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MULTIVARIATE MODELS FOR THE ESTIMATION OF EARTH'S ALBEDO ACROSS THE COASTAL REGION OF NIGERIA

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ABSTRACT

Studies on atmospheric thermal balancing, atmospheric radiative transmission, and the assessment and design of solar energy systems all depend on an accurate estimate of the Earth's albedo. This study compared the variability in albedo for two locations, Owerri and Ikeja distributed over Nigeria's coastline climatic regions, using monthly average daily observed meteorological data on global solar radiation alongside wind speed, mean temperature, surface pressure and relative humidity over thirty-nine-year period (1984-2022) from the National Aeronautics and Space Administration (NASA). 11 models in all, divided into three groups, were derived from regression models with two, three, and four variables were developed and tested using 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). All the developed models that stood out the most were ranked according to their suitability for estimating surface albedo. For Owerri, the three-variable regression model which relates wind speed, relative humidity and mean temperature, ALB7 (Eqn. 26g) performed best, while the two variable regression model which relates the relative humidity and mean temperature, ALB15 (Eqn. 27d) performed best for estimating surface albedo for Ikeja. The Earth's emitted surface temperature for Owerri ranged from 219.1845 K in August to 239.6133 K in January, while for Ikeja it varies from 221.4955 K in August to 238.7534 K in November. The longwave radiation at both locations is in the infrared part of the electromagnetic spectrum, as indicated by the maximum emission wavelength values.

Keywords: Albedo, Global solar radiation, Metrological parameters, Maximum wavelength, NASA

INTRODUCTION

Solar radiation data is a prerequisite for carrying out feasibility assessments for solar energy systems (Akpootu and Iliyasu, 2017). Since the amount of solar radiation that reaches the Earth's surface varies on the local climate, understanding the effects of sunlight passing through the atmosphere are crucial to many scientific disciplines as well as common knowledge (Audu and Isikwue, 2014). The amount of solar radiation that reaches the Earth's surface changes over time due to atmospheric absorption, reflection, and scattering. Akpootu and Iliyasu, (2017) highlighted the importance of albedo as the percentage of incident solar radiation that is reflected and dispersed back into space. The definition of albedo is connected to the reflection of solar radiation at a surface, which is the ratio of reflected solar radiation to incident solar radiation at a surface expressed mathematical as H_r/H_o where Hr is defined as the reflected radiation and H_o is the extraterrestrial radiation at the edge of the atmosphere and it is regarded as the incident solar radiation. Albedo can also be termed as reflection coefficient, reflectance or reflectivity of a surface; by this, many scientists have regarded Earth's surface albedo as the same as its planetary albedo (Iqbal, 1983).

In general, most models offer reasonable accuracy, though occasionally local weather patterns and prevailing atmospheric factors can motivate the creation and development of new models or the modification of the existing ones (Psiloglou and Kambezidis, 2009). Additionally, research relating to the correlation between terrestrial surfaces and solar radiation absorption—such as regional and global climate models—needs the surface albedo. (e.g. Dickinson, 1992; Knorr *et al*., 2001), or for numerical weather prediction (e.g. Viterbo and Betts, 1999). With the use of high-quality satellite observations, surface-albedo parameterizations have advanced remarkably in recent years (e.g., Pinty *et al*., 2000; Strugnell *et al*., 2001; Tsvetsinskaya *et al*., 2002; Liang *et al*., 2005; Wang *et al*., 2005, 2007). However, in most calculations, in the absence of ground-albedo measurements, an average value of 0.2 is typically used to represent the reflective qualities of bare, snow-free ground (Liu and Jordan, 1963). Nonetheless, data for seven Canadian locations (Iqbal, 1983) and 27 US locations (SOLMET, 1979) demonstrate a substantial seasonal dependence that is undoubtedly connected to the amount of snow cover.

As a result, one can utilize albedo as a surface attribute to ascertain a surface's brightness. Materials with high albedo and emittance achieve low temperatures when exposed to solar radiation, which reduces the transfer of heat to their surroundings, according to Prado and Ferreira (2005), as reported by Akpootu *et al*. (2020). Albedo is therefore an essential metric or input parameter for assessing the overall insolation on a structure or solar energy collector. It is also significant for research on the atmosphere's thermal balance (Akpootu *et al*., 2020). The quantity of sunlight that the Earth absorbs is influenced by its albedo. It is crucial to the Earth's surface energy balance because it establishes the rate at which incident solar radiation is absorbed. As a result, it directly impacts the energy budget of Earth and, consequently, global temperatures. The Earth warms up if it absorbs higher amounts of energy from the Sun than it expels back into space. Conversely, the Earth becomes colder if it reflects more solar radiation than it takes in. Studies of the Earth's atmosphere's albedo at various areas have been conducted (Akpootu *et al*., 2020).

Akpootu *et al*. (2020) conducted a comparison study to quantify the Earth's albedo and analyze its change with other meteorological parameters at two tropical sites in Nigeria. Their work employed shortwave solar energy balancing at the edge of the Earth's atmosphere to estimate and evaluate albedo variance in two selected locations, Gusau and Calabar, located in Nigeria's Sahelian and Coastal climatic regions.

Their findings show that the highest and lowest albedo values simulated for Gusau were in the months of August and February, with 0.4933 and 0.3720, respectively, while for Calabar, they were in August and January, with values of 0.6949 and 0.4218, respectively. The model used in their investigations was based on Babantunde's (2003) (generalized model), which was also utilized by other researchers for different regions in Nigeria (Audu and Isikwue, 2014; Akpootu *et al*., 2023; Babatunde, 2012). The emitting earth surface temperature for Gusau ranged between 235.1297 K in August and 252.4133 K in February, while for Calabar it ranged between 207.1236 K in August and 243.0097 K in January; these values were found to be very close to the standard emitting earth surface temperature value (255.0000 K). Similarly, the maximum emitting wavelength values for both locations indicated that the radiation is longwave and falls within the infrared range of the electromagnetic spectrum. Furthermore, their findings show that as albedo increases throughout the rainy season, mean temperature falls, indicating an inverse relationship.

The aforementioned makes it abundantly evident how important it is to accurately account for ground albedo in modern solar radiation applications. Similar earlier research estimated the Earth's surface albedo using Babatunde's generalized equation; however, when the estimated values from the generalized equations were compared with the measured values, a significant disparity was found, and also, albedo measuring devices are not available to most scientists in Nigeria, therefore, this study seeks to develop new multivariate regression models based on the availability of measured meteorological parameters for estimating Earth's surface albedo for the selected locations across the coastal region of Nigeria. Four approaches were used to compute the albedo values: One taken from the generally used one from literature and three are devised especially for this work. It aims to accomplish the following specific objectives: (i) to determine which models, using meteorological parameters, are best suited for calculating Earth's surface albedo in Owerri and Ikeja. (ii) to create regression models using two, three, and four variables in order to estimate the albedo of the Earth's surface for the locations under study. (iii) to rank these models in order to determine which is best suited for precise estimates at each location; and finally (iv) to examine correlations between estimated values and measured albedo values in order to provide a thorough assessment of the model's performance.

