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Integrated assessment of air quality in gas plants and its impact on health of attendants

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Abstract
Retail gas stations represent critical hotspots of air pollution due to emissions from fuel dispensing, vehicle exhaust, and storage activities. This study conducted an integrated assessment of air quality and its health implications for attendants in thirty (30) retail gas stations across Warri South Local Government Area, Delta State, Nigeria. Air pollutants including carbon monoxide (CO), hydrogen sulphide (H_2S), volatile organic compounds (VOCs), and particulate matter fractions (PM0.3–PM10) were monitored using calibrated portable instruments, while meteorological parameters were recorded concurrently. Structured questionnaires were also administered to 120 attendants to capture demographic profiles, awareness of risks, protective practices, and self-reported health symptoms. Results indicated that pollutant levels in forecourts were consistently above international guidelines. CO concentrations in high-traffic stations averaged 18.6 ± 1.1 ppm, surpassing the World Health Organization (WHO) 8-hour limit of 10 ppm. H_2S levels (0.04–0.09 ppm) exceeded the WHO 24-hour guideline of 0.004 ppm, while VOCs ranged between 1.5–2.8 ppm, far above the WHO benzene limit of 0.006 ppm. PM2.5 and PM10 concentrations peaked at 56.7 µg/m³ and 89.4 µg/m³, respectively, exceeding WHO thresholds by up to fourfold. Questionnaire findings revealed limited awareness of specific hazards, negligible personal protective equipment (PPE) usage, long shift durations, and high prevalence of respiratory irritation (53.3%), headaches (42.5%), and eye discomfort (32.5%). The study concludes that gas station attendants face significant occupational risks, with implications for surrounding communities. Recommendations include stricter enforcement of air quality standards, provision of PPE, installation of vapour recovery systems, and structured occupational health surveillance.

Keywords: Air quality assessment, gas station attendants, occupational exposure, particulate matter, Warri South LGA

Introduction

The intensification of petroleum retail activities within rapidly urbanising cities has heightened concerns regarding ambient air quality and occupational health, particularly in retail gas stations (Anígilájé *et al*., 2024; Kumari *et al*., 2023) [2, 16]. These facilities represent critical components of urban energy supply systems and are characterised by continuous fuel dispensing, high vehicular traffic density, underground fuel storage, and associated combustion processes (Kumari *et al*., 2023; Polyong & Thetkathuek, 2024) [16, 22]. Such activities generate complex mixtures of airborne pollutants that tend to accumulate within the immediate surroundings of gas stations, creating micro-environments of elevated exposure for workers and nearby residents (Heidari *et al*., 2024) [13].

Warri South Local Government Area of Delta State, Nigeria, is a major commercial and industrial hub where petroleum-related activities coexist with dense residential and commercial developments (Anígilájé *et al*., 2024; Oyewale *et al*., 2024) [2, 21]. Retail gas stations are widely distributed across major road networks, business districts, and community neighbourhoods within the area, often with limited spatial separation from homes, markets, and schools (Antwi *et al*., 2024) [4]. This close juxtaposition of fuel dispensing facilities and human settlements raises significant concerns regarding chronic exposure to air pollutants, particularly for gas station attendants who spend prolonged periods within these environments as part of their daily occupational routine (Kponi *et al*., 2024) [15].

Air quality within retail gas stations is influenced by a combination of operational practices and environmental conditions (Ghahri *et al*., 2024) [11]. Fuel evaporation during dispensing, fugitive emissions from storage tank vents, exhaust emissions from idling vehicles, and the resuspension of road dust collectively contribute to elevated concentrations of gaseous pollutants and particulate matter (Heidari *et al*., 2024) [13]. In tropical urban settings such as Warri South, prevailing high temperatures and relative humidity may further enhance hydrocarbon volatilisation and limit pollutant dispersion, thereby increasing ground-level concentrations within forecourts and adjacent work zones (Bankole *et al*., 2024) [7].

Gas station attendants constitute a high-risk occupational group due to the intensity and duration of their exposure (Sun *et al*., 2024) [25]. Unlike customers whose contact with fuel vapours is transient, attendants typically work extended shifts that may exceed eight hours per day, often with minimal use of personal protective equipment. Continuous inhalation of petroleum vapours, combustion by-products, and fine particulate matter has the potential to elicit a range of adverse health effects. These effects may manifest as acute symptoms such as respiratory irritation, headaches, dizziness, eye discomfort, and fatigue, while long-term exposure may predispose workers to chronic respiratory, cardiovascular, neurological, and systemic health conditions (El-Hagrasy *et al*., 2025) [9].

