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Ambient Air Quality Assessment and Human Health Risk in Lokoja, Kogi State

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Abstract

Ambient air quality assessment and human health risk in Lokoja, Kogi State, was carried out with reference to five major criteria air pollutants which include particulate matter (PM), nitrogen dioxide (NO2), sulfur (iv) oxide (SO2), carbon monoxide (CO) and ozone(O3). Three sampling locations were investigated by using mobile air quality monitoring devices twice daily for a period of 30 days. The measured air quality data were analyzed using one way ANOVA ($p<0.05$) while it spatial distribution was studied using the Box and Whiskers plots. The result showed that the mean concentrations (μg m–3) of the air pollutants are as follows: PM2.5 (140 ± 15), PM10 (151 ± 20), NO2 (162.3 ± 2.1), SO2 (179.9 ± 0.3), CO (202± 21) and O3 (163.4 ± 6.8). The influence of wind, temperature, pressure on atmospheric dynamics were also assessed. The mean levels of PM2.5, PM10, SO2, CO and O3 in all the air quality monitoring locations exceeded the Nigerian National ambient Air Quality Standards except the NO2 concentration at a certain place. ANOVA ($p<0.05$) analysis revealed no significant difference in the mean concentrations of the measured air pollutants. The findings revealed that anthropogenic activities in the environs are responsible for the observed air quality levels and continuous monitoring is hereby recommended in view of the adverse health implications.

Keywords: Pollutants, Air quality, Human Health Risk, Itel A70, Correlation, Lokoja

Introduction

Air pollution is one of the global major challenging environmental issues that both the developed and developing countries encountered. Particulate matters with the diameter at 2.5 μm and 10 μm (PM2.5 and PM10), carbon monoxide (CO), Nitrogen dioxide (NO2), sulphur dioxide (SO2) and ozone (O3) are pollutants that have been internationally recognized as environmentally priority air pollutants since they can constitute a threat to human and the environment [1]. The World Health Organization [2] estimates that air pollution kills seven (7) million people every year: 4.2 million from outdoor air pollution and 3.8 million from indoor pollution. Most (52%) of the mortality burden is related to cardio- metabolic conditions, particularly ischemic heart disease [3]. Sources of air pollution could be due to natural – or anthropogenic – source or both sources combined. But about 80 % of air pollution recently reported is anthropogenic sources that emanated from burning of fossil fuels, agricultural activities, waste in landfills, exhaust from factories and industries, mining operations, forest fires and fishing fleets. Atmospheric dynamics which are generally controlled by meteorological factors such as temperature, humidity, wind speed and direction for the release of atmospheric toxins to the environment.

Several researchers have reported various levels of pollution in the atmosphere. Mufuyai et al. [4] investigated heavy metals contamination in roadside dust along major traffic roads in Jos metropolitan Area Nigeria. They reported that the concentration of reparable dust at seven sampling stations in Jos metropolitan area, were measured weekly for three consecutive months (October 2012 to December 2012). The main sources of these heavy metals in the sampled area could be attributed to anthropogenic activities like open incineration of waste and vehicular traffic. Kediri et al. [5] reported indoor settled dust samples were collected from twenty- one offices within the seven College buildings of the University of Agriculture Makurdi, Nigeria. The results of this study also indicated anthropogenic sources of the metals. Lee and Hieu [6] investigated seasonal variations in mass concentrations of particulate matter (PM) and compositions of heavy metals in $PM_{2.5}$ and PM_{10} collected from a typical urban residential area in Ulsan, Korea. Principal component analysis for the heavy metals in $PM_{2.5}$ and PM_{10} identified industrial emissions and road dust (soil and traffic) as major sources at the sampling site. Gav et al. [7] reported air quality parameters and human health risk assessment in Nigeria. They recommend continuous public awareness campaigns, green transportation initiatives, and public health interventions as essential for sustainable air quality management. Feuyit et al. [8] reported Air Quality and Human Health Risk Assessment in the Residential Areas at the Proximity of the Nkolfoulou Landfill in Yaoundé Metropolis, Cameroon. They concluded that, the landfill operations might be supplying air pollutants to the neighboring residential areas. Oyewale et al. [9] reported ambient gaseous pollutants in an urban area in South Africa: levels and potential human health risk. This study determined the concentration levels and non-cancer risk of CO, SO_2, NO_2, and O_3 at an industrial area in Pretoria West, South Africa. They concluded that the recorded levels could not pose a non-cancer risk to susceptible individuals. Alberto et al. [3] reported mortality attributed to ambient fine particulate matter and nitrogen dioxide in Switzerland in 2019: Use of two-pollutant effect estimates. They concluded that the two-pollutant estimates led to paradoxical results and interpretation challenges.

