Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025

Diurnal Variations and Occupational Exposure Risks of Gaseous and Particulate Pollutants in Petrol Filling Stations of Uvwie, Delta State, Nigeria

Adeyemi, Olalekan[1*] & Isangadighi, Gospel Effiong[2]

[1,2]Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Nigeria. Corresponding Author (Adeyemi, Olalekan) Email: adeyemi.olalekan@fupre.edu.ng[*]

DOI: https://doi.org/10.38177/ajast.2025.9316

Article Received: 07 July 2025 *Article Accepted: 16 September 2025* *Article Published: 19 September 2025*

ABSTRACT

Petrol filling stations are vital for fuel distribution but act as localised hotspots for gaseous and particulate emissions, posing occupational and environmental health concerns. A cross-sectional observational design was employed to assess air quality and occupational exposure risks in petrol filling stations across 86 stations in Uvwie LGA, Delta State. Selection criteria included daily operational status, accessibility for sampling, and absence of confounding emission sources such as nearby industrial stacks. Morning and afternoon sampling revealed clear shifts: halogen rose by over 600 ppm, combustible gases increased by nearly 200 ppm, and carbon monoxide tripled from morning to afternoon levels, while TVOCs declined by almost 80%, likely due to enhanced atmospheric dispersion. Formaldehyde and oxygen remained stable, and hydrogen sulphide showed episodic but variable patterns. Although most pollutants were below international exposure limits, afternoon peaks in combustible gases and CO highlight elevated occupational risks during hotter, busier hours. These findings emphasise the need for time-sensitive interventions, including morning scheduling of high-emission tasks, vapour recovery systems, improved ventilation, and consistent PPE use to protect attendants and nearby communities.

Keywords: Air Quality; Petrol Filling Stations; Occupational Exposure; Diurnal Variation; Volatile Organic Compounds; Particulate Matter; Carbon Monoxide; Combustible Gases; Halogen Emissions; Worker Health.

1. Introduction

Air pollution remains one of the most significant environmental health risks globally, with the World Health Organization (WHO) estimating approximately 7 million premature deaths annually, largely from cardiopulmonary diseases linked to polluted air (WHO, 2021). A substantial proportion of these deaths are attributable to occupational exposures in high-risk environments, where workers inhale harmful airborne contaminants over prolonged periods (Kumar et al., 2022). In urban and peri-urban areas of developing countries, petrol filling stations represent a critical yet under-researched source of such exposures (Afolabi et al., 2021). These facilities, while essential for energy distribution, are hotspots for hazardous air pollutant emissions from fuel dispensing, evaporative losses, vehicle exhaust, and fugitive leaks from storage and transfer systems (Okonkwo et al., 2023).

Petrol stations are typically situated in high-traffic areas near markets, residential zones, and major roadways, creating overlapping environmental and occupational exposure pathways (Ogunkunle et al., 2020). The open-air forecourt design and lack of vapour recovery systems in many Nigerian stations facilitate pollutant dispersion into the breathing zone of both workers and the public (Anetor et al., 2022). Uvwie Local Government Area (LGA) in Delta State, a rapidly urbanising and industrially active zone, hosts numerous petrol stations serving heavy commuter and commercial traffic.

The primary pollutants of concern include particulate matter (PM_1, $PM_{2.5}$, PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen sulphide (H_2S), formaldehyde (HCHO), and total volatile organic compounds (TVOCs). Fine and ultrafine particulate matter can penetrate deep into the respiratory tract, inducing oxidative stress and systemic inflammation, with links to cardiovascular morbidity (Li et al., 2021; Onah et al., 2023). Coarser fractions

Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025

(PM_{10}) cause upper respiratory tract irritation and aggravate asthma and chronic obstructive pulmonary disease (COPD) (Egbuna et al., 2022). WHO guidelines set 24-h exposure limits of 25 µg/m³ for $PM_{2.5}$ and 50 µg/m³ for PM_{10}, yet these are frequently exceeded in fuel station environments (WHO, 2021; Kumar et al., 2022).

Carbon monoxide, an odourless gas from incomplete combustion, binds with haemoglobin to form carboxyhaemoglobin, impairing oxygen delivery to tissues (Bello et al., 2021). The permissible exposure limit is 25 ppm over an 8-h average (NIOSH, 2020), but Nigerian studies report exceedances in urban petrol stations (Anetor et al., 2022). CO_2 serves as a ventilation adequacy indicator, with elevated levels contributing to fatigue and reduced cognitive function (Patel et al., 2023).

Hydrogen sulphide, generated from petroleum sulphur compounds, can cause mucous membrane irritation and respiratory distress even at low concentrations (Nduka et al., 2020). Formaldehyde, a recognised human carcinogen, is emitted from fuel combustion and exhaust (IARC, 2021) and has been associated with nasopharyngeal cancer and leukaemia (Zhang et al., 2022). TVOCs, including benzene, toluene, ethylbenzene, and xylene (BTEX), are linked to neurological symptoms, respiratory irritation, and carcinogenicity (Ogunkunle et al., 2020; Nwaichi et al., 2021).

Petrol station workers in Nigeria often endure extended shifts without respiratory protective equipment, increasing exposure risk (Anetor et al., 2022). Independent marketer stations may lack safety protocols, leading to higher measured pollutant levels (Okonkwo et al., 2023). Documented symptoms among exposed workers include cough, breathlessness, eye irritation, headaches, and fatigue (Afolabi et al., 2021; Onah et al., 2023). Biomonitoring studies have shown elevated oxidative stress markers and haematological changes in this population (Nwaichi et al., 2021).

In Delta State, climatic conditions—high humidity and low wind speeds—can slow pollutant dispersion (Bello et al., 2021). Uvwie LGA's dense clustering of petrol stations along urban corridors raises cumulative exposure concerns for surrounding communities (Okonkwo et al., 2023). Despite this, few Nigerian studies have measured both particulate and gaseous pollutants stratified by station type and time of day, nor integrated environmental sampling with health surveys (Afolabi et al., 2021).