Despite the recognised hazards associated with petroleum-related air pollution, routine air quality monitoring and occupational health surveillance within retail gas stations remain limited in many Nigerian urban centres, including Warri South Local Government Area. Regulatory frameworks exist to guide environmental protection and workplace safety; however, enforcement is often inadequate, and empirical data on pollutant levels at gas

stations are scarce. Furthermore, there is limited integration between environmental measurements and health outcome assessments, resulting in fragmented understanding of exposure–health relationships among gas station attendants (Mendes *et al*., 2024) [18].

An integrated assessment of air quality is therefore essential for comprehensively characterising pollutant burdens within retail gas stations and elucidating their potential health implications. Such an approach enables simultaneous evaluation of multiple pollutants, spatial variability across different operational zones, and the influence of meteorological conditions on pollutant behaviour (Frydrych & Jurowski, 2024) [10]. When combined with health surveys of exposed workers, integrated assessments provide robust evidence for identifying high-risk exposure scenarios and informing targeted intervention strategies (Khoshakhlagh *et al*., 2023) [14].

Within this context, the present study undertakes an integrated assessment of air quality in retail gas stations located in Warri South Local Government Area, Delta State, Nigeria, and examines its impact on the health of gas station attendants. By generating location-specific data on airborne pollutants, evaluating exposure patterns across forecourts and surrounding areas, and documenting attendant health complaints, the study aims to address existing knowledge gaps and support evidence-based occupational and environmental health management. The findings are intended to inform policymakers, regulatory agencies, and facility operators on practical measures required to improve air quality, enhance worker protection, and reduce public health risks within urban petroleum retail environments.

Materials and Methods

Study Area

The study was carried out in Warri South Local Government Area, Delta State, Nigeria, an urban–industrial centre characterised by intensive petroleum retail activities, dense vehicular traffic, and close proximity of fuel stations to residential and commercial environments. The area lies within a low-lying tropical zone, with persistently high ambient temperatures and relative humidity, conditions that influence pollutant volatilisation, dispersion, and accumulation. Retail gas stations are widely distributed along major roads and commercial corridors, making the area suitable for assessing occupational and ambient air quality exposure associated with petroleum dispensing activities. Figure 1 shows their geospatial locations as captured by GPS.

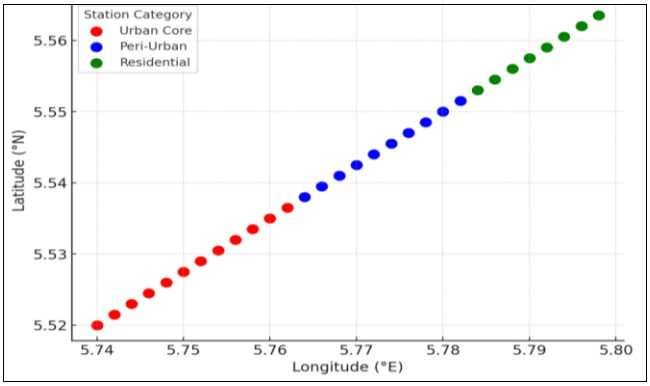

Fig 1: Georeferenced Sampling Stations within Warri South LGA

Study Design

A cross-sectional field-based study design was adopted, integrating environmental air quality monitoring with occupational health assessment. The design combined direct measurement of airborne pollutants, concurrent recording of meteorological parameters, spatial mapping of sampling locations, and administration of structured questionnaires to gas station attendants. This integrated approach enabled simultaneous evaluation of pollutant concentrations, exposure patterns, and self-reported health outcomes.

Selection of Gas Stations and Sampling Points

Thirty retail gas stations were purposively selected across Warri South Local Government Area to ensure adequate spatial coverage and representation of varying operational scales and land-use settings. Selection criteria included fuel dispensing intensity, proximity to residential or commercial areas, and accessibility for monitoring. At each station, three sampling points were established: the forecourt or dispensing area where attendants primarily operate, the storage or venting zone associated with underground fuel tanks, and a periphery point located approximately 50 m from the station boundary to represent background ambient conditions. This design yielded a total of 90 monitoring points across the study area.

Air Quality Parameters

Air quality monitoring focused on pollutants commonly associated with petroleum retail operations. Gaseous pollutants measured included carbon monoxide, hydrogen sulphide, total volatile organic compounds, oxygen concentration, and halogen gases. Particulate matter was quantified across multiple size fractions, including $PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, and PM_{10}, to capture ultrafine, fine, and coarse particles of occupational and public health relevance. Meteorological parameters measured concurrently included ambient temperature, relative humidity, barometric pressure, and altitude.