MATERIALS AND METHODS

Data Collection and Processing

Nigeria has two seasons: the rainy and the dry, since it is a tropical location (Akpootu, *et al*., 2020). Heavy rainfall is a hallmark of the wet season. The season spans the months of April through October. However, little to no rainfall and an atmosphere heavy in dust define the dry season. According to Akpootu, *et al*. (2020), the season lasts from November to March. Nigeria is divided into four climatic zones, according to Akpootu, *et al.* (2020) report: the Sahelian zone, Midland zone, Guinea savannah zone, and Coastal zone. The study location under consideration include Owerri (Latitude 5.48 ºN, Longitude 7.00 ºE, and altitude 91.0 m above sea level) and Ikeja (Latitude 6.58 ºN, Longitude 3.33 ºE, and altitude 39.4 m above sea level), both located in Nigeria's coastal climatic zone. The locations were chosen with consideration for variances in distance, latitude, longitude, and elevation within the same climatic zone, as well as the lack of prior research in the study area. To prevent potentially misleading indicators due to year-to-year volatility in meteorological conditions, the obtained data spans thirty-nine years (1984-2022), ensuring a good climatological average. The overall consistency of the daily and monthly averages of the meteorological parameters utilized in the research locations was used to ensure the quality of the meteorological measurements. The data contained measurements of surface pressure, relative humidity, mean temperatures, wind speed, global solar radiation, and measured albedo. The data acquired for Owerri and Ikeja were obtained from the National Aeronautics and Space Administration (NASA) website, which has been a reliable source of consistent quality data utilized by numerous authors in related literatures.

According to Akpootu and Rabiu (2019) as reported by Salafu *et al*. (2024), 1 Kwhm^{-2}day^{-1} = 3.6 MJm^{-2}day^{-1} is the result of converting global solar radiation data, which was originally in Kwhm^{-2}day^{-1} to MJm^{-2}day^{-1}, utilizing a conversion factor. The surface pressure measured in kPa was converted to hPa by multiplying by 10. The mean temperature is expressed as (ºC), the relative humidity as (%), and the wind speed as ms^{-1}. Averaging the daily results over a month can be used to estimate the mean daily extraterrestrial radiation on a horizontal surface, represented by H_o and quantified in $MJm^{-2}day^{-1}$, this can be done for each day of the month (Iqbal, 1983; Zekai, 2008; Saidur *et al*., 2009). The equations by Iqbal (1983) and Zekai (2008), as given by Akpootu and Abdullahi (2022), serve as the foundation for this computation.

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

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

The equation to find H_o uses the parameters I_{sc}, ϕ, ωs, and δ, they represent the solar constant, site latitude, mean sunrise hour angle, and solar declination, respectively. The computation also takes into account n, which is the total number of days in a year from January 1st to December 31st. As reported by Akpootu and Abdullahi (2022), Zekai (2008) and Iqbal (1983)'s methods are used to compute the mean sunrise hour angle and solar declination. These can be obtained by:

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

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

The expression presented by Babatunde (2003), reported by Akpootu *et al*. (2023a, b) would be used to calculate the shortwave solar energy balancing at the edge of the Earth's atmosphere.

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

The amount of extraterrestrial radiation that is transmitted from space to the ground surface is represented by the ratio H_m/H_o, where H_o is the clearness index (Babatunde and Aro, 1995; Udo 2000). where H_m is the measured global solar radiation (MJm^{-2}day^{-1}), and H_o is the extraterrestrial radiation (MJm^{-2}day^{-1}). According to Babatunde (2003), H_a represents absorbed solar radiation, $\frac{H_r}{H_o}$ represents the percentage of solar radiation reflected into space, and H_r is the shortwave reflected radiation, $\frac{H_a}{H_o}$ is referred to as the absorbance or absorption coefficient and indicates the portion of solar radiation that is absorbed. Babatunde (2003) states that the ratio $\frac{H_a}{H_o}$ should be negligible in comparison to the other ratios in equation (4) and can thus be disregarded, i.e., $\frac{H_a}{H_o} \ll 1$. Hence, equation (4) becomes

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

From equation (5), the following expression was used to estimate the reflectivity or albedo (Babatunde, 2003)

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

According to Wallace and Hobbs (2006), the Stefan-Boltzmann law gives the flux density of longwave radiation that the Earth emits, or F_E. This flux density is expressed as

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

where T_E is the Earth's temperature in Kelvin (K), and σ is the universal Stefan-Boltzmann constant, which has the value 5.67 x 10^{-8} $Wm^{-2}K^{-4}$. Additionally, F_E also given by Wallace and Hobbs (2006) as reported by Akpootu *et al.* (2023a, b) as

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

where F_S is the flux density of solar radiation incident upon the Earth (1368 Wm^{-2}) and $\frac{H_r}{H_o}$ is the Earth's planetary albedo for the research area. The following equation, which links the Earth's surface temperature, T_E, to its albedo for the study location (Mcllveen, 1992) as reported by Akpootu *et al.* (2023a, b), can be produced by combining equations (7) and (8).

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

Equation (9) indicates that when albedo increases, the temperature T_E would drop. The wavelength band that contains the majority of the energy associated with solar radiation is referred to as "shortwave" ($\lambda < 4\ \mu m$) in atmospheric science, while the band that includes the majority of terrestrial (Earth-emitted) radiation is referred to as "longwave" ($\lambda > 4\ \mu m$) (Akpootu *et al.*, 2020). The spectrum would normally be split into the regions depicted in figure 1 in the radiative transfer literature.

The range of wavelengths that the human eye can detect would constitute the relatively narrow visible region, which will span from wavelengths of 0.39 μm to 0.76 μm (Wallace and Hobbs, 2006). According to Wallace and Hobbs (2006), terrestrial radiation, or radiation emitted from Earth, will predominate in the remaining infrared region, whereas solar radiation will dominate the near infrared region, which stretches from the visible border up to around ~4 μm.

Although, microwave radiation has little effect on the Earth's energy balance, it is frequently employed in remote sensing applications due to its ability to pass through clouds (Wallace and Hobbs, 2006). Wien's displacement law (Wallace and Hobbs, 2006) would be used to determine the maximum wavelength of emission at temperature, or T_E.

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

λ_m is in micrometers and T_E in degree Kelvin

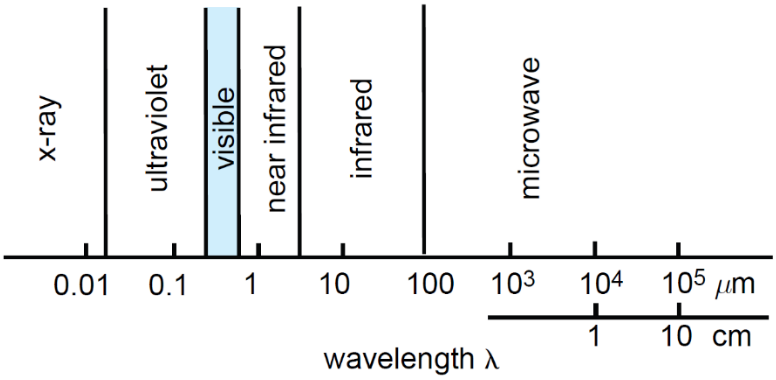

Figure 1: The Electromagnetic Spectrum (Wallace and Hobbs, 2006)

Developed Albedo Models

The proposed models for estimating Earth's surface albedo is based on two, three and four variable regression models. Multiple linear regression was used, with the observed albedo (Alb_{mea}) serving as the dependent variable and the four meteorological factors (WS, RH, T_{mean}, and PS) acting as independent variables based. The combination method has been adopted to ascertain the number of ways the meteorological parameters were combined, to make sure that no pertinent parameters are left out. The monthly average daily wind speed (ms^{-1}), monthly average daily relative humidity (%), monthly average mean temperature (°C), and monthly average daily atmospheric pressure (hPa) are represented respectively.

