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Research paper

Modeling the influence of cloudiness on diffuse horizontal irradiation under various sky conditions in Nigeria

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Abstract

In this study, modeling the influence of cloudiness on diffuse horizontal irradiation (DHI) in six tropical ecological zones in Nigeria (Latitude 4.75-13.067ºN and Longitude 3.333-13.16ºE) using 22-year data (July 1983- June 2005) was analysed for all sky and clear sky conditions. The result revealed that the absorption of DHI in the global horizontal irradiation (GHI) portion of the solar spectrum is greatly enhanced in the Southern tropical zones as a result of heavy presence of smog, cloudiness, and high water vapour parameters such as relative humidity, dew point temperature and precipitable water thereby increasing the diffuse fraction in the zone. However, in the Northern tropical zones, the absorption of DHI in the GHI portion of the solar spectrum lowered due to presence of low smog, cloudiness and low water vapour parameters thereby reducing the diffuse fraction in the region. The quadratic regression correlation model developed deeming from the model performance test indicates that the proposed model could be used to estimate DHI accurately over the six tropical ecological zones in Nigeria and other locations with comparable sky condition to Nigeria.

Keywords: *Equatorial Line; Diffuse Fraction; Clearness Index; Diffuse Horizontal Irradiation; Sky Conditions*

1. Introduction

Diffuse horizontal irradiation (DHI) is the component of global horizontal irradiation (GHI) reaching the earth's surface after having been scattered from the direct horizontal irradiation (BHI) by molecules, aerosols or suspended particular matter such as black carbon, organic carbon, dust and sea salt in the atmosphere. DHI plays an important role in determining the gross primary productivity, net ecosystem exchange of carbon dioxide, light use efficiency, changing colour of the sky and baseline for estimating and understanding DHI parameters such as DHI and GHI on the titles surfaces, diffuse Photosynthetically active radiation (PAR), near infrared radiation (NIR), reflected BHI and GHI.

Therefore, the accurate determination and clear understanding of the DHI parameters is required for many applications such as energy management, solar energy, light studies, architectural research, hydrological process and biometeorology, crop production, remote sensing of vegetable and carbon cycle modelling, development of thermal and electrical solar energy devices [1-4].

DHI arises as a result of the interaction between the solar radiation incident on the top of the earth's atmosphere and the matter within it. Thus, understanding how this radiometric flux interact with the matter within it and relates with its immediate environment thereby influencing diffuse light availability for energy, sky colour, agricultural, material and technological production and utilization for man's need is of almost important for modeling and estimating DHI in a particular geographical environment.

Measurement of DHI is often performed in many parts of the world by mounting a pyranometer on the axis of the ring on a roof top so as to receive only DHI, and the ring is normally adjusted regularly so as to ensure that the direct irradiance does not reach the pyranometer.

In spite of the enormous significance of DHI, there is no standard weather station able to measure this radiation component in Nigeria and often there is no data available in the location of interest except National Aeronautics and Space Administration (NASA) atmospheric science data among others satellite radiometric agencies across the globe.

To overcome these shortcomings, different estimation models have been proposed in different locations across the world [5-16].

It is therefore imperative to analyse DHI using GHI and clearness index obtained from NASA data. This will produce DHI data as a baseline for further scientific, environmental and atmospheric research without the substantial cost of the instrumentation network that would otherwise be needed [17-19]. The aim of this research paper is to develop an empirical model for estimating DHI in six tropical ecological zones in Nigeria.

2. Methodology

2.1. Acquisition of data and study area

The long term monthly mean daily diffuse horizontal irradiation (DHI), global horizontal irradiation (GHI), clearness index for clear sky (k_t) for the period of 1983-2005 for the selected state capitals and locations whose tropical ecological zones, coordinates and elevations listed in Table 1 and Fig. 1 were obtained from the National Aeronautics and Space Administration (NASA) atmospheric science data center. The GHI and DHI data measured in kwhm^{-2}day^{-1} were converted to MJm^{-2}day^{-1} using a factor of 3.6. The details of the study area are found in Nwokolo and Ogbulezie [19].

Table 1: States, State Capitals, Coordinates and Tropical Ecological Zones for the Selected Stations in Nigeria

States	State Capitals	Latitude (Degree North)	Longitude (Degree East)	Elevation (Meters)	Tropical Ecological Zones
Rivers	Port Harcourt	4.75	7.00	117	Mangrove Swamp
Imo	Owerri	5.485	7.035	176	Mangrove Swamp
Oyo	Ibadan	7.378	3.947	183	Tropical Rain Forest
FCT	Abuja	9.067	7.483	484	Guinea Savannah
Borno	Maiduguri	11.85	13.16	377	Sudan Savannah
Sokoto	Sokoto	13.067	5.233	331	Sahel Savannah