Instrumentation and Measurement Procedures

Portable, real-time monitoring instruments suitable for field deployment were used for all measurements. A multi-gas safety monitor was employed for simultaneous detection of carbon monoxide, hydrogen sulphide, oxygen, and combustible gases. Total volatile organic compounds were measured using a calibrated TVOC gas detector designed for petroleum-related hydrocarbons. Particulate matter concentrations were determined using an optical air particulate matter counter capable of measuring particle size distributions and mass concentrations. Meteorological parameters and geographical coordinates were recorded using handheld digital instruments equipped with global positioning system functionality.

Calibration and Quality Control

All instruments were calibrated prior to field deployment following manufacturers' specifications. Daily zero and span checks were conducted before and after sampling sessions to ensure data accuracy and consistency. Duplicate measurements were taken at selected stations to assess reproducibility, and background readings were obtained at distances greater than 100 m from gas stations to validate ambient conditions. Field personnel were trained to ensure

uniform instrument handling and standardised data recording procedures throughout the study period.

Sampling Schedule

Air quality monitoring was conducted over fourteen consecutive days to capture temporal variability across weekdays and weekends. Measurements were taken twice daily, during morning hours (07:00–10:00) and afternoon hours (13:00–16:00), corresponding to peak operational and traffic periods. At each sampling point, instruments were operated continuously for 30 minutes, and triplicate readings were obtained. Mean values were computed for subsequent statistical analysis.

Occupational Health Survey

Occupational health data were collected using a structured questionnaire administered to gas station attendants working at the selected stations. A total of 120 attendants participated in the survey, with approximately four respondents per station. The questionnaire captured information on socio-demographic characteristics, duration of occupational exposure, awareness of petroleum-related health risks, use of personal protective equipment, and self-reported respiratory, neurological, cardiovascular, and general health symptoms. Participation was voluntary, and informed consent was obtained prior to questionnaire administration.

Data Analysis

All environmental and questionnaire data were collated and organised using spreadsheet software before statistical analysis. Descriptive statistics were used to summarise pollutant concentrations and health variables, with results expressed as mean ± standard error of the mean. Inferential analyses were conducted to evaluate differences in pollutant levels across sampling zones and time periods, as well as associations between exposure categories and reported health outcomes. Statistical significance was set at $p < 0.05$. Spatial analysis was performed by importing georeferenced sampling coordinates into a geographic information system to visualise pollutant distribution patterns across Warri South Local Government Area.

Compliance Assessment

Measured pollutant concentrations were benchmarked against relevant international air quality guidelines and applicable national standards to assess compliance and potential health implications. Integrating environmental measurements with occupational health data provided a comprehensive framework for evaluating air quality conditions and associated health risks among gas station attendants within the study area.

Results and discussion

Table 1 presents the mean carbon monoxide (CO) concentrations measured across the different sampling points within retail gas stations in Warri South Local Government Area, categorised into high-traffic urban core, peri-urban corridors, and residential/community areas. The results demonstrate a clear spatial gradient in CO concentrations, with values consistently highest at the forecourts, intermediate at the storage or venting areas, and lowest at the periphery located 50 m from station boundaries. In high-traffic urban core stations, forecourt CO concentrations averaged 18.6 ± 1.1 ppm, markedly exceeding the World Health Organization 8-hour guideline value of 10 ppm. Storage and venting areas within the same category also recorded elevated levels (12.7 ± 0.8 ppm), while periphery concentrations declined to 7.3 ± 0.5 ppm, falling below the guideline threshold. A similar but less pronounced pattern was observed in peri-urban stations, where forecourt CO concentrations (12.4 ± 0.9 ppm) marginally exceeded the WHO limit, whereas storage/venting and periphery values remained below the recommended level. In residential/community stations, mean CO concentrations across all sampling points were generally lower, with forecourt levels (9.8 ± 0.7 ppm) approaching but not exceeding the guideline limit. Overall, the data indicate that forecourts, particularly in high-traffic urban locations, constitute the primary zones of CO exposure, reflecting the combined influence of fuel dispensing activities and vehicular exhaust emissions.

