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Assessment of Common Ambient Air Pollutants and Respiratory Health Outcomes among Road Construction Workers in Imo State, Nigeria

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ABSTRACT

Road construction workers are more likely to experience respiratory health problems because they are frequently exposed to air pollution. The purpose of this study was to assess the common ambient air pollutants and respiratory health outcomes among Nigerian road construction workers in Imo State. A cross-sectional study was conducted in Imo State, Nigeria, with 353 road construction workers from Imo State's three senatorial zones selected using a multistage sampling technique. Gas meters placed at key points were used to measure the ambient concentrations of carbon monoxide (CO), sulphur dioxide (SO_2), and suspended particulate matter (SPM) at construction sites. Respiratory symptoms and forced vital capacity (FVC) of the road construction workers were assessed by qualified health professionals. The mean CO, SO_2, and SPM concentrations in Imo West were 182.40±6.41ppm, 516.24±55.03µg/m^3, and 1956.22±30.75µg/m^3 respectively; in Imo East, 185.34±6.46ppm, 518.26±55.12µg/m^3, and 1960.17±30.79µg/m^3 respectively; and in Imo North, 187.51±6.49ppm, 520.14±55.34µg/m^3, and 1956.68±30.25µg/m^3 respectively. In all zones, CO, SO_2, and SPM levels significantly exceeded safe thresholds, according to the one-way ANOVA analysis ($p<0.05$) performed with SPSS. Among the most common respiratory health problems were coughing, 211 (59.77%); sneezing, 290(82.15%); catarrh, 79(22.38%); sore throat, 72(20.39%); asthma, 29(8.22%); short breath, 121(34.28%); pneumonia, 66(18.70%); headache, 133(37.68%); and wheezing, 170(48.16%). Mean FVC values were 2263.34±482.33 ml (Imo West), 2578.80±751.80 ml (Imo East), and 2382.78±610.42 ml (Imo North). To mitigate respiratory health risks, road construction workers are strongly recommended to consistently use personal protective equipment, particularly respiratory masks, during work activities.

INTRODUCTION

Road construction workers' respiratory health is seriously endangered by the exposure to hazardous pollutants such as dust, respirable crystalline silica (RCS), diesel exhaust fumes, and other toxic gases that come with road building activities (Boadu *et al.,* 2023; Sarabi *et al.,* 2025). Asthma, chronic bronchitis, and diminished lung function are among the respiratory disorders associated with these pollutants, which are produced by activities such as excavation, material handling, and heavy machinery operations (Kunar & Mandal, 2025; Landwehr *et al.,* 2023). Road building is a crucial industry in Nigeria, especially in Imo State, yet little is known about the risks to employees' occupational health (Bwala *et al.,* 2025). Effective interventions and regulations to safeguard these workers are hampered by the absence of thorough data on exposure to air pollutants and the health effects of those exposures. By measuring the concentrations of common ambient air pollutants, including SPM, CO, and SO_2, at road building sites in Imo State, Nigeria, and analyzing their relationship to worker respiratory health effects, this study fills this knowledge gap. In order to reduce occupational health risks in this population, this study measured pollutant exposure, ascertained the frequency of respiratory symptoms, and presented data to support the development of policies and focused interventions.

LITERATURE REVIEW

Road and industrialization construction activities expose workers to hazardous compounds that might harm their respiratory health, making it a major source of ambient air pollution (Abdullahi *et al.,* 2022; Hasan *et al.,* 2021; Sarabi *et al.,* 2025). Road construction workers' occupational health risks are increased by the physically taxing nature of road construction as well as exposure to pollutants from materials and processes. Significant air pollutants are produced by operations including site clearance, earthworks, material manufacture, and driving heavy machinery on unpaved roads (Wang *et al.,* 2025). According to a meta-analysis, the main occupational hazards causing respiratory disorders among road construction workers are dust, RCS, fumes, vapours, asbestos, fibres, and gases (Boadu *et al.,* 2023). Excavation, tunnelling, demolition, sandblasting, grinding, masonry, rock drilling, road grading, milling, and wood processing (such as cutting, planing, and sanding) are among the tasks that expose workers to dust (Boadu *et al.,* 2023). Handling fine particles of cement, fly ash, bricks, mortar, and sandstone, as well as mixing cement and concrete, are common operations that include RCS, a particularly dangerous pollutant (US Department of Labor Occupational Safety and Health Administration, 2024).

