Study on indoor pollutants emission in Akure, Ondo State, Nigeria

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Received 21 May 2023
Revised 12 October 2023
Accepted 27 November 2023

Abstract

Purpose – This study aimed to characterize the concentrations of indoor pollutants (such as carbon dioxide (CO_2), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), as well as particulate matter (PM) (PM_1, $PM_{2.5}$ and PM_{10}) in Akure, Nigeria, as well as the relationship between the parameters' concentrations.

Design/methodology/approach – The evaluation, which lasted four months, used a low-cost air sensor that was positioned two meters above the ground. All sensor procedures were correctly carried out.

Findings – CO_2 (430.34 ppm), NO_2 (93.31 ppb), O_3 (19.94 ppb), SO_2 (40.87 ppb), PM_1 (29.31 µg/m3), $PM_{2.5}$ (43.56 µg/m^3), PM_{10} (50.70 µg/m^3), temperature (32.4°C) and relative humidity (50.53%) were the average values obtained. The Pearson correlation depicted the relationships between the pollutants and weather factors. With the exception of April, which had significant SO_2 (18%) and low PM_{10} (49%) contributions, NO_2 and PM_{10} were the most common pollutants in all of the months. The mean air quality index (AQI) for NO_2 indicated that the AQI was "moderate" (51–100). In contrast to SO_2, whose AQI ranged from "moderate" to "very unhealthy," O_3's AQI ranged from "good" (50) to "unhealthy" (151–200). Since PM_1, $PM_{2.5}$ and PM_{10} made up the majority of PC1's contribution, both $PM_{2.5}$ and PM_{10} were deemed "hazardous."

Practical implications – The practical implication of indoor air pollution is long-term health effects, including heart disease, lung cancer and respiratory diseases such as emphysema. Indoor air pollution can also cause long-term damage to people's nerves, brain, kidneys, liver and other organs.

The authors are grateful to all the family members who provided one helping hand or another, especially the security of the sensor.

Funding: This research received no external funding.

Supplementary materials: Not applicable

Author contributions: Conceptualization, F.O.A., S.D.O. and A.A.; methodology, F.O.A. and D.S.; software, I.A.A.; validation, K.M.A., F.O.A. and A.A.; formal analysis, E.A.; investigation, F.O.A.; data curation, I.A.A. and S.D.O.; writing—original draft preparation, F.O.A. and A.A.; writing—review and editing, D.S., F.O.A., S.D.O. and A.A.; visualization, T.O. All authors have read and agreed to the published version of the manuscript.

Data availability statement: Data supporting the conclusions of this study are available on request from the authors.

Conflicts of interest: The authors declare no conflict of interest

Arab Gulf Journal of Scientific Research
Emerald Publishing Limited
e-ISSN: 2536-0051
p-ISSN: 1985-9899
DOI 10.1108/AGJSR-05-2023-0201

Originality/value – Lack of literature in terms of indoor air quality (IAQ) in Akure, Ondo State. With this work, the information obtained will assist all stakeholders in policy formulation and implementation. Again, the low-cost sensor used is new to this part of the world.

Keywords Indoor air quality, Pollutants, Air quality index, World health organization (WHO), United States environmental protection agency (USEPA), Nigeria

Paper type Research paper

Introduction

Indoor air quality (IAQ) is the term used to describe the air quality both inside and outside of buildings and other structures, particularly with regard to how it affects the well-being and convenience of building inhabitants. Your likelihood of experiencing indoor health issues can be decreased by being aware of and in control of common indoor contaminants. IAQ issues are acknowledged as significant health risks in low-, middle- and high-income nations alike. Because people spend a large percentage of their time indoors, indoor air is equally significant. Indoor air pollution impacts demographic groups that are especially sensitive due to their health status or age in homes, daycare centers, retirement homes and other unique contexts. Following an individual's contact with a pollutant or multiple exposures, some health impacts may become apparent quickly. Such symptoms include fatigue, headaches, nausea and throat, nose and eye discomfort. These immediate effects are typically transient and manageable. If the source of the pollution can be found, sometimes the only therapy required is to stop the patient from being exposed to it. Other consequences for health could manifest years after contact, only after prolonged or recurrent exposure or both. These side effects, which can include cancer, heart disease and certain respiratory illnesses, can be fatal or extremely disabling. Even if no symptoms are present, it is advisable to work on boosting the IAQ in your house (USEPA, Updated, 2022).

Along with climate change, air pollution is one of the largest environmental dangers to human health (WHO, 2021). Increasing air quality can support efforts to reduce emissions and combat climate change. Reducing emissions will also increase air quality. Countries that strive to meet these benchmark levels will be reducing global climate change while also protecting public health.

According to estimates, exposure to air pollution results in 7 million premature deaths per year and millions more healthy years of life lost. This may result in slowed lung development and function, respiratory infections and worsened asthma in children. The most frequent causes of early death in adults attributed to outdoor air pollution are ischemic heart disease and stroke, though proof is now mounting for other outcomes like diabetes and neurological diseases. This compares the disease burden caused by air pollution to other significant global health concerns, including poor diet and cigarette use. According to a fast scenario analysis conducted by the World Health Organization (WHO), the world could avert over 80% of $PM_{2.5}$-related fatalities if current air pollution levels were lowered to those suggested in the new recommendation. The burden of sickness would also be reduced as a result of meeting intermediate goals, with large populations and nations with high $PM_{2.5}$ concentrations seeing the greatest benefits.

In six pollutants, where research on the impacts of exposure on health is currently at its greatest, WHO's revised guidelines prescribe air quality levels (WHO, 2021). Particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO) are examples of what are known as "classical pollutants," but when these are addressed, other harmful pollutants are also impacted.

Particularly relevant to public health are the health concerns linked to PM with a diameter of 10 and 2.5 microns (m), respectively. Both $PM_{2.5}$ and PM_{10} have the ability to penetrate deeply into the lungs, but only $PM_{2.5}$ has the ability to enter the bloodstream, which predominantly affects the cardiovascular and respiratory systems while also having an impact on other organs. PM is largely produced by the combustion of fuel in a variety of industries, including transportation, energy, residential buildings, businesses and agriculture. The International Agency for Research on Cancer (IARC) of the WHO categorized outdoor air pollution and particle matter as carcinogenic in 2013.