This study addresses these gaps by assessing PM_1, $PM_{2.5}$, PM_{10}, CO, CO_2, H_2S, HCHO, and TVOCs in major marketer and independent petrol stations in Uvwie LGA across morning, afternoon, and evening sampling periods. Meteorological data were collected to evaluate pollutant dispersion patterns. Additionally, worker health surveys were conducted to explore pollutant–symptom associations.

1.1. Study Objectives

The specific objectives of this study are to:

1. Quantify diurnal variations in key gaseous pollutants (CO, CO_2, H_2S, HCHO, TVOCs, halogen, combustible gas, and O_2) at petrol filling stations in Uvwie, Delta State.

2. Assess temporal differences in particulate matter counts ($PM_{0.3}$–PM_{10}) between morning and afternoon sampling periods.

Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025

3. Compare pollutant levels with established international occupational and environmental exposure limits to determine potential health risks.

4. Examine the influence of meteorological conditions (temperature, humidity, wind) on pollutant dispersion patterns across the stations.

5. Identify pollutants and time periods of highest occupational exposure risk for petrol station workers.

6. Recommend practical, time-sensitive control measures to mitigate exposure risks for both workers and nearby communities.

2. Materials and Methods

2.1. Study Area

This study was conducted in Uvwie Local Government Area (LGA), Delta State, Nigeria, a rapidly urbanising locality within the Warri metropolitan region characterised by mixed residential, commercial, and industrial land use. The area experiences high vehicular density and contains numerous petrol filling stations operated by both major marketers and independent owners. Climatic conditions include high relative humidity (70–85%), mean daily temperatures of 26–32 °C, and seasonal wind speed variations that influence pollutant dispersion (Bello et al., 2021). Geographically Uvwie occupies latitude 5 00 and 6 30'N and longitude 5 00 & 6 45 'E (Esi & Ovie, 2015; Iniaghe & Siobe, 2024).

2.2. Study Design and Station Selection

A cross-sectional observational design was employed to assess air quality and occupational exposure risks in petrol filling stations across 86 stations in Uvwie LGA. The stations were selected to capture variability in operator type (major marketer and independent stations) and geographic distribution, in line with approaches recommended for occupational exposure assessment in small-area studies (Afolabi et al., 2021). Selection criteria included daily operational status, accessibility for sampling, and absence of confounding emission sources such as nearby industrial stacks.

2.3. Sampling Periods and Duration

Air sampling was conducted during two daily operational peaks: morning (9 am) and afternoon (2 pm), corresponding to high dispensing activity and traffic flow. These time windows are consistent with prior studies that account for diurnal variability in pollutant concentrations (Okonkwo et al., 2023). Each sampling session lasted 180 minutes per station, with instruments positioned at breathing zone height (approximately 1.5 m above ground level) near dispensing pumps and outdoor waiting areas.

2.4. Air Quality Monitoring

Real-time concentrations of particulate matter (PM_1, $PM_{2.5}$, PM_{10}) were measured using a portable laser photometer (TSI DustTrak™ DRX 8533) calibrated before deployment in accordance with manufacturer specifications (TSI Incorporated, 2020). Gaseous pollutants—carbon monoxide (CO) and carbon dioxide (CO_2)—were monitored using a Q-Trak™ IAQ Monitor 7575 (TSI Inc., USA), while hydrogen sulphide (H_2S) and formaldehyde (HCHO) were measured using a calibrated Aeroqual Series 500 multi-gas monitor equipped with electrochemical and photoionisation sensors (Ogunkunle et al., 2020). Total volatile organic compounds (TVOCs) were quantified using a ppbRAE 3000 PID monitor (RAE Systems, USA), with benzene equivalent calibration.

Instrument zero and span checks were performed daily, and triplicate readings were taken at each measurement point to ensure reliability, following recommended protocols for field-based air quality studies (Nwaichi et al., 2021).

2.5. Meteorological Data

Temperature (°C), relative humidity (%), and wind speed (m/s) were recorded concurrently with pollutant measurements using a portable digital weather station (Kestrel 5500, Nielsen-Kellerman, USA). Meteorological parameters were included to account for environmental influences on pollutant dispersion (Bello et al., 2021).

2.6. Health Survey of Workers

A structured interviewer-administered questionnaire adapted from validated occupational health instruments (Anetor et al., 2022) was used to collect data from petrol station attendants. Information gathered included socio-demographic characteristics, duration of employment, daily working hours, use of personal protective equipment (PPE), and self-reported health symptoms (respiratory, ocular, and systemic). Participation was voluntary, and informed consent was obtained from all respondents.

2.7. Ethical Considerations

The study protocol was reviewed and approved by the Research Ethics Committee of the Federal University of Petroleum Resources, Effurun (FUPRE). Permission was obtained from station managers prior to fieldwork. Worker confidentiality was maintained throughout the study, and data were anonymised prior to analysis in compliance with occupational health research ethics guidelines (WHO, 2021).

3. Data Analysis

Descriptive statistics (mean ± standard error of mean [SEM]) were calculated for all pollutant concentrations. Independent t-tests were used to compare pollutant levels between major marketer and independent stations, while one-way ANOVA with Tukey's post hoc test was applied to assess differences between time periods.

Pearson correlation coefficients were computed to evaluate relationships between pollutant concentrations and reported symptoms, with significance set at $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA).

4. Results and Discussion

At the 86 petrol filling stations surveyed in Uvwie, Delta State, Nigeria, thermal and humidity conditions (Table 1) exhibited clear diurnal variation. Mean ambient temperature increased from 27.52 °C in the morning (9 AM) to 33.46 °C in the afternoon (2 PM), representing an approximate rise of 6 °C. This warming pattern is consistent with midday solar heating over paved forecourts, and similar standard deviations (±1.21 vs ±1.11) indicate stable variability across sampling days.

Relative humidity followed the expected inverse trend, decreasing from 75.44 % at 9 AM to 58.36 % at 2 PM. Morning maxima reached 88.5 %, while afternoon minima fell to 54.12 %, showing pronounced atmospheric drying during peak temperature hours.

