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Application of Harmonic Analysis in the Preliminary Prediction of Air Temperature over Lagos and Abuja, Nigeria

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ABSTRACT

Harmonic Analysis technique has been employed in predicting the hourly air temperature variations over Lagos and Abuja, Nigeria. The variations in hourly air temperatures over the two stations are periodic and thus have strong tendency of being repeated the next day, if all other atmospheric variables are constant. It was observed that the variation in hourly air temperature in the two stations is dominated by the first harmonic, thus it fluctuates by one cycle with a period of 24 hours. Invariably, harmonic equations could be applied to hourly temperature prediction even on a large scale data. The maximum hourly air temperature occurred two hours on the average after the maximum solar irradiance has occurred in each station. It was found that the temperature of the air at a particular hour is dependent on that of the previous hour.

Keywords: Harmonic analysis; air temperature; prediction; solar irradiance; Nigeria;

1. INTRODUCTION

The climate system adjusts when one or more of external factors change, for example, global average temperatures would be expected to increase with an increase in solar output. Climatic predictions are made using climate system models as the Atmosphere-Ocean general circulation models (AOGCMs) (Cornwell and Danny Harvey, 2008; Gregory et al,

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2001 and Sokolov et al, 2001). These are mathematical expressions of the thermodynamics; fluid motions; chemical reactions; and radiative transfer of the complete climate system that are as comprehensive as allowed by computational feasibility and scientific understanding of their formulation. The ultimate aim is to model as much as possible the climate system, especially the complex feedbacks among the various components.

A number of models are in operation in various research institutes and universities Worldwide. Although the models are based on the same laws of physics, each has different ways of dealing with processes that cannot be represented explicitly by physical laws, such as formation of clouds and precipitation. Variations in these parameterizations lead to different regional projections of climate change, particularly for precipitation.

AOGCMs as well as many other climatic models cannot simulate all aspects of climate. The AOGCMs in particular have large uncertainties associated with clouds, it has difficulty portraying accurately precipitation patterns in mountainous regions and resolving important synoptic weather features (such as Mesoscale Convective Systems) that strongly influence precipitation patterns and amounts in many agricultural regions (Ebi and Mearns, 2002).

In the past, some researchers had employed harmonic analysis technique in studying temperature variations but none has been known to be carried out in Nigeria, especially with the Nigerian Environmental Climatic Observing Program (NECOP), real time data.

Lidija (2007) used harmonic analysis to investigate the seasonal cycle in temperature at five locations over the Mount Biokovo region (Croatia): namely, Makarska, Opuzen, estanovac, Imotski, and Vrgorac. The monthly averages of temperature as well as monthly means of minimum and maximum temperatures from 1961 to 1980 were subjected to harmonic analysis. The results were reported to have a good implication for botanical investigations.

Atsu and David (2000) used mean monthly average daily values of global irradiation for seven stations in Oman to develop harmonic models. Pertinent amplitudes and phase angles were obtained for each station. The results show the dominance of the first two harmonics in the southern stations, Salalah and Marmul and the dominance of only the first harmonic in the north, Buraimi and Seeb.

The mean annual variations of the air temperature over European and Mediterranean area have been studied using Harmonic Analysis. Basic data consist of the mean monthly values of air temperature from 1961-1990. It was found that the first 2 harmonic terms contribute, altogether, to the total variance of over 95%. (Makrogiannis and Balafoutis, 2001).

Harmonic analysis along side with other statistical methods has also been applied to study seasonal variability of the air temperature at Mlynany using mean hourly, monthly and annual values of the air temperature during the period of 1962-2002. The results showed that the air temperature trend at Mlynany has an increasing tendency and that the mean annual air temperature increased by about 1.4 °C during the investigated period, i.e., approximately by 0.34 °C per decade (Ostrozlik, 2003).

