Journal of Air Pollution and Health (Autumn 2024); 9(4):445-466

Original Article

Available online at http://japh.tums.ac.ir

Particulate matter concentrations and health risks associated with cow hides singeing in Abattoirs in Benin City, Nigeria

Aimuanmwosa Frank Eghomwanre*, Gracious Oghosa Edomwonyi

Department of Environmental Management and Toxicology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria

ARTICLE INFORMATION

Article Chronology:
Received 09 November 2024
Revised 07 December 2024
Accepted 16 December 2024
Published 30 December 2024

Keywords:
Abattoir; Health risks; Particulates; Risk factors; Workers

CORRESPONDING AUTHOR:

frank.eghomwanre@uniben.edu
Tel: (+23) 48078676606
Fax: (+23) 40902 164 4340

ABSTRACT

Introduction: The singeing of animals is one of the major sources of human exposure to air pollutants in abattoirs especially in developing countries and it can cause various adverse health effects among the workers. This study assessed the concentrations of particulate matter in selected abattoirs and examined the associated health risks among the workers in Benin City, Nigeria.

Materials and methods: Measurements of Particulate Matter ($PM_{2.5}$ and PM_{10}) were performed in three areas in the abattoirs for three months, and the noncarcinogenic risks of exposure to $PM_{2.5}$ and PM_{10} were determined via Hazard-Quotients (HQs) and Hazard Indices (HIs). The occurrence and relationship between the reported risk factors and health effects among abattoir workers were also examined using the modified American Thoracic Standard (ATS) respiratory symptoms questionnaire.

Results: The levels of $PM_{2.5}$ and PM_{10} in the hide roasting areas were significantly higher ($p>0.05$) than those at other sampling points across the abattoirs. The indoor and outdoor ratio (I/O) of the particulates was greater than 1.0 in almost all the abattoirs. The concentrations of $PM_{2.5}$ and PM_{10} were higher than the permissible air quality standards. The HQ values exceeded 1.0 in all the sampling areas, implying that exposure to particulate concentrations could result in adverse health effects in abattoirs. The chi-square test revealed significant associations between reported risk factors such as: age, work experience, duration of exposure, and use of Personal Protection Equipment (PPE) and health effects (dry cough, eye irritation, asthma, difficulty breathing, sore throat, and chest pain) among abattoir workers.

Conclusion: This study revealed that hide roasting at abattoirs results in poor air quality in the abattoir environment and contributes to adverse health effects among workers.

Please cite this article as: Eghomwanre AF, Edomwonyi GO. Particulate matter concentrations and health risks associated with cow hides singeing in Abattoirs in Benin City, Nigeria. Journal of Air Pollution and Health. 2024;9(4): 445-466.

Introduction

Air pollution is currently a significant problem worldwide because of its impact on individual and public health, which is caused by its critical risk factor for increased health effects [1]. Abattoirs, essential for meat production, can also be significant sources of air pollution, particularly in urban areas like Benin City, Nigeria. One of the primary contributors to this pollution is the process of singeing cow hides, which involves burning off hair and residual tissue using open flames. This practice releases Particulate Matter (PM) into the air, containing a complex mixture of solid and liquid particles, including dust, soot, and other harmful substances. To prepare the hide of the corpse for eating and to evoke flavours in the meat that are acceptable to customers, the fur on the skin of the animal must be removed during the singeing process [2]. This is often done by butchers in abattoirs over open flames using a variety of materials, such as firewood mixed with used motor oil, used tyres, plastics, and Liquefied Petroleum Gas (LPG), before being transported to marketplaces and sold to consumers [3, 4]. The smoke produced from wood during the burning of meat is one of the sources of particulate matter in abattoirs [5]. Particulate matter is a known pollutant that is an aggregate of solid and liquid particles with varying metric sizes, forms and chemical compositions released in the atmosphere [6]. PM has drawn much attention because of its significant impact on human health [7, 8]. The toxicity of particulate matter stems from its ability to permeate through the pulmonary system via alveolar obstruction [9]. The extent of penetration of particles is largely determined by the particle aerodynamic size [10]. They have been grouped as coarse particles with an aerodynamic diameter of ≤10 µm(µm) and fine particles with 2.5 µm or less. The inhalation of particulate matter, which is composed of tiny solid or liquid droplets, has been associated with several health problems [11]. The respiratory system is the first point of entry of particulate matter, although it can be detected in different organs of the body. In 2019, particulate matter pollution exposure resulted in the death of approximately 6.4 million people globally, of which 2.3 million were caused by fine particulate pollution from the utilization of biomass fuel for domestic purposes, whereas 4.1 million were caused by $PM_{2.5}$ ambient air pollution. In developing countries like Nigeria, where air quality regulations may be lax and occupational health and safety standards are often poorly enforced, abattoir workers and surrounding communities are particularly vulnerable to the health risks associated with PM exposure [12, 13]. Several health effects, such as shortness of breath, coughing, and irritation of the nose, throat, and eyes, have been linked to short-term exposure to particulate matter from cows singing in slaughterhouses [14, 15, 4]. Prolonged exposure has been associated with more severe health consequences, such as lung cancer, cardiovascular disease, chronic respiratory disorders, and unfavourable pregnancy outcomes [16]. Because of their extended exposure times and proximity to the source of pollutants, workers at abattoirs are especially vulnerable [17]. Moreover, the dispersal of particulate matter into the surrounding environment may also increase health concerns for people residing near abattoirs [18]. Health risk assessments of air pollution have been mostly adopted to determine the human health effects of particulate matter. Human health risk assessment analyses the degree of exposure of individuals to particulate matter concentrations based on pollutant levels and assesses the risk during a given period [19]. The risks posed to human health by particulate matter exposure have generally been evaluated using short-term exposure assessment, which provides information for long-term exposure prediction [20, 21] The singing of cowhides with wood and other materials is a common practice across Nigeria without any consideration of the detrimental health risks to the health of workers and neighbouring residents. The World Health Organization (WHO) has established stringent guidelines for outdoor air quality. For Particulate Matter (PM), specifically PM_{10} and $PM_{2.5}$, they recommend daily average limits of 45 and 15 µg/m³ respectively [6]. These guidelines are based on extensive scientific research linking exposure to these pollutants with various health problems. In contrast, the Nigerian Ambient Air Quality Standards (NAAQS), set by the Federal Environmental Protection Agency (FEPA) in 1999, allow a significantly higher limit for PM_{10}, at 150 µg/m³. While this standard may seem lenient compared to the WHO guidelines, it's important to note that even concentrations below these limits can have detrimental health effects [7]. Several studies have reported high levels of particulate matter exposure in several occupational settings, ranging from charcoal producers to food processing, agricultural burning on farms, wildland firefighters, bushfires, and domestic cooking [19]. Few researchers have conducted health risk assessment studies on air pollutants in abattoirs in Nigeria [16], but there are no reports on the associations between the reported risk factors among abattoir workers and respiratory health effects. While previous studies have explored the health risks associated with cowhide singeing, many have focused on the contamination of the hides themselves with heavy metals or other pollutants [16, 22-29], this study specifically targets Particulate Matter (PM) emissions from the singeing process, a direct air pollution concern for both workers and the surrounding community. By measuring PM concentrations, this study will provide quantitative data on the extent of air pollution caused by hide singeing. This information can be used to assess the severity of the health risks and inform potential mitigation strategies and policies. The study will also assess the potential health risks associated with exposure to these pollutants particularly their potential for causing respiratory and cardiovascular problems. By providing specific data on PM levels and health risks in Benin City, this study can contribute to a better understanding of the local environmental and health challenges. This information can be used to advocate for improved air quality regulations and safer working conditions in abattoirs. Addressing this gap could help decrease the exposure level of workers to high concentrations of particulate matter from different areas of the abattoir and help improve their respiratory health. The knowledge of the level of particular matter in abattoirs can assist in the implementation of targeted interventions and policy formulation to reduce exposure risk and promote the quality of life of abattoir workers. This study therefore assessed the concentrations of particulate matter in selected abattoirs and examined the associated health risks among the workers in Benin City, Nigeria.

