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Theoretical Confirmation of Seasonal and Solar Radiation Impacts on Outdoor Atmospheric Aerosols ($PM_{2.5}$, SO_2 and CO) in FCT Abuja, Nigeria

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ABSTRACT: Aerosols $PM_{2.5}$, SO_2 and CO were studied within the Federal Capital Territory of Nigeria (F.C.T Abuja), the area comprises of 6 (six) councils “AMAC, Abaji, Bwari, Kuje, Kwali and Gwagwalada”. The study covered a period of one year (2017-2018), irrespective of the seasonal variation of the study area, the impacts of aerosols on incident solar energy for the period was observed. The National Space Research and Development Agency (NASRDA) uses the atmospheric satellites (AS) data of within an altitude 6 Km from the ground level. The data came in NETCDF format, which was extracted by a specialized software called the Arc Map 10.4.1, converted and exported in DBF format which can be read by Microsoft excel. The study shows that the human population in F.C.T increased with (r= $2.6 \ \pm 1)$ months per year which negatively affect the aerosol concentrations and the seasonal impact analysis conform to adiabatic process with respect to the atmospheric variables, as the concentrations were found to be higher in dry than in wet season. Also the Solar radiation impact study reveals a change within solar insolation range of 5.5-6.5 Kwh/m^2/day(CO), 2.8-4.5 Kwh/m^2/day (SO_2) and 4.0-6.5 Kwh/m^2/day ($PM_{2.5}$) and a percentage decrease of 8.42 %, 29.50 %, and 2.87 % was recorded respectively. Which implies a relative impact of solar energy on aerosol (i.e. higher intensity solar energy also reduces a small fraction of the atmospheric aerosol) and vice-versa.

KEYWORDS: Biological Modeling, Atmospheric Aerosol, Seasonal Impact, Adiabatic process, Solar Radiation Impact & Energy forecasting.

1 INTRODUCTION

Air pollution produce aerosols which are especially felt in areas that record high economic growth and rapid urbanization, places in Nigeria such as Abuja, Kano, Lagos and Kaduna.etc. FCT Abuja is the least in population but yet the fastest growing city in the country with many compacted areas. Human activities are the major sources of these ubiquitous specks of matter due air pollutions called aerosols. But can also be found in the air over oceans, deserts, mountains, forests, ice, and every ecosystem. Their range in size is from a few nanometers less than the width of the smallest viruses to several tens of micrometers about the diameter of human hair. Despite their small size, they have major impacts on our climatic conditions and health of the inhabitants. [1]

1.1 IMPACT OF CLIMATE CHANGE ON AEROSOL

Aerosols absorb and scatter solar radiation, the solar radiation reflections to outer space (backscattering) result in reduction of incoming solar radiation to the earth’s surface, which also leads to a great loss of energy and a cooling of the climate system.

[1] Aerosols also interact with vegetation through changes in incoming solar Radiation, fraction of diffuse radiation and as a source of nutrients. These are other contributions to aerosol surface interactions with solar radiation. [2]

More evidence are stated on climatic change impact in this analysis with precision, which includes the aerosols impact in cloud formations. Indeed there would be far fewer clouds in the air without aerosols. It was found in most recent studies that, presence of large quantities of aerosols in the cloud, leads to more droplets of cloud cover than normal, but. Since cloud droplets are smaller and more numerous, clouds last longer before reaching the saturation point. [3], therefore reflection of sunlight will be stronger in a period when the aerosols concentration is lower than normal. This effect could have significant implications on the climate (solar intensity). As the clouds reflect more sunlight, less of the sun's energy reaches the surface of the earth, which then cools the earth. This implies that by putting more aerosols in the atmosphere, humans have the potential to alter their climatic system and cause global cooling. [4]

2 MATERIALS AND METHODS

2.1 STUDY AREA

Abuja is a place with latitude (9.0765 °N) and longitude (7.3986 °E) located in the West Africa. In year 2015, it was known as the fastest growing city in Africa. (nigeriarealestatehub.com) Abuja is the capital city of Nigeria located in the center of the country within the Federal Capital Territory (FCT).

