



Modelling the Earth's Solar Irradiance Across Some Selected Stations in Sub-Sahara Region of Africa

F. O. Aweda^{1*}, T. K. Samson²

¹ Physics and Solar Energy Programme, College of Agriculture Engineering and Science, Bowen University, Iwo, Osun State, Nigeria

² Statistics Programme, College of Agriculture, Engineering and Science, Bowen University, Iwo, Osun State, Nigeria

PAPER INFO

Paper history:

Received 06 July 2020

Accepted in revised form 24 September 2020

Keywords:

Autoregressive integrated moving average

Augmented dickey-fuller

Root mean square error

Solar irradiance

ABSTRACT

Solar radiation is an important parameter in the study of electricity and/or thermal system installation. Direct monthly irradiance data measurements of the earth's horizontal surface irradiance for the year 1985 to 2019 for nine stations (Sokoto, Birnin Kebbi, Maiduguri, Ilorin, Calabar, Port-Harcourt, Enugu, Iwo, and Ikeja) were collected from the archive of HelioClim satellite website. The stationarity of the series was determined using the time plot of the irradiance data between the periods under study but the formal test of stationarity was carried out using the Augmented Dickey-Fuller (ADF) test with a p-value less than 0.05 signifying stationarity. Different autoregressive integrated moving average (ARIMA) models were fitted to the irradiance data for each of the selected stations. The results revealed that Sokoto, Maiduguri, and Kebbi have their maximum solar irradiance at about 450 Wm^{-2} and their minimum at about 340 Wm^{-2} , while Ilorin has its maximum solar irradiance at about 440 Wm^{-2} and its minimum solar irradiance at about 370 Wm^{-2} . Ikeja, Iwo and Port-Harcourt, Calabar and Enugu have their maximum solar irradiance $< 440 \text{ Wm}^{-2}$ and their minimum solar irradiance at about 390 Wm^{-2} . It is therefore concluded that for Kebbi, Iwo and Maiduguri, the best model was ARIMA (3,0,3), for Calabar and Sokoto, it was ARIMA (2,0,2) while for other locations like Enugu, Ikeja, Ilorin and Port Harcourt, ARIMA (2,0,3) was the best model for forecasting irradiance in these study areas. The forecasted values of irradiance between January till December 2020 with its corresponding 95% confidence levels indicate good prediction of solar irradiance for future occurrence.

doi: 10.5829/ijee.2020.11.03.05

INTRODUCTION

This is a known fact that solar radiation data are acquired for the designing and installation of solar equipment Babar and Bostrom [1]. Solar radiation information is widely used in agriculture, forestry and biological processes Badescu [2]. As reported by Babar and Bostrom [1], solar radiation data is not easily obtained even though it is of great importance. However, in this case, the data for solar irradiance were considered for statistical modelling. Babar and Bostrom [1] state that, owing to constraints all over the world, solar radiation equipment is not installed at any weather stations, but for the betterment of research, an internet data or satellite data can perform the same function with the installed equipment data. In Nigeria, meteorological stations lack solar radiation equipment for the collection of solar data; however, satellite data can help in the study of solar radiation. Globally, the percentage of weather stations recording the solar radiation is small, roughly 10% as compared to the stations recording other climatological

quantities like temperature, precipitation, humidity, rainfall etc. Babar and Bostrom [1]. As reported by Badescu [2], weather stations recording short wave solar radiation to station recording temperature is 1:500. Analytically, the modelling of solar irradiance using statistical package sometimes is difficult and required some basic information for the completion of the solar irradiance model.

Mohandes et al. [3], Trajekovic et al. [4], Reddy and Ranjan [5] have used artificial neural network (IA) technique to estimate the solar radiation. The more solar radiation, induces more evaporation of water molecules As reported by Aweda et al. [6]. Aweda et al. [7], demonstrated that seasonal effect on evaporation rate occurs as a result of the dry or wet temperature of the environment. The technical modelling approaches along with performance of the fabricated solar systems for photovoltaic solar power generation and visible solar irradiation were extensively discussed in literature [8–12]. This fact comes as a result of solar radiation reaching the surface of the earth. The research questions that are

*Corresponding Author E-mail: francisaweda4@gmail.com (F. O. Aweda)

essential to be answered are (1) comparative analysis of the modelled solar irradiance and the actual values in the prediction of the solar irradiance (2) the significance of the forecasting of solar irradiance. The locations of study area are shown in Figure 1. In addition, geographical characteristics of all stations are summarized in Table 1.