Materials and methods

Study area

The Abattoirs used for this study are located at the Ikpoba slope area within the Ikpoba - Okha Local Council in Benin City which lies along latitudes 6°20′N to 6°58′N and longitudes 5°35′E to 5°41′E (Fig. 1). The area houses the largest number of abattoirs in the city and is located near residential houses, markets and motor parks. Abattoirs are motorable and easily accessible by beef consumers and traders, including restaurant owners, who buy and sell beef products daily. The abattoirs were made up of several workers, including butchers, meat buyers and sellers, and they hide roasters and cleaners. An average of eight to ten cows are slaughtered daily in each of the abattoirs in the location. The slaughterhouses, which are both public and privately owned, are divided into three sections, namely, the butchering section, which is also the place where the meat is sold to the customers, and the hide roasting section, which is built separately behind the slaughterhouse and the area outside of the abattoir. The abattoirs begin operations by 6 am when the cows are slaughtered and close by 4 pm daily. Compared with other workers, hide roasters usually leave the slaughterhouse late. They burn the hides of slaughtered meat with wood and kerosene and are often directly exposed to wood smoke without any protective equipment.

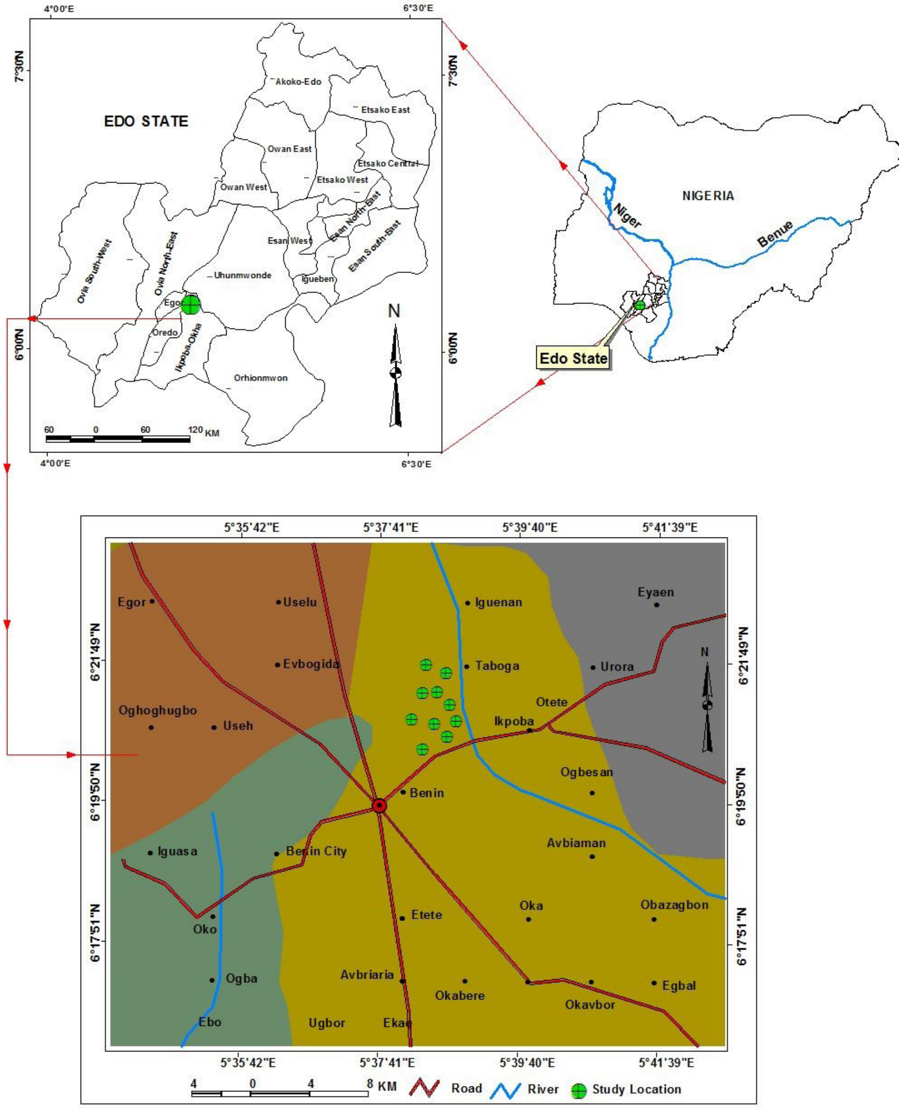

Fig. 1. Map of the study area showing the sampling sites

Selection of sampling points

Ten abattoirs (AB1 to AB10) were purposely selected from several slaughterhouses in the area for this study (Fig. 1). In addition to the size of the abattoir, the presence of a separate section for the open burning of cow hides and engagement in daily abattoir operations were criteria for selection. Three sampling points, A (cowhide roasting section), B (cow slaughtering section) and C (outside the abattoir) were selected for particulate matter monitoring across the abattoirs.

Air sampling procedure

The sampling of particulate matter ($PM_{2.5}$ and PM_{10}) was performed using a handheld portable smart air quality monitor (BR-Smart-126 series) manufactured by BLATN Sci. and Tech Co. Ltd. (Beijing, China). The BR-Smart-126 series is a real-time portable air quality device that can measure different aerodynamic metrics of particulate matter ($PM_{2.5}$ and PM_{10}) in µg/m^3 with a precision range of 0–9999 µg/m^3, a resolution of 1.0 µg/m^3 and a resolution of 1.0 µg/m^3. The meter is a portable real-time air quality monitoring device built with a high-precision sensor chip. It monitors air pollutants via a light scattering mechanism and converts atmospheric particulate concentrations into visual data. The samplers were calibrated before and after each sampling activity in line with the manufacturer's prescription to ensure that the data being collected were reliable and met the objectives of the study. At each sampling point A, B and C, the measurement is performed by pressing the start button, which begins the initialization process approximately two minutes before the screen is displayed. The readings of the concentration of the particulate of interest are taken at each sampling point in triplicate, and the start button is pressed to allow for another round of measurements at another sampling point. The equipment was placed approximately 2 m above ground level during each measurement to avoid interference from fugitive dust. The measurement was performed from 7 am when the roasting of the hides begins until 3 pm daily, including Saturdays, for twelve weeks across the ten (10) abattoirs. The data obtained were cleaned for outliers, and the mean particulate concentrations were determined statistically and then compared with the WHO 24-hour air quality standard [30, 6].

Measurement of meteorological parameters

Meteorological data, such as temperature, humidity, and wind speed, were collected simultaneously with air pollutant measurements at every sampling point. The ambient temperature and relative humidity were recorded with the aid of a Windmate 300. The meter has a temperature range of -20 - 60°C and accuracies of +/- 1°C and 0 -100% and +/- 3%, respectively.

Health risk assessment

Health risk assessment has been described as the estimation of the burden of mortality of disease effects to be expected from an observed exposure distribution, i.e., air pollution [31]. In this study, the noncancer risk from exposure via inhalation was considered. The assessment considered adult individuals (over 18 years of age) who were involved in abattoir work daily. The Hazard Quotient (HQ) was utilized to estimate the risk associated with PM exposure in the abattoirs. The hazard quotient is the ratio of the hypothetical exposure to pollutants and their concentrations without adverse health outcomes. The hazard level was categorized by the HQ values, as shown in Table 1 [32, 33].

Table 1. Categories of hazard

HQ value	Associated risk
<0.1	No hazard risk
0.1-1.0	Low hazard risk
1.1-10	Moderate hazard risk
>10	High hazard risk

The hazard quotient value was determined as follows:

$$HQ = \frac{LADD}{RfD} \quad (1)$$

Where LADD, i.e., the lifetime average daily dose (mg/kg day), is the exposure to pollutants via inhalation.

RfD is the reference dose (mg/kg day), i.e., the estimated level of human daily inhalation of pollutants without adverse health outcomes during a lifetime. The RfDs of $PM_{2.5}$ at 5 µg/m^3 and 10 µg/m^3 for PM_{10} according to [34, 35] were used in this study.

The Average Daily Dose (ADD) is determined by

$$LADD = \frac{CAxIRxEFxED}{BWxAT} \quad (2)$$

where CA is the mean concentration of pollutants (µg/m^3) at various sampling points.