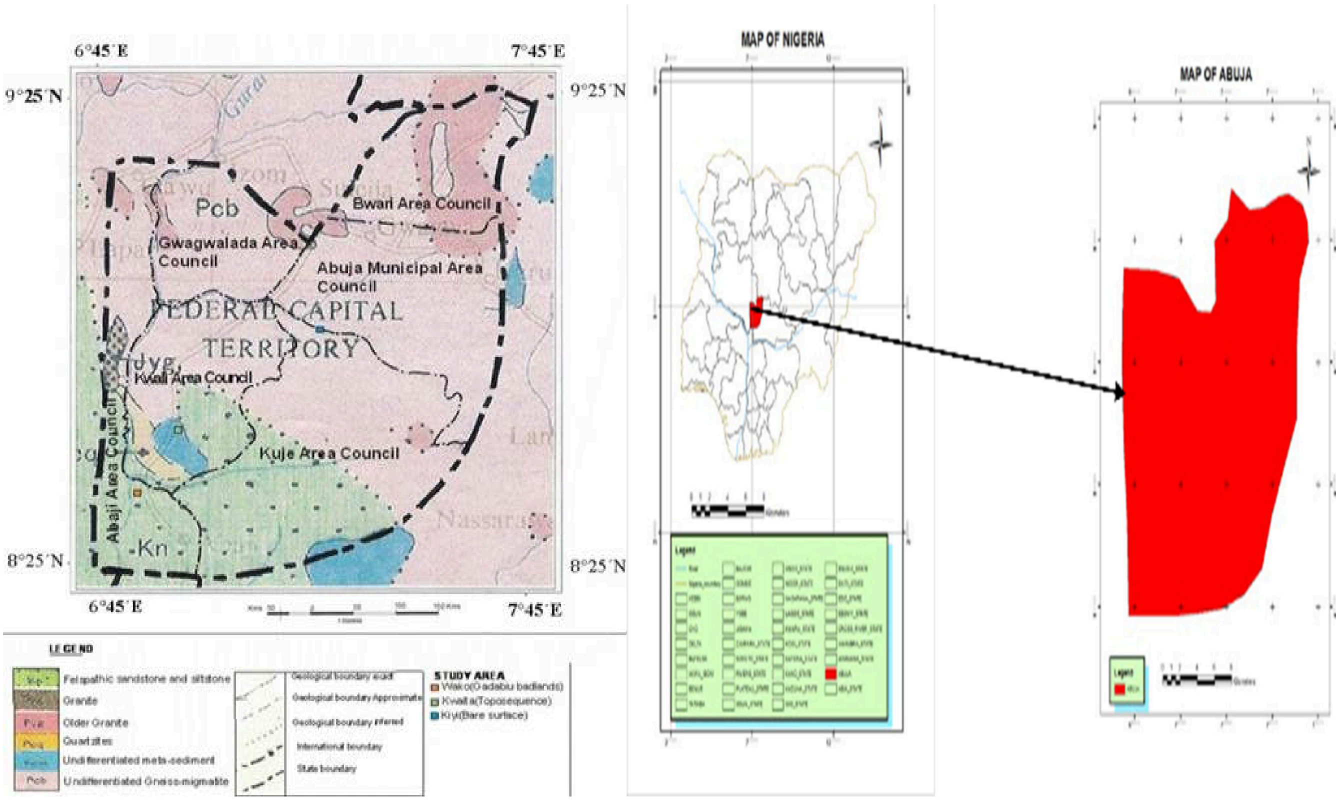

Fig. 1. Map of FCT Abuja (Source: Google Map)

2.2 METHODS OF DATA COLLECTION

Data was collected by National Space Research and Development Agency (NASRDA), Abuja Nigeria, through the ECMWF site. Which was extracted from the study regions for about four different time intervals: 00:00:00, 06:00:00, 12:00:00, and 18:00:00. For 16 out of 24 hours daily throughout the year 2017. The coordinates of Abuja was used to select the area to be downloaded. The Polar Atmospheric satellites information came in NETCDF format, which was extracted by a specialized software called the Arc Map 10.4.1 by following these procedures. Ma NETCDF layer was made together with the Copy Raster, tools in the Multi-dimensional toolbox of Arc Map 10.4.1 respectively. After extraction, Abuja shape file was clipped from Nigeria and imported into the software and the provinces in Abuja and then converted from features to points, from the tool in the data management toolbox and the coordinates of these points assigned using the "ADD XY CORDINATES" found in the coverage toolbox. The points and coordinates was used to extract values from the processed data using the "Extract multi-values to points" tool in the spatial analysis toolbox. The extracted values for the different provinces in Abuja were exported in DBF format which was read by Microsoft Excel. Finally the extracted values were imported into Excel window, the data cleaned, charts and graphs plotted to show trends and relationships. The process are repeated for all the variables obtained. And the annual solar irradiance data was collected from Nigerian Meteorological Agency NIMET. [4-6]

2.3 THEORETICAL BACKGROUND

The mean pollution index gives an absolute mean concentrations of the pollutant under study is calculated using equation 1.

$$Pollution\ mean\ concentration = \frac{\partial_{max} + \partial_{min}}{2} \qquad \textbf{(1)}$$

Where

$\boldsymbol{\partial_{max}}$ is the maximum concentration acquired daily for the period of one year

$\boldsymbol{\partial_{min}}$. is the minimum concentration acquired daily for the period of one year

These computations are presented in table 1 to 3. [6-8]

2.3.1 BIOLOGICAL MODELLING OF THE HUMAN POPULATION

Population increase rate of the F.C.T = 8.9 % per year, $\approx \frac{0.089}{12}$ = 0.0742 % per months

Study period = 1 year = 2017 – 2018 years = 12 months.