Governments from all over the world concur on the significance of air quality monitoring in order to reduce the effects of air pollution on human health and the environment (Yi *et al.*, 2015). Because of this, industrialized nations all over the world have categorically adopted methods that support promoting exposure monitoring of air contaminants. For instance, a network of air quality monitors is typically employed in developed nations to gather ongoing information on the most significant air contaminants in metropolitan areas (Solomon, Hopke, Froines, & Scheffe, 2008). This approach provides industrialized countries with information on air quality that aids in evaluating air pollution exposure and its health effects. A variety of assessment methods have been created to assess exposure to air pollution in order to achieve this (Fisher *et al.*, 2021). Regulation pollutants, such as nitrogen oxides (NOx, NO and NO_2) and PM (PM_{10} and $PM_{2.5}$), among others, have been acknowledged worldwide as environmental priority air pollutants because they can endanger both human health and the environment (Mustafić *et al.*, 2012; Castell *et al.*, 2017). This method makes use of permanent monitoring stations that can gather these contaminants. These operations are regarded as expensive because they range in price from €5,000 to €30,000 (Castell *et al.*, 2017; Madonsela, Maphanga, & Mahlakwana, 2023). According to Forbes and Rohwer (2008), a lack of funding is the main cause of the scant availability of data on air pollution exposure in Africa. The prohibitive costs associated with the installation and upkeep of stationary monitoring stations prevent developing nations from conducting effective air quality exposure (Castell *et al.*, 2017). Therefore, before being used in the fields, the low-cost sensors were conceived, designed and tested. The placement of several sensors across a limited region could have the advantage of enhancing standard monitoring networks with more precise geographic and temporal measurements (Table 1). The inexpensive sensors are helpful in both indoor and outdoor settings.

One of the primary research gaps in this study is the lack of comprehensive data specific to Akure and Ondo State regarding IAQ and pollutant emissions. Existing studies may not adequately cover this region, making it difficult to assess the extent of the problem accurately. Also, the research may need to identify specific pollutants that are prevalent in indoor environments in Akure, which may differ from those in other regions. Understanding the local sources of indoor pollution is crucial for effective mitigation strategies. Again, the study delves into the health effects of indoor pollutants on the local population in Akure. This could involve assessing the prevalence of respiratory diseases, allergies and other health conditions associated with indoor air pollution. Investigating the effectiveness of existing or potential mitigation strategies for reducing indoor pollutant emissions in Akure, Ondo State, is essential. Lastly, assessing the level of awareness and understanding of IAQ and pollutants among the local population is important. This study may identify gaps in knowledge and opportunities for behavior change interventions. By addressing these research gaps, a study on indoor pollutant emissions in Akure, Ondo State, Nigeria, can provide valuable insights into local air quality issues, contribute to public health knowledge and inform effective strategies for reducing indoor pollution in the region.

The study might have a limited sample size, which can restrict the representativeness of the findings. A small sample might not adequately capture the diversity of indoor pollutant sources and behaviors in Akure. Also, the study is focused on a specific geographic location (Akure, Ondo State), which may limit the generalizability of the results to other regions in Nigeria or globally. Again, indoor pollutant sources and behaviors can vary significantly across different regions. The study might not account for changing factors, such as evolving

City, country	Study	Results	Reference
Dhaka (Bangladesh)	Indicators of hospital IAQ and toxicity potentials	IAQ indicators had an overall average concentration of 104.1 ± 67.6 (PM_1), 137.4 ± 89.2 ($PM_{2.5}$), and 159.0 ± 103.3 (PM_{10} $\mu g/m^3$; 0.11 ± 0.02 (NO_2), 1047.1 ± 234.2 (CO_2), and 176.5 ± 117.7 (TVOC) ppm	Zaman *et al.* (2021)
Sulaymaniyah (Iraq)	Evaluation of CO_2 levels, interior temperature, and relative humidity	Buildings with non-centralized heating and unventilated systems have higher CO_2 levels than those with centralized systems Thermal comfort is influenced by weather and building placement	Alshrefy, Yousif, AL-Rifaee, and Mohammed (2020)
Cairo (Egypt)	IAP in houses varies seasonally	In the summer, when ventilation rates are higher, IAP is heavily influenced by atmospheric levels, but interior concentrations are more influenced by indoor sources in the winter, when indoor activities are more prevalent and ventilation is lower In both seasons, the volume of rooms and the number of occupants had an impact on indoor PM, CO, and CO_2 levels	Abdel-Salam (2021)
Akure (Nigeria)	Evaluation of Akure, South West, Nigeria's indoor air quality	Indoor PM_1, $PM_{2.5}$, and PM_{10} averages were 11.81, 10.03, and 7.242 $\mu g/m^3$, respectively	Abulude, Fagbayide, Akinnusotu, Makinde, and Elisha (2019)
Addis Ababa (Ethiopia)	Cook-stove indoor air pollution in Ethiopia	Clean, upgraded, and conventional stoves' geometric means of PM varied from 10.8 to 235, 23.6–462, and 36.4–591 $\mu g/m^3$, respectively	Embiale, Chandravanahi, Zewge, and Sahle-Demennie (2020)
Desa, Malaysia	An evaluation of air pollution at a construction site in Malaysia	The outcome reveals that the mean PM_{10} levels were 62.71 $\mu g/m^3$, the average $PM_{2.5}$ levels was 18.32 $\mu g/m^3$, and the average PM_1 concentration is 14.04 $\mu g/m^3$. When compared to $PM_{2.5}$ and PM_1, PM_{10} has the highest reading. The particulate matter content and climatic parameters do not significantly correlate. There is a strong correlation between some variables and the concentrations of CO, CO_2, SO_2, and NO_2	Saudi, Nurulshyha, Mahmud, and Rizman (2017)

(*continued*)

Table 1.
Literature review of studies on indoor assessment

City, country	Study	Results	Reference
Nsukka, Nigeria	NO_2, SO_2, and O_3 indoor concentration levels in homes in Nsukka, Nigeria	In the kitchens, the indoor concentrations of NO_2, SO_2, and ozone range from 15 to 722 µg/m^3 (median: 174, IQR: 74–336 µg/m^3), 3–101 µg/m^3 (median: 5, IQR: 4–9 µg/m^3), and 2–46 µg/m^3(median: 10, IQR: 5–15 µg/m^3). Contrary to SO_2 (3–4 µg/m^3) and O_3 (14–20 µg/m^3) median levels, which were respectively similar in all rooms within the urban home, NO_2 (94, IQR: 64–175 µg/m^3) concentrations in kitchens were at least two times higher than in other rooms	Agbo, Walgraeve, Eze, Ugwuoke, and Ukoha (2021)
Taiyuan, China	Among Students in Chinese Schools: A Longitudinal Investigation of Sick Building Syndrome (SBS) in Relation to SO_2, NO_2, O_3, and PM_{10}	There were favorable correlations between the contaminants and the newly developing symptoms of the skin, mucosa, and overall health	Zhang *et al.* (2014)
Coimbra, Portugal	Primary schools air quality exploratory research	Particularly in the fall and winter, the highest concentration levels discovered inside the rooms were crucial (5,320 ppm). In a few schools, the highest concentrations of VOC and PM_{10} average concentrations surpassed the legal standard. CO, formaldehyde, NO_2, SO_2, and O_3 levels (risk) were not significant	Ferreira and Cardoso (2013)

Table 1.

indoor pollutant sources due to technological advancements or changes in household behaviors. Acknowledging these limitations is essential for a comprehensive understanding of the study's scope and applicability. Researchers and policymakers should consider these constraints when interpreting the findings and planning future research or interventions related to IAQ in Akure or similar settings.