Due to man's quest for a better standard of living and the utilization of natural resources for rapid industrialization, urbanization consequently causes excessive air pollution that has negative impacts on humans [10]. Therefore, air pollution problems have continued to receive a great deal of interest worldwide and rose from 5th to 4th global leading death factor in 2019 due to its negative impacts on human health [11]. Human exposure to air pollutants is unavoidable in today's perspective, especially in the urban areas of most developing countries. Among the reported cases of extreme air pollution conditions that affect humanity include the issues of high blood pressure and other cardiovascular problems [12]. Air quality assessment and monitoring is also very important in determining the nature of population exposure to atmospheric pollutants which may result in a variety of health effects. Hence, there is an urgent need for assessing the air quality condition within Lokoja owing to increase in population as it affects the respiratory system, poses significant risks to cardiovascular health, and also increased the risk of certain cancers.

Materials and Methods

Materials

The material used in air quality monitoring includes the stations equipped with sensors and instrument (Itel model A665L) capable of measuring pollutants such as PM, NO_2, SO_2 CO and O_3.

Plate I: Picture of Itel A70 Mobile Device used for the Sampling

***The Study Area*:** Kogi is a state in the North-Central zone of Nigeria (see Figure 1), located on Latitude 7.750 45'N and Longitude 6.750 45' E, occupying a total area of 29,833 square kilometers with a population of 3,314,043 [13]. Lokoja, as the, capital of Kogi State, located on the west bank of the Niger River opposite the mouth of the Benue River. Formerly the capital of Kabba province, Lokoja (see Figure 2) was part of Kwara from 1967 to 1991, when it became the capital of the newly formed state of Kogi. The town was a trade centre for the yams, cassava (manioc), corn (maize), sorghum, beans, fish, palm produce, shea nuts, and cotton produced by the local Ebira people. The

Fulani herdsmen from the north drive their cattle across the Niger to Lokoja in the dry season. Cotton ginning and weaving and palm- and shea-kernel processing are important local activities. There are limestone and iron deposits in the vicinity and nearby Mount Patti. Some of the towns and communities in Lokoja include: Adankolo, Ahubana, Lokon-Goma, Meme-Bridge, Sarkin-Noma, Adana, Agbaja, Ageni, Agodo, Ahuji, Akpata, Baji, Banda, Batake, Budon, Choko-Choko, Denbor, Ebo and Eggan. Lokoja is a melting point of several ethnic groups and cultures. Its population numbered among others, the Igala, Bunu, Kakanda, Nupe, Gbagyi, Ebira, Yoruba, Hausa, Igbo and Bassa-Nge