In a recent study, air-water temperature relationship in the Illinois River (Peoria) was studied using Harmonic analysis. Its application to daily mean air, water temperature records for this location, indicates that the first harmonic accounts for a major portion of the total variance in the records. It was discovered that water temperature residuals are well correlated with air temperature residuals. This result enabled the development of a mathematical model whose parametric values were used for predicting water temperatures from air temperature records and this was seen to be stable from year to year (Kothandaraman, 2007). According to FAA (1975), the amount of solar energy received by any region of the earth varies with time of day, with seasons, and with latitude. These differences in solar energy create temperature variations. These temperature variations create forces that drive the atmosphere in its endless motions.

Since the challenges of climate change persist globally, the need for climatic models and better statistical methods for analyzing climatic variables will continue to grow. This study in its own way of improving on existing methods of analyzing climatic variables, used the descriptive statistics (e.g. mean) in the analysis, as well as developed a computer program for predicting the average hourly temperature over Lagos and Abuja, Nigeria. The identification and implementation of methods that will effectively enhance the study of atmospheric variables has posed a challenge over time. Thus the aim of this work is to employ the use of harmonic analysis technique in fitting a periodic function or model to carry out a preliminary prediction of hour to hour air temperature over Lagos and Abuja, Nigeria. Hence the work will help in providing useful information that will improve human and agricultural activities in these areas especially in this era of global erratic climatic change.

2. SOURCE OF DATA AND METHOD OF ANALYSIS

Lagos is in the south western part of Nigeria and lies approximately between longitude 2° 42' and 3° 22' east and between latitude 6° 22' and 6° 42' north. It stretches over along the guinea coast of the Bight of Benin on the Atlantic Ocean. On the other hand, Abuja is in the northern part of Nigeria at latitude 8° 56'north and longitude 7° 06'east. So the locations of these two cities make them liable to climatic variations due to ocean and desert effects respectively

The air temperature and solar irradiance data used for this work were obtained from Nigerian Environmental Climatic Observing Program (NECOP). NECOP is a new programme, about three years old, designed to establish a network of meteorological and climatological observing stations spatially located across Nigeria. NECOP's main objectives among other things is to make real time data available for meteorological and climatological research which will serve as a veritable tool for decision makers involved in emergency management, natural resources management, transportation and agriculture. The size of the NECOP real time data obtained in these stations is small; Abuja and Lagos have 8 and 12 months' data respectively. This does not allow for a long time climatic prediction of the area, hence, this research serves as a preliminary investigation to the climatic prediction in these areas.

2.1 Fundamental Theoretical Concepts

This work was carried out based on the harmonics series equation adapted from Panofsky and Brier (1960):

$$X_t = \overline{X} + \sum_{i=1}^{N/2}[A_i Sin(\frac{360}{P}it) + B_i Cos(\frac{360}{P}it)] \quad (1)$$

where N is the number of observations, the time series, $X_t =$ the time series, $\overline{X}$ = arithmetic mean, P= period of observation,

$$A_i = \frac{2}{N}\sum_{i=1}^{N/2}[XSin(\frac{360}{P}it)] \text{ , } B_i = \frac{2}{N}\sum_{i=1}^{N/2}[XCos(\frac{360}{P}it)] \text{ ,} \qquad (2)$$

A_i and B_i are coefficients

X = Observed value, t = time and i = number of harmonics.

In other words the time series equals the mean plus the sum of all N/2 harmonics.The first harmonic (or fundamental) has a period equal to the total period studied. The second harmonic has a period equal to half the fundamental period, the third harmonic a period of one – third of the fundamental and so on. It is not always required to determine all the N/2 harmonics; usually the first two, or at most three, harmonics describe the variation of the periodic function sufficiently well. The equation (1) can be re-written as;

$$X_t = \overline{X} + \sum_{i=1}^{N/2} C_i Cos[(\frac{360}{P}i(t - t_i)] \qquad (3)$$

where, $C_i = \sqrt{A_i^{\ 2} + B_i^{\ 2}}$ is the amplitude of the ith harmonic and $t_i = \frac{P}{360}arcSin(A_i / C_i)$ is the time at which the ith harmonic has a maximum.