Respiratory hazards are further increased by fumes,

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usually from welding, diesel exhaust, and asphalt (Kunar & Mandal, 2025). Road construction and repair require heavy machinery, most often diesel-powered. Chronic bronchitis and asthma are among the respiratory disorders linked to extended exposure to diesel exhaust fumes (Landwehr *et al.,* 2023; Mo *et al.,* 2022). Road construction workers, regrettably, frequently work long hours, increasing their exposure to dangerous materials and, as a result, the risk to their respiratory health (WHO, 2021). Road construction workers frequently work long shifts, which increases their exposure to these dangerous compounds and raises their risk of respiratory health problems issues (Boadu *et al.,* 2023; Yasmeen & Hafeez, 2023). Despite this data, there is a paucity of studies in Imo State to assess the occupational respiratory risks of road transport workers; hence, this study aims to contribute to the development of targeted treatments and policies to mitigate the hazards to respiratory health of road construction workers in the region.

MATERIALS AND METHODS

Population of the Study

The study population consisted of all road construction workers employed at construction sites across Imo State, Nigeria.

Study Area

This study was conducted among road construction workers aged 18 years and older in Imo State, located in the South-Eastern region of Nigeria. With a total area of roughly 5,100 km^2, Imo State is located between the lower River Niger and the upper and middle Imo River. Its latitudes range from 4°45'N to 7°15'N and its longitudes from 6°50'E to 7°25'E.

Sample Size Determination

Cochran's formula for cross-sectional research was used to determine the minimal sample size (Ogbeibu, 2014):

$n=(Z^2 Pq)/d^2$

Where p is the percentage of construction workers having respiratory issues (35.5%) from a prior study (Isara *et al.,* 2016), q is (1-p), d is the allowable margin of error (0.05), and n is the minimum sample size.

$\therefore$ $n=(1.96^2 X 0.355 X 0.645)/0.05^2= 351.85= 352$

A minimum sample size of 352 was established; in the end, 353 road construction workers participated in the survey.

Sampling Technique

The selection of the 353 participants was conducted using a multistage sampling technique. Imo State was divided into its three senatorial zones: Imo West, Imo East, and Imo North, in the initial phase. The major construction sites in each senatorial zone's local government areas were randomly selected from a compiled list of all construction sites for the second stage. In the third stage, individual road construction workers at these sites were selected using simple random sampling. A total of 121, 122, and 110 workers were recruited from Imo West, Imo East, and Imo North, respectively. Inclusion criteria included being employed as a road construction worker, being aged 18 years or older, and having at least six months of experience in the profession. Exclusion criteria included non-road construction workers, those who did not provide consent, and workers with acute illnesses.

Method of Data Collection

Data was collected using the following instruments:

- A structured questionnaire to capture demographic and health-related information.
- A sphygmomanometer measures blood pressure.
- A spirometer to assess forced vital capacity (FVC).
- Gas meters to measure ambient levels of CO, SO_2, and SPM at strategic locations on construction sites.

Method of Data Analysis

Data was entered and analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 23. Continuous and categorical variables were summarised using descriptive statistics, such as means and frequency distributions, respectively, and displayed in tabular form. With a 95% confidence interval and a significance level of 0.05, an analysis of variance (ANOVA) was used to assess variations in ambient air pollutant concentrations and the frequency of respiratory symptoms among the three senatorial zones.

Ethical Consent

Ethical approval was obtained from the Ethical Committee of the Department of Public Health, School of Health Technology, Federal University of Technology, Owerri, Imo State, Nigeria. Informed written consent was obtained from all participants prior to their inclusion in the study.

RESULTS AND DISCUSSION

A total of 353 male road construction workers from the three senatorial zones of Imo State, Nigeria (Imo East, Imo West, and Imo North), participated in this study. The data are summarized in Tables 1–7, where "n" denotes the number of participants and "%" represents the percentage.

Age Demographic Profile of Road Construction Workers

This study found that all the participants (road construction workers) were males. There were more 31–40-year-olds (33.43%) and 41-50-year-olds (27.76%), compared to the 18-30-year-olds (17.85%), as shown in Table 1. Road construction is a labour-intensive industry that involves heavy machinery, such as tractors, cement mixers, bulldozers, and excavators, which emit dust and gases, exposing workers to hazardous pollutants (Nikolay, 2018). The male majority in this study was comparable to earlier studies on road construction workers in Ghana's Western North, Ashanti, and Ahafo regions (Yankson *et al.,* 2023). The preponderance of men in construction may be due to the nature of the work, which involves hard labour such as removing rocks and dirt, constructing pavement, clearing vegetation, and building embankments.