Table 1: Mean Carbon Monoxide (CO) Concentrations across Sampling Points (ppm, Mean ± SEM)

Station Category	Forecourt	Storage/Venting Area	Periphery (50 m)	WHO Limit (8-hr avg: 10 ppm)
High-Traffic Urban Core	18.6 ± 1.1	12.7 ± 0.8	7.3 ± 0.5	10 ppm
Peri-Urban Corridors	12.4 ± 0.9	9.5 ± 0.6	5.8 ± 0.4	
Residential/Community Areas	9.8 ± 0.7	7.9 ± 0.5	4.1 ± 0.3	

Table 2 shows the mean hydrogen sulphide (H_2S) concentrations across the same sampling points and station categories. In contrast to carbon monoxide, H_2S concentrations were comparatively lower in absolute magnitude but consistently exceeded the WHO 24-hour guideline value of 0.004 ppm across all station categories and sampling points. High-traffic urban core stations recorded the highest H_2S levels, with forecourt concentrations averaging 0.09 ± 0.01 ppm and storage/venting areas recording 0.07 ± 0.01 ppm, both substantially above the guideline limit. Periphery concentrations, although reduced (0.03 ± 0.00 ppm), still exceeded recommended levels. Peri-urban stations exhibited a similar decreasing trend from forecourt to periphery, with mean values ranging from 0.06 ± 0.00 ppm at forecourts to 0.02 ± 0.00 ppm at periphery points. Residential/community stations recorded the lowest H_2S concentrations; however, even these values (0.01–0.04 ppm) remained several times higher than the WHO guideline. The persistence of elevated H_2S levels across all zones suggests a widespread background presence likely associated with fuel storage and handling processes, rather than isolated point sources alone.

Table 2: Mean Hydrogen Sulphide (H_2S) Concentrations across Sampling Points (ppm, Mean ± SEM)

Station Category	Forecourt	Storage/Venting Area	Periphery (50 m)	WHO Limit (24-hr avg: 0.004 ppm)
High-Traffic Urban Core	0.09 ± 0.01	0.07 ± 0.01	0.03 ± 0.00	0.004 ppm
Peri-Urban Corridors	0.06 ± 0.00	0.04 ± 0.00	0.02 ± 0.00	
Residential/Community Areas	0.04 ± 0.00	0.03 ± 0.00	0.01 ± 0.00	

Figure 2 illustrates the mean concentrations of volatile organic compounds (VOCs) measured across different station categories and operational zones within retail gas stations in Warri South Local Government Area. The bar chart presents a comparative assessment of VOC levels at the forecourt, storage or venting area, and periphery (50 m) for high-traffic urban core, peri-urban, and residential/community stations, with error bars indicating variability around the mean values.

The figure reveals a consistent spatial pattern in VOC distribution across all station categories, with concentrations highest at the forecourts, decreasing at the storage or venting areas, and lowest at the periphery. In high-traffic urban core stations, forecourt VOC concentrations were the highest overall, averaging approximately 2.8 ppm, followed by storage areas at about 2.0 ppm and periphery zones at 1.3 ppm. This pronounced gradient reflects the combined influence of intensive fuel dispensing activities and high vehicular turnover in urban core locations, which promote greater release and accumulation of fuel-related vapours.

Peri-urban stations exhibited a similar but moderately attenuated trend, with mean VOC concentrations of approximately 2.1 ppm at forecourts, 1.5 ppm at storage areas, and 1.0 ppm at the periphery. Although lower than values recorded in high-traffic urban stations, these concentrations remain substantial and indicate persistent exposure potential for attendants operating in these environments. Residential or community-based stations recorded the lowest VOC concentrations among the three categories; however, the same declining pattern from forecourt (approximately 1.5 ppm) to storage area (1.0 ppm) and periphery (0.7 ppm) was maintained.

The error bars shown in Figure 2 suggest relatively limited variability within each zone, indicating that VOC emissions are consistently elevated at forecourts regardless of station category. The systematic reduction in concentrations with increasing distance from the dispensing point underscores the dominant role of fuel handling and evaporation processes as primary sources of VOCs within gas stations.

