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ASSESSING THE HEALTH RISKS OF SAWMILL WORKERS ASSOCIATED WITH PARTICULATE MATTER TOXICITY: A CASE STUDY OF BENIN CITY, NIGERIA

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Background: Sawmills are essential to the timber industry, but they pose significant occupational health risks, primarily from airborne particulate matter (PM) pollution. **Objectives:** This study aims to assess the toxicity of PM and its link to reported respiratory problems among sawmill workers in Benin City, Nigeria. **Methods:** Quantitative measurements of $PM_{2.5}$ and PM_{10} were conducted in 10 randomly selected sawmills using a calibrated BR-SMART-126S handheld air quality detector. The toxicity potential of the measured PM concentrations was determined. A cross-sectional study involving 200 participants utilised a modified British Medical Research Council questionnaire to assess respiratory symptoms. A binomial logistic regression model was employed to identify factors associated with these symptoms. Data were analysed using SPSS v21.0 with descriptive statistics, chi-square tests, and bivariate logistic regression; significance was set at $p < 0.05$. Results were presented as medians, box plots, frequencies, percentages, cORs, and 95% CIs. **Results:** The particulate matter exposure levels among sawmill workers ranged from 32 – 36 μg/m^3 ($PM_{2.5}$) and 40 – 44 μg/m^3 (PM_{10}). The level of $PM_{2.5}$ exceeded the limit of 15 μg/m^3 set by the WHO. The toxicity potential (TP) values of $PM_{2.5}$ were greater than 1 at all the sampling sites. The prevalence rates of reported respiratory symptoms among workers were 31%, 26%, 29%, 26% and 23% for shortness of breath, wheezing, cough, chest pain, and sore throat, respectively. Work experience (cOR = 5.96; 95% CI: 1.243 – 28.629), daily duration of exposure (cOR = 3.51; 1.737 – 7.130), open burning of wood waste (cOR = 20.68; CI = 3.537 – 120.96) and use of diesel-powered generators (cOR = 16.44; CI = 5.660 – 47.752) in the sawmills were determining factors for reported respiratory symptoms among workers. **Conclusion:** The study found a high prevalence of respiratory health issues among workers. The key factors contributing to these problems include: longer employment, prolonged daily exposure, open burning of sawmill wastes and the use of diesel-powered generators: These generators release harmful emissions which increase the likelihood of respiratory symptoms.

Keywords: households; urbanization; circular economy; waste collection optimization; waste transportation; sustainable management.

INTRODUCTION

Globally, sawmills remain a foundational method for processing timber, especially for building and construction, due to persistent high demand (Olorunnisola, 2023). Projections have consistently shown a sharp increase in consumption, with global industrial timber use predicted to rise by 45% by the end of 2020 (FAO, 2001) and reaching 2.3 billion cubic meters in 2020, a 24% increase from 2015 (FIM, 2017). The World Bank even forecasts a quadrupling of this demand by 2050 (FIM, 2017).

However, this intensive processing has a significant drawback: the generation of particulate matter from wood waste. This waste constitutes a large portion of the global total, with Germany alone producing 11.9 million tons of waste wood in 2015 (Sommerhuber et al., 2015; Garcia & Hora, 2017). Studies worldwide have consistently linked exposure to particulate matter from this wood waste to a range of severe respiratory health issues and other environmental problems, highlighting the critical need for better waste management (Amoabeng et al., 2020; Ramasamy et al., 2015; Saejiw et al., 2009; Mong'are et al., 2017).

Nigeria's sawmilling industry has experienced a significant growth trajectory, though data is often fragmented. Historical data indicates intensive growth in sawmilling from over 500 in 1975 to approximately 1,200 by 1981, and later stabilized at 1,325 in 2010 (Adekunle et al., 2013). This rapid proliferation reflects the high demand for timber, which is primarily used in construction and furniture making.

The pace of development is particularly evident in timber-rich states like Edo, where Benin City has become a major hub. This concentration of sawmills has turned the industry into a vital part of the local economy, but it has also led to immense challenges in environmental and occupational health. A study on wood waste generation in Benin Metropolis found that a total volume of approximately 1,150 m^3 of wood waste is generated daily, which translates to about 1,075 tonnes (Adekunle et al., 2013). This scale of waste production highlights the intensity of sawmilling activities in the city. A large portion of this waste, up to 96% of the generated wood dust, enters the environment through the common practice of open burning (Okedere et al., 2017). This rapid and often unregulated expansion underscores the urgent need for research into the health and environmental impacts of this industry.

While Nigeria has labour legislation like the Factories Act of 1990 and the Employees' Compensation Act of 2010, enforcement is weak, especially in informal and semi-formal industries like sawmilling. This lack of oversight means many sawmill operators fail to provide personal protective equipment (PPE) such as safety goggles and respirators, leaving workers highly vulnerable to occupational hazards (Amoabeng et al., 2020). This issue is compounded by a significant lack of specific, up-to-date data on occupational diseases and injuries within Benin City's sawmilling sector. However, research from similar industries globally provides a strong basis for concern (Bello & Mijinyawa, 2010). Workers are particularly susceptible to respiratory diseases caused by inhaling wood dust, a known carcinogen linked to conditions like occupational asthma, chronic bronchitis, and various cancers (Ramasamy et al., 2015). Prolonged exposure to fine particulate matter ($PM_{2.5}$) can lead to an increased risk of chronic respiratory and cardiovascular problems, and even premature death, as these tiny particles can penetrate deep into the lungs and bloodstream (WHO, 2018; Thangavel et al., 2022). This critical gap in localized data underscores the urgent need for a comprehensive study to quantify these health risks.

Despite the environmental health threats posed by improper management, the establishment of sawmills in Nigeria continues to increase without proper attention given to their environmental and health impacts. Several studies have shown that improperly managed sawmill operations can become a public health threat, but research on the specific health effects of these activities in Nigeria remains limited (Elijah & Elegbede, 2018; Oguntoke et al., 2019; Amaechi & Okoduwa, 2023). Given the significant concentration of sawmills in Benin City and the lax implementation of occupational health and safety laws, this knowledge gap is particularly alarming. Additionally, Nigerian sawmill workers frequently lack access to proper personal protective equipment (PPE) and are often unaware of the long-term health dangers connected to their workplace (Olujimi et al., 2023). This highlights a critical gap in our understanding of the specific health burdens faced by this vulnerable population.

