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Assessment of Air Pollution and Health Hazard Associated with Selected Sawmills in Port Harcourt Metropolis

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Authors' contributions

This work was carried out in collaboration among all authors. Author HOS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HOS and OAI managed the analyses of the study. Author OAI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to assess air pollution and health hazards around selected sawmills within Port Harcourt metropolis. The physicochemical parameters of the air at the sawmilling sites were determined using onsite air quality analysers. The microbiological parameters were determined using the settling plate technique and the isolates identified based on their cultural and biochemical characteristics. Results showed that estimates of the monitored physicochemical parameters varied with prevalent human activity, time of exposure and atmospheric conditions. At Rumosi, SO_2, VOCs and TSP with a concentration 1.250 ppm, 550.500 ppm, 323.200 µg/m^3 respectively exceeded the Federal Ministry of Environment (FMEv) & World Health Organization (WHO) limit irrespective of the atmospheric condition, time and day of sampling, while the temperature, $PM_{2.5}$, PM_{10} and NO_2 with a concentration of 39.450^{o}C, 209 µg/m3, 348.350 µg/m3, 0.181ppm respectively varied and was within the FMEv acceptable standard. At SARS Road Sawmill 1, VOCs, PM_{10} and TSP exceeded the FMEv limit while at SARS Road Sawmill 2, SO_2, NO_2, VOCs, PM_{10} and TSP exceeded the FMEv limits. Microbiological analysis revealed that the bioaerosols

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contained 12 bacterial genera (Aeromonas, Citrobacter, Staphylococcus, Micrococcus, Klebsiella, Serratia, Pseudomonas, Proteus, Providencia, Shigella, Enterobacter and Bacillus) and 7 fungal genera (Penicillium, Fusarium, Geotrichium, Cladosporium, Rhizopus and Trichophyton and Aspergillus) with total heterotrophic bacterial count (THBC) and total fungal count (TFC) ranging from 2711-26980 CFU/m^3 and 373-12851 CFU/m^3 respectively. The study also showed that sawmills within Port Harcourt do not pay much attention to the provision and use of Personal Protective Equipment (PPE), as they were generally not provided. The sawmill workers commonly reported cough and chest pain which they admitted could be associated with their jobs. This study has shown that air around sawmill sites contains inhalable chemical and biological agents which could cause respiratory problems to workers with prolonged exposure and dose response. Sawmill operators should provide and enforce the use of PPE within their facility. It is recommended that sawmill workers and other visitors wear personal protective gadgets in the processing area of the sawmill factories. Further study to relate workers symptoms with emission is recommended.

Keywords: Sawmill; air pollution; health hazards; Port Harcourt.

1. INTRODUCTION

Wood and wood products are valuable resources for building construction and household furnishing. Wood is dubbed a multi-use raw material and the only renewable material used in building construction [1]. Given the number of buildings in existence and springing up, one could only imagine the amount of wood waste produced so far. The sheer volume of wood needed to meet all the building and furniture needs of the modern time suggests that, the wood processing industry would generate lots of waste.

Wood waste from sawmills includes, tree cut-offs, failed products, shavings and sawdust [2]. Wood dust are tiny in size and powdery wood shavings form about 10-13% of the total volume of the wood log chopped off during processing of woods timber [3,4]. The measure and sort of wood dust generated varies with the type of wood being cut and the machine blade used [5]. Wood dust are discharged alongside an assortment of harmful substances, such as terpenes, resin acids, aldehydes, fungi and their spores as well as bacteria growing on them into the environment [6,7]. All the inhalable by-products of wood processing are well known with respect to their health effects.

In recent years, attention has been drawn to the fact that person working or living near sawmills may be exposed to many harmful factors identified to include chemical and biological pollution agents, mechanical vibrations, noise, electromagnetic fields, lighting, static electricity, and variable microclimate [8-11]. Microorganisms growing on, within and outside of logs may become airborne during processing and be deposited in the respiratory tract when inhaled [12]. Control of exposure to wood dust and microbiological agents in woodworking environment is not easy. In fact, various types of wood are commonly used and they generate complex mixtures of dusts and microorganisms. Inhalation of these compounds can elicit immunotoxic and allergenic reactions in humans with implication on respiratory health as they cause nasal irritation, nasopharyngeal cancer, bronchial hyper-responsiveness, allergic alveolitis, asthma, chronic bronchitis, rhinitis, contact dermatitis and general decline in lung function [8, 9,12,13].

Bello and Mijinyawa [14] surveyed sawmills in south-western Nigeria and established that most operate with obsolete machines, with missing or faulty safety devices and the health and safety tenets were generally not complied with, while the operators are mostly untrained professionals. Tobin et al. [15] reported that sawmills operating in Nigeria face the hurdle of providing work environments where control of hazards is not given attention. Osagbemi et al. [16], Bamidele et al. [17], Agu et al. [18] and Johnson and Umoren [19], in their studies of occupational hazards and health problems reported among in their studies of occupational hazards and health problems reported among Sawmill workers in the Nigerian cities of Ilorin, Osogbo, Abakiliki and Uyo, all reported a generally poor use of Personal Protective Equipment (PPE). Where the affordable nose mask is not provided for workers, it is hard to expect that the better suited, more expensive Respiratory Protective Equipment (RPE) would be.

The sawmill business is a thriving enterprise in the Niger Delta because of the availability of sawmills in most areas of the city of Port

Harcourt. The collection, transportation and storage of sawmill waste in the city of Port Harcourt is challenging, as such operators often resort to incinerating the waste at site or heap them up until they can be moved, during which time moisture build up and biodegradation sets in. Information on the health and ecological implications of sawmill waste and bioaerosols produced during sawmilling operations in Rivers is not sufficient to compel action on operators to either purify the air from their site of operation before discharging into the air, or to locate their industry far away from residential areas or to find out ways to recover beneficial products from the waste [20].This study seeks to ascertain the extent of air pollution around sawmilling sites in Port Harcourt and the associated health hazards.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted, in Port Harcourt Local Government Area (PHALGA) of Rivers State. Rivers State is part of the Niger Delta province, which lies within the rainforest belt in Nigeria and at the Southern end of country bordering the Atlantic Ocean. Three sawmills within the city located at N04°52'80.916"E06°56'36.144" (Rumosi Sawmill), N04°53'33.732"E06°58'28.584" (SARS Road Sawmill 1) and N04°53'42.09" E06°59'31.188" (SARS Road Sawmill 2), were sampled (Fig. 1).