Two variables multivariate regression models:

$$Alb_{mea} = a + bWS + cRH \quad (11)$$
$$Alb_{mea} = a + bWS + cT_{mean} \quad (12)$$
$$Alb_{mea} = a + bWS + cPS \quad (13)$$
$$Alb_{mea} = a + bRH + cT_{mean} \quad (14)$$
$$Alb_{mea} = a + bRH + cPS \quad (15)$$
$$Alb_{mea} = a + bT_{mean} + cPS \quad (16)$$

Three variables multivariate regression models:

$$Alb_{mea} = a + bWS + cRH + dT_{mean} \quad (17)$$
$$Alb_{mea} = a + bWS + cT_{mean} + dPS \quad (18)$$
$$Alb_{mea} = a + bWS + cPS + dRH \quad (19)$$
$$Alb_{mea} = a + bRH + cT_{mean} + dPS \quad (20)$$

Four variables multivariate regression model:

$$Alb_{mea} = a + bWS + cRH + dT_{mean} + ePS \quad (21)$$

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

Accuracy of the Models

The following metrics were used to statistically test each model's effectiveness: Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-test and Coefficient of determination (R^2). The following equations are presented to calculate MBE, RMSE, and MPE, based on the method proposed by El-Sebaii and Trabea (2005) as reported by Akpootu and Mustapha (2015); Olomiyesan *et al.* (2021).

$$RMSE = \left(\frac{1}{n}\sum_{i=1}^{n}\left(Alb_{i,cal} - Alb_{i,mea}\right)^2\right)^{\frac{1}{2}} \quad (22)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(Alb_{i,cal} - Alb_{i,mea}\right) \quad (23)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{Alb_{i,mea}-A_{i,cal}}{Alb_{i,mea}}\right) \times 100 \quad (24)$$

According to Bevington (1969), one statistical technique used to assess mean values is the t-test, which makes use of a random variable with the symbol t and $n{-}1$ degrees of freedom. Additionally, according to Akpootu *et al*. (2019a, b), the t-test, a non-dimensional parameter, is considered significant at 95% if the value is < 2.20 and at 99% if it is < 3.12. Additionally, the equation by Akpootu *et al*. (2023a, b) can be expressed as follows:

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2-(MBE)^2}\right]^{\frac{1}{2}} \qquad (25)$$

The subscript i in equation 22, 23, and 24 denotes the albedo's ith value, while 'n' is the total number of albedo data. The calculated and measured albedo values are denoted by the subscripts "cal" and "mea," respectively. A low Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) of which falls withing the range of ±10% are preferable, and a value of zero for Mean Bias Error (MBE) is optimal (Almorox *et al*., 2005; Chen *et al*., 2004). As a result, the model performs better when the values of MBE, RMSE, MPE, and t-test are smaller. positive values of MBE and MPE indicate an average level of overestimation in the computed values, while negative values indicate an underestimation. The coefficient of determination (R^2) should aim to get closer to a value of 1, preferably reaching 100%, in order to produce a more accurate and trustworthy data modeling result (Akpootu *et al*., 2019c, d; Akpootu and Iliyasu 2015a, b). A robust and well-fitting model is suggested by the significant regression obtained between the anticipated/predicted and observed values.

RESULTS AND DISCUSSION

Examination of the variations of Owerri's maximum wavelength and surface temperature

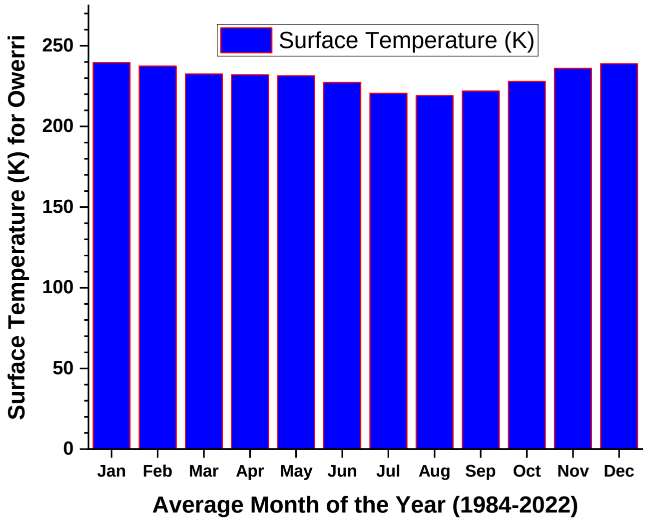

Figure 2: Monthly average daily surface temperature for Owerri

Figure 2 depicts the variation of the radiant temperature of the Earth's surface for the study location (Owerri). The highest emitting Earth surface temperature was observed in the month of January (239.6133 K) as expected due to the low value of albedo recorded this period, hence, increase in temperature is observed as a result of high amount of radiation been absorbed by the Earth's surface. The lowest emitting Earth surface temperature was observed in the month of August (219.1845 K), this is the cloudiest month for this region; the low temperature is expected due to cloud activities resulting in high reflection of solar radiation. In this study, surface temperatures varied from 219.1845 K to 239.6133 K. The results displayed an opposite relationship between the Earth's emitted surface temperature and the planetary albedo.

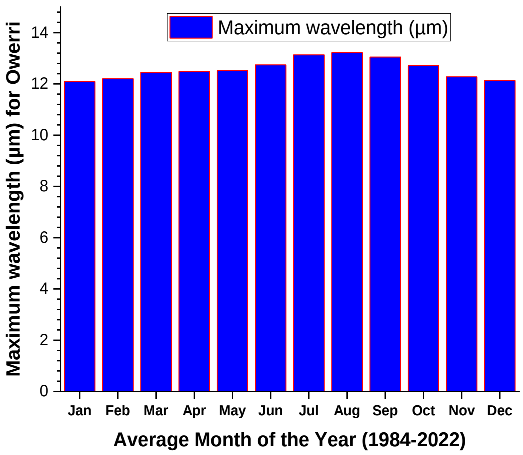

Figure 3: Variation of wavelength (µm) for Owerri

Figure 3 demonstrates the variability of the monthly average daily maximum emitting wavelength in the research area (Owerri). The highest peak wavelength was observed in the month of January (13.2172 µm) and the lowest value was observed in the month of August (12.0903 µm). The wavelength ranged between the values of 12.0903 µm to 13.2172 µm, these values agree with those reported in radiative transfer literatures by Wallace and Hobbs (2006), that for longwave radiation recording a value of $\lambda > 4$ µm, demonstrates that Owerri's radiation is terrestrial, or Earth-emitted, and falls within the infrared spectrum.

Multivariate Regression Models for Owerri

The results of multivariate regression models for two; three and four variable model for Owerri based on equation (11) to (21) are:

$$ALB1 = -0.0467 + 0.00482\,WS + 0.002635\,RH \quad (26a)$$

$$ALB2 = -0.017 + 0.0405\,WS + 0.00580\,T_{mean} \quad (26b)$$

$$ALB3 = -3.59 + 0.0164\,WS + 0.0374\,PS \quad (26c)$$

$$ALB4 = -0.0733 + 0.002710\,RH + 0.00104\,T_{mean} \quad (26d)$$

$$ALB5 = 0.78 + 0.002819\,RH - 0.0083\,PS \quad (26e)$$

$$ALB6 = -15.45 + 0.02099\,T_{mean} + 0.1504\,PS \quad (26f)$$

$$ALB7 = -0.0975 + 0.00831\,WS + 0.002577\,RH + 0.00199\,T_{mean} \quad (26g)$$

$$ALB8 = -15.57 - 0.0008\,WS + 0.02105\,T_{mean} + 0.1516\,PS \quad (26h)$$

$$ALB9 = 2.07 + 0.01206\,WS - 0.0213\,PS + 0.002797\,RH \quad (26i)$$

$$ALB10 = 1.02 + 0.002850\,RH - 0.00037\,T_{mean} - 0.0107\,PS \quad (26j)$$

$$ALB11 = 4.35 + 0.0142\,WS + 0.003055\,RH - 0.00309\,T_{mean} - 0.0435\,PS \quad (26k)$$

Statistical Indicators for Two Variable Regression Models for Owerri

The models' statistical analysis summaries, for ALB1 (Eqn 26a) to ALB6 (Eqn 26f) are provided below.