This study aims to address this gap by assessing the levels and toxicity of potential particulate emissions and their associated health effects. We will contribute new scientific knowledge by quantifying PM levels at different workstations and calculating the toxicity potential (TP) within sawmills in Benin City. Furthermore, this research will examine the respiratory health status of sawmill workers through a comprehensive questionnaire and investigate the association between PM exposure and respiratory symptoms. This new understanding will be instrumental in developing effective mitigation strategies to protect the respiratory health and improve the overall well-being of sawmill workers in the region. We hypothesize that a direct relationship exists between the levels of PM exposure and the prevalence of respiratory symptoms among the workers.

MATERIALS AND METHODS

Study Area

The study was conducted in Benin City, the capital of Edo State in Southern Nigeria, a major metropolitan area with a population of over 1.8 million as of 2022. The city's extensive forest resources and high timber demand make it a significant hub for sawmilling activities. Benin City is the capital of Edo State in southern Nigeria and a major hub for the country's sawmilling industry. Its strategic location and abundant timber resources have made it a centre for wood processing, primarily for construction and furniture manufacturing. The city's sawmilling industry is extensive, though there are no recent official census figures for the exact number of sawmills. However, based on various reports, the density is significant (Adekunle et al., 2013). The sawmills are not centrally located but are spread out in clusters across the city, often in areas with easy access to timber. Some of the most prominent areas with a high concentration of sawmills include Akpata, Egor, and Ikpoba Hill. The close proximity of these operations, often with minimal separation, contributes to high levels of pollution in these neighbourhoods. The specific study area was the Akpata neighbourhood, located within the Egor Local Government Area of Benin City. The sawmills in this area operates as a labour-intensive enterprise, employing a workforce of around 10 to 15 workers per location. The workers are involved in a range of tasks, including: Log transportation and Offloading, sawing and Trimming, finishing, and waste Management. The primary raw material for these sawmills is timber from Nigeria's forests. The wood species most commonly processed are various hardwoods used for furniture and construction. The sawmills are significant sources of pollution due to the following activities: Particulate matter (PM) emissions generated from wood cutting, shaping. Noise pollution from the constant operation of heavy machinery and generators creates significant noise, impacting both workers and nearby residents. Some sawmills use chemical preservatives to treat wood, which can release volatile organic compounds into the atmosphere. Due to inconsistent public power supply, most sawmills rely on diesel-powered generators, which release harmful vehicular emissions.

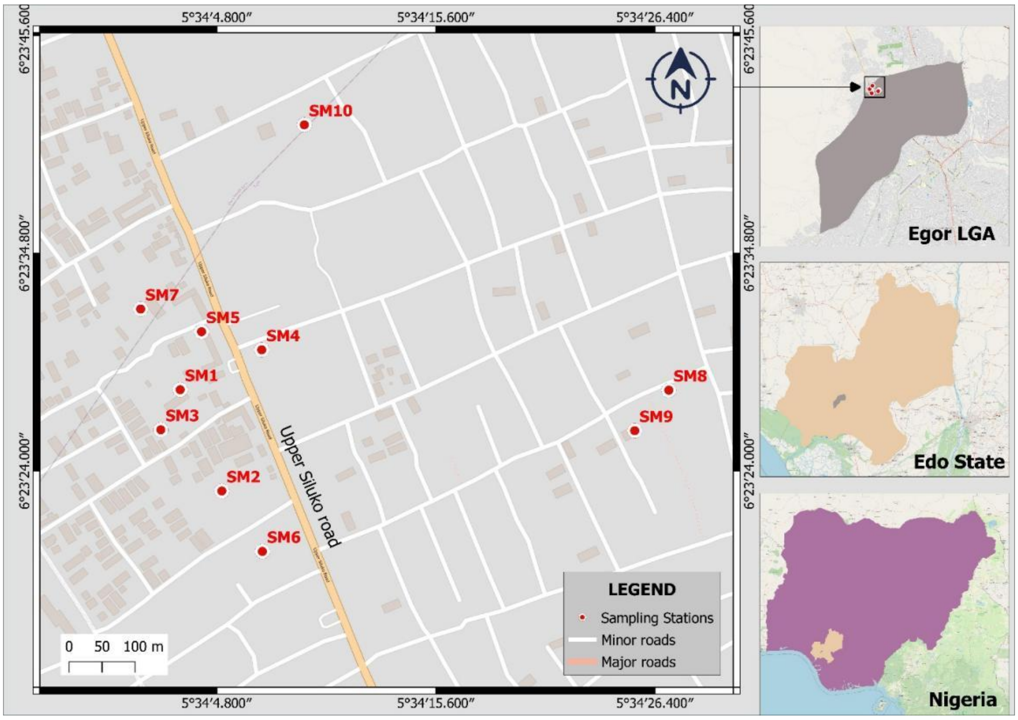

Figure 1. Map of study area showing selected sawmills

Selection of sampling sites and duration of sampling

Ten active sawmills (SM1 – SM10) in Egor Local Government area were randomly selected for a three-month study (March – May 2023) (Figure 1). Selection criteria included: operation for at least one year, availability of workers with at least one year of wood processing experience, and informed consent to participate. Concentrations of $PM_{2.5}$ and PM_{10} were systematically monitored at three distinct sampling points (A, B and C) within each sawmill. These points were strategically chosen based on their proximity to key pollution sources and their ability to represent different operational zones. This was done to effectively capture the spatial variability of particulate matter (PM) pollution and to allow for a comprehensive assessment of how various pollution sources, both inside and outside the sawmill, influence particulate levels.

Point A (Manufacturing Area): This point was located at the core of the sawmill operations, specifically where wood processing activities such as cutting and planning occur. It was selected to measure the highest concentration of particulate matter, as it is the point of origin for the majority of the dust.

Point B (Wood Storage Section): This point was located a calculated distance away from the main manufacturing area, specifically in the wood storage section. This area represents a secondary zone of exposure, where particulates can accumulate or settle.