The variance accounted for by the ith harmonic is except for the last harmonic where it is. If the ratio of this quantity to the total variance is formed, we have as the contribution of the ith harmonic. It can also be expressed in percentage. A harmonic with an overwhelming contribution would definitely account for most of the periodic variation in the data, while the contributions of other harmonics would be considered negligible.

2.2 Data Analysis

The method adopted for the analyses consists of the following statistical methods; harmonic analysis, spectral analysis and autocorrelation analysis. It is considered appropriate because, the temperature distribution is periodic. In other words, the hourly temperature measurements considered, has a considerable amount of cyclic variations and interdependencies over time. The following steps were taken in the data analyses:

1. Determination of the period of cyclic variation using the time series plot of the average hourly temperature observations for each station.
2. Harmonic analysis on the average hourly temperature observations for each station was performed using the sample size and period as inputs. This was carried out by fitting a periodic function of sinusoidal character to enhance the determination of the contribution of each harmonic (expressed as a percentage of total variation in the temperature measurements it accounts for), the amplitude of each harmonic and the time at which each harmonic is maximum.
3. Autocorrelation plots of the data were made in order to determine whether significant dependencies exist in the data. Hence, they were used to determine whether the air

temperature at a succeeding hour depends on that of the preceding hour. The package used for this is the SPSS statistical software.

4. The time series plots of the average hourly solar irradiance observations for each station were made. The turbo Pascal for windows programming language was used to implement the computations involved in the harmonic analysis. This is required because of the enormous computational tasks it involves. The program receives as input the period of the observation (P) and the sample size (N). It proceeds to read the hourly average temperature data from the input file and automatically fit a periodic function to the data, compute the contribution, the amplitude and the time at which each harmonic is maximum.

3. RESULTS AND DISCUSSION

The analyses and result presentations are made for each station using their hourly average air temperature and solar irradiance measurements. The time series plots and summary of the results of the harmonic analysis program using the hourly average air temperature data for each station are presented.

3.1 Analyses and Results for Lagos Station

The time series plots of hourly average air temperature and solar irradiance measurements for Lagos station are given in Figures 1, while the result of the run of the harmonic analysis program on the hourly average air temperature data is summarized in Table 1.

Using the average daily air temperature of 27.81 °C, the period of 24 hours and the sine and cosine coefficients of Table 1, the fitted periodic function X_t for the hourly average temperature of Lagos station is obtained using extracts from equation 1 as:

$$X_t = 27.81 + \sum_{i=1}^{3} [A_i Sin(15it) + B_i Cos(15it)] \tag{4}$$

where Ai and Bi are the coefficients of the sine and cosine respectively and the i's are integers ranging from 1 to 3 as given in Table 1. Equation 4 was employed in the harmonic analysis program so as to make a six days forecast of hourly average air temperature measurements for Lagos station. The result of this forecast is displayed with the corresponding actual and estimates of hourly average air temperature measurements in Table 2.

3.2 Analyses and Results for Abuja Station

The same process was used to carry out the analysis for Abuja and the results for the time series plots of air temperature and solar irradiance measurements for Abuja station are given in Figure 2. The fitted periodic function X_t for the hourly average temperature of Abuja Station is given as:

$$X_t = 27.89 + \sum_{i=1}^{3} [A_i Sin(15it) + B_i Cos(15it)] \tag{5}$$

where Ai and Bi are the coefficients of the sine and cosine respectively and the i's are integers ranging from 1 to 3 as given in Table 3.