In this region of the country, there is a lack of data on air quality, particularly IAQ. It would be appropriate if this gap were to be filled since the data produced has been a source of information for all stakeholders in mitigating air pollution worldwide. By addressing these research gaps, a study on indoor pollutant emissions in Akure, Ondo State, Nigeria, can provide valuable insights into local air quality issues, contribute to public health knowledge and inform effective strategies for reducing indoor pollution in the region. This study's objective is to assess the temperature, CO_2, NO_2, SO_2, O_3, PM_1, $PM_{2.5}$ and PM_{10} concentrations in an indoor setting in Akure, Ondo State, Nigeria. It is believed that this study would advance understanding and aid in the formulation of policies in Ondo State and throughout Nigeria.

Materials and methods

Oba-Ile town (Figure 1), located in Akure, Ondo State, Nigeria (latitude/longitude: 7 16 04.4 N 5 14 29.1 E), is the monitoring station used in this study. The community is surrounded by towns like Araromi, Owode, Akure, Igoba and Osi. All of the residents of these towns engage in extensive farming, which results in numerous forest fires, particularly during the dry season when farming and animal hunting are at their highest. The main road in the town between Akure, the capital city of Ondo State and Owode, where the state's airport is located, as well as the expressway connecting Ondo State to the west, east and northern parts of the country, are particularly busy with motorcycles, cars, minibuses and trailers. The study area is a residential building surrounded by unpaved roads (Figure 2). The building is made of a big parlor and three rooms with no extractors. At different times of the day, up to six people might be found in the flat (Figure 1), where typical everyday activities and events took place – utilizing a gas stove to cook meals (frying and baking), applying insecticides, utilizing a mosquito coil, lighting candles, etc. – all of which resulted in varied quantities of CO_2, SO_2, NO_2, O_3, PM_1, $PM_{2.5}$ and PM_{10}. The time of the various events was not carefully noted because the goal of this study was not to link gas concentration levels to a specific type of source, but some clues are given in relation to the most important events. The flat is divided into daylight and nighttime portions by a door. The door dividing the living room from the nighttime section was kept closed during the trial, and the experimental apparatus was put in the daytime space.

A group of researchers from the Italian National Agency for New Technologies, Energy and the Environment (ENEA), Department of Sustainable Development, Brindisi Research Center, Italy, designed and tested SentinAir (Plate 1) the low-cost sensor used for this study (Suriano, 2020, 2021). The sensor was placed at the center of the building near the kitchen. The majority of the meals are prepared in the completely electric cooker, which includes a hob, oven and grill since there is no central gas heating in the house. The sensor protocol was followed to the letter. For 4 months, the sensor measured temperature, relative humidity, PM_1, $PM_{2.5}$, PM_{10}, CO_2, O_3, NO_2 and SO_2. Four meters above the ground, the sensor box was installed on a rack. The distance between the residential building and the unpaved roads was around 6 meters.

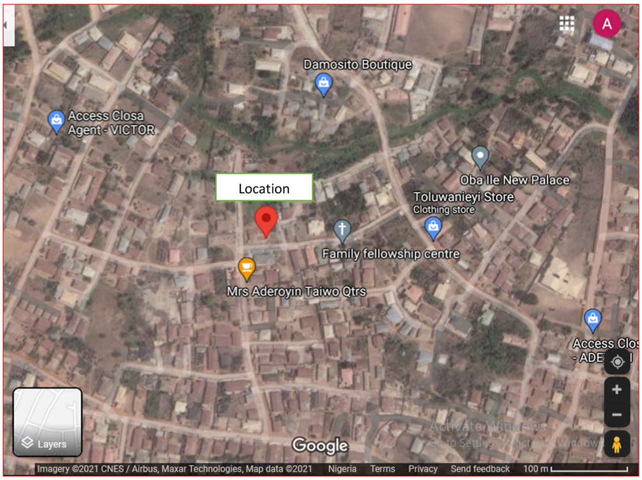
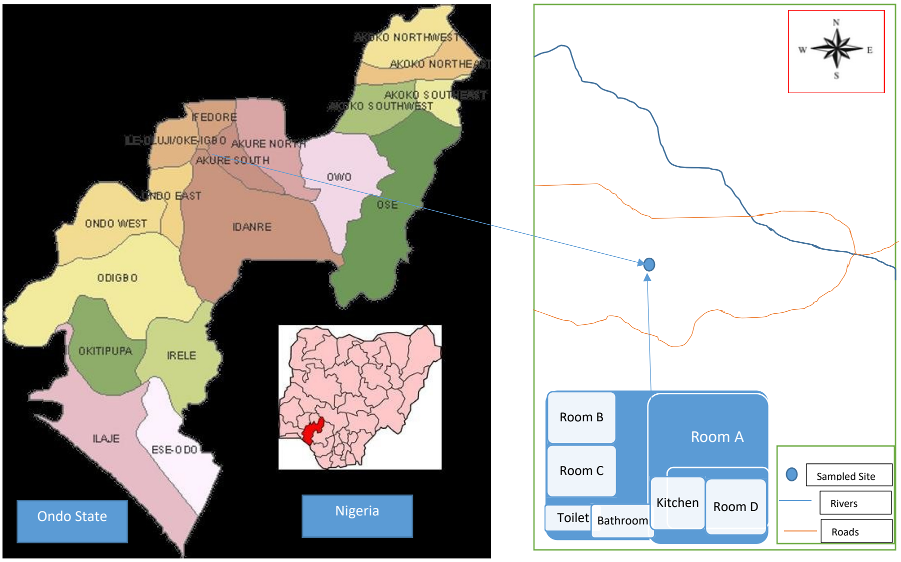


Figure 1. shows the location of the site



Maps of Ondo State and Nigeria

B – Layout of the building

Source(s): Salau *et al.* (2016)

Figure 2. The study area is a residential building surrounded by unpaved roads

At the conclusion of the evaluation, the collected sensor data was examined and evaluated. The basic description, the Pearson sample correlation coefficient (r), the matrix plot and the PCA were all computed using the Minitab version.