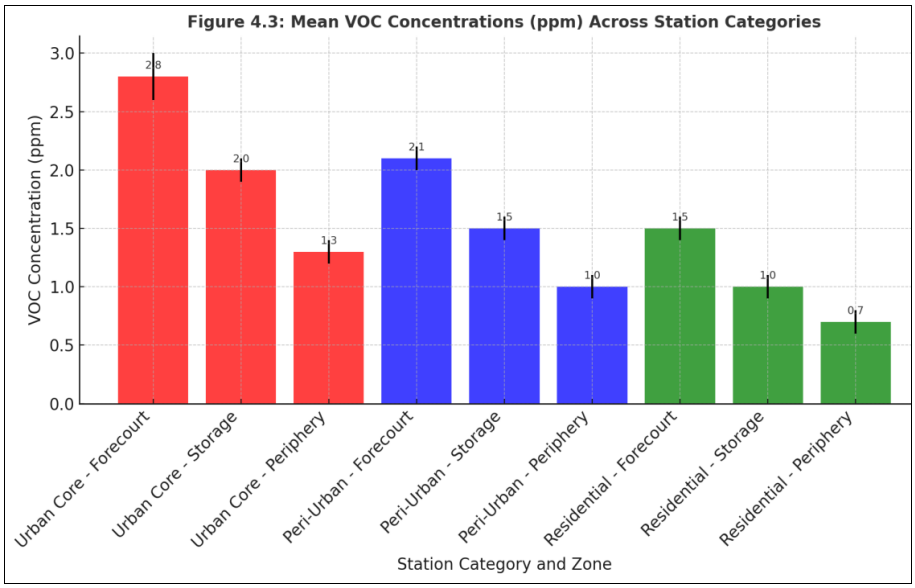

Fig 2: Mean VOC Concentrations (ppm) Across Station Categories. (Bar chart with error bars showing higher VOC levels at forecourts compared to storage and periphery zones)

Table 3 presents the mean concentrations of particulate matter across multiple aerodynamic size fractions ($PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{2.5}$, and PM_{10}) measured in retail gas stations within Warri South Local Government Area, categorised into high-traffic urban core, peri-urban corridors, and residential/community areas. The results show a clear spatial and size-dependent gradient in particulate matter concentrations. Across all size fractions, the highest mean values were consistently recorded in high-traffic urban core stations, followed by peri-urban stations, with the lowest concentrations observed in residential/community areas. In urban core locations, $PM_{2.5}$ and PM_{10} concentrations averaged 56.7 ± 2.9 µg/m³ and 89.4 ± 4.6 µg/m³, respectively, indicating substantial particulate loading in areas characterised by intense vehicular activity and fuel dispensing operations. Peri-urban stations exhibited moderately lower but still elevated concentrations, with $PM_{2.5}$ averaging 38.2 ± 2.1 µg/m³ and PM_{10} averaging 63.7 ± 3.2 µg/m³. demonstrated that even in residential or community-based stations, particulate matter levels remained appreciable, with $PM_{2.5}$ and PM_{10} concentrations of 27.5 ± 1.5 µg/m³ and 48.1 ± 2.6 µg/m³, respectively. The progressive decline in particulate matter concentrations from urban to residential settings reflects the combined influence of traffic density, fuel-related emissions, and resuspension of road dust, while the persistence of elevated fine and coarse particles across all station categories highlights the potential for chronic exposure among attendants and nearby residents.

Table 3: Mean Particulate Matter Concentrations (µg/m³, Mean ± SEM) Across Station Categories

Station Category	PM0.3	PM0.5	PM1.0	PM2.5	PM10
High-Traffic Urban Core	62.5 ± 3.1	48.2 ± 2.7	38.9 ± 2.3	56.7 ± 2.9	89.4 ± 4.6
Peri-Urban Corridors	44.3 ± 2.4	33.6 ± 1.8	25.1 ± 1.5	38.2 ± 2.1	63.7 ± 3.2
Residential/Community Areas	31.8 ± 1.7	22.4 ± 1.2	18.6 ± 1.0	27.5 ± 1.5	48.1 ± 2.6

Table 4 summarises the meteorological parameters recorded concurrently with air quality measurements across the same station categories. Mean ambient temperatures were highest in high-traffic urban core stations (32.8 ± 0.7 °C) and gradually decreased through peri-urban (31.2 ± 0.6 °C) to residential areas (30.6 ± 0.5 °C). Relative humidity exhibited an inverse trend, with the lowest mean values in urban core locations (71.4 ± 1.9%) and progressively higher levels in peri-urban (74.3 ± 2.0%) and residential areas (76.8 ± 1.8%). Barometric pressure remained relatively stable across all categories, ranging narrowly between 1005.6 and 1007.8 hPa, while altitude varied only slightly, reflecting the generally low-lying topography of Warri South Local Government Area.