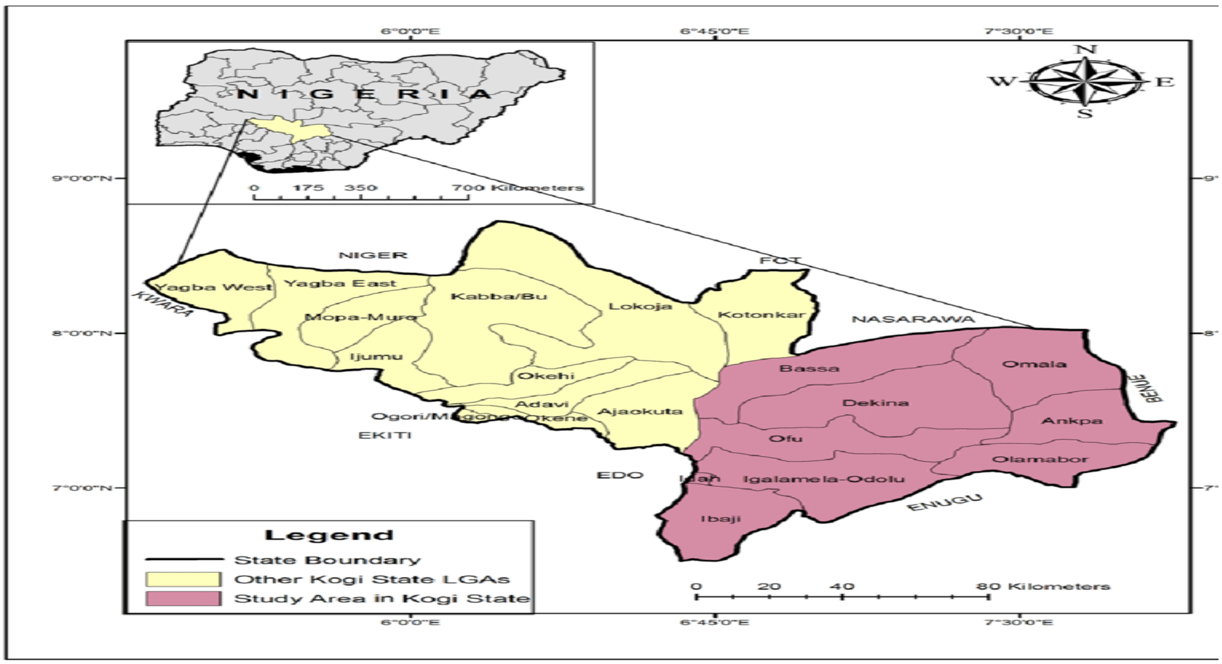

Figure 1: Map of in Nigeria Showing Kogi State

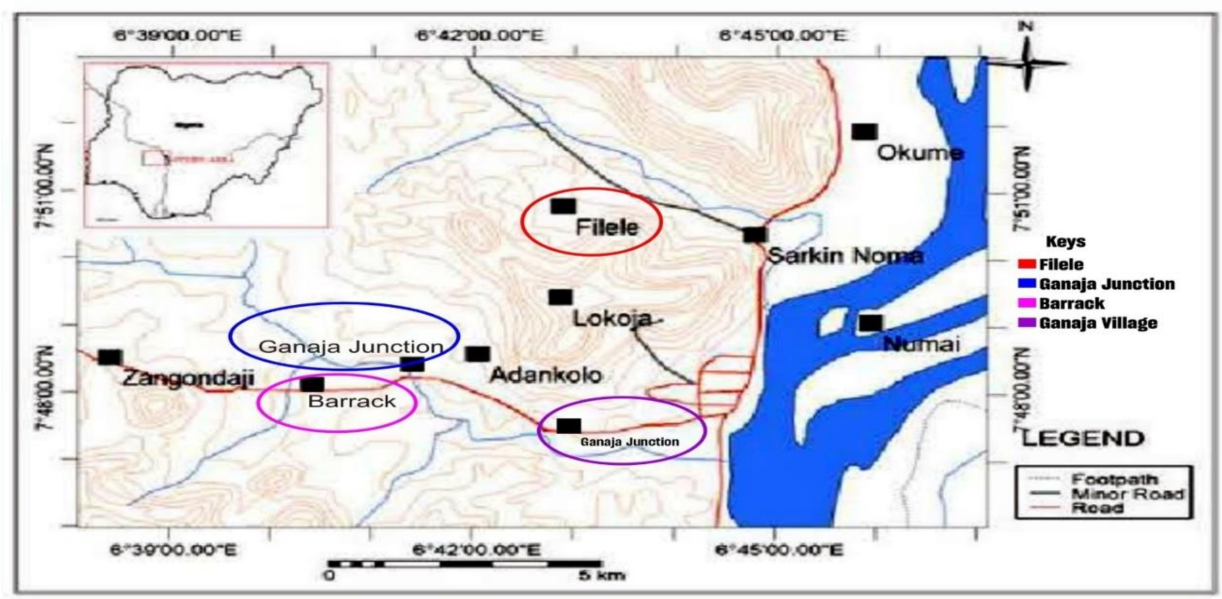

Figure 2: Map of Kogi State indicating the Sampling Area, Lokoja

Methods

*I*n this research, mobile monitoring techniques (Plate 1) was employed, utilized to provide a comprehensive understanding of air quality parameters twice daily for thirty (30) consecutive days (23rd November, 2023 to 22nd December, 2023). This includes the use of air quality monitoring stations equipped with sensors and instrument (Itel model A665L) capable of measuring pollutants such as PM, NO_2, SO_2 CO and O_3. Analyzing air quality data is crucial to identify patterns, trends, and potential sources of pollution. Data analysis techniques, such as statistical analysis and geographical information systems (GIS), help in evaluating the spatial distribution of pollutants and their correlation with health outcomes.

Data Collection: The measurements of air pollutants were performed twice daily (morning: 8. 00 – 9. 00 AM and evening: 5.00 – 6.00 PM) and the average values was recorded each of the air pollutants investigated for the period of thirty (30) day consecutively. The concentration of gases and particulates (PM_{10} and $PM_{2.5}$) were measured using a handheld mobile phone (Itel A70). For each day, concentrations were measured after every 20 minutes giving a total of 6 readings per day for each gas and particulates at 4.5 m height. Before measurements, two different networks were used to calibrate according to the manufacturer's instructions.

***Health Risk Assessment*:** To estimate the possible health risks that exposure to CO, NO_2, SO_2, and O_3 could pose to residents of the study area, human health risk assessment (HHRA) of the inhalation exposure pathways was conducted. The HHRA is a tool used by regulatory agencies to assist in the formulation of policies that protect public health against the harmful effects of air pollution [14]. The human health risk assessment framework used in this study has four components hazard identification, dose-response assessment, exposure assessment, and risk characterization.

$$HQ = \frac{EC}{MRL} \qquad (1)$$

where EC = exposure concentration (μg/m^3) and MRL = minimal risk level (μg/m^3).

$$CR = IUR \times EC \qquad (2)$$

where IUR = inhalation unit risk (μg/m^3)$^{-1}$. HQ and CR are unitless.