Table 1: Statistical error indicators for the modeled two variable regression models for Owerri

Models	MBE	RMSE	MPE	t-test	R^2
ALB1	0.00005	0.0043	-0.0838	0.0369	91.67
ALB2	0.0003	0.0127	-0.6790	0.0815	26.37
ALB3	0.0002	0.0129	-0.6339	0.0481	24.78
ALB4	-0.0001	0.0043	0.0159	0.1025	91.57
ALB5	0.0028	0.0051	-1.5898	2.1990	91.65
ALB6	-0.0034	0.0093	1.6203	1.3094	65.74

Table 1 provide a synopsis of the statistical validation carried out on Owerri two-variable regression model. With the highest R^2 value of 91.67% and the lowest values for RMSE and t-test, at 0.0043 and 0.0369, respectively, ALB1 (Eqn 26a) stands out. It also has the lowest values for MBE and MPE, with an estimated value that is overestimated by 0.00005 and underestimated by 0.0838%. Additionally, the results indicated that the MPE values for ALB1 (Eqn 26a) to ALB6 (Eqn 26f) were within the ±10% permissible limit. Furthermore, there is statistical significance at 95% for the t-test for ALB1 (Eqn 26a) through ALB6 (Eqn 26f).

Table 2: Ranking of modeled two variable multivariate regression models for Owerri

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB1	1	1	2	1	1	6
ALB2	4	5	4	3	5	21
ALB3	3	6	3	2	6	20
ALB4	2	2	1	4	3	12
ALB5	5	3	5	6	2	21
ALB6	6	4	6	5	4	25

A concise overview of the rankings derived from the two variable multivariate regression models for Owerri can be found in the table above. Table 2 made it evident that each model's ranks span between 6 and 25. Overall, the results show that model ALB1 (Eqn 26a) outperforms the other five models in this category in terms of accuracy and performance when calculating the earth's albedo for Owerri, and therefore, the albedo model that relates wind speed and relative humidity was found more suitable in the two variable regression category for Owerri

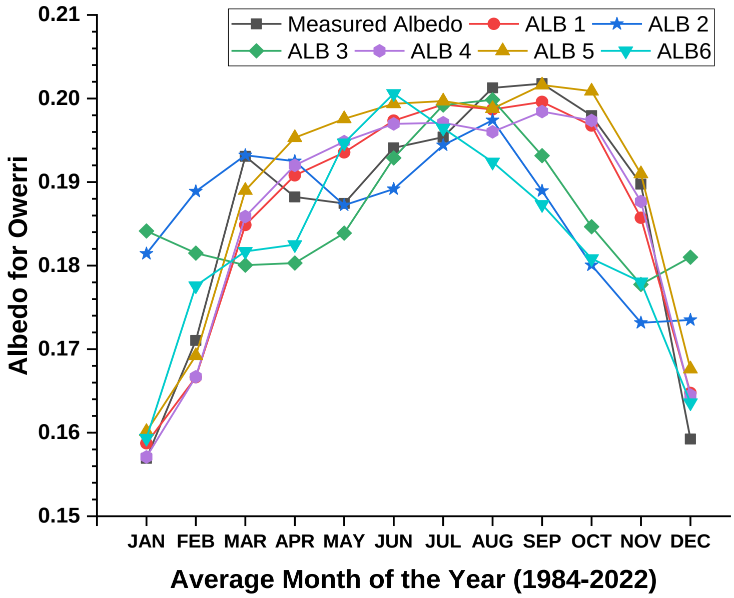

Figure 4: Correlation of the measured and the developed two variables multivariate regression models for Owerri

Figure 4 shows the correlation of the measured albedo and the developed two variable multivariate regression models for Owerri. The figure implies ALB1 (Eqn 26a); ALB2 (Eqn 26b); ALB3 (Eqn 26c); ALB4 (Eqn 26d); ALB5 (Eqn 26e) and ALB6 (Eqn 26f) respectively. The figure clearly shows that every developed model overstated the albedo that was observed in January, ALB2 (Eqn 26b) overestimated the measured albedo in February, March April and December, underestimated the measured albedo in May through November. Based on the developed two variable multivariate regression models, ALB1 (Eqn 26a) showed a comparable trend of fluctuation with the measured albedo and was found to be the most appropriate model for estimating earth surface albedo in Owerri when compared to other estimated models in this category.

Statistical Error Values for Three Variable Multivariate Regression Model

The models' statistical evaluation summaries ALB7 (Eqn 26g) to ALB10 (Eqn. 26j) are provided below.

Table 3: Statistical error values of the modeled three variable multivariate regression equations for Owerri

Models	MBE	RMSE	MPE	t-test	R^2
ALB7	-0.0001	0.0040	0.0101	0.0908	92.45
ALB8	-0.0025	0.0090	1.1399	0.9695	65.75
ALB9	0.00257	0.0047	-1.4350	2.1928	93.11
ALB10	-0.0049	0.0065	2.5666	3.7598	91.65

Table 3 reveals the model statistical evaluation conducted on the developed three variable multivariate regression models that were assessed for the study location. Among these, ALB7 (Eqn 26g) was found to have the lowest MBE and MPE, with an underestimated value of 0.0001 and an overestimation of 0.0101%, respectively. It also shows the lowest values of RMSE and t-test, with values of 0.0040 and 0.0908, respectively; ALB9 (Eqn 26i) has the highest value of R^2, with an estimated value of 93.11%. Moreover, the MPE values of all developed three variable multivariate regression models were within the ±10% permissible limit., and the t-tests for ALB7 (Eqn 26g), ALB8 (Eqn 26h) and ALB 9 (Eqn 26i) both at 95% and 99% exhibit statistical significance.

Table 4: Ranking of the modeled three variable multivariate models for Owerri

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB7	1	1	1	1	2	6
ALB8	2	4	2	2	4	14
ALB9	3	2	3	3	1	12
ALB10	4	3	4	4	3	18

Table 4 summarized the rankings obtained by employing the three-variable multivariate regression models that were developed for Owerri. Each of the developed three variable regression models yields a rank that ranges from 6 to 18. In Owerri, equation ALB7 (Eqn 26g) outperforms the other developed three variable regression models in terms of estimating Earth's surface albedo for this category, according to the overall findings from the results. Therefore, the albedo model that relates wind speed, relative humidity and mean temperature was found more suitable.

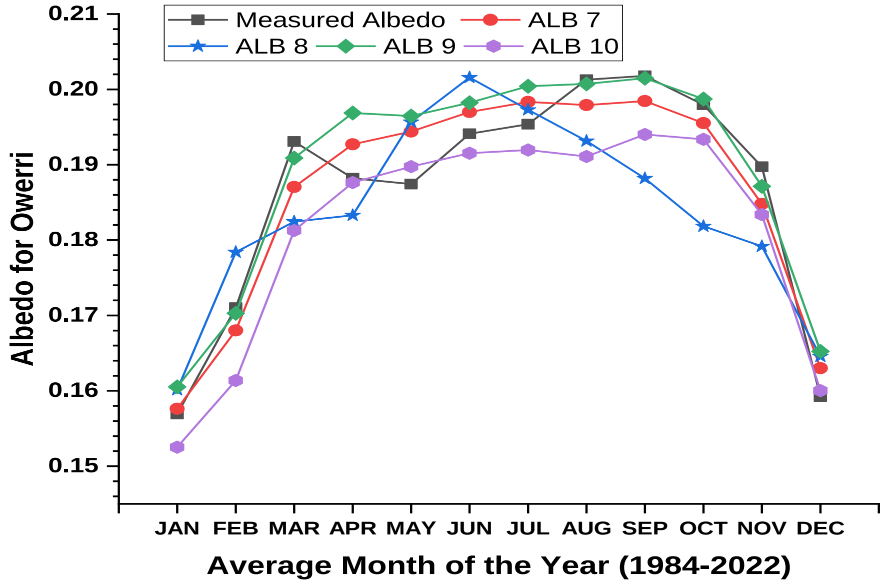

Figure 5: Correlation of the measured albedo and three variable regression model for Owerri

Figure 5 depicts the correlation between the developed three variable regression models developed for Owerri and the measured albedo. The figure implies ALB7 (Eqn 26g); ALB8 (Eqn 26h); ALB9 (Eqn 26i) and ALB10 (Eqn 26j) respectively. The figure makes it clear that, for the months of January through April, June to November the developed three-variable regression model ALB10 (Eqn 26j) underestimated the measured albedo and all the developed three-variable regression model, except for ALB8 (Eqn. 26h) which underestimated the measured and ALB10 (Eqn. 26j) in the months of April, September to November. ALB8 (Eqn. 26h) overestimated the measured albedo in the of January, February, May through July and in December. The model ALB7 (Eqn 26g) demonstrated a close pattern of fluctuation with the observed albedo and was reported to be the most suitable model for estimating earth surface albedo in Owerri based on the developed three variable multivariate regression models in comparison to other developed models in this category.