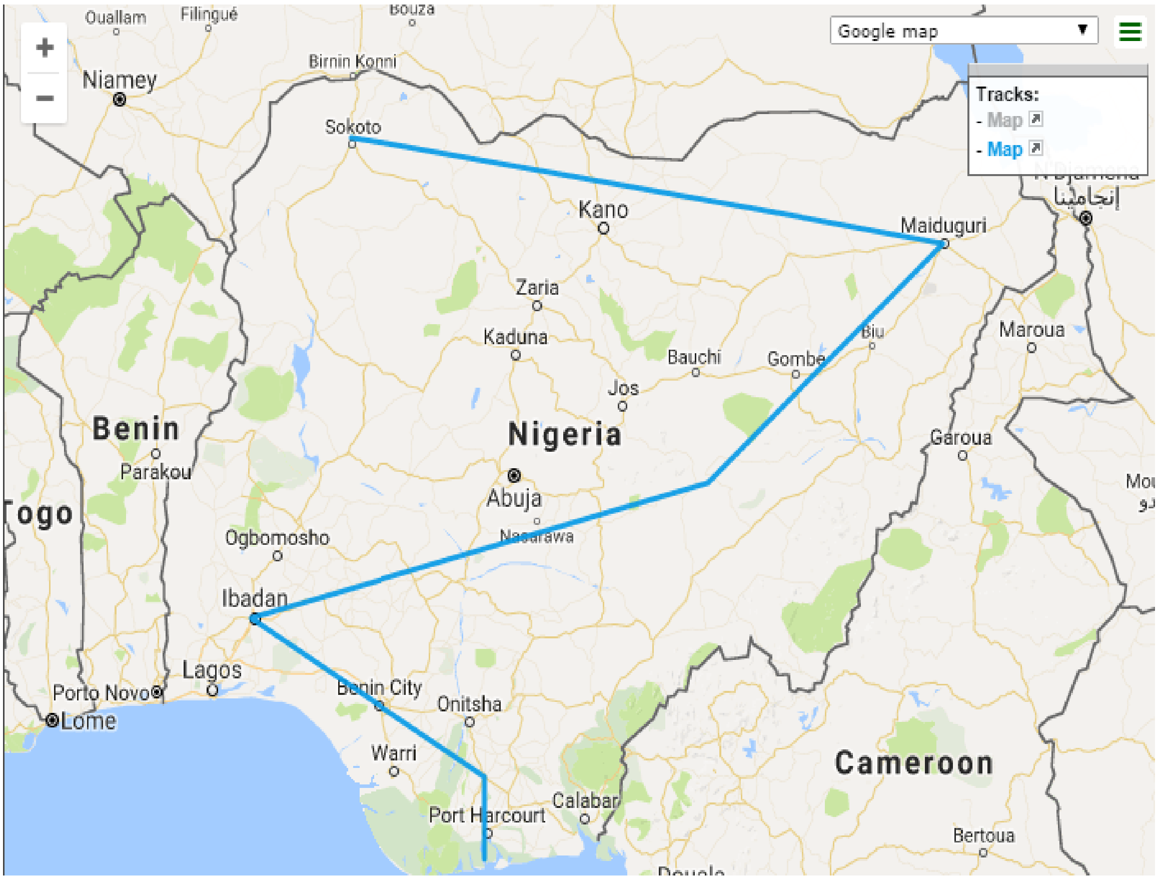

Fig. 1: Map of Nigeria Showing the Study Stations.

2.2. Model development

The modelling of DHI involves the correlation of monthly mean daily DHI to meteorological data such as GHI and clearness index. Several researchers proposed simple quadratic and polynomial equations which relates DHI fraction and clearness index [5-10].
In order to generate an appropriate model for the study stations in addition to previous models, a quadratic correlation expression which is based on meteorological parameters such as DHI, GHI and clearness index for all sky and clear sky conditions (k_t) are investigated in this research paper in the form:

$$\frac{DHI}{GHI} = a + bk_t + ck_t^2 \quad (1)$$

Where a, b, and c are the empirical coefficients, DHI and GHI retain their usual meaning and k_t the clearness index is given as follows:

$$k_t = \frac{GHI}{H_o} \quad (2)$$

Where H_o is the extraterrestrial solar radiation on the horizontal surface is given as follows:

$$H_o = \frac{24}{\pi} I_{SC} \left(1 + 0.033\cos\frac{360n}{365}\right) \times \left(\cos\varphi\cos\delta\sin\omega_S + \frac{2\pi\omega_S}{360}\sin\varphi\sin\delta\right) \quad (3)$$

Where I_{SC} the solar constant, φ is the latitude, δ is the solar declination and n the number of days of the year starting from first January. The daily extraterrestrial solar radiation is the solar radiation intercepted by horizontal surface during a day without the atmosphere and hourly extraterrestrial radiation has similar definition. For a given month, the solar declination (δ) and the mean sunrise hour angle (ω_S) can be evaluated by the following equations (4) and (5) respectively.

$$\delta = 23.45\sin\left[\frac{360(n+284)}{365}\right] \quad (4)$$

$$\omega_S = \cos^{-1}[-\tan\delta\tan\varphi] \quad (5)$$

A computer statistical software program (IBM SPSS 22) was used to compute the regression constants at 95% confidence level employed to obtaining the correlation coefficient (R), coefficient of determination (R^2), adjusted coefficient of determination (R_a^2) and standard error of estimation.

2.3. Estimation metrics

To determine the error and performance of the predictive models, Willmott [20] suggested mean bias error (MBE), mean percentage error (MPE) and root mean square error (RMSE) as good statistical indicator for evaluating the error between the observed and predicted (model) values. These relations are given as:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{O_i - P_i}{O_i}\right)\times 100$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i - P_i\right)^2}$$

Where O_i and P_i are the observed and predicted DHI and other symbols retain their usual meaning.

3. Results and discussions

3.1. Variation of atmospheric parameters

The monthly mean daily GHI, DHI and Clearness Index (K_t) for clear sky and all sky conditions for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto representing the six tropical ecological zones are presented in Table 2. The monthly and seasonal variations are observed for DHI and clearness index for clear sky and all sky conditions are shown in Fig. 2. It is also observed that DHI increases with latitude from Lat. 4.4 – 13.03°N along the typical ecological zones from Northern tropical zones of Sahel Savannah (FNZSS) of Sokoto to the far Southern tropical zones of mangrove swamp (FSZMS) of Port Harcourt as expected for a tropical sits Burari [21]. This variation was mainly due to trends in cloudiness and associated atmospheric moisture with the movement of the Hadley cell circulation system along the equatorial line.

The Nigeria weather condition is classified into two seasons: Dry and wet season. Dry reason is attributed to the influence of inter tropical convergence zone (ITCZ) producing tropical Continental (TC) associated with dry and dusty North – East winds (easterlies) which blows from the Sahara Desert and finally prevail over Nigeria; thus producing the dry season conditions. The implication is that there is a prolonged dry season in the far North, while the far south undergoes short dry periods annually.

With the movement of the ITCZ into the Northern hemisphere, the rain-bearing south westerlies prevail as far inland as possible to bring rainfall during the rainy season. This results to prolonged rainy season in the far South while the far North undergoes short rainy periods annually [22].

The dry season is from November to March while the wet season start in April and ends in October. The rainy season is characterized by overcast and heavy rain clouds. This give rise to the relatively high DHI and low clearness index as observed between the months of May-October compared to the dry season months for all sky condition while clearness index is relatively high under clear sky weather as shown in Fig. 2.