METHODOLOGY

Data collection

The monthly data of solar irradiance of the earth horizontal surface for the year 1985 to 2019 for nine stations (Sokoto, Birnin Kebbi, Maiduguri, Ilorin, Calabar, Port-Harcourt, Enugu, Iwo and Ikeja), located in Nigeria as shown above, were collected from the archive of HelioClim website of soda (<http://www.soda-pro.com>). These stations are spread over Nigeria. The assessment of the data was done on the 1st of February, 2020 at about 8:00 pm local time of Nigeria. Based on literature [9] that is MERRA-2 Meteorological Re-Analysis. The parameter height is at 2m above sea level.



Figure 1. Map of Nigeria showing the locations of study area [8]

Data usage

The data used in this study were monthly irradiance data between 1985 and 2019. The stationarity of the series was determined using the time plot of the irradiance data between the periods under study but the formal test of stationarity was carried out using the Augmented Dickey-Fuller (ADF) test with a p-value less than 0.05 signifying stationarity. Different ARIMA models were fitted to the irradiance data for each of the selected locations namely: Kebbi, Calabar, Enugu, Ikeja, Ilorin, Iwo, Maiduguri, Port Harcourt and Sokoto. The performance of these time series models was compared using Root Mean Square Error (RMSE) and the model with the least RMSE was considered as the best forecasting model. The model diagnostic checking was carried out using the Ljung Box statistics and p-values greater than 0.05 indicates a good fit. The best forecasting ARIMA model among the proposed models for each of the location was used to forecast irradiance for January to December 2020.

The autoregressive integrated moving average model [ARIMA (p,d,q)] in terms of B operator can be expressed mathematically as follows:

$$\lambda_p(B)(1 - B)^d X_t = \theta_q(B)\epsilon_t \tag{1}$$

where,

$$\lambda_p(B) = 1 - \lambda_1 B - \lambda_2 B^2 - \dots - \lambda_p B^p \tag{2}$$

$$\theta_q(B) = 1 - \theta_1 B - \theta_2 B^2 - \dots - \theta_q B^q \tag{3}$$

Also, $BX_t = X_{t-1}$ and $B\epsilon_t = \epsilon_{t-1}$.

RESULTS AND DISCUSSIONS

The graphs of irradiance for each of the selected location were plotted and the figures obtained are shown in Figures 2-10. These graphs showed that the irradiance was stationary as there is no trend in the data. Result of stationary using ADF test is presented in Table 2 and the

TABLE 1. Geographical characteristics of the stations

Location	Latitude	Longitude	Altitude (m)	Climatic Classification	Vegetation
Maiduguri	11.8333	13.1500	354	Tropical Continental	Sudan Savanna
Sokoto	13.0059	5.2476	281	Desert Climate	Short-grass Savanna
Birnin Kebbi	12.4661	4.1995	239	Desert Climate	Short-grass Savanna
Ilorin	8.5000	4.5500	209	Tropical hinterland	Guinea; Savanna
Iwo	7.6292	4.1872	231	Tropical hinterland	High Forest
Calabar	4.9828	8.3345	95	Tropical	Rainforest and Mangrove
Port-Harcourt	4.8242	7.0336	13	Tropical Monsoon	Mangrove and Fresh Water Swamp
Enugu	6.4599	7.5489	231	Tropical Savanna	Savanna
Ikeja	6.6059	3.3490	36	Tropical	Mangrove and Fresh water Rainforest