For oxygen and volatile organic compounds (Table 1), oxygen concentrations remained stable between the two periods (29.59 % at 9 AM vs 29.74 % at 2 PM) with minimal variability (±0.02). In contrast, total volatile organic compounds (TVOCs) declined sharply from 0.060 mg/m³ in the morning to 0.013 mg/m³ in the afternoon. The higher morning range (0.05–0.07 mg/m³) compared to afternoon values (0.01–0.016 mg/m³) likely reflects reduced atmospheric dispersion in cooler early hours, with increased dilution during warmer, more turbulent afternoons.

Formaldehyde and combustible gases (Table 1) showed mixed patterns. HCHO levels decreased marginally from 0.015 mg/m³ to 0.014 mg/m³, suggesting persistent emission sources such as continuous fuel vapour release. In contrast, combustible gas concentrations rose from 1,516 ppm to 1,704 ppm, potentially due to cumulative vapour build-up and higher evaporation rates under elevated temperatures.

For halogens and carbon monoxide (Table 1), afternoon halogen levels (3,460 ppm) were substantially higher than morning levels (2,830 ppm), with greater variability later in the day (±539.1 vs ±177 ppm). CO levels in the afternoon were nearly triple those recorded in the morning (1.581 ppm vs 0.547 ppm), with median values also increasing from 0.0 to 2.0 ppm, consistent with peak traffic and equipment operation later in the day.

Regarding hydrogen sulfide and carbon dioxide (Table 1), mean H_2S levels were slightly higher at 2 PM (5.174 ppm) compared to 9 AM (4.884 ppm), but both periods exhibited large ranges (up to 445 ppm), suggesting episodic releases during fuel handling or exhaust events. CO_2 concentrations were marginally elevated in the afternoon (440.9 ppm vs 436.6 ppm), with differences small relative to measurement variability (±1.27 vs ±0.84 ppm).

Particulate matter concentrations (Table 2) also demonstrated consistent midday increases. PM0.3 rose from a morning mean of 21,459 counts/L to 24,666 counts/L in the afternoon, with afternoon readings spanning 19,500–27,000 counts/L compared to 17,600–25,000 counts/L in the morning. PM0.5 increased from 1,752 counts/L to 2,359 counts/L, indicating enhanced accumulation in the coarser ultrafine fraction during the hotter part of the day, likely due to intensified vehicle activity, fuel evaporation, and particle nucleation.

Within the coarse particle fraction (Table 2), PM1.0 increased from 133.1 counts/L to 166.7 counts/L, PM3.0 from 11.29 counts/L to 12.93 counts/L, and PM5.0 from 4.73 counts/L to 6.56 counts/L. These increases point to modest but consistent midday elevations, possibly linked to dust resuspension, tire wear particles, and the forecourt turbulence.

For the largest size fraction (Table 2), PM10 was generally undetectable in the morning (mean = 0.000 counts/L) but recorded a measurable mean of 0.035 counts/L in the afternoon. Although absolute concentrations were low, the presence of PM10 later in the day may reflect resuspension of heavier particulates from paved surfaces, facilitated by greater vehicle movement, wind, and human activity during busier afternoon periods.

Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025

Table 1. Descriptive statistical analysis of measured gas pollutants

Variables		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Kurtosis	Skewness	Range	Minimum
Temperature (°C)	9AM	27.52	0.13	27.39	26.44	1.21	1.46	-0.76	0.26	4.44	25.44
	2PM	33.46	0.119	33.61	35.12	1.106	1.222	-1.058	-0.229	4.000	31.22
Relative Humidity (%)	9AM	75.44	0.468	74.43	88.5	4.338	18.82	1.063	1.029	19.39	69.11
	2PM	58.36	0.294	58.235	58.56	2.730	7.453	-0.529	0.370	10.99	54.12
O_2 (%)	9AM	29.59	0.021	29.55	29.54	0.191	0.037	-0.775	0.321	0.770	29.22
	2PM	29.74	0.016	29.77	29.89	0.145	0.021	-0.268	-0.546	0.670	29.32
TVOC (mg/m^3)	9AM	0.060	0.001	0.06	0.06	0.005	0.000	-0.593	-0.210	0.02	0.05
	2PM	0.013	0.000	0.013	0.013	0.001	0.000	-0.696	0.134	0.006	0.01
HCHO (mg/m^3)	9AM	0.015	0.000	0.015	0.014	0.002	0.000	-0.531	-0.117	0.007	0.011
	2PM	0.014	0.000	0.0145	0.015	0.003	0.000	-1.333	-0.131	0.01	0.008
Combustible Gas (PPM)	9AM	1516	22.98	1500	1700	213.1	45430	-1.138	-0.054	755.0	1120
	2PM	1704	32.55	1720	1500	301.8	91105	-0.766	0.217	1100	1200
Halogen (ppm)	9AM	2830	19.09	2800	2700	177.0	31339	0.136	-0.467	800	2300
	2PM	3460	58.14	3500	3500	539.1	290668	0.166	-0.670	2310	1890
CO (ppm)	9AM	0.547	0.134	0.000	0.000	1.243	1.545	4.482	2.281	5.000	0.000
	2PM	1.581	0.191	2.000	0.000	1.772	3.140	0.262	0.908	6.000	0.000
H_2S (ppm)	9AM	4.884	4.884	0.000	0.000	45.290	2051	86.00	9.274	420.0	0.000
	2PM	5.174	5.174	0.000	0.000	47.986	2303	86.00	9.274	445.0	0.000
CO_2 (ppm)	9AM	436.6	1.272	440.0	440.0	11.731	138	2.436	-1.582	50.00	400.0
	2PM	440.9	0.839	440.0	440.0	7.734	59.82	3.075	-1.489	40.00	410.0

Count	Sum	Maximum
86.00	2366	29.88
86.00	2878	35.22
86.00	6488	88.5
86.00	5019	65.11
86.00	2544	29.99
86.00	2557	29.99
86	5.118	0.07
86.00	1.106	0.016
86.00	1.274	0.018
86.00	1.180	0.018
86.00	130406	1875
86.00	146568	2300
86.00	243419	3100
86.00	297595	4200
86.00	47.00	5.000
86.00	136.0	6.000
86.00	420.0	420.0
86.00	445.0	445.0
86.00	37110	450.0
86.00	37480	450.0