The lowest DHI of 4.46 $MJm^{-2}day^{-1}$ occurred in the months of November and December for Sokoto while the lowest clearness index for clear sky weather registered 0.52 in the months of February and November for Owerri and Ibadan. This is due to the presence of relatively low clouds and dry season as low cloud absorb more BHI than DHI in the solar spectrum thereby producing low magnitude of DHI received in the zone. The clearness index for all sky recorded 0.33 in the month of September for Port Harcourt. This is due to the presence of heavy smog and clouds, and prolonged rainfall as clouds absorb more DHI component than in the BHI component thereby producing low clearness index in the zone. These results are comparable to the report of Theophile and Rene [10] in Cameroun.

The highest values of DHI of 8.28 $MJm^{-2}day^{-1}$ recorded in the months of March and April for Port Harcourt. This is because clouds absorbed more DHI component of radiation than BHI as a result of heavy smog, low clearness index and prolonged rainfall thereby enhancing the amount of DHI received in the zone. The highest clearness index for all sky conditions is 0.69 recorded in the month of February for Sokoto. However, Sokoto registered the highest value of clearness index of 0.60 under clear sky condition in the months of March, April and June. This could be attributed to the presence of low smog and clouds with associated dry harmattan breeze that blows and prevailed over Sokoto and its environs.

Table 2: A) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values for Port Harcourt.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	18.72	0.54	0.53	6.73	6.78
FEBUARY	18.86	0.52	0.53	7.49	7.42
MARCH	17.28	0.46	0.55	8.28	8.11
APRIL	16.56	0.44	0.58	8.28	8.11
MAY	15.23	0.42	0.57	7.85	7.87
JUNE	12.74	0.36	0.55	7.42	7.53
JULY	11.66	0.33	0.55	7.31	7.37
AUGUST	12.31	0.34	0.57	7.67	7.65
SEPTEMBER	12.35	0.33	0.58	7.88	7.75
OCTOBER	13.25	0.36	0.59	7.78	7.81
NOVEMBER	15.16	0.44	0.55	7.38	7.48
DECEMBER	17.82	0.53	0.54	6.66	6.79
AVERAGE	15.16	0.42	0.56	7.56	7.55
SUM	181.94	5.07	6.69	90.72	90.65

Table 2: B) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values (DHI) for Owerri.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	19.91	0.58	0.54	6.23	6.24
FEBUARY	20.12	0.56	0.52	7.09	7.01
MARCH	19.15	0.51	0.55	8.03	7.82
APRIL	18.32	0.49	0.58	8.21	7.98
MAY	16.99	0.47	0.56	7.85	7.87
JUNE	15.52	0.44	0.55	7.63	7.77
JULY	13.86	0.39	0.55	7.67	7.76
AUGUST	13.57	0.37	0.58	7.92	7.89
SEPTEMBER	14.18	0.38	0.59	8.17	8.04
OCTOBER	15.37	0.42	0.58	7.85	7.93
NOVEMBER	17.42	0.51	0.53	7.02	7.21
DECEMBER	19.04	0.57	0.53	6.16	6.27
AVERAGE	16.96	0.47	0.56	7.49	7.48
SUM	203.47	5.68	6.66	89.82	89.81

Table 2: C) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values (DHI) for Ibadan.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	20.45	0.60	0.55	5.87	6.56
FEBUARY	20.66	0.57	0.53	6.80	7.17
MARCH	20.05	0.53	0.55	7.78	7.74
APRIL	18.90	0.50	0.56	8.17	7.90
MAY	17.75	0.48	0.56	7.85	7.82
JUNE	16.34	0.45	0.54	7.70	7.79
JULY	14.87	0.41	0.55	7.81	7.85
AUGUST	14.08	0.38	0.57	8.03	8.01
SEPTEMBER	15.08	0.40	0.58	8.21	8.16
OCTOBER	16.45	0.45	0.57	7.74	7.84
NOVEMBER	18.40	0.54	0.52	6.70	6.92
DECEMBER	19.66	0.59	0.55	7.76	6.47
AVERAGE	17.72	0.49	0.55	7.37	7.36
SUM	212.69	5.90	6.63	88.42	88.28

Table 2: D) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values (DHI) for Abuja.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	21.17	0.66	0.59	4.93	4.99
FEBUARY	21.92	0.63	0.57	5.94	6.00
MARCH	22.57	0.61	0.57	6.88	6.74
APRIL	21.82	0.58	0.59	7.70	7.34
MAY	20.09	0.54	0.57	7.78	7.75
JUNE	18.22	0.49	0.56	7.81	7.91
JULY	15.98	0.43	0.57	8.06	8.09
AUGUST	15.08	0.40	0.59	8.24	8.17
SEPTEMBER	17.03	0.46	0.58	8.14	8.22
OCTOBER	19.12	0.54	0.56	7.09	7.14
NOVEMBER	21.53	0.66	0.60	5.08	5.07
DECEMBER	21.10	0.67	0.61	4.50	4.43
AVERAGE	19.64	0.56	0.58	6.85	6.82
SUM	235.62	6.67	6.96	82.15	81.85

Table 2: E) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values (DHI) for Maiduguri.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	20.20	0.64	0.59	4.90	5.14
FEBUARY	22.68	0.66	0.60	5.22	5.16
MARCH	24.12	0.66	0.61	6.08	5.75
APRIL	23.83	0.63	0.60	7.09	6.57
MAY	22.90	0.60	0.60	7.24	6.95
JUNE	21.49	0.57	0.59	7.38	7.37
JULY	19.55	0.52	0.58	7.88	7.95
AUGUST	18.50	0.49	0.57	8.24	8.18
SEPTEMBER	20.05	0.54	0.57	7.00	7.63
OCTOBER	21.20	0.61	0.59	6.19	6.30
NOVEMBER	21.02	0.66	0.61	4.82	4.95
DECEMBER	19.26	0.63	0.58	4.79	5.14
AVERAGE	21.23	0.60	0.59	6.45	6.43
SUM	254.81	7.23	7.09	77.44	77.13

Table 2: F) Monthly Mean Daily Values of Global Horizontal Irradiation (GHI), Diffuse Horizontal Irradiation (DHI), Clearness Index (K_t) Under All Sky Conditions and Clear Sky, Observed (Obs) and Predicted (Pre) Values for Sokoto.