Point C (Outside the Wood Processing Area): This point was strategically placed at the perimeter of the sawmill, capturing the particulate levels that migrate from the main operational areas to the surrounding environment. It was selected to assess the impact of the sawmill's emissions on the immediate vicinity.

Sampling of ambient particulate matter

The sampling was carried out using BR-SMART-126S handheld air quality detector made by BLATN Science and Technology Co, Ltd, (Beijing, China). The sampler employs various sensing technologies to measure various pollutants. For the measurement of particulate matter concentrations, it employs laser scattering technology by directing a laser beam through the air samples. When the particles ($PM_{2.5}$ and PM_{10}) pass through the beam, they scatter the light. The detector measures the intensity of the scattered light, which is proportional to the concentration of the atmospheric particles. The sensor signals are processed by the detectors electronic which display the processed data on the detector's screen showing the real-time readings for $PM_{2.5}$ and PM_{10}. The device has a measurement range, accuracy and resolution of 0-999 μg/m^3 and 0-999 μg/m^3, ±15%, and 0.001 mg/m^3 for $PM_{2.5}$ and PM_{10} respectively. At the sampling points A, B and C), the meter was turned on by holding the power button for a few seconds until the device turned on. The device is calibrated before use according to the manufacturer's recommendation to meet the objective of the study. It was positioned 2 m above the ground to ensure that fugitive dust would not have an impact on the readings. The measurements were carried out weekly in triplicate for twelve weeks between 7 am to 6 pm, the sawmill work hours across the sawmills. The concentrations of PM in μg/m^3 displayed on the screen were recorded in triplicates and the average values were computed and compared to the WHO 24 hour air quality standard (WHO, 2021).

Toxicity potential of PM concentrations

Toxicity potential (TP) is a measure used to assess the human health risks of air pollution. It helps us understand the negative impact of air pollutants emitted from various anthropogenic activities (Ayodele et al., 2016; Chamseddine et al., 2019). In this study, the TP associated with fine and coarse particulate matter at different sampling sites of selected sawmills was calculated. We used the formulae below to estimate these TP values.

$$TP = \frac{C_p}{S_p}. \quad (1)$$

The TP value is calculated by dividing the measured concentration of the pollutant (C_p) by the standard guideline value (S_p). WHO (2021) recommends a standard guideline value of 15 μg of $PM_{2.5}$ and 45 μg of PM_{10} per cubic meter of air. A TP value greater than 1 indicates that the concentration of the pollutant exceeds the recommended guideline value, posing a potential health risk at the sawmills.

Questionnaire-based survey

The questionnaire survey was carried out simultaneously with the particulate matter sampling at the selected sawmills. The target respondents were sawmill workers, wood sellers and buyers who had been in the sawmill industry for at least one year before this study. The sample size was estimated using a formula based on the prevalence of respiratory symptoms among sawmill workers reported in previous studies (Neghab et al., 2008). The formula is as follows:

$$N = \frac{z^2pq}{d^2}, \quad (2)$$

where $q = (1 - p)$ is the complement of p;

$$N = \frac{z^2p(1-p)}{d^2}, \quad (3)$$

where N is the minimum sample size; z is the confidence interval, which is equivalent to a confidence coefficient of 1.96 for a 95% confidence level of 0.595; p is the prevalence of asthma-related symptoms, which is 15.5% or 0.155; d is the desired level of precision, which is 0.05.

To ensure a 95% confidence interval with a specific margin of error, a sample size of 201 is necessary. The British Medical Research Council (MRC) respiratory symptoms questionnaire (MRC, 1960), a validated tool previously used in Nigeria (Ugheoke et al., 2009), was adapted for this study to better suit the local context and target population. The questionnaire was modernised to improve clarity and cultural relevance. To address potential language barriers and ensure accurate understanding, the questions were tested beforehand and made clearer with additional explanations in Pidgin and Bini languages by the trained interviewers. This step was crucial for ensuring that participants, who may not be fluent in English, could accurately report their symptoms and other relevant information. The questionnaire was pre-tested in sawmills in another study area within the state. Based on this pre-testing, the content was refined to include sections on possible contributory factors to air pollution specifically relevant to sawmills. These factors included sawmill work experience, work section, smoking status, exposure duration, energy sources within the sawmill, open burning of wood waste, and the use of personal protective equipment. This modification was made to ensure a comprehensive assessment of how occupational and environmental factors might influence the reported respiratory symptoms.

Exclusion criteria

People who had a history of asthma, tuberculosis, chest or respiratory problems, or had been previously diagnosed with these conditions by a doctor were not included in the study. This was done to avoid skewing the results.

Data analysis

The data obtained from this study were statistically and graphically analysed using SPSS version 21.0. The particulate matter measurements were analysed using descriptive statistics, and the median of the concentrations with the toxicity index presented in a box and Wiskers plots indicated by the line in the centre of the box. The questionnaire data were also analysed using descriptive statistics, and results were presented as frequencies and percentages. For questionnaire data to identify relationships between self-reported respiratory symptoms, a chi-square test was employed. Significant reported risk factors were further examined using bivariate logistic regression, where the reported contributory factors to air pollution in sawmills were considered independent variables, and respiratory symptoms were the dependent variable. Results were presented as crude odds ratios (cORs) and 95% confidence intervals (95% CIs). All data analyses were performed using SPSS statistical software version 21.0. Statistical significance was set at $p < 0.05$.

RESULTS

Concentrations of ambient particulate matter in sawmills

The median concentrations of ambient particulate matter ($PM_{2.5}$ and PM_{10}) at the different sections across the selected sawmills are presented in the box and Whisker's plot as revealed in Figure 2. The median concentrations of $PM_{2.5}$ ranged between 32 – 36 μg/m^3 while the median PM_{10} levels ranged between 40 – 44 μg/m^3 across the sawmills. Sections A and B, which are inside the sawmill had the highest $PM_{2.5}$ concentrations (36 and 34 μg/m^3) and PM_{10} of 44 μg/m^3 respectively.

