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Original Research Article

Investigation of Downward Longwave Radiation under Clear-Sky Condition Using Atmospheric Emmisivity Equations Over Ikeja, Nigeria

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Abstract

Downward Longwave Radiation (DLR) plays a crucial role in sustaining the temperature of the Earth's surface and is vital for maintaining the planet's energy equilibrium. In this study, eight different emissivity equations were utilized to estimate DLR models and to investigate which is more suitable for evaluating DLR in Ikeja, when statistically tested using five validation indices of Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-statistic and Index of Agreement (IA). The impact of some meteorological parameters on DLR was investigated. The data used were obtained from the National Aeronautics and Space Administration (NASA) for a period of 39 years (1984 to 2022), the meteorological parameters are monthly average temperature, relative humidity (RH), DLR and Global Solar Radiation (GSR). Findings indicated that Ikeja recorded its highest value of DLR in April with 425.6915 Wm^{-2}, and its lowest value was in January with 406.2774 Wm^{-2}. The Kruk *et al.* model was found more accurate for evaluating DLR in Ikeja, indicating that in the absence of measured DLR data, Kruk *et al.* model is highly recommended for estimating DLR in Ikeja. As the temperature is low during the rainy season, the DLR is high and as the temperature is high during the dry season, the DLR is low. The DLR and RH are high during the rainy season and low during the dry season. The average DLR and GSR values obtained were found to be 418.1707 Wm^{-2} and 195.5164 Wm^{-2} respectively, this indicate that the DLR values are twice as much as the GSR during the period under investigation.

Keywords: DLR, Emissivity Equations, Ikeja, Meteorological Parameters, NASA.

1. INTRODUCTION

The Earth's atmospheric weather and climate are naturally controlled by the Sun. The amount of solar energy that reaches the Earth's surface has changed over the past few decades, especially since the industrial revolution [1]. A portion of the shortwave radiation that is absorbed by the Earth's surface, atmosphere, and clouds can be reemitted as longwave radiation. Additionally, the Earth's surface and atmosphere have the ability to absorb and reflect the longwave radiation that is released [2]. The energy available at an evaporating surface is calculated using the energy balance principles, and in order to do so, precise information regarding net radiation is required. Occasionally, the energy available at an evaporating surface is measured by measuring net radiation. The accuracy of the measurements or estimates of the other parameters used as input determines how precise the net radiation value obtained from the radiation balance is [3]. The abundance of water vapour and aerosols, such as cloud water droplets, CO$_2$, and O$_3$ molecules, which release heat infrared energy, affects the quantity of downward longwave radiation [4]. Because longwave radiation is non-traditional, it is difficult and expensive to measure compared to shortwave radiation, which is why meteorological stations rarely use it [5].

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The most important component of the surface energy balance is the downward longwave radiation (DLR), which is about twice as much as the downward shortwave radiation that reaches the Earth's surface [6]. The DLR at the earth's surface has significantly increased during the process of global warming [7]. The warming and moistening of the atmosphere, both of which contribute favourably to this trend, are intimately related to the rise in DLR. Gaining a comprehensive grasp of the complex spatiotemporal changes in DLR is necessary for improving weather forecasting, climate modelling, and water cycle simulations. It is also critical for comprehending the ramifications of these fluctuations. Regrettably, errors in DLR are significantly more pronounced compared to errors in any other element of the surface energy budget, this is most likely because there aren't many high-quality DLR observations available [7].

The unclouded sky DLR is frequently calculated using parameterizations that consider water vapour density and surface air temperature. At the temperature measured at screen level, it is assumed that the clear sky radiates towards the surface like a grey body. Many DLR parameterisation methods have been developed, where the screen-level temperature and water vapour pressure are used to calculate the effective emissivity of clear sky. Alternatively, these parameterisation formulas use localised coefficients with defined functions. An essential part of the energy exchange mechanism between the Earth's surface and atmosphere is DLR reaching the surface [8-11]. Nonetheless, the emissivity would be less than one $(\varepsilon < 1)$ in an environment with a homogeneous, isothermal atmosphere and not reliant on temperature unless the atmosphere maintained a consistent level of greyness. It is anticipated that emissivity in the real environment will vary according to temperature, T_a [8, 12]. Furthermore, some research has shown that the dew point temperature (T_d) might affect the measured emissivity [13], water vapour pressure (e_a) and atmospheric temperature (T_a) [14-17], relative humidity (RH) and T_a [18], and may also be influenced by the total amount of water vapor [19].