Table 1: Age Demographic Profile of Road Construction Workers

Age group (years)	Imo West n(%)	Imo East n(%)	Imo North n(%)	Total n(%)
18-30	18(5.1)	22(5.38)	23(6.51)	63(17.85)
31-40	43(12.18)	38(10.76)	37(10.48)	118(33.43)
41-50	35(9.92)	31(8.78)	32(9.07)	98(27.76)
Above 50	25(7.08)	31(8.78)	18(5.10)	74(20.96)

Awareness of Air Pollution Across Senatorial Zones

Across the three senatorial zones, the majority of respondents strongly agreed with the following statements: road construction is a major source of dust (70.21%, n=248), dust can cause respiratory problems (93.01%, n=328), road construction materials contain harmful chemicals (87.81%, n=310), workers should consistently use personal protective equipment (PPE) (87.85%, n=310), rain and cold weather reduce dust levels (64.06%, n=226), and sunny weather promotes distant air movement (65.31%, n=231), as shown in Table 2. However, 0.53% (n=4) disagreed that road construction materials contain hazardous chemicals, and 5.33% (n=38) disagreed that road construction is a significant source of dust.

Table 2: Response of all subjects in Imo State on Air Pollution Awareness

Information on Air Pollution	Strongly Agree (%)	Agree (%)	Disagree (%)	Strongly Disagree (%)
GENERAL (ALL THE THREE ZONES)				
Road construction is a major source of dust	274(70.21)	27(7.03)	38(5.33)	0(0.00)
Dust can cause respiratory health problems	303(93.01)	15(3.90)	0(0.00)	0(0.00)
Road construction materials contain harmful chemicals	322(87.81)	38(9.64)	4(0.53)	0(0.00)
Workers should always wear their PPE	311(87.85)	35(9.89)	0(0.00)	0(0.00)
Rain and cold weather reduce dust	278(64.06)	76(33.45)	0(0.00)	0(0.00)
Sunny weather promotes distant air movement	229(65.31)	40(11.30)	0(0.00)	0(0.00)
IMO WEST				
Road construction is a major source of dust	97(82.45)	7(8.50)	4(1.50)	0(0.00)
Dust can cause respiratory health problems	82(73.30)	5(5.00)	0(0.00)	0(0.00)
Road construction materials contain harmful chemicals	95(85.57)	8(7.30)	0(0.00)	0(0.00)
Workers should always wear their PPE	106(91.24)	10(9.17)	0(0.00)	0(0.00)
Rain and cold weather reduce dust	85(77.55)	10(8.86)	0(0.00)	0(0.00)
Sunny weather promotes distant air movement	94(86.90)	15(10.56)	0(0.00)	0(0.00)
IMO EAST				
Road construction is a major source of dust	90(80.45)	7(9.50)	4(1.50)	0(0.00)
Dust can cause respiratory health problems	93(88.30)	9(6.00)	0(0.00)	0(0.00)
Road construction materials contain harmful chemicals	99(85.44)	7(6.35)	0(0.00)	0(0.00)
Workers should always wear their PPE	91(84.24)	18(13.18)	0(0.00)	0(0.00)
Rain and cold weather reduce dust	90(82.50)	15(12.86)	0(0.00)	0(0.00)
Sunny weather promotes distant air movement	98(89.90)	13(10.02)	0(0.00)	0(0.00)
IMO NORTH				
Road construction is a major source of dust	87(78.45)	10(9.11)	1(1.90)	0(0.00)
Dust can cause respiratory health problems	96(90.28)	12(9.60)	0(0.00)	0(0.00)
Road construction materials contain harmful chemicals	102(95.44)	4(6.35)	0(0.00)	0(0.00)
Workers should always wear their PPE*	91(85.29)	16(12.10)	0(0.00)	0(0.00)
Rain and cold weather reduce dust	100(92.92)	11(8.30)	0(0.00)	0(0.00)
Sunny weather promotes distant air movement	88(79.43)	11(9.02)	0(0.00)	0(0.00)

**PPE: Personal Protective Equipment*

Ambient Air Pollutant Levels Across Senatorial Zones

The mean concentrations of ambient air pollutants at construction sites are presented in Table 3. Imo West had 1940.50 ± 24.15 µg/m³ of suspended particulate matter (SPM), Imo East had 1960.17 ± 30.79 µg/m³, and Imo North had 1956.68 ± 30.25 µg/m³. These variations were statistically significant ($p<0.001$). Significant differences ($p<0.05$) were also seen in the levels of carbon monoxide (CO), which were 183.50 ± 2.17 ppm in Imo West, 185.34 ± 6.46 ppm in Imo East, and 187.51 ± 6.49 ppm in Imo North. Sulfur Dioxide (SO_2) levels were 499.17 ± 42.92 µg/m³ in Imo West, 518.26 ± 55.12 µg/m³ in Imo East, and 520.14 ± 55.34 µg/m³ in Imo North, with significant differences ($p<0.001$).