For acute exposures (exposure lasting 24 hours or less), $EC = CA$, where CA = contaminant concentration in air (μg/m^3). Hence, equations (**1**) and (**2**) become

$$HQ = \frac{CA}{MRL} \qquad (3)$$

$$CR = IUR \times CA \qquad (4)$$

Hazard Identification: Hazard identification is a process of recognizing if a pollutant present in an environment is likely to induce adverse human health effects should exposure to that pollutant occur [15]. The identification of CO, NO_2, SO_2, and O_3 as injurious to human health in this study was achieved through a review of existing literature.

Exposure Assessment: The exposure assessment describes the population exposed to the pollutant and the magnitude and duration of exposure to the pollutant. In this study, 265,400 human populations (Adults and Children) living in Lokoja metropolis are the likely receptors of levels of the pollutants [16]

Risk characterization: Risk characterization is the quantitative estimation of the health risk of exposure to a pollutant. It reflects the probability of an adverse health outcome occurring among healthy and/or sensitive individuals [17]. In this investigation, the risk of exposure to the pollutants was determined by estimating the Hazard Quotient (HQ) for non-carcinogens [18]. The health risk of exposure to CO, NO_2, SO_2, and O_3 through the inhalation route was estimated using Equations (5) and (6).

$$ADD_{inh=C \times InhR \times EF \times EDBW \times ATADDinh \times =C \times InhR \times EF \times EDBW \times AT} \qquad (5)$$

$$HQ = ADD_{INH}/RfC \qquad (6)$$

where: ADD is the average daily dose of CO, NO_2, SO_2, and O_3 through the inhalation route, C is the concentration of CO, NO_2, SO_2, and O_3 in ambient air, InhR is the inhalation rate (m^3/day), ED is the exposure duration (days), BW is the body weight of the exposed group (kg), AT is the averaging time (days), EF is the exposure frequency (days/year), HQ is the hazard quotient and RfC is the reference dose for pollutant.

$$ADD = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT} \quad [19] \qquad (7)$$

Where: ADD: Average Daily Dose, CA: Concentration of air pollutants, IR: Inhalation Rate

ET: Exposure Time, EF: Exposure Frequency, ED: Exposure Duration, BW: Body weight and AT: Average Time.

An HQ > 1.0 suggests the likelihood of sensitive individuals experiencing non-cancer health effects through exposure to a pollutant [20].

$$HQ = \frac{ADD}{RfD} \quad [19] \qquad (8)$$

where: ADD: Average Daily Dose and Rfd: Reference Dose

Statistical Analysis: The recorded values of air pollution parameters were analyzed using Analysis of Variance (ANOVA) at 95 % confidence interval and fisher's grouping method using version IBM 30.0.0 SPSS. Pearson correlation coefficient matrix was also employed to study possible correlation (at $\alpha = 0.05$ level of significance) between the air quality parameters.

Results and Discussion

The mean results of the major atmospheric pollutants ($PM_{2.5}$, PM_{10}, O_3, CO, NO_2, and SO_2) analysis of Lokoja metropolis are presented in Table 1 along with their standard deviations. The weekly distributions of atmospheric pollutants of Lokoja metropolis are presented bar charts as shown in Figures 3 – 5 along with their standard deviations.

Table 1: Mean Concentration of Air Quality Parameters from Sampling Sites

Parameters	Mean ± SD
$PM_{2.5}$, µg/m^3	139.7±15
PM_{10}, µg/m^3	150.6±20
NO_2, µg/m^3	162.3±2.1
$S0_2$, µg/m^3	179.9±0.3
CO, µg/m^3	202.3±21
O_3, µg/m^3	163.4±6.8
UV, nm	188.4±2.1

Particulate Matters (PM): It is a complex mixture of solids and liquids suspended in the air, including carbon, complex organic chemicals, sulphates, nitrates, mineral dust, and water, emitted by both natural and man-made sources such as combustion processes, industrial activities, and transportation. PM is classified depending on size and composition. Fine particles (PM2.5) have a diameter ≤2.5 µm, whereas coarse particles (PM10) have a diameter ≤10 µm. Figure 3 illustrates how the fine particulate matter (PM2.5) concentration in Lokoja fluctuated significantly over time. Week 1 had the greatest ambient PM2.5 concentration (32.6 ug/m^3), Week 5 had 27.5 ug/m^3, and Week 3 had the lowest PM2.5 concentration (12.5 ug/m^3).

