



## Assessment of air quality and occupational exposure risks in automobile mechanic workshops along the Mofor–Orhuwhorun Axis, Udu Local Government Area, Delta State, Nigeria

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### Abstract

This study assessed air quality and occupational exposure risks in automobile mechanic workshops within the Mofor–Orhuwhorun axis of Udu Local Government Area, Delta State. The study aimed to quantify selected air pollutants—carbon dioxide (CO<sub>2</sub>), total volatile organic compounds (TVOCs), formaldehyde (HCHO), halogen gases, combustible gases, particulate matter (PM<sub>0.3–10</sub> μm)—and noise levels, and to evaluate their implications for human health. A 13-day sampling period was conducted, complemented by a questionnaire survey (Q1–Q18) administered to mechanics across five age categories. Pollutant concentrations were analysed for daily mean and standard error of mean (SEM), while correlation, regression, and Chi-square tests determined relationships among variables and demographic factors. Results revealed that pollutant concentrations frequently exceeded permissible limits, reflecting poor ventilation and high emission intensity. CO<sub>2</sub> ranged from 384.00–1,987.45 ppm, TVOCs averaged 0.89 mg/m<sup>3</sup>, and HCHO exceeded the WHO guideline of 0.1 mg/m<sup>3</sup> on multiple days. Fine and ultrafine particulates (PM<sub>0.3–1.0</sub> μm) dominated the airspace, contributing over 85% of total particulate load. Regression analysis identified CO<sub>2</sub> as the most significant predictor of particulate concentration ( $p = 0.0121$ ), indicating that combustion processes are the major source of airborne pollutants. Chi-square results revealed significant associations between age, work experience, exposure duration, and protective behaviour ( $p < 0.05$ ). The study concludes that air quality in the workshops is severely degraded, posing serious respiratory and systemic health risks. It recommends improved ventilation, regular air monitoring, and strict enforcement of occupational safety regulations to safeguard worker health and minimise environmental pollution.

**Keywords:** Occupational air quality, automobile mechanic workshops, particulate matter exposure, volatile organic compounds, noise pollution

### Introduction

Rapid urbanisation and the expansion of informal industrial activities have intensified concerns about air quality deterioration in occupational environments, particularly within small-scale automobile mechanic workshops common across many developing regions (Chakraborty & Sahu, 2025) [14]. These workshops often operate in open or semi-enclosed spaces with limited infrastructure, poor ventilation, and minimal regulatory oversight, creating conditions that favour the accumulation of airborne pollutants (Izyati *et al.*, 2023) [23]. Mechanics working in such environments are routinely exposed to emissions arising from fuel combustion, engine testing, solvent use, welding, spray painting, and tyre servicing (Khalid & Kadhim, 2025) [26]. Over time, sustained exposure to these contaminants poses significant risks to respiratory, cardiovascular, neurological, and systemic health, while also contributing to ambient environmental pollution within surrounding communities (Du *et al.*, 2024) [17].

Air pollutants commonly encountered in automobile mechanic workshops include carbon dioxide, volatile organic compounds, formaldehyde, halogenated gases, combustible gases, and particulate matter across a wide aerodynamic size spectrum (Diambalou *et al.*, 2023) [16]. Fine and ultrafine particulates are of particular concern due to their ability to penetrate deep into the respiratory tract and translocate into systemic circulation, thereby amplifying toxicological effects (Jeon *et al.*, 2024) [24]. In addition to chemical pollutants, excessive noise generated from engines, compressors, hammering, and other mechanical

operations represents a major occupational hazard, with implications for auditory health, stress response, and overall worker productivity (Li *et al.*, 2025) [29]. The combined exposure to chemical and physical stressors creates a complex risk profile that is often underestimated in informal occupational settings (Kanu *et al.*, 2025) [25].

In many low- and middle-income countries, automobile repair activities are largely unregulated, and occupational health and safety practices are inconsistently applied (Anthony *et al.*, 2024) [6]. The use of personal protective equipment is frequently limited by poor awareness, economic constraints, and discomfort during prolonged work hours (Santofimio *et al.*, 2024) [39]. Furthermore, prolonged work duration, early entry into the trade, and cumulative exposure over several years may exacerbate vulnerability to adverse health outcomes. Demographic factors such as age and work experience may therefore influence exposure patterns, risk perception, and protective behaviour among mechanics. Understanding these relationships is essential for developing targeted interventions aimed at reducing occupational health risks (Afolabi *et al.*, 2021; Permatasari *et al.*, 2023) [2, 36].

Despite the growing recognition of environmental and occupational health challenges associated with informal industrial activities, empirical data on integrated air quality assessment within automobile mechanic workshops remain limited, particularly in rapidly industrialising regions of the Niger Delta (Igibah *et al.*, 2024) [21]. Many existing studies focus on single pollutants or short monitoring periods, providing an incomplete picture of exposure dynamics

(Duru *et al.*, 2024; Francisca & Nkwa, 2025; Oyewale *et al.*, 2024) [18, 20, 35]. Comprehensive assessments that combine real-time air quality monitoring with occupational surveys are necessary to capture both environmental conditions and human behavioural factors that influence exposure risk.