Several studies have been carried out to investigate DLR. Cho *et al.*, [20], examined the evaluation of parameterizations for clear and overcast skies for daily downwelling longwave radiation across various land surfaces in Florida, USA. According to their findings, the Brunt [21], equation fared marginally better on every site they examined for their research. Cho *et al.*, [22], used the daily and monthly mean data recorded at King Sejong Station from 1996 to 2006 to investigate the impacts of air temperature, specific humidity, and cloudiness on the variation of downward longwave irradiance and their long-term trends. Their results showed that, after adjusting for the small warming effect of cloudiness, the net cooling effect from air temperature and specific humidity is what causes the reduction in DLR. Other studies include [23 – 28], to mention but a few.

The radiation balance equation at the surface as reported by Tanaka *et al.*, [29], is given by

$$R_n = \hat{S}_d - S_{ref} + L_d - L_{surface} \qquad (1)$$

where $\hat{S}_d$ is the incident solar radiation flux, S_{ref} is the reflected solar radiation flux which is related to albedo, L_d is the atmospheric longwave radiation flux or DLR and $L_{surface}$ is the surface longwave radiation flux which is related to the Earth's surface temperature and albedo as well [29].

The objectives of this paper are to (i) Compute and compare eight emissivity equations for Ikeja situated across the coastal region of Nigeria (ii) Estimate eight DLR for Ikeja and compare the eight emissivity equations based on the estimated DLR using five statistical validation indices for Ikeja (iii) Rank the eight emissivity equations to ascertain which of the equation reliably estimate DLR for Ikeja (iv) Correlate the estimated DLR with the measured DLR for Ikeja (v) Examine the impact of meteorological parameters on DLR for Ikeja.

2. METHODOLOGY

The climatic data for air temperature, relative humidity (RH), Downward Longwave Radiation (DLR) and Global Solar Radiation (GSR) for Ikeja (Lat. 6.58°N, Long. 3.33°E) over a thirty – nine years (1984 to 2022) period used in this study were sourced from NASA.

The equation for the clear-sky, L_d has the general form as reported in [5, 30].

$$L_d = \varepsilon_a \sigma T_a^4 \qquad (2)$$

where T_a is the air temperature near-surface, ε_a is the emissivity of the clear-sky atmosphere and $\sigma = 5.67051 \times 10^{-8}\ \mathrm{Wm^{-2}k^{-4}}$ is the Stefan-Boltzmann constant. Stefan-Boltzmann's law for the radiation emitted by a grey substance at uniform temperature serves as the inspiration for equation (2), as stated in [5] and [30]. All the equations analyzed in this study assumed that ε_a is a function of temperature and/or vapor pressure near the ground.

The relationship between water vapour pressure, e_a and relative humidity is given by the expression as reported by [31, 33].

$$e_a = \frac{He_s}{100} \qquad (3)$$

where

$$e_s = a\exp\left(\frac{bt}{t+c}\right) \qquad (4)$$

Where H is the relative humidity (%), t is the Celsius temperature (°C) and e_s is the saturation vapour pressure (hPa) at temperature (°C). The values of the coefficients $a, b, and\ c$ (for water and ice) are presented in [34]. In this study, that for water were adopted and are given as $a = 6.1121$, $b = 17.502$ and $c = 240.97$ and are valid between -20°C to + 50°C with an accuracy of $\pm 0.20\%$.

The eight (8) emissivity equations of clear-sky parameterizations based on air temperature, $T(K)$, and water vapour pressure, e_a (Pa) can be obtained as follows:

(i) The emissivity of clear-sky parameterizations, according to Swinbank *et al.* [12] is given by

$$\varepsilon_a = 9.365 \text{ x } 10^{-6} T^2 \qquad (5)$$

(ii) The emissivity of clear-sky parameterizations, according to Idso and Jackson [8]:

$$\varepsilon_a = 1 - 0.261\exp[-7.77 \text{ x } 10^{-4}(273 - T)^2] \qquad (6)$$

(iii) The emissivity of clear-sky parameterizations, according to Brutsaert [14]:

$$\varepsilon_a = 0.643\left(\frac{e_a}{T_a}\right)^{\frac{1}{7}} \qquad (7)$$

(iv) The emissivity of clear-sky parameterizations, according to Idso [16]:

$$\varepsilon_a = 0.70 + 5.95\times10^{-7} e_a \exp\left(\frac{1500}{T_a}\right) \qquad (8)$$