The average PM2.5 concentration varies depending on the day of the week and the time of day (morning and evening). The mean concentration of all sites was 139.7 ug/m^3. All PM2.5 concentration levels were lower than the 80 ug/m^3 NESREA limit [8] Similar results for PM2.5 (33>25 µg/m^3) in the assessment of Air Quality Characteristics across Various Land-Uses in Port-Harcourt Metropolis were reported. However, the results are higher than those reported in Abuja (49.62 ug/m^3) and Benin city (49.41 ug/m^3) in Nigeria [21]

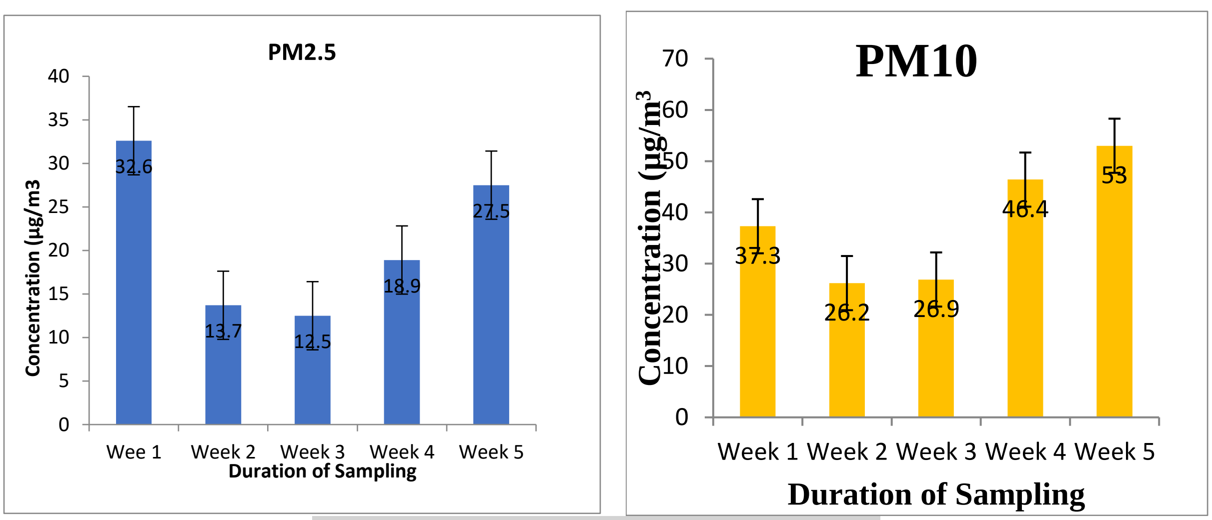

Figure 3: Weekly distribution of PM in the samples

Particulate Matter 10 (PM_{10}: The ambient PM_{10} levels in Lokoja fluctuated from week one to week five (Figure 3). Week 5 had the greatest ambient concentration of PM_{10} (53 ug/m^3), whereas week 2 had the lowest concentration (26.2 ug/m^3). The average concentration of PM_{10} was 150.0 ug/m^3. All PM_{10} concentrations were within the NESREA limit of 250 ug/m^3. The findings suggested that the concentration of ambient PM10 in Lokoja, regardless of time of day or week, poses no harm to health. The results of this study clearly suggest that $PM_{2.5}$ has a greater impact on health than PM_{10}. This outcome is consistent with prior finding [22]. However, it is greater than the published values of 17.29±21.76 and 18.89±27.15 µg/m^3 for indoor air quality [23]

Distribution of NO_2: Figure 4 shows the NO_2 values recorded at several sites, which ranged from 2.14 to 4.6 ppm. However, NO_2 levels were higher at week 1 than at other locations, with week 2 being the lowest. The reported values are in the following increasing order: Weeks 1, 2, 3, 4, and 5. The observed elevated levels of NO_2 at particular stations might be attributed to increased vehicle traffic, and increased commercial activity, such as the use of power generation sets. While majority of the regions under observation showed higher NO_2 concentrations, the average concentrations is above the yearly (53 ppb) US NAAQSUS (National Ambient Air Quality Standard) NO_2 guideline limits [22]. The mean NO_2 concentrations observed in this study, ranging from 2.14 to 4.6 ppm, are comparatively lower than values reported in some other air pollution studies conducted in the region.