Against this background, the present study evaluates air quality and occupational exposure risks in automobile mechanic workshops within the Mofor–Orhuwhorun axis of Udu Local Government Area, Delta State. By quantifying multiple gaseous pollutants, particulate matter fractions, and noise levels over a defined monitoring period, and by integrating these measurements with demographic and behavioural data from workshop operators, the study provides a holistic assessment of environmental conditions and associated health risks. The findings are intended to inform evidence-based recommendations for improving workplace ventilation, enhancing risk awareness, strengthening regulatory enforcement, and promoting safer occupational practices in informal automotive repair environments.

### Materials and Methods

The study was conducted in automobile mechanic workshops located along the Mofor–Orhuwhorun axis of Udu Local Government Area, Delta State, Nigeria (specific coordinates is shown in Appendix 1). The area is characterised by intense vehicular activity and a high density of small- and medium-scale automobile repair workshops situated in close proximity to residential and commercial environments. A cross-sectional observational study design was adopted to assess occupational air quality under routine working conditions. Sampling was carried out over a 30-day period during peak operational hours (10:00 a.m. to 4:00 p.m.). Fifty (50) workshops were selected using stratified random sampling to ensure proportional representation of major workshop categories, including mechanical repair, panel-beating, and spray-painting units. Site-specific characteristics such as workshop size, ventilation condition, and proximity to major roadways were documented to contextualise pollutant distribution.

Air quality monitoring focused on gaseous pollutants and particulate matter. Carbon monoxide (CO), hydrogen sulphide (H<sub>2</sub>S), and volatile organic compounds (VOCs) were measured at breathing height (approximately 1.5 m) using calibrated portable gas analysers. Readings were taken at 30-minute intervals. Particulate matter fractions (PM<sub>0.3</sub>, PM<sub>0.5</sub>, PM<sub>1.0</sub>, PM<sub>2.5</sub>, and PM<sub>10</sub>) were simultaneously measured using a laser-based particle counter. Ambient temperature and relative humidity were recorded concurrently using a digital thermo-hygrometer to evaluate meteorological influences on pollutant dispersion. Vehicular traffic density around each workshop was manually counted using a digital counter to estimate the contribution of mobile emission sources. All measurements were geo-referenced using Global Positioning System coordinates to ensure spatial accuracy.

Occupational health risk assessment was conducted to estimate potential inhalation exposure risks. Non-carcinogenic risk for each pollutant was evaluated using the Hazard Quotient (HQ), calculated as

$$HQ = (C \times IR \times EF \times ED) / (RfD \times BW \times AT)$$

where C is the measured pollutant concentration (mg/m<sup>3</sup>), IR is the inhalation rate (20 m<sup>3</sup>/day for adults), EF is the exposure frequency (250 days/year), ED is the exposure

duration (10 years), RfD is the reference dose (mg/kg/day), BW is the average body weight (70 kg), and AT is the averaging time for non-carcinogenic effects, defined as

$$AT = 365 \times ED$$

The cumulative non-carcinogenic risk was expressed as the Hazard Index (HI), calculated as the sum of individual hazard quotients:

$$HI = \sum HQ$$

An HI value greater than 1 was interpreted as indicative of potential adverse health effects.

Carcinogenic risk was assessed using the Incremental Lifetime Cancer Risk (ILCR), calculated as:

$$ILCR = CDI \times SF$$

where CDI is the chronic daily intake (mg/kg/day), derived from the exposure parameters in the HQ equation, and SF is the cancer slope factor for the pollutant. ILCR values exceeding  $1 \times 10^{-4}$  were considered unacceptable based on standard risk characterisation criteria.

Structured questionnaire used for this study is shown in Appendix 2.

Statistical analyses were performed using SPSS version 25.0. Descriptive statistics, including mean values and standard errors of the mean ( $\pm$ SEM), were computed for all measured parameters. Differences among workshop categories were evaluated using analysis of variance at a significance level of  $p < 0.05$ . Exploratory data analysis techniques were applied to visualise relationships between air pollutants and meteorological variables. Correlation and regression analyses were conducted to identify key predictors of pollutant concentrations within the workshops. Where data deviated from normality, appropriate non-parametric tests were applied to ensure robust statistical inference.

Quality control measures included pre-calibration of all monitoring instruments according to manufacturer specifications prior to each sampling session. Background measurements were obtained from non-workshop control locations to establish baseline pollutant levels. Triplicate measurements were taken at each site to minimise instrumental and observational error. Standardised field and analytical procedures were consistently followed to ensure data reliability, reproducibility, and overall methodological rigour.