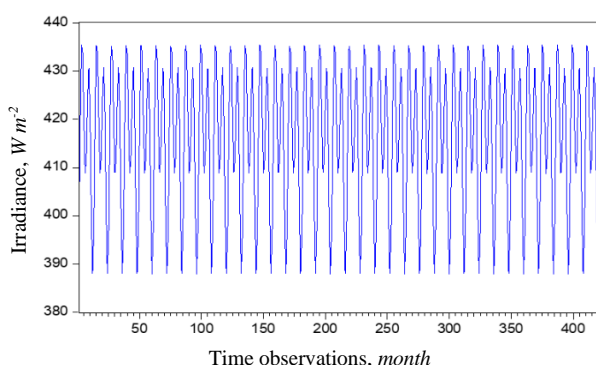


Figure 2. Time plot for irradiance in Calabar

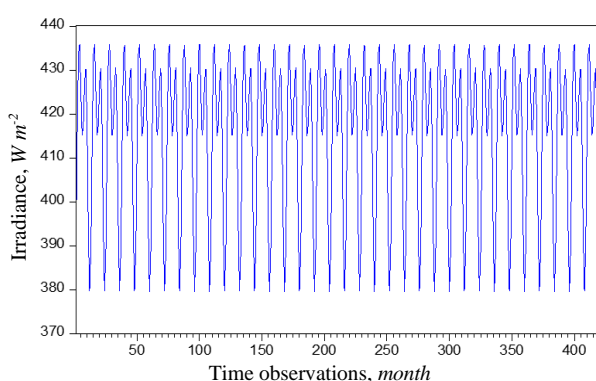


Figure 3. Time plot for irradiance in Enugu

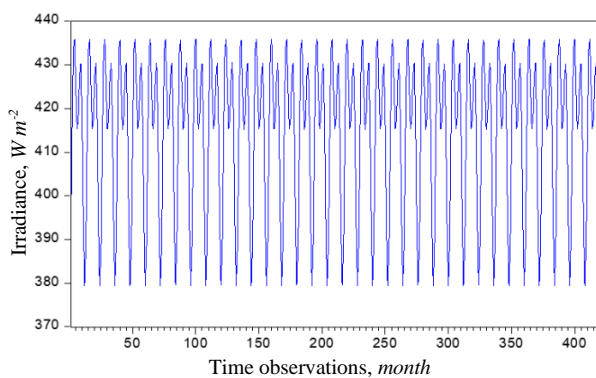


Figure 4. Time plot for irradiance in Ikeja

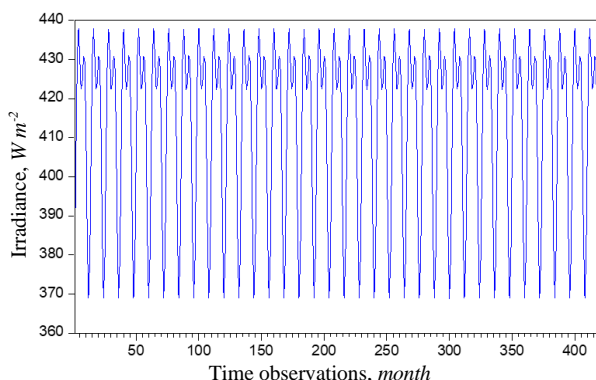


Figure 5. Time plot for irradiance in Ilorin

result revealed p-values less than 0.05 ($p < 0.05$) which indicates that irradiance series in all the selected locations were stationary. Therefore, different Autoregressive Moving Average (ARMA) models were fitted to the data for each of the location and the parameter estimates of these models were shown in Table 3. Result revealed that all the AR and MA terms in these models are significant. The significance of the Autoregressive (AR) terms in all the estimated models shows that the previous values of irradiance have significant effect on the present value of irradiance while the significance of the Moving Average (MA) terms is an indication that the past errors in irradiance also have a significant effect on the present value of irradiance. Result of model selection and model diagnostic checking is presented in Table 4. Result in Table 4 revealed that the p-values of the Ljung-Box statistic were all greater than 0.05 ($p > 0.05$) meaning that all the models adequately predict the irradiance. This also implies that the models are of good fit to the irradiance data. The selection of the best model among the proposed models was based on the forecasting performance meaning that the model with the least value of Root Mean Square Error, is the best model with results as presented in Table 4 which shows that the best model for forecasting irradiance in each of the locations are as follows: In Kebbi, Iwo and Maiduguri, ARIMA (3,0,3) was the best model, for Calabar and Sokoto locations, it was ARIMA (2,0,2) while other locations like Enugu, Ikeja, Ilorin and Port Harcourt have ARIMA(2,0,3) as the best model for forecasting irradiance in their respective study areas. The forecasted values of irradiance between January 2020 and December 2020 with its corresponding 95% confidence levels are presented in Table 5.

Figures 2- 10 show the plot of solar irradiance for all the stations considered. The plots show that stations such as Sokoto, Maiduguri and Kebbi have their maximum solar irradiance at about 450 W m^{-2} with the minimum at about 340 W m^{-2} . This is because these stations are located in the northern part of the country which may likely have higher temperature as compared to other stations. The plots of the station in Ilorin have its

