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ASSESSMENT OF THE EFFECTS OF SAWMILLS ON AIR AND NOISE QUALITY IN PROXIMITY TO RESIDENTIAL AREAS IN BENIN CITY, NIGERIA

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Abstract
This study assessed the effects of sawmill activities on air and noise quality in selected locations within Benin City, Southern Nigeria. Air quality parameters such as temperature, relative humidity, formaldehyde (HCHO), total volatile organic compounds (TVOCs), particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), carbon monoxide (CO), and carbon dioxide (CO_2), were measured at three sawmill locations and a control site using standard methods. Noise levels were assessed to determine the extent of noise pollution in the study area. Additionally, 200 structured questionnaires were administered to residents near sawmill areas to evaluate their perception of air and noise pollution and associated health impacts. The results revealed that air pollutant concentrations were consistently higher in sawmill locations compared to the control site. Formaldehyde concentrations ranged from 0.03–0.09 mg/m³, TVOC levels varied from 0.16–0.3 mg/m³. Particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}) concentrations ranged from 21-41 µg/m³, 43-71 µg/m³ and 73-113 µg/m³, carbon monoxide ranged from 0-2 ppm, while carbon dioxide levels fluctuated between 381–460 ppm. Noise levels in sawmill areas were significantly above WHO and FMEnv guidelines, ranging from 72.8–99.3 dB. Demographic analysis indicated that a large proportion of respondents (84%) were within the economically active age group (18–44 years) and 50% of them had lived in the area for over six years. A significant percentage of respondents (41%) agreed that sawmill activities contribute to poor air quality, 51% agreed that children and elderly are vulnerable to sawmill operations, 52% agreed to difficulty in concentration due to excessive noise from sawmill operations, and 50% agreed that presence of sawmills around residential areas should not be allowed. The study draws the conclusion that sawmill activities contribute to air and noise pollution in residential areas, with potential health risks for nearby residents. It recommends stricter environmental regulations, proper zoning of sawmill operations and the implementation of emission control measures to mitigate the adverse effects of sawmill activities on public health and environmental quality.

Keywords: *Sawmill operations, Air pollution, Noise pollution, Total volatile organic compounds (TVOCs), Residential areas*

Introduction

The timber industry is a crucial part of Nigeria's economy, providing essential raw materials for construction, furniture making, and paper production (Ayodele and Adetayo, 2024). The growth of sawmills has been pivotal in meeting the increasing demand for processed wood, contributing significantly to job creation and economic development (Olawuni, and Okunola, 2014). However, sawmill operations are often associated with severe environmental challenges, particularly air and noise pollution (Aletan, and Garba, 2020). Sawmills generate large quantities of airborne particulate matter (PM), including fine dust particles and chemical emissions, which can degrade air quality in surrounding areas (EPA South Australia, 2001).

The operation of sawmills in close proximity to residential areas presents significant environmental, public health, and social challenges (Akinnubi, 2015; Emmanuel *et al.,* 2020). Airborne pollutants released from sawmill activities, such as particulate matter ($PM_{2.5}$ and PM_{10}), can penetrate deep into the respiratory system, leading to various health problems, including asthma, bronchitis, and chronic obstructive pulmonary disease (COPD) (Raimi *et al*., 2020; Kyung, and Jeong, 2020). Fine particulate matter, in particular, has been identified as a leading cause of respiratory illnesses and premature mortality worldwide (WHO, 2021). Noise pollution generated by sawmill machinery exacerbates these challenges, contributing to stress, hearing impairment, and a reduction in the overall quality of life for nearby residents (Omubo-Pepple *et al.,* 2010). Communities living near sawmills report higher complaints of noise disturbance compared to those in areas with less industrial activity (Ayodele and Adetayo 2024). Additionally, the improper disposal of sawmill waste, including sawdust and wood shavings, contributes to environmental degradation and exacerbates air pollution (Fagbenro and Abdulfatai, 2018). The problem is compounded by the lack of comprehensive air quality and noise monitoring in Nigeria, particularly in regions with significant industrial activity (Akanji *et al.,* 2024).

In addition, noise generated by machinery during sawing operations contributes to noise pollution, which can affect the quality of life and health of nearby residents (Aletan, and Garba, 2020). In many urban and semi-urban areas of Nigeria, sawmills are located close to residential zones due to poor urban planning and rapid industrialization (Ebekozien *et al.,* 2021). This proximity poses significant health risks to nearby residents, who are exposed to pollutants such as wood dust, volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx) (Ayodele and Adetayo 2024). Continuous exposure to these pollutants has been linked to respiratory diseases, cardiovascular problems, and other serious health conditions, especially in vulnerable populations such as children and the elderly (Olalekan *et al.,* 2020). Furthermore, noise pollution from sawmill operations has been shown to cause stress, hearing loss, and sleep disturbances among residents living in close proximity (Omubo-Pepple *et al.,* 2010). Globally, pollution has become a pressing environmental and public health concern, particularly in developing countries where environmental regulations are not strictly enforced (Omer, 2024). Despite the known risks, many sawmills in Nigeria continue to operate without adequate environmental controls, further compounding the problem of air and noise pollution in residential areas (Adeoye *et al.,* 2014; Raimi *et al.,* 2020). This study aims to address this gap by investigating air and noise quality in areas close to sawmills and providing evidence-based recommendations for mitigating the negative impacts on local residents.

Study Area

This study, conducted in Benin City, the capital of Edo State, southern Nigeria (latitude 6° 20′ 5.95″ N, longitude 5° 36′ 13.49″ E) (Dimuna and Olotuah, 2020), a major urban center with a large population and proximity to both forested and residential areas, investigated the air quality impacts of the active sawmill industry located near residential communities. Three sawmill locations within Benin City (Location 1: N 06° 21.581′ E 005° 37.471′, Location 2: N 06° 22.690′ E 005° 36.601′, Location 3: N 06° 27.395′ E 005° 35.268′) were selected based on their proximity to residential zones and operational intensity to analyze sawmill emission effects on air quality. These sites, chosen to represent varying distances and directions relative to residential areas, facilitated a comprehensive analysis of air pollutant dispersion. A control location (N 06° 23.889′ E 005° 37.858′) with minimal industrial activity, far from major sawmill operations, was included to establish baseline air quality levels for comparison, helping to isolate sawmill-related pollution (See figure 1 below).

Benin City is situated within the humid tropical rainforest zone, experiences significant rainfall (1,500-2,500 mm annually) and consistent temperatures (25-28°C average monthly) (Rawlings and Seghosime, 2022). The climate features a rainy season (April-October) with a slight dip in August, and a dry season (November-March) often influenced by the cold, dusty harmattan winds from the Sahara in December and January (Atedhor *et al.,* 2011).