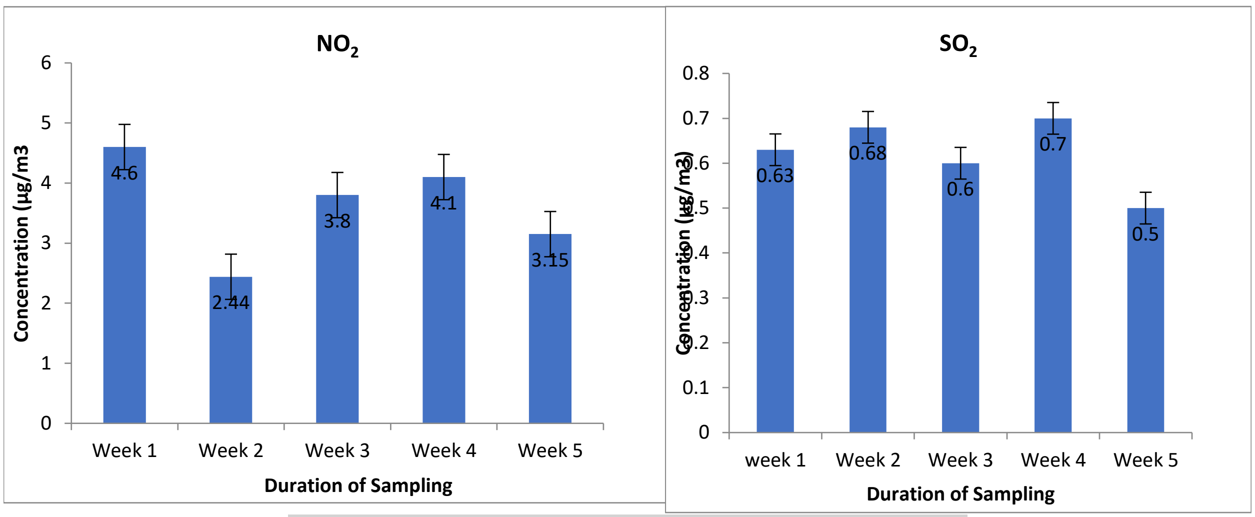

Figure 4: Weekly distribution of NO_2 and SO_2 in the samples

***Distribution of SO_2*:** The SO_2 values at the measured locations, which varied from 0.50 to 0.70 ppm, are shown in Figure 4. By week five, SO_2 levels had increased. The following is the order of the reported values: Weeks 4, 2, 3, and 5. There may be a connection between the elevated levels of NO_2 and SO2 at some stations and the presence of tricycles with three-stroke engines, as well as an increase in commercial activity that includes the use of power generating sets. The values were above the permissible NESREA limit of 0.1ppm. It goes without saying that persons in Lokoja will be more vulnerable to SO_2-related health issues in the morning and evening.

***Distribution of CO*:** Figure 5 displays the CO levels results for the whole research region. The findings showed that the levels varied across the research area, ranging from 311.5 to 572.0 µg/ m^3. All of the locations, week 5, had elevated CO levels, according to observations. The large traffic volume, various business operations, widespread use of power generators, and other home activities such burning biomass are thought to be contributing factors to the documented high values. The values were far above the permissible limit (10ppm) of NESREA. The concentration of CO for all the days of the weeks were above permissible limit of NESREA with an average value of 202.3±21µg/m^2. The implication of this result is that people living in Lokoja including both traders, transport workers and passengers will be invariably be exposed to CO on a long run. The results of this study are significantly higher than those found in Abuja's motor parks [24], where a high CO concentration of 21.4 µg/ m^2 was found, with consequent consequences on park workers, visitors, and vendors.