$\boldsymbol{X\ is\ the\ individual\ population}$

$\boldsymbol{r\ is\ the\ growth\ rate\ of\ the\ human\ population}$

$$\frac{dy}{dx} = \boldsymbol{rX} \qquad \textbf{(2)}$$

$$\mathbf{t}\frac{dy}{dx} = \boldsymbol{rX} + \mathbf{t} \qquad \textbf{(3)}$$

Therefore (1) can be expressed as:

$$\boldsymbol{X(t) = X(0)e^{rt}} \qquad \textbf{(4)}$$

=> $$\frac{dy}{dx} = \boldsymbol{f(X,t)} \qquad \textbf{(5)}$$

If $$\boldsymbol{f(X,t) = X(t)T(t)} \qquad \textbf{Case. 1}$$

=> $$\frac{dy}{dx} + \boldsymbol{P(t)X = Z(t)}$$

If $$\boldsymbol{f(X,t) = X(t)T(t)} \qquad \textbf{Case. 2}$$

$$\frac{X(12)}{X(0)} = \boldsymbol{e^{12r}} = \mathbf{12 + 0.00742 = 12.00742}$$

$$\mathbf{ln(12.00742) = 12}\boldsymbol{r}$$

=> $$\mathbf{r = 0.207\ months} \approx \mathbf{2.6}\ \boldsymbol{months\ per\ year}$$

This implies that human population in F.C.T increased with (r= 2.6 $\pm$ 1) months per year, which will also increase the human activity rate, that leads to a higher concentrations in aerosols.

2.3.2 SEASONAL AND SOLAR RADIATION IMPACT

Naturally during rainy season, air quality is generally better. The particulate matters concentrations are mostly higher in the months of November to March and it usually gives a lower trend in the wet season which normally started from April and ended October. Rain makes a solid particles (dust) stick to ground, in such a way that more pressure would be required to kick them up, also according to adiabatic processes, dew point temperature of the atmospheric aerosol depend on the water vapor content, therefore a range should be taken, the air parcel will keep expanding during the unsaturated (dry adiabatic lapse rate) until it reaches a saturation point (Moist adiabatic lapse rate) then compression will begin thereby leading to a speedy movement before condensation. Figure 2. Represents the adiabatic process of the seasonal (Dry to Wet) variation of atmospheric aerosols in Abuja, Nigeria.