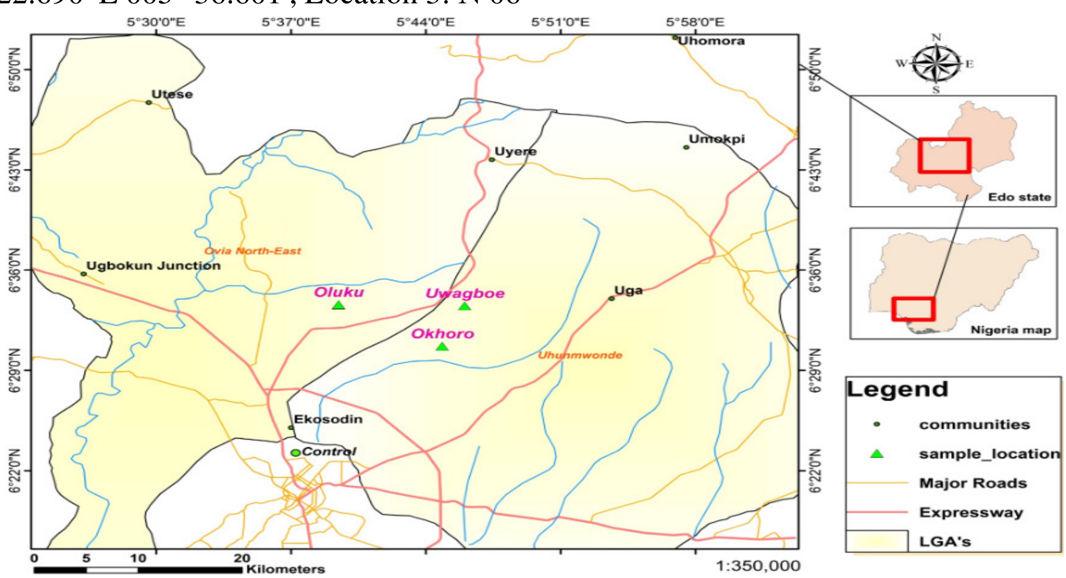

Fig. 1: Map of the study area showing sampling locations and the control area

Recent climate change has led to irregular rainfall, with a double peak in July and September (Rawlings and Seghosime, 2022). Wind patterns are generally mild (1.5-3.5 m/s) with seasonal shifts in direction (Osatohanmwen *et al.,* 2017). The study area, with an estimated population of 203,500 (Ojo and Ekun, 2024), has grown due to various institutions, businesses, and amenities, including sawmills, and is characterized by mixed-income households engaged in local trading, craftsmanship, and small-scale businesses. Agriculture, involving the cultivation of crops like cassava, yam, and maize, and animal husbandry, is also a significant economic activity (Unufe and Ikponmwosa, 2021). Strong social interactions, community activities, and a diverse linguistic (Bini being the majority language) and religious landscape (Christianity, Islam, and traditional African worship) contribute to the area's vibrant social fabric (Amaechi and Okoduwa, 2023). Trading and small-scale businesses are also crucial to the local economy (Ojo and Ekun, 2024).

Research Design

This study utilized a cross-sectional descriptive and quantitative survey method to evaluate the impact of sawmill operations on air and noise pollution in residential areas of Benin City, Edo State. The cross-sectional design facilitated data collection at a single time point to assess the relationship between exposure to sawmill pollutants and resident health outcomes. Primary data was gathered through direct field measurements of air and noise pollution and structured closed-ended questionnaires administered to residents living near sawmills. Relevant literature and regulatory guidelines served as secondary data sources. The study population comprised residents aged 18 and above residing near sawmills who had knowledge of sawmill operations and their environmental effects. Willing residents in the study area were included, while non-residents and unwilling participants were excluded. A simple random sampling technique was used for questionnaire respondents to ensure equal participation opportunities. For environmental measurements, purposive sampling was employed to select locations anticipated to have the highest air and noise pollution levels, allowing for a thorough assessment of pollution dispersion. The questionnaire distribution across the three study locations was balanced (66, 66, and 68).

Data Collection

Data for this study was collected using a well-structured and easy-to-understand closed-ended questionnaire. This instrument gathered socio-demographic information (age, marital status, education, occupation) and residents' perceptions of environmental and health risks from nearby sawmills using a Likert scale ("strongly disagree" to "strongly agree"). Two hundred questionnaires were randomly distributed to residents in the three selected sawmill locations, and all were completed, resulting in a 100% completion rate. Air quality parameters, specifically carbon monoxide, volatile organic compounds, and particulate matter, were measured near the three sawmill sites using portable air samplers. These pollutants were chosen due to their common presence in air pollution studies and their known health effects in industrial areas. Temperature and humidity were also recorded to assess their influence on pollutant concentrations. Furthermore, noise levels were measured in decibels (dB) using a sound level meter to evaluate the impact of sawmill operations on the community's noise environment, which can contribute to stress and other health problems (Rathipe, and Raphela, 2022).

Determination of Air Quality

Air quality measurements were taken daily between 8:00 AM – 11:00 AM and 5:00 PM – 7:00 PM at each sampling site for three days and the mean values were computed. These results were compared against the concentration limits set by the World Health Organization (WHO) and the Federal Ministry of Environment (FMEnv). A portable nine-in-one multifunctional air quality monitor equipped with a hygrometer and thermometer was used to determine relative humidity and temperature, respectively.

Table 1: AQI level ratings

AQI	Health concern level	Air pollution level
0-50	Good Level	Level 1
51-100	Moderate	Level 2
101-150	Unhealthy for sensitive groups	Level 3
151-200	Unhealthy	Level 4
201-300	Very Unhealthy	Level 5
300 and above	Hazardous	Level 6

Noise Level Measurement

Noise levels were measured using a digital sound level meter (SLM) at each study location. Readings were taken at different periods of the day (morning and evening) for three days to account for variations in noise emissions. Measurements were recorded, and the mean noise level was calculated. The results were compared against the WHO and FMEnv recommended limits, which specify:

Daytime (07:00 AM – 10:00 PM): ≤55 dB (WHO) and ≤90 dB (FMEnv)

Nighttime (10:00 PM – 07:00 AM): ≤45 dB (WHO)

Parameters of Interest

This study investigated the impact of sawmill operations on nearby residents by examining meteorological conditions, air quality, and noise levels, all of which significantly affect human health and well-being (Raimi *et al*., 2020). Ambient temperature was monitored for its influence on air quality and pollutant dispersion, as well as its potential health impacts on vulnerable populations (Kalisa *et al.,* 2018). Relative humidity levels were assessed for their effects on the concentration and behavior of airborne pollutants, as humidity can exacerbate or irritate the respiratory system (Guarnieri *et al.,* 2023). Key air quality parameters measured included carbon monoxide (CO), a product of incomplete combustion known to cause respiratory issues (Adhikari and Ozarska, 2018); carbon dioxide (CO_2), an indicator of poor ventilation that can lead to various symptoms (WHO, 2021); volatile organic compounds (VOCs), emitted from sawmills and other sources with potential respiratory and other health effects (Pat-Mbano and Nkwocha, 2012); and particulate matter (PM_{10} and $PM_{2.5}$), fine inhalable particles linked to respiratory and cardiovascular problems (UNEP, 2022). Finally, noise intensity from the sawmills was quantified using sound pressure level (SPL) measured in decibels (dB) to assess the noise pollution impact on the community (ISO 1996-1, 2016).

Data Analysis

Data analysis was performed using Microsoft Excel 2013 and SPSS version 16, following data cleaning for accuracy. Descriptive statistics (frequency counts and percentages) summarized the questionnaire data. The Chi-Square (X^2) test was used to examine relationships between variables across the study locations at a 5% significance level ($p = 0.05$). Results were presented in tables and figures to clearly illustrate demographic distributions, air quality perceptions, and noise pollution impacts.

Results

Table 2 – 4 presents the air meteorological data and pollutant parameters for the study location and the control site during both morning and evening periods. In location 1, the morning temperatures ranged from 29-32°C, increasing to 32-34°C in the evening. Relative humidity decreased from 62-64% in the morning to 57-60% in the evening. Formaldehyde (HCHO) concentrations rose from 0.03-0.04 mg/m³ in the morning to 0.05-0.08 mg/m³ in the evening. Total volatile organic compounds (TVOCs) also increased from 0.18-0.22 mg/m³ in the morning to 0.26-0.30 mg/m³ in the evening. Particulate matter ($PM_{1.0}$: 17-25 µg/m³, $PM_{2.5}$: 41-49 µg/m³, PM_{10}: 71-79 µg/m³) in the morning was lower than evening levels ($PM_{1.0}$: 31-35 µg/m³, $PM_{2.5}$: 59-65 µg/m³, PM_{10}: 91-99 µg/m³). Carbon monoxide (CO) remained at 0-1 ppm in both periods. Carbon dioxide (CO_2) levels increased from 389-407 ppm in the morning to 432-450 ppm in the evening. Consequently, the air quality index (AQI) was higher in the evening (104-115) than in the morning (88-91).

Similar trends were observed at Location 2. Morning temperatures (29-34°C) were comparable to evening (32-33°C), while relative humidity decreased from 62-65% to 58-61%. HCHO concentrations increased from 0.03-0.04 mg/m³ (morning) to 0.05-0.07 mg/m³ (evening), and TVOCs rose from 0.17-0.21 mg/m³ (morning) to 0.22-0.27 mg/m³ (evening). Particulate matter ($PM_{1.0}$: 19-27 µg/m³, $PM_{2.5}$: 39-47 µg/m³, PM_{10}: 69-77 µg/m³) was again lower in the morning than in the evening ($PM_{1.0}$: 23-39 µg/m³, $PM_{2.5}$: 51-61 µg/m³, PM_{10}: 87-95 µg/m³). CO remained at 0-1 ppm throughout. CO_2 levels increased from 381-405 ppm (morning) to 419-440 ppm (evening), and the AQI was higher in the evening (96-108) than in the morning (85-90).