Table 5: Four variable model Statistical Error indicators for Owerri

Errors	MBE	RMSE	MPE	t-test	R^2
ALB11	0.0004	0.0038	-0.2452	0.3228	93.41

The four variable regression model equation ALB11 (Eqn 26k) as seen in Table 5, has overestimation of MBE with 0.0004 in it estimated value, an underestimation of MPE of 0.2452%. The t-test recorded a value of 0.3228, which both at 95% and 99% exhibit statistical significance, recording an R^2 value of 93.41%.

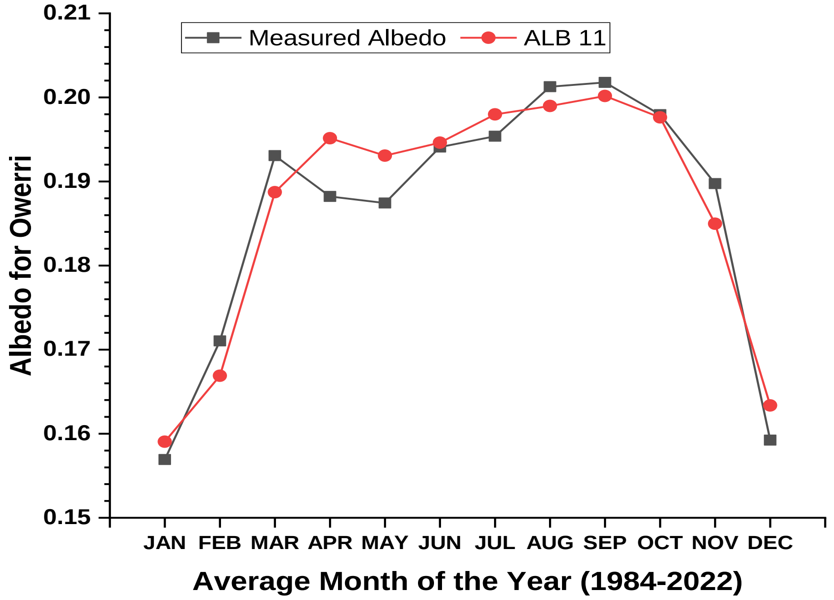

Figure 6: Analysis of four variable regression model for Owerri

Figure 6 shows the comparison between the measured and developed four variables regression model for Owerri. The ALB11 (Eqn 26k) overestimated the measured albedo in the month of January, April to July and in December. The underestimation occurred in the months of February and March, and from August to November.

Statistical Error Indicator for Calculated Albedo (existing model) for Owerri

The result for the calculated albedo (existing model) is based on equation 6 by Babatunde (2003)

Table 6: Statistical Error indicator for calculated albedo (existing model) for Owerri

Errors	MBE	RMSE	MPE	t-test	R^2
Calculated Albedo	0.3439	0.3465	-184.3900	26.7070	72.4411

The statistical error estimates for the calculated albedo (existing model) (Eqn 6) for Owerri are shown in Table 6. It is evident from the values in the table that the calculated albedo has an RMSE value of 0.3565, an overestimation of MBE value of 0.3439; the model also has a very high MPE value, with an underestimated value of 184.3900% when compared to the developed values shown in Table 1, 3 and 5, and R^2 value of 72.4411%. The MPE values fall outside of the acceptable range (MPE < ±10%), the t-test of 26.7070 is not statistically significant at both 95% and 99% level of confidence.

Table 7: Statistical overview of the top-performing in all categories for Owerri

MODELS	MBE	RMSE	MPE	t-test	R^2 (%)
ALB1	0.00005	0.00428	-0.08381	0.03687	91.67
ALB 7	-0.00011	0.00407	0.01007	0.09084	92.45
ALB 11	0.00037	0.00382	-0.24523	0.32279	93.41
ALB CAL	0.34389	0.34653	-184.38955	26.70730	72.4411

Table 8: Ranking of Owerri's top-performing models in each category

MODELS	MBE	RMSE	MPE	t-test	R^2	RANKING
ALB1	1	3	2	1	3	7
ALB 7	2	2	1	2	2	7
ALB 11	3	1	3	3	1	10
ALB CAL	4	4	4	4	4	16

From table 7 and 8, the develop regression model, ALB1 (Eqn 26a) and ALB7 (Eqn 26g) model category were found to have the best albedo estimation for Owerri. However, further examination between ALB1 (Eqn 26a) and ALB7 (Eqn 26g) reveals that ALB1 was ranked 8 while ALB7 was ranked 7, indicating that the three variable regression model ALB7 (Eqn 26g), which relates the mean temperature, relative humidity and wind speed was reported to be most suitable for albedo estimation in Owerri.

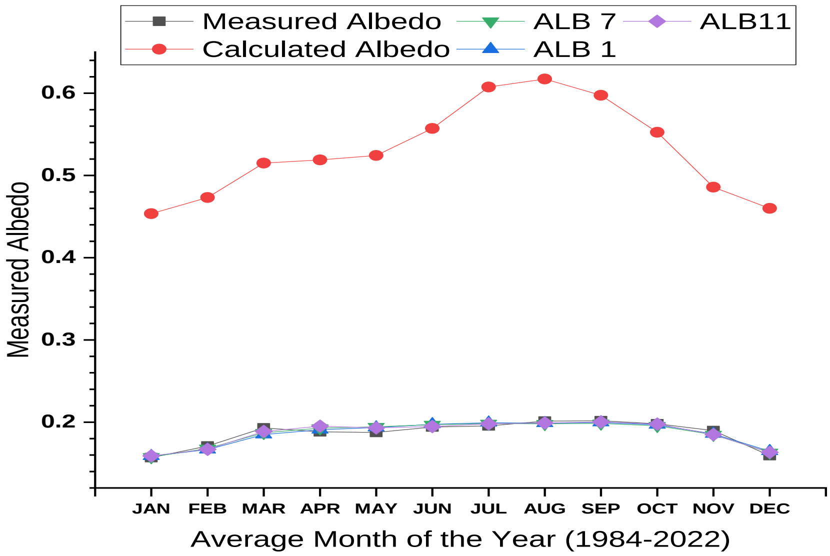

Figure 7: Correlation of the measured albedo, calculated albedo (existing model), best ranked developed two, three and four multivariate models for Owerri

Figure 7 depicts the correlation of measured/observed albedo, calculated (existing model), best ranked developed two, three and four models for Owerri. The figure implies that ALB1 (Eqn 26a); ALB7 (Eqn 26g); ALB11 (Eqn. 26k) and Calculated Albedo (Eqn 6). The figure clearly indicates that the calculated albedo overestimated both the measured albedo and the best developed two, three and four models from the months of January to December. The best-ranked developed two, three, and four models observed an analogous trend of variability with the albedo measurement, ALB7 (Eqn 26g);

the model relating the wind speed, relative humidity, and mean temperature, based on the two, three, and four models in comparison to the computed albedo (existing model), was found to be the best appropriate model for estimating Earth's emitting surface albedo in Owerri.