Dust (soil, gravel, wood, silica, non-silica mineral, and demolition dust) and diesel exhaust emissions from heavy-duty vehicles and stationary engines are common pollutants found at construction sites (Toronto Environmental Alliance, 2024). Carbon monoxide, hydrocarbons, sulphur and nitrogen compounds, and carbon dioxide are all present in diesel exhaust (Geldenhuys *et al.,* 2022). The measurements made for this study showed that the concentrations of common ambient air pollutants from these common sources far exceeded the World Health Organization (WHO)'s acceptable criteria.

Ambient SPM Levels Across Senatorial Zones

The SPM levels, particularly $PM_{2.5}$ and PM_{10}, were significantly elevated in this study (Table 3). Due to their deep penetration into the lungs, the elevated SPM levels raise the risk of lung disease, emphysema, and lung cancer (Cohen *et al.,* 2005). $PM_{2.5}$ is particularly dangerous as it contributes to asthma, cardiovascular disease, and early mortality due to its toxic components, which include heavy metals and carcinogenic organic compounds (Cohen *et al.,* 2005). The study's high SPM levels (1906–1981 µg/m³) and the 158.07–1763.37 µg/m³ SPM range reported in Chinese building sites (Fang *et al.,* 2025) both point to the urgent need for dust management measures.

Table 3: Suspended Particulate Matter (SPM) Levels at Construction Sites across Senatorial Zones in Imo State

GPS Location North	GPS Location East	SPM (µg/m³)
IMO WEST		
5.4882°	7.0175°	1930
5.4859°	7.0171°	1906
5.4840°	7.0180°	1934
5.4833°	7.0169°	1940
5.4851°	7.0173°	1977
5.4889°	7.0182°	1956
Mean ± Standard deviations:		1940.5 ± 24.15
P-value:	<0.0001	
IMO EAST		
5.7822°	7.0390°	1942
5.7835°	7.0388°	1956
5.7830°	7.0398°	1923
5.7846°	7.0383°	1959
5.7892°	7.0381°	1960
5.7851°	7.0398°	1941
Mean ± Standard deviations:		1960.17 ± 30.79
P-value:	0.01	
IMO NORTH		
5.8191°	7.3411°	1945
5.8170°	7.3406°	1933
5.8186°	7.3424°	1909
5.8198°	7.3439°	1962
5.8182°	7.3401°	1981
5.8169°	7.3453°	1963
Mean ± Standard deviations:		1956.68 ± 30.25
P-value:	<0.001	

Ambient CO Levels Across Senatorial Zones

Elevated CO levels portend major health risks because haemoglobin has a stronger affinity for CO than oxygen and forms carboxyhaemoglobin (HbCO), which reduces oxygen delivery to tissues and leads to hypoxia (Offiah *et al.,* 2022). While chronic CO exposure can lead to melancholy, memory loss, and in extreme situations, central nervous system and heart poisoning or death, acute exposure can elicit symptoms including light-headedness, disorientation, headaches, and vertigo. Haemoglobin has a greater affinity for CO than oxygen, and forms carboxyhaemoglobin (HbCO), which lowers oxygen delivery to tissues and causes hypoxia (Offiah *et al.,* 2022). This makes elevated CO levels a serious health risk. While chronic CO exposure can lead to melancholy, memory loss, and in extreme situations, central nervous system and heart poisoning or death, acute exposure can elicit symptoms including light-headedness, disorientation, headaches, and vertigo (Mishra & Krishnan, 2016). As seen in Table 4, the study's measured CO levels (180–189 ppm) were much higher than the maximum CO range of 2.10–2.27 ppm recorded at another construction site in Lagos State, Nigeria, and well beyond the 100ppm threshold considered harmful to human health (Owolabi *et al.,* 2024). These disparities could have been caused by differences in the various geographic locations' seasonal weather patterns, human activities, and meteorological circumstances.