(v) The emissivity of clear-sky parameterizations, according to Sugita and Brutsaert [35]:

$$\varepsilon_a = 0.714\left(\frac{e_a}{T_a}\right)^{0.0687} \qquad (9)$$

(vi) The emissivity of clear-sky parameterizations, according to Duarte *et al.*, [30]:

$$\varepsilon_a = 0.625\left(\frac{e_a}{T_a}\right)^{0.131} \qquad (10)$$

(vii) The emissivity of clear-sky parameterizations, according to Kruk *et al.*, [5]:

$$\varepsilon_a = 0.576\left(\frac{e_a}{T_a}\right)^{0.202} \qquad (11)$$

(viii) The emissivity of clear-sky parameterizations, according to Prata *et al.*, [36]:

$$\varepsilon_a = \{1-(1+\xi)\exp[-(1.2+3.0\xi)^{0.5}]\} \qquad (12)$$

where

$$\xi = 0.465\left(\frac{e_a}{T_a}\right)$$

2.1 Accuracy Assessment of the Models

By computing the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t statistic and Index of Agreement (IA) for each model, the estimated DLR values derived from the emissivity equations were compared with the measured/observed DLR values for Ikeja. The formula according to El-Sebaii and Trebea [37], as reported by [38 – 40] was used to calculate the MBE, RMSE, and MPE.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(L_{d\,i,cal} - L_{d\,i,mea}\right) \qquad (13)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(L_{d\,i,cal} - L_{d\,i,mea})^2\right]^{\frac{1}{2}} \qquad (14)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{L_{d\,i,mea} - L_{d\,i,cal}}{L_{d\,i,mea}}\right)\times100 \qquad (15)$$

The quantity t, called the t statistic (or briefly t - test), is given by the expression according to Bevington [41], as reported by [42, 43].

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2}\right]^{\frac{1}{2}} \qquad (16)$$

The Index of Agreement (IA) is given by the expression according to Willmott [44], as reported by Akpootu *et al.* [45].

$$IA = 1 - \frac{\sum_{i=1}^{n}\left(L_{d\,i,cal} - L_{d\,i,mea}\right)^2}{\sum_{i=1}^{n}\left(\left|L_{d\,i,cal} - \bar{L}_{d\,i,mea}\right| + \left|L_{d\,i,mea} - \bar{L}_{d\,i,mea}\right|\right)^2} \qquad (17)$$

From equations (13) – (17), $L_{di,mea}$, $L_{di,cal}$ and n are respectively the ith measured and ith calculated values of monthly DLR and the total number of observations [46–48], have suggested that a low RMSE and MPE are preferable, and that a zero value for MBE is optimal. As a result, the model performs better if the MBE, RMSE, MPE, and t-test values are smaller. The average level of overestimation in the computed values is provided by positive MPE and MBE values, whereas underestimating is provided by negative values [49], stated that the computed t-value must be less than the critical value for the crucial t-value, that is, at a level of significance and degree of freedom ($t_{critical} = 2.20$, $df = 11$, $p < 0.05$) for 95% and ($t_{critical} = 3.12$, $df = 11$, $p < 0.01$) for 99% [50], has reported that the percentage error between −10% and +10% is the acceptable range. The better the model, the closer the IA values are to 1.0 (100%) [48]. IA and MPE are expressed in percentages

(%), whereas MBE and RMSE are expressed in Wm^{-2}. The t-test is unitless.

3. RESULTS AND DISCUSSION

Table 1: Statistical error indicators for the eight estimated DLR models over Ikeja

Models	MBE	RMSE	MPE	t	IA
Swinbank *et al*., (DLR1)	-35.1950	36.0054	8.4068	15.3668	0.1898
Idso & Jackson (DLR2)	-31.2374	32.2026	7.4606	13.2402	0.2064
Brutsaert (DLR3)	-12.7191	14.0025	3.0375	7.2034	0.4203
Idso (DLR4)	18.7515	19.6153	-4.4821	10.8031	0.3888
Sugita & Brutsaert (DLR5)	-37.6712	38.1027	9.0006	21.8524	0.1893
Duarte *et al*., (DLR6)	-34.5306	34.9844	8.2530	20.3907	0.2100
Kruk *et al*., (DLR7)	-2.8034	6.8205	0.6698	1.4954	0.7384
Prata *et al*., (DLR8)	-16.4608	17.4505	3.9314	9.4237	0.3591

The statistical validation test for the eight estimated DLR models is summarized in Table 1 for this study. From the above table, it was observed that Kruk *et al*., [5]. (DLR7) had the lowest values for Mean Bias Error (MBE) and Mean Percentage Error (MPE) with underestimation of 2.8034 Wm^{-2} and overestimation of 0.6698 in its estimated values respectively and also had the lowest values of 6.8205 Wm^{-2} for RMSE and 1.4954 for t statistic which indicated that Kruk *et al*., [5]. (DLR7) performed better when compared to other models in this study. Kruk *et al*., [5]. (DLR7) also shown the highest IA value of 0.7384 (73.84%) which suggested that it outperformed other models in this study. The results indicated that the MPE for all the eight estimated DLR models fall within the acceptable range of ± 10 % while the t – test value for Kruk *et al*., [5]. (DLR7) is statistically significant at the 95 % and 99 % confidence level, whereas the t – test values for the other estimated DLR models for this study are not.