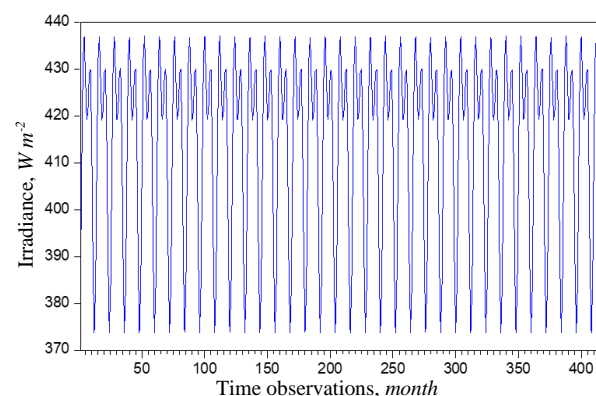


Figure 6. Time plot for irradiance in Iwo

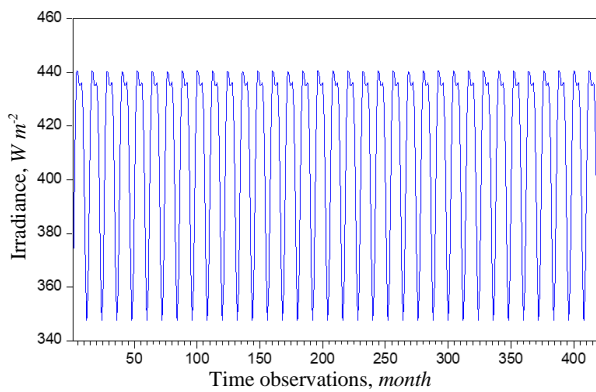


Figure 7. Time plot for irradiance in Kebbi

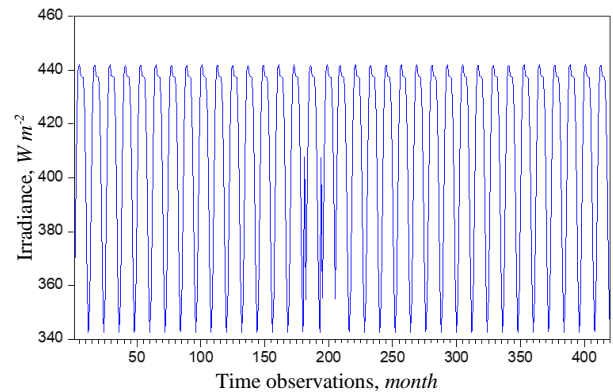


Figure 10. Time plot for irradiance in Sokoto

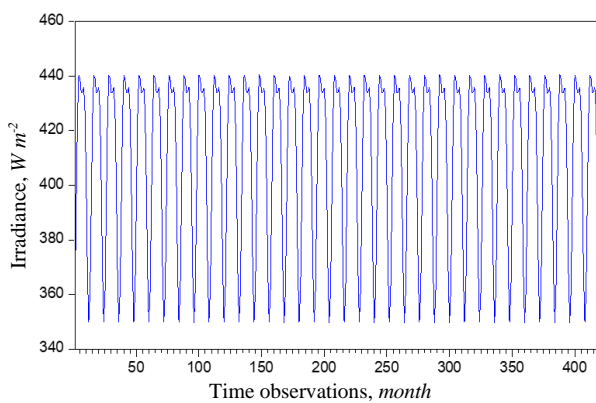


Figure 8. Time plot for irradiance in Maiduguri

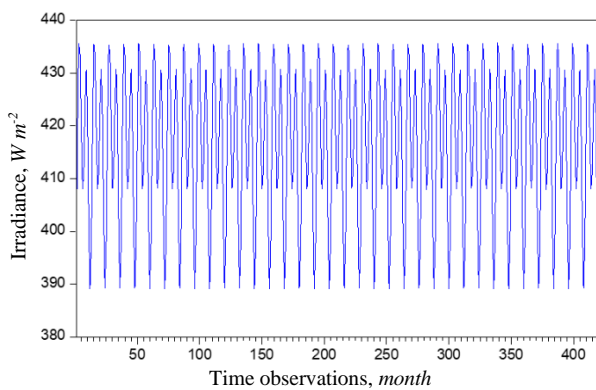


Figure 9. Time plot for irradiance in Port Harcourt

maximum solar irradiance at about 440 W m^{-2} and its minimum solar irradiance at about 370 W m^{-2} . This low in solar radiation occurs because the station is located in the central part of the country. The plots of stations such as Ikeja, Iwo and Port-Harcourt, Calabar and Enugu located in the southern part of the country have their maximum solar irradiance $< 440 \text{ W m}^{-2}$ and their minimum solar irradiance at about 390 W m^{-2} revealed that those stations are located in the coastal region of the country see Figure 1 above.

TABLE 2. Summary results of stationarity using ADF test

Locations	ADF test statistic	P-value	Remarks
Calabar	-9.7949	0.0000	Stationary at level
Enugu	-11.0178	0.0000	Stationary at level
Ikeja	-11.0812	0.0000	Stationary at level
Ilorin	-8.7770	0.0000	Stationary at level
Iwo	-11.4993	0.0000	Stationary at level
Bernin Kebbi	-7.3064	0.0000	Stationary at level
Maiduguri	-7.46483	0.0000	Stationary at level
Port Harcourt	-9.5375	0.0000	Stationary at level
Sokoto	-7.7435	0.0000	Stationary at level

TABLE 3. Model estimation for the different locations (Kebbi, Calabar, Enugu, Ikeja and Ilorin)

Location	Models	AR 1	AR 2	AR 3	MA 1	MA 2	MA 3
Kebbi	ARIMA (2,0,2)	1.659 (0.0000)	-0.662 (0.0000)	-	-1.620 (0.0000)	-0.9999 (0.0000)	-
	ARIMA (2,0,3)	1.623 (0.0000)	-0.628 (0.0000)	-	-2.320 (0.0000)	-1.941 (0.0000)	-0.596 (0.0000)
	ARIMA (3,0,3)	2.072 (0.0000)	-1.795 (0.0000)	0.721 (0.0000)	-1.843 (0.0000)	-1.310 (0.0000)	-0.413 (0.0000)