Month	GHI ($MJm^{-2}day^{-1}$)	k_t All Sky	k_t Clear Sky	Obs DHI ($MJm^{-2}day^{-1}$)	Pre DHI ($MJm^{-2}day^{-1}$)
JANUARY	19.69	0.65	0.60	4.64	4.97
FEBUARY	23.08	0.69	0.63	4.68	4.90
MARCH	24.73	0.68	0.64	5.62	5.48
APRIL	25.74	0.68	0.64	6.30	5.78
MAY	25.31	0.66	0.63	6.52	6.04
JUNE	24.88	0.65	0.64	6.44	6.09
JULY	22.54	0.59	0.62	7.34	7.14
AUGUST	20.63	0.55	0.60	7.99	8.05
SEPTEMBER	21.64	0.59	0.59	7.09	7.00
OCTOBER	21.71	0.64	0.60	5.72	5.76
NOVEMBER	20.84	0.67	0.62	4.46	4.77
DECEMBER	18.90	0.64	0.60	4.46	4.83
AVERAGE	22.47	0.64	0.62	5.94	5.90
SUM	269.68	7.69	7.41	71.28	70.81

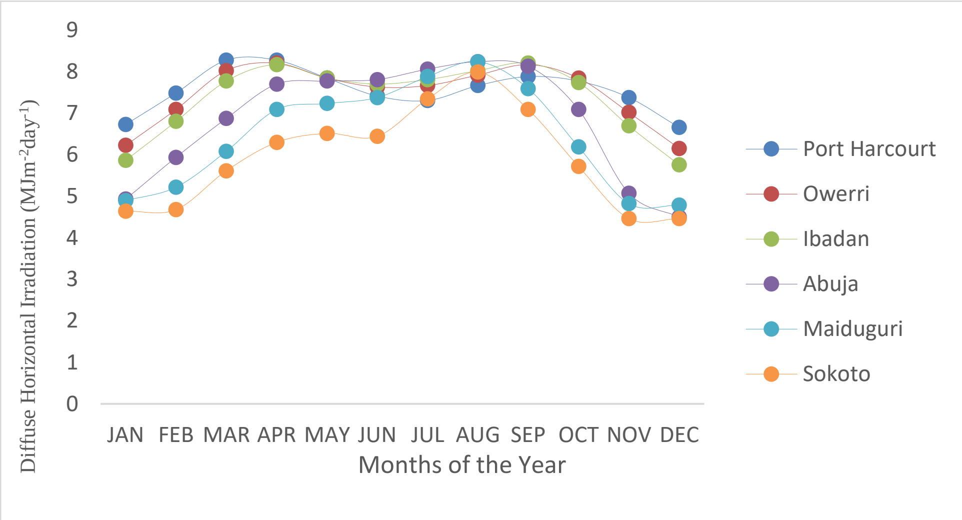

Fig. 2: A) Comparison between Observed Diffuse Horizontal Irradiation for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto.

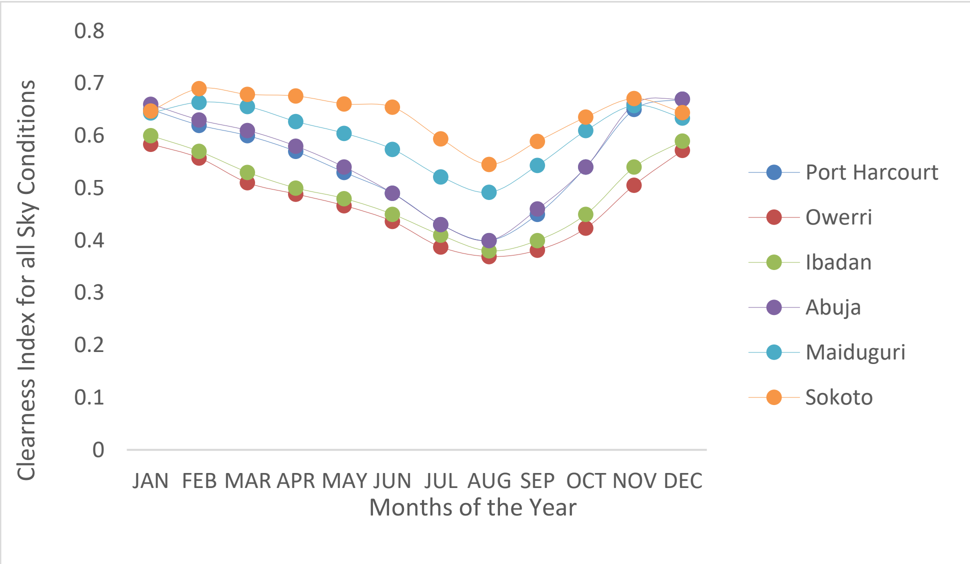

Fig. 2: B) Variation of Clearness Index for All Sky Conditions with the Months of the Year for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto.

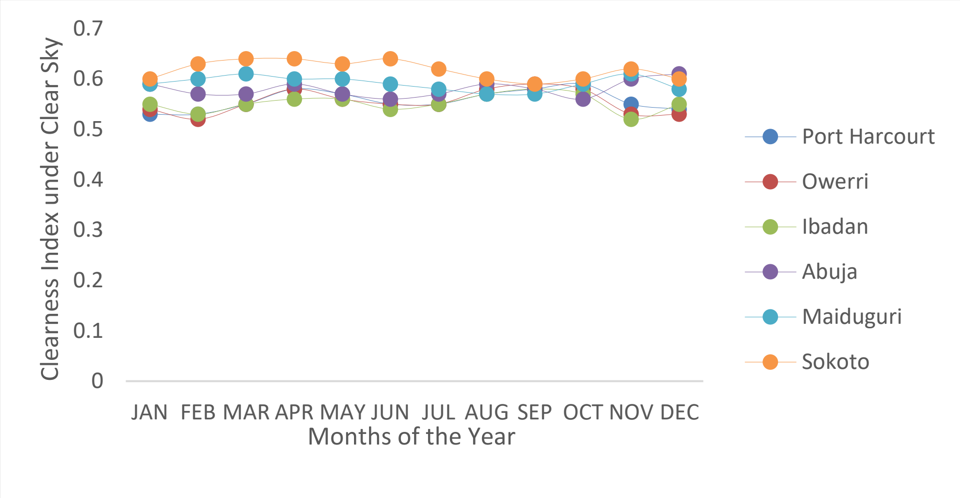

Fig. 2: C) Variation of Clearness Index Under Clear Sky with Months of the Year for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto.