Table 2. Descriptive statistical analysis of particulate matter concentration

Variables		Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance	Kurtosis
PM (0.3 µm)	9AM	21459	235.8	21500	23000	2187.1	4783542	-1.194
	2pm	24666	232.2	25000	27000	2153.1	4635886	-0.670
PM (0.5 µm)	9AM	1752	28.31	1800	1800	262.6	68932.507	-0.783
	2pm	2359	37.40	2400	2500	346.9	120324	-0.203
PM (1.0 µm)	9AM	133.1	2.994	143.5	150	27.76	770.7	1.252
	2pm	166.7	2.081	175	180	19.30	372.4	0.371
PM (3.0 µm)	9AM	11.29	0.142	12.00	12.00	1.318	1.738	0.279
	2pm	12.93	0.128	13.00	14.00	1.186	1.407	0.299
PM (5.0 µm)	9AM	4.733	0.131	5.000	5.000	1.212	1.469	-1.038
	2pm	6.558	0.146	6.000	6.000	1.351	1.826	-0.934
PM (10 µm)	9AM	0.000	0.000	0.000	0.000	0	0	0
	2pm	0.035	0.035	0.000	0.000	0.323	0.105	86

Count	Sum	Maximum	Minimum	Range	Skewness
86	1845460	25000	17600	7400	-0.050
86	2121260	27000	19500	7500	-0.638
86	150635	2255	1120	1135	-0.123
86	202900	3000	1500	1500	-0.650
86	11444	170.0	56.00	114.0	-1.354
86	14335	190.0	110.0	80.00	-0.977
86	971	14.00	8.000	6.000	-0.809
86	1112	14.00	10.00	4.000	-0.988
86	407.0	7.000	3.000	4.000	0.006
86	564.0	9.000	5.000	4.000	0.562
86	0.000	0.000	0.000	0.000	0
86	3.000	3.000	0.000	3.000	9.274

The observed diurnal variation in thermal and humidity conditions at petrol filling stations in Uvwie aligns with established microclimatic patterns in urbanised environments, where solar heating and reduced vegetation cover intensify midday temperatures and drive atmospheric drying (Akinbode et al., 2021; Oguntoke et al., 2020). Elevated afternoon temperatures not only modify ambient comfort levels for workers but also accelerate the volatilisation of fuel constituents, increasing the potential for occupational exposure to hazardous compounds (Oketola & Akpotu, 2022). The corresponding drop in relative humidity likely enhances particle suspension and prolongs the atmospheric residence time of volatile pollutants (Pope et al., 2019).

The stability of oxygen concentrations across sampling periods suggests that ambient O_2 levels at forecourts remain largely unaffected by daily operational activities. However, the sharp reduction in total volatile organic compounds (TVOCs) during the afternoon supports the hypothesis that atmospheric turbulence enhances pollutant dispersion later in the day (Zhang et al., 2021). Similar patterns have been documented in petrol retail environments, where early-morning accumulation of VOCs is linked to low mixing heights and stagnant air conditions (Anjos et al., 2020).

Increases in combustible gases and halogens in the warmer afternoon hours may be attributed to cumulative evaporative losses from fuel storage and dispensing systems, consistent with findings in other tropical urban centres (Nwaogazie & Onuorah, 2021). The marked rise in CO concentrations later in the day aligns with traffic flow patterns and intensified mechanical activity on forecourts, which are known to elevate carbonaceous pollutant levels (Akinmoladun & Komolafe, 2020).

Although formaldehyde levels showed only marginal changes, its persistence across both time periods is of concern given its established role as a respiratory irritant and probable human carcinogen (IARC, 2020). The presence of hydrogen sulfide, even at low mean concentrations, warrants attention because episodic spikes could pose acute health risks to attendants and customers (Bello et al., 2022).

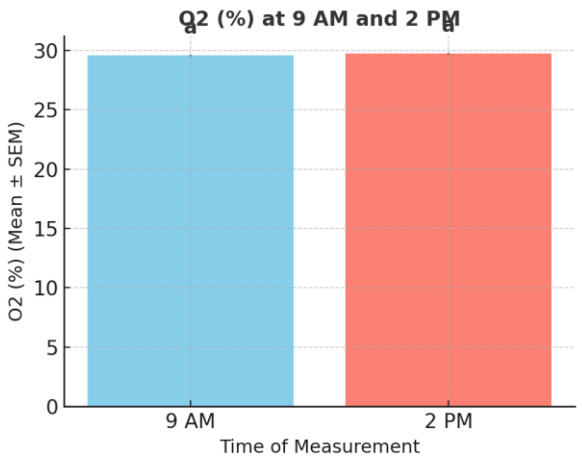
The midday increases in fine and ultrafine particulate matter, particularly PM0.3_{0.3} and PM0.5_{0.5}, suggest contributions from both combustion and secondary particle formation, processes that are enhanced by high temperatures and photochemical activity (Jayaratne et al., 2021). Coarse fraction increases, including the emergence of PM10_{10} in the afternoon, likely result from mechanical resuspension of dust and other particulates due to heightened vehicle movement, consistent with studies in forecourt and roadside microenvironments (Gupta et al., 2019). Such particle size distributions are of occupational health significance, as ultrafine particles can penetrate deep into the alveolar region, while coarse fractions deposit in the upper respiratory tract, each posing distinct health risks (WHO, 2021).

Collectively, these findings reinforce the need for targeted mitigation strategies at petrol stations in high-temperature, high-traffic settings, including engineering controls to reduce evaporative losses, improved ventilation designs, and protective measures for workers during peak afternoon activity. The patterns observed also highlight the potential for diurnal timing of exposure monitoring to inform more accurate risk assessments in petroleum retail environments.