2.2 Sample Collection

Air samples were analyzed *in situ* at the three sawmills for their physicochemical parameters. To determine the microbiological quality of the air, media plates (Nutrient Agar & Potato Dextrose Agar) were exposed within the saw mills for 20minutes and 10meters away from the sawmill as a control point. Exposed media plates were transported to the laboratory for analysis. Samples were collected in the morning from 8am-9am and in the afternoon from 1pm-2pm for 4days.

2.3 Physicochemical Analyses of Air Samples

Air quality analyser Areoqual series 500 was used to measure relative humidity, wind speed, volatile organic compounds (VOCs), carbon monoxide (CO) carbon dioxide (CO_2), nitrogen oxide (NO_2), ozone (O_3), hydrogen sulphide (H_2S), methane (CH_4), sulphur oxide (SO_2), Sound meter Extech 407742 model was used to measure noise, Aerocet MetOne 531S model was used to measure suspended particulate matter and Meteorological meter Extech 4in1 model was used to measure the temperature.

2.4 Determination of Microorganism Present in Air Samples

Preparation of Nutrient Agar was done by weighing 28g of Nutrient agar in 1000ml of distilled water. The settling plate technique as described by Mbakwem-Aniebo et al. [21] was used for the isolation of microorganism in the air. In this technique, standard 90 mm diameter Petri dishes containing 18ml of sterile culture media (Nutrient Agar and Potato Dextrose Agar) were opened at the sawmill sites for 20 minutes, after which the Petri dishes were closed and placed in the incubator at 37°C for 24 hours for possible bacterial growth while the PDA plates were incubated at room temperature for five days for the determination of fungi. Enumeration was done using the Omeliansky's formula: $N=5a \times 10^4/bt$ (where a is actual plate count, b is the surface area of the Petri dish and t is the exposure time in minutes) and expressed in CFU/m^3.

2.5 Purification and Characterization of Isolates

The bacterial and fungal colonies formed on the media were repeatedly sub-cultured on NA to obtain pure isolates which were later subjected to a battery of biochemical tests, morphological and cultural characteristics.

2.6 Instrument for Data Collection

A structured questionnaire comprising four sections was used for the collection of data on the health impacts of sawmill operations on workers. Section A consists of 4 questions to draw out socio demographic information of the respondent, section B consists of 3 questions to elicit response on occupational impact, section C consists of 4 questions on health status and impact and section D consist of 9 questions to gather information on safety awareness of workers. Each sawmill had 4 workers and all the workers took part in the study.

2.7 Statistical Analysis

Descriptive statistics was used for the depiction of data. Data analysis was done using Microsoft Excel and SPSS v 25, for bar chats and one-way analysis of variance (ANOVA) respectively.

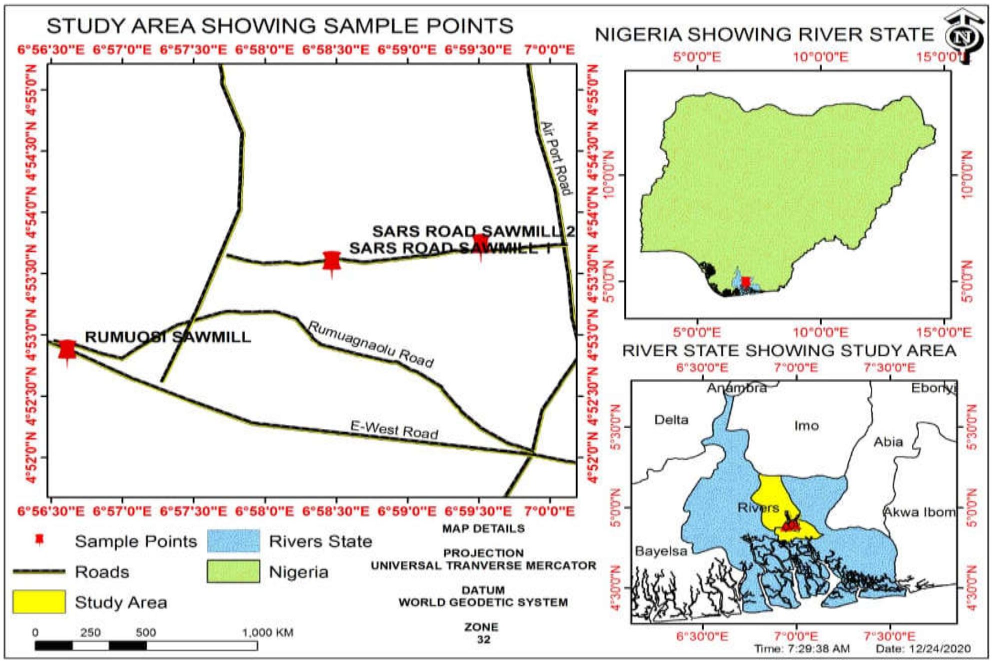

Fig. 1. Map of study area

3. RESULTS AND DISCUSSION

3.1 Physicochemical Parameters of Air Samples

Results showing the physicochemical parameters of air samples at the three sampling locations are presented in Table 1-3. The physicochemical results revealed variable concentrations of air pollutants across the sampling location, which were mostly higher inside the sawmill than outside (control). Table 1 shows that the mean value for SOx ranged from 0.125 to 0.350 ppm; NOx from 0.014 to 0.181 ppm; VOC from 48.00 to 9550.500 ppm; CH_4 from 3.000 to 64.000 ppm; CO from 6.000 to 56.000 ppm; CO_2 varied from 836.000 to 1280.000 ppm; O_3 from 0.400 to 0.450 ppm; NH_3 from 0.100 to 0.750 ppm; H_2S from 0.150 to 0.900 ppm; $PM_{2.5}$ from 54.000 to 209.100 µg/m^3; PM_{10} varied from 112.000 to 348.350µg/m^3; TSP from 164.250 to 424.100 µg/m^3; noise level from 55.000 to 87.800 db; wind speed varied from 0.600 to 1.650 m/s; temperature from 28.950 to 39.450 ^{0}C and relative humidity from 57.500 to 82.650 %.

Table 2 shows that the mean values for SOx ranged from 0.000 to 0.050 ppm; NOx from 0.011 to 0.018 ppm; VOC from 10.500 to 281.000 ppm; CH_4 from 1 to 11 ppm; CO from 0.000 to 10.500 ppm; CO_2 from 783.000 to 1000.000 ppm; O_3 from 0.000 to 0.100 ppm; NH_3 from 0.000 to 0.450 ppm; H_2S from 0.000 to 0.750 ppm; $PM_{2.5}$ from 45.450 to 63.900 µg/m^3; PM_{10} from 79.100 to 153.850 µg/m^3; TSP from 109.750 to 199.050 µg/m^3; noise level from 50.950 to 77.400 db; wind speed from 0.250 to 2.350 m/s; temperature from 30.650 to 34.650 ^{0}C and relative humidity from 60.650 to 73.950 %.