Table 2: Ranks derived from the analysis of the eight estimated DLR models over Ikeja

MODELS	MBE	RSME	MPE	t	IA	RANK
Swinbank *et al*., (DLR1)	7	7	7	6	7	34
Idso & Jackson (DLR2)	5	5	5	5	6	26
Brutsaert (DLR3)	2	2	2	2	2	10
Idso (DLR4)	4	4	4	4	3	19
Sugita & Brutsaert (DLR5)	8	8	8	8	8	40
Duarte *et al*., (DLR6)	6	6	6	7	5	30
Kruk *et al*., (DLR7)	1	1	1	1	1	**5**
Prata *et al*., (DLR8)	3	3	3	3	4	16

The ranking summary based on the statistical validation test for the eight estimated DLR models over Ikeja is presented in table 2. It is clear from the table that the ranks obtained from each of the estimated DLR models vary between 5 and 40. Kruk *et al*., [5]. (DLR7) demonstrates superior accuracy in comparison to the other estimated DLR models based on the statistical validation test as it has the lowest ranking value of 6 and therefore was found to be most suitable for estimating DLR for Ikeja.

Figure 1 illustrates the variation of the measured DLR with the eight estimated DLR models over Ikeja. From the illustration, it was observed that Idso [16]. (DLR4) overestimated the measured DLR and other evaluated DLR models from the month of January to December while Sugita & Brutsaert [35]. (DLR5) underestimated the measured DLR and other evaluated DLR models from January to December except for Swinbank *et al*., [12]. (DLR1) which underestimates the measured DLR and other evaluated DLR models from July to September. Swinbank *et al*., [12]. (DLR1), Sugita & Brutsaert [35]. (DLR5) had similar patterns of variation especially from the month of July with value 372.8641 Wm^{-2} and 372.9400 Wm^{-2} respectively and in the month of August with value 370.4214 Wm^{-2} and 370.7676 Wm^{-2} respectively as well as the month of September with value 374.1879 Wm^{-2} and 374.2794 Wm^{-2} respectively. Kruk *et al*., [5]. (DLR7) has a comparable pattern of variation with the measured DLR and was found to be the most appropriate model for estimating DLR for Ikeja when compared to other models in this category.