Location 3 followed the same pattern for most parameters. Morning temperatures (28-33°C) were lower than evening (34-36°C), while relative humidity decreased from 62-66% to 58-60%. HCHO concentrations increased from 0.03-0.05 mg/m³ (morning) to 0.07-0.09 mg/m³ (evening), and TVOCs rose from 0.16-0.21 mg/m³ (morning) to 0.18-0.28 mg/m³ (evening). Particulate matter ($PM_{1.0}$: 21-27 µg/m³, $PM_{2.5}$: 43-49 µg/m³, PM_{10}: 73-83 µg/m³) was lower in the morning compared to the evening ($PM_{1.0}$: 33-41 µg/m³, $PM_{2.5}$: 61-71 µg/m³, PM_{10}: 95-113 µg/m³). CO was 0 ppm in the morning but increased to 1-2 ppm in the evening. CO_2 levels rose from 399-405 ppm (morning) to 439-460 ppm (evening). In contrast, the control site consistently exhibited lower pollutant concentrations and more stable meteorological conditions. Temperatures were lower and more stable (morning: 24-27°C, evening:

26-28°C), while relative humidity was higher and more stable (morning: 75-77%, evening: 71-74%). HCHO (morning: 0-0.03 mg/m³, evening: 0.02-0.08 mg/m³), TVOCs (morning: 0.01-0.04 mg/m³, evening: 0.01-0.11 mg/m³), and particulate matter ($PM_{1.0}$: morning 3-5 µg/m³, evening 5-7 µg/m³; $PM_{2.5}$: morning 7-9 µg/m³, evening 10-12 µg/m³; PM_{10}: morning 14-18 µg/m³, evening 17-20 µg/m³) were significantly lower than at the sawmill locations. CO levels were also lower (morning: 0-0 ppm, evening: 0-1 ppm), and CO_2 concentrations were substantially lower and more stable (morning: 391-395 ppm, evening: 393-412 ppm).

Overall, the control site demonstrated significantly better air quality compared to all three sawmill locations, highlighting the impact of sawmill emissions on air pollution in the study area. Across the three sawmill locations in Benin City, air meteorological data and pollutant parameters consistently showed higher values in the evening compared to the morning, with the exception of relative humidity, which was generally higher in the morning.

Table 2: Air Meteorological Data and Air Pollutant Parameters in Location 1

	Location 1		**Control**			
	Morning	**Evening**	**Morning**	**Evening**		
Parameter	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**WHO Guidelines**	**FMEnv Guidelines**
Temperature (0C)	30.667±1.528	33±1.00	25.667±1.528	27±1.00	No specific guideline	No specific standard
	29-32	32-34	24-27	26-28		
Relative Humidity (%)	63.000±1.00	58.667±1.528	76.000±1.00	72.333±1.528		
	62-64	57-60	75-77	71-74	No specific guideline	No specific standard
Formaldehyde HCHO (µg/m3)	0.037±0.006	0.067±0.015	0.013±0.015	0.057±0.032		
	0.03-0.04	0.05-0.08	0-0.03	0.02-0.08	30-minute Mean: ≤0.1 mg/m^3	≤0.03 mg/m^3
Total Volatile Organic Compound	0.200±0.020	0.283±0.021	0.027±0.015	0.047±0.055	No specific guideline	No specific standard
(TVOC) (µg/m3)	0.18-0.22	0.26-0.30	0.01-0.04	0.01-0.11		
Particulate Matter	20.333±4.163	33.000±2.00	4.000±1.00	6.000±1.000	-	-
PM1.0 (µg/m3)	17-25	31-35	3-5	5-7	-	-
Particulate Matter	45.667±4.163	62.333±3.055	8.000±1.00	11.000±1.000	Annual Mean: ≤5 µg/m	Annual Mean: ≤25 µg/m
PM2.5 (µg/m3)	41-49	59-65	7-9	10-12	24-hour Mean: ≤15 $\mu g/m^3$	24-hour Mean: ≤35 $\mu g/m^3$
Particulate Matter	75.667±4.163	95.667±4.163	15.667±2.082	18.667±1.528	Annual Mean: ≤15 µg/m	Annual Mean: ≤40 µg/m
PM10 (µg/m3)	71-79	91-99	14-18	17.20	24-hour Mean: ≤45 $\mu g/m^3$	24-hour Mean: ≤70 $\mu g/m^3$
Carbon Monoxide	0.667±0.577	0.667±0.577	0.000±0.00	0.333±0.577		
CO (ppm)	0-1	0-1	0-0	0-1	24-hour Mean: ≤4 mg/m^3	8-hour Mean: ≤10 ppm
Carbon dioxide	399.333±9.292	443.000±9.644	393.000±2.00	401.000±9.849		
CO_2 (ppm)	389-407	432-450	391-395	393-412	Mean: ≤5,000 ppm	≤800 ppm
Air Quality Index	89.333±1.528	110.333±5.686	22.333±2.517	28.333±1.528	Calculated based on pollutant	Similar to international
AQI	88-91	104-115	20-25	27-30	concentration	practices
Air Quality Rating	Moderate	Unhealthy for sensitive groups	Good	Good		

Table 3: Air Meteorological Data and Air Pollutant Parameters in Location 2

	Location 2		**Control**			
	Morning	**Evening**	**Morning**	**Evening**		
Parameter	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**WHO Guidelines**	**FMEnv Guidelines**
Temperature (0C)	31.333±2.517	32.667±0.577	25.667±1.528	27±1.00	No specific guideline	No specific standard
	29-34	32-33	24-27	26-28		
Relative Humidity (%)	63.333±1.528	59.667±1.528	76.000±1.00	72.333±1.528		
	62-65	58-61	75-77	71-74	No specific guideline	No specific standard
Formaldehyde HCHO (µg/m3)	0.033±0.006	0.060±0.010	0.013±0.015	0.057±0.032	30-minute Mean: ≤0.1	
	0.03-0.04	0.05-0.07	0-0.03	0.02-0.08	mg/m^3	≤0.03 mg/m^3
Total Volatile Organic Compound	0.187±0.021	0.247±0.025	0.027±0.015	0.047±0.055	No specific guideline	No specific standard
(TVOC) (µg/m3)	0.17-0.21	0.22-0.27	0.01-0.04	0.01-0.11		
Particulate Matter	22.333±4.163	32.333±8.327	4.000±1.00	6.000±1.000	-	-
PM1.0 (µg/m3)	19-27	23-39	3-5	5-7	-	-
Particulate Matter	43.667±4.163	56.333±5.033	8.000±1.00	11.000±1.000	Annual Mean: ≤5 µg/m	Annual Mean: ≤25 µg/m
PM2.5 (µg/m3)	39-47	51-61	7-9	10-12	24-hour Mean: ≤15 µg/m^3	24-hour Mean: ≤35 µg/m^3
Particulate Matter	73.000±4.00	91.000±4.000	15.667±2.082	18.667±1.528	Annual Mean: ≤15 µg/m	Annual Mean: ≤40 µg/m
PM10 (µg/m3)	69-77	87-95	14-18	17.20	24-hour Mean: ≤45 µg/m^3	24-hour Mean: ≤70 µg/m^3
Carbon Monoxide	0.667±0.577	0.667±0.577	0.000±0.00	0.333±0.577		
CO (ppm)	0-1	0-1	0-0	0-1	24-hour Mean: ≤4 mg/m^3	8-hour Mean: ≤10 ppm
Carbon dioxide	395.000±12.490	431.333±10.970	393.000±2.00	401.000±9.849		
CO_2 (ppm)	381-405	419-440	391-395	393-412	Mean: ≤5,000 ppm	≤800 ppm
Air Quality Index	87.333±2.517	102.000±6.000	22.333±2.517	28.333±1.528	Calculated based on	Similar to international
AQI	85-90	96-108	20-25	27-30	pollutant concentration	practices
Air Quality Rating	Moderate	Unhealthy for sensitive groups	Good	Good		