Calabar	ARIMA (1,0,2)	0.999 (0.000)	-	-	-1.965 (0.000)	-0.999 (0.000)	-
	ARIMA (1,0,3)	0.998 (0.0000)	-	-	-2.344 (0.0000)	-2.331 (0.0000)	-0.965 (0.0000)
	ARIMA (2,0,2)	1.491 (0.0000)	-0.492 (0.0000)	-	-1.959 (0.0000)	-0.998 (0.0000)	-
Enugu	ARIMA (1,0,2)	0.999 (0.0000)	-	-	-1.968 (0.0000)	-1.0000 (0.0000)	-
	ARIMA (2,0,2)	1.533 (0.0000)	-0.535 (0.0000)	-	-1.960 (0.0000)	-0.998 (0.0000)	-
	ARIMA (2,0,3)	1.321 (0.0000)	-0.323 (0.0000)	-	-2.639 (0.0000)	-2.402 (0.0000)	-0.737 (0.0000)
Ikeja	ARIMA (1,0,2)	0.999 (0.0000)	-	-	-1.988 (0.0000)	-0.999 (0.0000)	-
	ARIMA (2,0,2)	1.535 (0.0000)	-0.537 (0.0000)	-	-1.619 (0.0000)	-0.997 (0.0000)	-
	ARIMA (2,0,3)	1.330 (0.0000)	-0.332 (0.0000)	-	-2.609 (0.0000)	-2.345 (0.0000)	-0.707 (0.0000)
	ARIMA (3,0,3)	1.879 (0.000)	-1.790 (0.0000)	0.911 (0.000)	-1.623 (0.0000)	-0.980 (0.0000)	-0.289 (0.0000)
Ilorin	ARIMA (1,0,2)	0.999 (0.0000)	-	-	-1.956 (0.0000)	-0.971 (0.0000)	-
	ARIMA (1,0,3)	0.998 (0.0000)	-	-	-2.492 (0.0000)	-2.471 (0.0000)	-0.960 (0.0000)
	ARIMA (2,0,3)	1.151 (0.000)	-0.154 (0.0020)	-	-2.448 (0.0000)	-2.422 (0.0000)	-0.948 (0.0010)
Iwo	ARIMA (1,0,2)	0.999 (0.0000)	-	-	-1.986 (0.0000)	-0.998 (0.0000)	-
	ARIMA (2,0,3)	1.372 (0.0000)	-0.374 (0.0000)	-	-2.565 (0.0000)	-2.262 (0.0000)	-0.665 (0.0000)
	ARIMA (3,0,3)	1.842 (0.0000)	-1.679 (0.0000)	0.837 (0.0000)	-1.783 (0.0000)	-1.219 (0.0000)	-0.381 (0.0000)
Maiduguri	ARIMA (2,0,2)	1.514 (0.0000)	-0.516 (0.0000)	-	-1.958 (0.0000)	-0.997 (0.0000)	-
	ARIMA (2,0,3)	1.496 (0.0000)	-0.500 (0.0000)	-	-1.668 (0.0000)	-1.676 (0.014)	-0.973 (0.049)
	ARIMA (3,0,3)	1.894 (0.0000)	-1.489 (0.0000)	0.593 (0.0000)	-2.207 (0.0000)	-2.053 (0.0000)	-0.789 (0.0000)
Port Harcourt	ARIMA (1,0,2)	0.999 (0.0000)	-	-	-1.965 (0.0000)	-0.999 (0.0000)	-
	ARIMA (1,0,3)	0.998 (0.0000)	-	-	-2.509 (0.0000)	-2.491 (0.0000)	-0.968 (0.0000)
	ARIMA (2,0,2)	1.454 (0.0000)	-0.455 (0.0000)	-	-1.963 (0.0000)	-1.000 (0.0000)	-
	ARIMA (2,0,3)	1.211 (0.0000)	-0.213 (0.0000)	-	-2.686 (0.0000)	-2.493 (0.000)	-0.785 (0.0000)
Sokoto	ARIMA (1,0,2)	0.996 (0.0000)	-	-	-0.731 (0.0000)	-0.455 (0.0000)	-
	ARIMA (2,0,2)	1.254 (0.0000)	-0.258 (0.008)	-	-0.527 (0.0000)	-0.366 (0.0000)	-
	ARIMA (2,0,1)	1.4670 (0.0000)	-0.4700 (0.0000)	-	-0.289 (0.0000)	-	-

MA 1- Moving average of order 1, MA 2- Moving average of order 2, MA 3- Moving average of order 3, AR 1- Autoregressive model of order 1, AR 2- Autoregressive model of order 2, AR 3- Autoregressive model of order 3

