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ARTICLE

Indoor Particulate Matter Assessment in a Northern Nigerian Abattoir and a Residential Building

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ABSTRACT

Indoor air pollution in buildings puts people at risk of developing respiratory and cardiovascular diseases. Particulate matter (PM) exposure is known to cause these health issues. Preliminary efforts were made in this study to assess the quantity and quality of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} present in an abattoir and a residential building in northern Nigeria. Canree A1 low-cost sensor was used to monitor the locations, 8 hourly for two weeks. The results showed that the average values ($\mu g/m^3$) of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} in an abattoir were 62.74, 161.94, and 199.08, respectively, and in a residential building were 28.70, 83.31, and 103.71. The average Air Quality Index (AQI) of the abattoir office was Very Unhealthy, while the living room of the residential building was unhealthy. The $PM_{2.5}$, and PM_{10} levels were higher than the international (WHO) and national (FMEnv) standard limits, indicating a potential danger to building occupants. It is expected that the indoor environment of the locations will be improved by the use of good ventilators (adequate windows and doors) and the provision of good extractors.

1. Introduction

World Health Organisation reported that air pollution killed more people in one year than AIDS, malaria, and tuberculosis combined. Over 91% of the world-wide people resides in polluted areas which are elevated more than WHO standards for particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) which are four important pollutants in terms of pub-

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lic health. According to Cohen et al. [1] and Wambebe and Duan [2], ambient $PM_{2.5}$ (particulate matter less than 2.5 micrometers in diameter) is present in up to 16.5% of the reported premature deaths each year (4.2 million), they also reported an estimated 1.7 million lung cancer-related deaths.

Particulate matter (PM) exposure has been linked to negative health outcomes. PM sensitivity has been reported to be higher in children under the age of 15, the elderly (over the age of 65), and people who have weakened immune systems and/or pre-existing medical problems [3]. According to surveys of human activity patterns, the average individual spends 87% of their day in confined building structures [4]. As a result, individual contact is mainly due to indoor PM.

Indoor Air Pollution in buildings is the cause of high risk of respiratory and cardiovascular diseases which has affected many people especially the vulnerable. Results of studies with respect to the microbial contaminants in indoor air have been reported in different locations which include residential, hospitals, schools, museums, abattoirs, office and other environments [5-8] but, there were little or no work of indoor air assessment in abattoirs. Literature (Table 1) from abattoirs related research delved on the effects (health risk) of oxides of gases and volatile organic compounds on the people present [7-11]. Also many studies on the microbial contaminants have been studied [6,12-15]. To close or remove the above gap, in this work, we made efforts in quantifying the indoor air quality of an abattoir and living room of a residential building. We are of the opinion that this work will add knowledge to the issues on abattoirs in terms of indoor air quality. An office in the abattoir is the case study in this work.

The study was aimed at reporting the findings of an assessment of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} held at an abattoir and a residential building.

Table 1. Summary of relevant previous studies of PM concentrations in indoor microenvironments on the study of other cities