Table 4: Air Meteorological Data and Air Pollutant Parameters in Location 3

	Location 3		Control			
	Morning	**Evening**	**Morning**	**Evening**		
Parameter	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**±SD (Min-Max)**	**WHO Guidelines**	**FMEnv Guidelines**
Temperature (0C)	30.333±2.517 28-33	35±1.000 34-36	25.667±1.528 24-27	27±1.00 26-28	No specific guideline	No specific standard
Relative Humidity (%)	63.667±2.082 62-66	59±1.000 58-60	76.000±1.00 75-77	72.333±1.528 71-74	No specific guideline	No specific standard
Formaldehyde HCHO (µg/m3)	0.040±0.010 0.03-0.05	0.08±0.010 0.07-0.09	0.013±0.015 0-0.03	0.057±0.032 0.02-0.08	30-minute Mean: ≤0.1 mg/m^3	≤0.03 mg/m^3
Total Volatile Organic Compound (TVOC) (µg/m3)	0.187±0.025 0.16-0.21	0.233±0.050 0.18-0.28	0.027±0.015 0.01-0.04	0.047±0.055 0.01-0.11	No specific guideline	No specific standard
Particulate Matter PM1.0 (µg/m3)	23.667±3.055 21-27	37.000±4.000 33-41	4.000±1.00 3-5	6.000±1.000 5-7	- -	- -
Particulate Matter PM2.5 (µg/m3)	45.667±3.055 43-49	67.000±5.292 61-71	8.000±1.00 7-9	11.000±1.000 10-12	Annual Mean: ≤5 µg/m 24-hour Mean: ≤15 µg/m^3	Annual Mean: ≤25 µg/m 24-hour Mean: ≤35 µg/m^3
Particulate Matter PM10 (µg/m3)	77.000±5.292 73-83	104.333±9.018 95-113	15.667±2.082 14-18	18.667±1.528 17.20	Annual Mean: ≤15 µg/m 24-hour Mean: ≤45 µg/m^3	Annual Mean: ≤40 µg/m 24-hour Mean: ≤70 µg/m^3
Carbon Monoxide CO (ppm)	0.000±0.000 0-0	1.333±0.577 1-2	0.000±0.00 0-0	0.333±0.577 0-1	24-hour Mean: ≤4 mg/m^3	8-hour Mean: ≤10 ppm
Carbon dioxide CO_2 (ppm)	402.000±3.00 399-405	452.000±11.358 439-460	393.000±2.00 391-395	401.000±9.849 393-412	Mean: ≤5,000 ppm	≤800 ppm
Air Quality Index AQI	90.000±2.000 88-92	120.000±11.136 108-130	22.333±2.517 20-25	28.333±1.528 27-30	Calculated based on pollutant concentration	Similar to international practices
Air Quality Rating	Moderate	Unhealthy for sensitive groups	Good	Good		

Carbon dioxide (CO_2) concentrations during the study period across the study locations and control site is shown in figure 2. In Locations 1, 2, and 3, CO_2 levels consistently showed higher values in the evenings (ranging from 432-460 ppm) compared to the mornings (ranging from 381-399 ppm), indicating an accumulation of emissions likely due to increased daily activity. Location 3 recorded the highest CO_2 values among the sawmill sites. Conversely, the control site exhibited significantly lower and more stable CO_2 levels, ranging from 391 ppm to 412 ppm across the three days, highlighting the impact of sawmill operations on carbon dioxide accumulation in the environment.

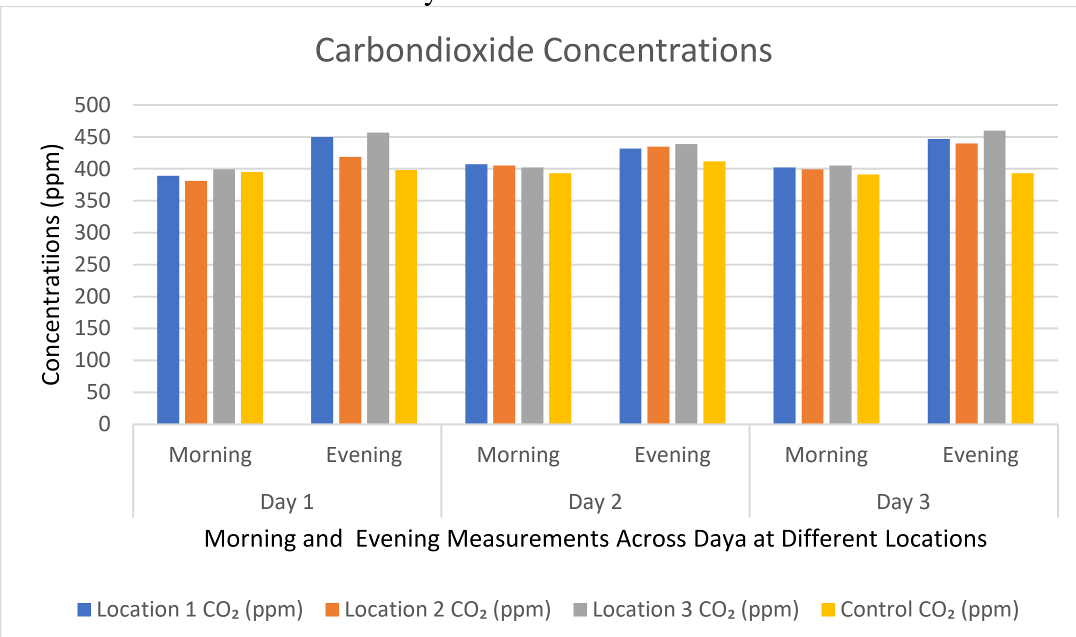

Fig. 2: Carbon Dioxide (CO_2) Concentrations Across All Locations

Noise Levels in the Study Locations

Table 5 presents the noise levels recorded across the study locations during both morning and evening periods. Noise levels were assessed across study locations during morning and evening periods (figure 3) and over three consecutive days. Significant variations in noise levels were observed, with areas near active sawmill operations consistently exhibiting higher decibel readings compared to the control site. Specifically, Location 1 showed morning noise levels ranging from 83.80-94.30 dB and evening levels from 79.40-97.60 dB, with the highest recorded level occurring in the evening. Location 2 presented morning levels between 76.50-91.70 dB and notably higher evening levels of 93.90-98.10 dB, where the peak noise was also recorded. In contrast, Location 3 displayed its highest noise levels (80.60-99.30 dB) in the morning and lower levels (72.80-95.40 dB) in the evening. The highest noise levels for Locations 1 (97.6 dB) and 2 (98.1 dB) were recorded on Day 1 in the evening, while Location 3's peak (99.3 dB) was observed on Day 2 in the morning. The lowest levels for Locations 1 (79.4 dB) and 3 (72.8 dB) were on Day 3 in the evening, and for Location 2 (76.5 dB) on Day 2 in the morning. The control site consistently registered significantly lower noise levels, ranging from 40.30-44.10 dB in the morning and 39.70-45.80 dB in the evening across all measurements. These values are within permissible limits set by the WHO and Nigerian environmental standards, strongly suggesting that the elevated noise pollution at the other locations is directly attributable to the sawmill operations."

Table 5: Noise Quality Data from the Study Area

	Location 1 ±SD (Min-Max)	**Location 2** ±SD (Min-Max)	**Location 3** ±SD (Min-Max)	**Control** ±SD (Min-Max)	**WHO Guidelines**	**Nigerian Standards (FMEnv)**
Morning (dB)	262.80±5.88 83.80-94.30	251.80±7.61 76.50-91-70	267.00±9.49 80.60-99.30	127.90±2.04 40.30-44.10	Daytime (07:00–22:00): ≤55 dB	Daytime (07:00–22:00): ≤90 dB
Evening (dB)	269.80±9.43 79.40-97.60	288.70±2.14 93.90-98.10	258.40±11.84 72.80-95.40	128.10±3.05 39.70-45.80	Nighttime (22:00–07:00): ≤40 dB	Nighttime (22:00–07:00): ≤80 dB