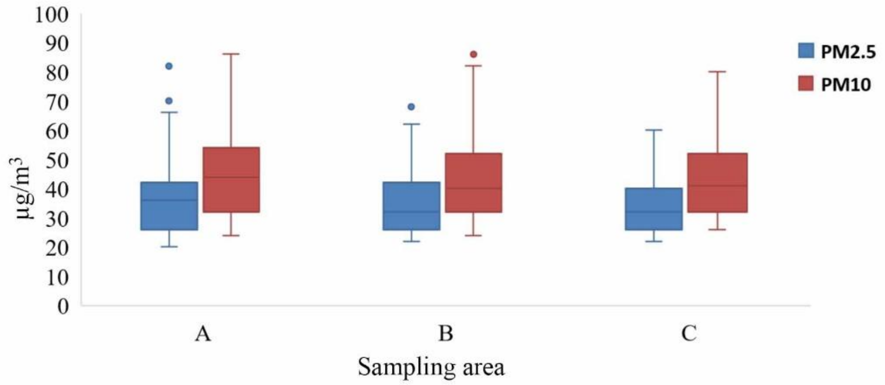

Figure 2. Concentrations of particulates at selected sawmills

Toxicity potential of particulates across the sawmills

The calculated toxicity potential of the level of particulates $PM_{2.5}$ and PM_{10} at the different sections across the sawmill's ranges from 2.13 to 2.40 and 0.88 to 0.97, respectively (Figure 3). The toxicity potentials of the particulates were higher in section A. The TP values of $PM_{2.5}$ were greater than one in all the sections, irrespective of the sampling locations. This indicates that the measured $PM_{2.5}$ concentrations consistently exceeded the recommended WHO guideline value, posing a potential health risk. Conversely, the TP values of PM_{10} were lower than one in all the sampling locations, indicating a higher TP value of $PM_{2.5}$ than PM_{10} at the sawmills.

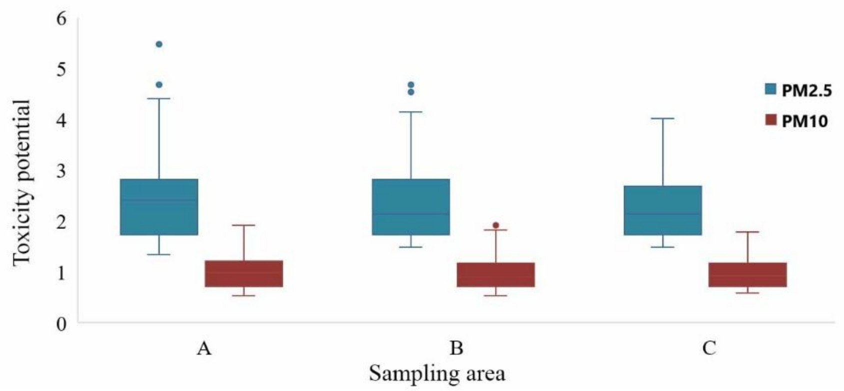

Figure 3. Toxicity potential of particulate matter at the sampling points

Cross-sectional survey

Sociodemographic, workplace, and behavioural characteristics

This study included 201 workers from various sections across ten selected sawmills. Of these, 200 participated, resulting in a 99.5% response rate. Only one worker declined participation and was excluded from the study. Table 1 presents the sociodemographic characteristics of the participants. The respondents between the age of 35 – 44 years were more compared to workers of other age ranges. Those belonging to the age range of 18 and 24 years were less than one percent of the respondents who participated in the survey. The respondents above 55 years were about 17%. Of the total respondents, more than eighty-six percent earn above an average of fifty-thousand naira monthly. Approximately forty-four percent of the respondents have spent 4 to 9 years in the sawmills. The majority (49%) of the respondents work in the sawmill manufacturing area while the participants who work in the polishing, loading, and cleaning sections represent 9.0, 17.0, and 5.5% respectively. The percentage proportion of respondents who spent above eight hours in the sawmills was higher (56.0%) compared to those who spent less than 8 hours daily. Of the 200 respondents 73.0% opined that sawmill waste is openly burnt. Most (67.5%) of the sawmills utilise gasoline or diesel generating sets for alternative sources of power due to the incessant electricity supply in the study area. Eighty-three percent do not use personal protective equipment during work time.

Prevalence of respiratory symptoms among sawmill workers

The prevalence of shortness of breath, wheezing, cough, chest pain and sore throat among sawmill workers were 31%, 26%, 29%, 26% and 23% respectively (Figure 4).

Table 1. Socio-demographic, workplace and behavioural characteristics of sawmill workers

Variables	Frequency, n	Percentage, %	Variables	Frequency, n	Percentage, %
Gender			**Sawmill work section**		
Male	182	91.0	Manufacturing area	97	48.5
Female	18	9.0	Polishing	18	9.0
Age			Loader	34	17.0
18 – 24years	1	0.5	Workshop cleaner	11	5.5
25 – 34 years	30	15.0	Others	40	20.0
35 – 44 years	83	41.5	**Exposure duration**		
45 – 54 years	53	26.5	< 8 hours	14	7.0
> 55 years	33	16.5	8 hours	74	37.0
Income/month			> 8 hours	112	56.0
N 10000	6	3.0	**Use of generator sets**		
N 20000	6	3.0	Yes	135	67.5
N 30000	15	7.5	No	65	32.5
> N 50000	173	86.5	**Open burning of sawmill waste**		
Sawmill work experience			Yes	146	73.0
< 4years	63	31.5	No	54	27.0
4 – 9 years	87	43.5	**Use of PPE**		70.6
10 – 14 years	35	17.5	Yes	33	16.5
15 – 20 years	15	7.5	No	167	83.5
Current smoking status					
Yes	44	22.0			
No	156	78.0			