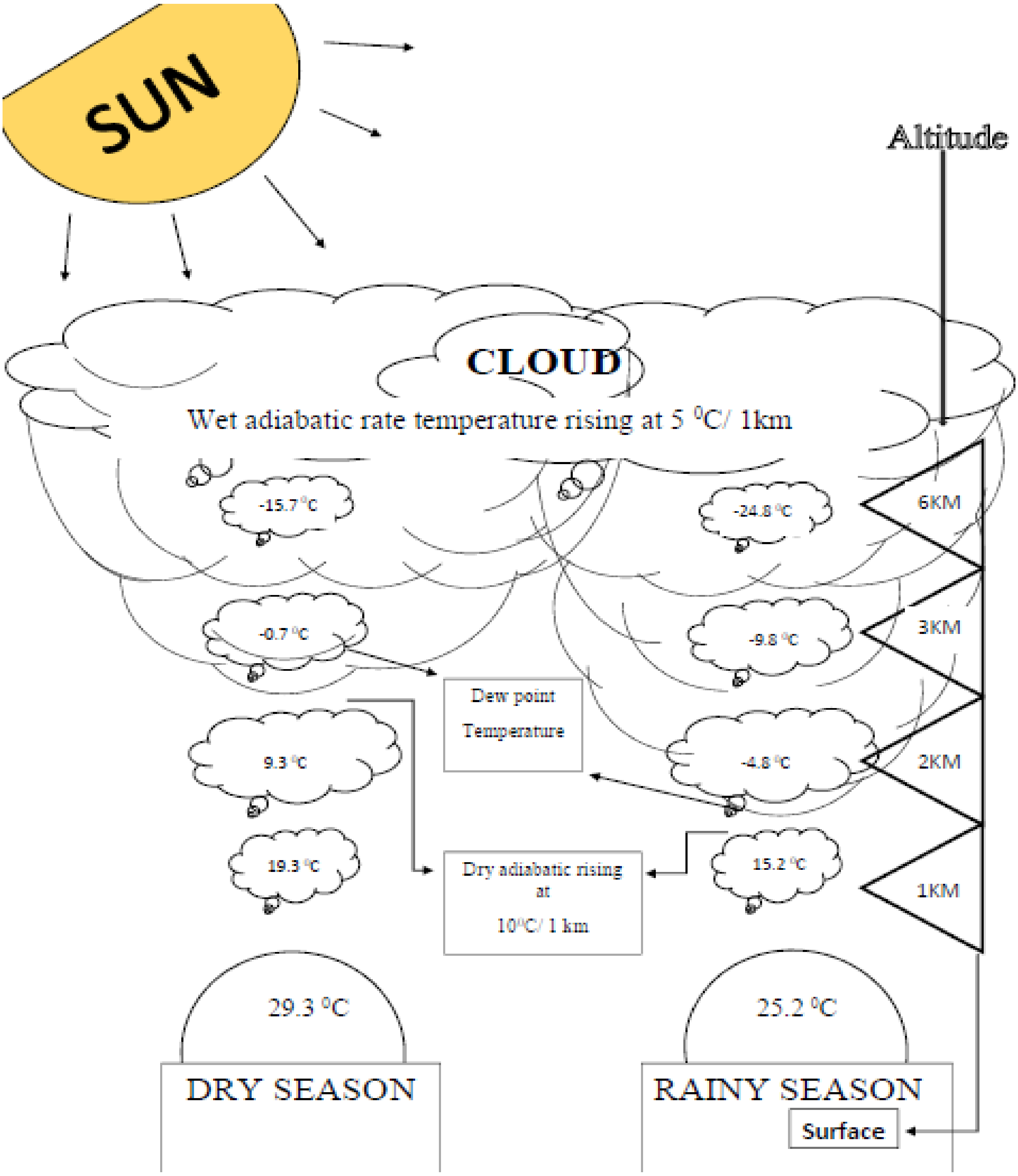

Fig. 2. Adiabatic process for seasonal variation of atmospheric aerosols in Abuja, Nigeria

For Solar Radiation, it was analyzed for the same locations, and the trend of the pollutants was considered irrespective of the normal seasonal variation, this will give a proper images for the impacts of aerosols and thereby understanding the impacts of a solar radiation on aerosol. This was carried out by comparing the monthly mean solar radiation incident on a horizontal surface of Abuja, with the pollutant concentrations.

$$\delta_g = \delta_d + \delta_b \cos(z) \quad (6)$$

Where

δ_g = irradiance on a horizontal surface, δ_d = diffuse irradiance, δ_b = direct beam irradiance on a surface perpendicular to the direct beam, z = Sun's zenith angle. [9]

As presented in equation 6, only the period when solar zenith angle that coincide with the latitude of Abuja is at minimum can validate a maximum solar irradiance. From table 4, the peak solar irradiance in a horizontal surface was achieved in a month of February.

3 RESULTS AND DISCUSSION

Concentrations of $PM_{2.5}$, SO_2 and CO were observed and the trend is higher in dry than in wet season. This agrees with a recent studies carried out by Akinfolarin OM, Boisa, Obunwo, Ede and Gobo. The higher concentrations reported could be attributed a scavenging effect of the atmosphere and dissolving gaseous pollutants during the wet season. Where there is high rainfall, air quality is generally better. The particulate matters in all the area councils were mostly higher in the months of November to March and shows lower trend in the wet season which usually started from April and ended in October as shown in Table 1 to 3. It was demonstrated with a clear graphical format stated in Figure 3 to 5. Many Studies have shown that suspended particulate matter in industrial zones are higher due to emissions from Auto-mobile machineries, roads, wind-blown and a dust from some construction industry and their vehicles which can also be washed away by a regular rainfall. [10-11], [12]

3.1 SEASONAL IMPACT RESULT

Concentrations of $PM_{2.5}$, SO_2 and CO were observed and the trend is higher in dry than in wet season. This agrees with Air quality study in Port Harcourt, Nigeria. [10], [12]

As represented in Table 1 to 3 The result of the $PM_{2.5}$, SO_2 & CO seasonal impact analysis shows that the pollutant concentrations in all the area councils were found to be higher in dry than in wet season with maximum of about a percentage 93.5 % drop from 1.0×10^{-6} to 6.5×10^{-8}ppm for SO_2, 47.09 % drop from 4.2201 to 2.2328 µg/m³ for $PM_{2.5}$ and 33.33 % drop from 1.5×10^{-3} to 1.0×10^{-3}ppm for CO. The result can be compared with a study on aerosols impact on human health in Abuja, Nigeria, specifically the emission of CO to general public. During the wet season CO was 5 ppm 8 hourly mean below all standards which rises slightly to above 15 ppm 8 hourly mean between Tukpechi, Tuje town and Chibiri districts, which is aproximately about 66.66 % drop. [13]