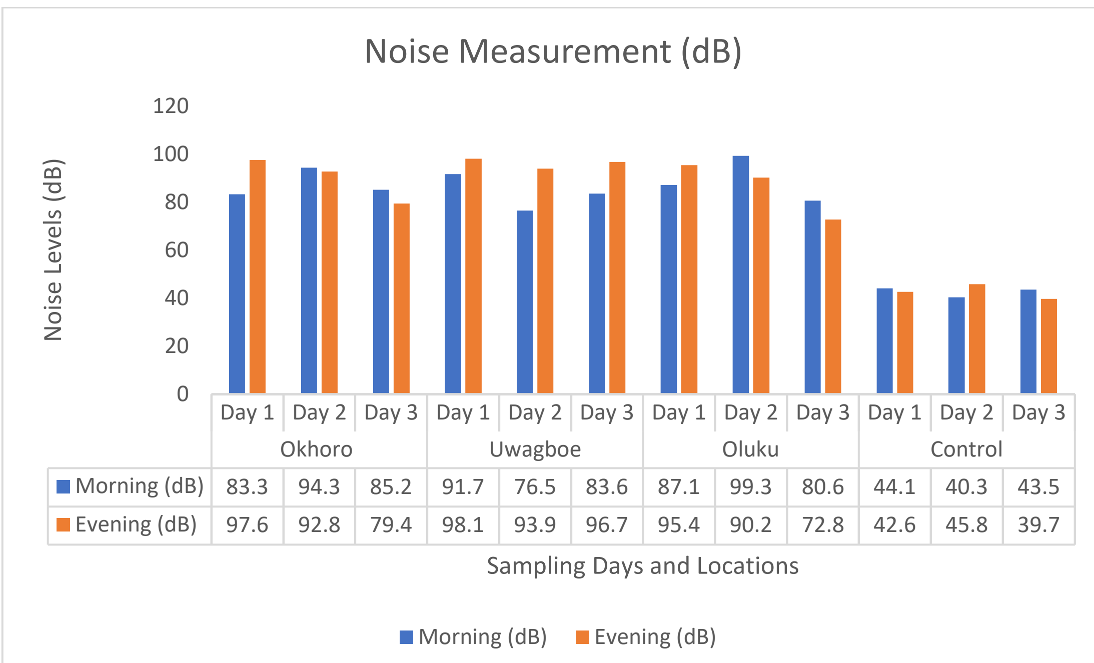

Fig. 3: Noise Levels across All Locations

Demographic Characteristics of Respondents in the Study Area

Table 6 shows the demographic characteristics of the study respondents, utilizing frequency counts and percentages. The gender distribution was evenly split, with 50% male and 50% female participants. The age distribution was as follows: 36% were aged 18-24 years, 30% were 25-34 years, 18% were 35-44 years, 9% were 45-54 years, and 7% were 55 years and above. In terms of occupation, 34% were involved in industrial work, 22% in business, 20% in farming, 14% in education, and 10% in other occupations. Regarding the duration of residence near sawmills, 35% had lived there for 1-5 years, 31% for 6-10 years, 19% for over 10 years, and 15% for less than a year. The chi-square goodness of fit analysis revealed no significant difference in the gender distribution ($p > 0.05$), highly significant differences ($p<0.01$) was exhibited in the age range and occupation of respondents while a significant difference ($p<0.05$) was exhibited in the duration residence have lived in the area.

Table 6: Demographic Characteristics of Respondents in the Study Area

	Variables		Location 1	Location 2	Location 3	Frequency (n)	Percentage (%)	p-values
1	Gender	Male	36	24	40	100	50	p>0.05
		Female	30	42	28	100	50	
2	Age Range	18-24	24	28	20	72	36 [a]	
		25-34	16	20	24	60	30 [a]	p<0.01
		35-44	14	8	14	36	18 [b]	
		45-54	6	6	6	18	9 [c]	
		55+	6	4	4	14	7 [c]	
3	Occupation	Farming	10	16	14	40	20 [b]	
		Industry	26	18	24	68	34 [a]	
		Business	14	14	16	44	22 [b]	p<0.01
		Education	10	8	10	28	14 [c]	
		Other	6	10	4	20	10 [c]	
4	How long have you lived near the sawmill area?	Less than 1 year	10	8	12	30	15 [b]	
		1-5 years	20	24	26	70	35 [a]	p<0.05
		6-10 years	20	24	18	62	31 [a]	
		More than 10 years	12	14	12	38	19 [b]	

p>0.05 – no significant difference, p<0.05 – significant difference, p<0.01 – high significant difference; similar superscript indicates area of no significant while different superscripts indicate area of significance

Perception of Respondents to the Presence of Sawmills Near Residential Environments

Respondents' views on poor air quality caused by sawmill activities are presented in figure 17-18 below. The data collected in this study were obtained using frequency counts and percentages.

The findings indicate that a significant proportion of respondents believed that sawmill activities reduce air quality, with 16% strongly agreeing and 25% agreeing. Regarding dust levels, a substantial 45% agreed or strongly agreed that the air felt dusty in residential areas. Similarly, a large majority (65%) agreed or strongly agreed that sawmills produce foul smells. An even greater percentage (70%) agreed or strongly agreed that air pollution from sawmills affects human health. Concerning specific health impacts, 45% agreed or strongly agreed they experienced breathing difficulties due to sawmill emissions, while 40% agreed or strongly agreed that respiratory illnesses like asthma and cough had increased. Also, that 41% of respondents (16% strongly agree, 25% agree) perceive that sawmill activities significantly degrade air quality. However, 20% were neutral, while 39% (25% disagree, 14% strongly disagree) disagreed. A chi-square test indicated a highly significant difference in these perceptions ($p < 0.01$). Figure 19 shows that 45% of respondents (10% strongly agree, 35% agree) believe that sawmill operations increase particulate matter (PM) levels in the atmosphere. In contrast, 13% were neutral, and 42% (21% disagree, 21% strongly disagree) disagreed. A chi-square test confirmed a highly significant difference in these views ($p < 0.01$).

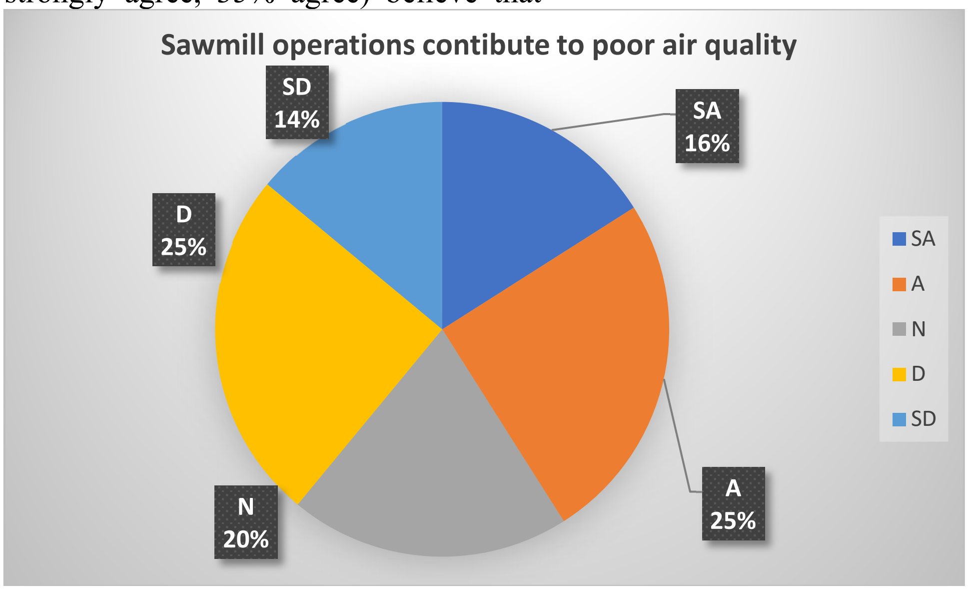

Fig. 4: Sawmill Operations Contribute to Poor Air Quality

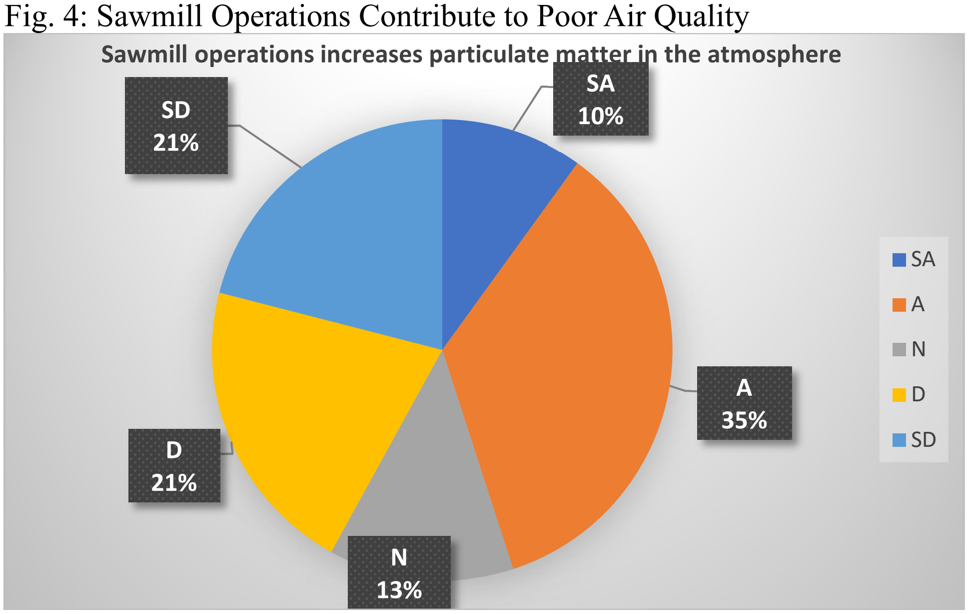

Fig. 5: Sawmill Operations Increase Particulate Matter in the Atmosphere

In table 7, a majority (51%) of respondents agreed that children and the elderly are more vulnerable to pollution, while 43% perceived sawmill noise as a major disturbance. Regarding the disruption of sleep and daily activities by noise, 40% agreed, and 44% acknowledged the presence of loud sounds and vibrations. A significant percentage (52%) agreed that sawmill noise makes concentration difficult, and 41% had considered relocating due to the noise. The chi-square tests revealed significant differences in perceptions of noise disturbance ($p<0.05$), difficulty in concentration ($p<0.05$), and relocation considerations ($p<0.01$), but no significant differences for sleep disruption and loud sounds/vibrations ($p>0.05$).