Country (City)	Study	Main Findings	References
Saudi Arabia (Dammam)	Assessment of air quality in Dammam slaughter houses, Saudi Arabia	Average levels of NO_2 and CO were lower than their AQGs. SO_2 and VOCs exceeded the air quality guidelines. Bacterial and fungal strains contaminated slaughterhouse	[6]
Nigeria (Obinze and Egbu)	Assessment Of Air Quality In Livestock Farms And Abattoirs In Selected LGAs Of Imo State	The result of air quality parameters were above Federal Ministry of Environment (FMEnv) air quality standard. Abattoir Results: 31.2 μg/m^3, 0.64 ppm, 0.17 ppm, 1.04 ppm and 1.93 ppm for $PM_{2.5}$, SO_2, NH_3, NO_2 and H_2S in the wet season and 29.8 μg/m^3, 0.67 ppm, 0.13 ppm, 0.53 ppm and 1.7 ppm for $PM_{2.5}$, SO_2, NH_3, SO_2, and H_2S in the dry season.	[10]
Nigeria (Ntak Inyang)	Determination of Some Air Pollutants and Meteorological Parameters in Abattoir, Ntak Inyang in Uyo L.G.A of Akwa Ibom State in Nigeria	The result showed that NO_2, SO_2, H_2S, CO, NH_3, Cl_2, HCN, TVOC, $PM_{2.5}$ and PM_{10} were higher than that of FEPA standard limit. Results revealed correlations between particulate matter, the gases, and meteorological parameters.	[16]
Nigeria (Ilorin)	Integrated Assessment of the Air Quality around the Environs of Dr. Abubakar Sola Saraki Memorial Abattoir, Ilorin, Kwara State, Nigeria	The $PM_{2.5}$, PM_{10}, HCHO and Volatile Organic Compounds were higher than WHO limits. High temperature was favorable to thermophiles biological activities.	[14]
Nigeria (Ile-Ife)	Assessment of the impacts of abattoir activities on ambient air quality and health risk associated with exposure to $PM_{2.5}$ and PM_{10}, H_2S, SO_2 and NH_3	The results indicated that the average concentrations of $PM_{2.5}$, PM_{10} and NO_2 were higher than the WHO, NAAQS, and FMEnv) limits. Air Quality Index showed that the ambient air quality in respect of CO and NH_3 was very good, moderate for PM_{10} and was very poor for NO_2 and SO_2. All the HQ values exceeded the threshold value, set at the unity.	[7]
Saudi Arabia (Abha)	Particulate matter concentration and health risk assessment for a residential building during COVID-19 pandemic in Abha, Saudi Arabia	PM concentration was exceeding 300 μg/m^3 (unhealthy) for all particle sizes of $PM_{0.3}$, $PM_{0.5}$, PM_1, and $PM_{2.5}$ except for PM_{10}. CO_2 concentration was 700 ppm. With influential habit (aromatic smoke), these concentrations increased 2–28 times for PM. The hazard quotient value greater than 1 revealed potential health risk to the inhabitants.	[11]

Table 1 continued

Country (City)	Study	Main Findings	References
Cameroon (Yaounde)	Air Quality and Human Health Risk Assessment in the Residential Areas at the Proximity of the Nkolfoulou Landfill in Yaound´e Metropolis, Cameroon	At the location 30% of the daily mean concentrations of $PM_{2.5}$ and PM_{10} crossed the daily safe limits. The values of cancer risk (CR) due to the inhalation of CH_2O were >10−6 while those of hazard index (HI) due to the inhalation of CH_2O, H_2S, and SO_2 were <1. The landfill operations might be supplying air pollutants to the neighbouring residential areas.	[9]
South Korea	Measurement of Particulate Matter ($PM_{2.5}$) and Health Risk Assessment of Cooking-Generated Particles in the Kitchen and Living Rooms of Apartment Houses	The $PM_{2.5}$ concentration increased 3.8 times more than the 24 h standard (50 μg/m^3). The $PM_{2.5}$ concentration in the living room was slightly greater than that in the kitchen.	[17]

2. Materials and Methods

Nigeria is one of the countries in West Africa with the capital at the Federal Capital Territory (FCT), Abuja. Nigeria has 36 states and has the highest population in Africa. Nigeria shares the boundaries in the north with Niger, in the east Chad and Cameroon, south - the Gulf of Guinea, and the west - Benin. The country derived its named from the Niger River [18]. The country has two climates - rainy and dry periods. Each period lasts six months. This study took place at FCT, Abuja in the northern part of Nigeria (Table 2).