According to this study from table 1, $PM_{2.5}$ trend during the wet season gives a range from 2.1189 - 2.9883 µg/m³, 3.2821 - 3.8348 µg/m³, 4.0832 - 4.4903 µg/m³, 4.0001 - 4.0881 µg/m³, 2.2348 - 2.4098 µg/m³ and 3.5324 - 3.6788 µg/m³ while in dry season are 2.5439 - 3.2161 µg/m³, 3.4126 - 3.9654 µg/m³, 4.2311 - 4.8828 µg/m³, 4.0386 - 4.0986 µg/m³, 2.4038 - 2.7349 µg/m³, 3.6340 - 3.8035 µg/m³ for Abaji, AMAC, Bwari, Gwagwalada, Kuje and Kwali respectively. This result relates with $PM_{2.5}$ study by "Rumuolumeni, Oginigba, Eleme and Omuanwa". which reveals a concentrations ranging from 8.90-22.40 µg/m³, 18.70-34.75 µg/m³, 11.05-31.35 µg/m³ and 2.90 - 7.85 µg/m³ in wet season and 181.35-245.65 µg/m³, 148.85-300.35 µg/m³, 149.90-182.30 µg/m³ and 143.80 156.75 µg/m³ in dry season in four different places of Port Harcourt. According to adiabatic processes, the whole system depend on the surface temperature, therefore the study areas will be safer in wet than in dry season. [9]

The Lower concentrations reported in wet season, could be attributed to a scavenging effect of the atmosphere and dissolving gaseous pollutants during the season. Where there is high rainfall, air quality is generally better. Therefore particulate matters in all the area councils were mostly higher in the months of November to March and shows lower trend in the wet season which usually started from April and ended October. Many studies have shown that suspended particulate matter in industrial zones are higher due to emissions from Auto-mobile machineries, roads, wind-blown and dust from some construction industry and their vehicles. [11]

3.2 SOLAR RADIATION IMPACT RESULT

Investigation of the solar radiation impact on aerosols was done by taking a comparism of the aerosol data with solar radiation data as presented in Table 1, 2 & 3**,** with the PMC in Table 4.

According to this study, $PM_{2.5}$, CO & SO_2 will have less effect unless the aerosol residence time is long enough. Solar radiation range within 3.8-4.5 Kwh/m^2/day for CO, 2.8-4.5 Kwh/m^2/day for SO_2 and 4.0-6.5 Kwh/m^2/day for $PM_{2.5}$. Aerosol will only accumulate in the environment and worsen the effect if the radiation stays within such range of values and the concentrations will increased over the threshold. Figure 3 shows a decrease in the concentrations of SO_2 with an increase in solar irradiance in the month of February, August and December to January. Figure 4 shows a decrease in the concentrations of CO with an increase in solar irradiance in the month of February to March, August, and October and Figure 5 shows a decrease in the concentrations of $PM_{2.5}$ with an increase in solar irradiance in the month of March, June, and December and vice versa. The trend of pollutants in this study, irrespective of the normal seasonal variation in solar radiation, and with orientation of the graphs presented on the listed Figures implies that an in increase in aerosol concentration leads to a decrease in solar radiation also and vice versa. This agrees with a recent study carried out by Akinfolarin, et al. [11], [12]

The Solar radiation impact result for $PM_{2.5}$, SO_2 & CO shows that the pollutant concentrations in all the area councils decreases at different solar zenith angle that coincided with the latitude of the study area is achieved, which happen to be in the peak of the dry season from “January to March” with percentage drop of 29.50 % drop from 2.8-4.5 Kwh/m^2/day for SO_2, 2.87 % drop from 4.0-6.5 Kwh/m^2/day for $PM_{2.5}$ and 8.42 % drop from 5.5-6.2 Kwh/m^2/day for CO. The result can be compared with a study reported in 2007, the study confirmed that an Aerosols warms locally the atmosphere by up to 0.98Kday^{-1}, whereas they can cool the earth’s surface by up to 2.9Kday^{-1}. Which indirectly reduced the aerosols concentrations down to 50 % of its initial value which correlate with a study from the literature review by Chou & Hatzianastassiou *et al*. [2], [14]

Table 1. Monthly Mean Data for Particulate Matter ($PM_{2.5}$) for 16 hours.