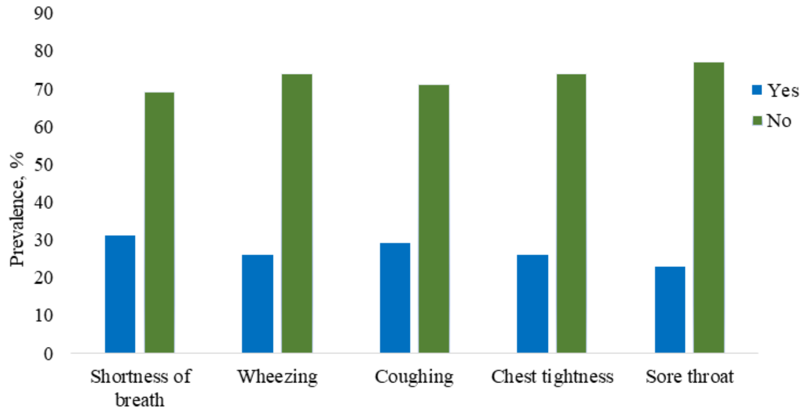

Figure 4. Prevalence of respiratory symptoms among sawmill workers

Factors associated with respiratory symptoms among sawmill workers

The result of the associations between the reported factors and respiratory symptoms among the sawmill workers, as obtained by the chi-square test of significance and the multivariate analysis, was summarized in Table 2 and Figures 5 to 9, respectively. Sawmill work experience, duration of exposure, use of the diesel-powered generator in the sawmill, open burning of sawmill waste, and use of PPE were significantly associated with some of the respiratory symptoms reported by the respondents. The number of years spent in sawmill work is significantly associated with reported sore throat among workers ($p = 0.034$) (Figure 5). Workers who had work experience for 15 – 20 years reported a higher percentage of cases (46.7%) of sore throats compared to those who had fewer years of work experience. The odds of having a sore throat were nearly six times higher (cOR = 5.96) for workers with 10 – 14 years of sawmill experience compared to those with less than 5 years of experience. This association was statistically significant (95% CI: 1.243 – 28.629) (Table 2).

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Table 2. Associations between reported risk factors and respiratory symptoms among sawmill workers using binary logistic regression without adjustments

Factors	Shortness of breath cOR (95%Cl)	Wheezing cOR (95%Cl)	Cough cOR (95%Cl)	Chest tightness cOR (95%Cl)	Sore throat cOR (95%Cl)
Work experience					
< 4 years	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
4 – 9 years	2.27(0.289 – 17.957)	1.28(0.290 – 5.661)	2.05(0.425 – 9.958)	1.30(0.314 – 5.387)	2.27(0.433 – 11.946)
10 – 14 years	4.40(0.574 – 33.015)	1.06(0.255 – 4.480)	2.77(0.580 – 13.312)	1.16(0.292 – 4.620)	**5.96(1.243 – 28.629)***
15 – 20 years		1.30(0.266 – 6.389)	**5.72(1.009 – 32.458)***	1.21(0.260 – 5.667)	4.72(0.939 – 23.737)
Daily exposure duration					
< 8 hours	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
8 hours	2.56(0.882 – 7.455)	2.04(0.868 – 4.833)	1.84(0.397 – 8.547)	1.99(0.479 – 8.325)	1.15(0.001 – 1.001)
> 8 hours	**3.51(1.737 – 7.130)***	4.52(0.509 – 40.095)	1.96(0.836 – 4.599)	2.18(0.970 – 4.931)	1.57(0.693 – 3.590)
Use of deisel-powered generator					
Yes	**16.44(5.660 – 47.752)***	0.33(0.151 – 0.751)	0.15(0.068 – 0.355)	1.17(0.525 – 2.620)	1.21(0.512 – 2.892)
No	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
Open burning of sawmill waste					
Yes	**20.68(3.537 – 120.96)***	2.86(0.942 – 8.718)	1.09(0.434 – 2.76)	0.58(0.263 – 1.284)	1.12(0.438 – 2.875)
No	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
Use of PPE					
Yes	0.02(0.001 – 0.209)	0.06(0.008 – 0.542)	0.13(0.033 – 0.564)	0.93(0.374 – 2.480)	0.42(0.131 – 1.406)
No	1(ref.)	1(ref.)	1(ref.)	1(ref.)	1(ref.)
$^{a}PM_{2.5}$	1.42(0.374-5.447)	1.60(0.608-4.192)	1.16(0.455-2.986)	0.43(0.172-1.114)	1.36(0.530-3.515)

Ref – reference group; OR – crude odd ratios; CI – confidence interval; * – significant at p > 0.05; a – $PM_{2.5}$ above 15 µg/m^3

Similarly, Workers with 15 – 20 years of experience in sawmills were 5.72 times more likely to report a cough compared to those with less experience. This finding was statistically significant, as evidenced by the 95% confidence interval of 1.009 to 32.458.

Figure 6 shows the association between the working hours and the occurrence of respiratory symptoms among the sawmill workers. The number of hours spent at work daily is sore throat (29.5%, p = 0.018). The multivariate logistic model showed that workers who spend more than 8 hours daily in sawmills had a twelve-fold increase in the odds of reporting shortness of breath (cOR = 12.72; CI = 1.074 – 150.663) compared to those who spend less than eight hours (Table 2). This association was statistically significant (p = 0.001).

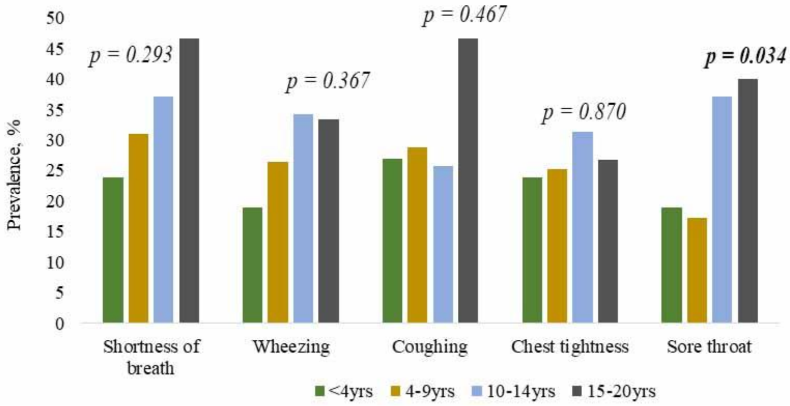

Figure 5. Association of respiratory effects with work experience

Study found that sawmills using diesel-powered generators had a significantly higher percentage of workers reporting shortness of breath (69.2%, p = 0.001), wheezing (47.7%, p = 0.001), and coughing (56.6%, p = 0.001) compared to those using electricity (Figure 7). The use of diesel generators was associated with a sixteen-fold increase in the odds of shortness of breath among exposed workers (cOR = 16.44; CI = 5.660 – 47.752) (Table 2).