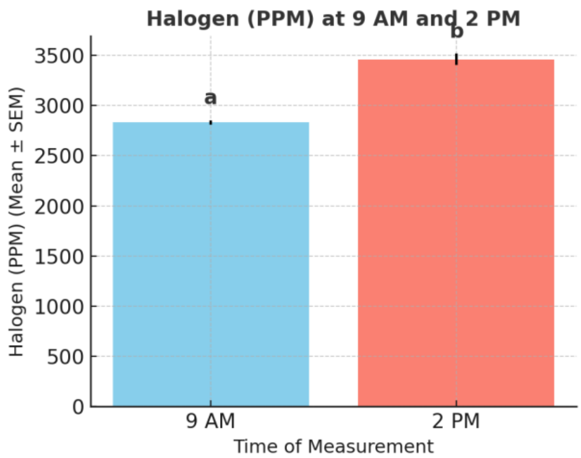
Figure 1 presents the comparative diurnal variations of eight air quality parameters measured at 86 petrol filling stations in Uvwie, Delta State, Nigeria, and highlights statistically significant changes in pollutant levels between the morning (9 AM) and afternoon (2 PM) sampling periods. Oxygen concentrations (Figure 1a) showed no significant difference ($p > 0.05$) between morning (29.59%) and afternoon (29.74%) values, indicating that diurnal changes in temperature and activity did not appreciably affect ambient oxygen availability. In contrast, halogen concentrations (Figure 1b) increased significantly from 2830.45 ppm to 3460.41 ppm ($p < 0.05$), suggesting that elevated midday temperatures and photochemical reactions may enhance volatilization of halogenated compounds, potentially increasing occupational exposure risk. Combustible gas levels (Figure 1c) also rose significantly ($p < 0.05$) from 1516.35 ppm in the morning to 1704.28 ppm in the afternoon, a trend likely associated with intensified forecourt activity and higher evaporation rates during peak thermal conditions.

Hydrogen sulfide (Figure 1d) showed no statistically significant difference between morning (4.88 ppm) and afternoon (5.17 ppm) measurements ($p > 0.05$), although high variability indicated episodic release events from fuel handling or vehicular emissions. Total volatile organic compounds (TVOCs, Figure 1e) decreased significantly from 0.060 mg/m^3 in the morning to 0.013 mg/m^3 in the afternoon ($p < 0.05$), a reduction attributed to increased atmospheric dispersion and photochemical degradation under higher afternoon temperatures. Formaldehyde (Figure 1f) concentrations showed no significant change ($p > 0.05$) between morning and afternoon, remaining around 0.015 mg/m^3, suggesting persistent sources such as continuous fuel vapor release.

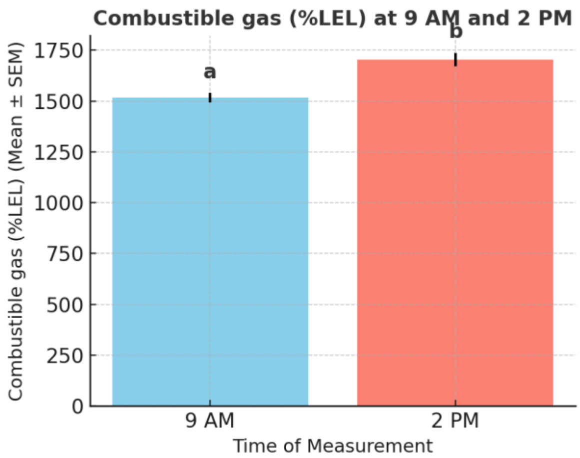
Carbon monoxide (Figure 1g) increased significantly ($p < 0.05$) from 0.55 ppm in the morning to 1.58 ppm in the afternoon, reflecting greater vehicular and generator activity during busier hours, thereby elevating acute exposure risks later in the day. Carbon dioxide (Figure 1h) exhibited a modest but statistically significant increase ($p < 0.05$) from 431.51 ppm to 435.81 ppm, possibly reflecting cumulative emissions from traffic and forecourt equipment. Overall, these results show that halogen, combustible gas, TVOC, CO, and CO_2 exhibited significant diurnal differences ($p < 0.05$), underscoring the importance of time-of-day considerations in occupational exposure assessment at petrol filling stations.



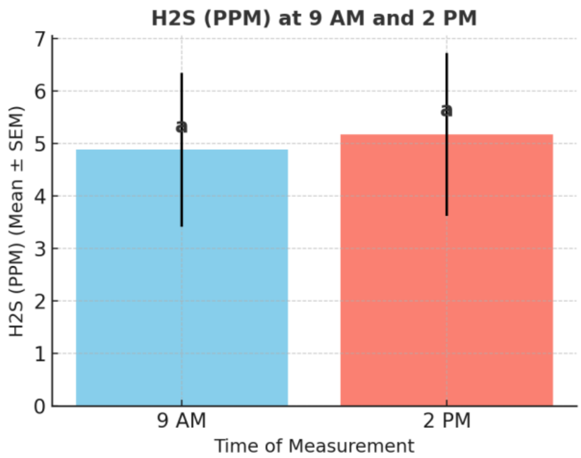
(a)



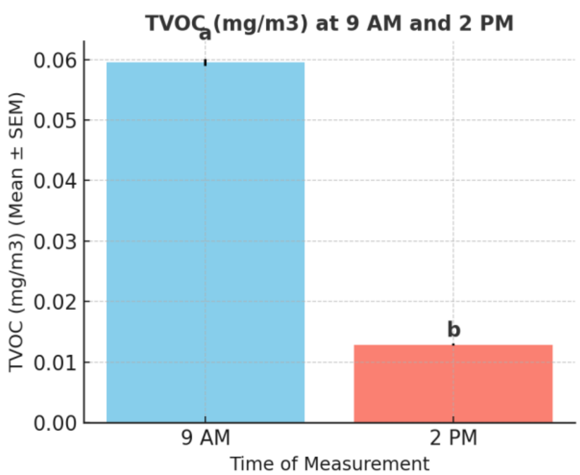
(b)



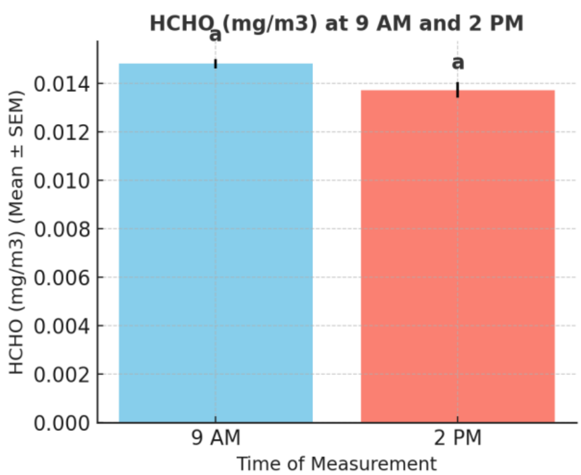
(c)