A low-cost monitoring device (Canāree A1) was used in this study. $PM_{1.0}$, $PM_{2.5}$, and PM_{10} concentrations were monitored at the indoor locations of an abattoir (Office) and a residential building (Living room) in FCT, Abuja (Figure 1). The floors of the locations were made of ceramic. The office of the abattoir has a fan working during the monitoring period (August to September 2022). The only window and door were left opened during the periods. At the building location, there was an air conditional operating during the periods for at least 20 h per day, but all the windows and doors were locked during the period. At the abattoir, slaughtering, burning of woods and tyres to roast goats and cows, and commercial activities were the anthropogenic activities recorded, but at the residential building, there were cooking activities such as baking, roasting, frying, and the use of perfume. The monitoring took place during the school vacation and so lots of inhabitants' time were spent in the living room in which the sensor was mounted. The methodology of the manufacturer was strictly followed. The device was configured and registered to a SenseiAQ Cloud Account using SenseiAQ Software Version 1.2.3 (Download: https://github.com/PieraSystems/SenseiAQ). The data obtained was subjected to analysis with Minitab and Excel software.

Table 2. The Location, Description, and the Coordinates of the PM Monitoring

Location	Description	Coordinate
New Karu	Abattoir	9°0'40.794" N; 7°34'46.698" E; Altitude: 444 m a.s.l
Abacha Road	Residential	9°1'22.416" N; 7°35'19.812" E; Altitude: 409 m a.s.l

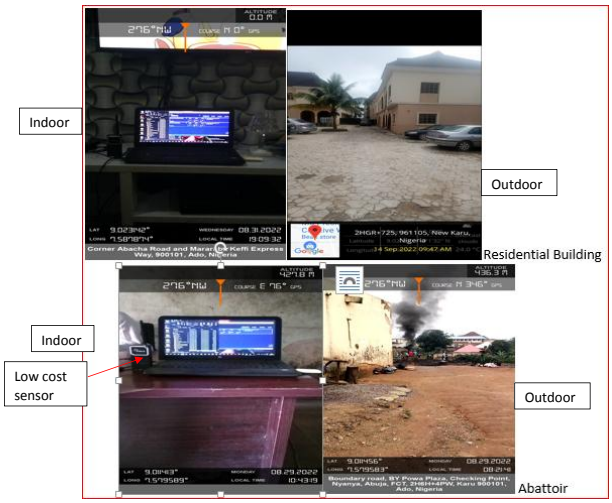


Figure 1. Description of the Locations

3. Results and Discussion

Table 3 shows the particulate matter concentrations of the two locations. The results showed the average values (μg/m^3) of abattoir as 62.74, 161.94 and 199.08 and residential building as 28.70, 83.31, and 103.71 of $PM_{1.0}$, $PM_{2.5}$, and PM_{10} respectively. It is evident from the results that abattoir indoor (office) values were more compared to that of residential. The reasons can be explained by the more anthropogenic activities (the burning of tyres and woods for roasting of goats and cows) which released

more PM, another reason was due to the small door and window of the office which trapped the emissions indoor, the available fan present in the office could not extract much because there was no cross ventilation. In the case of the residential building, although high values were reported, this was due to the emission released from the cooking (especially from frying and baking) activities from the kitchen. The air conditional working during the monitoring assisted by extracting the excess fumes. When there was no cooking, the elevated PM recorded was due to the activities (use of perfume and sweeping) of the occupants in the room. The StDev and CofVar were high especially in $PM_{2.5}$, and PM_{10} this showed that there were large variations between the minimum and maximum concentrations. These can be picked when there were no activities that will trigger the elevations. From the table, it was observed that the results obtained were far above the WHO and FEPA the implication of this is that the individuals within the environment are prone to health hazard.

Figure 2 depicts the particulate matter contributions in each location. $PM_{2.5}$ was the most heavily contributed (66%) in the residential, followed by $PM_{1.0}$ (23%), implying that more $PM_{2.5}$ was emitted during cooking activities, which is supported by Kumar et al. [21]. More PM_{10} (47%) was emitted in the case of the abattoir. The findings agreed with those of Jonah [16] and Sawyerr et al. [14], who found higher levels of PM_{10} than $PM_{2.5}$ in abattoirs.