3.2. Influence of clearness index on diffuse horizontal irradiance (DHI)

Similar weather variation and characteristics range (0.538-0.816) were observed between the annual clearness index under all sky conditions and DHI for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto as show in Table 3. This reveals that DHI is optimally controlled by clearness index under all sky conditions in Nigeria in spite of the low correlation obtained under clear sky.

The minimum correlation of 0.538 was reported for Sokoto in the FSZNS whereas in the FSZMS 0.8164 was registered for Port Harcourt. This discrepancy is due to increase in monthly mean value of DHI in the growing season where the clearness index reduced greatly in FSZMS compared to FNZSS under all sky conditions, thus, the absorption of DHI compared to BHI in the global horizontal irradiation (GHI) portion of the solar spectrum is greatly enhanced in the FSZMS of Port Harcourt and slightly reduced to the North Central and finally decreased greatly in the FNZSS of Sokoto.

Remarkable decreases in correlation were found on clear sky conditions as compared to all sky conditions from the Southern part of Nigeria to FNZSS of Sokoto. The minimum correlation of 0.0023 was registered for Sokoto while the maximum correlation of 0.5577 was reported for Owerri. This deviation could be attributed to further decrease of DHI compared to BHI in the global horizontal irradiation (GHI) portion of the solar spectrum from the Southern Nigeria to the FNZSS of Sokoto as a result of the increase in cloudiness and associated atmospheric moisture as clouds absorbs more mixture content contributed by heavy clouds from the harmattan breeze that flows and prevailed over Northern tropical zones thereby culminating into lower correlation between the DHI and clearness index under clear sky conditions for all the zones.

Table 3: Statistical Results for Estimating the Influence of Clearness Index on Diffuse Horizontal Irradiation in Terms of Their Capability for Predicting the Diffuse Horizontal Irradiation for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto

Locations	Sky Conditions	b_0	b_1	R^2
Port Harcourt	All Sky	14.273	-13.50	0.816
	Clear Sky	-1.874	16.922	0.4369
Owerri	All Sky	10.814	-7.031	0.5577
	Clear Sky	-5.400	23.21	0.5767
Ibadan	All Sky	12.059	-9.542	0.6915
	Clear Sky	-7.4955	26.902	0.2838
Abuja	All Sky	14.076	-13.008	0.7956
	Clear Sky	35.705	-49.757	0.3333
Maiduguri	All Sky	18.049	-19.256	0.7411
	Clear Sky	33.121	-45.136	0.2365
Sokoto	All Sky	19.008	-20.404	0.5376
	Clear Sky	7.8579	-3.1059	0.0023

3.3. Correlation analysis

The following observations were deduced from the analysis of the result presented in Table 2. This is comparable to the result reported Theophile and Rene [10]. From the Table 2, it can be seen that the annual DHI for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto are 90.72 $MJm^{-2}day^{-1}$, 89.82 $MJm^{-2}day^{-1}$, 88.42 $MJm^{-2}day^{-1}$, 82.15 $MJm^{-2}day^{-1}$, 77.44 $MJm^{-2}day^{-1}$ and 71.28 $MJm^{-2}day^{-1}$. The radiation obtained throughout the year is high under all sky conditions for six tropical ecological zones in Nigeria. This indicates that crops have high potential for gross primary productivity, net ecosystem exchange of carbon dioxide and light use efficiency at any time of the months in the growing season (April – October) provided other atmospheric conditions such as soil moisture content, temperature and relative humidity are favourable.

The empirical constants of the proposed model varied for b_o, b_1, b_2, R, R^2, R_a^2 and standard error of estimation from one tropical ecological zone to another under various sky conditions as shown in Table 4. This could be attributed to the seasonal variation of DHI principally caused by the influence of latitude, presence of smog, clearness index, relative humidity, rainy and dry seasons, and the movement of the Hadley cell circulation system along the equatorial line in the atmosphere which differs from one tropical ecological zone to another.

The intercept b_o ranged from 0.907 – 2.132; slope, b_2, between -0.721 – -4.750 and b_2 ranged of 0.195 – 2.852 were obtained from the correlations under all sky conditions. These values are within the range observed by several researchers [9-10, 14-15]. However, the values obtained for clear sky conditions were higher than all sky conditions. This is because DHI is greatly enhanced under all sky conditions than clear sky conditions.

The correlation coefficient, R, of 0.968 – 0.997 exist between the independent variable (diffuse fraction, K_d). This implies that the predictive models adequately estimated the observed values of DHI as a result of high positive correlation between the observed and predicted values of DHI under all sky conditions. This is comparable to the report in literature [9-10, 14-15]. However, the correlation coefficient was greatly lowered under clear sky conditions in the six tropical zones. This is because under clear sky conditions, BHI is greatly enhanced resulting in the reduction of DHI in the solar spectrum.

The coefficient of determination (R^2) is generally high for the six zones investigated in the study. This means that the regression line fit in the sets of data adequately. The value of coefficient of determination ranged from 0.937 – 0.997. This implies that 93.7 – 99.7% of the clearness index can be accounted using diffuse fraction under all sky conditions. This values are within the range of the report of numerous researchers [9-10, 14-15]. However, the value was lowered under clear sky conditions because BHI was highly enhanced than DHI in the solar spectrum.

The adjusted coefficient of determination for all sky conditions recorded 0.923 – 0.996 with the corresponding range 0.01237 – 0.00809 of standard error from the FNZSS of Sokoto to the FSZMS of Port Harcourt revealing that the proposed model fit for making generalization within the study area (Nigeria) other locations with comparable sky conditions to Nigeria while the values were lowered under clear sky conditions because BHI was greatly enhanced than DHI in the solar spectrum.

The scattered plot diagrams showing the variation of the observed and predicted DHI for the six stations are shown in Fig. 3. A linear curve fit with intercept of zero was applied to plot in order to produce the proposed model. The coefficient of determination of 0.9765, 0.99044, 0.99783, 0.9913, 0.9654 and 0.946 respectively were recorded for Port Harcourt, Owerri, Ikeja, Abuja, Maiduguri and Sokoto. These values are within what is expected for a tropical site.