This result follows same trend as that reported by Babatunde (2003), atmospheric parameters responsible for the reflection of global solar radiation in the study location is majorly cloud activities and aerosols.

Examination of the variations of Ikeja's maximum wavelength and surface temperature

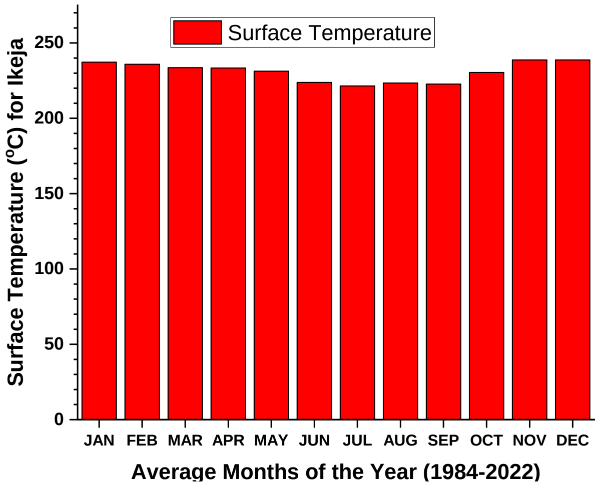

Figure 8: Monthly average daily surface temperature for Ikeja

Figure 8 reveals the variation of the radiant temperature of the Earth's surface for the study location (Ikeja). The highest emitting Earth surface temperature was observed in the month of November (238.7534 K) as expected due to the low value of albedo recorded this period, hence, increase in temperature is observed as a result of high amount of radiation been absorbed by the Earth's surface. The lowest emitting Earth surface temperature was observed in the month of August (221.4955K), this is the cloudiest month for this region; the low temperature is expected due to cloud activities resulting in high reflection of solar radiation. In this study, surface temperatures varied from 221.4955 K to 238.7534 K. The results displayed an opposite relationship between the Earth's emitted surface temperature and the planetary albedo.

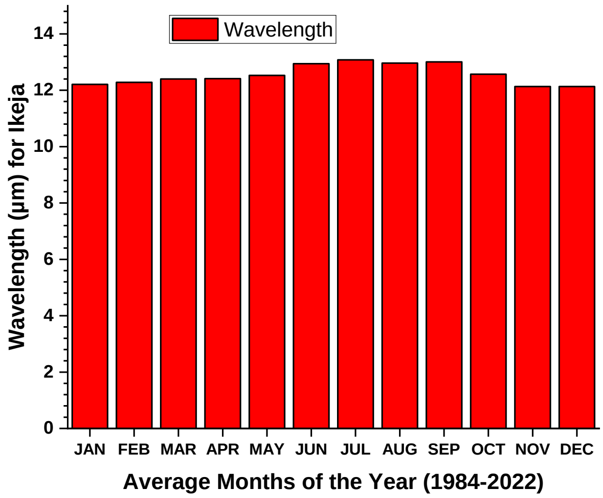

Figure 9: Variation of wavelength (µm) for Ikeja

Figure 9 demonstrates the variability of the monthly average daily maximum emitting wavelength in the research area (Ikeja). From clear observation the peak wavelength was recorded in the month of July (13.0793 µm) and the minimum value was observed in the month of November (12.1339 µm). The wavelength ranged between the values of 12.1339 µm to 13.0793 µm, these values agree with that reported in radiative transfer literatures by Wallace and Hobbs (2006), that for longwave radiation ($\lambda > 4$ µm) demonstrates that Ikeja's radiation is terrestrial, or Earth-emitted, and falls within the infrared spectrum.

Regression Models for Ikeja

The results of the developed two variable multivariate regression models for Ikeja based on equation (11) to (21) are:

$$ALB12 = -0.0441 + 0.00281\,WS + 0.002300\,RH \quad (27a)$$

$$ALB13 = 0.2555 + 0.01237\,WS - 0.00482\,T_{mean} \quad (27b)$$

$$ALB14 = -3.42 + 0.01176\,WS + 0.0353\,PS \quad (27c)$$

$$ALB15 = 0.0773 + 0.002069\,RH - 0.00363\,T_{mean} \quad (27d)$$

$ALB16 = -2.20 + 0.002089\,RH + 0.0216\,PS$ (27e)

$ALB17 = -3.85 - 0.00292\,T_{mean} + 0.0405\,PS$ (27f)

$ALB18 = 0.0771 - 0.00093\,WS + 0.002132\,RH - 0.00374\,T_{mean}$ (27g)

$ALB19 = -0.74 + 0.01198\,WS - 0.00368\,T_{mean} + 0.0096\,PS$ (27h)

$ALB20 = -2.19 + 0.00007\,WS + 0.0216\,PS + 0.002085\,RH$ (27i)

$ALB21 = 3.29 + 0.002240\,RH - 0.00728\,T_{mean} - 0.0310\,PS$ (27j)

$ALB22 = 3.26 - 0.00058\,WS + 0.002278\,RH - 0.00732\,T_{mean} - 0.0308\,PS$ (27k)

Two Variable Regression Models for Ikeja

The modeled two-variable statistical analysis summaries for ALB12 (Eqn 27a) to ALB17 (Eqn 27f) are provided below.

Table 9: Statistical error values of the modeled two variable equations for Ikeja

MODELS	MBE	RMSE	MPE	t-test	R^2
ALB12	0.000051	0.005974	-0.174736	0.028249	73.18
ALB13	-0.000068	0.007500	-0.201365	0.029885	57.73
ALB14	0.008561	0.011433	-5.730555	3.747102	56.84
ALB15	-0.000002	0.005286	-0.113123	0.001452	74.33
ALB16	-0.002543	0.006160	1.500791	1.502892	76.34
ALB17	-0.000845	0.008481	0.235193	0.332036	46.47

Table 9 provide a synopsis of the statistical validation carried out on Ikeja's two-variable regression model. It was observed that ALB15 (Eqn 27d) stands out with the lowest value for RMSE with a recorded value of 0.005286, it also exhibits the lowest value for MPE, recording an underestimation of 0.113123% in its estimated value. ALB15 (Eqn 27d) has the lowest value for MBE and t-test, with an underestimated value of 0.000002 in its estimated value and 0.001452 in its estimated value, respectively, while ALB16 (Eqn 27e) has the highest R^2 value of 76.34%. Furthermore, the results indicate that the MPE values for all the developed two variable multivariate regression models are within the ±10% permissible limit., and the t-tests for ALB12 (Eqn 27a), ALB13 (Eqn 27b), ALB15 (27d), ALB16 (Eqn 27e) and ALB17 (Eqn 27f) are significant both at 95% and 99% confidence level.

Table 10: Ranking of the modeled two variable multivariate regression models for Ikeja

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB12	2	2	2	2	3	11
ALB13	3	4	3	3	4	17
ALB14	6	6	6	6	5	29
ALB15	1	1	1	1	2	6
ALB16	5	3	5	5	1	19
ALB17	4	5	4	4	6	23

Table 10 depicts the ranking obtained from the modeled two variable multivariate regression models for Ikeja. According to the table, each model's ranking ranges from 6 to 29. The overall findings conclude that, in estimating the earths albedo for Ikeja, the model relating relative humidity and mean temperature; model ALB15 (Eqn 27d) displays better performance and accuracy than the other five models in this category.