The time series of the results are depicted in Figures 3 and 4. The trends in the abattoir show a high increase during heavy smoke emission, followed by a decrease during smoke dispersal away from the location. The high concentration of PM indoors was caused by the high concentrations of smoke in the office. The increase in recorded concentrations could be attributed to the insufficient ventilation provided by the rotating fan, small window, and door. The concentrations of PM in residential buildings vary as well; the lowest trend (value) was obtained during normal occupant activities in the living room, while the highest values up to the maximum trend were obtained during frying activities in the kitchen (the escape of the emission into the living room). The presence of a working air conditioner helped contribute to the low trends observed.

Figures 3 and 4 show that the trends in PM are irregular, the increases in the concentration for specific measurements in specific locations at specific times, could be due to the burning of tyres, woods, and frying activities both in the abattoir and residential building. The high PM trends were higher than the international (WHO) and national (FMEnv) standard limits.

Table 3. Particulate Matter Concentrations in the two locations (Abattoir and Residential)

	Abattoir			Residential		
	$PM_{1.0}$	$PM_{2.5}$	PM_{10}	$PM_{1.0}$	$PM_{2.5}$	PM_{10}
Mean	62.74	161.94	199.08	28.70	83.31	103.71
StDev	76.14	224.61	262.34	58.07	229.73	274.23
CoffVar (%)	121.36	138.69	131.78	202.30	275.76	264.42
Minimum	6.91	15.60	19.52	2.51	7.12	10.03
Maximum	720.62	3038.45	3468.66	642.40	2567.33	2069.37
Q1	77.97	201.02	249.69	13.05	28.84	38.68
Q3	17.80	37.68	49.30	26.60	60.46	76.87
Skewness	2.82	4.33	4.00	7.64	8.01	8.01
Kurtosis	10.52	33.8	29.19			
*WHO [19] FEPA/	-	15	45	66.65	71.77	71.78
FMEnv [20]	-	-	150			

*24 h, FEPA-Federal Environmental Protection Agency, Federal Ministry of Environment

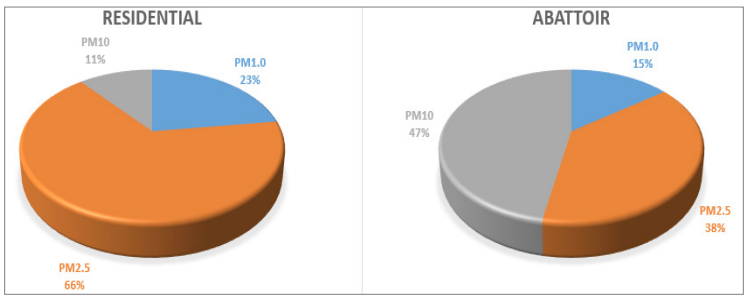
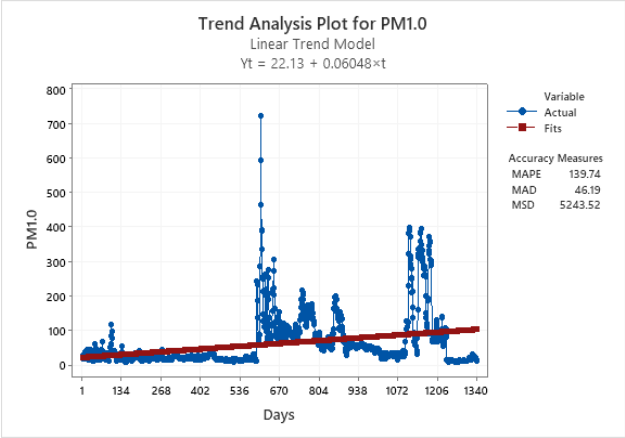
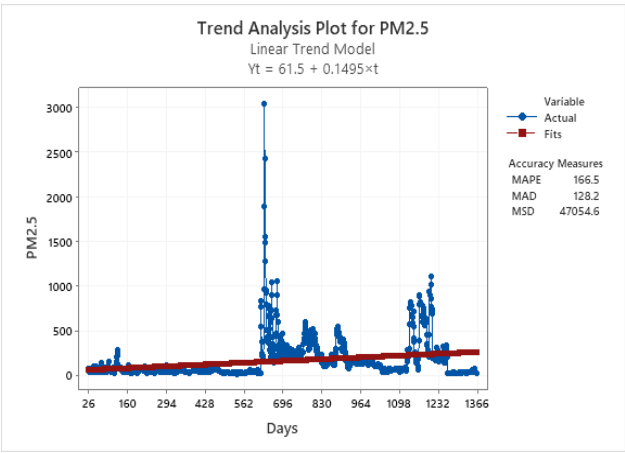