In accordance with World Health Organization recommendations, the mean $PM_{2.5}$ and PM_{10} values were calculated (WHO, 2023). The 24-h mean for $PM_{2.5}$ is 10 $\mu g/m^3$, the yearly mean is 25 $\mu g/m^3$ and the standards for PM_{10} are 20 $\mu g/m^3$ and 50 $\mu g/m^3$, respectively. These mean values were used to determine the air quality index (AQI). Equation (1) was used to generate the indices for each pollutant (the average of the total sum from each sampling location) (USEPA, 2018):

$$AQI_{pollutant} = \frac{Pollutant\ Concentration}{WHO\ Standard} \text{ X } 100 \quad (1)$$

The health consequences of breathing dirty air for a few hours or days are what the AQI is worried about. The AQI ratings (AirNow, 2018) are shown in Table 6. The table also shows the $PM_{2.5}$ and PM_{10}-specific pollutant concentration ranges. Generally speaking, the better the air quality, the lower the AQI is (USEPA, 2014).

Results and discussion

Table 2 depicts the basic description of the parameters studied. The minimum and maximum values for the month of January are as follows: CO_2 (306.90–561 ppm), NO_2 (0.00–266.00 ppb), O_3 (0.00–45.00 ppb), SO_2 (0.00–95.00 ppb), PM_1 (22.00–37.00 $\mu g/m^3$), $PM_{2.5}$ (33.00–53.00 $\mu g/m^3$) and PM_{10} (37.00–67 $\mu g/m^3$). The standard deviations of O_3, PM_1, $PM_{2.5}$ and PM10 were less than 10, meaning low variations in the evaluations for the month. The coefficient of variation (%) also depicted low variations in CO_2, O_3, PM_1, $PM_{2.5}$ and PM_{10}

Plate 1.
Picture of the low-cost sensor (SentinAir)

(<12%). The mean results for the month of April showed as follows: CO_2 (292.99 ppm), NO_2 (95.71 ppb), O_3 (26.50 ppb), SO_2 (104.37 ppb), PM_1 (16.43 μg/m^3), $PM_{2.5}$ (25.17 μg/m^3) and PM_{10} (28.24 μg/m^3). The Q1 and Q3 were CO_2 (224.03 and 310.38), NO_2 (64 and 111), O_3 (22 and 31), SO_2 (102 and 127), PM_1 (10 and 19), $PM_{2.5}$ (16 and 29) and PM_{10} (17 and 32). The overall results, which are the summary of the four months, depicted the minimum and maximum values of the months at a glance, while the skewness and kurtosis were CO_2 (0.4 and 4.79), NO_2 (1.24 and 1.40), O_3 (0.38 and −0.25), SO_2 (2.51 and 6.43), PM1 (3.80 and 24.30), $PM_{2.5}$ (3.60 and 32.16) and PM_{10} (2.95 and 25.94). There were differences in the concentrations obtained in the different months. For example, the PM values obtained for the months of November, December and January were higher than that of April. The simple reason was that there was less rainfall, RH and high temperatures in these months (Zhang & Jiang, 2017).

From Table 3, it could be observed that other studies showed higher values of CO_2 than our study. The following could explain the differences in the results: (1) Since CO_2 is extensively absorbed by the atmosphere after being released by factories, automobiles and other sources, its concentration is rather constant across the world. Depending on how near sources or sinks you are, there may be some variations (Climate Portal, 2021); (2) plants absorb more CO_2 through photosynthesis throughout the day or in the spring and summer

	CO_2 (ppm)	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	PM_1 (µg/m^3)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)	Temp (°C)	RH (%)
January									
Mean	399.85	79.40	19.08	26.19	28.17	42.14	51.16	32.38	54.82
Std Dev	47.17	47.48	6.59	21.66	2.70	4.08	5.81	1.76	4.88
CoeffVar	11.80	59.80	34.56	82.72	9.58	9.69	11.36	5.44	8.91
Min	306.90	0.00	0.00	0.00	22.00	33.00	37.00	26.50	46.40
Q1	363.00	54.00	15.00	0.00	26.00	39.00	47.00	26.50	46.40
Q3	423.40	79.50	22.00	44.00	30.00	45.00	55.00	33.50	55.95
Max	561.00	266.00	45.00	95.00	37.00	53.00	67.00	35.20	69.80
Skewness	0.97	2.42	1.50	0.43	0.51	0.34	0.31	−1.52	1.50
Kurtosis	0.41	5.55	2.94	−0.05	0.03	−0.28	−0.30	1.71	1.66
April									
Mean	282.99	95.71	26.50	104.37	16.43	25.17	28.24	39.26	33.02
Std Dev	93.74	52.32	7.90	41.69	12.34	19.37	21.64	3.06	9.34
CoeffVar	33.13	54.66	2.81	39.94	75.13	76.96	76.63	7.81	28.28
Min	274.60	22.00	0.00	0.00	0.00	1.00	1.00	26.50	22.80
Q1	224.03	64.00	22.00	102.00	10.00	16.00	17.00	37.60	26.10
Q3	310.38	111.00	31.00	127.00	19.00	29.00	32.00	41.40	37.18
Max	882.70	356.00	58.00	203.00	178.00	288.00	306.00	43.60	71.50
Skewness	1.69	1.75	0.41	−1.66	6.68	7.09	6.20	−1.23	1.57
Kurtosis	4.18	2.86	0.61	1.74	72.93	78.93	64.37	2.09	2.55
November									
Mean	451.26	112.37	21.85	39.31	24.06	35.98	41.23	32.48	55.77
Std Dev	92.06	76.28	15.21	93.08	13.70	21.44	24.24	3.23	11.30
CoeffVar	20.40	67.88	69.59	236.76	56.94	59.59	58.78	9.93	20.27
Min	217.00	0.00	0.00	0.00	0.00	0.00	4.00	23.40	31.70
Q1	391.08	58.00	9.00	0.00	17.00	25.00	26.00	30.00	47.98
Q3	495.70	135.00	35.00	8.00	27.00	41.00	50.00	35.10	64.00
Max	1307.60	296.00	90.00	316.00	267.00	443.00	481.00	40.40	105.40
Skewness	1.74	1.17	0.38	2.27	5.15	5.58	4.60	0.30	0.14
Kurtosis	10.13	0.17	−0.91	3.41	63.96	70.34	54.13	−0.72	0.40
December									
Mean	453.35	70.66	16.54	25.87	37.45	55.25	65.05	30.62	50.43
Std Dev	122.70	58.73	13.00	22.92	15.00	22.18	22.61	4.88	14.18
CoeffVar	27.06	76.61	78.43	88.58	39.95	40.15	34.76	15.93	28.11
Min	32.90	0.00	0.00	0.00	20.00	22.00	29.00	17.50	17.50
Q1	377.35	26.25	4.00	1.00	29.00	44.00	53.00	27.80	41.30
Q3	509.87	105.00	26.00	41.00	42.00	62.00	72.00	33.60	58.90
Max	1464.90	339.00	95.00	92.00	241.00	403.00	430.00	53.90	276.00
Skewness	0.90	0.90	0.51	0.62	3.53	4.26	4.50	0.56	1.95
Kurtosis	6.14	1.25	0.49	−0.33	22.76	33.54	37.99	2.53	18.91
Overall									
Mean	430.34	93.31	19.94	40.87	29.31	43.56	50.70	32.46	50.53
Std Dev	120.23	67.48	13.776	67.24	16.03	24.08	26.6	4.84	14.24
CoeffVar	27.94	72.32	69.02	164.51	54.69	55.29	52.76	14.90	28.17
Min	332.90	0.00	0.00	0.00	0.00	0.00	1.00	17.50	17.50
Q1	357.40	52.00	9.00	0.00	20.00	31.00	34.00	29.60	40.00
Q3	494.90	114.00	30.00	47.00	34.00	50.00	62.00	35.40	60.50
Max	1464.90	365.00	95.00	316.00	267.00	443.00	481.00	53.90	76.00
Skewness	0.74	1.24	0.38	2.51	3.80	3.60	2.95	0.25	0.83
Kurtosis	4.79	1.40	−0.25	6.43	24.30	32.16	25.94	0.74	8.19