### Results and Discussion

Table 1 summarises the daily mean  $\pm$  SEM of key air quality parameters and noise levels recorded in automobile mechanic workshops over the 13-day monitoring period. The results indicate substantial temporal variability and consistently elevated pollutant burdens, reflecting the combined influence of combustion activities, solvent use, mechanical operations, and poor ventilation typical of informal automotive repair environments. Collectively, the findings demonstrate a severely degraded occupational microenvironment with potential short- and long-term health implications for exposed workers.

Carbon dioxide (CO<sub>2</sub>) concentrations remained close to global outdoor background levels during the initial sampling days but increased sharply from Day 6 onward, peaking at

approximately 1,980 ppm on Day 7. Such elevated concentrations substantially exceed thresholds associated with well-ventilated outdoor air and are indicative of inadequate air exchange and accumulation of combustion-derived emissions (WHO, 2021; Satish *et al.*, 2012) [40, 50]. Elevated CO<sub>2</sub> in occupational settings is widely recognised as a surrogate marker for poor ventilation and co-exposure to other combustion-related pollutants, which may contribute to fatigue, impaired cognitive performance, and exacerbation of respiratory symptoms during prolonged exposure (Allen *et al.*, 2016) [4].

Total volatile organic compounds (TVOCs) showed minimal concentrations during the early days but increased markedly from Day 6, reaching sustained peaks of approximately 2.0 mg/m<sup>3</sup> between Days 7 and 10. These concentrations far exceed recommended guideline values for outdoor environments and are consistent with intensified use of fuels, lubricants, degreasers, solvents, and spray-painting materials within the workshops (WHO, 2021; Bari *et al.*, 2020) [9, 50]. Chronic exposure to elevated TVOCs has been associated with mucosal irritation, headaches, neurobehavioural disturbances, and systemic toxicity, particularly in poorly ventilated occupational settings (Rumchev *et al.*, 2007; Kim *et al.*, 2021) [27, 38].

Formaldehyde (HCHO) concentrations exceeded guideline limits on several days, with pronounced elevations between Days 4 and 10 and a maximum value recorded on Day 8. Formaldehyde emissions in automobile workshops are commonly linked to fuel combustion, exhaust gases, and degradation of resin-containing materials and solvents (Zhang *et al.*, 2020) [53]. Recurrent exceedance of guideline limits is of significant concern, given formaldehyde's strong irritant properties and its classification as a human carcinogen following chronic inhalation exposure (IARC, 2018; WHO, 2021) [50].

Halogen gas concentrations exhibited pronounced fluctuations, with extreme peaks observed between Days 9 and 11 that exceeded established occupational exposure limits. These elevations are likely associated with refrigerant handling, air-conditioning servicing, and the use of halogenated cleaning agents and cooling fluids (Calvert *et al.*, 2020) [13]. Acute exposure to high halogen concentrations can result in respiratory tract irritation and pulmonary injury, while chronic low-level exposure has been linked to long-term respiratory dysfunction and increased susceptibility to occupational lung disease (NIOSH, 2019).

Combustible gas concentrations remained below critical

safety thresholds throughout the study period but displayed episodic elevations, particularly between Days 4 and 6. These fluctuations likely reflect intermittent fuel leakage, engine testing, and storage-related emissions. Although the measured concentrations did not reach explosion limits, sustained exposure to combustible gases in poorly regulated workshops increases the risk of fire hazards and contributes to cumulative inhalation exposure (OSHA, 2020) [33].

Noise levels varied widely across the monitoring period. While most days recorded values close to or slightly below recommended limits, extreme exceedances approaching 100 dB were observed on Days 2, 12, and 13. Such intermittent high-intensity noise exposure is characteristic of hammering, engine revving, and heavy mechanical operations and is well documented as a major occupational hazard in automobile repair settings (Basner *et al.*, 2014) [10]. Repeated exposure to noise levels above recommended thresholds significantly increases the risk of noise-induced hearing loss, stress-related disorders, and reduced work efficiency (WHO, 2018) [49].

Particulate matter data reveal a dominance of fine and ultrafine particles (PM<sub>0.3</sub> and PM<sub>0.5</sub>) throughout the sampling period, with pronounced peaks between Days 7 and 10. The predominance of these fractions is particularly concerning, as ultrafine particles possess high pulmonary deposition efficiency and the ability to translocate into systemic circulation, thereby inducing oxidative stress, inflammation, and cardiovascular effects (Oberdörster *et al.*, 2005; Schraufnagel *et al.*, 2019) [32, 41]. The temporal concurrence of elevated particulate counts with high CO<sub>2</sub> and TVOC concentrations strongly implicates combustion-related activities as the primary sources of airborne particulates within the workshops.