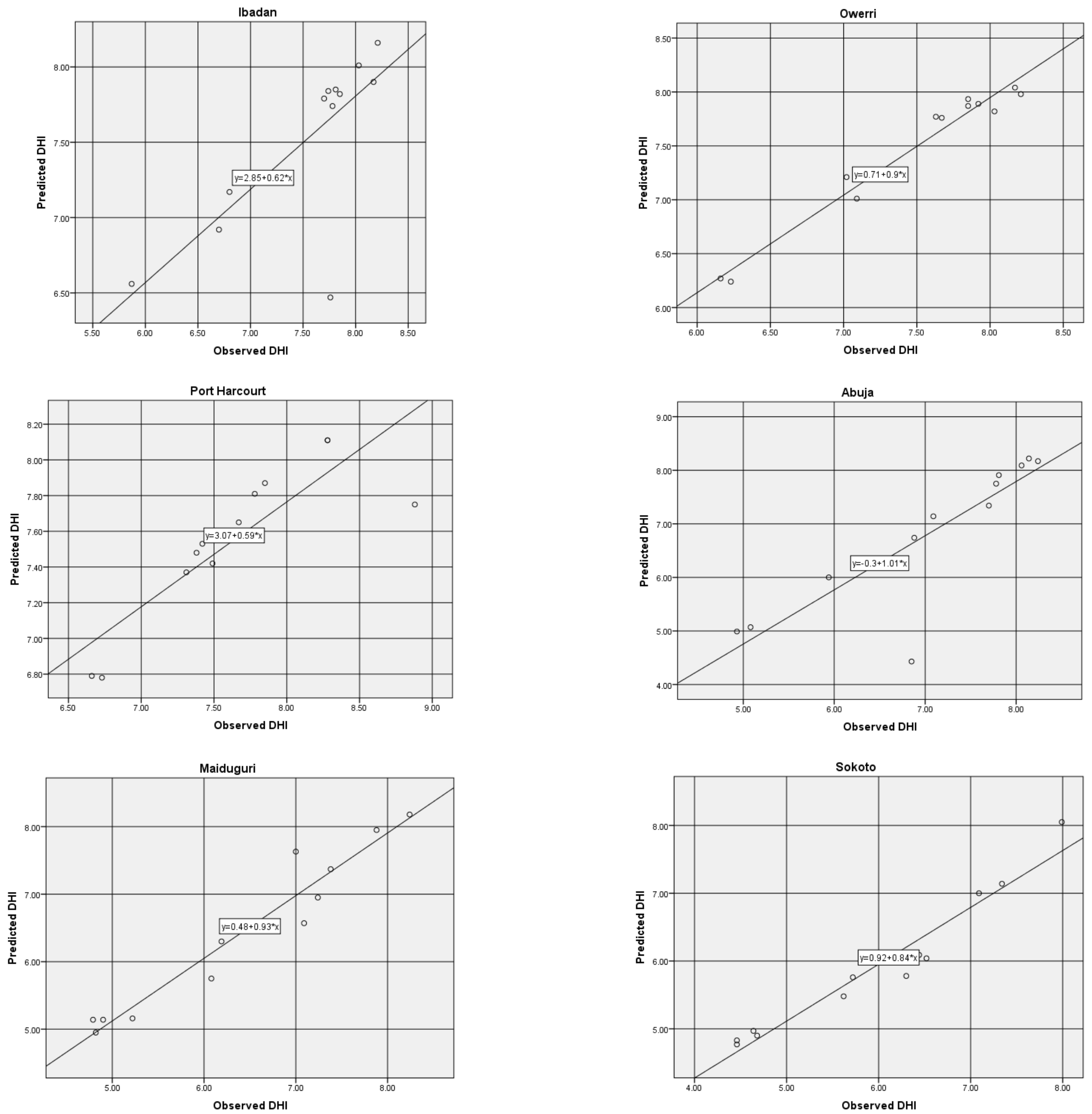

Fig. 3: Comparison Between Observed and Predicted Values (in $Mjm^{-2}day^{-1}$) of Diffuse Horizontal Irradiance (DHI) for Port Harcourt, Owerri, Ibadan, Abuja, Miaduguri and Sokoto Stations Under All Sky Condition.

Table 4: Statistical Results for The Validation of the of Predicted (Model) Diffuse Horizontal Irradiation (DHI) in Terms of Their Capability for Estimating the Diffuse Horizontal Irradiation Under Various Sky Conditions for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto

Stations	Sky Conditions	b_o	b_1	b_2	R	R^2	R_a^2	Standard Error
Port Harcourt	All Sky	1.011	-1.091	-0.195	0.997	0.995	0.993	0.00809
	Clear Sky	-34.62	122.42	-106.44	0.783	0.612	0.526	0.06860
Owerri	All Sky	0.987	-1.003	-0.257	0.997	0.993	0.991	0.00869
	Clear Sky	-13.81	47.649	-39.80	0.716	0.512	0.403	0.08690
Ibadan	All Sky	0.942	-0.825	-0.447	0.997	0.994	0.993	0.00804
	Clear Sky	20.86	-77.77	73.75	0.656	0.430	0.304	0.07984
Abuja	All Sky	0.981	-1.020	-0.195	0.999	0.997	0.996	0.00681
	Clear Sky	-49.95	175.55	-153.0	0.522	0.273	0.111	0.10607
Maiduguri	All Sky	0.907	-0.721	-0.456	0.998	0.996	0.971	0.01237
	Clear Sky	29.75	-96.05	78.178	0.750	0.563	0.466	0.05298
Sokoto	All Sky	2.132	-4.750	2.852	0.968	0.937	0.923	0.01511
	Clear Sky	0.678	-1.082	-	0.475	0.208	0.129	0.05089

3.4. Model performance

The performance of the model is evaluated and compared using statistical parameters R, R^2, R_a^2 , standard error of the estimation, MBE, MPE and RMSE for each zone. The summary of the error is presented in Tables 5 and Fig. 4. The mean error parameters were observed to be vary from one zone to another and from one month to another. This could be attributed to the influence of clearness index, latitude, presence of heavy smog, rainy and other atmospheric parameters on each zone. It can also be noted that the prediction of DHI can be evaluated with reasonable accuracy with the model in the six zones studied.