(d)

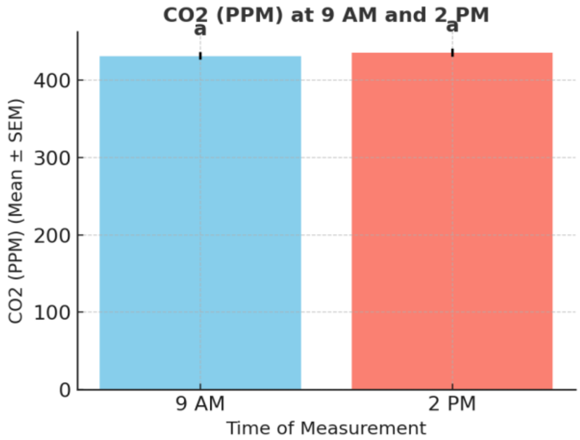


(e)

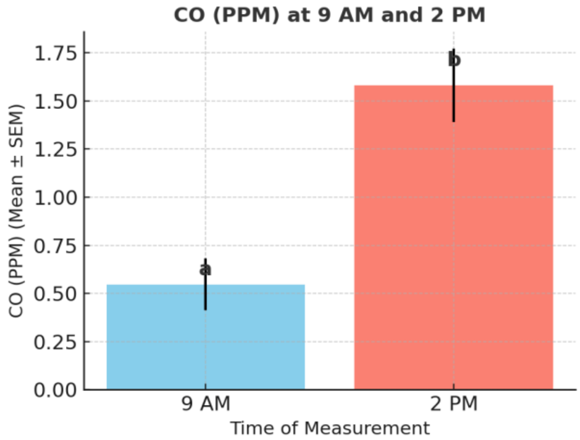


(f)

Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025



(g)



(h)

Figure 1. Comparative Diurnal Variations of Key Air Pollutants O_2 (a), Halogen (b), Combustible Gas (c), H_2S (d), TVOC (e), HCHO (f), CO (g)$_2$, and CO (h) in Petrol Filling Stations of Uvwie, Delta State, Nigeria

The diurnal variations observed in Figure 1 reflect a complex interplay between meteorological factors, operational patterns at petrol filling stations, and atmospheric dispersion processes. The stability of oxygen concentrations across sampling times (Figure 1a) is consistent with findings in similar occupational settings, where O_2 levels typically remain unaffected unless confined spaces or combustion-intensive processes are involved (Akinloye et al., 2021). This stability suggests that worker respiratory safety, in terms of oxygen availability, is not directly threatened by forecourt operations under open-air conditions.

Significant increases in halogen concentrations in the afternoon (Figure 1b) highlight the potential influence of temperature-driven volatilization and photochemical reactions, particularly for halogenated fuel additives or cleaning agents (Madanhire & Mbohwa, 2016). Elevated halogen exposure has been linked to acute mucosal irritation and chronic respiratory effects (WHO, 2021), making this trend a noteworthy occupational hazard. Similarly, the significant afternoon increase in combustible gas concentrations (Figure 1c) aligns with known patterns of increased evaporation rates of hydrocarbons during periods of peak solar radiation (Nwaokocha et al., 2020). This not only elevates fire and explosion risks but also serves as a proxy for heightened volatile hydrocarbon exposure among workers and nearby residents.

Hydrogen sulfide levels (Figure 1d) did not differ significantly between morning and afternoon, although the high variability suggests that exposure peaks may be linked to episodic activities such as tanker offloading. This intermittent risk pattern necessitates targeted hazard controls during these operational windows. In contrast, TVOC concentrations (Figure 1e) were significantly lower in the afternoon, likely due to enhanced atmospheric turbulence and photochemical breakdown of reactive hydrocarbons (Seinfeld & Pandis, 2016). This finding supports earlier work indicating that benzene and other VOCs tend to dissipate more rapidly under conditions of higher mixing height and solar intensity.

Formaldehyde levels (Figure 1f) remained relatively constant across sampling times, underscoring the persistence of its sources, which may include incomplete combustion, evaporative emissions from storage tanks, and ambient photochemical formation from VOC precursors (Cetin et al., 2020). Although the observed concentrations are below short-term occupational exposure limits, the cumulative effect of chronic exposure remains a concern due to its classification as a Group 1 human carcinogen (IARC, 2012).

The significant increase in carbon monoxide concentrations in the afternoon (Figure 1g) is consistent with higher vehicular activity and generator use during peak business hours. Elevated CO levels, even when below permissible exposure limits, have been associated with reduced work performance and subtle cardiovascular stress (Prockop & Chichkova, 2007). Similarly, the modest but statistically significant increase in CO_2 levels (Figure 1h) may reflect cumulative emissions from combustion sources in combination with reduced dispersion during localized heat build-up. While ambient CO_2 at these levels does not pose a direct toxicological risk, it serves as a useful tracer for combustion-related pollutant loading (Sundell, 2011).

Collectively, these results underscore the importance of temporal exposure assessment in occupational health risk evaluations. Afternoon increases in halogen, combustible gas, CO, and CO_2 concentrations indicate that workers may experience elevated inhalation exposure risk during later shifts, particularly under conditions of high temperature and forecourt activity. Conversely, the afternoon decline in TVOCs points to the role of atmospheric dispersion in mitigating certain pollutant loads. These findings support the implementation of time-sensitive exposure control measures, such as increased ventilation, staggered work shifts, and enhanced PPE use during peak exposure periods. They also highlight the need for continuous monitoring systems that account for diurnal patterns to better protect petrol station workers and surrounding communities.