Overall, the integrated results presented in Table 1 demonstrate a complex and hazardous exposure scenario characterised by simultaneous exposure to gaseous pollutants, particulate matter, and excessive noise. This cumulative exposure burden aligns with previous evidence identifying informal automobile mechanic workshops as high-risk occupational microenvironments, particularly in rapidly urbanising regions with limited enforcement of occupational health regulations (Amegah & Agyei-Mensah, 2017; Adeyemi & Bello-Adedipe, 2025) [1, 5]. The findings underscore the urgent need for improved ventilation, routine air quality monitoring, adoption of cleaner work practices, and strengthened occupational safety education and regulatory enforcement to mitigate adverse health outcomes among automobile mechanics.

**Table 1:** Daily Mean  $\pm$  SEM of Air Quality and Noise Parameters in Automobile Mechanic Workshops over a 13-Day Sampling Period

Day	CO <sub>2</sub> (ppm)	TVOC (mg/m <sup>3</sup> )	HCHO (mg/m <sup>3</sup> )	Halogen (ppm)	Combustible Gas (ppm)	Noise (dB)
1	410.0 $\pm$ 5.0	0.02 $\pm$ 0.01	0.01 $\pm$ 0.00	10.0 $\pm$ 5.0	460 $\pm$ 50	45 $\pm$ 2
2	420.0 $\pm$ 5.0	0.02 $\pm$ 0.01	0.04 $\pm$ 0.00	48.0 $\pm$ 4.0	10 $\pm$ 5	100 $\pm$ 100
3	430.0 $\pm$ 5.0	0.03 $\pm$ 0.01	0.07 $\pm$ 0.02	34.0 $\pm$ 2.0	300 $\pm$ 90	48 $\pm$ 3
4	450.0 $\pm$ 6.0	0.15 $\pm$ 0.03	0.26 $\pm$ 0.01	23.0 $\pm$ 1.5	890 $\pm$ 30	55 $\pm$ 2
5	470.0 $\pm$ 7.0	0.10 $\pm$ 0.02	0.21 $\pm$ 0.01	12.0 $\pm$ 1.0	740 $\pm$ 50	55 $\pm$ 2
6	690.0 $\pm$ 140	0.72 $\pm$ 0.20	0.15 $\pm$ 0.01	3.0 $\pm$ 1.0	820 $\pm$ 90	44 $\pm$ 2
7	1,980.0 $\pm$ 15	2.00 $\pm$ 0.00	0.14 $\pm$ 0.02	14.0 $\pm$ 2.0	410 $\pm$ 10	43 $\pm$ 2
8	1,790.0 $\pm$ 12	2.00 $\pm$ 0.00	0.27 $\pm$ 0.01	39.0 $\pm$ 3.0	470 $\pm$ 10	40 $\pm$ 1
9	1,660.0 $\pm$ 10	2.00 $\pm$ 0.00	0.24 $\pm$ 0.01	102.0 $\pm$ 5.0	540 $\pm$ 10	42 $\pm$ 1
10	1,470.0 $\pm$ 15	1.85 $\pm$ 0.05	0.18 $\pm$ 0.01	108.0 $\pm$ 4.0	520 $\pm$ 10	45 $\pm$ 2
11	1,270.0 $\pm$ 20	1.60 $\pm$ 0.03	0.12 $\pm$ 0.01	65.0 $\pm$ 4.0	400 $\pm$ 15	42 $\pm$ 2
12	1,010.0 $\pm$ 12	1.35 $\pm$ 0.03	0.09 $\pm$ 0.02	22.0 $\pm$ 4.0	50 $\pm$ 20	100 $\pm$ 100
13	1,350.0 $\pm$ 80	1.20 $\pm$ 0.02	0.07 $\pm$ 0.03	2.0 $\pm$ 1.0	55 $\pm$ 10	100 $\pm$ 2

Table 2 summarises the daily mean concentrations of airborne particulate matter across six size fractions measured in automobile mechanic workshops over a 13-day period. The results show clear size-dependent and temporal variations, reflecting fluctuating workshop activities and emission sources.

Fine and ultrafine particles overwhelmingly dominated the particulate profile.  $PM_{0.3}$  recorded the highest concentrations throughout the monitoring period, peaking at approximately 98,200 particles/L on Day 9, while  $PM_{10}$  remained almost negligible (<1 particle/L). This distribution indicates that combustion-related activities, welding fumes, metal grinding, and exhaust emissions were the principal sources of particulate pollution, as these processes predominantly generate sub-micrometre aerosols. Coarser particles ( $PM_{3.0}$ – $PM_{10}$ ) occurred only in trace amounts, suggesting limited dust resuspension and rapid settling of larger particles.

Temporal trends revealed lower particulate counts during the initial days, followed by progressive increases that culminated in peaks between Days 8 and 10, corresponding with intensified mechanical operations such as engine testing, spray painting, and welding. A subsequent decline towards the end of the sampling period likely reflects

reduced workload or improved natural ventilation. The relatively low variability observed in fine particle fractions indicates persistent emission sources, whereas greater variability in coarser particles reflects sporadic mechanical disturbances.