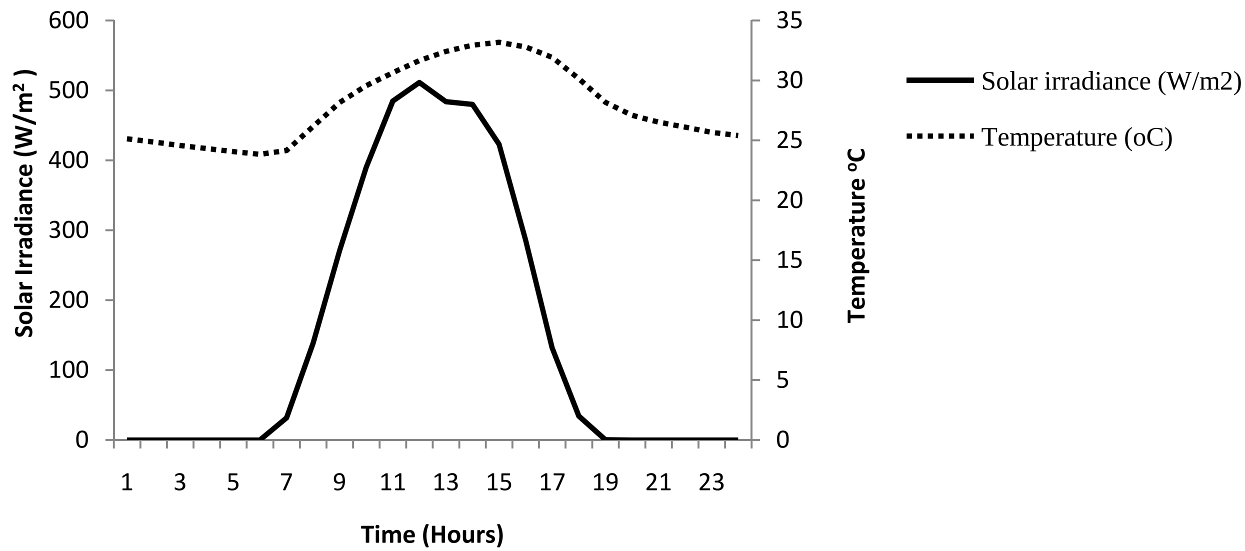

Fig. 1. Time Series plots of hourly air Temperature and Solar Irradiance for Lagos Station

Table 1. Result extracts from the run of harmonic analysis program on the hourly average air of temperature of Lagos

Harmonics	Sine Coefficients (A_i)			Cosine Coefficients (B_i)			Amplitude	Time harmonic is maximum(h)	Percentage Contribution
	A1	A2	A3	B1	B2	B3			
1st	-1.7720	0	0	-2.2585	0	0	2.87	14.54	86.72
2nd	0	0.6593	0	0	0.8699	0	1.09	13.24	12.54
3rd	0	0	0.0746	0	0	-0.1017	0.13	13.07	0.17

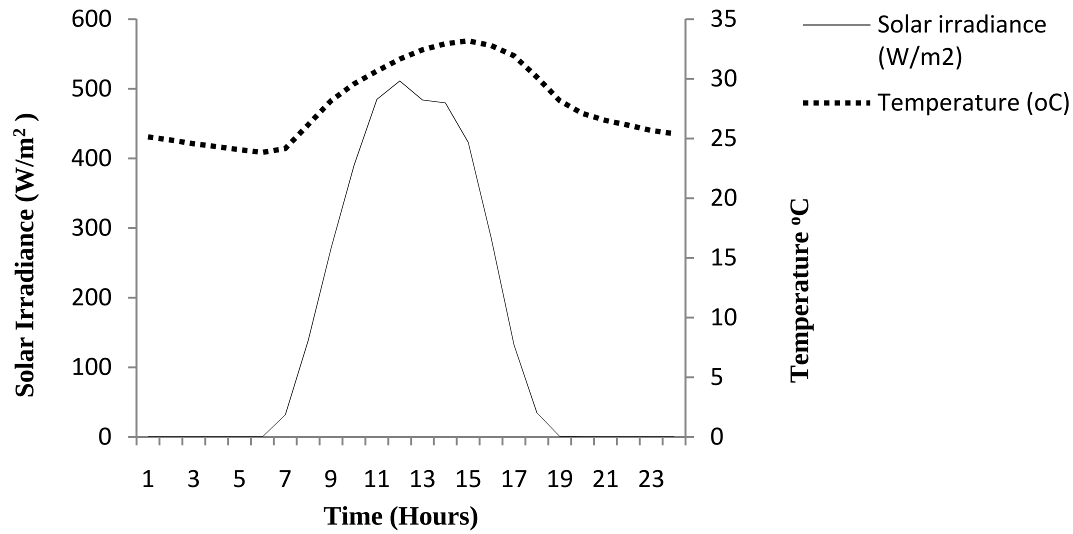

Fig. 2. Time Series plots of hourly air temperature and solar irradiance for Abuja Station