From Table 5, it is obvious that the MBE at Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto are close to zero ranging from 0.00005 to 0.03992 indicating that the model is efficient for estimating DHI adequately for any tropical ecological zone in Nigeria and locations with similar climatological conditions. It is also clear that MPE for the six tropical ecological sites studied is equally close to zero implying that the model best predicted the observed values of DHI in the stations analyzed. RMSE indicates that there is error in the predicted data of the model when compared to the observed data. This error is close to zero (0.3022 – 0.8908) in the six tropical sites evaluated, revealing that the model is most suitable for the zones. From the statistical test results of the six tropical ecological zones (Table 5), it can be seen that the six tropical ecological zones has the values of standard error of estimation, MBE, MPE and RMSE very close to zero, and R, R^2, and R_a^2 values very near to 1.0 as recommended by Ituen et al. [23]. Therefore, it can be said that the model is very suitable for estimating monthly mean DHI for six tropical ecological zones analysed in this research paper and thus, could be employed for predicting monthly mean daily DHI in any station across the globe that has similar climatological characteristics with Nigeria.

Table 5: A) Statistical Results for the Validation of the Predictive Models of Diffuse Horizontal Irradiation in Terms of Their Capability for Estimating the Diffuse Horizontal Irradiation under All Sky Conditions for Southern Tropical Zones (Port Harcourt, Owerri And Ibadan)

	Port Harcourt			**Owerri**			**Ibadan**		
Months	MBE	MPE	RMSE	MBE	MPE	RMSE	MBE	MPE	RMSE
JANUARY	-0.0039	-0.0574	0.0134	-0.0014	-0.0219	0.0047	0.0015	0.0259	0.0047
FEBUARY	0.0063	0.0797	0.0207	0.0071	0.1003	0.0246	0.0047	0.0696	0.0246
MARCH	0.0143	0.1718	0.0493	0.0170	0.2114	0.0588	0.0144	0.1849	0.0588
APRIL	0.0141	0.1707	0.0490	0.0186	0.2272	0.0646	0.0230	0.2820	0.0646
MAY	-0.0017	-0.0221	0.0060	-0.0020	-0.0258	0.0070	-0.0012	-0.0155	0.0070
JUNE	-0.0092	-0.1236	0.0317	-0.0112	-0.1469	0.0388	-0.0121	-0.1568	0.0388
JULY	-0.0048	-0.0652	0.0165	-0.0078	-0.1011	0.0269	-0.0040	-0.0505	0.0269
AUGUST	0.0012	0.0154	0.0041	0.0022	0.0278	0.0076	0.0075	0.0932	0.0076
SEPTEMBER	0.0116	0.1467	0.0401	0.0107	0.1314	0.0372	0.0046	0.0562	0.0372
OCTOBER	-0.0027	0.0343	0.0092	-0.0070	-0.0892	0.0242	-0.0134	-0.1731	0.0242
NOVEMBER	-0.0079	-0.1073	0.0274	-0.0161	-0.2298	0.0559	-0.0033	-0.0495	0.0559
DECEMBER	-0.0101	-0.1609	0.0371	-0.0097	-0.1569	0.0334	-0.0108	-0.1879	0.0334
AVEAGE	0.0005	0.0011	0.0254	0.00005	-0.0061	0.0319	0.0009	0.0065	0.0319
SUM	0.0062	0.0136	0.3045	0.0005	-0.0733	0.3839	0.0110	0.0785	0.3839

Table 5: B) Statistical Results for the Validation of the Predictive Models of Diffuse Horizontal Irradiation in Terms of Their Capability under All Sky Conditions for Estimating the Diffuse Horizontal Irradiation for Northern Tropical Zones (Abuja, Maiduguri and Sokoto)

	Abuja			**Maiduguri**			**Sokoto**		
Months	MBE	MPE	RMSE	MBE	MPE	RMSE	MBE	MPE	RMSE
JANUARY	-0.0046	-0.0937	0.0160	-0.0202	-0.4120	0.0699	-0.0270	-0.5807	0.0934
FEBUARY	-0.0049	-0.0832	0.0171	0.0052	0.1000	0.0181	-0.0183	-0.3919	0.0635
MARCH	0.0110	0.1594	0.0380	0.0279	0.4589	0.0967	0.0109	0.1948	0.0379
APRIL	0.0307	0.3986	0.1064	0.0433	0.6099	0.1498	0.0435	0.6906	0.1507
MAY	0.0025	0.0317	0.0085	0.0221	0.3057	0.0766	0.0397	0.6098	0.1376
JUNE	-0.0084	-0.1074	0.0291	0.0009	0.0128	0.0033	0.0291	0.4524	0.1010
JULY	-0.0025	-0.0304	0.0085	-0.0058	-0.0730	0.0199	0.0169	0.2299	0.0585
AUGUST	0.0060	0.0723	0.0206	0.0054	0.0651	0.0186	-0.0045	-0.0562	0.0155
SEPTEMBER	-0.0067	-0.0822	0.0232	-0.0029	-0.0380	0.0099	0.0080	0.1123	0.0276
OCTOBER	-0.0037	-0.0526	0.0129	-0.0100	-0.1665	0.0357	-0.0029	-0.0509	0.0101
NOVEMBER	0.0003	0.0061	0.0011	-0.0108	-0.2234	0.0373	-0.0256	-0.5741	0.0888
DECEMBER	0.0057	0.1268	0.0198	-0.0291	-0.6082	0.1009	-0.0306	-0.6863	0.1061
AVEAGE	0.0021	0.0288	0.0251	0.0022	0.0026	0.0531	0.0033	-0.0042	0.0742
SUM	0.0253	0.3454	0.3011	0.0258	0.0314	0.6369	0.0400	-0.0502	0.8908