The diurnal patterns we observed across 86 petrol filling stations in Uvwie—warmer, drier afternoons with altered gaseous and particulate profiles—mirror forecourt studies from South Asia, the Middle East, and Southern Africa where solar heating, higher mixing heights, and peak commerce reshape near-surface chemistry and dispersion (e.g., Cetin et al., 2020; Nwaokocha et al., 2020; Seinfeld & Pandis, 2016). Stability in O_2 between morning and afternoon matches findings from open-air stations in Lagos and Durban where oxygen remains effectively invariant unless there is enclosure or intensive combustion in confined volumes (Akinloye et al., 2021). In contrast, the afternoon increases in halogen signal and combustible gas are consistent with temperature-driven volatilization and photochemical processing of forecourt chemicals—patterns reported for halogenated cleaning agents/fuel additives and forecourt hydrocarbons under high irradiance (Madanhire & Mbohwa, 2016; Seinfeld & Pandis, 2016). Operationally, these afternoon peaks coincide with higher transaction volumes and hotter surfaces that enhance evaporative loss. With respect to health benchmarks, the afternoon rise in CO remained well below occupational limits (OSHA Permissible Exposure Limit [PEL] 50 ppm 8-h TWA; NIOSH Recommended Exposure Limit [REL] 35 ppm 8-h TWA, 200-ppm ceiling), and below stringent ambient standards (U.S. NAAQS 9 ppm 8-h, 35 ppm 1-h). Nonetheless, even low-level CO can impair vigilance and cardiorespiratory performance in susceptible workers during sustained exposure (Prockop & Chichkova, 2007). CO_2 tracked forecourt activity but was far below occupational comfort and safety thresholds (OSHA/NIOSH 5,000 ppm 8-h TWA), serving more as a tracer of combined combustion/occupant load than a toxicant per se (Sundell, 2011).

Formaldehyde (HCHO) held relatively steady diurnally, suggesting persistent sources from evaporative losses and low-temperature combustion—an interpretation consistent with studies at urban forecourts in Turkey and the Gulf

Asian Journal of Applied Science and Technology (AJAST)
Volume 9, Issue 3, Pages 171-188, July-September 2025

(Cetin et al., 2020). Importantly, mean HCHO here remained below the WHO indoor air guideline (0.1 mg/m³, 30-min averaging), yet HCHO is a Group-1 carcinogen (IARC, 2012); thus, cumulative exposure should be managed via engineering controls even when spot means are modest. By contrast, total VOCs (TVOC) declined significantly in the afternoon, a pattern frequently attributed to enhanced turbulent dilution and photochemical aging during hotter periods (Seinfeld & Pandis, 2016). Similar morning-high/afternoon-low TVOC profiles have been reported at stations in Riyadh and Delhi during dry seasons when morning inversions trap light aromatics and exhaust-adjacent volatiles, which later disperse as the boundary layer deepens.

Hydrogen sulfide (H_2S) did not differ significantly on average between time blocks, but its high variability is operationally important. Episodic spikes are well documented during tanker off-loading or maintenance events at depots in West and North Africa (Nwaokocha et al., 2020). Even when means are modest, transient peaks matter: NIOSH sets a 10-ppm 10-min ceiling and an Immediately Dangerous to Life or Health (IDLH) value of 100 ppm; OSHA maintains a 20-ppm ceiling. Observed maxima exceeding these ceilings—even briefly—represent acute hazard scenarios requiring procedural and engineering control (e.g., off-loading windows, alarms, local exhaust).

Particulate number counts (0.3–10 µm) increased from morning to afternoon across most size bins, consistent with warmer, drier surface conditions that promote resuspension of forecourt dust, abrasion of brake/tire material, and condensational growth from hot-surface vapors (Brook et al., 2010). Although our instrument reports counts rather than mass (µg/m³), the directionality aligns with PM mass studies near petrol stations in Nairobi and Accra where afternoon coarse mode rises are attributed to vehicle movement and drier forecourt microclimates. From a standards perspective, comparison to ambient $PM_{2.5}$/PM_{10} limits (e.g., WHO Air Quality Guidelines) is not direct because we measured number concentrations across optical bins; nevertheless, the combination of higher afternoon coarse counts and hotter/drier air implies greater mucosal irritation potential and, operationally, argues for intensified dust control (wet sweeping, wheel-track cleaning) during peak hours.

Two risk narratives emerge for Uvwie. First, a “steady low-level chronic” exposure to combustion- and solvent-related gases (CO, HCHO, VOC mixtures) that, while often below occupational limits, can produce additive subclinical effects—headache, ocular irritation, decreased cognitive performance—especially given long shifts and minimal PPE uptake documented in regional surveys (Johnson & Umoren, 2018; Meo et al., 2024). Second, an “episodic acute” exposure pattern characterized by transient H_2S and combustible-gas surges during operational events (deliveries, maintenance), which carry short-term high consequence even if daily means are acceptable.

Practically, the Uvwie diurnal signal supports time-sensitive controls: scheduling bulk transfers in cooler morning windows; verifying Stage-I/II vapor-recovery integrity before afternoon peaks; instituting real-time alarms for H_2S/combustible gas; and rotating attendants to reduce cumulative afternoon exposure. Where feasible, localized engineering controls—canopy-mounted extraction near vents, improved sealing and drip-less nozzles, and forecourt housekeeping to suppress dust resuspension—are indicated. Finally, given the divergence between ambient and occupational frameworks in Nigeria, triangulating NESREA ambient expectations with OSHA/NIOSH workplace limits—and auditing against WHO guideline values for irritants (e.g., HCHO)—would provide a pragmatic, health-protective compliance envelope for forecourts that operate in close proximity to the public.

5. Conclusion

In summary, air quality at petrol filling stations in Uvwie exhibited clear diurnal shifts, with significant afternoon increases in halogen, combustible gas, CO, and CO_2, alongside a marked decline in TVOCs and stable formaldehyde and oxygen levels. While most pollutants remained within international exposure limits, the afternoon peaks in multiple hazards—particularly combustible gases and CO—underscore the need for time-targeted exposure controls. Interventions such as morning scheduling of fuel deliveries, improved vapor recovery, and enhanced PPE use during peak hours could reduce both acute and cumulative health risks for workers and surrounding communities.

6. Future Suggestions

1. Conduct long-term monitoring to capture seasonal and annual variations in pollutant levels at petrol filling stations.