The particle size hierarchy ( $PM_{0.3} > PM_{0.5} > PM_{1.0} \gg PM_{3.0}$ – $PM_{10}$ ) has important health implications, as over 85% of the total particulate load comprised respirable ultrafine particles capable of deep lung penetration and systemic translocation. Prolonged exposure to such particles has been linked to chronic respiratory and cardiopulmonary disorders (Ayoade *et al.*, 2022; Okobia & Olagoke, 2021; WHO, 2021) [8, 34, 50]. The predominance of ultrafine particles also implies potential secondary environmental contamination through re-entrainment into surrounding airspaces (Audignon-Durand *et al.*, 2023; Moreno-Rios *et al.*, 2021) [7, 30].

Overall, Table 2 highlights severe particulate pollution within automobile mechanic workshops, underscoring the need for improved ventilation, emission control measures, routine air monitoring, and stricter enforcement of occupational safety practices to mitigate health risks (Eidem *et al.*, 2024; Kim *et al.*, 2021; Zhou *et al.*, 2022) [19, 27, 54].

**Table 2:** Mean and standard error of mean (SEM) of particulate matter counts by particle size (0.3–10  $\mu\text{m}$ ) in automobile mechanic workshops. Submicron particles ( $PM_{0.3}$ – $0.5 \mu\text{m}$ ) dominated the airborne particle load, contributing over 90 % of total measured particulates

Particle Size ( $\mu\text{m}$ )	Mean Particle Count (particles/L)	Standard Error of Mean (SEM)
$PM_{0.3} \mu\text{m}$	64,873.64	4,881.94
$PM_{0.5} \mu\text{m}$	4,288.96	408.86
$PM_{1.0} \mu\text{m}$	231.33	9.69
$PM_{3.0} \mu\text{m}$	16.53	0.87
$PM_{5.0} \mu\text{m}$	7.41	0.68
$PM_{10} \mu\text{m}$	0.29	0.29

Table 3 presents the Pearson correlation coefficients ( $r$ -values) showing the strength and direction of relationships among gaseous pollutants, noise levels, and particulate matter size fractions measured in automobile mechanic workshops. The analysis provides insight into the interdependence of pollutants and helps to identify which parameters tend to vary together, suggesting common emission sources or shared environmental controls.

A strong positive correlation was observed between carbon dioxide ( $\text{CO}_2$ ) and total volatile organic compounds (TVOCs) ( $r = 0.79$ ), indicating their concurrent increase and suggesting co-emission from combustion-related activities such as vehicle exhaust, fuel evaporation, and engine idling (Seoyeong *et al.*, 2024; Yu *et al.*, 2024) [43, 52]. This relationship reinforces the use of elevated  $\text{CO}_2$  as an indicator of poor ventilation and accumulation of organic vapours within the workshops (Senthong *et al.*, 2025) [42].  $\text{CO}_2$  also showed strong positive correlations with fine particulate matter ( $PM_{0.3}$  and  $PM_{0.5}$ ;  $r = 0.81$  and  $0.77$ , respectively), confirming that combustion processes substantially contribute to ultrafine particulate loading.

TVOCs were strongly correlated with  $PM_{0.5}$  ( $r = 0.85$ ), implying that increased organic vapours promote the formation or surface adsorption of ultrafine particles through condensation and gas–particle partitioning

mechanisms (Deshmukh *et al.*, 2025; Sun *et al.*, 2025) [15, 44]. In contrast, formaldehyde (HCHO) exhibited weak or negative correlations with  $\text{CO}_2$  ( $r = -0.30$ ) and TVOCs ( $r = -0.27$ ), indicating emissions from distinct non-combustion sources such as solvents, degreasers, and surface coatings (Kim *et al.*, 2023; Ricklund *et al.*, 2023) [37]. Halogen gases showed moderate correlations with  $\text{CO}_2$  ( $r = 0.45$ ) and TVOCs ( $r = 0.70$ ), suggesting shared sources related to refrigerant handling and solvent use, while combustible gases displayed weak associations with other pollutants, reflecting episodic or localised emissions (Lee *et al.*, 2025; Zhang *et al.*, 2024) [28].

Noise levels exhibited weak correlations with gaseous and particulate pollutants ( $r = -0.06$  to  $0.19$ ), confirming that acoustic exposure is primarily driven by mechanical operations rather than emission intensity (Toker *et al.*, 2025) [45]. Overall, the correlation structure demonstrates that  $\text{CO}_2$ , TVOCs, and fine particulates ( $PM_{0.3}$ – $0.5$ ) form a coherent group of combustion-derived pollutants in poorly ventilated workshops (Caciara *et al.*, 2024; Xia *et al.*, 2024; Wang *et al.*, 2024) [12, 48, 51]. These findings suggest that interventions targeting ventilation and combustion control could simultaneously reduce multiple pollutant exposures, underscoring the need for integrated air quality management strategies.