The study found a strong association between the open burning of sawmill wastes and the development of respiratory symptoms among workers. The chi-square test revealed significantly higher percentages of workers reporting shortness of breath (41.1%, p = 0.001), wheezing (32.2%, p = 0.001), and cough (p = 0.019) in sawmills that practiced open burning compared to those using alternative waste management methods (Figure 8).

Furthermore, the odds of experiencing shortness of breath were twenty times higher (cOR = 20.68; CI = 3.537 – 120.96) among workers in sawmills who practiced open burning compared to those who did not (Table 2).

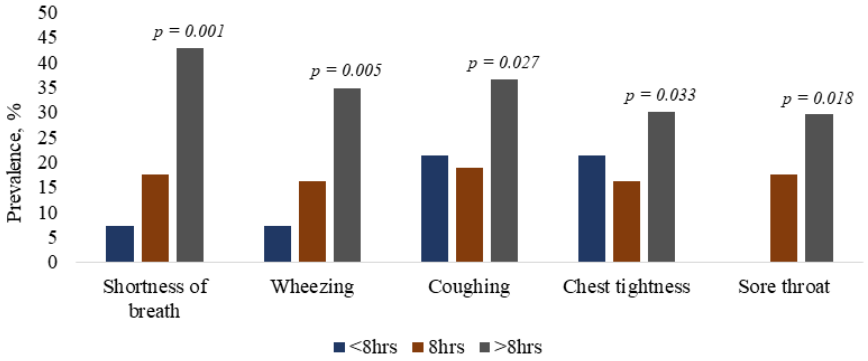

Figure 6. Association of respiratory effects with duration of exposure

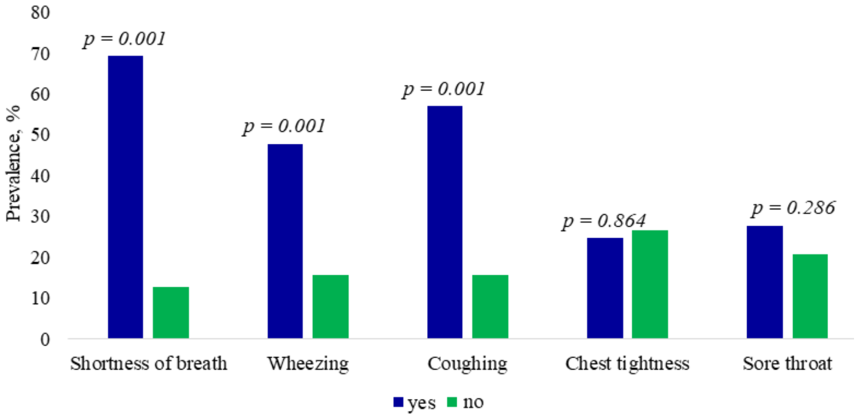

Figure 7. Association of respiratory effects with the use of a diesel generator

The findings of this study revealed that the percentage of workers who do not use personal protective equipment (PPE) were significantly associated with higher prevalence respiratory symptoms such as shortness of breath (36.5%, p = 0.001), wheezing (30.5%, p = 0.001) and cough (36.5%, p = 0.002) compared to those who use PPE (Figure 9).The study revealed that the levels of $PM_{2.5}$ above the recommended above the WHO recommended standards were associated with higher odds of reported respiratory symptoms among the workers; shortness of breath (cOR = 1.42, Cl; 0.374 – 5.447), wheezing (cOR = 1.60, Cl: 0.608 – 4.192), cough (cOR =1.16, Cl; 0.455 – 2.986) and sore throat (cOR = 1.36, Cl; 0.53 – 3.515). However, the association was not significant (p> 0.05).

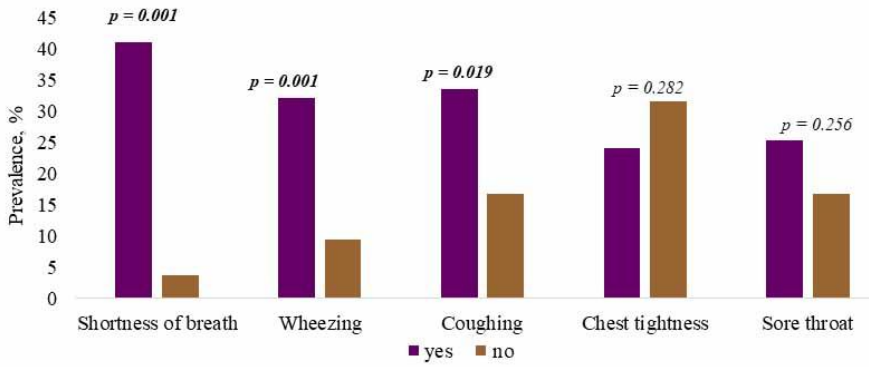

Figure 8. Association of respiratory effects with open burning of sawmill wastes

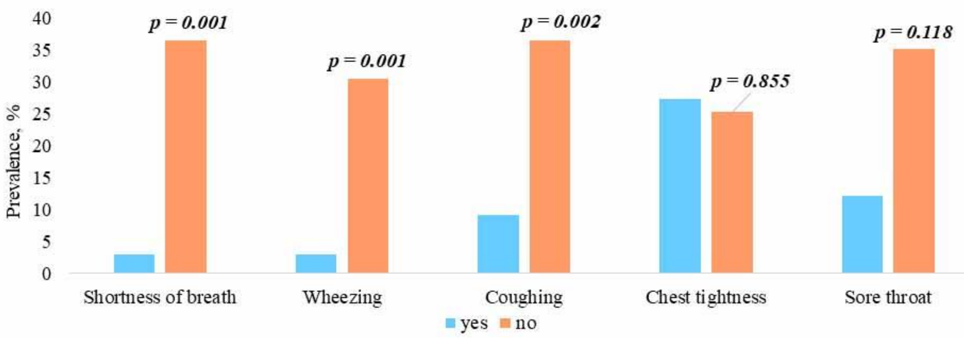

Figure 9. Association of respiratory effects with the use of PPE among sawmill workers