Table 2.
Basic description of the results

Table 3. Comparisons of results of this study with others

City, country	Results (mean) CO_2	NO_2	O_3	SO_2	PM_1	$PM_{2.5}$	PM_{10}	Temp	RH	References
Akure, Nigeria	430.34	93.31	19.94	40.87	29.31	43.56	50.70	32.46	50.53	This Study
Lucknow City, India	–	–	–	–	–	149.4	–	–	–	Taushiba *et al.* (2023)
Dhaka, Bangladesh	1047.1	0.11	–	–	104.1	137.4	159.0	–	–	Zaman *et al.* (2021)
Twelve Global Cities	567	–	–	–	–	–	–	27.00	66.00	Kumar *et al.* (2022a, 2022b)
Twelve Global Cities	–	–	–	–	45.00	65.00	–	–	–	Kumar *et al.* (2022a, 2022b)
Abha, Saudi Arabia	650	–	–	–	4000	1100.00	90.00	–	–	Algarni, Khan, Khan, and Mubarak (2021)
Dammam, Saudi Arabia	963	0.19	0.02	1.46	240.00	192.00	442.00	40.4	42.3	Salama and Berekaa (2016)
Xi'an, China	622.5	–	–	–	148.0	222.0	333.0	17.1	74.4	Niu *et al.* (2015)
Minneapolis, USA	564.0	15.40	25.5	–	–	35.5	–	–	–	Gonzalez, Boies, Swanson, and Kittelson (2022)
Cyprus	518.0	–	–	–	10.60	14.60	16.10	29.30	46.40	Konstantinou *et al.* (2022)
Surabaya City, Indonesia	–	0.10	–	–	28.35	43.60	70.96	–		Syafei *et al.* (2020)
Saudi Arabia	–	0.09	0.09	0.61	–	–	–	37.29	29.82	Radaideh (2017)
Obrikom and Omoku, Nigeria	686.0	0.02	–	0.05	–	25.20	55.9	27.50	74.30	Oweisana *et al.* (2021)
Dammam, Saudi Arabia	406.30	0.00	0.07	0.60	–	118.30	195.20	23.70	24.00	Shafi and Khelif (2021)
Lanzhou, China	–	–	–	–	–	53.2	124.54	–	–	Filonchyk and Yan (2018)
Ogbomoso, Nigeria					17.9–32.3	26.5–60.5	154.5–230.8	–	–	Jelili, Gbadegesin, and Alabi (2020)
Abuja and Benin, Nigeria			–	–		30.79–139.06	29.31–165.39	–	–	Lala, Onwunzo, Adesina, and Sonibare (2023)
Lagos, Nigeria			32.52–38.7		–	69.28	107.38	–	–	Abulude *et al.* (2021)
Awka, Nigeria	10925	ND	ND	ND	–	11.5	26.5	–	–	Ezeonyejiaku *et al.* (2022)

than they emit through respiration (Copernicus Atmosphere Monitoring Service, 2019). As a result, air concentrations of CO_2 decline. Due to the Industrial Revolution and the exponential growth of manufacturing activity worldwide, the concentration of CO_2 has risen particularly (Blokhin, 2023). In comparison to other research, this study's average NO_2 level was higher (Table 4). Cooking, baking, mosquito coils, garbage burning, candle burning, outdoor vehicle emissions and other sources of pollutants could be the causes (Lee & Wang, 2006). In addition, CO, VOCs, SO_2, NO_2, $PM_{2.5}$ and PM_{10} were discovered in the mosquito coil's emissions, according to Hogarh *et al.* (2018). The O_3 values in our study are higher than those found in earlier research. There are numerous causes to blame for the disparity, including (i) O_3 is generated on warm, sunny days when the temperature is high and the relative humidity is low; (ii) the fact that O_3 levels are frequently higher in rural than urban regions and (iii) that sunlight causes pollutants released by vehicles, power plants, industrial boilers, refineries, chemical plants and other sources to chemically react with one another is still a truth (USEPA, 2023). These facts are supported by the study's findings because of the study location's rural setting, low RH and high temperature. The study's PM_1 is higher than the levels recorded for Indonesia (28.25 $\mu g/m^3$) and Cyprus (10 $\mu g/m^3$) by Syafei *et al.* (2020) and Konstantinou *et al.* (2022), respectively. The $PM_{2.5}$ levels reported in this study are significantly lower than those discovered in Bangladesh (159.0 $\mu g/m^3$), Saudi Arabia (1100.00 $\mu g/m^3$), China (222.0 $\mu g/m^3$) and India (149.4 $\mu g/m^3$) Zaman *et al.* (2021), Niu, Guinot, Cao, Xu, and Sun (2015) and Taushiba *et al.* (2023), respectively, but significantly higher than 69.28 $\mu g/m^3$ and 11.5 $\mu g/m^3$ by Abulude *et al.* (2021) and Ezeonyejiaku, Okoye, Ezeonyejiaku, and Obiakor (2022), respectively. The PM_{10} results from our investigation were lower than those of Salama and Berekaa (2016), Niu *et al.* (2015), Filonchyk and Yan (2018) and Shafi and Khelif (2021) but higher than the one (54.9 $\mu g/m^3$) obtained by Oweisana, Gobo, Daka, and Ideriah (2021). It was found that $PM_{2.5}$ exceeded the WHO standard by 30 times (24 hours) and 88 times (annually), while PM_{10} exceeded it by 10 times (24 hours) and 32 times (annually) when the pollutants' data from this study were compared with the WHO 2021 standard (Table 4). NO_2 occurred 3.65 times annually and 14.6 times continuously. O_3 was 1.58 times during peak season, although less than 100 was advised for exposure for 8 hours, while SO_2 was 7.9 times for 24 hours. The consequences of the discrepancies may lead to health issues or even death. The issue with WHO scientific guidelines is that they have a global viewpoint and ignore the distinct economic circumstances of each country. The primary goal of the air quality standards that make up the legal framework for the repeated exposure threshold and limit is to develop a standardized method of defending against the detrimental effects of air pollution on both human health and the ecosystem as a whole (WHO, 2021).