Figure 2. Contributions of Particulate Matter from the Locations





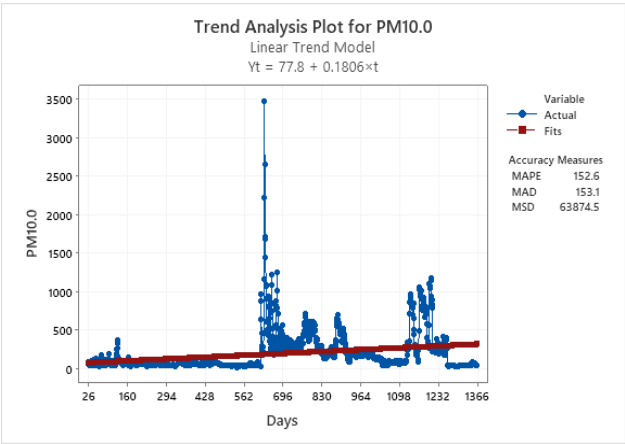
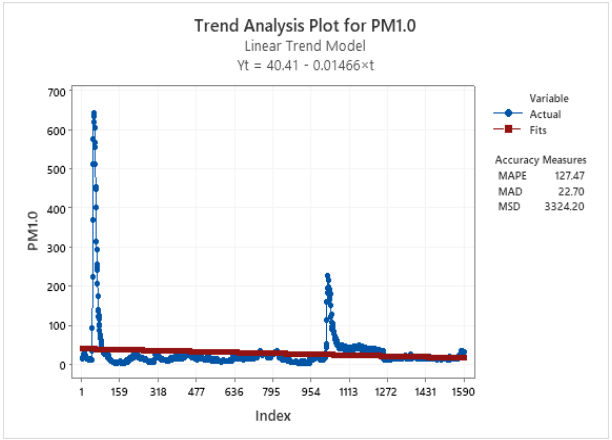
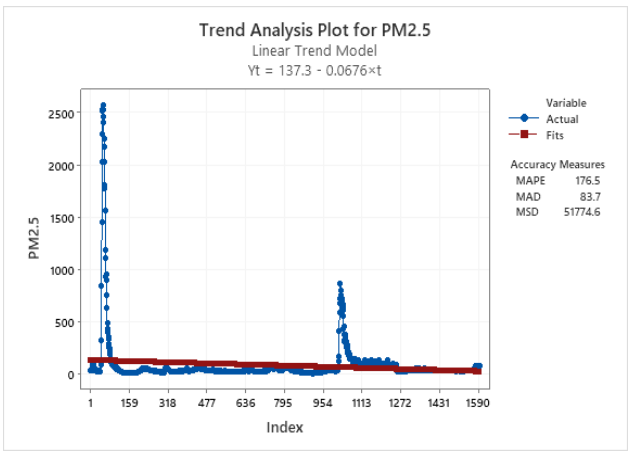