IR = Inhalation rate (m^3),

EF = Exposure frequency (days/year),

ED =Exposure duration (years),

Body weight (kg)

AT=Average time (yrs)

The total noncarcinogenic risk was obtained by calculating the Hazard Index (HI) to estimate the exposure risk attributed to the different particulate matter metrics at the same time. This is represented in Equation 3.

$$HI = HQ_1 + HQ_2 \ldots\ldots + HQn \quad (3)$$

Table 2. Exposure factors for particulates in abattoirs

Parameters	Symbol	Unit	Values	References
Baseline concentrations				
PM_{10}		µg/m^3	10	[16]
$PM_{2.5}$		µg/m^3	5	[35]
Inhalation rate	IR	m^3/day	14.25	[36]
Exposure duration	ED	hours	8	[16]
Body weight	BW	kg	62.8	[36]
Exposure frequency	EF	-	0.85	[36]
Average time	AT	Years	70	[37]

Questionnaire survey

The prevalence of respiratory health effects (dry cough, shortness of breath, eye irritation, asthma, difficulty breathing and sore throat) among abattoir workers (cleaners, butchers, meat sellers and buyers, and hide roasters) and the reported risk factors in the abattoir environment were also examined using the modified respiratory symptoms questionnaire [38]. Two hundred and two (202) well-structured questionnaires were collected from ten slaughterhouses. The sample size (202) was obtained using the Cochran formula [39] based on the prevalence rate of 25.2% reported in previous studies [40]. Out of the 289 questionnaires, a total of 202 respondents participated in the survey, including cleaners (49), butchers (50), buyers and sellers (50) and hide roasters (53) across the ten selected abattoirs. The questionnaire comprises three sections: A: Sociodemographic; age, sex, level of education and level of income; B: reported risk indicators among workers; work experience, duration of exposure, smoking status and use of personal protective equipment among workers; and C: reported health symptoms among workers; dry cough, asthma, difficulty breathing, sore throat, shortness of breath and chest pain. All the participants voluntarily participated in the study and had no family history of asthma, tuberculosis, chest or respiratory disorders or previous diagnosis by a physician.

Data analysis

The air quality data obtained were subjected to descriptive (mean, standard deviation) and inferential (analysis of variance) statistical analyses using SPSS for Windows version 22.0. The differences between the sociodemographic features of the different categories of abattoir workers were analysed using the chi-square test of significance. Furthermore, the associations between reported risk factors and health effects among abattoir workers were also determined using the chi-square test, and a value of $p<0.05$ was considered statistically significant.

Results and discussion

Mean concentrations of particulate matter in abattoirs

The mean concentrations of $PM_{2.5}$ and PM_{10} during the period of sampling across the abattoirs are presented in Figs. 2 and 3. The concentrations of $PM_{2.5}$ ranged between 29.6 and 796.8 µg/m^3 throughout the sampling sites. The highest values of 354.7 to 796.8 µg/m^3 were obtained at point A, i.e., the cowhide roasting area, whereas the lowest values of 29.6 to 131.4 µg/m^3 were measured at point C, outside the abattoir (Fig. 1). The concentration of PM_{10} varied from 879.7 to 342 µg/m^3, 75.3 to 320 µg/m^3 and 43.3 to 141.4 µg/m^3 at sampling points A, B and C, respectively. The concentrations of PM_{10} are in the order of A>B>C. The elevated concentrations of $PM_{2.5}$ and PM_{10} were recorded at the point of hide roasting (A), which is an indication that the particulate matter could have originated from the burning of the cow fur. High levels of particulates have been previously reported at the discharge point, i.e., the point where the animal is burnt and processed [16]. The level of particulates reported in this study was higher than that reported by several authors [16, 22-28]. The high concentrations of particulates recorded in this study could be attributed to the direct measurement of PM levels at the point and period of hide burning, which was informed by the possibility of direct exposure of the hide roasters to the emitted smoke. The reduction in the concentrations of the particulates at the entrance and within the abattoir could be explained by the distances of these areas from the major pollutant source A (the point of roasting of the cowhides). The level of air pollutants has been reported to decrease with increasing distance from pollution sources [41, 42]. This finding contrasts with the report of [16], who recorded higher PM concentrations at sampling points away from the pollution source in an abattoir facility in Ile Ife, Nigeria. This was attributed to the action of wind, which dispersed the particles from the point of discharge. The mean concentrations recorded in this study were above the 24-h recommended air quality guidelines of 15, 45, and 150 µg/m^3 by the [6] and [30]. This poses a serious health risk for abattoir workers, particularly those involved directly in the roasting of cow hides by abattoirs. The ease with which particulates, especially those with an aerodynamic diameter of less than 10, can enter the lungs of exposed individuals aggravates the associated health challenges [24]. Long-term exposure to particulate matter can lead to serious health outcomes, including skin irritation, breathing difficulty, asthma and cough [5, 43]. Thus, alternative energy sources for processing cowhides and the consistent use of face masks by hide roasters to reduce exposure to smoke are needed. The effects of location on the variations in the concentrations of $PM_{2.5}$ and PM_{10} across the sampling abattoirs were determined via one-way analysis of variance at $p<0.05$ and are presented in Table S3. The results revealed that the measurements of $PM_{2.5}$ and PM_{10} throughout the abattoirs indicated that the significant values were less than 0.05 (Table S3). This finding revealed that there was a significant variation in the mean values of $PM_{2.5}$ and PM_{10} across the abattoirs. The observed difference in the mean values could be due to variations in microclimatic conditions, the location, time of the measurements and the influence of prevailing anthropogenic factors in the study areas.