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Abaji	3.2161	3.0994	2.5439	2.4550	2.4550	2.9883	2.5661	2.1189	2.7772	3.0110	3.0995	3.4355
AMAC	3.8348	3.5126	3.4126	3.4126	3.8348	3.6237	3.3237	3.2821	3.4237	3.7348	3.8349	3.9654
Bwari	4.4903	4.2322	4.2311	4.2134	4.3903	4.4903	4.2590	4.0978	4.0832	4.2903	4.3032	4.8828
Gwagwalada	4.1581	4.0981	4.0386	4.0658	4.0881	4.0881	4.0281	4.0001	4.0081	4.0281	4.0986	4.2201
Kuje	2.5838	2.4838	2.4038	2.4008	2.4068	2.4098	2.3228	2.2328	2.2348	2.3608	2.4794	2.7349
Kwali	3.6885	3.6778	3.6340	3.6240	3.6388	3.6788	3.6104	3.5334	3.5328	3.5324	3.6385	3.8035

Table 2. Monthly Mean Data for Carbon-monoxide CO (ppm) for 16 hours.

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Abaji	0.0015320	0.0015536	0.0013607	0.0013399	0.0011009	0.0010441	0.0009998	0.0319271	0.0009952	0.0010036	0.0011849	0.0011922
AMAC	0.0014587	0.0015112	0.0013123	0.0013304	0.0010933	0.0010301	0.0009809	0.0314333	0.0009769	0.0009913	0.0011616	0.0011712
Bwari	0.0014234	0.0014770	0.0012736	0.0013177	0.0010829	0.0010143	0.0009605	0.0307851	0.0009568	0.0009781	0.0011323	0.0011408
Gwagwalada	0.0014896	0.0015260	0.0013214	0.0013315	0.0010938	0.0010303	0.0009808	0.0313319	0.0009770	0.0009931	0.0011602	0.0011671
Kuje	0.0015054	0.0015505	0.0013614	0.0013448	0.0011053	0.0010494	0.0010064	0.0322351	0.0010016	0.0010069	0.0011966	0.0012075
Kwali	0.0015262	0.0015539	0.0013644	0.0013419	0.0011027	0.0010470	0.0010037	0.0320883	0.0009990	0.0010054	0.0011909	0.0011995

Table 3. Monthly Mean Data for Sulphur-dioxide SO_2 (ppm) for 16 hours.

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Abaji	0.00000092666	0.0000006	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000001	0.0000000	0.0000001	0.0000005	0.0000008
AMAC	0.04166755185	0.0000006	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000001	0.0000000	0.0000002	0.0000005	0.0000007
Bwari	0.08333420440	0.0000006	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000000	0.0000001	0.0000002	0.0000005	0.0000007
Gwagwalada	0.12500091320	0.0000006	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000001	0.0000000	0.0000002	0.0000005	0.0000008
Kuje	0.16666756806	0.0000005	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000001	0.0000000	0.0000001	0.0000005	0.0000008
Kwali	0.20833425113	0.0000006	0.0000008	0.0000003	0.0000002	0.0000001	0.0000001	0.0000001	0.0000000	0.0000001	0.0000005	0.0000008

Table 4. Monthly Mean irradiation incident on a horizontal surface of Abuja (Marionhs) kwh/m^2/day and a Monthly Average surface temperature (Mast) For In °C

Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Marionhs [14] (kwh/m^2/day)	5.88	6.09	6.27	6.06	5.58	5.04	4.73	4.19	4.73	5.31	5.98	5.86
Mast (°C) [14]	27.6	29.3	30.2	28.9	27.3	26.0	25.1	25.2	24.9	26.3	26.9	26.7

Table 5. Summary of Seasonal Impact Analysis on Aerosol

Aerosol	Maximum concentrations November to March	Minimum concentrations April to October
PM_2	4.2201 μg/m³	2.2328 μg/m³
SO_2	1.0×10^{-6}ppm	6.5×10^{-8}ppm
CO	1.5×10^{-3}ppm	1.0×10^{-3}ppm

Table 6. Summary of Solar Radiation Impact Analysis on Aerosol

Aerosol	Approximate solar Irradiance that might lead to a change in Aerosol Concentration of the study area (kwh/m²/day)	Percentage Decrease in Aerosol due Incident Solar radiation
PM_2	4.0-6.5	2.87 % Decrease from Jan – Mar.
SO_2	2.8-4.5	29.50 % Decrease from Jan-Mar.
CO	5.5-6.2	8.42 % Decrease from Feb-Mar.