Also, a plurality (48%) agreed on the positive contribution of sawmills to the local economy, while 50% believed they should not be located in residential areas. A similar proportion (49%) favoured government regulation of sawmill emissions, and a majority (54%) claimed awareness of existing air pollution regulations. Regarding personal safety, 41% reported using protective measures. A substantial majority (63%) believed healthcare services adequately address sawmill-related health concerns. The chi-square tests revealed significant differences in responses concerning the economic contributions ($p<0.01$), the need for environmental regulations ($p<0.01$), awareness of government policies ($p<0.01$), and the adequacy of healthcare services ($p < 0.01$). However, no significant differences were found in opinions regarding the residential placement of sawmills ($p > 0.05$) and the use of protective measures ($p > 0.05$).

Table 7: Perception of Respondents to the Presence of Sawmills Near Residential Environment

	Variables		Location 1	Location 2	Location 3	Frequency (n)	Percentage (%)	p-values
7	Children and elderly are vulnerable to sawmill operations	SA	4	10	12	26	13 [b]	
		A	28	20	28	76	38 [a]	
		N	10	14	8	32	16 [b]	p<0.01
		D	14	8	14	36	18 [b]	
		SD	10	14	6	30	15 [b]	
8	Noise causes significant disturbance from sawmill operations	SA	20	22	18	60	30 [a]	
		A	2	8	16	26	13 [b]	
		N	10	12	10	32	16 [b]	p<0.05
		D	20	18	14	52	26 [a]	
		SD	14	6	10	30	15 [b]	
9	Noise disrupts my sleep and daily activities	SA	18	24	14	56	28	
		A	8	6	10	24	12	
		N	14	12	12	38	19	p>0.05
		D	8	8	18	34	17	
		SD	18	16	14	48	24	
10	Loud sounds or vibrations sawmill operations	SA	22	20	22	64	32	

		A	4	4	16	24	12	
		N	20	16	10	46	23	$p>0.05$
		D	16	12	14	42	21	
		SD	4	14	6	24	12	
11	Difficult to concentrate due to noise from sawmill operations	SA	24	16	18	58	29 [a]	
		A	14	18	14	46	23 [a]	
		N	2	8	10	20	10 [b]	$p<0.05$
		D	8	12	12	32	16 [b]	
		SD	18	12	14	44	22 [a]	
12	Considered relocating due to noise pollution from sawmill operations	SA	14	20	20	54	27 [a]	
		A	2	12	14	28	14 [b]	
		N	18	14	14	46	23 [a]	$p<0.01$
		D	28	14	12	54	27 [a]	
		SD	4	6	8	18	9 [c]	

Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D), Strongly disagree (SD)