The meteorological patterns presented in Table 4 provide important context for interpreting the particulate matter distributions in Table 3. Higher temperatures in urban core stations are likely to enhance atmospheric turbulence and fuel volatilisation, while lower relative humidity may reduce particle agglomeration, favouring the persistence of finer particulates. Conversely, higher humidity in residential areas may promote hygroscopic growth of particles, contributing to the observed PM_{10} fractions despite lower emission intensity. The limited variation in barometric pressure and altitude suggests that differences in particulate matter concentrations are driven primarily by local emission sources and activity patterns rather than by large-scale atmospheric or topographic effects.

Table 4: Meteorological Parameters Recorded Across Station Categories (Mean ± SEM)

Station Category	Temperature (°C)	Relative Humidity (%)	Barometric Pressure (hPa)	Altitude (m)
High-Traffic Urban Core	32.8 ± 0.7	71.4 ± 1.9	1005.6 ± 2.1	8.2 ± 0.5
Peri-Urban Corridors	31.2 ± 0.6	74.3 ± 2.0	1007.8 ± 2.2	9.1 ± 0.4
Residential/Community Areas	30.6 ± 0.5	76.8 ± 1.8	1006.2 ± 1.9	7.6 ± 0.3

Table 5 presents the prevalence of self-reported health complaints among gas station attendants (n = 120) working in retail fuel stations within Warri South Local Government Area. The data indicate a high burden of respiratory-related symptoms, with more than half of the respondents (53.3%) reporting respiratory irritation manifested as cough, wheeze, or sore throat. This was followed by headache and dizziness, reported by 42.5% of attendants, suggesting frequent acute neurological or systemic responses to occupational exposure. Eye irritation was reported by nearly one-third of respondents (32.5%), while fatigue or general weakness affected 28.3% of the workforce. Less frequently reported, but clinically relevant, were cardiovascular symptoms such as palpitations or chest pain (15.0%) and neurological complaints including poor concentration and memory lapses (10.0%). The distribution of symptoms reflects a predominance of irritative and neuro-respiratory complaints, consistent with prolonged exposure to fuel vapours, combustion by-products, and fine particulate matter in gas station environments.

Table 5: Prevalence of Reported Health Complaints among Gas Station Attendants (n = 120)

Reported Health Complaint	No. of Respondents (%)
Respiratory irritation (cough, wheeze, sore throat)	64 (53.3%)
Headache and dizziness	51 (42.5%)
Eye irritation	39 (32.5%)
Fatigue/weakness	34 (28.3%)
Cardiovascular symptoms (palpitations, chest pain)	18 (15.0%)
Neurological complaints (poor concentration, memory lapses)	12 (10.0%)

Table 6 summarises the demographic characteristics of the respondents. The workforce was predominantly young and economically active, with the majority of attendants falling within the 25–34-year age group (44.2%), followed by those aged 18–24 years (35.0%). Individuals aged 45 years and above constituted a relatively small proportion (5.8%), indicating limited long-term retention or survival within this occupation. Males accounted for 57.5% of respondents, while females represented 42.5%, reflecting a moderately gender-diverse workforce. In terms of occupational exposure duration, nearly half of the respondents (46.7%) had worked for between one and three years, while 33.3% had spent four years or more in the occupation, indicating substantial cumulative exposure for a significant fraction of attendants. Educational attainment was predominantly secondary level (60.0%), with only 10.0% having tertiary education, suggesting potential limitations in occupational health awareness and risk perception among the majority of workers.

Table 6: Demographic Characteristics of Respondents (n = 120)

Variable	Category	Frequency (%)
Age Group (years)	18–24	42 (35.0)
	25–34	53 (44.2)
	35–44	18 (15.0)
	≥45	7 (5.8)
Gender	Male	69 (57.5)
	Female	51 (42.5)
Work Duration (years)	<1	24 (20.0)
	1–3	56 (46.7)
	4–6	28 (23.3)
	≥7	12 (10.0)
Education Level	Secondary	72 (60.0)
	Post-secondary	36 (30.0)
	Tertiary	12 (10.0)

Table 7 presents data on the reported use of personal protective equipment (PPE) among gas station attendants. The findings reveal notably low levels of regular PPE use across all categories. Only 12.5% of respondents reported regular use of nose masks or respirators, while the majority (59.2%) indicated that they never used any form of respiratory protection. Glove use was even less common, with 77.5% of attendants reporting that they never used gloves during routine work activities. Protective eyewear showed the poorest compliance, with 89.2% of respondents indicating that they had never used it. Occasional use of PPE was reported by a minority of respondents, suggesting that protective practices are largely inconsistent and non-routine.