**Table 3:** Pearson Correlation Matrix

	CO2	TVOC	HCHO	HALOGEN	COMBUSTIBLE GAS	NOISE db	PC 0.3	PC 0.5um	PC 1.0um
CO2 ppm MEAN	1	0.791	-0.297	0.446	-0.062	-0.06	0.811	0.773	-0.263
TVOC mg m3 MEAN	0.791	1	-0.272	0.703	-0.187	0.19	0.726	0.845	-0.28
HCHO mg m3 MEAN	-0.297	-0.272	1	0.084	-0.502	0.079	-0.37	-0.333	-0.07
HALOGEN ppm MEAN	0.446	0.703	0.084	1	-0.141	-0.143	0.576	0.57	-0.138
COMBUSTIBLE GAS ppm MEAN	-0.062	-0.187	-0.502	-0.141	1	-0.589	0.393	0.02	0.509
NOISE db MEAN	-0.06	0.19	0.079	-0.143	-0.589	1	-0.307	-0.11	-0.127
PC 0.3um MEAN	0.811	0.726	-0.37	0.576	0.393	-0.307	1	0.75	0.175
PC 0.5um MEAN	0.773	0.845	-0.333	0.57	0.02	-0.11	0.75	1	-0.234
PC 1.0um MEAN	-0.263	-0.28	-0.07	-0.138	0.509	-0.127	0.175	-0.234	1

This table presents the pairwise correlation coefficients (r) among air quality and particulate parameters.

**Highlights**

- Strong positive correlation between CO<sub>2</sub> (ppm) and PC<sub>0.3um</sub> (r = 0.81) — indicating that rising CO<sub>2</sub> is associated with higher fine particulate concentration.
- TVOC (mg/m<sup>3</sup>) also shows strong correlation with PC<sub>0.5um</sub> (r = 0.85).
- Combustible gas (ppm) and HCHO (mg/m<sup>3</sup>) are moderately negatively correlated (r ≈ -0.50).

Table 4 presents the results of a multiple linear regression analysis examining the relationship between fine particulate matter (PM<sub>0.3</sub> μm) and selected gaseous pollutants—CO<sub>2</sub>, TVOCs, HCHO, halogens, combustible gases, and noise levels—in automobile mechanic workshops. The analysis identifies which air quality parameters significantly predict variations in the concentration of ultrafine particulates, thereby revealing the key drivers of particulate pollution within these occupational environments.

The regression analysis identified carbon dioxide (CO<sub>2</sub>) as the most significant predictor of ultrafine particulate matter (PM<sub>0.3</sub>) concentrations, with a positive coefficient (β = 26.49) and a statistically significant p-value (p = 0.0121). This indicates that increases in CO<sub>2</sub> were associated with substantial rises in PM<sub>0.3</sub>, confirming combustion-related activities—such as engine idling, fuel combustion, and welding—as the dominant sources of ultrafine particles in the workshops. Elevated total volatile organic compounds also showed a positive association with PM<sub>0.3</sub>, supporting the contribution of solvent use and fuel evaporation to particulate formation through secondary organic aerosol processes (Bralewska *et al.*, 2024) [11].

Other predictors, including TVOCs, formaldehyde, and halogen gases, exhibited positive but statistically insignificant relationships with PM<sub>0.3</sub>, suggesting secondary or activity-specific contributions to particulate loading. Combustible gas and noise variables showed weak or inconsistent effects and were therefore not retained as significant predictors, indicating their episodic nature and limited influence on overall fine particle concentrations. The negative, non-significant intercept implies that background particulate levels are influenced by external or unmeasured factors.

Overall, the findings demonstrate that CO<sub>2</sub> is a reliable proxy for ultrafine particulate accumulation in automobile mechanic workshops, underscoring the central role of combustion emissions and poor ventilation in shaping air quality. These results highlight the importance of targeted control measures, particularly improved ventilation and combustion management, to effectively reduce particulate

exposure and associated health risks in these occupational environments (Vinnikov *et al.*, 2023) [47].

**Table 4:** Regression Summary

Variable	Coefficient	Std. Error	t-value	p-value
Constant	-3028.99	10408.11	-0.29	0.7827
CO <sub>2</sub> (ppm)	26.49	6.90	3.84	0.0121
TVOC (mg/m <sup>3</sup> )	5114.45	6852.52	0.75	0.4890
HCHO (mg/m <sup>3</sup> )	3568.26	2538.42	1.41	0.2188
Halogen (ppm)	171.09	118.28	1.45	0.2077

**Dependent variable:** PC<sub>0.3um</sub> (Mean particle count)  
**Predictors:** CO<sub>2</sub>, TVOC, HCHO, Halogen, Combustible Gas, and Noise.

- CO<sub>2</sub> concentration is a significant positive predictor (p = 0.0121) of particle count (PC<sub>0.3um</sub>).
- Other variables (TVOC, HCHO, Halogen) show positive but statistically insignificant relationships.
- Model suggests that indoor combustion-related emissions dominate fine particulate loading.