Figure 3. Trends Analysis of the Particulate Matter (Abattoir)





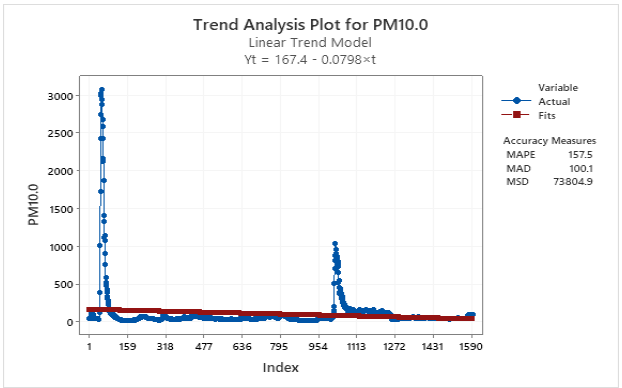


Figure 4. Trends Analysis of the Particulate Matter (Residential)

The AQI for the two locations is shown in Tables 4 and 5. These figures were derived from the USEPA [22]. The Abattoir $PM_{2.5}$ mean value was 161.94 (μg/m^3), translating to an AQI of 212, and the category was Very Unhealthy. While the minimum and maximum values were moderate and hazardous, respectively. The hazardous to sensitive group implies that everyone should take steps to minimize their risk when particle pollution levels are in this range. Remaining indoors – in a building or a room with filtered air – and reducing your activity levels are the best methods for lowering the amount of particulate emissions you inhale in to the lungs. Regrettably, the suggestion was not followed because there were no extractors or adequate ventilation. In the same location, the average AQI (123) for PM_{10} was Unhealthy for Sensitive Groups, while the maximum was above > 500, as with $PM_{2.5}$. When particle pollution levels are within this range, every individual should strive to take bold and significant steps to reduce their contact. The average AQI in the residential building was unhealthy; the minimum (30), while good, put people with respiratory or heart disease, the elderly, and children at risk. Individuals who are unusually sensitive to PM_{10} AQI values of 75 should avoid prolonged or heavy exertion. The moderate AQI category for PM_{10} in the residential building matched the findings of Odekanle et al. [7] in an abattoir in Ile-Ife, Nigeria.

Table 4. *Explanations and Conversions of Particulate Matter Concentrations to AQI Using AQI Calculator (Abattoir)

	$PM_{2.5}$
Concentration (μg/m^3)	**161.94 (mean)**
AQI	212
AQI Category	Very Unhealthy
Sensitive Group	People with respiratory or heart disease, the elderly and children are the groups most at risk
Effects	Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population
Cautionary Statement	People with respiratory or heart disease, the elderly and children should avoid any outdoor activity; everyone else should avoid prolonged exertion
Concentration (μg/m^3)	**15.60 (Minimum)**
AQI	58
AQI Category	Moderate
Sensitive Group	People with respiratory or heart disease, the elderly and children are the groups most at risk
Effects	People with respiratory or heart disease, the elderly and children are the groups most at risk
Cautionary Statement	Unusually sensitive people should consider reducing prolonged or heavy exertion
Concentration (μg/m^3)	**3038.45 (Maximum)**
AQI	**Above > 500 level**
AQI Category	Hazardous
Sensitive Group	Pollution is hazardous at these levels. Everyone should take steps to reduce their exposure when particle pollution levels are in this range
Effects	
Cautionary Statement	Staying indoors – in a room or building with filtered air – and reducing your activity levels are the best ways to reduce the amount of particle pollution you breathe into your lungs
	PM_{10}
Concentration (μg/m^3)	**199.08 (mean)**
AQI	123
AQI Category	Unhealthy for Sensitive Groups
Sensitive Group	People with respiratory disease are the group most at risk
Effects	Increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma
Cautionary Statement	People with respiratory disease, such as asthma, should limit outdoor exertion
Concentration (μg/m^3)	**19.52 (minimum)**
AQI	18
AQI Category	Good
Sensitive Group	People with respiratory disease are the group most at risk
Effects	None