Table 2. A display of six day forecasts of hourly average air temperature for Lagos station against corresponding actual and model estimate values

Time (hours)	Actual values	Model estimate	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	26.12558	26.23237	26.23224	26.23209	26.23194	26.2318	26.23165	26.2315
2	25.90969	26.04728	26.04703	26.04674	26.04645	26.04616	26.04587	26.04558
3	25.67863	25.7426	25.74228	25.74187	25.74146	25.74105	25.74065	25.74024
4	25.52735	25.38249	25.3822	25.3818	25.3814	25.381	25.3806	25.38019
5	25.32274	25.108	25.10787	25.10767	25.10746	25.10726	25.10706	25.10686
6	25.1858	25.09245	25.09256	25.09275	25.09295	25.09314	25.09334	25.09354
7	25.13093	25.4746	25.47496	25.47567	25.47637	25.47708	25.47779	25.47849
8	26.11177	26.29686	26.29739	26.29859	26.29978	26.30097	26.30217	26.30337
9	27.67049	27.47581	27.47637	27.47789	27.4794	27.48091	27.48243	27.48394
10	28.96102	28.81898	28.81946	28.82102	28.82259	28.82415	28.82572	28.82728
11	30.15553	30.08168	30.08199	30.08332	30.08465	30.08598	30.0873	30.08863
12	30.96593	31.04007	31.04021	31.04108	31.04195	31.04283	31.0437	31.04457
13	31.46434	31.55163	31.55166	31.55197	31.55228	31.55259	31.5529	31.55321
14	31.53841	31.58176	31.58175	31.58152	31.58129	31.58106	31.58083	31.5806
15	31.09327	31.19243	31.19246	31.19181	31.19116	31.1905	31.18985	31.18919
16	30.61407	30.50542	30.50553	30.50461	30.50369	30.50277	30.50185	30.50093
17	29.90146	29.66023	29.66042	29.65939	29.65837	29.65735	29.65632	29.6553
18	28.82394	28.78355	28.7838	28.78281	28.78181	28.78081	28.77982	28.77882
19	27.69301	27.97572	27.976	27.97513	27.97426	27.97339	27.97252	27.97165
20	27.18907	27.30842	27.30868	27.30801	27.30733	27.30666	27.30598	27.30531
21	26.91292	26.82357	26.82378	26.82332	26.82287	26.82242	26.82197	26.82152
22	26.66257	26.52761	26.52774	26.52749	26.52725	26.527	26.52676	26.52652
23	26.48699	26.38458	26.38465	26.38454	26.38444	26.38434	26.38423	26.38413
24	26.28558	26.31823	26.31827	26.3182	26.31813	26.31806	26.31799	26.31792
Daily average	27.81	27.81						
Standard deviation	2.18	2.17						

Table 3. Result extracts from the run of harmonic analysis program on the hourly average air temperature of Abuja Station

Harmonics	Sine Coefficients (A_i)			Cosine Coefficients (B_i)			Amplitude	Time harmonic is maximum (h)	Percentage Contribution
	A1	A2	A3	B1	B2	B3			
1st	-2.8162	0	0	-3.3405	0	0	4.37	4.37	91.69
2nd	0	0.8930	0	0	0.7896	0	1.1 9	1.19	6.83
3rd	0	0	0.2955	0	0	0.2171	0.37	0.37	0.65