Table 5 presents the estimated non-carcinogenic and carcinogenic health risks associated with inhalation exposure to key air pollutants measured in automobile mechanic workshops, expressed as hazard quotients (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR). The results indicate an extremely high cumulative non-cancer risk and unacceptable carcinogenic risk, underscoring severe occupational health concerns.

For non-carcinogenic effects, all assessed pollutants recorded HQ values far exceeding the safety benchmark of unity, indicating substantial potential for adverse health outcomes. Carbon dioxide (CO<sub>2</sub>) exhibited an exceptionally high HQ (4192.66), reflecting chronic exposure to elevated concentrations in poorly ventilated environments. Although CO<sub>2</sub> is not classified as a classical toxicant, sustained exposure at high levels is known to impair respiratory function, cognitive performance, and cardiovascular regulation, particularly in enclosed occupational settings (Satish *et al.*, 2012; Allen *et al.*, 2016) [4, 40]. Its dominant contribution to the hazard index highlights the critical role of inadequate ventilation in amplifying overall exposure risk.

Combustible gases (expressed as propane) also showed an extremely high HQ (5855.39), suggesting severe non-cancer risk. Chronic inhalation of hydrocarbon gases has been associated with central nervous system effects, hypoxia, and increased risk of accidental fire or explosion, especially in confined workshops lacking gas detection and control systems (NIOSH, 2019; OSHA, 2020) [33]. Similarly, halogen gases (as chlorine) recorded a very high HQ (816.10), consistent with their strong respiratory irritant properties and capacity to induce airway inflammation and

pulmonary injury following repeated exposure (ATSDR, 2010; Calvert *et al.*, 2020) [13].

Total volatile organic compounds (TVOCs, benzene-equivalent) and formaldehyde (HCHO) also contributed substantially to non-cancer risk, with HQ values of 20.49 and 45.01, respectively. These findings align with extensive evidence linking chronic VOC and aldehyde exposure to mucosal irritation, neurotoxicity, and respiratory morbidity in occupational environments (Kim *et al.*, 2021; Zhang *et al.*, 2020) [27, 53]. When aggregated, the hazard index (HI = 10,929.65) far exceeds the acceptable threshold (HI > 1), clearly indicating a high likelihood of combined adverse health effects due to simultaneous exposure to multiple pollutants (USEPA, 2011).

With respect to carcinogenic risk, both TVOCs (benzene-equivalent) and formaldehyde produced ILCR values of  $5.05 \times 10^{-3}$  and  $2.25 \times 10^{-3}$ , respectively. The combined cancer risk ( $7.30 \times 10^{-3}$ ) is several orders of magnitude higher than the commonly accepted benchmark of  $1 \times 10^{-4}$ , signifying an unacceptable lifetime cancer risk for exposed workers. Benzene is a well-established human carcinogen associated with leukaemia and other haematological malignancies, while formaldehyde exposure has been linked to nasopharyngeal cancer and leukaemia (IARC, 2018; WHO, 2021) [50]. The magnitude of the estimated ILCR

strongly suggests that prolonged occupational exposure in these workshops could significantly elevate cancer risk over a working lifetime.

Overall, Table 5 demonstrates that air pollution in automobile mechanic workshops poses both severe non-carcinogenic and carcinogenic health risks. The dominance of CO<sub>2</sub>, combustible gases, and halogens in the hazard index highlights the combined effects of combustion emissions, chemical handling, and poor ventilation, while the carcinogenic risk is driven primarily by benzene-equivalent VOCs and formaldehyde. These findings are consistent with previous occupational risk assessments in informal industrial settings, which report elevated hazard indices and unacceptable cancer risks due to inadequate emission control and regulatory oversight (Amegah & Agyei-Mensah, 2017; Adeyemi & Bello-Adedipe, 2025) [1, 5].

The results emphasise the urgent need for intervention measures, including improved ventilation, substitution of hazardous solvents, installation of local exhaust systems, routine air monitoring, and strict enforcement of occupational exposure limits. Without such controls, continued exposure is likely to result in significant long-term health burdens among automobile mechanics and contribute to broader environmental health risks in surrounding communities.

**Table 5:** Summary of Hazard Quotients (HQ), Hazard Index (HI) and Incremental Lifetime Cancer Risk (ILCR)

Pollutant	Input Concentration (C)	C (mg/m <sup>3</sup> )	CDI (mg/kg·day)	RfD (mg/kg·day)	HQ	SF ((mg/kg·day) <sup>-1</sup> )	ILCR	Carcinogenic?
CO <sub>2</sub>	1190.25 ppm	2142.45	419.266	0.1	4192.661	—	—	No
TVOC (benzene-eq.)	0.89 mg/m <sup>3</sup>	0.89	0.174	0.0085	20.490	0.029	$5.05 \times 10^{-3}$	Yes
Formaldehyde (HCHO)	0.23 mg/m <sup>3</sup>	0.23	0.045	0.001	45.010	0.05	$2.25 \times 10^{-3}$	Yes
Halogen (as Cl <sub>2</sub> )	28.76 ppm	83.405	16.322	0.02	816.098	—	—	No
Combustible gas (as propane)	497.70 ppm	897.631	175.662	0.03	5855.388	—	—	No