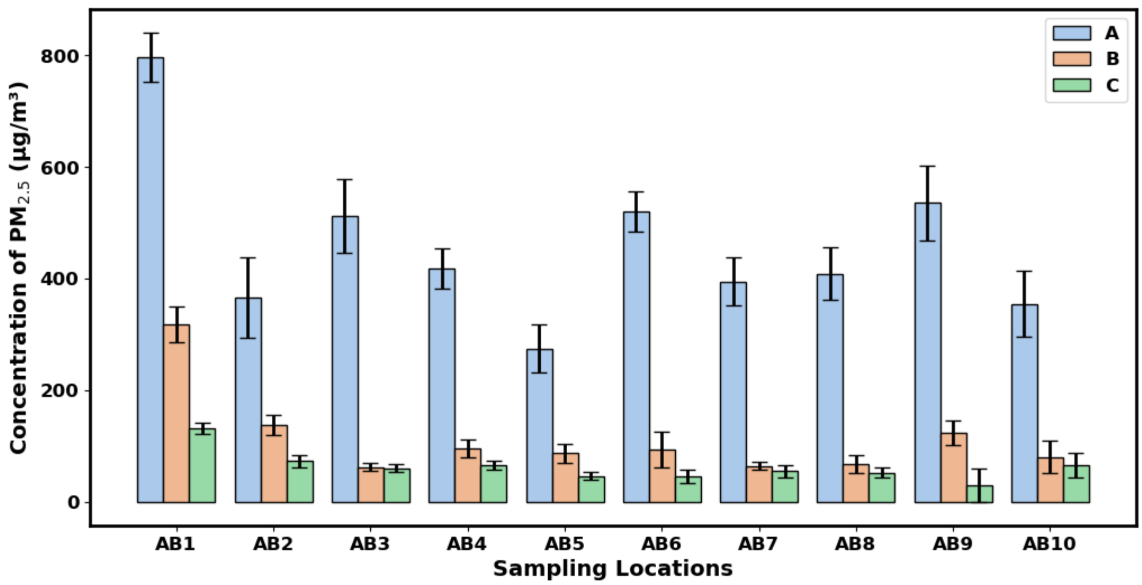

Fig. 2. Mean concentrations of $PM_{2.5}$ at the sampling points at Abbatoirs

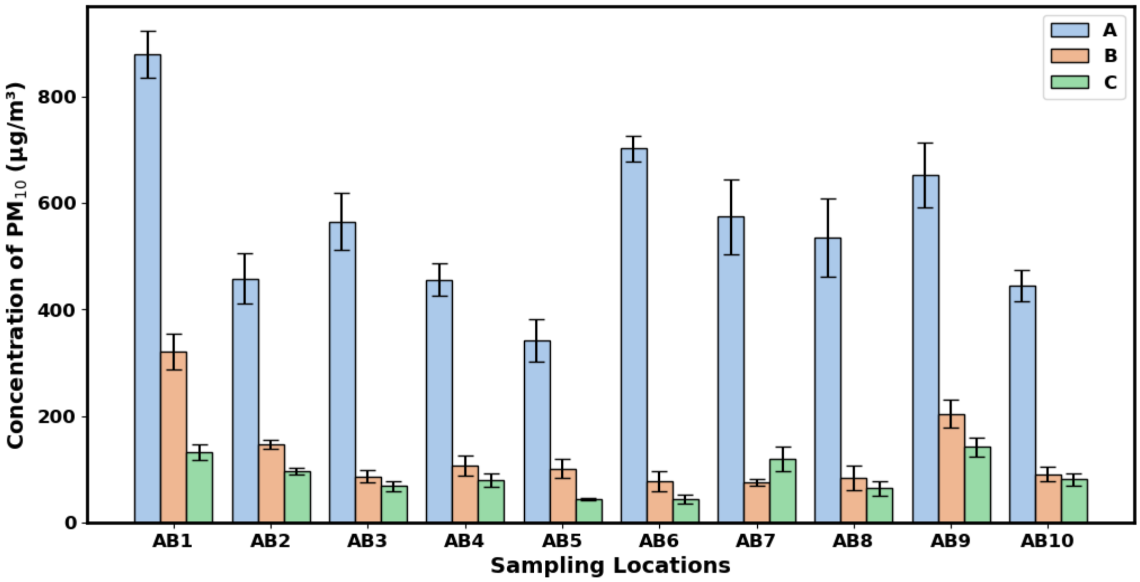

Fig. 3. Mean concentrations of PM_{10} at the sampling points at Abbatoirs

Indoor and outdoor (I/O) ratio of particulate concentrations

To assess indoor air quality, indoor and outdoor pollutant levels are often compared using indoor-outdoor (I/O) ratios [44]. These ratios are calculated by dividing the average indoor concentration of a pollutant by its average outdoor concentration. In this study, the ratios of the mean concentrations of particulates within and outside the abattoirs were determined for various abattoirs in the study area. I/O ratios>1 indicate that the indoor concentrations of particulate surpass the outdoor probably due to the indoor sources. The I/O ratio of 1.0 implies indoor concentrations are in a state of equilibrium with outdoor sources, while the I/O ratio of less than 1.0 implies that the indoor levels are lower than the outdoor concentrations due to the prevailing outdoor factors. The result revealed that the I/O ratios of both the $PM_{2.5}$ and PM_{10} across the abattoir exceeded 1 except at AB7 where the I/O ratio was less than 1 for PM_{10} (Fig. 4). The result suggests that the indoor sources of PM were more compared to the outside abattoir environment. This could be due to the location of the abattoir directly opposite the section of cowhide roasting, resulting in the direct infiltration of smoke into the abattoir. The design of the abattoir which is open without windows also aids the direct infiltration of pollutants there by increasing the pollutant levels within the abattoir. This finding is similar to the reports of several authors who reported an I/O ratio between 0.8 and 1.12 in different indoor and outdoor environments [45, 46].

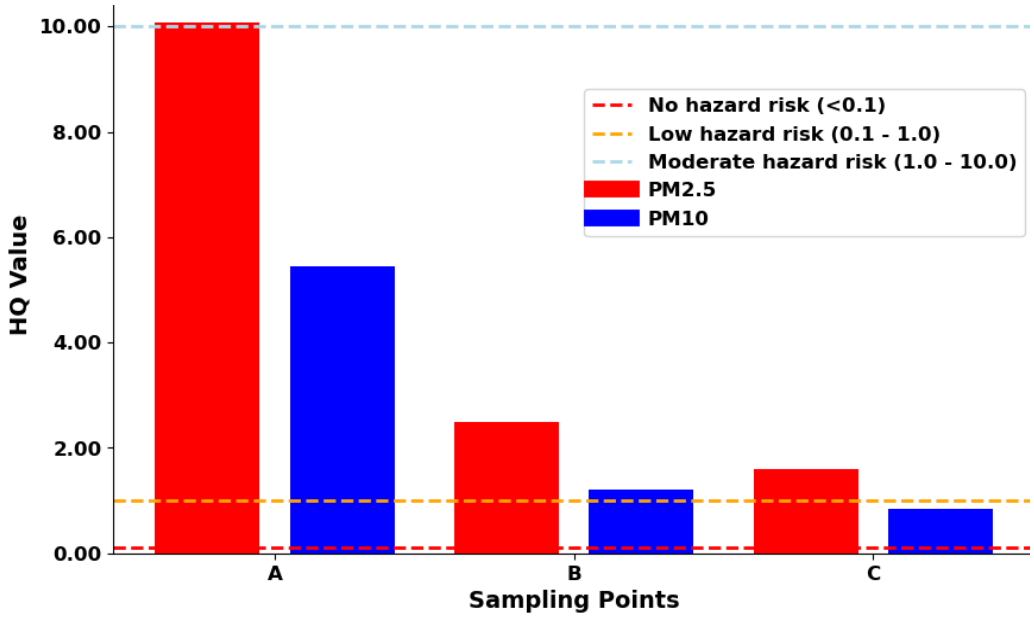

Fig. 4. HQ values for individuals in the abattoirs

Correlations between meteorological parameters and particulate matter concentrations

The Pearson correlation coefficient (r) indicating the strength of the linear relationship between the ambient temperature, relative humidity, wind speed and particulate matter concentration at the various sampling points is presented in Table 3. At sampling point, A, the ambient temperature was strongly and positively correlated with $PM_{2.5}$ ($r=0.791$, $p<0.05$) and moderately correlated with PM_{10} ($r=0.548$, $p<0.05$). The strong influence of temperature on the particulate concentrations at sampling point A could be attributed to the increase in the ambient temperature at the point of hide roasting, thereby contributing to the increase in the ground-level concentrations of particulates. This is further supported by [47], who reported that increased levels of ambient pollutants monitored in an environment experiencing higher temperatures could lead to the downward movement of pollutants and consequently higher ground-level concentrations [48], explained that when the temperature of the ambient air is higher than the temperature of the pollutant, the concentrations of pollutants at the ground level increase. The correlations between temperature and the particulates at the other sampling points (B and C) were very weak for $PM_{2.5}$ (r = 0.081, -0.028) and PM_{10} (0.124, 0.058) and statistically insignificant. This could be due to the lower temperatures associated with the sampling points, i.e., the entrance and inside of the abattoirs, hence the lower concentrations of particulates measured at these points. Strong and moderate significant negative correlations between ambient relative humidity and the $PM_{2.5}$ (-0.789, p= 0.000) and PM_{10} (r = -0.574, p = 0.000) concentrations were revealed at the point of open burning of cowhides. This association is due to the relatively low relative humidity due to the increased temperature, which does not support the adsorption of water vapour onto particles in this area [49]. However, the relationships between ambient relative humidity and the $PM_{2.5}$ and PM_{10} concentrations at sampling points B and C were statistically insignificant (r=0.075, 0.034, 0.026 and 0.139, respectively). The study also revealed a significant negative correlation between $PM_{2.5}$ ($r=-0.788$, $p<0.005$) and PM_{10} ($r=-0.572$, $p<0.005$) and wind speed at sampling point A. The recorded wind speed at sampling point A was relatively low; hence, the negative association also corroborated the increased level of particulates at processing point A. This finding contrasts with that of [16], who reported a positive association between the particulates at the discharge point in selected abattoir facilities, resulting in reduced concentrations of particulate matter at the discharge point. The relationship between the prevailing wind speed and the recorded levels of particulates at the entrance and inside the abattoirs was statistically insignificant, except for

PM_{10} at sampling point C, which exhibited a weak positive association ($r = 0.2777$, $p = 0.000$).

Human health risk assessment

A human health risk assessment was also performed in this study based on the calculated noncancer risks of $PM_{2.5}$ and PM_{10}, and the results are presented in Figures 4 and 5. Hazard Quotient (HQ) values were utilized to estimate the noncarcinogenic risks associated with ambient $PM_{2.5}$ and PM_{10} exposure at various points in the abattoir. The HQ values for the exposed individuals across the sampling points were 10.08, 2.48 and 1.60 for $PM_{2.5}$ and 5.44, 1.21 and 0.84 for PM_{10}. (Fig. 4). HQ values above 1.0 generally indicate that the concentrations of pollutants under study are likely to cause health effects, whereas HQ values less than 1.0 are unlikely to cause any health effects on exposed individuals [50]. In this study, the HQ values of $PM_{2.5}$ and PM_{10} exceeded 1.0 except for the HQ of PM_{10} at sampling point C (Figure 4). The HQ and HI values in the area where the roasting of the hides (10.8, 5.44 and 19.0) was carried out were higher than those estimated at points B (2.48, 1.21 and 4.67) and C (1.60, 0.84 and 3.01) Fig. 5. This implies that exposure to the concentrations of particulates in the study area is likely to cause serious adverse health effects on exposed individuals. The results indicate that there is an increased risk of exposure to adverse health effects by abattoir workers at the point of hide roasting compared with those working within the abattoir.

This study is similar to the findings of [50], who reported adverse effects of exposure to $PM_{2.5}$ from biomass burning. This finding is also supported by a report indicating that distance from the pollution source could reduce the risk of exposure to the adverse health effects of particulate pollution (51). A reduction of approximately twenty-five percent in the concentration of $PM_{2.5}$ was also reported at a 400 m distance from the pollution source [52]. In contrast, [16] reported that individuals exposed to particulate matter at a distance of 100 m from the point of burning of hides in an abattoir facility were more likely to experience adverse health effects than those at the discharge point.