The contributions of each pollutant for several months were shown in the donut-shaped visual diagrams (Figure 3). In January, April, November and December, respectively, NO_2 (12%), PM_{10} (61%), SO_2 (18%), PM_{10} (49%), NO_2 (16%), PM_{10} (62%) and NO_2 (10%), PM_{10} (63%) were the concentrations. The average overall result supported the findings. In this investigation, average pollutant concentrations were discovered together with low secondary pollutant concentrations. It is connected to RH and typical temperatures. The particle concentrations are highest at 10 nm in diameter, but they get progressively higher as the size goes up. Bousiotis *et al.* (2023) made this observation; however, their findings were related to higher-than-average temperatures, the planetary boundary layer (PBL) heights, wind speeds and lower-than-average RH.

Using Pearson's correlation analysis, the study's parameters' correlation coefficient was determined. RH and CO_2 ($p = 0.46$) and PM_1 and CO_2 ($p = 0.33$), $PM_{2.5}$ and CO_2 ($p = 0.32$) and PM_{10} and CO_2 ($p = 0.34$) all showed only minor associations. RH and Temp, however, displayed marginally significant negative associations (Figure 4 and Table 5). Strong positive associations between PM_1, $PM_{2.5}$ and PM_{10} were all observed ($p = 0.97$). Significant correlations between pairs typically imply that they have a combined or common origin,

Pollutant	Averaging time	Interim target 1	2	3	4	AQG level
$PM_{2.5}$ μg/m^3	Annual	35	25	15	10	5
	24 – hour*	75	50	37.5	25	15
PM_{10} μg/m^3	Annual	70	50	30	20	15
	24 – hour*	150	100	75	50	45
O_3 μg/m^3	Peak Season	100	70	–	–	60
	8 – hour[a]	160	120	–	–	100
NO_2 μg/m^3	Annual	40	30	20	–	10
	24 – hour[a]	120	50	–	–	25
SO_2 μg/m^3	24 – hour[a]	125	50	–	–	40
CO mg/m^3	24 – hour[a]	7	–	–	–	4

Note(s): [a]99th percentile (i.e. 3–4 exceedance days per year)
[b]Average of daily maximum 8-h mean O_3 concentration in the six consecutive in six months with the highest six-month running-average O_3 concentration
Source(s): WHO (2021)

Table 4.
WHO 2021 pollutants air quality guideline (AQG)

whereas weak correlations show that they have separate origins (Baguma *et al.*, 2022; Opolot *et al.*, 2023). As a result, the couples' positive correlation points to possible anthropogenic and related pathways into the terrestrial environment as a result of their shared origins, reciprocal dependences and identical transport patterns.

Consider the AQI as an indicator with a scale of 0 to 500. The quantity of air pollution and the resulting health risk increase with increasing AQI values (AirNow, updated 2018). As an illustration, an AQI score of 50 or less indicates healthy air quality, whereas one of over 300 indicates hazardous air quality (Table 6). The short-term global ambient air quality guidelines for the protection of public health are typically equivalent to an ambient air level of 100 for each pollutant. In general, AQI levels of 100 or less are considered to be good. Air quality is unhealthy when AQI values are over 100 – initially for some vulnerable groups of individuals, then for everybody as AQI values rise. There are six groupings that make up the AQI. A varying level of medical concern relates to each group. Additionally, each group has a unique color. Individuals can immediately detect if the air quality in their neighborhoods has reached harmful levels (Wambebe & Duan, 2020). The AQI of the five contaminants assessed in this investigation is shown in Table 6. They were shown the mean, maximum, minimum and range. The maximum AQI was 152 (unhealthy for sensitive groups), but the mean of the NO_2 showed that the AQI was within the range of "moderate" (51–100). O_3 AQI ranged from "good" (50) to "unhealthy" (151–200), whereas SO_2 ranged from "moderate" to "very unhealthy." Both $PM_{2.5}$ and PM_{10} were classified as "hazardous," but $PM_{2.5}$ was more prevalent (>400) than PM_{10}. Table 7 shows how these AQI incidences have an impact. A $PM_{2.5}$ AQI of 121, for instance, indicates that some members of the general population and members of vulnerable groups may experience health impacts. The general public is likely to be impacted," while "Health warning of emergency conditions: everyone is more likely to be affected" is displayed on >400.

Extraction of the eigenvalues and eigenvectors from the correlation matrix was used to replace principal component analysis (PCA) and determine the number of significant principal components and the proportion of total variance that each one accounted for. PM_1, $PM_{2.5}$ and PM_{10} accounted for the majority of PC1's contribution of 38.20% of the variance. The major contributor to PC2's explanation of 24.5% of the variance is temperature. The findings (Table 8) indicate that they might explain 77.30% of the entire variance based on eigenvalues greater than 1 at $p > 0.05$ (Zhang, Li, Zhang, Zhao, & Norback, 2014) RH, CO_2 and O_3. In PC3, the eigenvalue (1.32) explained approximately 14.50% of the overall variation.