**HI (ΣHQ) = 10,929.647 | Total ILCR (TVOC + HCHO) =  $7.30 \times 10^{-3}$**

**Notes and Assumptions**

- **Exposure factors:** IR = 20 m<sup>3</sup>/day, EF = 250 days/year, ED = 10 years, BW = 70 kg, AT = 365 × 10 = 3650 days.
- ppm→mg/m<sup>3</sup> conversion at 25 °C and 1 atm: mg/m<sup>3</sup> = ppm × MW / 24.45.
- **Surrogates used for species in ppm:** Halogen as chlorine (MW = 70.906), Combustible gas as propane (MW = 44.097).
- **Toxicity values:** CO<sub>2</sub> RfD = 0.1 mg/kg·day; TVOC (benzene-equivalent) RfD = 0.0085 mg/kg·day, SF = 0.029 (mg/kg·day)<sup>-1</sup>; HCHO RfD = 0.001 mg/kg·day, SF = 0.05 (mg/kg·day)<sup>-1</sup>; Halogen (as Cl<sub>2</sub>) RfD = 0.02 mg/kg·day; Combustible gas (as propane) RfD = 0.03 mg/kg·day.
- $HQ = (C \times IR \times EF \times ED) / (RfD \times BW \times AT)$ ;  $HI = \Sigma HQ$ ;  $ILCR = (C \times IR \times EF \times ED \times SF) / (BW \times AT)$ .
- **Interpretation thresholds:** HI > 1 indicates potential non-cancer risk; ILCR >  $1 \times 10^{-4}$  considered unacceptable by the stated criterion.

- Values are based on study mean concentrations (Table 4.2); alternative surrogates or toxicity values would change numerical results but likely not the overall risk signal.

Table 4.6 presents the Chi-square analysis assessing the association between respondents' age groups and their responses to occupational, behavioural, and health-related questionnaire items (Q1–Q18). The results indicate that age significantly influenced selected aspects of work experience, exposure duration, and safety practices, while most other responses were independent of age.

Statistically significant associations (p < 0.05) were observed for three variables: years of experience (Q1), daily working hours (Q2), and use of protective measures (Q7). Years of experience showed the strongest association with age ( $\chi^2 = 42.35$ , p = 0.00003), with older respondents reporting substantially longer service durations. This suggests greater cumulative exposure to occupational hazards among older mechanics, consistent with evidence linking prolonged employment to increased health risk (Siabi *et al.*, 2022; Jakobsen *et al.*, 2024). Daily working hours also varied significantly with age ( $\chi^2 = 29.46$ , p = 0.003), as older workers more frequently reported working beyond eight hours per day, implying extended exposure periods and heightened susceptibility to chronic effects (Cellier *et al.*, 1995; Hansen, 2014).

Use of personal protective equipment differed across age groups ( $\chi^2 = 10.92, p = 0.027$ ). Younger workers reported more occasional PPE use, whereas older workers demonstrated inconsistent or minimal compliance, possibly reflecting differences in risk perception and reliance on experience rather than formal safety practices (Onguto *et al.*, 2020; Donkor *et al.*, 2023). These patterns align with earlier findings that age-related differences in safety behaviour are influenced by both experience and attitudes toward occupational risk (Gyekye & Salminen, 2009; Siabi *et al.*, 2022).

Other questionnaire items showed no significant age dependence, suggesting broadly uniform perceptions of air quality and health symptoms across age categories. Nevertheless, observed trends indicated increased awareness with age, though this did not consistently translate into protective behaviour. Overall, Table 4.6 highlights age as a key determinant of occupational exposure and safety behaviour, underscoring the need for age-responsive safety training, targeted risk communication, and enforcement of PPE compliance to reduce health risks among automobile mechanics.

**Table 6:** Chi-square Analysis of Age Group vs Questionnaire Responses

Question	Chi2	df	p value	Significance
Q1	42.3482	12	2.91E-05	Significant (p<0.05)
Q2	29.46032	12	0.003365	Significant (p<0.05)
Q3				NS
Q4	4.26015	4	0.371942	NS
Q5				NS
Q6				NS
Q7	10.91918	4	0.027487	Significant (p<0.05)
Q8				NS
Q9	7.682571	4	0.103923	NS
Q10	9.245455	12	0.681835	NS
Q11	13.83442	12	0.311407	NS
Q12				NS
Q13				NS
Q14	3.904081	4	0.419143	NS
Q15	5.011965	4	0.286072	NS
Q16	10.71184	4	0.030001	Significant (p<0.05)
Q17	4.827052	8	0.775891	NS
Q18				NS

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