Table 3. Correlations between the meteorological parameters and particulate matter concentrations at the different sampling points

	TEMPa	RHa	WSa	TEMPb	RHb	WSb	TEMPc	RHc	WSc
$PM_{2.5}$a	0.791**	-0.789**	-0.788**	-0.383**	-0.003	0.126	-0.004	0.067	0.040
PM_{10}a	0.548**	-0.574**	-0.572**	0.213**	-0.086	0.097	0.013	-0.083	0.084
$PM_{2.5}$b	0.081	0.075	0.134	-0.051	-0.071	0.000	0.205*	-0.074	-0.204*
PM_{10}b	0.124	0.026	0.114	-0.044	-0.081	-0.041	0.240**	-0.084	-0.216*
$PM_{2.5}$c	-0.028	0.034	0.122	-0.141	-0.037	0.017	0.188*	-0.012	-0.176*
PM_{10}c	-0.058	0.139	0.277**	-0.176*	-0.021	0.027	0.267**	-0.024	-0.071

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

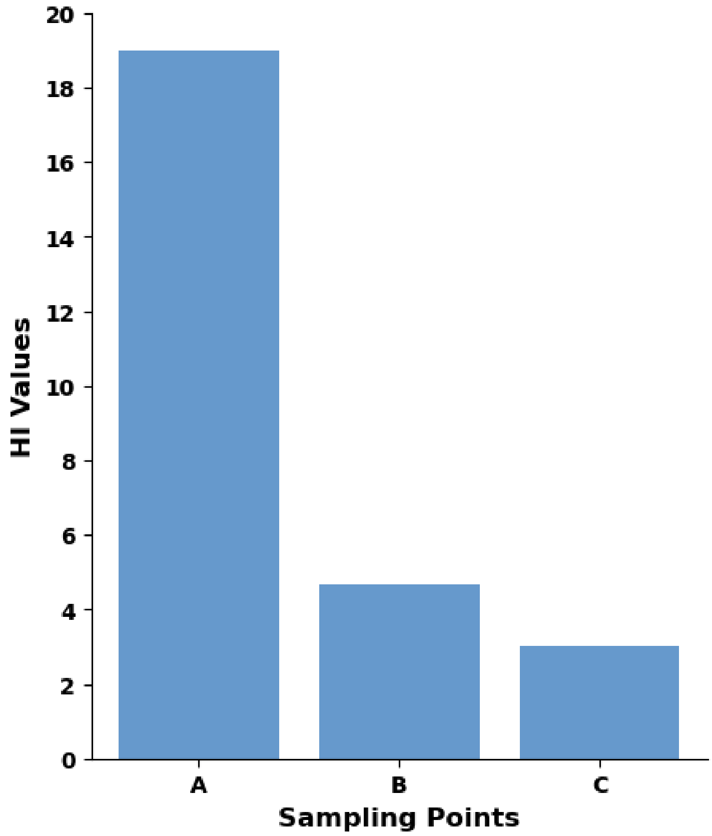

Fig. 5. HI values for individuals in the abattoir

Questionnaire survey

Sociodemographic characteristics among Abattoir workers

Table 4 shows the comparison of the sociodemographic characteristics of the categories of abattoir workers. The abattoir workers within the age range of 25-34 years had the highest percentage (78%) of participants, whereas those above the age of 55 years had the lowest percentage (6.9%). There were more female workers (62.8%) than male workers (37.2%). This is because the bulk of the work (buyers and sellers, hide roasting, and cleaners) is carried out by females. Males are mostly engaged in the butchering and processing of cows in the abattoir. The educational level of the workers revealed that 54.9% of the total respondents were primary school certificate holders, which was higher than those who had attained secondary (10.4%) or tertiary (6.0%) education or no formal education (34.5%). Among the 202 abattoir workers, 59 (29.2%) had spent 11-15 years on abattoir work, which was significantly higher than the number of workers with work experience lower than 11 years. Fifty percent of the respondents reported 8 – 12 hours of exposure to the abattoir environment daily, while 75.3% of them did not use any type of personal protective equipment. Compared with nonsmokers, only 17.8% of the workers smoked (82.2%). The chi-square test revealed that there was a significant difference between the different categories of workers in terms of age, sex, level of education, work experience, duration of exposure, use of PPE and smoking status ($P<0.05$) (Table 4).

Table 4. Sociodemographic comparison between the various abattoir workers

Variables	Frequency (%) Cleaners (n = 49)	Butchers (n = 50)	Meat sellers and buyers (n = 50)	Hide roasters (n = 53)	Total Freq (%)	*p* -Value
Age						0.016_a^*
18-24years	13(46.4)	7(25.0)	4(14.3)	4(14.3)	28(13.8)	
25-34yrs	14(17.9)	18(23.1)	25(32.1)	21(26.9)	78(38.6)	
35-44yrs	12(21.1)	17(29.8)	15(26.3)	13(22.8)	57(28.3)	
45-54yrs	7(28.0)	6(24.0)	6(24.0)	6(24.0)	25(12.4)	
>55yrs	3(21.4)	2(14.3)	0(0.0)	9(64.3)	14(6.9)	
Gender						0.001_a^*
Male	9(12.0)	49(65.3)	15(20.0)	2(2.7)	75(37.2)	
Female	40(31.5)	1(0.8)	35(27.6)	51(40.2)	127(62.8)	
Level of Education						0.001_a^*
None	11(19.0)	14(24.1)	13(22.4)	20(34.5)	58(28.7)	
Primary	37(33.3)	32(28.8)	19(17.1)	23(20.7)	111(54.9)	
Secondary	0(0.0)	2(9.5)	9(42.9)	10(47.6)	21(10.4)	
Tertiary	1(8.3)	2(16.7)	9(75.0)	0(0.0)	12(6.0)	
Level of Income						0.001_a^*
#20,000	48(77.4)	1(1.6)	0(0.0)	13(21.0)	62(30.6)	
#40,000	0(0.0)	24(49.0)	2(4.1)	23(46.9)	49(24.3)	
#50,000	1(2.0)	24(47.1)	10(19.6)	16(31.4)	51(25.2)	
#100000	0(0.0)	1(2.5)	38(95.0)	1(2.5)	40(19.9)	
Work experience						0.001_a^*
1-5yrs	19(40.4)	15(21.3)	4(8.0)	12(24.0)	50(24.7)	
6-10yrs	19(40.4)	10(21.3)	8(17.0)	10(21.3)	47(23.3)	
11-15yrs	6(10.2)	9(15.3)	23(39.0)	21(35.6)	59(29.2)	
16-20yrs	5(11.6)	16(37.2)	15(34.9)	7(16.3)	46(22.8)	
Duration of exposure						0.001_a^*
<8 hrs	3(3.3)	42(45.7)	45(48.9)	2(2.2)	92(45.5)	
8 -12 hrs	42(41.6)	8(7.9)	5(5.0)	46(45.5)	101(50.0)	
>12 hrs	4(44.4)	0(0.0)	0(0.0)	5(55.6)	9(4.5)	
Use of PPE						0.001_a^*
Yes	22(44.0)	20(40.0)	3(6.0)	5(10.1)	50(24.7)	
No	27(17.8)	30(19.7)	47(30.9)	48(31.6)	152(75.3)	
Smoking status						0.001_a^*
Yes	1(2.8)	28(77.8)	5(13.9)	2(5.6)	36(17.8)	
No	48(28.9)	22(13.3)	45(27.1)	51(30.7)	166(82.2)	

$_a$ Chi square test, * Statistically significant, p≤0.05

Prevalence of reported health effects among Abattoir workers

The prevalence of health effects among exposed abattoir workers is shown in Table 5. The results revealed a significant difference in the prevalence of reported respiratory health effects (sore throat, shortness of breath, chest pain, eye irritation, and skin rashes) at p > 0.05 except for dry cough, asthma or difficulty breathing (p>0.05) among the workers. The prevalence rates of dry cough, asthma, difficulty breathing sore throat, shortness of breath, chest pain, eye irritation, and skin rashes among the workers were 66.3%, 18.3%, 32.7%, 34.7%, 23.7%, 25.2%, 45.5% and 37.1%, respectively (Table 5). The high occurrence of respiratory health effects reported among the workers further supports the high concentrations of particles recorded during the quantitative assessments. Furthermore, organic dust particles, including bioaerosols, reportedly exacerbate respiratory symptoms among workers at abattoirs [53]. Few studies have been conducted on the occurrence of respiratory effects among workers in slaughterhouses, especially in Nigeria; hence, the challenge of comparing these results with those of similar studies in the region, except a few in other parts of the world, remains. This finding is similar to the reports of [53, 40], who reported a similar prevalence of respiratory health disorders among slaughter workers. The prevalence of difficulty breathing (34.8%), shortness of breath (47.9%), eye irritation (39.1%) and skin rashes (41.3%) was significantly higher among hide roasters than among other abattoir workers. Sore throat (41.1%) and chest pain (56.9%) were significantly more common among the cleaners. The significant increase in the prevalence of respiratory effects among the hide roasters can be explained by direct exposure to smoke from the burning of biomass used for cowhide processing.