Table 4: A display of six day forecasts of hourly average air temperature for Abuja station with the corresponding actual and model estimate values

Time (hours)	Actual Values	Model estimate	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	25.12854	25.42899	25.42872	25.42844	25.42815	25.42787	25.42758	25.42729
2	24.86314	25.05427	25.05377	25.05319	25.05262	25.05204	25.05146	25.05088
3	24.55841	24.48655	24.48599	24.48529	24.48459	24.48389	24.4832	24.4825
4	24.31314	23.94387	23.94351	23.943	23.94249	23.94199	23.94148	23.94098
5	24.0585	23.70719	23.70719	23.70719	23.70719	23.70719	23.70719	23.70719
6	23.82845	23.99094	23.99133	23.992	23.99268	23.99335	23.99403	23.99471
7	24.14677	24.85139	24.85206	24.85337	24.85468	24.85599	24.8573	24.85861
8	26.15181	26.17359	26.17435	26.17608	26.17781	26.17953	26.18126	26.18299
9	28.15987	27.73381	27.7345	27.73636	27.73822	27.74008	27.74194	27.7438
10	29.56465	29.29547	29.296	29.29775	29.29949	29.30123	29.30297	29.30471
11	30.63991	30.68409	30.68443	30.68591	30.68738	30.68885	30.69032	30.69179
12	31.65394	31.80629	31.80647	31.8076	31.80873	31.80987	31.811	31.81213
13	32.42111	32.6163	32.61637	32.61712	32.61786	32.6186	32.61935	32.62009
14	32.94031	33.06601	33.06601	33.0663	33.06659	33.06687	33.06716	33.06744
15	33.17894	33.08242	33.08243	33.08216	33.0819	33.08163	33.08137	33.0811
16	32.78699	32.59509	32.59519	32.59432	32.59344	32.59257	32.59169	32.59082
17	31.92814	31.59908	31.59934	31.59791	31.59649	31.59506	31.59364	31.59221
18	30.14124	30.21032	30.21077	30.20901	30.20725	30.20549	30.20372	30.20196
19	28.16695	28.66876	28.66934	28.66757	28.6658	28.66403	28.66227	28.6605
20	27.09332	27.27191	27.27247	27.27104	27.2696	27.26817	27.26674	27.2653
21	26.51549	26.26344	26.26385	26.26296	26.26207	26.26117	26.26028	26.25939
22	26.10429	25.73195	25.73214	25.73178	25.73142	25.73105	25.73069	25.73033
23	25.66376	25.57575	25.57578	25.57573	25.57568	25.57563	25.57559	25.57554
24	25.12854	25.42899	25.42872	25.42844	25.42815	25.42787	25.42758	25.42729
Daily average	27.89	27.89						
Standard deviation	3.23	3.21						

The result of six days forecast of hourly average air temperature measurements for Abuja is displayed with the corresponding actual and model estimates of hourly average air temperature measurements in Table 4.

The maximum hourly average air temperature and solar irradiance and the time at which they occurred for each station are displayed in Table 5.

Table 5. A time distribution of maximum air temperature and maximum solar irradiance across the stations

Station	Maximum Air Temperature (^oC)	Time (hours)	Maximum Solar Irradiance (W/m^2)	Time (hours)	Maximum Air Temperature (^oC)
Lagos	31.53841	14h (2 P.M)	457.2712	12h (Noon)	31.53841
Abuja	33.17894	15h (3 P.M)	511.1827	12h (Noon)	33.17894

Observations show that the equations (1) – (5) exhibit a good fit to the hourly average temperature of Lagos and Abuja, as they produced very close estimates of the actual hourly average air temperatures, yielded the same mean (average daily air temperature) as that of the actual data and very close standard deviation of the actual data and that of the model estimates as shown in tables 2 and 4 respectively. It can also be observed from Tables 1 and 3 that the first harmonic dominates the periodic components in the hourly average air temperature of all the stations since it has the highest contribution of 86.72% and 91.69%, for Lagos and Abuja stations respectively. This shows that the hourly air temperature of each station fluctuates by one cycle. This implies that the contributions of the second and third harmonics for each station is negligible thus, the information about them is discarded. This result is in agreement with the work of Kothandaraman, (2007) in which the application of harmonic analysis to daily mean air, water temperature records indicated that the first harmonic accounted for a major portion of the total variance in the records.