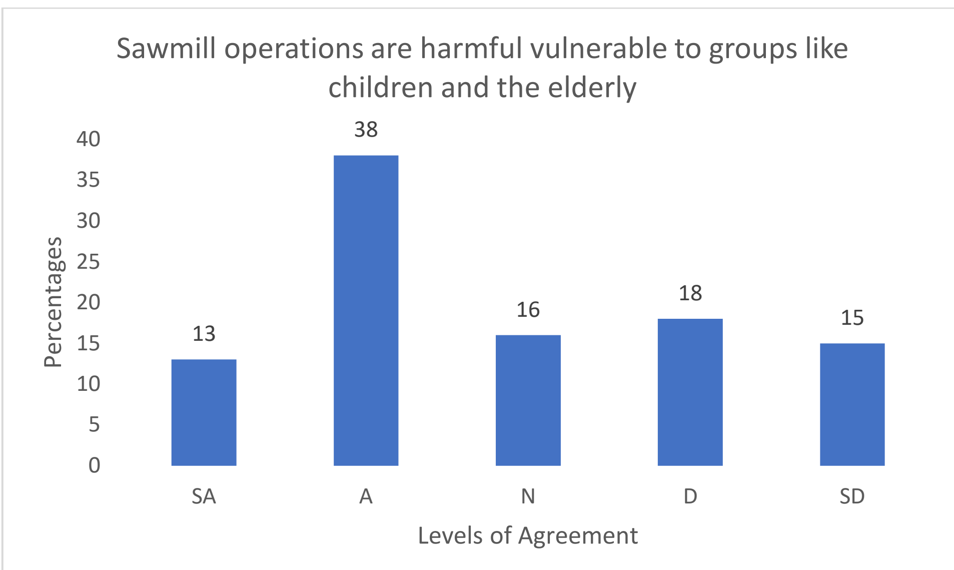

Fig. 6: Children and Elderly are More Vulnerable to Sawmill Operations

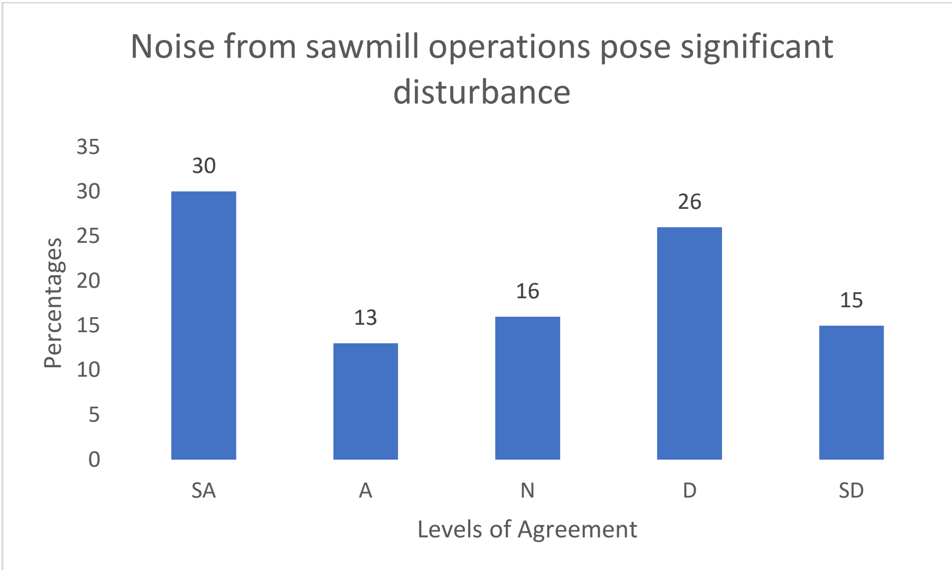

Fig. 7: Noise from Sawmills Causes Significant Disturbance

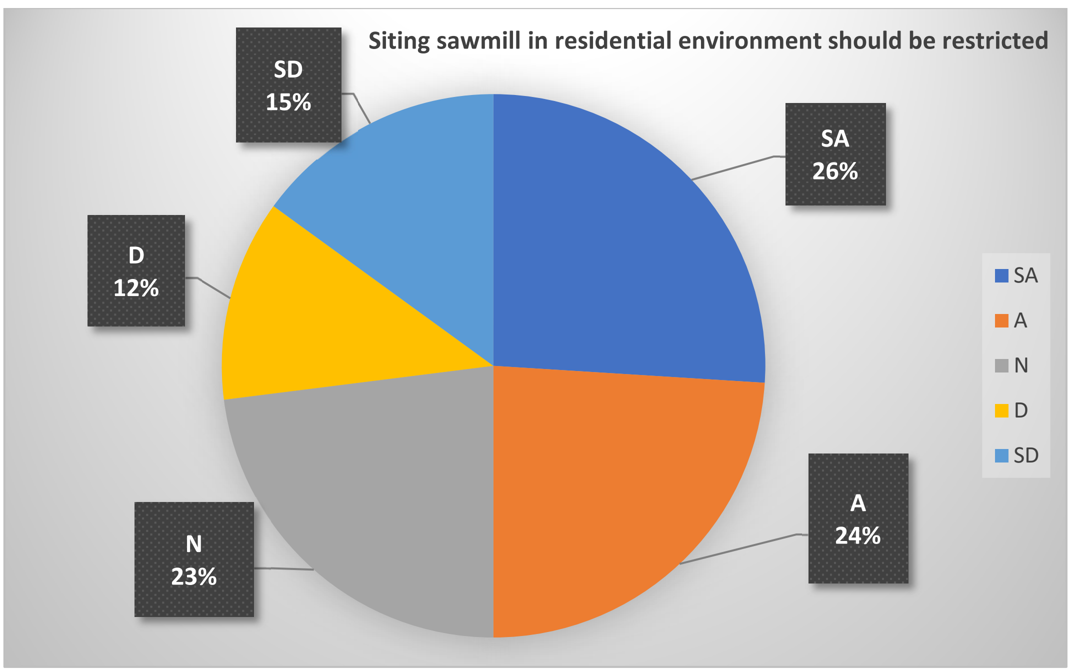

Fig. 8: Sawmills Should Not Be Allowed in Residential Areas

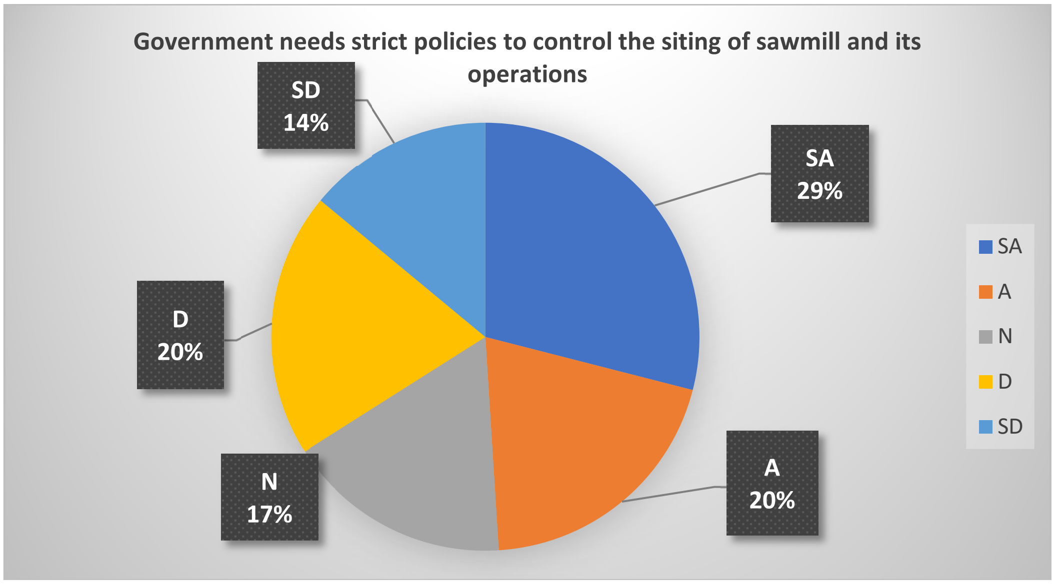

Fig. 9: Need for Environmental Policies to Regulate Sawmill Pollution

Discussion

Ambient Air Pollutants

Sawmill operations significantly contribute to air pollution by releasing various pollutants, including formaldehyde (HCHO), total volatile organic compounds (TVOCs), particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}), carbon monoxide (CO), and carbon dioxide (CO_2). These pollutants not only degrade air quality but also pose severe health risks to sawmill workers and residents in surrounding areas. The findings from this study align with previous research on the impact of industrial air pollution and provide information about the need for regulatory enforcement and pollution control measures. This study confirms that sawmill operations are a significant source of air and noise pollution in surrounding residential areas, necessitating stronger regulatory oversight.

Formaldehyde (HCHO) is a colorless gas naturally emitted from wood as a result of the degradation of chemical components such as cellulose, hemicellulose, and lignin (Salem and Böhm, 2013). Industrial activities, including sawmill operations, significantly contribute to formaldehyde emissions, particularly in high-temperature environments. The International Agency for Research on Cancer (IARC) reports that formaldehyde concentrations in remote outdoor areas are typically below 0.001 mg/m³, while urban locations experience levels up to 0.02 mg/m³.

Elevated levels of formaldehyde (0.03–0.09 mg/m³), exceeding IARC background levels (≤0.02 mg/m³), and total volatile organic compounds (0.16–0.3 mg/m³) were measured, indicating potential health risks for workers and residents, as highlighted by IARC and USEPA classifications (Ajayi and Dosumu, 2002; Salem and Böhm, 2013; USEPA, 2021). Evening peaks in HCHO and TVOCs aligned with temperature-dependent emissions (Pat-Mbano and Nkwocha, 2012; Salem and Böhm, 2013). Furthermore, Salem and Böhm (2013) identified temperature and humidity as key factors influencing formaldehyde emissions, with higher temperatures increasing emissions. This aligns with the findings of this study, where formaldehyde levels were generally higher in the evening when temperatures were elevated. This suggests that sawmill emissions play a significant role in the elevated formaldehyde concentrations observed in the study area.

Particulate matter (PM) is one of the most critical pollutants associated with sawmill activities. $PM_{1.0}$, $PM_{2.5}$, and PM_{10} are tiny particles suspended in the air, originating from wood dust, combustion of sawmill waste, and machinery exhaust emissions. These particles are small enough to be inhaled deep into the lungs, posing serious health risks (Olalekan *et al*., 2020). In this study, PM_{10} concentrations ranged from 69–113 µg/m³, $PM_{2.5}$ ranged from 39–71 µg/m³, and $PM_{1.0}$ ranged from 17–41 µg/m³ across all locations. The highest PM_{10} concentration of 113 µg/m³ was recorded in the evening at Location 3, while the lowest concentration of 69 µg/m³ was observed in the morning at Location 2. Similarly, the highest $PM_{2.5}$ concentration of 71 µg/m³ was recorded in the evening at Location 3, whereas the lowest $PM_{2.5}$ concentration of 39 µg/m³ was observed in the morning at Location 2. $PM_{1.0}$ followed the same trend, with the highest value of 41 µg/m³ recorded in the evening at Location 3 and the lowest value of 17 µg/m³ recorded in the morning at Location 1. PM concentrations were consistently higher in the evening, indicating an accumulation of pollutants throughout the day due to ongoing sawmill activities. The control site exhibited significantly lower particulate matter concentrations, with PM_{10} values ranging from 28–45 µg/m³, $PM_{2.5}$ from 22–33 µg/m³, and $PM_{1.0}$ from 12–20 µg/m³. These values indicate that sawmill operations substantially increase PM concentrations in the surrounding air. The study by Olujimi *et al*. (2023) further supports these findings, reporting $PM_{2.5}$ and PM_{10} concentrations of 53.1±0.60 µg/m³ and 101±0.47 µg/m³, respectively, in sawmill environments, both significantly above the WHO guideline limits of 15 µg/m³ and 45µg/m³, respectively. These elevated levels highlight the potential health risks for sawmill workers and nearby residents, as exposure to high PM concentrations has been linked to respiratory diseases, reduced lung function, and other health complications. Carbon monoxide (CO) and carbon dioxide (CO_2) are major gaseous pollutants emitted during the combustion of wood and sawdust in sawmill operations. CO is a colourless, odourless gas produced from incomplete combustion, while CO_2 is a byproduct of wood processing and burning activities (Donahue *et al*., 2021).