Table 7: Reported Use of PPE among Attendants

PPE Type	Regular Use (%)	Occasional Use (%)	Never Used (%)
Nose masks/respirators	15 (12.5)	34 (28.3)	71 (59.2)
Gloves	9 (7.5)	18 (15.0)	93 (77.5)
Protective eyewear	3 (2.5)	10 (8.3)	107 (89.2)

Discussion

The findings of this study provide a comprehensive assessment of air quality conditions and associated health outcomes among gas station attendants in Warri South Local Government Area, highlighting clear spatial, occupational, and environmental gradients in pollutant exposure. The integration of gaseous pollutants, particulate matter, meteorological parameters, and self-reported health data offers robust insight into the occupational risk profile of retail gas station environments within an urban Nigerian setting.

Carbon monoxide concentrations presented in Table 1 demonstrate a pronounced exposure gradient across station categories and operational zones, with the highest levels consistently recorded at forecourts, particularly within high-traffic urban core stations. Forecourt concentrations in these locations exceeded recommended guideline limits, underscoring the combined impact of vehicular exhaust emissions and fuel dispensing activities. The progressive reduction in carbon monoxide concentrations from forecourt to periphery reflects the dilution effect with increasing distance from emission sources, yet the persistence of elevated values at storage and venting zones suggests ongoing contributions from fugitive emissions associated with underground fuel tanks (Animashaun *et al*., 2023; Gonzalez *et al*., 2022) [3, 12]. In peri-urban and residential stations, lower carbon monoxide levels indicate reduced traffic density and operational intensity; however, forecourt concentrations approaching guideline thresholds still represent a potential occupational hazard for attendants working prolonged shifts (Shinohara *et al*., 2024) [24].

Hydrogen sulphide concentrations, as shown in Table 2, were consistently elevated across all station categories and sampling zones, exceeding health-based guideline values even at periphery locations. Unlike carbon monoxide, hydrogen sulphide did not show sharp spatial attenuation, suggesting a more diffuse and persistent background presence. This pattern points to fuel storage and handling processes as continuous sources of sulphur-containing vapours. The highest concentrations observed in urban core stations further emphasise the influence of operational scale and station throughput on pollutant levels. Chronic exposure to low-level hydrogen sulphide, as implied by these findings, raises concerns regarding cumulative neurological and respiratory effects among attendants (Azad *et al*., 2024; Mak *et al*., 2024) [5, 17].

Volatile organic compound concentrations illustrated in Figure 2 reinforce the dominance of forecourts as primary exposure zones within gas stations. Across all station categories, VOC levels were highest at dispensing points, decreased at storage areas, and were lowest at periphery zones. The elevated VOC concentrations in high-traffic urban core stations reflect intense fuel handling activities and increased vehicular turnover, while the comparatively lower but persistent levels in peri-urban and residential stations indicate that VOC exposure remains a concern even in less congested settings. The relatively low variability around mean values suggests consistent emission patterns across stations, highlighting the routine nature of VOC exposure for attendants (Bahino *et al*., 2025) [6]. The presence of measurable VOC concentrations at periphery locations also implies potential exposure risks for nearby residents (Kumari *et al*., 2023) [16].

Particulate matter concentrations across multiple size fractions, presented in Table 3, reveal substantial particulate loading within gas station environments, particularly in urban core locations. Fine and coarse particulate matter levels were highest in high-traffic stations, reflecting the combined influence of vehicular emissions, fuel combustion residues, and resuspended road dust. The persistence of elevated $PM_{2.5}$ and PM_{10} concentrations across peri-urban and residential stations indicates that particulate pollution is not confined to heavily trafficked zones alone. Fine particles, in particular, pose heightened health risks due to their ability to penetrate deep into the respiratory tract, suggesting a plausible link with the high prevalence of respiratory symptoms reported by attendants (Wang *et al*., 2025; Zhong *et al*., 2024) [26, 28].

Meteorological conditions summarised in Table 4 provide important context for interpreting pollutant behaviour. Higher ambient temperatures recorded in urban core stations may enhance fuel evaporation and pollutant volatilisation, thereby increasing gaseous and particulate concentrations at ground level. Lower relative humidity in these areas may further favour the persistence of fine particles, while higher humidity in residential settings may promote particle growth but does not appear sufficient to offset emission-related increases. The minimal variation in barometric pressure and altitude across station categories indicates that local emission sources and operational activities, rather than broader atmospheric or topographic factors, are the primary drivers of observed pollution patterns (Edwards *et al*., 2025; Yuan *et al*., 2025) [8, 27].