TABLE 4. Model diagnostic, fitness and forecasting performance of the different models

Location	Models	Ljung Box statistics	P-value	R ²	RMSE
Kebbi	ARIMA (2,0,2)	23.143	0.058	0.688	18.486
	ARIMA (2,0,3)	9.137	0.762	0.698	18.204
	ARIMA (3,0,3)	5.079	0.955	0.705	18.017
Calabar	ARIMA (1,0,3)	6.796	0.942	0.901	19.808
	ARIMA (1,0,2)	15.843	0.393	0.902	19.984
	ARIMA (2,0,2)	10.980	0.688	0.917	19.894
Enugu	ARIMA (1,0,2)	17.213	0.306	0.275	19.674
	ARIMA (2,0,2)	11.942	0.611	0.256	19.552
	ARIMA (2,0,3)	4.844	0.978	0.238	19.436
Ikeja	ARIMA (1,0,2)	16.911	0.324	0.263	19.688
	ARIMA (2,0,2)	15.801	0.326	0.258	19.678
	ARIMA (2,0,3)	5.001	0.975	0.223	19.423
Ilorin	ARIMA (3,0,3)	2.497	0.998	0.205	19.300
	ARIMA (1,0,2)	20.149	0.166	0.247	19.345
	ARIMA (1,0,3)	7.655	0.907	0.275	19.014
	ARIMA (2,0,3)	6.781	0.913	0.277	19.001
Iwo	ARIMA (1,0,2)	18.206	0.252	0.053	19.495
	ARIMA (2,0,3)	5.518	0.962	0.086	19.197
	ARIMA (3,0,3)	2.943	0.996	0.099	19.081
Maiduguri	ARIMA (2,0,2)	17.763	0.218	0.668	18.401
	ARIMA (2,0,3)	16.152	0.241	0.667	18.442
	ARIMA (3,0,3)	4.367	0.976	0.679	18.117
	ARIMA (1,0,2)	15.687	0.403	0.037	20.027
Port- Harcourt	ARIMA (1,0,3)	5.656	0.974	0.993	19.833
	ARIMA (2,0,2)	10.887	0.695	0.015	19.941
	ARIMA (2,0,3)	4.411	0.986	0.988	19.832
Sokoto	ARIMA (1,0,2)	7.517	0.9220	0.548	23.755
	ARIMA (2,0,2)	7.992	0.9342	0.551	23.706
	ARIMA (2,0,1)	8.200	0.9019	0.533	24.135

RMSE- Root Mean Square Error, bolded values are the least Root Mean Square Error

TABLE 5. Forecasted values of irradiance for January 2020 to December 2020 at its 95% confidence limits

Months	Kebbi			Calabar			Enugu		
	Irradiance	LCL	UCL	Irradiance	LCL	UCL	Irradiance	LCL	UCL
Jan-20	357.34	351.38	363.29	390.92	383.36	398.48	387.32	381.03	393.61
Feb-20	386.89	362.82	410.97	397.62	370.5	424.75	404.65	378.97	430.33
Mar-20	412.86	361.44	464.29	400.37	349.83	450.91	414.42	361.78	467.06
Apr-20	419	340.68	497.32	401.17	329.56	472.77	416.74	338.94	494.54
May-20	406.44	309.17	503.71	401	310.92	491.08	416.63	317.87	515.4
Jun-20	388.14	280.41	495.87	400.36	294.03	506.7	415.75	299.22	532.29
Jul-20	377.17	263.88	490.46	399.5	278.7	520.3	414.62	282.59	546.65