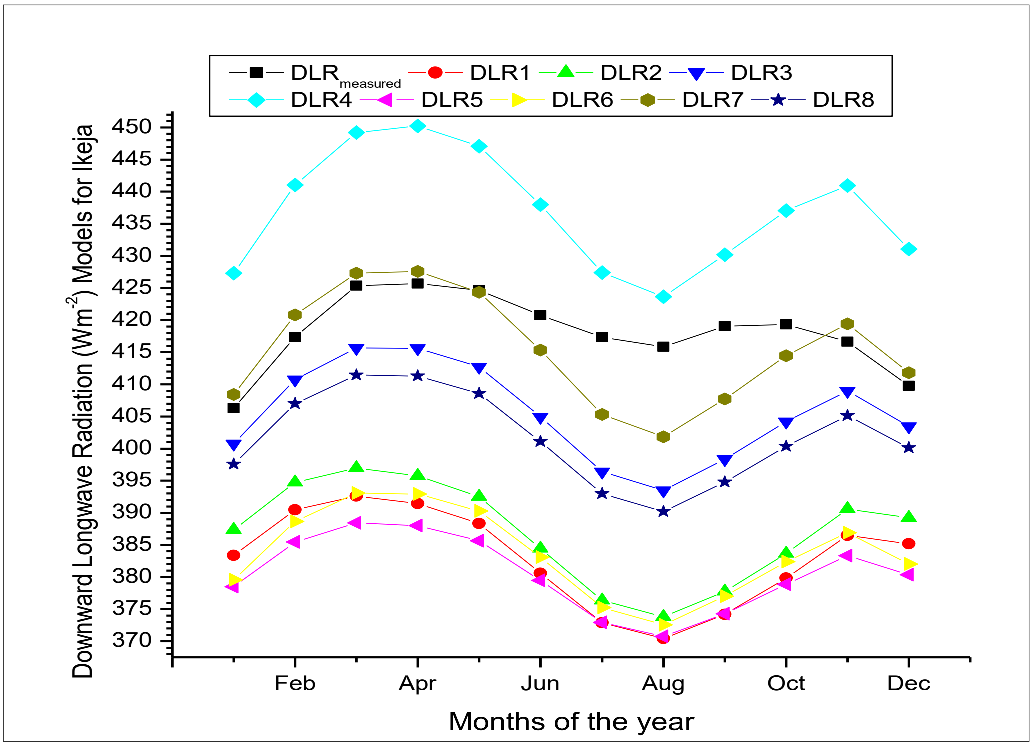

Figure 1: Variation of measured DLR with the eight estimated DLR models over Ikeja

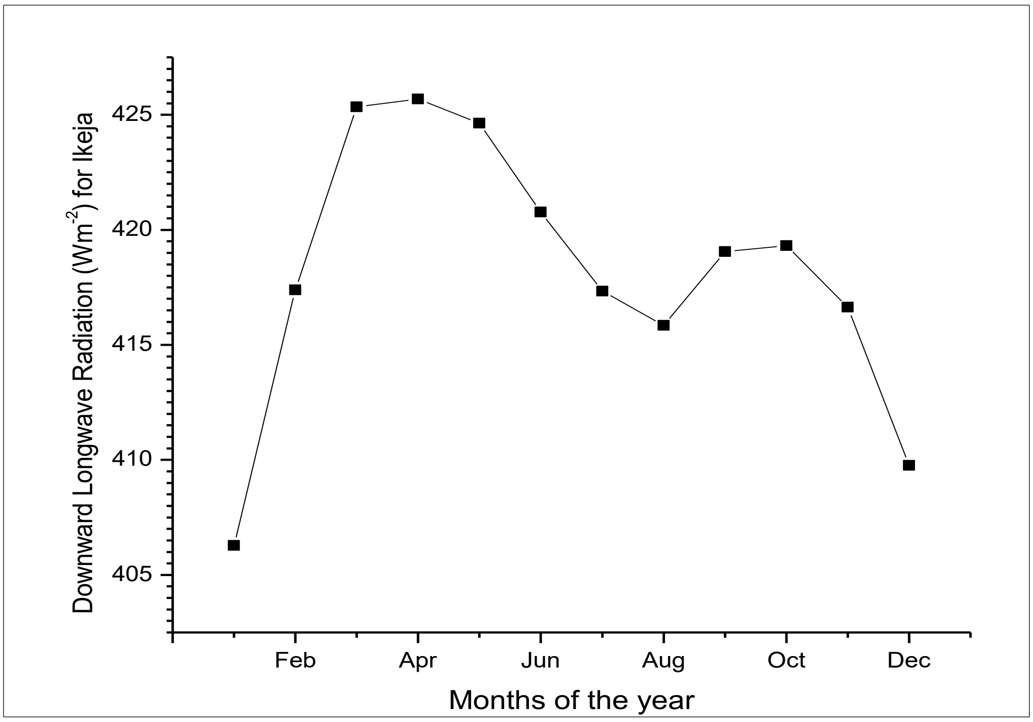

Figure 2: Variation of the measured DLR over Ikeja

Figure 2 illustrates the variation of DLR over Ikeja for the period under investigation. The DLR at Ikeja shows gradual increase from a minimum value of 406.2774 Wm^{-2} in the month of January until it reaches its peak at 425.6915 Wm^{-2} in the month of April and decreases gradually until it gets to 415.8485 Wm^{-2} in August. It then suddenly increases and reached another high value of 419.3126 Wm^{-2} in the month of October and drastically drop to 409.7626 Wm^{-2} in December. The maximum value of DLR was observed in April with 425.6915 Wm^{-2} and the minimum value was observed in the month of January with 406.2774 Wm^{-2}. This suggests that the changes in the variation can be linked to the rainfall patterns in Ikeja over the period under investigation. The results show that high values of DLR are observed during the rainy season (April to October) with an average value of 420.3786 Wm^{-2} and low values are observed during the dry season (November to March), with an average value of 415.0797 Wm^{-2}. The noticeable drop in the value of DLR for Ikeja is due to August break which indicates a short period of dryness. The high values which were observed during the rainy season (April to October) are due to increased cloud cover and moisture in the atmosphere, which trap heat and prevent it from escaping back into space and this results in a greater amount of DLR which was observed in Ikeja as 425.6915 Wm^{-2} in the month of April that is being emitted towards the Earth's surface. This means that during the rainy season in Ikeja, the combination of cloud cover, moisture in the atmosphere, humidity, and weather patterns lead to high values of DLR in the city while the lower values which was observed during the dry season in the city of Ikeja are due to clear skies which allow for more direct sunlight to reach the Earth's surface, leading to higher daytime temperatures and subsequently lower longwave radiation.