Table 3 shows that at the mean values for SOx ranged from 0.000 to 0.125 ppm; NOx from 0. 0.024 to 0.094 ppm; VOC from 115.000 to 342.500 ppm; CH_4 from 8.000 to 39.500 ppm; CO from 1.000 to 10.500 ppm; CO_2 from 757.000 to 1430.000 ppm; O_3 from 0.000 to 0.350 ppm; NH_3 from 0.000 to 0.450 ppm; H_2S from 0.000 to 0.350 ppm; $PM_{2.5}$ from 55.100 to 132.050 µg/m^3; PM_{10} from 107.800 to 347.050 µg/m^3; TSP from 160.900 to 487.550 µg/m^3; noise level from 66.650 to 88.700 db; wind speed from 1.200 to 2.450 m/s; temperature from 31.200 to 35.000^{o}C and relative humidity from 51.000 to 71.050 %.

3.2 Microbiological Parameters of Air Samples

Fig. 1 presents the results for the Total heterotrophic bacterial count (THBC). On Day 1, THBC values ranged from 11318-26980 CFU/m^2, 4028-12615 CFU/m^2 and 2711-13598 CFU/m^2 at Rumosi Sawmill, SARS Road Sawmill 1and at SARS Road Sawmill 2 in that order while on Day 2, the values ranged from 1572-10297 CFU/m^2, 1769-3517 CFU/m^2 and 3458-10257 CFU/m^2 at Rumosi Sawmill, SARS Road Sawmill 1and at SARS Road Sawmill 2 respectively. Fig. 2 presents the results for the Total Fungal count (TFC). On Day 1, the values ranged from 4716-10120 CFU/m^2, 2063-12851 CFU/m^2, 530-6347 CFU/m^2 at Rumosi Sawmill, SARS Road Sawmill 1and at SARS Road Sawmill 2 respectively while on Day 2, the values ranged from 2417-7605 CFU/m^2, 531-7506 CFU/m^2, 373-4087 CFU/m^2, at Rumosi, SARS Road Sawmill 1 and at SARS Road Sawmill 2 correspondingly.

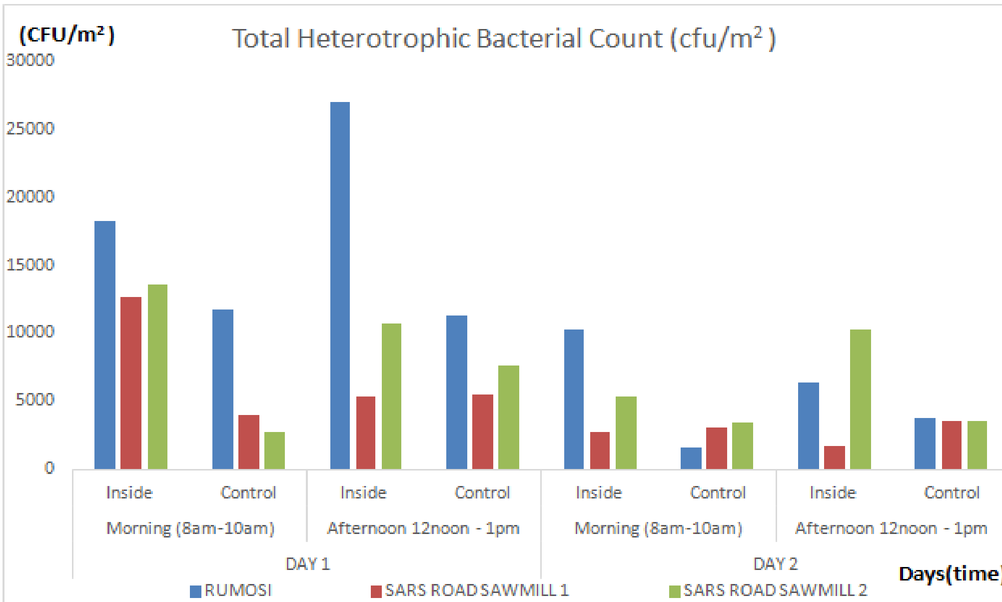

Fig. 2(a). Total Heterotrophic Bacterial Count (THBC)

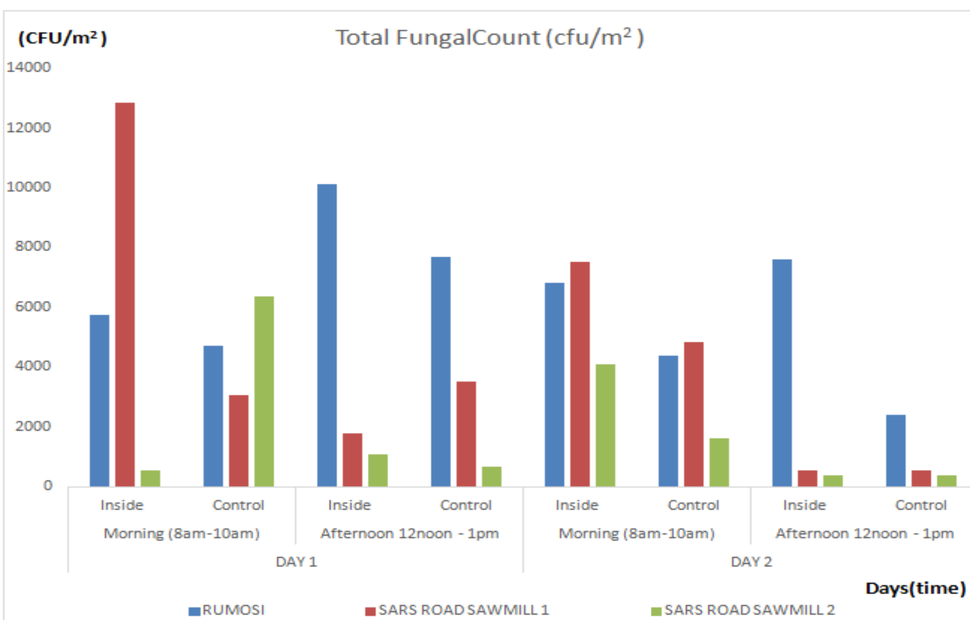

Fig. 2(b). Total Heterotrophic Fungal Count (THFC)