DISCUSSION

The concentrations of particulates in this study were higher at the sampling sections where wood manufacturing and processing involving woodwork activities such as planning of wood and wood storage are done. The various activities in this section could be responsible for the higher level of particulates due to the increased generation of wood dust compared to the other sections. This finding is similar to the reports of Olujimi et al. (2023) who recorded high levels of particulates at the location of the planning machine and plank-selling sections in sawmills around the Abeokuta metropolis which was linked to the proximity of the sections particularly the plank-selling area to a highway. Generally, the concentrations of particulates in this study are lower than those reported by Tobin et al. (2016); Neghab et al. (2018); Olalekan et al. (2018). This dissimilarity could be attributed to the season of sampling. The data collection in this study occurred during the wet season. Increased relative humidity during this period, due to high rainfall, can enhance the adsorption of water vapor onto particulate matter (Onuorah et al., 2019). This leads to the settling and dry deposition of particles, potentially resulting in lower concentrations of particulate matter in the air. Other factors for decreased concentrations of particulates in this study might be the reduction in the intensity of activities in the sawmills, the geographical location of the selected sawmills, the type of air monitoring equipment and the timing of sampling. The median concentrations of $PM_{2.5}$ in this study exceeded the recommended threshold of 25 µg/m^3 of the WHO, (2021). The level of PM_{10} obtained in this study was within the 45 µg/m^3 regulatory standard of WHO, (2021). The increased concentration of $PM_{2.5}$ recorded in the sampling areas across the sawmills is a concern for the workers. Exposure to elevated concentrations of fine particulate matter in the air is linked to adverse health outcomes, including asthma, chronic obstructive pulmonary disease, and other respiratory conditions (Lelieveld et al., 2015; Eghomwanre et al., 2022; Eghomwanre & Oguntoke, 2022a; Eghomwanre & Oguntoke, 2022b). Gu et al. (2018) also found that exposure to wood dust can adversely affect both the upper and lower respiratory tracts, resulting in a range of non-malignant respiratory diseases that can significantly impact the health of unprotected workers in the wood industry. The toxicity potentials of the particulates were higher in section A. This further explains the increased concentrations of particulate matter in the section due to the increased particle-generating activities such as wood cutting and plaining in sampling point A. A TP value exceeding one in an area signifies the presence of elevated levels of particulate matter, posing a potential health risk to nearby residents (Zaman et al., 2021). The values of TP of $PM_{2.5}$ obtained in this study revealed that the ambient air quality in the sawmill environment has exerted a high and severe toxicity potential on the sawmill workers. This could adversely affect the health of the exposed workers. It is therefore vital to educate the sawmill workers about the occupational risk associated with their job and engage in routine air quality monitoring in the area.

The absence of studies on the toxicity potential of particulates in sawmills limits the ability of the findings to be compared with related studies. However, studies on the toxicity potentials of PM conducted during the dry periods of the year in other microenvironments revealed higher TP values for $PM_{2.5}$ and PM_{10} (Zaman et al., 2021; Abulude et al., 2019; Oghenovo et al., 2019). This present study revealed that the sawmills in the study area are dominated by the male probably due to the strenuous nature and occupational risks involved. The physically demanding nature of tasks like sawing, sanding wood, and operating heavy machinery may deter female participation due to potential energy expenditure This finding is in line with the reports of Amaechi & Okoduwa, 2023; Agbana et al., 2016), and also in tandem with the reports in other regions where the rate of women working in the sawn wood subsector was only 6.8% in Turkey (Uraz et al., 2010). This study also revealed the young people between the age range of 18 and 24 years are not interested in the sawmill work as an occupation. This finding is in tandem with the reports of other authors outside Nigeria (Agbana et al., 2016; Sütçü & Semerci, 2019). On the contrary, Johnson & Umoren (2018) found that four out of ten respondents were under the age of 30 years in a study conducted in Uyo, Nigeria. The decreased percentage proportion of respondents under the age of 55 years in this study indicates that many sawmill workers have long-term exposure to occupational hazards due to spending a significant portion of their lives within the sawmill environment. The number of years of experience of sawmill workers in this study is similar to the findings of Johnson & Umoren (2018) who reported that about forty-six percent of respondents have spent ten years and above in their survey. Regular, frequent, and prolonged exposure to particular Matter in occupational settings can increase the risk of adverse health effects in these workers (Saejiw et al., 2009). An onsite assessment of the sawmill in the study area revealed that most of the sawmillers burn their waste openly on the sawmill premises. This finding is supported by (Olawuni & Okunola, 2014) who reported that sawmill operations often generate significant smoke pollution, primarily due to the burning of sawmill waste. This ranks as the second most critical environmental concern associated with sawmills. The study by Oguntoke et al (2013) found that burning wood waste as a waste management strategy in sawmills significantly deteriorates air quality. This polluted air is frequently inhaled by sawmill workers, posing a potential risk to their health. Most (67.5%) of the sawmills utilise gasoline or diesel generating sets for alternative sources of power due to the incessant electricity supply in the study area. The poor use of PPE among sawmill workers during work time in this study is similar to Johnson & Umoren (2018) who found that one-tenth of the workers in their study make use of PPE due to a lack of awareness of exposure to air pollution-related effects in the work environment. This study found a high prevalence of reported respiratory symptoms among the workers. This is affirmed by the quantitative monitoring of particulate matter in the sampling areas that showed that the concentrations of particulates especially those of aerodynamic diameter of ≤ 2.5µg/m^3 were obviously above the recommended air quality standards set by the World Health Organisation (WHO, 2021). The prevalence of respiratory symptoms such as wheezing, chest tightness and cough with phlegm among workers in this study is higher than the reports of the study done in Jos, Nigeria (Chirdan & Akosu, 2004). With cough (52.5%), sneezing (56.7%), wheezing (9.2%), shortness of breath (6.7%), chest tightness (13.3%) and a study in Benin City, Nigeria with wheeze (0.9%), chest tightness (2.0%), cough with phlegm (3.5%) and breathlessness (2.6%), but higher prevalence of cough (41.2%) and when compared to this study. This suggests that symptoms affecting the lower respiratory tract were more common than those primarily affecting the upper respiratory tract, such as cough and phlegm in this study. This trend could be due to the higher toxicity potential value for $PM_{2.5}$ which had earlier reported in this study compared to TP values of PM_{10}. $PM_{2.5}$, when inhaled can penetrate the lungs without being filtered by the nose hair and irritate the lower part of the respiratory tract causing respiratory symptoms such as wheezing, and chest tightness (Chandra & Rosdiana, 2022). The finding in this study is also higher than reports of the study conducted in Northeast Thailand by Soongkhang et al. (2015) with Cough (18.8%), Phlegm (15.7%), Wheezing (5.9%), and Breathlessness (7.8%).