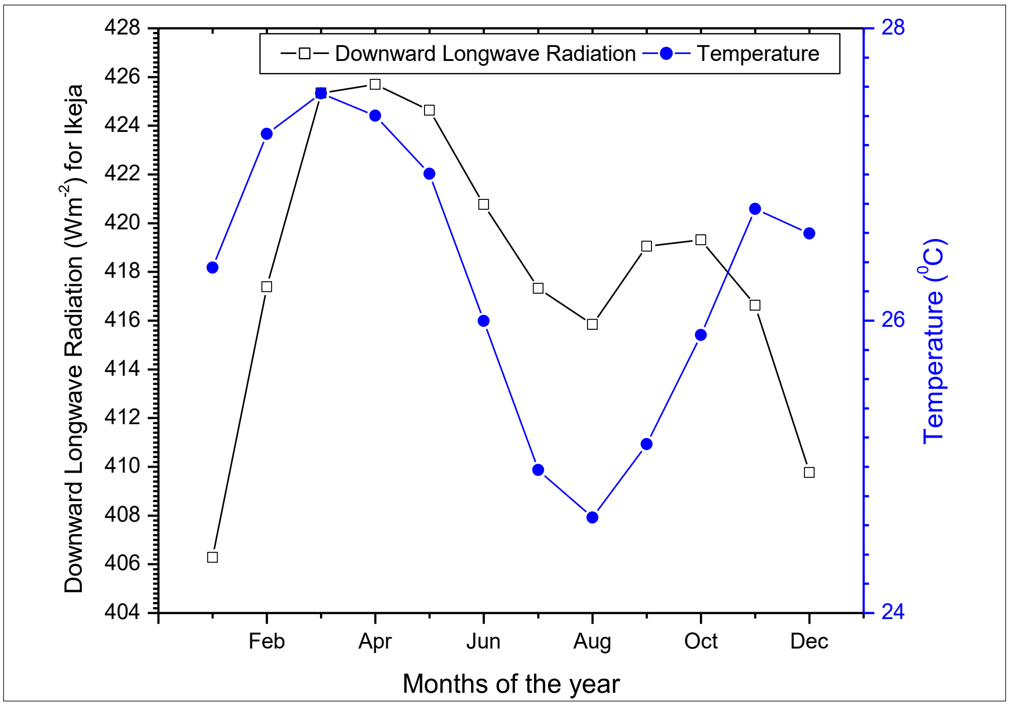

Figure 3: Variation of the measured DLR with temperature over Ikeja

The comparison between the measured DLR with temperature in Ikeja is illustrated in figure 3. It is evident from a careful observation that both the temperature and the measured DLR increased from the month of January and reached its highest point with the value 27.5536 °C and 425.6915 Wm^{-2} in the month of March and April respectively. The temperature and DLR experienced a decline with value 24.6521 °C and 415.8485 Wm^{-2} respectively in the month of August. From the month of August, the measured DLR and temperature was observed to have a slight increase to October and November with the value of 419.3126 Wm^{-2} and 26.7649 °C respectively and decreased in December. The average value of the measured DLR during the rainy and dry seasons are 420.3786 Wm^{-2} and 415.07974 Wm^{-2} respectively while the average value of the temperature during the rainy and dry seasons are 25.8701℃ and 26.9106 ℃ respectively. This indicates that the measured DLR is high during the rainy season with a low temperature which implies that the decrease in temperature during the rainy season contributes to higher levels of DLR as cooler temperatures can result in more heat that is being radiated back to the surface of the earth, while during the dry season, the measured DLR is low with a slightly high temperature because of the combination of fewer clouds, lower humidity, and higher surface temperatures during the dry season results in lower DLR compared to the rainy season.