Table 5. Comparison of reported health effects among Abattoir workers

Variables	Frequency (%)					
	Cleaners (n = 49)	Butchers (n = 50)	Meat sellers and buyers (n = 50)	Hide roasters (n = 53)	Total Freq (%)	*p* -Value
Dry cough						0.308 $_a$
Yes	36(26.9)	35(26.1)	33(24.6)	30(22.4)	134(66.3)	
No	13(26.9)	15(22.1)	1(25.0)	23(33.8)	68(33.7)	
Asthma						0.305$_a$
Yes	5(8.3)	9(15.0)	10(27.0)	13(35.1)	37(18.3)	
No	44(31.0)	41(28.9)	40(24.2)	40(24.2)	165(81.7)	
Difficulty in Breathing						0.064$_a$
Yes	10(15.2)	14(21.2)	19(28.8)	23(34.8)	66(32.7)	
No	39(28.7)	36(26.5)	31(28.8)	30(34.8)	136(67.3)	
Sore throat						0.001 $_a^*$
Yes	29(41.1)	18(25.7)	10(14.3)	13(18.6)	70(34.7)	
No	20(15.2)	32(24.2)	40(30.3)	40(30.3)	132(66.3)	
Shortness of breath						0.001 $_a^*$
Yes	5(10.4)	17(35.4)	3(6.3)	23(47.9)	48(23.7)	
No	44(28.6)	33(21.4)	47(30.5)	30(19.5)	154(76.3)	
Chest pain						0.001 $_a^*$
Yes	29(56.9)	12(23.5)	1(2.0)	9(17.6)	51(25.2)	
No	20(13.2)	38(25.2)	49(32.5)	44(29.1)	151(74.8)	
Eye Irritation						0.001$_a^*$
Yes	13(14.1)	23(25.0)	20(21.7)	36(39.1)	92(45.5)	
No	36(32.7)	27(24.5)	30(27.3)	17(15.5)	110(54.5)	
Skin Rashes						0.001 $_a^*$
Yes	13(17.3)	18(24.0)	13(17.3)	31(41.3)	75(37.1)	
No	36(28.3)	32(25.2)	37(29.1)	22(17.3)	127(62.9)	

$_a$Chi square test, *Statistically significant, p≤0.05

Associations between reported risk factors and health effects among Abattoir workers

The relationships between the reported risk factors and respiratory health effects among abattoirs were examined using the chi-square test, which indicated that associations with p-values greater than 0.05 had no significant relationships (Table 6). The results revealed that the age of workers was significantly associated with reported health symptoms. There was a significantly higher occurrence of reported health effects among abattoir workers aged 45-54 years ($p > 0.05$) than among workers in other age ranges. [54] suggested that ageing may increase the vulnerability of individuals to developing respiratory symptoms, particularly in response to environmental pollutants. The respondents with 16 to 20 years of work experience reported a significantly higher occurrence of dry cough (46%, $p = 0.003$), whereas those who had spent 6 to 10 years at the abattoir had a significantly higher prevalence of sore throat (46.3%, $p = 0.016$) than did those with other years of work experience. This finding is similar to a study that reported a significant relationship between the number of working hours among intensive poultry workers and various respiratory health problems in Pakistan [55]. This further indicates that the greater the length of workers' years of experience is, the greater the risk of exposure and occurrence of health effects among workers [56]. The duration of exposure at the abattoir was significantly associated with only chest pain (36.6%, $p=0.001$) among the respondents. This finding is in tandem with the findings of the National Institute of Occupational Safety and Health [56], which opined that long hours of working and repeated movement within the work environment predispose workers to health effects. The percentage occurrence of dry cough among those who smoked (66.7%) was significantly greater than that among nonsmokers (41.7%) ($p = 0.006$). Several studies have reported significant associations between smoking and symptoms of respiratory diseases [57, 58]. The occurrence of reported health effects was higher in respondents who did not use personal protective equipment (PPE) than in those who used PPE, but the association was not statistically significant ($p>0.05$). Onsite assessment during this study revealed that there was no use of PPE among the workers, especially the hide roasters who were directly exposed to high levels of smoke pollution. The use of PPE by workers to reduce occupational exposure and health effects has been reported by [59].

Table 6. Associations between reported risk factors and health effects among Abattoir workers

Factors	Dry cough		Eye Irritation		Asthma		Difficulty in breathing		Sore throat		Shortness of breath		Chest pain	
	Freq (%)	P value	Freq (%)	p value	Freq (%)	p value	Freq (%)	P value	Freq (%)	p value	Freq (%)	P value	Freq (%)	P value
Age		0.001$_a$*		0.050		0.019$_a$*		0.004$_a$*		0.160		0.239		0.099
18-24years	8(28.7)		8(28.6)		0(0.0)		9(32.1)		10(35.7)		6(21.4)		7(25.0)	
25-34yrs	21(26.9)		38(48.7)		18(23.1)		14(17.9)		23(29.5)		16(20.5)		15(19.2)	
35-44yrs	17(29.8)		24(42.1)		10(17.5)		25(43.9)		27(47.4)		19(33.3)		13(22.8)	
45-54yrs	18(72.0)		17(68.0)		8(32.0)		13(52.0)		7(28.0)		3(12.0)		9(36.0)	
>55yrs	4(28.6)		5(3.7)		1(7.1)		5(35.7)		3(21.4)		4(28.6)		7(50.0)	
Abattoir work		0.033$_a$*		0.327		0.107		0.081		0.016$_a$*		0.230		0.193
experience														
1-5yrs	12(24.0)		18(36.0)		8(16.0)		13(26.0)		18(36.0)		13(26.0)		11(22.0)	
6-10yrs	10(21.3)		19(40.4)		5(10.6)		14(29.8)		22(46.8)		14(29.8)		18(38.3)	
11-15yrs	25(42.4)		30(50.8)		13(22.0)		19(32.2)		14(23.7)		11(18.6)		11(18.6)	
16-20yrs	20(46.0)		23(53.5)		9(20.9)		17(39.5)		13(30.2)		8(18.6)		10(23.3)	
>20yrs	1(33.3)		2(66.7)		2(66.7)		3(100)		3(100.0)		2(66.7)		1(33.3)	
Duration of exposure		0.518		0.632		0.809		0.434		0.355		0.531		0.001$_a$*
<8 h	27(29.3)		39(42.4)		18(19.6)		26(28.3)		27(29.3)		19(20.7)		11(12.0)	
8 -12 h	38(37.6)		48(47.5)		18(17.8)		36(35.6)		40(39.6)		26(25.7)		37(36.6)	
>12 h	3(33.3)		5(55.6)		1(11.1)		4(44.4)		3(33.3)		3(33.3)		3(33.3)	
Smoking status		0.046$_a$*		0.006$_a$*		0.081		0.246		0.509		0.501		0.154
Yes	17(47.2)		24(66.7)		10(16.3)		14(38.9)		12(33.3)		8(22.2)		39(23.5)	0.154
No	51(30.7)		68(41.0)		27(27.8)		52(31.3)		58(34.9)		40(24.1)		12(33.3)	
Use of PPE		0.390		0.059		0.408		0.064		0.865		0.084		0.580
Yes	54(35.5)		75(49.3)		30(19.7)		55(36.2)		52(34.2)		41(27.0)		40(26.3)	
No	98(64.5)		77(50.7)		122(80.1)		97(63.8)		100(65.8)		111(73.0)		112(73.7)	

$_a$Chi square test, *Statistically significant, p≤0.05

Conclusion

This study assessed the concentrations of particulate matter in different areas of selected abattoirs and examined the associated risk factors and health risks to abattoir workers. The results indicated that the level of particulates was highest in the area where hides are being roasted, implying a high risk of exposure to air pollutant-related health effects on the hide roasters. The study also revealed that the concentrations of particulates across the sampling points were far above the national (FEPA) and international (WHO) recommended air quality standards. This is a serious public health concern for workers at abattoirs. The ambient temperature and relative humidity were found to be significantly associated with increased particulate matter concentrations, particularly at the point of cowhide burning. There was an increased risk of workers being exposed to adverse health effects across the sampling areas, as revealed by the estimation of the noncarcinogenic risk assessment. The risk was found to be highest at the point of cowhide signing, implying that the continuous practice of open hide burning results in the deterioration of air quality in the abattoir environment and subsequently contributes to the increased risk of adverse health effects. The study also revealed significant associations between reported sociodemographic factors, including age, sex, and other risk factors such as duration of exposure, the use of PPE, and reported health effects among the different abattoir workers. Generally, the prevalence of reported health effects was significantly higher among hide roasters across abattoirs. There is a need to consider alternative energy sources for processing cowhides and the consistent use of face masks by hide roasters to reduce exposure to smoke. For proper and effective control of this occupational health hazard among abattoir workers, the introduction of subsidies for alternative clean energy sources by the government to discourage the use of biomass for hide processing, education and training on the effects of short- and long-term exposure to air pollutants among abattoir workers, interventions such as the provision of face masks to workers as part of safe work procedures and the enforcement of existing laws governing abattoir operations are highly recommended.