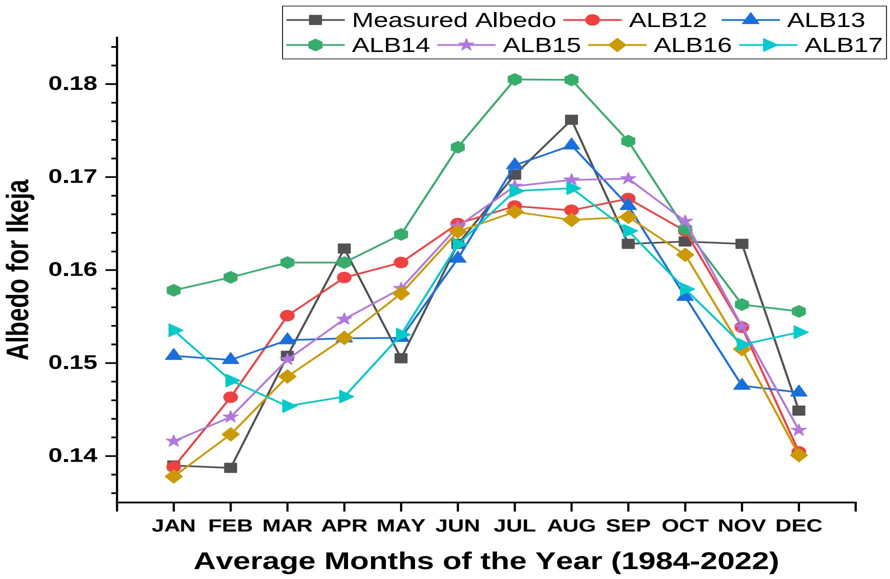

Figure 10: Correlation of two variable regression models for Ikeja

Figure 10 depicts the correlation of the measured albedo and the developed two variable multivariate regression models for Ikeja. This figure implies that ALB12 (Eqn 27a); ALB13 (Eqn 27b); ALB14 (Eqn 27c); ALB15 (Eqn 27d); ALB16 (Eqn 27e) and ALB17 (Eqn 27f). It appears evidently from the figure ALB14 (Eqn. 27c) overestimated the measured albedo in the month of January to March, May to October and December, likewise it underestimated the measured albedo in April and November. The model ALB15 (Eqn. 27d) demonstrated a close pattern of fluctuation with the observed albedo and showed a comparable trend of fluctuation with the measured albedo, and was found to be the most appropriate model for estimating earth surface albedo in Ikeja when compared to other estimated models in this category. Thus, the albedo model relating the wind speed and atmospheric surface pressure was found most suitable in this category.

Statistical Error Values for Three Variable Multivariate Regression Model for Ikeja

The three variable regression models' statistical analysis summaries, from Equation 27g to Equation 27j, are provided below.

Table 11: Statistical error values of the modeled three variable models for Ikeja

Models	MBE	RMSE	MPE	t-test	R^2
ALB 18	0.0001	0.0053	-0.1889	0.0733	79.04
ALB 19	0.0013	0.0076	-1.1044	0.5951	42.03
ALB 20	0.0073	0.0092	-4.7886	4.3023	76.34
ALB 21	0.0059	0.0079	-3.9074	3.8245	80.11

Table 11 summarized the distinct validation tests for the developed three variables multivariate regression models evaluated for the location under study (Ikeja). It was observed that ALB18 (Eqn 27g) stands out with the lowest value of MBE, RMSE, MPE and t-test recording an overestimated value of 0.0001, 0.0053, an underestimated value of 0.1889 % and 79.04 %, respectively. Furthermore, ALB21 (Eqn 27j) has the highest value of R^2 at 80.11 %, the results indicated that the MPE value for all the three variable multivariate models fall within the ±10% permissible limit. And the t-test for ALB18 (Eqn 27g) and ALB19 (Eqn 27h) exhibit statistical significance at 95% confidence level.

Table 12: Ranking of the modeled three variable multivariate models for Ikeja

Models	MBE	RMSE	MPE	t-test	R^2	RANK
ALB18	1	1	1	1	2	6
ALB19	2	2	2	2	4	12
ALB20	4	4	4	4	3	19
ALB21	3	3	3	3	1	13

The ranking derived from the three variable multivariate regression models for Ikeja is shown in Table 12. The table revealed the ranks earned by each model fall between 6 and 19. Overall, the results show that when calculating the earth's albedo for Ikeja, model ALB18 (Eqn 27g), relating wind speed, relative humidity, and mean temperature, outperforms and is more accurate than all of the three variable models in its category.

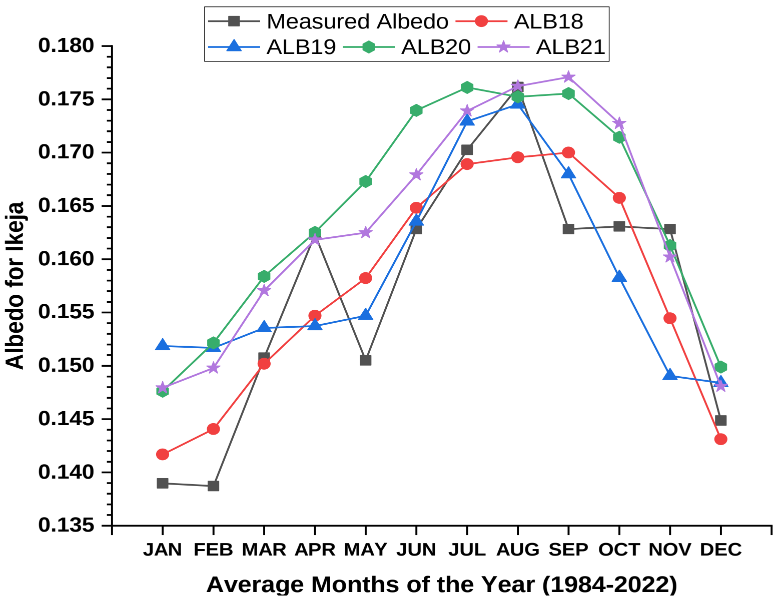

Figure 11: Analysis of three variable regression model for Ikeja

Figure 11 depicts the correlation of the measured albedo and the developed three variable multivariate regression models for Ikeja. Clear observation shows that the ALB20 (Eqn 27i) overestimated the measured albedo and all the other developed model from January to July and December, except for ALB19 (Eqn 27h) which overestimated the measured albedo and other developed model in the month of January. ALB21 (Eqn 27j) overestimating the measured and all other developed model in the months of August to October. ALB18 (Eqn 27g) demonstrated a close pattern of fluctuation with the observed albedo and was found to be the best model for determining Ikeja's earth surface albedo based on the comparison of previous estimated models in this category.

Statistical Error Indicators of Four Variable Model for Ikeja

The results of the developed four variable multivariate regression model for Ikeja is giving below:

Table 13: Ranking of the modeled four variable multivariate models for Ikeja

MODELS	MBE	RMSE	MPE	t-test	R^2 (%)
ALB22	-0.0031	0.0060	1.8535	1.9757	80.1300

The four variable regression model equation ALB22 (Eqn 27k) as seen in Table 13, has underestimation of MBE with a recorded of value of 0.0031 in it estimated value, an overestimation of MPE with a recorded value of 1.8535 % in its estimated values. The RMSE and Coefficient of determination (R^2) recorded are 0.0060 and 80.1300 % respectively. Furthermore, there is statistical significance at 95% for the t-test with a recorded value of 1.9757 and the MPE value fall within the ±10% permissible limit.