Aug-20	378.24	260.75	495.73	398.52	264.66	532.37	413.41	267.54	559.27	
Sep-20	386.92	264.32	509.53	397.48	251.7	543.26	412.17	253.73	570.61	
Oct-20	395.09	265.49	524.7	396.42	239.64	553.2	410.93	240.91	580.95	
Nov-20	397.21	259.47	534.94	395.35	228.32	562.38	409.69	228.89	590.5	
Dec-20	393.19	247.81	538.57	394.28	217.64	570.92	408.46	217.54	599.37	
		Ikeja			Ilorin			Iwo		
Months	Irradiance	LCL	UCL	Irradiance	LCL	UCL	Irradiance	LCL	UCL	
Jan-20	386.91	380.60	393.23	372.96	366.26	379.65	381.87	377.15	386.60	
Feb-20	403.90	378.27	429.52	384.22	359.23	409.20	403.52	385.74	421.30	
Mar-20	413.50	361.13	465.88	389.34	339.74	438.95	415.69	381.34	450.04	
Apr-20	415.86	338.49	493.22	389.22	317.39	461.05	407.66	361.32	454.00	
May-20	415.80	317.55	514.06	388.28	298.88	477.69	390.56	339.14	441.98	
Jun-20	414.95	298.96	530.95	387.23	283.14	491.31	382.73	329.59	435.87	
Jul-20	413.84	282.37	545.31	386.16	269.27	503.04	390.31	335.52	445.09	
Aug-20	412.64	267.36	557.92	385.09	256.73	513.45	403.09	344.53	461.64	
Sep-20	411.42	253.58	569.26	384.02	245.19	522.85	407.35	342.91	471.80	
Oct-20	410.19	240.78	579.59	382.96	234.44	531.47	400.09	330.59	469.59	
Nov-20	408.96	228.78	589.13	381.89	224.34	539.45	390.25	317.92	462.58	
Dec-20	407.73	217.46	598.00	380.83	214.78	546.89	387.90	313.88	461.92	
		Maiduguri			Port Harcourt			Sokoto		
Months	Irradiance	LCL	UCL	Irradiance	LCL	UCL	Irradiance	LCL	UCL	
Jan-20	359.03	353.05	365.00	396.10	390.05	402.16	333.29	301.72	364.85	
Feb-20	384.59	359.38	409.80	410.87	386.52	435.22	330.99	266.53	395.46	
Mar-20	403.09	347.30	458.87	417.94	369.10	466.78	329.07	231.01	427.12	
Apr-20	403.89	317.43	490.36	418.71	348.10	489.32	327.24	201.86	452.63	
May-20	393.04	284.51	501.56	418.15	330.01	506.29	325.45	177.29	473.61	
Jun-20	382.23	260.39	504.07	417.30	314.43	520.16	323.67	155.85	491.49	
Jul-20	378.41	248.02	508.81	416.39	300.67	532.10	321.91	136.65	507.16	
Aug-20	380.82	243.06	518.58	415.47	288.23	542.70	320.15	119.12	521.18	
Sep-20	384.66	238.83	530.49	414.54	276.79	552.29	318.40	102.90	533.91	
Oct-20	386.09	231.26	540.92	413.62	266.15	561.10	316.67	87.75	545.59	
Nov-20	384.51	220.63	548.38	412.71	256.14	569.27	314.94	73.48	556.40	
Dec-20	381.66	209.55	553.76	411.79	246.68	576.90	313.22	59.97	566.48	

UCL- Upper Confidence Limit, LCL- Lower Confidence Limit

CONCLUSION

The study modelled solar irradiance in nine locations in Nigeria using different forms of ARIMA models. The study made use of satellite data from the satellite application facility on MERRA-2 Meteorological Re-Analysis data of the HelioClim website. Findings revealed that in Kebbi, Iwo and Maiduguri, the best forecasting ARIMA model was ARIMA (3,0,3), for Calabar and Sokoto, it was ARIMA (2,0,2) while for

other locations like Enugu, Ikeja, Ilorin and Port Harcourt, ARIMA (2,0,3) was the best model for forecasting irradiance in these study areas. However, it is therefore concluded that the forecasted values of irradiance between January 2020 and December 2020 with its corresponding 95% confidence levels indicate good prediction of solar irradiance for future occurrence. More so, the implication shows that the northern part has high-temperature difference as compared to the southern part of the country. It is therefore recommended that

adequate precautionary measures and policies be made to help mitigate the effects of high-temperature in the northern part of the country.

ACKNOWLEDGEMENT

This work was conducted based on data from the HelioClim Satellite Application facility on MERRA-2 Meteorological Re-Analysis [9].