Financial supports

No funding was received for conducting this study.

Competing interests

The authors declare no conflicts of interests.

Acknowledgements

The authors would like to acknowledge the management of the Edo State Butchers' Association for their approval, support and the abattoir workers who voluntarily participated in the study.

Ethical considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission/ redundancy, etc.) have been completely observed by the authors.

References

1. Santos UP, Arbex MA, Braga ALF, Mizutani RF, Cançado JED, Terra-Filho M, et al. Environmental air pollution: respiratory effects. Brazilian Journal of Pulmonology. 2021, 8;47(1): e20200267. doi: 10.36416/1806-3756/ e20200267.

2. Aya FC, Nwite JN. Implication of

Roasting Goats with Tyres on Human Health and the Environment in Abakaliki, Ebonyi State in Nigeria. Journal of Pollution Effects and Control. 2016;4(153):1-4. doi.104172/2375-4397.1000153.

3. Ekanem AM, Ijezie AE, Udo IA, Ekrikpo UE, Idung AU. Meat singeing practices and knowledge of its effects on health and environment among butchers in Uyo, Nigeria. Journal of Advances in Medical and Pharmaceutical Sciences. 2020;23-33. https://doi.org/10.9734/jamps/2020/v22i730182.

4. Ojinnaka MC, Ubaka IT, Obeta NA, Okudu HO. Quality Evaluation of Edible Beef Skin Produced Using Different Singeing Methods. Asian Journal of Food Research and Nutrition.2023; 2(4):770-777.http://journalajfm.com/index.php/AJFRN/article/.

5. Wambebe NM, Duan X. Air Quality Levels and Health Risk Assessment of Particulate Matters in Abuja Municipal Area, Nigeria. Atmosphere. 2020; 11:817. https://doi.org/10.3390/atmos11080817.

6. World Health Organization. WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. 2021.

7. Kaur M, Chandel J, Malik J, Naura AS. Particulate matter in COPD pathogenesis: an overview. Inflammation Research. 2022; 71(7):797-815. doi: 10.1007/s00011-022-01594-y.

8. Harrison RM. Airborne particulate matter. Philosophical Transactions of the Royal Society A. 2020;378(2183):20190319.

9. Pinkerton KE, Green FH, Saiki C. Distribution of particulate matter and tissue remodelling in the human lung. Environmental Health Perspectives. 2000; 108(11):1063–1069. doi: 10.1289/ehp.001081063.

10. Heal MR, Kumar P, Harrison RM. Particles, air quality, policy and health. Chemical Society Reviews. 2012;41(19):6606-30.

11. Cheung K, Daher N, Kam W, Shafer MM, Ning Z, Schauer JJ, Sioutas C. Spatial and temporal variation of chemical composition and mass closure of ambient coarse particulate matter (PM10–2.5) in the Los Angeles area. Atmospheric environment. 2011 May 1;45(16):2651-62.

12. Thurston GD, Burnett RT, Turner MC, Shi Y, Krewski D, Lall R, Ito K, Jerrett M, Gapstur SM, Diver WR, Pope III CA. Ischemic heart disease mortality and long-term exposure to source-related components of US fine particle air pollution. Environmental health perspectives. 2016 Jun;124(6):785-94.

13. Ostro B, Hu J, Goldberg D, Reynolds P, Hertz A, Bernstein L, Kleeman MJ. Associations of mortality with long-term exposures to fine and ultrafine particles, species and sources: results from the California Teachers Study Cohort. Environmental health perspectives. 2015 Jun;123(6):549-56.

14. Jimoda LA, Sulaymon ID, Alade AO, Adebayo GA. Assessment of environmental impact of open burning of scrap tyres on ambient air quality. International Journal of Environmental Science and Technology. 2018 Jun;15:1323-30.

15. Shang J, Khuzestani RB, Huang W, An J, Schauer JJ, Fang D, Cai T, Tian J, Yang S, Guo B, Zhang Y. Acute changes in a respiratory inflammation marker in guards following Beijing air pollution controls. Science of the total environment. 2018 May 15;624:1539-49.

16. Odekanle EL, Sonibare OO, Odejobi OJ, Fakinle BS, Akeredolu FA. Air emissions and health risk assessment around abattoir facility. Heliyon. 2020 Jul 1;6(7).

17. Abulude FO, Feyisetan AO, Arifalo KM, Akinnusotu A, Bell, LJ. Indoor particulate matter

assessment in a northern Nigerian abattoir and a residential building. Journal of Atmospheric Science Research. 2022; 5(4), 20-28. http://dx.doi.org/10.30564/jasr.v5i4.5104.

18. Uyo CN, Njoku JD, Iwuji MC, Ihejirika CE, Njoku-Tony RF. Assessment of air quality in livestock farms and abattoirs in selected LGAs of Imo State. Assessment, 2021; 7(8):54-68 https://www.ijaar.org/articles/v7n8/ste/ijaares-v7n8-Aug21-p7859.pdf.

19. Umoh V, Peters E. The relationship between lung function and indoor air pollution among rural women in the Niger Delta region of Nigeria. Lung India. 2015; 32(2):199 doi: 10.4103/0970-2113.152672

20. Kim H, Kang K, Kim T. Measurement of particulate matter ($PM_{2.5}$) and health risk assessment of cooking-generated particles in the kitchen and living rooms of apartment houses. Sustainability. 2018;10(3):843. https://doi.org/10.3390/su10030843.

21. Ibe FC, Opara AI, Amaobi CE, Ibe BO. Environmental risk assessment of the intake of contaminants in aquifers in the vicinity of a reclaimed waste dumpsite in Owerri municipal, Southeastern Nigeria. Applied Water Science. 2021;11(2):1-19. https://doi.org/10.1007/s13201-020-01355-4.

22. Elemile OO, Raphael DO, Omole DO, Oloruntoba EO, Ajayi EO, Ohwavborua NA. Assessment of the impacts of abattoir effluent on the water quality of groundwater in a residential area of Omu-Aran, Nigeria. Environmental Sciences Europe. 2019; 31: 16. https://enveurope.springeropen.com/articles/10.1186/s12302-019-0201-5.

23. Jonah AE. Determination of Some Air Pollutants and Meteorological Parameters in Abattoir, Ntak Inyang in Uyo LGA of Akwa Ibom State in Nigeria. International Journal of Science and Management Studies, 2020; 3(6), 1-8. http://dx.doi.org/10.51386/25815946/ijsms-v3i6p101.

24. Ebe TE1, Udensi JU, Ojiaku A, Ejiogu CC, Nwachukwu J, Egbuawa O, et al. Air Quality Assessment in Abattoir Facility, Obinze, Owerri West, Imo State, Nigeria American Journal of Environmental Protection. 2023; 11(2):49-55 doi:10.12691/env-11-2-3.

25. Mamhobu-Amadi, WC, Kinigoma BS, Momoh Y, Oji A. Investigation of The Impact of Some Abattoir Activities on Air Quality. International Journal of Innovative Research and Advanced Studies. 2019; 6(7):174-181. https://www.ijiras.com/2019/Vol_6-Issue_7/paper_25.pdf.

26. Wokoma OAF, Edoghotu, AJ, Gboeloh LB, Onyeche EC, Alikor E, Owoh AA. Assessment of Air Quality Around Selected Abattoirs in Port Harcourt Metropolis, Rivers State, Nigeria, Journal of Environmental Science, Toxicology and Food Technology. 2020;16(11):32-37, DOI: 10.9790/2402-1611023237.

