavily laden with harmattan dust, and the lowest values were observed in September (0.2323). The average albedo was found to be 0.2829 and 0.2700 during the rainy and dry seasons, respectively. This suggests that albedo is higher during the dry season than during the rainy season, which explains why the mean temperature recorded a higher value during the wet season and a low value in the dry. These findings are consistent with the report by Audu *et al.* (2014), which states that, on the one hand, if the Earth reflects more solar energy than it absorbs, it becomes colder and vice versa.

Figure 1b shows that the trend pattern of the measured albedo and the clearness index are nearly identical. The trends show that the clearness index value increases in tandem with the albedo value. The highest values of the clearness index and measured albedo were noted in the months of March and January, at 0.3082 and 0.6499, respectively, and the lowest values were recorded in the months of September and August, at 0.2323 and 0.5288, respectively. There is a percentage difference of 28.137% to 38.795% between the observed albedo and the clearness index.

Figure 1c's result indicates that, from January to March, the trends of global solar radiation and albedo are nearly identical. While albedo increases in the opposite direction from September to December, global solar radiation increases in September and October, when it is at its lowest. The months of March and April saw the highest values of albedo and global solar radiation, measuring 0.3082 and 23.7951 $MJm^{-2}day^{-1}$, respectively. The months of September and December saw the lowest values, measuring 0.2323 and 19.3495 $MJm^{-2}day^{-1}$, respectively. The outcome also demonstrates that, with the exception of the months of August through December, when the rainy season peaked and the start of the harmattan dry season, when an opposite trend was seen, which is most likely the result of cloud and aerosol activity, the variation of solar radiation with albedo depicts almost a direct relationship. Indicating that the global solar radiation is higher during the wet season, the average value of global solar radiation was found to be 21.7948 $MJm^{-2}day^{-1}$ in the wet season and 20.8820 $MJm^{-2}day^{-1}$ in the dry season.

Between figures 2a and 2d, the study area's maximum albedo value was recorded in March, with a value of 0.3082, while the lowest value was recorded in April. It was observed that the variation of surface pressure with albedo shows an almost opposite relationship, with the highest albedo recorded in March matching the lowest recorded surface pressure in April. From April to August, the surface pressure value increased; from September to October, it slightly decreased; and from December, it increased in line with the trend. The months of January and April had the highest and lowest surface pressure readings of 953.7821 hPa and 949.441 hPa, respectively. In comparison to the low value of 951.6810 recorded in the wet season, the average value of atmospheric pressure attains a higher value of 952.6605 hPa during the dry season. A similar correlation between the measured albedo and wind speed is shown in Figure 2b. As one can see from the results, both the measured albedo and wind speed increase with increasing wind speed, with September marking the lowest value for both. Wind speed records for the months of September and February ranged from 0.9031 m/s to 2.0874 m/s, respectively, for the minimum and maximum values. Since there is more moisture in the atmosphere during the rainy season, Figure 2c's variation of relative humidity with albedo shows a direct opposite relationship. The highest albedo recorded in the month of March corresponds to the lowest value recorded for relative humidity during the dry season, while the highest value of relative humidity was recorded in the month of August. These values are 78.889 % and 20.7654 %, respectively, representing the highest and lowest values of relative humidity. The average relative humidity values for the wet and dry seasons are 61.3544 % and 27.4033 %, respectively. This indicates that the relative humidity is higher in the rainy season than it is in the dry season. According to figure 2di, the mean temperature reached its highest point in May (30.0192 ^{o}C) and lowest point in January (20.4284 ^{o}C), respectively. The outcome also demonstrates that, with the exception of the months of August through December, when the rainy season peaked and the start of the harmattan dry season, which results in a slightly opposite relationship, the change of mean temperature with albedo reflects practically a direct relationship.

The variance in the average mean temperature of the two seasons in the study area is shown in Figure 2dii. The wet season runs from April to October, while the dry season spans from November to March. The average temperature recorded for both seasons is 27.36 ^{o}C and 22.97 ^{o}C, respectively. This suggests that the dry season in Kano is colder than the wet season. which explains why March, which is within the dry season, saw the highest recorded value of the observed albedo. This implies that the reflection of short-wave solar radiation back to the atmosphere is majorly dust and aerosol present in the atmosphere due to Kano's proximity to the Sahara Desert.