The six days forecasts of hourly average temperatures for each station as shown in Tables 3, 2 and 4 respectively, depict a strong indication that the hourly air temperatures across the two stations have the tendency of being repeated in every twenty four hours provided all other intervening atmospheric variables are kept constant. The results in Tables 1and 3, show that the first harmonic is maximum at times of 14.54h and 15.07h for Lagos and Abuja, respectively, which give close estimate of the time at which the actual value of the maximum hourly average air temperature occurred for each station as shown in table 5. This result further validates the fitted periodic function to the data for each station. This result also supports the periodic nature of air temperatures as ascertained by Ostrozlik, (2003), Lidija, (2007) and Makrogiannis, and Balafoutis, (2001).

Figures 1, 2 and 5 show that the solar irradiance for each station is low in the morning hours, highest in the afternoon and again low towards the evening hours. For the Lagos station, solar heating starts increasing from 7h (7a.m), peaks at 12h (12 noon), and reduces from 13h (1p.m), while in Abuja station, solar heating also starts increasing from 6h (6a.m), peaks at 12h (12 noon), and reduces from 13h (1p.m). Figures 1 and 2 show the fluctuations in average hourly air temperatures for each station. For Lagos, the air temperature starts increasing at 8h (8a.m), peaks at 14h (2p.m), and reduces from 15h (3p.m).the air temperature of the Abuja station starts increasing at 7h (7a.m), peaks at time 15h (3p.m) reduces from 14h (2p.m).

It could be seen from Table 5 that the maximum air temperatures is not the same across the two stations and neither did it occur at the time for which the solar irradiance is maximum for each station. The maximum average hourly temperature occurs 2hrs after the maximum average hourly solar heating had occurred in Lagos, while in Abuja, it occurs after 3 hours. This could be attributed to the fact that the stations differ in the nature of geophysical features they are endowed with. These physical features such as water bodies, hills and mountains differ in their specific heat capacities.

The rate of radiation loss at the different locations could be explained by the Stefan–Boltzman law, which relates the total energy radiated per unit surface area of a body in unit time to the fourth power of its thermodynamic or surface temperature. Thus, since these surfaces differ in their surface temperatures, their respective radiation loses cannot be equal to the solar irradiance at the same time, affirming the reason why maximum air temperatures did not occur at the same time of the day across all stations and neither did it occur at the time for which the solar irradiance is maximum for each station. This could also be explained by a phenomenon of solar and terrestrial balance which asserts that the maximum air temperature occurs at the time when the solar heating and the energy lost by these surfaces (terrestrial radiation) are equal. In addition, amount of solar energy received by any region varies with the time of the day, season and latitude and this difference in solar energy creates temperature variations (FAA, 1975).

4. CONCLUSION

From the results of the analyses made for each station, we have drawn the following conclusions:

- We have deduced that the variations in hourly air temperatures across Lagos and Abuja, Nigeria are periodic and thus have strong tendency of being repeated the next day, if all other atmospheric variables are constant.

- Furthermore, the hourly air temperatures and solar irradiance vary across each station, and that their respective maximum air temperatures never occurred at the time when the solar irradiance is a maximum. The maximum hourly air temperature occurs 2hrs on the average after the maximum solar irradiance has occurred in each station.

- Equally observed is that the temperature of the air at a later hour depends on that of the previous hours for each station. Interestingly, it is also noted that the Nature of features (hills, water bodies, mountains, etc.) could have effects in variations in the average hourly temperature across stations.

- The harmonic equations exhibit a good fit to the hourly average temperature of Lagos and Abuja and hence can be applied to hourly temperature prediction irrespective of the length of the data

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