27. Victor SO. Integrated Assessment of the Air Quality around the Environs of Dr. Abubakar Sola Saraki Memorial Abattoir, Ilorin, Kwara State, Nigeria, International Journal of Innovative Science and Research Technology. 2020;5(6):241-246 doi:Ijisrt20jun270.

28. Vincent EW, Jimmy OA, Meelubari BK. The Epidemiology of Cardio-vascular Diseases about the Air Quality of Abattoirs in Port Harcourt, Nigeria. World Journal of Cardiovascular Diseases. 2016; 6:94-107. doi: 10.4236/wjcd.2016.64011.

29. Ajanaku AO, Oyelami BA, Eniola O. Ugege BH. Perceived Health Implications of Abattoir Activities on Residential Neighborhoods: A Case Study Of Bodija Abattoir, Ibadan, Nigeria, Nigerian Journal of Agriculture, Food and Environment. 2019;15(2): 36-42. https://www.eruditescholars.net.

30. FEPA, 1999. National Guidelines

for Environmental Audit in Nigeria. Federal Environmental Protection Agency. Federal Government Press, Abuja, Nigeria. Part1,pp1-154.

31. Bhat TH, Jiawen G, Farzaneh, H. Air Pollution Health Risk Assessment (AP-HRA), Principles and Applications. International Journal of Environmental Research and. Public Health. 2021; 18:1935. DOI:10.3390/ijerph18041935.

32. Lina, ND, Engelbrecht JC, Wright CY, Oosthuizen MA, Thabethe, NDL. Human health risks posed by exposure to PM_{10} for four life stages in a low socio-economic community in South Africa. Pan African Medical Journal. 2014; 18:206. https://doi.org/10.11604/pamj.2014.18.206.3393.

33. Lemly A. Evaluation of the Hazard Quotient Method for Risk Assessment of Selenium. Ecotoxicology and Environmental Safety. 1996; 35:156–162. https://doi.org/10.1006/eesa.1996.0095.

34. Oliveira, BFA, Igotti E, Artzxo P, Saldiva PHN, Juger WL Hacon S. Risk assessment of $PM_{2.5}$ to child residents in Brazilian Amazon region with biofuel production. Environmental Health. 2012;11, 64. https://doi.org/10.1186/1476-069X-11-64.

35. Kumar S, Goyal P. Health Risk of Ambient $PM_{2.5}$ Concentration: A Case Study of New Delhi, India. International Journal of Agricultural Sustainability. 2019; 1:10–16.

36. Hyungkeun Kim, Kyungmo K, Taeyeon K. Measurement of particulate matter ($PM_{2.5}$) and health risk assessment of cooking-generated particles in the kitchen and living rooms of apartment houses. Sustainability. 2018; 10:1–13. https://doi.org/10.3390/su10030843.

37. US EPA. Concepts, Methods, and Data Sources for Cumulative Health Risk Assessment of Multiple Chemicals, Exposures and Effects: A Resource Document (Final Report, 2008). https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=190187.

38. Society AT. Standards for the diagnosis and care of patients with chronic obstructive lung disease. American Journal of Respiratory and Critical Care Medicine. 1995;152: S78-S121. doi: 10.1164/ajrccm/136.1.225.

39. Cochran WG. Sampling Techniques. 3rd Edition, John Wiley & Sons, New York.1977.

40. Kasaeinasab A, Jahangiri M, Karimi A, Tabatabaei HR, Safari S. Respiratory disorders among workers in slaughterhouses. Safety and health at work. 2017 Mar 1;8(1):84-8.

41. Faus-Kessler T, Kirchner M, Jakobi G. Modelling the decay of concentrations of nitrogenous compounds with distance from roads. Atmospheric Environment. 2008. 42:4589–4600. https://doi.org/10.1016/j.atmosenv.2008.01.073.

42. Liu SV, Chen FL, Xue J. A meta-analysis of selected near-road air pollutants based on concentration decay rates. Heliyon. 2019 Aug 1;5(8). https://doi.org/10.1016/j.heliyon.2019.e02236.

43. Eghomwanre AF, Oguntoke O, Taiwo AM. Levels of indoor particulate matter and association with asthma in children in Benin City, Nigeria. Environmental Monitoring and Assessment. 2022 Jul;194(7):467. https://doi.org/10.1007/s10661-022-10135-3.

44. Bhat MA, Eraslan FN, Awad A, Malkoç S, Üzmez ÖÖ, Döğeroğlu T, et al. Investigation of indoor and outdoor air quality in a university campus during the COVID-19 lockdown period. Building and. Environment 2022; 219:109176. Doi: 10.1016/j.buildenv. 2022.10917.

45. Chen C, Zhao B. Review of the relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. Atmospheric Environment. 2011; 45(2):275–288.

46. Singrakphon V, Chart-asa C, Chaikaew P. Meteorological Conditions and PM2. 5 Impact on COVID-19 Case Fatality Ratios (CFR) in Bangkok Metropolitan Region. Applied Environmental Research. 2024 Apr 3;46(2).

47. Jacobson MZ. Fundamentals of atmospheric modelling, 2nd edition, Cambridge University Press, New York. 2005; pp120-125.

48. Baumbach G, Vogt U, Hein KRG, Oluwole AF, Ogunsola OJ, Olaniyi HB. Air pollution in a large tropical city with high traffic density–results of measurements in Lagos, Nigeria. The Science of the Total Environment. 1995; 169:25–31. https://doi.org/10.1016/0048-9697(95)04629-F.

49. Onuorah CU, Leton TG, Momoh YOL. Influence of meteorological parameters on particle pollution ($PM_{2.5}$ and PM_{10}) in the tropical climate of Port Harcourt, Nigeria. Archives of Current Research International. 2019; 19(1):1–12. https:// doi. org/ 10. 9734/ acri/ 2019/ v19i1 30149.

50. Gilbert F, Serge N, John NL, Samuel L. Air quality and human health risk assessment in the residential areas at the proximity of the Nkolfoulou landfill in Yaoundé Metropolis, Cameroon. Journal of Chemistry. 2019; 9:3021894. http://dx.doi.org/10.1155/2019/3021894.

51. Oliveira BFA, Igotti E, Artzxo P, Saldiva PHN, Juger WL, Hacon S. Risk assessment of $PM_{2.5}$ to child residents in Brazilian Amazon region with biofuel production. Environmental Health. 2012; 11:64 https://doi.org/10.1186/1476-069X-11-64.

52. Hitchins J, Morawska L, Wolff R, Gilbert D. Concentrations of submicrometric particles from vehicle emissions near a major road. Atmospheric Environment. 2000, 34:51–59. https://doi.org/10.1016/S1352-2310(99)00304-0.

53. Ramadan MA, Mohammed RS, Safwat SEA. Assessment of ventilatory functions and associated inflammatory markers among workers in slaughterhouses. International Archives of Occupational and Environmental Health. 2024; 97, 891–900. https://doi.org/10.1007/s00420-024-02094-8.

54. Rabe KF, Hurd S, Anzueto A, Barnes PJ, Buist SA, Calverley P, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: Gold executive summary. American Journal of Respiratory and Critical Care Medicine. 2007;176(6):532–555. doi: 10.1164/rccm.200703-456S.

55. Yasmeen R, Ali R, Tyrrel S, Nasir ZA. Assessment of Respiratory Problems in Workers Associated with Intensive Poultry Facilities in Pakistan. Safety and Health at Work. 2020;11:(1)118-124 https://doi.org/10.1016/j.shaw.2019.12.011.

56. Chen L, Eisenberg CJ, Durgam S, MSChE CI, Mueller C. Evaluation of Eye and Respiratory Symptoms at a Poultry Processing Facility-Oklahoma. US Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2012 Mar.

57. Eghomwanre AF, Oguntoke O. Concentrations of indoor gaseous air pollutants and risk factors associated with childhood asthma in Benin City, Nigeria. Environmental Monitoring and Assessment. 2022;94(5): 391. https://doi.org/10.1007/s10661-022-10026-7.

58. Ozoh OB, Aderibigbe SA, Ayuk AC, Desalu OO, Oridota OE, Olufemi O, et al. The prevalence of asthma and allergic rhinitis in Nigeria: A nationwide survey among children, adolescents and adults. PloS one. 2019 Sep 13;14(9):e0222281.

59. Rousset N, Brame C, Galliot P, Cleuziou AC, Goizin G, Hassouna M, et al. Dust concentrations, and dust exposure of workers

in the air of poultry houses during specific" working task"[Conference poster]. 2017: 928-933.