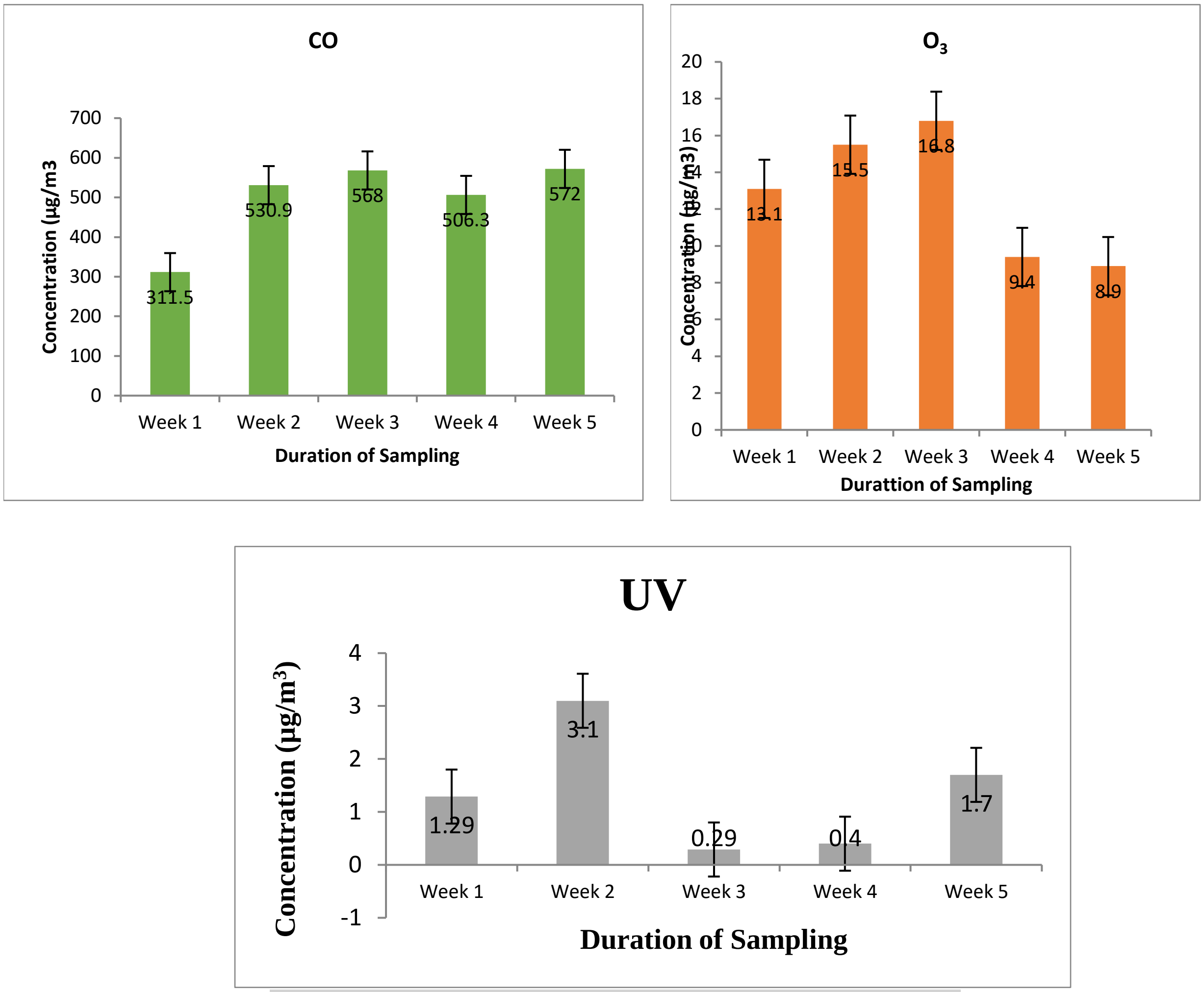

Figure 5: Weekly distribution of CO, O_3 and UV in the samples

Distribution of O_3 and UV: The investigated areas exhibited several tropospheric O_3 column concentration variations between study periods (Figure 5). The highest concentrations of O_3 levels (16.8 µg/ m^2) were identified in week 3, while the lowest O_3 concentrations (8.9 µg/ m^2) were observed in week 5. The readings, which ranged from 121 to 122 mole m^2, were greater than those recorded for Aba, Benin, Ibadan, Kaduna, Kano, Lagos, Onitsha, Port Harcourt, and Umuahia [23]. The highest UV was recorded in week 2 while the least was week 3. O_3 and UV have direct proportional relationship. The mean value of UV was calculated to be 188.4± 2.1nm

***Distribution of Visibility*:** Particles and gases in the atmosphere scatter and absorb light, reducing visibility (Table 2). The concentration of gases and suspended particles causes distant objects to look hazy, lose contrast, and shift in apparent color. The majority of the reduction in vision is caused by the scattering of aerosol particulate matter with a diameter equal to the wavelength of light, or around 0.52 µm, a process known as Mie scattering [25] the result in the study area showed a distribution range of 9-10 µm.

Table 2: Mean Concentration of Atmospheric dynamics Parameters from Sampling Sites

Parameters	Mean ± SD
Visibility (mile)	225.8±1
Temperature (°C)	279.8±22
Humidity (%)	359.01±18
Pressure (inHg)	507.1±3
Wind (mph)	3.650±3

Distribution of Temperature and Humidity: The mean temperature in the research region is reported to be 279.8 ± 22 °C. It is generally recognized that warmer temperatures are frequently linked to denser urban housing, which creates an urban heat island [26]. Lokoja has open markets with a large number of everyday traders as well as densely populated buildings. These are the urban hotspots and thermal sinks in the research region. It has been noted that these features have the ability to both absorb and release heat. These may be responsible for the high temperature recorded in the study areas. The mean relative humidity obtained was 359.01±18. Temperature and relative humidity have a direct correlation with one another. Lower temperatures lead to higher relative humidity measurements, whereas higher temperatures produce a reduction in relative humidity.