Table 1. Physicochemical parameters of air at Rumosi sawmill

		Day 1				Day 2				
		Morning		**Afternoon**		**Morning**		**Afternoon**		
		Inside	**Control**	**Inside**	**Control**	**Inside**	**Control**	**Inside**	**Control**	**FMEv**
SOx, ppm		0.350	0.200	0.200	0.150	0.250	0.150	1.250	0.350	0.01-0.1
NOx, ppm		0.046	0.039	0.076	0.014	0.075	0.042	0.181	0.097	0.04-0.06
VOC, ppm		305.000	287.000	550.500	339.000	312.000	48.000	479.500	316.500	0.5
CH_4, ppm		64.000	31.000	22.500	2.500	49.000	11.500	35.000	3.000	-
CO, ppm		9.500	6.500	16.000	11.500	19.000	10.500	56.000	13.000	50
CO_2, ppm		1099.500	988.500	973.000	1030.000	836.500	960.000	1280.000	941.500	-
O_3, ppm		0.500	0.045	0.225	0.040	0.350	0.450	0.350	0.150	-
NH_3, ppm		0.350	0.300	0.450	0.100	0.750	0.250	0.400	0.250	-
H_2S, ppm		0.900	0.150	0.400	0.150	0.700	0.250	0.750	0.250	-
Suspended	$PM_{2.5}$	71.600	69.700	209.100	68.600	63.000	54.900	165.550	65.100	115
Particulate	PM_{10}	163.150	145.500	348.350	161.250	136.850	116.900	224.750	112.200	150
Matter, μg/m^3	TSP	224.050	165.900	323.200	203.100	188.150	164.250	424.100	188.800	115-150
Noise, dB		87.800	71.550	87.700	70.900	55.000	58.050	85.650	59.500	59.500
Wind speed, m/s		0.400	1.100	1.050	1.100	0.600	0.450	1.200	1.650	
Air Temp (Ambient) ^oC		28.950	29.950	31.300	39.450	33.050	33.450	31.450	34.450	29.5-36.9
Wind direction		SW	SW	SW	NW	NE	NW	SE	NW	-
Relative Humidity, %		82.650	80.900	60.300	57.500	65.150	68.550	70.900	62.800	4.90-75.9

Table 2. Physicochemical parameters of air at SARS Road sawmill 1

		Day 1				Day 2				
		Morning		Afternoon		Morning		Afternoon		
		Inside	Control	Inside	Control	Inside	Control	Inside	Control	FMEV
SOx, ppm		0.000	0.000	0.000	0.050	0.100	0.000	0.100	0.000	0.01-0.1
NOx, ppm		0.018	0.011	0.026	0.017	0.029	0.015	0.023	0.011	0.04-0.06
VOC, ppm		150.500	100.500	281.000	150.000	142.000	32.000	116.000	10.500	0.5
CH_4, ppm		11.000	1.500	9.500	2.000	5.000	1.000	4.000	1.500	-
CO, ppm		3.500	0.100	10.500	0.500	1.500	0.000	0.000	0.000	50
CO_2, ppm		945.000	865.000	1000.000	785.000	946.500	971.000	956.500	783.000	-
O_3, ppm		0.100	0.040	0.010	0.000	0.010	0.010	0.010	0.010	-
NH_3, ppm		0.200	0.100	0.450	0.000	0.200	0.000	0.150	0.000	-
H_2S, ppm		0.750	0.450	0.350	0.000	0.150	0.000	0.100	0.000	-
Suspended	$PM_{2.5}$	63.900	60.900	52.850	45.450	63.800	52.050	35.700	46.800	115
Particulate	PM_{10}	153.850	133.950	124.500	120.900	142.650	115.600	79.100	99.550	150
Matter, $\mu g/m^3$	TSP	199.050	155.700	164.450	129.500	196.700	161.000	109.750	123.600	115-150
Noise, Db		54.250	50.950	55.850	77.400	51.850	68.350	70.050	70.650	65
Wind speed, m/s		1.600	1.200	1.350	2.350	0.250	1.250	0.600	1.400	-
Air Temp (Ambient) ^oC		30.650	32.900	31.500	34.650	32.300	33.950	32.550	31.500	29.5-36.9
Wind direction		NE	NE	SE	SE	SE	NW	NE	SE	-
Relative Humidity, %		71.400	73.950	68.200	60.650	68.950	64.300	69.700	67.900	4.90-75.9

Table 3. Physicochemical parameters of air at SARS Road sawmill 2

		Day 1				Day 2				
		Morning		Afternoon		Morning		Afternoon		
		Inside	Control	Inside	Control	Inside	Control	Inside	Control	FMEV
SOx, ppm		0.100	0.000	0.000	0.000	0.125	0.000	0.100	0.000	0.01-0.1
NOx, ppm		0.080	0.024	0.081	0.025	0.083	0.030	0.094	0.045	0.04-0.06
VOC, ppm		293.000	183.000	342.500	260.50	325.000	148.50	255.000	115.000	0.5
CH_4, ppm		38.500	14.500	22.500	11.000	39.500	9.000	31.000	8.000	-
CO, ppm		10.500	1.000	8.500	1.000	9.500	1.500	7.000	1.000	50
CO_2, ppm		1430.00	757.000	1175.00	785.00	1195.00	930.00	1255.00	791.000	-
O_3, ppm		0.030	0.030	0.010	0.100	0.350	0.000	0.100	0.050	-
NH_3, ppm		0.400	0.100	0.160	0.100	0.100	0.000	0.450	0.000	-
H_2S, ppm		0.150	0.150	0.200	0.000	0.350	0.000	0.250	0.000	-
Suspended	$PM_{2.5}$	65.350	65.100	66.350	55.100	132.050	64.050	78.400	50.800	115
Particulate	PM_{10}	116.300	141.000	110.100	140.05	347.050	107.80	143.700	95.150	150
Matter, μg/m^3	TSP	130.550	161.550	133.600	160.90	487.550	163.85	310.900	109.850	115-150
Noise, Db		66.650	72.300	68.550	72.400	88.700	72.800	84.800	75.500	75.500
Wind speed, m/s		0.750	1.500	1.200	2.000	0.450	1.400	1.200	2.450	-
Air Temp (Ambient) ^oC		31.200	31.700	31.900	33.900	32.700	33.650	32.650	35.000	29.5-36.9
Wind Direction		SE	NW	SE	SE	NE	NE	SE	SE	-
Relative Humidity, %		67.500	65.800	68.050	71.050	67.150	65.350	55.550	51.000	4.90-75.9

Table 4 shows the biochemical characteristic of the bacterial isolates. The bacterial isolates were identified as belonging to the genera Aeromonas, Citrobacter, Staphylococcus, Micrococcus, Klebsiella, Serratia, Pseudomonas, Proteus, Providencia, Shigella, Enterobacter and Bacillus. The fungal isolates were identified as species of yeast, Penicillium, Fusarium, Geotrichium, Cladosporium, Rhizopus, Trichophyton, *Aspergillus flavus and Aspergillus niger.*