Table 7. Comparism between the Maximum Concentrations Acquired and Annual Standard Based On WHO Guidelines

Aerosol	Max. Concentration acquired. [14]	Approved Annual Standard.[14] (WHO/NIOSH)
PM_2	4.8828 μg/m³	10 μg/m³
SO_2	0.20 ppm	20 μg/m³ or 0.00002 ppm
CO	0.0015886 ppm	0.01ppm

Table 8. Approximate human population increase in a year

STATE	Human Population[4]		Average population[4] increase
	2017	2018	
FCT ABUJA	3,247,608	3,564,126	8.9 %

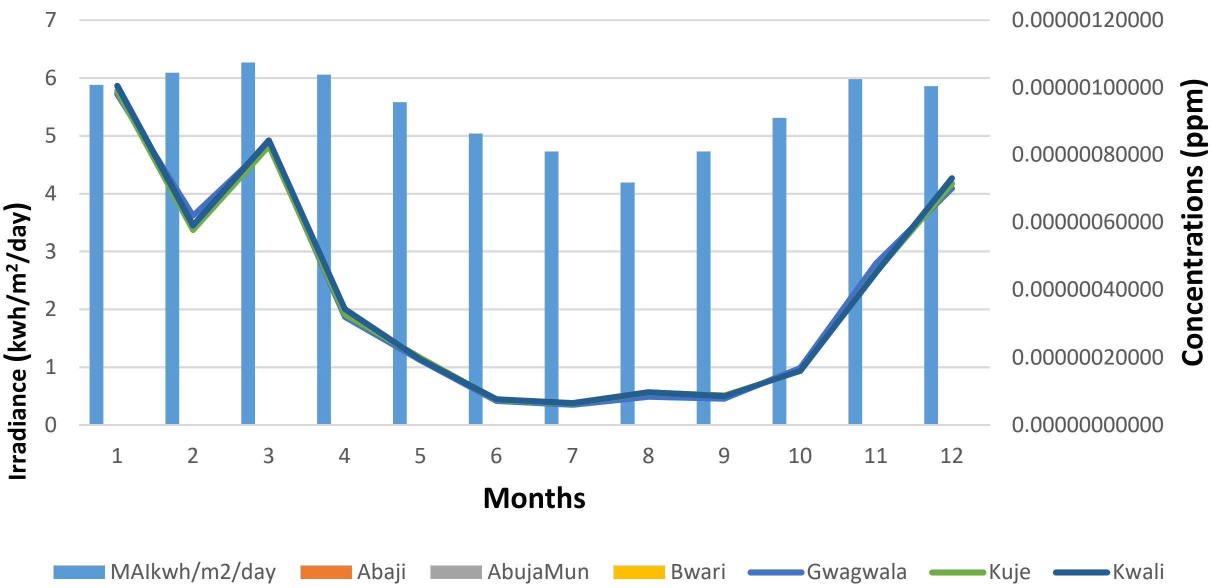

Fig. 3. Sulphur dioxide (SO_2) monthly mean concentration versus the monthly Mean Radiation incident

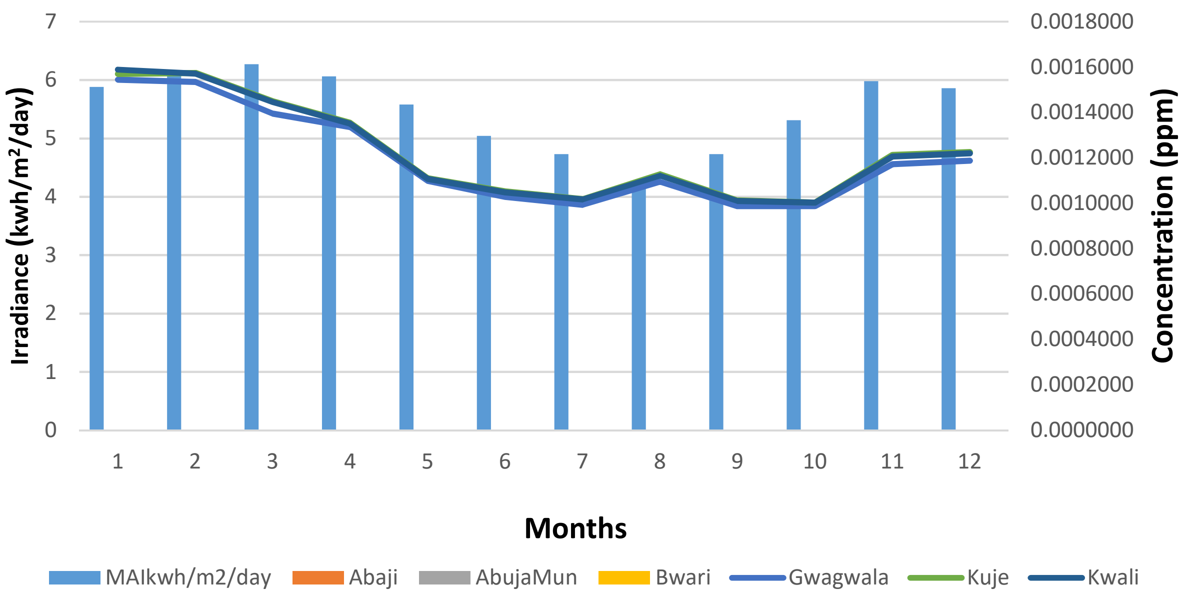

Fig. 4. Carbon monoxide (CO) monthly mean concentration versus the monthly Mean Radiation incident