Figure 3a shows the variance of the observed albedo with the newly developed multivariate regression models for three categories (two, three, and four-variable models). For the two-variable category, The figure indicates a significant deviation, with the ALB6 (Eqn. 27) showing a significant amount of overestimation compared with the observed measured earth's surface albedo data and other developed models throughout the months of April, May, and August to December, and an underestimate between January and February, June to July. A critical analysis revealed that, according to the values and rankings of the error indicators displayed in tables 1a and 1b, the ALB2 (Eqn. 23) in this study performed better for the two variable regression model for the study location. The accuracy test results for the developed two-variable model for Kano shown that the MPE values in equation 23 (ALB2) attain the satisfactory range (MPE ≤ ±10%). Similarly, the t-test values demonstrate significance at 95% to 99% confidence level, with a coefficient of determination (R^2) of 95.3%. The comparison between the three variable regression albedo models for Kano and the observed albedo is shown in Figure 3b. It is clear that for the months of January through August and December, ALB10 (Eqn. 31) underestimated the measured albedo and other developed albedo models, whereas for the months of September through November, it overestimated both. Based on the values and ranking of the error indicators shown in tables 2a and 2b, an evaluative analysis revealed that the ALB7 (Eqn.28) in this study performed better for the three variable regression model for the study location. The accuracy test results for the developed three-variable model for Kano showed that equation 28 (ALB7) MPE values attain the acceptable range (MPE ≤ ±10%). In a similar vein, the t-test values are significant at 95% to 99% confidence level, with a coefficient of determination (R^2) of 95.58%.

A comparison of the developed four variable regression model for Kano and the measured data is shown in Figure 3c. It is clear that, throughout the year, the generated model ALB11 (Eqn. 32) underestimated the measured albedo, with the exception of the months of March, July, and August, when it overestimates it. Table 3 presented the results of the various validation tests conducted on the developed four-variable regression model. It is evident that the model has overestimated MBE and underestimated MPE values of 0.0039 and 1.4434, respectively, and that the t-test value and RMSE values are 0.0061 and 2.6941, respectively. The MPE value is found to be within the satisfactory range (MPE ≤ ±10%), and the t-test value is significant at the 99% confidence level, achieving a high level of Coefficient of determination (R^2) at 95.95%. The correlation between the measured and calculated albedo (Eqn. 6) for Kano is shown in Figure 4. It is clear that the calculated albedo (generalize equation-Eqn. 6) significantly overestimated the measured albedo, with a correspondingly large value throughout the entire year, or literally from January to December. However, a nearly identical opposite trend is also visible, with the highest value occurring in August, falling to a minimum in November, and reaching its lowest in January.

The statistical error values for the calculated albedo (Eqn. 6) for Kano are provided in Table 4. The table displays values that indicate that the calculated albedo (Eqn. 6) has a high t-test and RMSE of 7.546 and 0.1253%, respectively. The model also exhibits an extremely high MPE value, with an estimated value underestimation of 43.6767% and an overestimation of MBE with a value of 0.1147 when compared to the developed values shown in Tables 1, 2, and 3. With a coefficient of determination (R^2) of 13.89%, the accuracy test results show that the MPE values are not significant at the 95% or 99% confidence level and are not within the satisfactory range (MPE ≤ ±10%).

Figure 5, tables 5a and 5b show that the calculated albedo (Eqn. 6) clearly overestimated the measured and developed albedo, resulting in a large value throughout the months of the year, from January to December. Additionally, an almost opposite trend can be observed, with the highest value in August, decreasing to a minimum in November, and reaching its lowest value in January. The disparity between the measured albedo and the calculated albedo (generalize equation-Eqn.6) by Audu *et al.*, (2014) and Babatunde (2003) may be due to the equation's focus on cloud cover as the primary atmospheric parameter that contributes to the reflection of solar radiation globally, without taking other parameters into account that may also function as strong reflectors of solar radiation. The overall results indicate that the Earth's surface albedo over Kano may be more accurately and efficiently estimated using the three-variable multivariate regression model ALB7, which relates wind speed, relative humidity, and mean temperature. The multivariate models developed in this study was found to outperformed those investigated by Audu *et al.* (2014) for Kano and generalized method proposed by Babatunde (2003).

CONCLUSION

Comparing the developed multivariate regression models with the generalized approach model used for the study location (Kano), reveals that the new models follow similar trends as the measured albedo and perform better than the generalized approach model from literature.

The model involving wind speed, relative humidity, and mean temperature, known as ALB7 (Eqn. 28), was reported to be the best fit for calculating Earth's surface albedo over Kano.

$$ALB7 = 0.1412 + 0.04615\,WS - 0.000115\,RH + 0.002506\,T_{mean}$$

The variation of Earth surface albedo with meteorological parameters depicts a close relationship with clearness index and wind speed, an inverse relationship with surface pressure and relative humidity was observed, while for global solar radiation and mean temperature, a trend of similar relationship was observed during the dry season and an inverse relationship during the wet season.

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