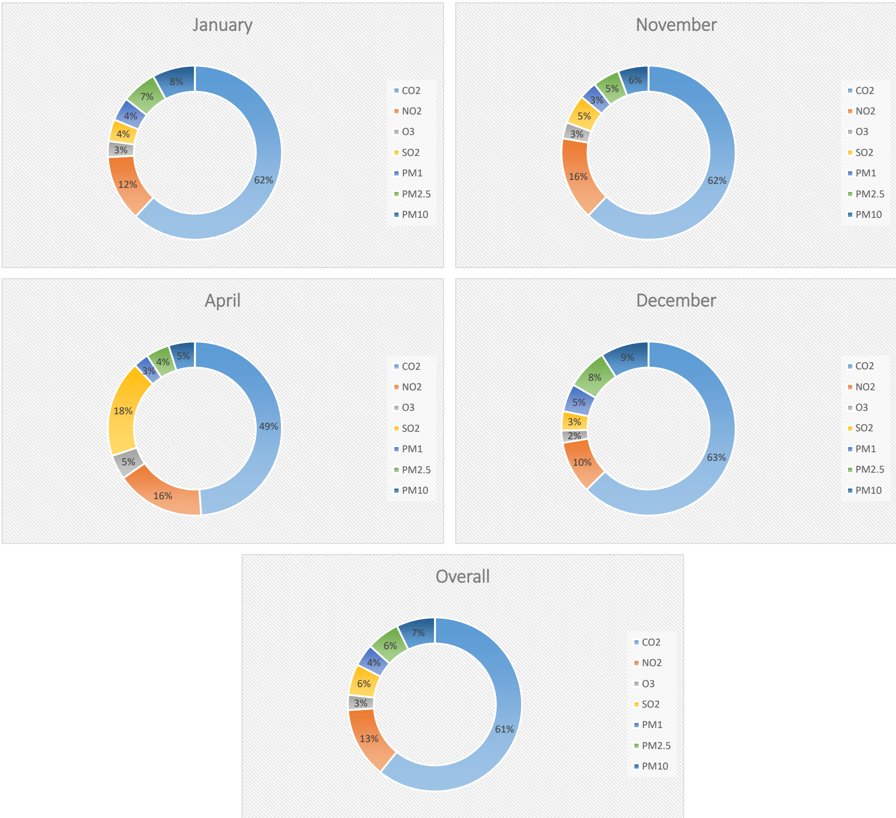


Figure 3.
Depicts the contributions of the pollutants within the four months of evaluations

This principal component (PC) can be seen as a representation of effects from single points, such as frying, cooking and insecticide application.

The variables with the greatest impact on each component are shown on the loading plot in Figure 5. The figure shows loadings from −1 to 1. Loadings that are near −1 or 1 show that the variable has a significant impact on the component. Loadings that are not far from 0 show that the variable has little effect on the component. The variable factor map shown in Figure 5 shows which PCA quadrant each individual pollutant belonged in. The first group (top right) consists of climatic variables (RH) and pollutants (CO_2). PM_1, $PM_{2.5}$ and PM_{10} are in the second group in quadrant 2, which is in the center (bottom right). The third group includes the quadrant three elements of temperature: SO_2, NO_2 and O_3. The first and third groups have a significant impact on the components, as seen above.

The dendrogram diagram and the eight amalgamation steps are shown in Table 9 and Figure 6, respectively. The similarities are listed in Table 9, ranging from 15.97 to 99.46. The similarities displayed wide variances, and there were 2, 3 and 2 clusters. To assess whether there were any existing parallels among the study's obtained parameters, cluster analysis was also conducted. Figure 6 shows the dendrogram of several contaminants and climatic

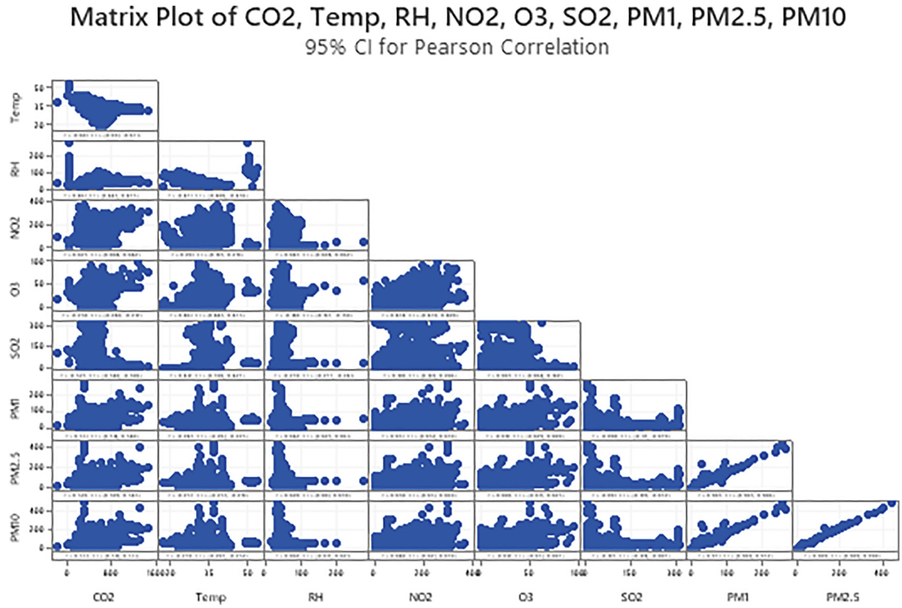


Figure 4.
Matric Plot of the parameters studied

Table 5.
Pearson correlation of the pollutants and the meteorological parameters

CO_2	1								
Temp	−0.68	1							
RH	0.46	−0.47	1						
NO_2	0.02	0.20	0.04	1					
O_3	−0.23	0.46	−0.15	0.47	1				
SO_2	−0.32	0.42	−0.26	0.12	0.08	1			
PM_1	0.33	−0.24	0.04	0.05	−0.01	−0.10	1		
$PM_{2.5}$	0.32	−0.24	0.02	0.05	0.01	−0.09	*0.99*	1	
PM_{10}	0.34	−0.27	0.00	0.04	−0.01	−0.11	*0.97*	*0.99*	1
	CO_2	Temp	RH	NO_2	O_3	SO_2	PM_1	$PM_{2.5}$	PM_{10}

Table 6.
The air quality index (AQI) of the pollutants (overall)