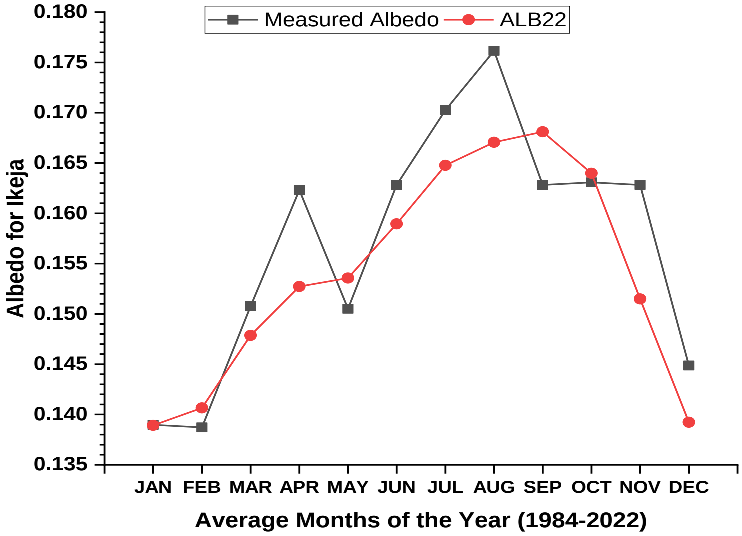

Figure 12: Analysis of four variable regression model for Ikeja

Figure 12 depicts the correlation of the observed and developed four variables multivariate regression model for Ikeja. It is evident that the developed model ALB22 (Eqn 27k) underestimated the measured albedo in the months of January, March to April, June to August and November to December; and overestimated the measured albedo in the months of February, May, September and October.

Statistical Error Indicator for Calculated Albedo (existing model) for Ikeja

The result for the calculated albedo (existing model) is based on equation 6 by Babatunde (2003).

Table 14: Statistical Error indicator for calculated albedo (existing model) for Ikeja

MODELS	MBE	RMSE	MPE	t	R^2
ALB CAL	0.3695	0.3720	-235.5067	28.6811	51.6404

Table 14 displays the statistical error estimates for the computed albedo (existing model) for Ikeja using equation 6. The values in the table clearly show that the calculated albedo (Eqn 6) has MBE value and RMSE value of an overestimation of 0.3695 and 0.3720, respectively; the model also has a very high MPE value, with an underestimated value of 235.5067% when compared to the developed values shown in Tables 9, 11 and 13, and a low R^2 value of 51.64%. The accuracy test results for the calculated albedo (Eqn 6) for Ikeja, with a t-test value of 28.6811, The MPE values fall outside of the acceptable range (MPE < ±10%), is not statistically significant at both 95% and 99% level of confidence.

Table 15: Summary of the best-performing models for Ikeja in each category

MODELS	MBE	RMSE	MPE	t-test	R^2
ALB15	-0.000002	0.005286	-0.113123	0.001452	74.330000
ALB18	0.000117	0.005282	-0.188876	0.073302	79.040000
ALB22	-0.003063	0.005985	1.853498	1.975717	80.130000
ALBcal	0.369543	0.372006	-235.506711	28.681116	51.640400

Table 16: Ranks attained for Ikeja's top-performing models in each category

MODELS	MBE	RMSE	MPE	T	R^2	RANKING
ALB15	1	2	1	1	3	8
ALB18	2	1	2	2	2	9
ALB22	3	3	3	3	1	13
ALBcal	4	4	4	4	4	20

From table 15 and 16, the develop two variable regression model, ALB15 (Eqn 27d) which relates relative humidity and mean temperature was found to perform best in estimating albedo for Ikeja

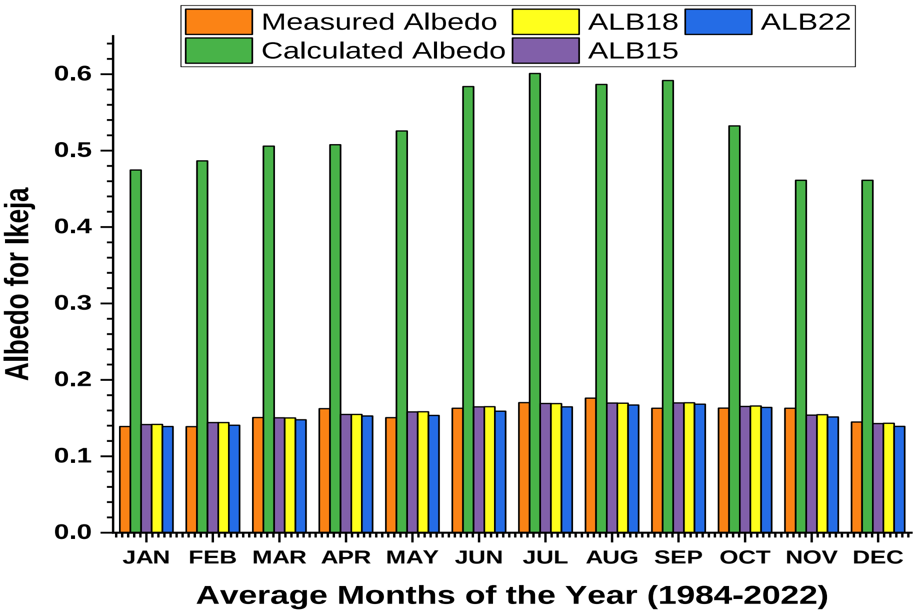

Figure 13: Correlation of the observed albedo, calculated albedo (existing model), best ranked developed two, three and four multivariate regression model for Ikeja

Figure 13 presents the comparison between measured albedo, calculated (existing model - Eqn 6), best ranked developed two, three and four multivariate regression models for Ikeja. The figure implies that ALB15 (Eqn 27d); ALB18 (Eqn 27g); ALB22 (Eqn 27k) and Calculated Albedo (Eqn 6). From clear observation, it is evident from the figure that the calculated albedo (Eqn 6) overestimated both the measured albedo and the best developed two, three and four multivariate regression models from the month of January all through to December. The best ranked developed two, three and four multivariate regression models has close values with the measured albedo and ALB15 (Eqn 27d) which relates relative humidity and mean temperature was stated to be the ideal model for calculating earth emitting surface albedo in Ikeja based on the two, three and four multivariate regression models as compared to the calculated albedo (equation 6). This result follows same trend as that reported by Babatunde (2003), atmospheric parameters responsible for the reflection of global solar radiation in this study area is majorly cloud activities and aerosols.

CONCLUSION

This present investigation employed a dataset covering thirty-nine years (1984 to 2022) to develop new surface albedo estimation models. The dataset included measurements of mean temperature, relative humidity, atmospheric pressure, wind speed, and monthly average of global solar radiation.

Five validation indices - MPE, MBE, RMSE, R^2 and t-test, were used to develop and evaluate a total of eleven models—three categories—based on two, three, and four variable regression models. The outcomes derived from the models developed for Owerri, two variable models' category, ALB1 (Eqn 26a) was found appropriate; ALB7 (Eqn 26g) was found appropriate for three variable category and ALB11 (Eqn 26k) was found appropriate for four variable categories. Likewise, for Ikeja in two variable models' category, ALB15 (Eqn 27d) was found appropriate; ALB18 (Eqn 27g) was found appropriate for three variable category and ALB22 (Eqn 27k) was found appropriate for four variable categories. All the developed models that stood out the most were ranked according to their suitability for estimating surface albedo. For Owerri, the three-variable regression model ALB7 (Eqn. 26g) which relates the wind speed, relative humidity and mean temperature performed best, while ALB15 (Eqn. 27d) which relates relative humidity and mean temperature performed best for estimating surface albedo for Ikeja, which are located in Nigeria's coastal climatic zones. The fact that each model's validation indicator values and multivariate regression equations vary between Owerri and Ikeja shows that the models are typically site-specific and need to be calibrated before being used to predict surface albedo values in any location other than the one for which they were developed, since the meteorological parameter values vary depending on the locations latitude and longitude. Hence, when albedo measure data are unavailable and the site exhibits similar climatic conditions as the research area, the output of the recently developed albedo models can be utilized to estimate surface albedo. The result also showed that these models performed better and preferred as compared to the generalized used equation for albedo estimation as provided by Babatunde (2003). The emitting Earth surface temperature for Owerri ranged from 219.1845 K in August to

239.6133 K in January, while for Ikeja varies from 221.4955 K in August to 238.7534 K in November. The emitted wavelength values for both study area indicate that the radiation is longwave and is present in the electromagnetic spectrum's infrared region.

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