3.3 Socio Demographic Characteristic of Respondents

Results for the socio demographic characteristic of respondents are presented in Tables 6. Tables 6 shows that for Rumosi sawmill, all respondents 4(100%) were male and married. Majority of the respondents were aged 35-44 years. The four respondents had primary, junior secondary, senior secondary and OND as their level of education. Each of the four respondents had their job designation as wood packing and stacking, mechanic, machine operator and supervisor/manager. Most 3(75%) had worked for 6-10 years and only 1(25%) had worked 11-20 years. A majority 3(75%) had never smoked cigarette. For SARS Road sawmill 1, all respondents 4(100%) were male and single. Majority were aged 35-44 years, while 2(25%) each were aged 25-34 and<18 years. All four respondents had primary, junior secondary, senior secondary and OND each as their level of education. Each of the four respondents had their job designation as wood packing and stacking, driver, apprentice and supervisor and manager. Majority 3(75%) had worked for 0-1 year, while 1(25%) had worked for 2-5 years. Equal number 2(25%) had either smoked or never smoked cigarette. For SARS Road sawmill 2, all respondents 4(100%) were male of which 3(75) are married and 1(25%) single. All four respondents were aged 35-44 years. Majority of the respondents 3(75%) had just primary education, while 1(25%) had secondary school education. Majority had their job designation as wood packing and stacking 2(50%), while 1(25%) each had theirs as either apprentice or supervisor/manager. Majority 3(75%) had worked for 2-5 year, while 1(25%) had worked for 0-1 years. All respondents 4(100%) had never smoked cigarette.

3.4 Health and Safety Provisions by Employer

Tables 7 show information on Health and Safety provisions by employer at the 3 locations, where 2(50%) admitted to receiving or not receiving medical examination before starting work at Rumosi sawmill, while all respondents from SARS Road Sawmill 1and 2 received medical examination. At Rumosi, equal number of respondents 2(50%) each, admitted having been trained either by an external group engaged by the employer or by fellow employee, while 100% (4) of workers at SARS Road Sawmill 1and 2 were trained by fellow employee. Majority of the respondents 3(75%) answered no to the availability of medical service for first aid and treatment by employer at Rumosi sawmill while 100% (4) of works at SARS Road Sawmill 1and 2, also admitting the same. For Rumosi sawmill, majority of the respondents 3(75%) said they had no provision of PPE, with just 1(25%) answering in the affirmative, hand glove, safety boot and eye goggle as the PPE provided . For SARS sawmill 1and 2, 4(100%) affirmed that PPE was not provided by the employer.

3.5 Safety Awareness and Attitude of Employees

Tables 8 show results of safety awareness and attitude of employees. Majority of the respondent, 2(50%) for Rumosi sawmill and SARS Road Sawmill 1, considered the use of PPE as important, while 4(100%) for SARS Road Sawmill 2 considered it as important. For both Rumosi and SARS Road Sawmill 1, equal number of respondents 2(50%) either admitted to PPE being of benefit to them or they do not know if it is whereas 4(100%) for SARS sawmill 2 considered it of benefit. Majority of the respondent rarely use PPE, 3(75%) for Rumosi and 4(100%) for SARS Road Sawmill 1 and 2.1(25%) admitted to using PPE sometimes. For Rumosi, all the respondent 4(100%) said the reason they do not use PPE was because they find it inconveniencing while for SARS Road Sawmill 1 and 2 non availability was the reason given for not using PPE.

3.6 Prevalence of Respiratory Symptoms among the Sawmill Workers

Result on the prevalence of respiratory symptoms among the sawmill workers at Rumosi Sawmill revealed that majority of the respondent 3(75) reported only having cough while working at the sawmill. At SARS Road Sawmill 1, majority of the respondent 3(75) reported having cough and 1(25%) reported having chest pain and difficulty in breathing. At SARS Road Sawmill 2,

Table 4. Biochemical test for isolates

Isolate Code	Catalase	Oxidase	Citrate	Indole	Glucose	Lactose	mr	vp	Butt	Slant	Gas	H_2S	Motility	Sucrose	Gram stain	Possible genera
X_1	+	-	+	+	+	+	-	+	A	A	-	-	-	+	Rod pink	*Aeromonas* sp.
X_2	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Cocci purple	*Staphylococcus* sp.
X_3	+	-	+	-	+	+	-	-	A	B	-	-	-	-	Rod pink	*Serratia* sp.
X_{2b}	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Cocci purple	*Staphylococcus* sp.
X_{1b}	+	-	-	-	-	-	+	+	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_{3b}	-	-	+	+	+	-	-	-	A	B	-	-	+	-	Rod pink	*Serratia sp.*
X_{1c}	+	-	+	+	+	+	-	+	A	A	-	-	-	+	Rod pink	*Aeromonas* sp.
X_{2c}	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Rod pink	*Klebsiella* sp.
X_{3c}	+	-	-	+	-	-	+	+	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_4	+	-	-	-	-	+	+	-	B	B	-	-	-	-	Rod pink	*Pseudomonas* sp.
X_{4b}	+	-	+	+	+	-	+	-	A	A	+	-	+	-	Rod pink	*Proteus* sp.
X_{4c}	+	-	+	-	+	-	-	+	A	B	-	-	+	-	Rod purple	*Bacillus* sp.
X_5	+	-	-	-	-	-	+	+	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_6	+	-	-	-	-	+	+	-	A	B	-	-	-	-	Rod pink	*Providencia* sp.
X_7	+	-	+	-	-	+	+	-	B	B	-	-	-	-	Rod pink	*Pseudomonas* sp.
X_{7b}	+	-	+	-	+	-	-	+	A	B	-	-	-	-	Rod purple	*Bacillus* sp.
X_{7c}	-	-	+	+	+	-	-	-	A	B	-	-	+	-	Rod pink	*Serratia* sp.
X_{7d}	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Cocci purple	*Staphylococcus* sp.
X_{7e}	+	-	-	-	-	-	+	-	A	B	-	-	-	-	Rod pink	*Shigella* sp.
X_{7f}	+	-	+	-	-	-	+	-	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_{7g}	+	-	+	-	+	+	-	+	A	B	-	-	-	-	Rod pink	*Enterobacter* sp.
X_{7h}	+	-	+	-	+	+	-	+	A	A	-	-	+	+	Rod pink	*Aeromonas* sp.
X_{7i}	+	-	+	-	+	+	-	+	A	A	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_{7j}	+	-	+	-	+	-	-	-	A	B	-	-	+	-	Rod pink	*Serratia* sp.
X_8	+	-	+	-	+	+	+	-	A	B	-	-	+	+	Rod pink	*Citrobacter* sp.
X_{8b}	+	-	+	+	+	-	+	-	A	A	+	-	+	-	Rod pink	*Proteus* sp.
X_{8c}	-	-	+	+	+	-	-	-	A	B	-	-	+	-	Rod pink	*Serratia* sp.
X_9	+	-	-	-	-	-	+	+	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_{10}	+	-	+	-	+	+	-	+	A	A	-	-	-	-	Rod pink	*Aeromonas* sp.
X_{11}	+	-	-	-	-	-	+	+	A	B	-	-	-	-	Cocci purple	*Micrococcus* sp.
X_{12}	+	-	+	-	+	-	-	+	A	B	-	-	+	-	Rod purple	*Bacillus* sp.
X_{13}	+	+	-	-	-	-	-	-	B	B	-	-	-	-	Rod pink	*Pseudomonas* sp.
X_{14}	+	-	+	+	+	+	-	+	A	A	-	-	-	+	Rod pink	*Aeromonas* sp.
X_{15}	+	-	+	-	+	+	+	-	A	B	-	-	+	-	Rod pink	*Citrobacter* sp.