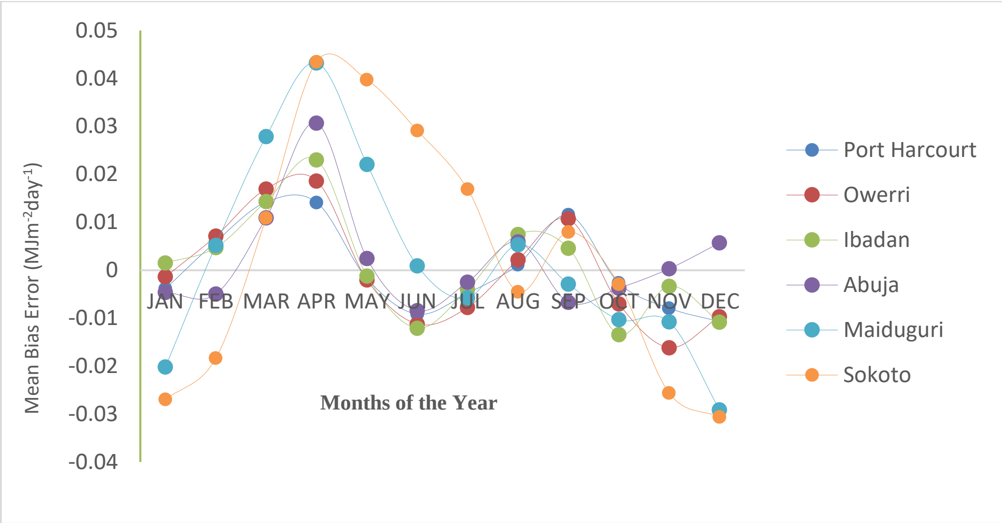

Fig. 4: A) Variations of Mean Bias Error Over Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto under All Sky Condition.

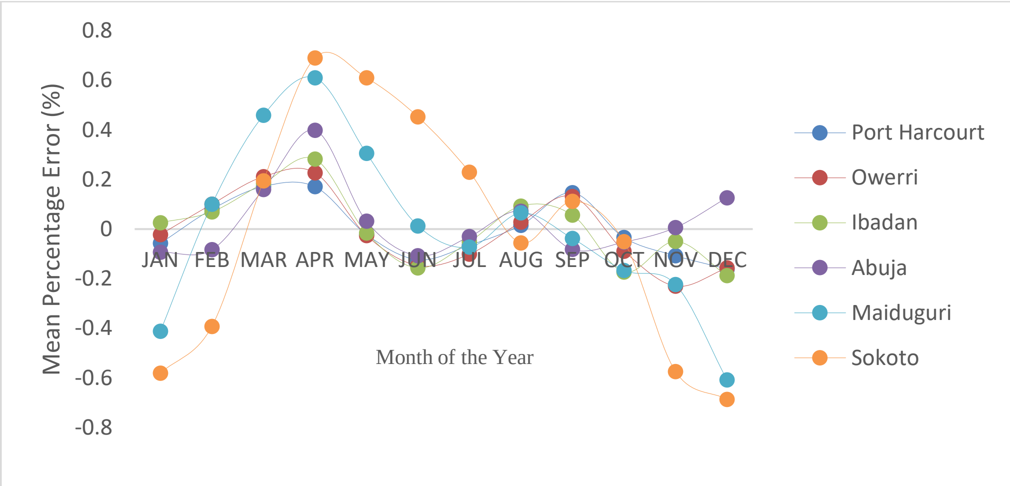

Fig. 4: B) Variation of Mean Percentage Error for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto under All Sky Condition.

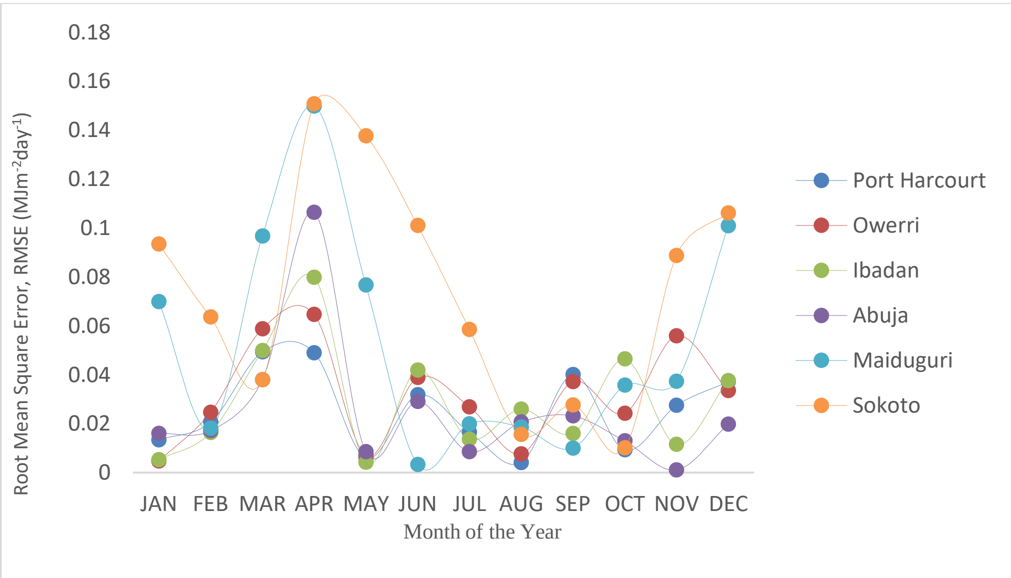

Fig. 4: C) Variation of RMSE for Port Harcourt, Owerri, Ibadan, Abuja, Maidugurri and Sokoto under All Sky Condition.

4. Conclusion

The analysis of the influence of clearness index on diffuse fraction based on the radiation data recorded for Port Harcourt, Owerri, Ibadan, Abuja, Maiduguri and Sokoto representing the six tropical ecological zones in Nigeria were investigated for all sky condition and clear sky. It was revealed that the absorption of DHI in the GHI portion of the solar spectrum is greatly enhanced in the Southern tropical zones as a result of high relative humidity and prolonged rainy season, presence of heavy smog and low clearness thereby increasing the diffuse fraction in the zone. While the absorption of DHI in the GHI portion of the solar spectrum lowered in the Northern tropical zones a result of high influence of prolonged dry season, high clearness index, low relative humidity, low smog that decreases the DHI thereby reducing the diffuse fraction in the region. This research paper is the first attempt to qualify DHI parameters in the six tropical ecological zones in Nigeria; thus our model can be used to estimate DHI parameters for locations with similar climatological condition where GHI data are readily available.

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