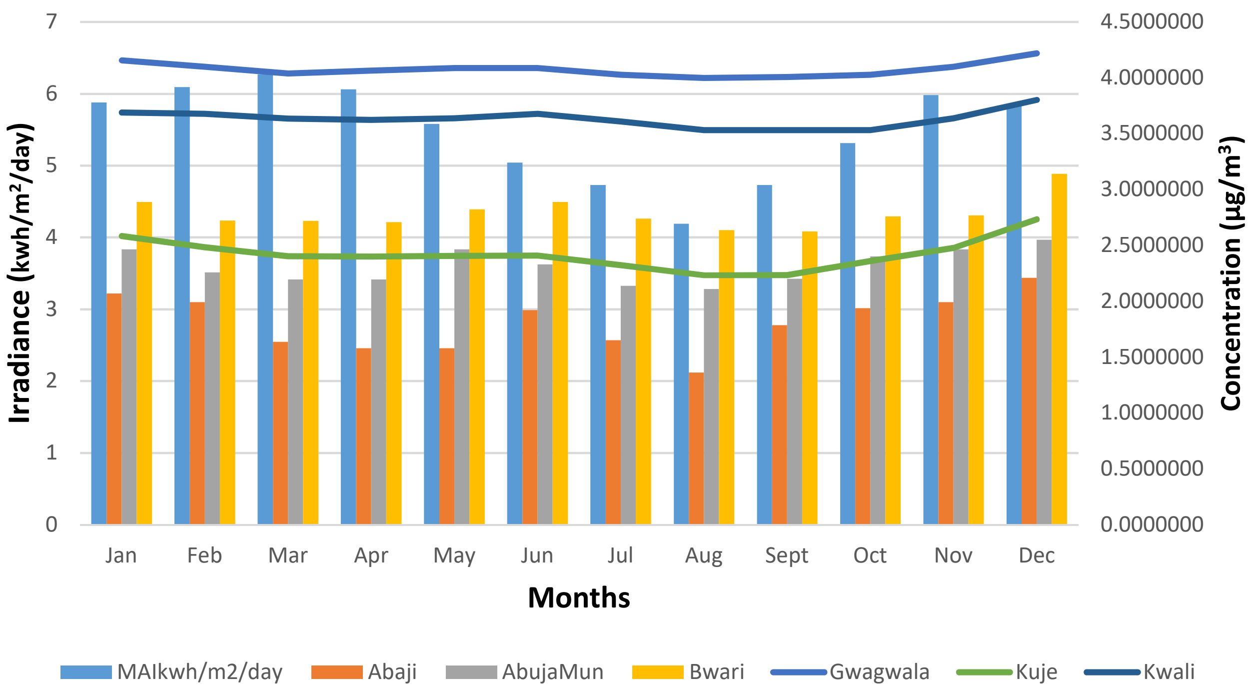

Fig. 5. Particulate Matter ($PM_{2.5}$) monthly mean concentration versus the monthly Mean Radiation incident

4 CONCLUSIONS

Findings on seasonal impact analysis indicates an increase in aerosol concentrations with a decrease in solar insolation and vise versa. The study implies that human population in FCT Abuja increase in about (2.6 ± 1) months per year, irrespective of the general mortality in human, these reveals a relative increase in human activity rate that may resulted in higher emission in outdoors. The concentration ratio from dry to wet season drops in order of about $8.4\times 10^{-2}\%$, $7.5\times 10^{-3}\%$ & $9.4\times 10^{-15}\%$ in $PM_{2.5}$, CO and SO_2 respectively. The study also confirmed that solar radiation of higher intensity also reduces a small fraction of the atmospheric aerosol down to 2.87 %, 8.42 % & 29.50 %, in $PM_{2.5}$, CO and SO_2 respectively. These percentage will increase and accumulate in the environment and worsen the effect over time, only if the approximate radiation intensity was maintained. The effects is as a result of the cloud saturations, leading to a temporal raindrop which was indirectly due to solar radiation and also due to the atmospheric instability.

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