Isolate Code	Catalase	Oxidase	Citrate	Indole	Glucose	Lactose	mr	vp	Butt	Slant	Gas	H_2S	Motility	Sucrose	Gram stain	Possible genera
X_{16}	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Rod pink	*Klebsiella* sp.
X_{17}	+	-	+	-	+	-	-	+	A	B	-	-	+	-	Rod purple	*Bacillus* sp.
X_{18}	+	-	+	-	+	+	-	+	A	A	-	-	-	+	Cocci purple	*Staphylococcus* sp.

Key: - Negative, + Positive, A-Acid B-Base, mr- methyl red, vp- vogues prausker

Table 5. Identification of fungal isolates from air samples

Isolate code	Macroscopy	Microscopy	Possible Isolate
F_1	Yellow-grey mycelia turning black with age	Presence of dark furling head on branched hyphae	*Aspergillus* niger
F_2	Cottony with reverse reddish brown colour, circular	Septate hyphae, presence of conidia	*Trichophyton* sp.
F_3	Blue-greenish convex, circular, dry and rough surface with margin	Presence of conidiophore in transparent hyphae looking like brush in cluster	*Penicillium* sp
F_5	Highly dense fluffy mycelia that produces dark spores with age	Presence of sporangium and long hyphae	*Rhizopus* sp.
F_6	Yellow raised smooth and dull surface circular entire	Large purple cocci	(yeast)
F_7	Dry white colony with rough surface that look yeast-like	Branched septate hyphae	*Geotrichum* sp.
F_8	Fast growing woolly greenish mycelia with folded surface and white margin	Unbranched septate haphae. Presence of conidia	*Aspergillus* flavus
F_9	White fluffy aerial mycelium with smooth surface and circular	Septate hyphae bearing spores	*Fusarium* sp.
F_{10}	Presence of greyish drowny mycelia with entire and circular shape	Septate unbranched hyphae	*Cladosporium* sp,
F_{11}	Creamed raised smooth and shiny, circular and entire	Purple cocci	(yeast)

Table 6. Socio demographic characteristic of respondents (SARS Road Sawmill 1)

		Rumosi Sawmill		SARS Road Sawmill 1		SARS Road Sawmill 2	
Variable	**characteristic**	**Frequency**	**(%)**	**Frequency**	**(%)**	**Frequency**	**(%)**
Sex	Male	4	100	4	100	4	100
	Female	-	-	-	-	-	-
Age	< 18	-	-	1	25	-	-
	18-24	-	-	-	-	-	-
	25-34	-	-	1	25	4	100
	35-44	3	75	2	50	-	-
	45-54	1	25	-	-	-	-
Marital Status	Married	4	100	-	-	1	25
	Single	-		4	100	3	75
Level of Education	Primary	1	25	1	25	3	75
	Junior Secondary	1	25	1	25	-	-

		Rumosi Sawmill		SARS Road Sawmill 1		SARS Road Sawmill 2	
Variable	**characteristic**	**Frequency**	**(%)**	**Frequency**	**(%)**	**Frequency**	**(%)**
	Senior Secondary	1	25	1	25	1	25
	Diploma	-	-	-	-	-	-
	OND	1	25	1	25	-	-
	BSc and above	-	-	-	-	-	-
Job Designation	Wood packing and stacking	1	25	1	25	2	50
	Mechanic	1	25	-	-	-	-
	Driver	-		1	25	-	-
	Machine operator	1	25	-	-	-	-
	Apprentice	-		1	25	1	25
	Supervisor and Manager	1	25	1	25	1	25
Period of engagement in current job	0-1 years	-	-	3	75	1	25
	2-5 years	-	-	1	25	3	75
	6-10 years	3	75	-	-	-	-
	11-20 years	1	25	-	-	-	-
	21-30 years	-	-	-	-	-	-
Ever smoked cigarette	Yes	1	25	2	50	-	
	No	3	75	2	50	4	100

Table 7. Health and safety provisions by employers at the sawmills

		Rumosi Sawmill		SARS sawmill 1		SARS sawmill 2	
Variable	**Characteristic**	**Freq.**	**(%)**	**Freq.**	**(%)**	**Freq.**	**(%)**
Medical examination carried out by employer before starting work at sawmill	Yes	2	50	-	-	-	-
	No	2	2	4	100	4	100
	No	2	50	4	100	4	100
Any training received for the job at the sawmill	Yes, by an external group engaged by the employer	2	50	-	-	-	-
	Yes, by a fellow employee	2	50	4	100	4	100
	No training received	-	-	-	-	-	-
Availability of medical service for first aid and treatment by the employer	Yes	1	25	-	-	-	-
	No	3	75	4	100	4	100
Provision of PPE by employer	Yes	1	25	-	-	-	-
	No	3	75	4	100	4	100
Type of PPE provided	Hand glove	√	-	-	-	-	-
	Face mask	-	-	-	-	-	-

		Rumosi Sawmill		SARS sawmill 1		SARS sawmill 2	
Variable	**Characteristic**	**Freq.**	**(%)**	**Freq.**	**(%)**	**Freq.**	**(%)**
	Apron	-	-	-	-	-	-
	Safety boot	√	-	-	-	-	-
	Helmet	-	-	-	-	-	-
	Eye goggle	√	-	-	-	-	-
	Ear plug or muff	-	-	-	-	-	-