	NO_2	O_3	SO_2	$PM_{2.5}$	PM_{10}
Mean	93	18	56	121	46
Maximum	152	174	206	462	371
Minimum	0	0.00	0.00	0.00	1.00
Range	0.00-152	0.00-174	0.00-206	0.00-462	1.00-371
	Good (≤50)	Moderate (51 – 100)	Unhealthy for Sensitive Groups (101 – 150)	Unhealthy (151 – 200) Very Unhealthy (201 – 300)	Hazardous (≥301

Source(s): CPCB (2014)

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	≤50	Air quality is satisfactory, and air pollution poses little or no risk
Yellow	Moderate	51 – 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution
Orange	Unhealthy for Sensitive Groups	101 – 150	Members of sensitive groups may experience health effects. The general the public is less likely to be Affected
Red	Unhealthy	151 – 200	Some members of the general public may experience health effects; members of sensitive group may experience more serious health effects
Purple	Very Unhealthy	201 – 300	Health alert: The risk of health effects is increased for everyone
Maroon	Hazardous	≥301	Health warning of emergency conditions: everyone is more likely to be affected

Table 7. AQI color codes, levels of concern and description

Variable	PC1	PC2	PC3
Eigenvalue	3.44	2.21	1.32
Variability (%)	38.20	24.50	14.50
Cumulative (%)	38.20	62.70	77.30
CO_2	0.36	0.29	−0.28
Temperature	−0.34	−0.42	0.06
Relative humidity	0.18	0.37	−0.44
NO_2	−0.33	−0.29	−0.67
O_3	−0.13	−0.39	−0.49
SO_2	−0.19	−0.30	0.11
PM_1	0.47	−0.30	0.09
$PM_{2.5}$	0.47	−0.31	0.09
PM_{10}	0.48	−0.30	0.10

Table 8. Principal component analysis of the parameters

factors derived using Ward's method of linking and Euclidean distance as a comparison metric. The findings indicated that the study's parameters (also known as variables) were divided into two main clusters. CO_2, RH, PM_1, $PM_{2.5}$ and PM_{10} combined to create cluster 1, whereas temperature, SO_2, NO_2 and O_3 made up cluster 2. The findings suggested that a certain cluster of contaminants may have come from anthropogenic sources (Kabir *et al.*, 2022; Abulude, Oluwafemi, Arifalo, Elisha, & Kenni, 2023).

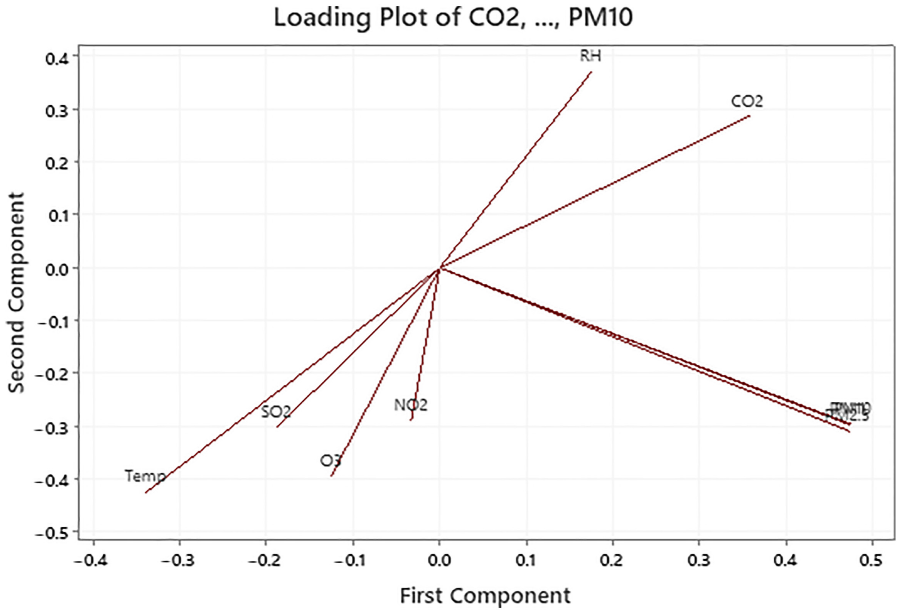


Figure 5.
Loading Plots of the parameters

Table 9.
The cluster analysis table of the pollutants and meteorological parameters: amalgamation steps

Step	Number of clusters	Similarity level	Distance level	Clusters joined		New cluster	Numberof obs in new Cluster
1	8	99.4572	0.01086	8	9	8	2
2	7	98.5271	0.02946	7	8	7	3
3	6	73.7224	0.52555	4	5	4	2
4	5	73.5661	0.52868	1	3	1	2
5	4	70.5915	0.58817	2	6	2	2
6	3	54.1684	0.91663	2	4	2	4
7	2	50.1004	0.99799	1	7	1	5
8	1	15.9682	1.68064	1	2	1	9

Conclusion

The study used a cheap sensor to assess the IAQ in Akure, Ondo State, Nigeria. Temperature, RH, PM_1, $PM_{2.5}$, PM_{10}, CO_2, SO_2, NO_2, O_3 and other parameters were resolute. The findings revealed that (i) the concentrations of the pollutants were above the WHO 2021 guidelines, (ii) there were associations between the pollutants and meteorological parameters and (iii) the majority of the pollutants in PC1 were PM_1, $PM_{2.5}$ and PM_{10}. According to the pollutants' AQI, certain people in general and those in sensitive groups might have health effects.

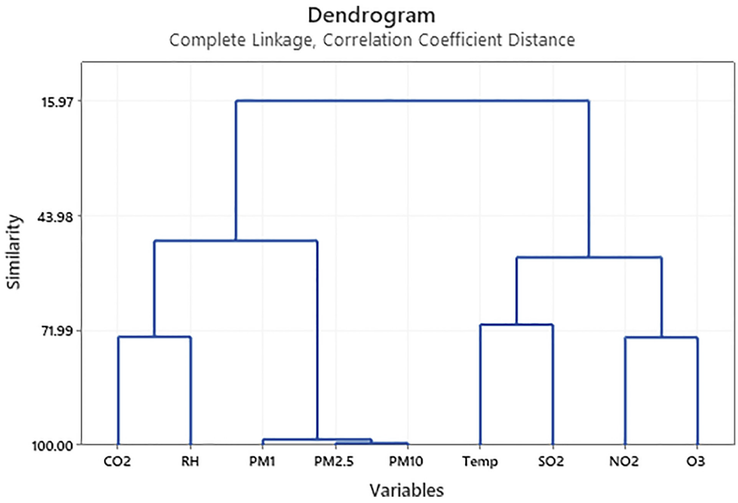


Figure 6.
Dendrogram diagram showing the groupings and clusters of the pollutants and the meteorological parameters

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