The occupational health implications of these environmental conditions are evident in the self-reported health complaints presented in Table 5. Respiratory irritation emerged as the most prevalent symptom, affecting over half of the respondents, followed by headache and dizziness, eye irritation, and fatigue. These symptoms align with the documented exposure to carbon monoxide, hydrogen

sulphide, volatile organic compounds, and fine particulate matter, all of which are known to elicit irritative and neuro-respiratory effects (Akintoye & Sawyerr, 2025; Nalini *et al*., 2025) [1, 19]. Although cardiovascular and neurological complaints were reported by a smaller proportion of attendants, their occurrence is noteworthy given the relatively young age profile of the workforce.

Demographic characteristics presented in Table 6 indicate that gas station attendants in Warri South are predominantly young adults, many of whom have already accumulated several years of occupational exposure. The concentration of workers within the 18–34-year age bracket suggests that health effects observed at this stage may have long-term implications if exposure continues unchecked (Orduvwe *et al*., 2025) [20]. The predominance of secondary-level education may also influence awareness of occupational hazards and adherence to safety practices, potentially exacerbating vulnerability (El-Hagrasy *et al*., 2025) [9].

The patterns of personal protective equipment use presented in Table 7 reveal widespread non-compliance with basic occupational safety measures. The majority of attendants reported never using respiratory protection, gloves, or protective eyewear, despite routine exposure to airborne pollutants. This lack of PPE use likely contributes to the high prevalence of reported symptoms and underscores systemic gaps in occupational health training, provision of protective gear, and enforcement of safety protocols within retail gas stations (Anígilájé *et al*., 2024; Reducing Workplace Violence in Gas Stations and Convenience Stores: For Employees., 2024) [2, 23].

Collectively, the findings from Figure 2 and Tables 1–7 demonstrate a convergence of elevated pollutant concentrations, unfavourable micro-environmental conditions, prolonged occupational exposure, and inadequate protective practices among gas station attendants in Warri South Local Government Area. The results highlight forecourts in high-traffic urban stations as critical exposure hotspots, while also revealing that peri-urban and residential stations are not free from risk. These observations underscore the need for targeted interventions, including improved vapour recovery systems, enhanced station design, routine air quality monitoring, and strengthened occupational health policies aimed at reducing exposure and protecting worker health in urban petroleum retail environments.

Conclusion

This study provides a comprehensive evaluation of air quality conditions and associated health outcomes among gas station attendants in Warri South Local Government Area, Delta State, Nigeria. The findings demonstrate that retail gas stations constitute significant occupational exposure environments, characterised by elevated concentrations of gaseous pollutants, volatile organic compounds, and particulate matter across different station categories and operational zones.

Forecourts consistently emerged as the primary hotspots of pollutant exposure, particularly within high-traffic urban core stations, where carbon monoxide, hydrogen sulphide, and volatile organic compound levels were highest. Although pollutant concentrations generally declined with increasing distance from dispensing points, measurable levels persisted at storage areas and periphery zones, indicating sustained emission sources and potential exposure risks for both workers and nearby residents. The widespread exceedance of health-based guideline values for hydrogen sulphide across all station categories further underscores the chronic nature of exposure within these environments.

Particulate matter concentrations across multiple size fractions revealed substantial fine and coarse particle burdens, especially in urban and peri-urban stations. The persistence of elevated $PM_{2.5}$ and PM_{10} levels, combined with prevailing meteorological conditions that favour pollutant accumulation, suggests an increased risk of respiratory and systemic health effects. These environmental findings are corroborated by the high prevalence of self-reported respiratory, neurological, and irritative symptoms among attendants, despite the relatively young age profile of the workforce.

The study also highlights critical deficiencies in occupational safety practices, notably the low and inconsistent use of personal protective equipment. The combination of prolonged work duration, limited protective measures, and continuous exposure to airborne pollutants places gas station attendants at heightened risk of both acute and long-term health effects. This situation reflects broader gaps in occupational health awareness, provision of safety resources, and regulatory enforcement within the petroleum retail sector.

Overall, the findings underscore the need for urgent and coordinated interventions to improve air quality management and worker protection in retail gas stations within Warri South Local Government Area. Strengthening vapour control systems, enforcing the use of appropriate personal protective equipment, implementing routine air quality monitoring, and enhancing occupational health education are essential steps toward mitigating exposure-related risks. By addressing these issues, policymakers, regulatory agencies, and station operators can contribute to safer working environments and improved public health outcomes in urban petroleum retail settings.

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