Table 8. Safety awareness and attitude of sawmill employees

		Rumosi Sawmill		SARS Sawmill 1		SARS Sawmill 2	
Variable	**Response**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Attitude to use of PPE	Not important	1	25	1	25	-	-
	Important	2	50	2	50	4	100
	Indifferent	1	25	1	25	-	-
Is PPE of any benefit to you	No	-	-	-	-	-	-
	Don't know	2	50	2	50	0	-
	Yes	2	50	2	50	4	100
Frequency of PPE use	Always	-	-	-	-	-	
	Rarely	3	75	4	100	4	100
	Sometimes	1	25	-	-	-	-
Reason for non-use of PPE	Don't know how to use	-	-	-	-	-	-
	Dislike PPE	-	-	-	-	-	-
	Expensive to purchase	-	-	-	-	-	-
	Not aware of PPE	-	-	-	-	-	-
	Slow down speed of work	-	-	-	-	-	-
	Inconveniencing	4	100	-	-	-	-
	Non available	-	-	4	100	4	100

Table 9. Prevalence of respiratory symptoms among the sawmill workers

		Rumosi Sawmill		SARS Sawmill 1		SARS Sawmill 2	
Variable	**Response**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
Cough	Yes	3	75	3	75	3	75
	No	1	25	1	25	1	25
Chest pain	Yes			1	25	3	75
	No	4	100	3	75	1	25
Sputum production	Yes						
	No	4	100	4	100	4	100
Shortness of breath	Yes						
	No	4	100	4	100	4	100
Dysnoea	Yes						
	No	4	100	4	100	4	100
Wheeze	Yes						
	No	4	100	4	100	4	100
Recurrent chest pain	Yes					2	50
	No	4	100	4	100	2	50
Difficulty in breathing	Yes			1	25		
	No	4	100	3	75	4	100

majority of the respondent 3(75) reported having cough and majority 3(75%) also reported having chest pain, while 2(50%) reported having recurrent chest pain while working at the sawmill.

3.7 Discussion

This work was carried out to ascertain the extent air pollution around sawmilling site in Port Harcourt and the associated health hazards. In the present study, ambient temperature at sawmilling sites and concentrations of VOCs, CO, CO_2, NO_2, O_3, H_2S, CH_4, SO_2 and suspended particulate matter were measured and compared with the Federal Ministry of Environment (FMEV) and World Health Organisation (WHO) Standards. Results showed that estimates of the monitored physicochemical parameters varied with time and site of sampling. At Rumosi, SO_2, VOCs and TSP concentrations exceeded the FMEv & WHO limit irrespective of the time and day of sampling, while the temperature, $PM_{2.5}$, PM_{10}, & NO_2 varied within and Control the FMEV & WHO acceptable standard. At SARS Road Sawmill 1, VOCs, PM_{10}, TSP and noise level exceeded the FMEV limit. At SARS Road Sawmill 2, SO_2, NO_2, VOCs, PM_{10}, TSP and noise level also exceeded the limit. SO_2, VOCS, CO, CH_4, NH_3, NO_2, O_2 and O_3 were significantly different across locations ($P<0.05$), while NO_2 ($p=0.408$), CO_2 ($p=0.286$), H_2S ($p=0.055$) $PM_{2.5}$ ($p=0.087$), PM_{10} ($p=0.278$), TPS ($p=0.259$), noise ($p=0.071$), wind speed (0.332) temperature (0.948) and relative humidity (0.364) were not.

The VOCs concentrations at the three location were distressingly high and raise concern for the respiratory health of workers at the sawmills. The VOCs level reported in this study is higher than value reported by Raimi et al. [22] ranged from 0.2-30 ppm, in a study of sawmills in Ilorin, Kwara State. Wood processing activities at sawmills include the use of many chemicals preservatives and other chemicals discharged from the machineries. These chemicals are released into the ambient air causing elevated levels of VOC in surrounding environment hence increasing the levels of concentration of photochemical oxidants [22]. Elevated levels of VOCs could lead to respiratory problems and may cause distress to asthmatics among industrial workers. These VOCs react with primary anthropogenic pollutants especially, NO_2, SO_2 and anthropogenic organic carbon compounds-to produce haze of secondary pollutants [22].

At the time of sampling, the suspended particulate matter especially PM_{10} and TSP were distressingly high within the sawmill and at the control points, exceeding the Federal Ministry of Environment (FMEv) & World Health Organization (WHO) standards which is a cause for concern. Rumosi sawmill, SARS Road sawmill 1, and SARS Road sawmill 2 recorded the highest PM_{10} with a mean value of 348.350µg/m^3, 153.850µg/m^3, 347.050µg/m^3 respectively and least mean value of 112.200µg/m^3, 79.100µg/m^3, 95.150µg/m^3 respectively. Adeoye et al. [23] in a descriptive cross-sectional study carried out in 84 sawmills in Osun State reported that total suspended particles matter in the sawmill environments were high and they could cause various degrees of pulmonary impairment. Raimi et al. [22] similarly reported high PM_{10} values in their studies. At Rumosi sawmill and SARS Road Sawmill 1, $PM_{2.5}$ highest mean value of 209.100 µg/m^3 & 132.050 µg/m3 respectively, exceeded the FMEv and WHO standard. Giannadaki et al. [24] noted that PM is a major concern as a cause for poor health and premature death globally. Natural causes contribute significantly to PM levels in Nigeria which is a sub-Saharan country. Having industrial pollution contributing to elevated levels of PM would only further aggravate an already fragile situation. Prolonged exposure to high concentration levels of PM_{10} may cause irritation of the respiratory tract and bronchitis [25].

Increased level of Particulate Matter (PM) within and around the sawmill can also be a contributing factor to climate change and visibility degradation has a direct & indirect effect on climate change [26].

High SO_2 concentration was observed at Location 1 and 3. Adelagun et al. [27] also reported a high SO_2 concentration ranging from 0.23 – 0.60ppm in a study of sawmills at Ebute-Meta, Lagos State. Areas with high SO_2 concentrations are susceptible to acid rain and other associated hazards caused by pollution. Elevated values of CO and NO_2 were also detected in this study, which might have implication for human health and also exert climatic effects. NO_2 is also in respiratory diseases while carbon monoxide a muscle paralyzing and neurotoxic compound can lead to death presumably due to asphyxiation. The mean temperatures measured in this study are well within tolerable limit of a tropical climate.