Table 4: Carbon Monoxide (CO) Levels at Construction Sites across Senatorial Zones in Imo State

GPS Location North	GPS Location East	CO (ppm)
IMO WEST		
5.4882°	7.0175°	183
5.4859°	7.0171°	181
5.4840°	7.0180°	183
5.4833°	7.0169°	182
5.4851°	7.0173°	187
5.4889°	7.0182°	185
Mean ± Standard deviations:		183.5 ± 2.17
P-value:	<0.0001	
IMO EAST		
5.7822°	7.0390°	185
5.7835°	7.0388°	186
5.7830°	7.0398°	184
5.7846°	7.0383°	180
5.7892°	7.0381°	185
5.7851°	7.0398°	189
Mean ± Standard deviations:		185.34 ± 6.49
P-value:	<0.0001	
IMO NORTH		
5.8191o	7.3411°	188
5.8170o	7.3406°	185
5.8186o	7.3424°	181
5.8198o	7.3439°	180
5.8182o	7.3401°	185
5.8169o	7.3453°	187
Mean ± Standard deviations:		187.51 ± 6.49
P-value:	0.02	

Ambient SO_2 Levels Across Senatorial Zones

This study's ambient SO_2 levels were significantly higher ($p<0.001$) across senatorial zones, as shown in Table 5, which could have an impact on respiratory health. Although SO_2 is primarily absorbed by the upper airways' mucous membranes, increased ventilation (e.g., during physical labour) can deliver higher doses to the lungs, causing bronchoconstriction, reduced lung function, and respiratory symptoms (Adetoun-Mustapha *et al.,* 2011; Thacher *et al.,* 2013).

Long-term exposure to SO_2 has been linked to respiratory issues even at lower doses (0.4–3.0 ppm); however, attribution is made more difficult by confounding factors, including co-exposure to other pollutants (Rodney *et al.,* 2024). The high SO_2 values (499–520 μg/m³) in this study, which were higher than the average level of 17.95±7.44 μg/m³ recorded in India (Singh *et al.,* 2023) suggest a significant risk to the respiratory health of Nigerian road construction workers.

Table 5: Sulphur dioxide (SO_2) Levels at Construction Sites across Senatorial Zones in Imo State

GPS Location North	GPS Location East	SO_2 (μg/m³)
IMO WEST		
5.4882°	7.0175°	460
5.4859°	7.0171°	559
5.4840°	7.0180°	453
5.4833°	7.0169°	477
5.4851°	7.0173°	510
5.4889°	7.0182°	536
Mean ± Standard deviation:		499.17 ± 42.92
P-value:	<0.0001	
IMO EAST		
5.7822°	7.0390°	466
5.7835°	7.0388°	557
5.7846°	7.0383°	449
5.7892°	7.0381°	590
5.7851°	7.0398°	544
Mean ± Standard deviations:		518.26 ± 55.12
P-value	<0.0001	
IMO NORTH		
5.8191°	7.3411°	449
5.8170°	7.3406°	578
5.8186°	7.3424°	461
5.8198°	7.3439°	480
5.8182°	7.3401°	503
5.8169°	7.3453°	522
Mean ± Standard deviations:		520.14 ± 55.34
P-value:	<0.0001	

Prevalence of Respiratory Health Problems Among Road Construction Workers

The findings of similar studies, including Ekpenyong *et al.* and Isara *et al.,* in Nigeria (Ekpenyong *et al.,* 2012; Isara *et al.,* 2016), and Mandal & Dutta (2022) in India which reported similar respiratory function impairment among

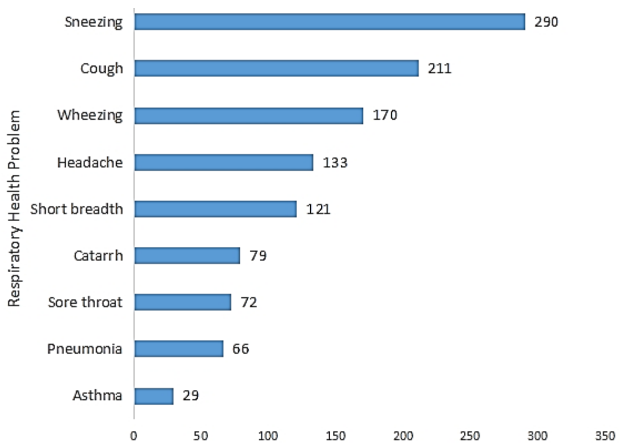

Figure 1: Distribution of Respiratory Health Problems among Road Construction Workers in Imo State

workers exposed to ambient air pollutants, are consistent with the high prevalence of symptoms like sneezing (82.15%, n=290), coughing (59.77%, n=211), wheezing (48.16%, n=170), headache (37.68%, n=133), shortness of breath (34.28%, n=121), catarrh (22.38%, n=79), sore throat (20.39%, n=72), pneumonia (18.70%, n=66), and asthma (8.22%, n=29) in this study (Figure 1).