The increased prevalence of some of the respiratory symptoms among the respondents could be due to the high rate of non-compliance with the use of PPE (83.5%) occasioned by the poor awareness of the risks of exposure to air pollutants in the sawmill environment. However, the prevalence of respiratory symptoms found in this study is contrary to the findings of a study conducted in southwest Ethiopia by Fentie et al. (2019), which reported higher rates of cough (41.4%), phlegm (34.3%), wheezing (12.4%), chest pain (32.9%), and breathlessness (21.5%). The statistically significant association between number of years of experience in sawmills and higher percentage of reported cases of respiratory symptoms among workers This association might be attributed to the increased accumulation of dust within the respiratory system over prolonged periods of workplace exposure (Ugheoke, et al., 2009; Chaiear et al., 2018; Awoke et al., 2021). Previous studies have also reported a significant association between the presence of at least one respiratory symptom and the number of years of work experience among woodworkers. Prolonged exposure to wood dust has been found to have a detrimental effect on lung function. The severity of respiratory problems is largely determined by the duration of exposure, as supported by Okwari et al. (2005); Ugheoke et al. (2009); Mahmood et al. (2015) specifically observed a correlation between decreased lung function and the length of time spent working in the sawmill industry among workers in Sulaimani city, Iraq. The study also showed that workers who spend more than 8 hours daily significantly increased the cases of shortness of breath among sawmill workers. Sawmill workers often work long hours to increase production, as reported by Mensa-Yawson et al. (2023). This is a concern as Rathipe & Raphela (2023) found that working more than 9 hours without hearing protection increases the risk of respiratory health problems. The use of diesel generators was also significantly associated with increased in the odds of shortness of breath among exposed workers. Due to Nigeria's unreliable electricity supply and the growing number of sawmills, diesel generators have become a common alternative power source. However, this has led to increased emissions of pollutants, including particulate matter, which can negatively impact human health (Nnaji & Chiedozie, 2014). The study found a strong association between the open burning of sawmill wastes among workers and the development of respiratory symptoms compared to those using alternative waste management methods.

Open burning of wood waste releases harmful pollutants into the environment, including noxious gases and particulates (Mohagheghzadeh et al., 2006). The study found that 73% of sawmill workers relied on open-dump burning to dispose of waste, significantly polluting the air quality within the workplace. This aligns with previous research by (Oguntoke et al., 2013; Olujimi et al., 2023), which found a strong link between the open burning of waste in sawmills and the presence of respiratory symptoms among woodworkers. The findings of this study revealed that the non-usage of personal protective equipment (PPE) among sawmill workers was significantly associated with higher prevalence respiratory symptoms compared to those who use PPE. This finding aligns with the reports of previous studies which found a significant association between the use of PPE and exposure to occupational health hazards among sawmill workers (Osagbemi et al., 2010; Adeoye et al., 2014; Onowhakpor et al., 2017; Elechi & Warmate, 2019). The low use of PPE might be due to the delayed manifestation of health effects from hazards like air pollutants, leading workers to underestimate the need for protection. However, the use of PPE was not a significant determining factor for occurrence of respiratory symptoms among the respondents. Similarly, Tungu et al. (2015); Asfaw, et al. (2018) found no difference in occupational respiratory symptoms between those who used personal protective equipment (PPE) and those who did not. This finding was attributed to the quality of the PPE used and the presence of other measures to ensure compliance with PPE use. This study has some limitations which include the challenge of workers recall effect, the workers with severe health problems might have already left their jobs. The study did not include lung function tests, which could have provided more precise information about respiratory health. The qualitative data relies entirely on participant self-reports, which can be affected by recall bias and other subjective factors. Also, the study did not take into account the effect of possible confounding variables on the association between the reported risk factors and respiratory outcomes. The study also needs to continuously monitor exposure levels over the entire work shift to accurately assess the link between particulate matter and respiratory symptoms.

CONCLUSION

This study revealed that sawmill workers are exposed to levels of fine particulate matter ($PM_{2.5}$) that exceed the World Health Organization's safety limits. The exposure levels of $PM_{2.5}$ had high toxicity potentials and posed significant health risks to workers in various sawmill sections. The study found a high prevalence of respiratory health issues among workers. The key factors contributing to these problems include: longer employment, prolonged daily exposure, open burning of sawmill wastes and the use of diesel-powered generators: These generators release harmful emissions which increase the likelihood of respiratory symptoms. A significant portion of workers do not use personal protective equipment (PPE). This is a major concern and necessitates immediate action. To improve worker safety and health, the following measures are crucial; creation of awareness among workers about the health risks associated with air pollution in their workplace. Employers should ensure the provision of appropriate PPE, such as face masks, and ensure their proper and consistent use by all workers. These measures would assist in reducing workers' exposure to air pollution and mitigate the associated health risks.

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Author's statements

Contributions

Conceptualization: A.F.E.; Data curation: A.F.E., U.B.O.; Formal analysis: A.E.F.; Investigation: A.F.E., U.B.O.; Methodology: A.F.E.; Writing – original draft: U.B.O.; Writing – review & editing: A.F.E., U.B.O.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

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Data availability statement

Data used for the study would be made available on request.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

The study was conducted in full compliance with ethical principles. Before any data were collected, the research team obtained written informed consent from the authorities of the sawmiller union, owners of the sawmills and participants. The consent form clearly outlined the study's purpose, procedures, potential risks, and benefits and explicitly stated that participation was voluntary and that households could withdraw at any time without penalty.

Additional information

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