The geometric mean of THBC was 8846 CFU/ m^3 (inside) and 4182 CFU/ m^3 (Control) while the mean THF was 4921 CFU/ m^3 (inside) and 3349 CFU/ m^3 (Control). Comparison of the mean THBC and TFC revealed no statistical significant difference across the three locations for both THBC and TFC. The proposed occupational exposure limit (OEL) for spores is $1\text{-}10^5$ spores/m^3 and values of TFC in this study fell within the limit. Sawane and Sawane [28] reported a mean of 72.26 x 10^3 CFU/m^3 for bacteria 65.91 x 10^3 CFU/m^3 for fungi in their work, which is close in range with this study. Tobin et al. [15] reported TVC and TFC > 4162.99 CFU/m^3. Park et al. [29] reported a much lesser mean levels of airborne bacteria and fungi (1.864 CFU/m^3 and 2.252 CFU/ m^3) than reported in this study. The indoor/outdoor concentrations ratio of bacteria and fungi in this study are 2.0 and 1.5. However, there was no statistical significant difference between the indoor and outdoor microbial counts. Park et al. [29] in their study reported a higher ratio of 3.7 and 4.1 for bacteria and fungi respectively. The difference in value might be attributed to the sampling sites, as all the sites in this study were semi-enclosed which could allow for air current to disperse the airborne microorganisms and their spores further from the operating site.

The bacteria isolated from the air at the sawmills are species of *Aeromonas, Citrobacter*, *Staphylococcus*, *Micrococcus*, *Klebsiella*, *Serratia*, *Pseudomonas*, *Proteus, Providencia, Shigella, Enterobacter* and *Bacillus*. Okafor-Elenwo et al. [30] isolated five bacteria species from the bioaerosols and sawdust collected from sawmills at Okoda, Edo State among which are *Bacillus*, *Klebsiella, Micrococcus, Staphylococcus,* and *Serratia* which were also isolated in the present study. Park et al. [29], Oppliger et al. [31] as well as Baranu and Edmund [32] have all reported similar microorganisms in other sawmill factories. The bacteria in the organic dust may infiltrate into the lungs and release endotoxins that may most likely cause adverse health effects in humans that are exposed to sawdust. The airborne fungi may also cause chronic infections such as pulmonary aspergillosis and aspergilloma, particularly in immune-compromised humans that are exposed to sawdust [30]. *Pseudomonas* species are endotoxin-producing bacteria with some known to cause respiratory infections. According to Dutkiewicz et al [11], gram-negative bacteria pose the greatest risk among bacteria present in wood processing sites, because of their ability to produce endotoxins. Gioffre et al. reported that people working in wood factories may be exposed to high levels of inhalable endotoxins.

The fungi isolated from the air at the sawmills are species of *Penicillium*, *Fusarium*, *Geotrichium*, *Cladosporium*, *Rhizopus* and *Trichophyton, Aspergillus*. Okafor-Elenwo et al. [30] similarly isolated *Aspergillus*, *Cladosporium* and *Penicillium.* Sawmills bioaerosols have been reported to contain fungal spores of *Aspergillus*, *Penicillium*, *Rhizopus* and *Mucor* in several studies conducted in Europe [6,33,34]. *Aspergillus* and *Penicillium* were identified to induce IgE-mediated sensitization, and to cause atopic respiratory diseases among subjects in Croatia [35]. Allergenic fungi associated with wood products pose great risk for respiratory diseases [11]. Species of *Penicillium* and *Aspergillus* are reported to cause symptoms of allergic respiratory diseases.

Reports from previous studies on the occupational hazards of sawmilling operations overwhelming concurred that workers exposed to the inhalable fraction of the waste are at risk of respiratory anomalies. A survey of the socio-demographic characteristic of the respondents revealed that all respondents are male, majority of which were middle aged 35-44, married, with minimal education (primary and secondary). This goes to affirm that the industry is dominated by the masculine gender, obviously because of risk involved in heavy lifting and operation of machineries. Brefo [2] posited that sawmill operation is dominated by male than female because women fear to engage in activities that are dangerous and requiring physical strength. Agu et al. [18] and Omole et al. [36] in agreement with this study reported that most sawmills workers in Nigeria have just secondary school level of education. A greater portion of the respondents in this study affirmed that medical examination was not provided by employer before starting work at sawmill, nor any training provided for the job and no medical service for first aid and treatment were provided by the employer. Provision of training opportunities for workers before employment can greatly help in the reduction of workplace incidence and accident. Tobin et al. [15] reported that sawmills operating in Nigeria face the hurdle of providing work environments where control of hazards is not given attention.

Adeoye et al. [23] reported that the issue of the use of PPE was not given serious attention in sawmills sampled in Osun State, as majority were not having the PPE required for sawmilling operations, except for three sawmills out of 10 that had one person each using hand gloves and one sawmill with two persons using goggle. Osagbemi et al. [15], Bamidele et al. [17], Agu et al. [18] and Johnson and Umoren [19], in their studies of occupational hazards and health problems reported among Sawmill workers in the Nigerian cities of Ilorin, Osogbo, Abakiliki and Uyo, all reported a generally poor use of PPE.

In the present study, all the respondents at one location mentioned that they find the use of PPE inconvenient as reason for non-use, while all respondents at the other two locations said non-availability as their reason for non-use of PPE. Faremi et al. [37] reported inconvenience and forgetfulness as reason given by sawmill workers for non-utilization of PPE. Agu et al. [18] reported unawareness of PPE and non-availability as the major reasons for non-use of PPE among sawmill workers.

Majority of the respondent in this study agreed to the importance of using PPE as they considered it beneficial to them. Similarly, majority of respondents in the study by Faremi et al. [37] accented to the importance and benefit of using PPE. The awareness level regardless did to translate to more usage in the present study because PPE were generally unavailable.

The respiratory symptoms reported by respondents in this study were cough and chest pain. By nature of the waste generated in sawmills which is often high in particulate matter, it is expected that obstruction of respiratory and chest congestion, leading to pain, would occur. Tobin et al. [15] reported a high prevalence of respiratory symptoms among sawmill workers in Egor, Edo State, of which cough and phlegm production were commonly reported. Agu et al. [18] stated that the most frequently reported respiratory symptoms among sawmill workers in Abakiliki were cough chest pain. Brefo [2] also reported cough as the predominant health problem reported by sawmill workers in Ghana. Faremi et al. [37] reported difficulty in breathing as the commonly reported occupational hazard among sawmill workers in Ile Ife, Osun State.

4. CONCLUSION

The present study has shown that the air at sawmills in Port Harcourt contain particulate matter made up of gaseous toxicants, microorganisms and wood dust, which pollute the air and impact on the health of workers. It was shown that sawmills within Port Harcourt do not pay much attention to the provision and use of PPE, as they were generally not provided. The study also showed that workers commonly reported cough and chest pain which they associated to their jobs. It is necessary to improve the occupational health conditions of workers at these sawmill.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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