REFERENCES

- Babar, B., & Boström, T., 2016, Estimating solar irradiation in the Arctic, *Renewable Energy and Environmental Sustainability*, 1(34): 1–5. <https://doi.org/10.1051/rees/2016048>
- Badescu, V., 2008, *Modeling solar radiation at the earth's surface, Modeling Solar Radiation at the Earth's Surface: Recent Advances*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-540-77455-6>
- Mohandes, M., Rehman, S., & Halawani, T. O., 1998, Estimation of global solar radiation using artificial neural networks, *Renewable Energy*, 14(1–4): 179–184. [https://doi.org/10.1016/S0960-1481\(98\)00065-2](https://doi.org/10.1016/S0960-1481(98)00065-2)
- Trajković, S., Todorović, B., & Stanković, M., 2001, Estimation of FAO Penman c factor by RBF networks, *FACTA UNIVERSITATIS Series: Architecture and Civil Engineering*, 2(3): 185–191. Retrieved from <http://facta.junis.ni.ac.rs/aace/aace2001/aace2001-02.pdf>
- Reddy, K. S., & Ranjan, M., 2003, Solar resource estimation using artificial neural networks and comparison with other correlation models, *Energy Conversion and Management*, 44(15): 2519–2530. [https://doi.org/10.1016/S0196-8904\(03\)00009-8](https://doi.org/10.1016/S0196-8904(03)00009-8)
- Aweda, F. O., Akinpelu, J. A., Falaiye, O. A., & Adegboye, J. O., 2016, Temperature Performance Evaluation of Parabolic Dishes Covered with Different Materials in Iwo, Nigeria, *Nigerian Journal of Basic and Applied Sciences*, 24(1): 90-97. <https://doi.org/10.4314/njbas.v24i1.14>
- Aweda, F. O., Oyewole, J. A., Falaiye O. A., & Opatokun, I. O., 2018, Estimation of Evaporation rate in Ilorin Using Penman Modified Equation, *Zimbabwe Journal of Science and Technology*, 13: 20–25. Retrieved from <https://www.researchgate.net/publication/331787585>
- A Holst, 2020, *Encyclopedia Britannica*. Clean Air Act.
- Baumgartner, J., Höltinger, S., & Schmidt, J., 2018, Evaluation of technical modelling approaches for data pre-processing in machine learning wind power generation models, In *20th EGU General Assembly, Proceedings from the conference held 4-13 April, 2018 in Vienna, Austria (Vol. 20, pp. 2018–14305)*. Retrieved from <https://ui.adsabs.harvard.edu/abs/2018EGUGA..2014305B/abstract>
- Rahman, M. R., Hossain, M. S., Shehab Uddin, S., & M Ibrahim, A. S., 2019, Fabrication and Performance Analysis of a Higher Efficient Dual-Axis Automated Solar Tracker, *Iranian (Iranica) Journal of Energy and Environment*, 10(3): 171–177. <https://doi.org/10.5829/ijee.2019.10.03.02>
- S. Jain, & U. Chandrawat, 2018, Photocatalytic Degradation of Sulfamethoxazole in Visible Irradiation Using Nanosized NiTiO₃ Perovskite, *Iranian (Iranica) Journal of Energy and Environment*, 9(1): 31–40. <https://doi.org/10.5829/ijee.2017.09.01.05>
- Okundamiya, M. S., & Omorogiuwa, O., 2015, Viability of a Photovoltaic Diesel Battery Hybrid Power System in Nigeria, *Iranian (Iranica) Journal of Energy and Environment*, 6(1): 5–12. <https://doi.org/10.5829/idosi.ijee.2015.06.01.03>

Persian Abstract

DOI: 10.5829/ijee.2020.11.03.05

چکیده

تابش خورشید پارامتر مهمی در مطالعه نصب برق و / یا سیستم حرارتی است. اندازه‌گیری مستقیم داده‌های تابش ماهانه تابش افقی سطح زمین برای سال ۱۹۸۵ تا ۲۰۱۹ برای نه ایستگاه (سوکوتو، بیرنین کبی، مایدوگوری، ایلورین، کالابار، بندر هارکورت، انوگو، ایوو و ایکجا) از اهداف وبسایت ماهواره‌ای HelioClim جمع‌آوری شده است. ثابت بودن این مجموعه با استفاده از نمودار زمانی داده‌های تابش بین دوره‌های مورد مطالعه تعیین شد اما آزمون رسمی ایستایی با استفاده از آزمون دیکی-فولر افزوده (ADF) با مقدار p کمتر از ۰/۰۵ به معنای ثابت بودن انجام شد. مدل‌های متحرک خودکارگرایانه مختلف (ARIMA) به داده‌های تابش برای هر یک از ایستگاه‌های انتخاب شده برازش داده شدند. نتایج نشان داد که حداکثر تابش خورشید Maiduguri و Kebbi در حدود 450 Wm^{-2} و حداقل آن‌ها در حدود 340 Wm^{-2} است، در حالی که حداکثر تابش خورشیدی خود را در حدود 440 Wm^{-2} و حداقل تابش خورشیدی آن در حدود 370 Wm^{-2} دارند. Iwo, Ikeja, Calabar, Port-Harcourt و Enugu حداکثر تابش خورشیدی خود را $>440 \text{ Wm}^{-2}$ و کمترین تابش خورشید را در حدود 390 Wm^{-2} دارند. بنابراین نتیجه‌گیری شد که برای Maiduguri و Iwo, Kebbi بهترین مدل ARIMA (3,0,3) برای Calabar و Sokoto، ARIMA (2,0,2) بود، در حالی که برای مکان‌های دیگر مانند Enugu, Ilorin, Ikeja و Port-Harcourt، ARIMA (2,0,3) بهترین مدل برای پیش‌بینی تابش در این مناطق مورد مطالعه بود. مقادیر پیش‌بینی شده تابش بین ژانویه تا دسامبر سال ۲۰۲۰ با سطح اطمینان ۹۵٪ مربوطه، پیش‌بینی خوبی از تابش خورشید برای وقوع در آینده را نشان می‌دهد.