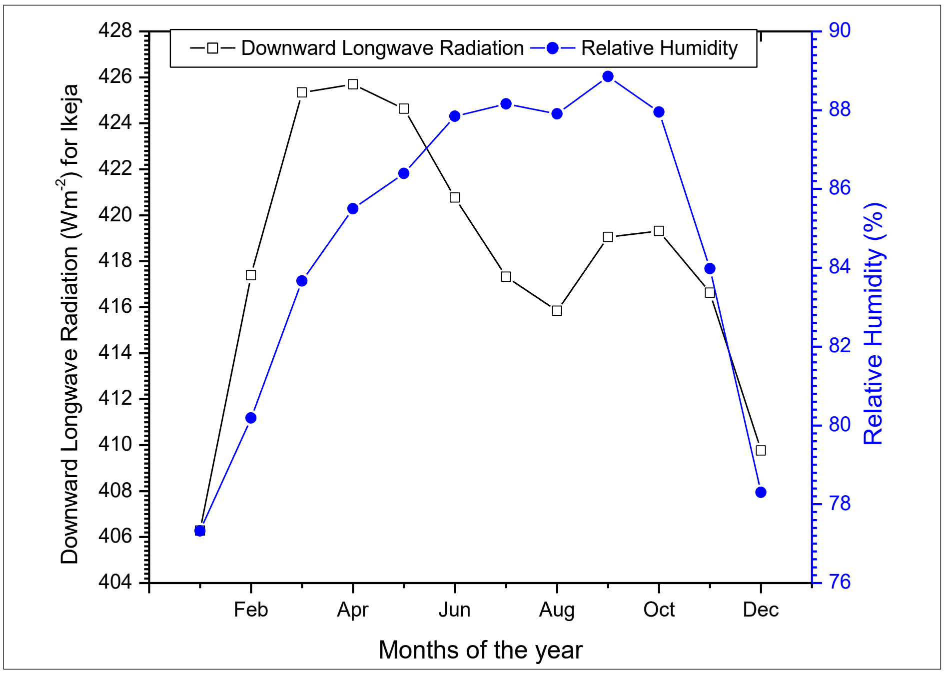

Figure 4: Variation of the measured DLR with relative humidity over Ikeja

It was observed in figure 4 that the measured DLR with relative humidity in Ikeja gradually rose throughout the month of January. As the measured DLR reached its peak in the month of April with the value of 425.6915 Wm^{-2}, the relative humidity reached a high value of 88.1590 % in the month of July. The DLR and RH have a slight decrease in the month of August. The measured DLR alongside with the relative humidity have a slight increase from the month of August and reached a high value of 419.3126 Wm^{-2} in the month of October while the relative humidity reached its peak with the value of 88.8569 % in the month of September and they both decreases to a minimum value in the month of December. The average measured DLR during the rainy season is 420.3786 Wm^{-2} and 415.07974 Wm^{-2} during the dry season. While the average relative humidity during the rainy and dry seasons are 87.5160 % and 80.6928 % respectively. From the result, it is clear that the measured DLR and relative humidity are high during the rainy season and low during the dry season. This implies that the presence of moisture in the air influences cloud formation, which in turn affects the amount of DLR during the rainy season while during the dry season, there is typically a decrease in cloud cover and precipitation, which result in less moisture in the atmosphere and this leads to the fact that the air has a reduced capacity to hold water vapour which means there is less water vapour in the air to absorb and trap the longwave radiation emitted by the Earth's surface which leads to decrease in DLR during the dry season.