Carbon monoxide (CO) is a colorless, odorless, and highly toxic gas produced from the incomplete combustion of carbon-based fuels, while carbon dioxide (CO_2) is a major greenhouse gas emitted during combustion processes. The presence of these gases in the atmosphere can be linked to industrial activities, vehicle emissions, and biomass burning, including sawmill operations. The CO concentrations recorded in this study ranged from 0–2 ppm, with the highest concentration of 2 ppm observed in Location 3 on Day 2 (Evening). The lowest concentration (0 ppm) was recorded in multiple locations and periods, including Location 2 (Day 1, Evening) and Location 1 (Day 2, Morning). These values remain below the Federal Ministry of Environment (FMEnv) limit of 10 ppm for ambient air quality. However, prolonged exposure to even low CO concentrations in enclosed spaces may pose health risks, especially for sawmill workers and nearby residents. CO_2 levels ranged from 381–460 ppm across all study locations. The highest CO_2 concentration of 460 ppm was recorded in Location 3 on Day 3 (Evening), while the lowest concentration of 381 ppm was recorded in Location 2 on Day 1 (Morning). The control site had significantly lower CO_2 levels, with a range of 391–412 ppm, indicating that sawmill activities contribute to elevated CO_2 emissions in the study area. There were notable disparities between the findings of this study and those reported by Ramasamy *et al*. (2015) regarding CO and CO_2 concentrations from sawmill emissions. This study recorded lower CO levels (0–2 ppm), while Ramasamy *et al.*, (2015) reported significantly higher concentrations (3.5–9.2 ppm). The lower CO values in this study may be attributed to better ventilation in outdoor sawmill environments, whereas Ramasamy *et al*. (2015) likely conducted measurements in enclosed or poorly ventilated workspaces, where CO buildup is more pronounced. Variations in fuel type and machinery efficiency may also contribute to the disparity. Older or poorly maintained sawmill equipment tends to emit higher CO levels due to incomplete combustion, whereas more modern or well-maintained equipment in this study may have resulted in lower emissions. CO_2 concentrations in this study ranged from 381–460 ppm, whereas Ramasamy *et al*. (2015) recorded significantly higher values (500–1350 ppm). The higher CO_2 levels in Ramasamy *et al*. (2015) suggest greater combustion activity, potentially from wood burning, diesel-powered sawmill machinery, or biomass decomposition in more enclosed sawmill settings. The lower CO and CO_2 levels in this study suggest that sawmill emissions in this area may be less severe than those reported by Ramasamy *et al*. (2015). However, the higher CO_2 levels in sawmill locations compared to the control site confirm that sawmill activities remain a significant contributor to localized air pollution. Differences in climatic conditions, sawmill operational scale, and emission control measures between the two studies may also explain the observed variations.

Noise Levels

The noise levels recorded in the study areas indicate that sawmill operations contribute significantly to environmental noise pollution. The measured noise levels in all sampled locations often exceeded the World Health Organization (WHO) recommended daytime limit of 55 dB for residential areas (WHO, 2021). At certain periods, noise levels reached values as high as 99.3 dB, which are comparable to the levels reported in similar studies on industrial noise pollution (Omubo-Pepple *et al*., 2010). Sawmill activities involve the operation of heavy-duty machinery such as circular saws, planers, and wood chippers, all of which contribute to high noise levels. These machines, combined with the continuous movement of logs, vehicles, and human activity within sawmill premises, create a persistent noise problem. The noise levels recorded in this study ranged from 76.5–99.3 dB in the morning and 72.8–98.1 dB in the evening across all sawmill locations. The highest noise level of 99.3 dB was recorded in Location 3 (Morning, Day 2), while the lowest noise level of 72.8 dB was observed in Location 3 (Evening, Day 3). The control site exhibited significantly lower noise levels, ranging from 40.3–44.1 dB in the morning and 39.7–45.8 dB in the evening, indicating that sawmill activities are the primary contributors to high noise levels in the study area. Exposure to excessive noise levels has been linked to numerous health issues, including hearing loss, increased stress levels, and cardiovascular diseases (Münzel *et al.*, 2018). In the study locations, many respondents reported experiencing headaches, sleep disturbances, and difficulty concentrating due to the continuous exposure to sawmill noise. Similar findings were observed by Ayininuola and Muibi (2010), who noted that noise levels in Nigerian sawmills often exceed safe thresholds, thereby increasing the risk of auditory and non-auditory health effects among workers and residents. Research by Münzel *et al*. (2018) suggests that prolonged exposure to environmental noise can elevate blood pressure, leading to long-term cardiovascular risks. The findings from this study align with their observations, as some respondents reported experiencing symptoms of stress, irritability, and increased fatigue due to sawmill noise pollution. Moreover, the WHO (2021) emphasizes that chronic exposure to noise levels exceeding 85 dB can lead to permanent hearing damage. The study by Aremu *et al*. (2015) on noise pollution from sawmill activities in Ilorin, Nigeria, reported background noise levels between 58.1–64.86 dB(A) and machine-generated noise levels ranging from 81.1–112.3 dB(A), with 73% of the readings exceeding the recommended dB(A) limit. Also, a study by Omubo-Pepple *et al*. (2010) in Port Harcourt, Nigeria, found that sawmill noise levels ranged between 70 and 90 dB, consistent with the findings of this research. Such high noise levels can significantly affect residents' quality of life and require mitigation measures such as enforcing zoning regulations, using noise barriers, and implementing better machine maintenance practices to reduce noise emissions.

Perceptions of Air Quality and Noise Levels

Residents living near sawmills expressed concerns about air quality deterioration due to sawmill operations. A significant proportion of respondents (up to 45%) believed that sawmills contribute to increased levels of particulate matter and airborne pollutants in their surroundings. Many respondents reported experiencing breathing difficulties (45%), coughing and symptoms commonly associated with exposure to airborne sawdust and volatile organic compounds (VOCs) (40%). The perception that sawmill emissions negatively affect health is consistent with studies that have established a link between air pollution and respiratory illnesses (Oguntoke *et al*., 2019). Similarly, Olalekan *et al*. (2020) reported a direct correlation between sawmill operations and increased cases of asthma, bronchitis, and other respiratory issues in nearby communities. The qualitative responses also show the impact of sawmill activities on daily life. Respondents described difficulties in keeping their homes free from dust, frequent cleaning due to wood dust settling on surfaces, and concerns about long-term exposure effects. Such findings align with research showing that communities exposed to high particulate concentrations experience a reduced quality of life and increased health burdens (Pat-Mbano and Nkwocha, 2012).

Noise pollution from sawmills was another major concern among respondents. 43% reported significant disturbances caused by the continuous operation of machinery such as saws, planers, and chippers. The most commonly mentioned effects of noise exposure included sleep disturbances (40%), and difficulty concentrating during the day (52%). 41% of respondents stated that the noise from sawmills was so disruptive that they had considered relocating to quieter areas. However, financial constraints and property ownership prevented them from moving. This aligns with studies that have identified economic limitations as a barrier to relocation for individuals experiencing environmental stressors (Ayininuola and Muibi, 2010). Some residents who worked night shifts found it particularly difficult to rest during the day due to the continuous noise. Previous research Previous studies (Ayininuola and Muibi, 2010; Omubo-Pepple *et al*., 2010) supports these findings, indicating that long-term exposure to high noise levels contributes to increased stress levels and sleep deprivation.

Comparison between Perceived and Measured Pollution Levels

Interestingly, while respondents consistently reported high levels of air and noise pollution, some of their perceptions differed from the actual measured pollution levels. For example, while many believed that air pollution was consistently high throughout the day, monitoring data revealed that pollutant concentrations varied, with peak emissions occurring during active working hours. This suggests that public perception is influenced not only by actual exposure but also by individual sensitivity and awareness of pollution sources. Studies suggest that public perception of pollution is often influenced by sensory irritation (smell, visibility of dust) rather than real-time concentration levels (Pat-Mbano and Nkwocha, 2012). Similarly, while most respondents perceived noise pollution to be uniformly excessive, actual measurements indicated that noise levels varied depending on proximity to sawmill operations and the type of machinery in use. Such differences show the importance of integrating both qualitative and quantitative data when assessing environmental health risks.

Conclusion

Sawmill operations have implications for air quality and noise pollution in residential areas, contributing to elevated levels of harmful pollutants and excessive noise exposure. The presence of formaldehyde (HCHO), total volatile organic compounds (TVOCs), particulate matter (PM1.0, PM2.5, PM10), carbon monoxide (CO), and carbon dioxide (CO_2) in high concentrations raises concerns about public health, particularly for vulnerable populations such as children and the elderly. Noise measurements frequently surpassed national and international guidelines, leading to reported cases of sleep disruption, stress, and reduced cognitive performance among nearby residents. The qualitative responses indicated growing concerns about both air and noise pollution, with many residents expressing dissatisfaction with the current regulatory framework. The study strongly recommends stricter environmental regulations, proper zoning, emission and noise control measures, community education, and continuous monitoring to mitigate these impacts. Addressing sawmill pollution is crucial for public health and environmental sustainability, considering the contribution of these operations to both local pollution and broader climate change concerns through CO_2 and particulate matter emissions and potential deforestation

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