Table 4 continued

	$PM_{2.5}$
Cautionary Statement	None
Concentration (µg/m^3)	
AQI	**3468.66**
AQI Category	Hazardous
Sensitive Group	Pollution is hazardous at these levels. Everyone should take steps to reduce their exposure when particle pollution levels are in this range
Effects	
Cautionary Statement	Staying indoors – in a room or building with filtered air – and reducing your activity levels are the best ways to reduce the amount of particle pollution you breathe into your lungs.

*There is no standards for $PM_{1.0}$ so the explanations and conversions could not be made

Table 5. *Explanations and Conversions of Particulate Matter Concentrations to AQI Using AQI Calculator (Residential)

	$PM_{2.5}$
Concentration (µg/m^3)	**83.31 (mean)**
AQI	165
AQI Category	Unhealthy
Sensitive Group	People with respiratory or heart disease, the elderly and children are the groups most at risk
Effects	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population
Cautionary Statement	People with respiratory or heart disease, the elderly and children should avoid any outdoor activity; everyone else should avoid prolonged exertion
Concentration (µg/m^3)	**7.12 (Minimum)**
AQI	30
AQI Category	Good
Sensitive Group	People with respiratory or heart disease, the elderly and children are the groups most at risk
Effects	None
Cautionary Statement	None
Concentration (µg/m^3)	**2567.33 (Maximum)**
AQI	**Above > 500 level**
AQI Category	Hazardous
Sensitive Group	Pollution is hazardous at these levels. Everyone should take steps to reduce their exposure when particle pollution levels are in this range
Effects	
Cautionary Statement	Staying indoors – in a room or building with filtered air – and reducing your activity levels are the best ways to reduce the amount of particle pollution you breathe into your lungs
	PM_{10}
Concentration (µg/m^3)	**103.71 (mean)**
AQI	75
AQI Category	Moderate
Sensitive Group	People with respiratory disease are the group most at risk
Effects	Unusually sensitive people should consider reducing prolonged or heavy exertion
Cautionary Statement	Unusually sensitive people should consider reducing prolonged or heavy exertion
Concentration (µg/m^3)	**10.03 (minimum)**
AQI	9
AQI Category	Good
Sensitive Group	People with respiratory disease are the group most at risk
Effects	None
Cautionary Statement	None

Table 5 continued

	$PM_{2.5}$
Concentration (μg/m^3)	
AQI	**3069.37**
AQI Category	Hazardous
Sensitive Group	Pollution is hazardous at these levels. Everyone should take steps to reduce their exposure when particle pollution levels are in this range
Effects	
Cautionary Statement	Staying indoors – in a room or building with filtered air – and reducing your activity levels are the best ways to reduce the amount of particle pollution you breathe into your lungs.

*There is no standards for $PM_{1.0}$ so the explanations and conversions could not be made

4. Conclusions

A low-cost monitoring device (Canāree A1) was used in this study to assess the indoor $PM_{1.0}$, $PM_{2.5}$, and PM_{10} concentrations at an abattoir (Office) and a residential building (Living room) in FCT, Abuja. The results depicted that abattoir PM concentrations were higher than those of the residential building due to the continuous activities (burning of tyres and woods) at the abattoir. Also, the results obtained in this study showed that the PM values both locations surpass the recommended standard limits of WHO and FEPA/FMEnv. The AQI obtained in the study for the average and maximum fell between moderate and hazardous which are potential danger or threat to the occupants of the buildings and the environment. Mitigation efforts should be ensured to either reduce or stop the man-made activities causing the emission of the particles into the air and efforts too should be made to provide adequate ventilation and air extractors within the buildings in the two locations.

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Conflict of Interest

The authors declare no conflict interest.

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