Comparing Respiratory Health Issues Among Senatorial Zones

The distribution of respiratory symptoms among senatorial zones is shown in Table 6. Over half (56.50%, n=69) of Imo West, 58.50% (n=75) of Imo East, and 56.40% (n=62) of Imo North reported coughing. In Imo West, 76.45% (n=90), Imo East, 75.11% (n=88), and Imo North, 80.10% (n=85) of respondents reported sneezing. In Imo West, 21.47% (n=24), Imo East, 20.32% (n=26), and Imo North, 20.72% (n=28) of the population reported having diarrhoea. Headache was reported by 40.03% (n=45) in Imo West, 36.83% (n=44) in Imo East, and 42.14% (n=46) in Imo North. Wheezing was reported by 49.12% (n=54) in Imo West, 44.15% (n=52) in Imo East, and 53.45% (n=55) in Imo North.

Table 6: Sulphur dioxide (SO_2) Levels at Construction Sites across Senatorial Zones in Imo State

Health Problem	Imo West		Imo East		Imo North	
	n	%	n	%	N	%
Cough	69	56.50	75	58.50	62	56.40
Sneezing	90	76.45	88	75.11	85	80.10
Catarrh	24	21.47	26	20.32	28	20.42
Sore throat	23	20.05	24	19.50	20	19.87
Asthma	8	6.49	10	7.32	7	5.45
Short breadth	40	35.80	42	37.59	33	29.23
Pneumonia	26	18.43	27	20.36	24	18.90
Headache	45	40.03	44	36.83	46	42.14
Wheezing	54	49.12	52	44.15	55	53.45

Comparison of Forced Vital Capacity Values Across Senatorial Zones

Mean Forced Vital Capacity (FVC) values were 2263.34 ± 482.33 ml in Imo West, 2578.80 ± 751.80 ml in Imo East, and 2382.78 ± 610.42 ml in Imo North, as shown in Table 7. Seventeen workers had reduced FVC values of 0-1000ml according to spirometry results (Table 7), which may indicate respiratory impairment (Mason *et al.,* 2010). The workers' infrequent FVC monitoring exposes a gap in occupational health surveillance, as gradual lung function deterioration may not be detected until serious harm is already done (Lynch *et al.,* 2021; Wallbanks *et al.,* 2024).

Table 7: Comparison of Forced Vital Capacity values of Road Construction Workers at different Senatorial zones

		Imo West		Imo East		Imo North	
FVC (ml)	**Total**	**N**	**%**	**n**	**%**	**N**	**%**
0 – 1000	17	6	5.0	7	5.7	4	3.6
1001 – 2000	63	24	19.8	19	15.6	20	18.2
2001 – 3000	200	66	55.0	68	55.7	66	60.0
3001 – 4000	63	20	16.7	23	18.9	20	18.2
4001 – 5000	10	5	4.2	5	4.1	0	0.0
Total	353	121	100.00	122	100.00	110	100.00
Min (Max)		1250 (3270)		1190 (4118)		1885 (4491)	
Mean ± Std Dev		2263.3 ± 482.3		2578.8 ± 751.80		2382.8 ± 610.4	
P-value		P=0.17					

CONCLUSIONS

This study evaluated ambient air pollutant levels at road construction sites in Imo State, Nigeria, and their impact on workers' respiratory health. The key findings were that road construction workers are exposed to high levels of ambient air pollutants (CO, SO_2, SPM) exceeding WHO safe limits. The respiratory symptoms, such as wheeze, sneezing, coughing, and shortness of breath, were highly prevalent, with FVC values indicating compromised lung function in some workers. A proportion of employees were ignorant of the dust and chemical hazards associated with road building. These findings highlight the urgent need for protective measures, including mandatory high-quality PPE, routine health monitoring with spirometry, and environmental controls like cleaner fuels and dust suppression, strict enforcement of air quality regulations, and worker education awareness campaigns. Future research should include longitudinal studies to assess long-term effects, biomonitoring for health impacts, indoor-outdoor exposure comparisons, and comparative geographic comparisons in other regions to support national policy development. Immediate action is critical to safeguard workers' respiratory health and ensure compliance with environmental and occupational safety standards.

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