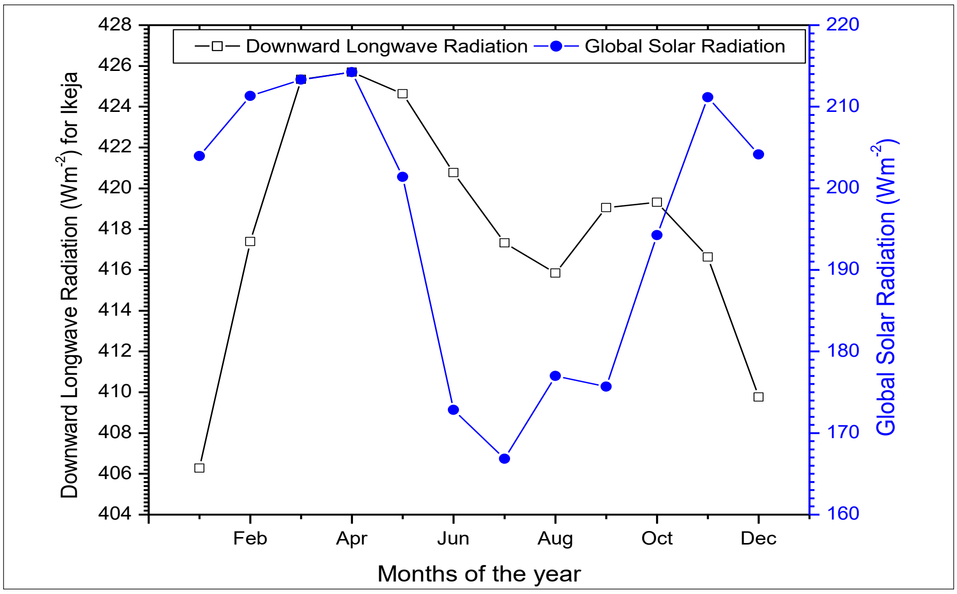

Figure 5: Variation of the measured DLR with global solar radiation over Ikeja

Figure 5 displays the variation of the measured DLR with global solar radiation for Ikeja. The measured DLR and the global solar radiation increase throughout the month of January and reached their peak with the value 425.6915 Wm^{-2} and 214.2415 Wm^{-2} respectively in the month of April respectively. The global solar radiation reduces to its minimum value of 166.8483 Wm^{-2} in the month of July while the measured DLR decreases to 415.8485 Wm^{-2} in the month of August. It was observed that the DLR decreases in the month of August whereas the global solar radiation increases in the month of August which implies that the patterns of variation observed in the month of August are due to the combination of lower cloud cover and moisture as well as the Earth's orbital position and tilt. The global solar radiation slightly decreases in the month of September and increases in the month of November while the measured DLR slightly increases from the month of August to October and both the measured DLR and global solar radiation finally decreases in the month of December. This decrease in DLR and global solar radiation in the month of December are due to lower temperatures leading to reduction in the amount of water vapour that the air can hold which reduces the incoming solar radiation as the sun's rays are less direct and have to pass through a greater thickness of the atmosphere before reaching the Earth's surface and this leads to lower level of energy input into the Earth's system resulting in lower levels of DLR during the dry season months. The average value of the measured DLR during the rainy and dry seasons are 420.3786 Wm^{-2} and 415.07974 Wm^{-2} respectively while the average value of the global solar radiation during the rainy and dry seasons are 186.0409 Wm^{-2} and 208.7821 Wm^{-2} respectively. This clearly shows that the measured DLR is high during the rainy season while the global solar radiation is low during the rainy season. It was also observed that the measured DLR is low during the dry season while the global solar radiation is high during the dry season. The average DLR and GSR values obtained in this study were found to be 418.1707 Wm^{-2} and 195.5164 Wm^{-2} respectively indicating that the DLR is slightly above twice the values of the GSR. This finding is in line with the study reported by Trenberth *et al.* [51] and Wild *et al.* [52] where they reported that the global mean surface energy budget, DLR is dominant surface energy input (333 W m^{-2} in global mean and 306 W m^{-2} over land), contributing around twice as much energy as absorbed solar radiation (161 W m^{-2} in global mean and 184 W m^{-2} over land).

4. CONCLUSION

This study employed eight emissivity equations to estimate DLR in Ikeja situated across the coastal region of Nigeria so as to ascertain which of the emissivity equations is most accurate and suitable for evaluating DLR based on five (5) statistical validation indices of Mean Bias Error (MBE), Mean Percentage Error (MPE), Root Mean Square Error (RMSE), t statistic and Index of agreement (IA). The impact of meteorological parameters on DLR was also investigated. The meteorological parameters of temperature, RH, GSR, and DLR for Ikeja in this present study were sourced from NASA covering a period of thirty-nine years from 1984 to 2022. The results obtained from this study led to the following conclusions:

I. The Kruk *et al*., (DLR7) was found to be the most suitable and accurate model for evaluating DLR in Ikeja situated across the coastal region of Nigeria, as it has the lowest ranking value of five (5) when statistically tested using the MBE, MPE, RMSE, t – statistic and IA as compared to other estimated DLR models.
II. The correlation patterns of variation of the measured DLR with the eight estimated DLR models, indicated that the Kruk *et al*., (DLR7) performed better for estimating DLR in Ikeja, as it was observed to have a similar pattern of variation with the measured DLR which attests to its closeness in values.
III. The peak value of DLR was recorded as 425.6915 Wm^{-2} in the month of April during the rainy season while its minimum value was recorded as 406.2774 Wm^{-2} in the month of January during the dry season.
IV. The average values of DLR during the rainy season was observed to be 420.3786 Wm^{-2} while during the dry season, it was observed to be 415.0797 Wm^{-2} which implies that DLR is higher during the rainy season and lower during the dry season in Ikeja which is situated in the coastal region of Nigeria.
V. It was found that DLR is higher with low temperature during the rainy season and lower with high temperature during the dry season. DLR and RH are higher during the rainy season and lower during the dry season. DLR is higher with a lower GSR during the rainy season while DLR is lower with a higher GSR during the dry season. The average values of the DLR are slightly higher than twice the values of GSR for the studied period.

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