Distribution of Pressure and Wind: The trend is such that daytimes are relatively windy, whilst evenings are often quiet. The wind speed in the area ranges from 1.3 to 5.66 m/s, with the greatest average of 3.1 m/s recorded in week 4. Wind speeds cause pressure variations ranging from 1008.7 to 1012.3 millibars, with the lowest in week 4 and the highest in the week 2. During high pressure systems, the air is often quiet, allowing pollution levels to accumulate.

Potential human health risk of the air pollutants
For both adults and children, the average daily dosage and hazard quotient were used to estimate the possible risks to human health associated with each pollutant. Each air pollutant's unique Hazard Quotient (HQ) was determined by dividing the expected daily intake by the reference doses (RfD). The potential human health risk assessment for each pollutant through average daily dose and hazard quotient were calculated for both adult and children as presented in Tables 3 and 4, respectively.

Table 3: Calculated Values of Average Daily Dose of Air Quality Parameters in Adult and Children.

Air Quality Parameter	ADD (mg/kg/day)	
	ADULT	CHILDREN
$PM_{2.5}$	1.656	2.707
PM_{10}	1.785	2.918
NO_2	1.984	3.145
SO_2	2.133	3.486
CO	2.398	3.919
O_3	1.943	3.166
UV	2.234	3.650

Table 4: Calculated Values of Hazard Quotient of Air Quality Parameters in Adult and Children

Air Quality Parameters	HQ	
	ADULT	CHILDREN
$PM_{2.5}$	331.2	541.34
PM_{10}	162.27	265.27
NO_2	39.68	62.90
SO_2	92.74	151.57
CO	8.881	14.52
O_3	24.91	40.59
UV	16.55	27.04

Compared to previous research done by Francis *et al.* [22], our findings have shown that the population has DDI (Table 3) and HQ (Table 4) values that are many times higher. The non-cancer health guideline is being exceeded since the HQ is more than 1. Therefore, it is imperative to carry out a thorough toxicological impact's investigation.

Table 5: Spearman's Rank Correlation for Air Quality in Lokoja, Kogi State

	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO_2	O_3	Temp.^{o} C
$PM_{2.5}$	1.00						
PM_{10}	0.323	1.00					
NO_2	0.398	0.520	1.00				
SO_2	0.038	0.336	0.253	1.00			
CO_2	0.077	0.319	0.214	0.211	1.00		
O_3	-0.070	-0.056	-0.121	0.069	0.302	1.00	
Temp.	0.056	-0.094	-0.137	0.107	0.209	0.222	1.00

Correlation is significant at the 0.05 level (2-tailed)

Spearman's Rank Correlation: In order to investigate any possible relationships between the various contaminants, Sperman's correlation was used (Table 5). The most powerful correlation that was seen was between PM_{10} and NO_2 (r = 0.52), showing a positive statistical relationship. A likely cause could be a related source: vehicle traffic emissions, industrial activities, or combustion processes. This would mean that policies aimed at reducing those sources of emission might have successful outcomes for both PM_{10} and NO_2 concentration levels. Other pollutant pairings were positively correlated, including NO_2 and CO_2, SO_2 with other parameters, and O_3 with temperature. On the contrary, most of the pairings are weakly negatively correlated (r = -0.121 to -0.09), reflecting minor inverse relationships that are unlikely to be of statistical significance.

The negative association of relative temperature and PM_{10} was small (r = -0.094) yet statistically significant, suggesting that PM_{10} might slightly decrease with increasing temperatures due to improved atmospheric dispersion or reduced heating emissions. Such seasonal effects will better inform tailored policies on the management of PM_{10} concentrations at different times of the year.

The very weak negative correlation between O_3 and $PM_{2.5}$ is represented by r = -0.07, which indicates no significant interaction due to their different formation processes. Ozone forms through the photochemical reaction, whereas $PM_{2.5}$ comes from either direct emissions or secondary particle formation. Though their relationship is weak, addressing their individual sources remains vital for comprehensive improvement in air quality.

Conclusion

The World Health Organization's (WHO) requirements were clearly far lower than the mean concentration values for CO, SO_2, and NO_2 across the tested site when looking at the distribution of the primary air quality indices. These are the primary air pollutants that have the greatest impact on people's health and welfare. This raises concerns about deliberate attempts to reduce the current and potential surge. To achieve this, it is necessary to limit to the use of modern agricultural practices, road construction that adheres to work ethics, bush/wood burning fires, and soil erosion, which are the main sources of particulate matter. Additionally, reducing SO_2, NO_2, and CO will inevitably reduce the secondary sources that are produced in the atmosphere through interactions. Ground level ozone would be improved by using catalyst-inverted automobiles to reduce emissions, chimneys in industrial boilers and power plants and reducing petrol flaring in refineries by capturing and converting it to secondary products. These would re-establish environmental sustainability and faith in health.

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