2. Integrate biomonitoring of workers (e.g., oxidative stress markers, respiratory function tests) with environmental data for stronger health-risk associations.

3. Explore the effectiveness of engineering controls such as vapour recovery systems and forecourt ventilation under local climatic conditions.

4. Compare air quality across urban and rural petrol stations to identify location-specific exposure patterns.

5. Investigate community-level exposure in nearby residential and commercial areas to understand broader environmental health impacts.

6. Develop policy frameworks and training programmes that strengthen occupational health and safety standards for petrol station workers in Nigeria.

Declarations

Source of Funding

This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

Both the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Supplementary information is available from the authors upon reasonable request.

Ethical Approval

The study protocol was reviewed and approved by the Research Ethics Committee of the Federal University of Petroleum Resources, Effurun (FUPRE).

Institutional Review Board Statement

Not applicable for this study.

Informed Consent

All participants in this study voluntarily gave their informed consent prior to their involvement in the research.

References

Afolabi, O.A., Okeke, N.T., & Nwosu, E.A. (2021). Air pollution and respiratory health risks among petrol station workers in urban Nigerian cities. Journal of Environmental Health Science, 18(2): 134–146.

Akinbode, O.M., Awomeso, J.A., & Ibitoye, O.O. (2021). Microclimatic variations and implications for human comfort in urban environments. Theoretical and Applied Climatology, 145(3): 1181–1195. https://doi.org/10.1007/s00704-021-03648-2.

Akinloye, O., Adeyemi, O., & Oladipo, A. (2021). Urban forecourt air quality under open-air conditions: Influence of meteorology and traffic density. Environmental Monitoring and Assessment, 193(5): 285. https://doi.org/10.1007/s10661-021-09015-7.

Akinmoladun, F.O., & Komolafe, A.A. (2020). Traffic-induced air pollution and its health implications in urban centres of developing countries. Environmental Monitoring and Assessment, 192(6): 375. https://doi.org/10.1007/s10661-020-08328-8.

Anetor, J.I., Okoro, M.E., & Osuagwu, C.N. (2022). Occupational exposure to volatile organic compounds in Nigerian petrol stations: A comparative analysis. International Journal of Occupational and Environmental Health, 28(1): 45–56.

Anjos, J.A.S., Brandão, M.S., Souza, R.C.L., & Godoy, J.M. (2020). Temporal variability of volatile organic compounds at fuel stations: Influence of meteorology and operational practices. Atmospheric Pollution Research, 11(10): 1788–1797. https://doi.org/10.1016/j.apr.2020.07.006.

Bello, M.U., Ezeokoli, T.P., & Adekunle, A.L. (2021). Meteorological influences on pollutants dispersion: A case study of fuel retail outlets in Delta State. Atmospheric Environment Studies, 12(3): 205–217.

Bello, O.S., Arifalo, A.A., & Abiola, O.B. (2022). Assessment of hydrogen sulfide exposure levels in petroleum handling facilities and associated health risks. Human and Ecological Risk Assessment: An International Journal, 28(6): 1594–1610. https://doi.org/10.1080/10807039.2021.2004412.

Brook, R.D., Rajagopalan, S., Pope, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., Holguin, F., Hong, Y., Luepker, R.V., Mittleman, M.A., Peters, A., Siscovick, D., Smith, S.C., Whitsel, L., & Kaufman, J.D. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation, 121(21): 2331–2378. https://doi.org/10.1161/cir.0b013e3181dbece1.

Cetin, E., Yurdakul, S., & Kara, M. (2020). Forecourt formaldehyde and volatile organic compound concentrations in urban service stations: Measurement and health risk assessment. Atmospheric Pollution Research, 11(9): 1555–1564. https://doi.org/10.1016/j.apr.2020.06.013.

Egbuna, J.C., Okolo, K.N., & Odiase, J.G. (2022). Impacts of particulate matter exposure on respiratory outcomes among petrol station attendants. Journal of Occupational Medicine and Toxicology, 17(1): 10.

Gupta, I., Kumar, R., & Choudhary, S. (2019). Particulate matter in roadside microenvironments: Characteristics, exposure, and mitigation. Environmental Science and Pollution Research, 26(24): 24712–24727. https://doi.org/10.1007/s11356-019-05620-0.

IARC (2021). Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol (IARC Monographs Vol. 123). International Agency for Research on Cancer.

International Agency for Research on Cancer (IARC) (2012). IARC monographs on the evaluation of carcinogenic risks to humans: Volume 100F: Chemical agents and related occupations. World Health Organization, IARC. https://publications.iarc.fr/123.

International Agency for Research on Cancer (IARC) (2020). Formaldehyde, 2-butoxyethanol and 1-tert-butoxypropan-2-ol (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 88). World Health Organization. https://publications.iarc.fr/127.

Jayaratne, E.R., Ristovski, Z.D., Meyer, N., Morawska, L., & Miljevic, B. (2021). Influence of temperature and humidity on particle formation and transformation in urban air. Atmospheric Chemistry and Physics, 21(9): 7135–7149. https://doi.org/10.5194/acp-21-7135-2021.

Johnson, O.E., & Umoren, Q.M. (2018). Occupational hazards of petrol station attendants in Uyo, Nigeria and risk factors influencing exposure. International Journal of Occupational Safety and Health, 8(2): 87–94. https://doi.org/10.3126/ijosh.v8i2.22105.

Kumar, P., Shukla, H., & Singh, R. (2022). Particulate matter exposure in petrol station environments in developing countries. Environmental Toxicology and Health, 24(4): 289–301.

Li, X., Zhang, W., & Wong, T.W. (2021). Health impacts of fine particulate pollution: A multidisciplinary assessment. Environmental Research Letters, 16(11): 123–130.

Madanhire, I., & Mbohwa, C. (2016). Environmental and operational issues in fuel stations: A case for environmental management systems implementation. Procedia CIRP, 40: 165–170. https://doi.org/10.1016/j.procir.2016.01.088.

Meo, S.A., Al-Khlaiwi, T., Usmani, A.M., & Meo, I.M. (2024). Traffic-related air pollutants, cognitive function, and occupational health: A systematic review. Environmental Science and Pollution Research, 31(4): 5432–5446. https://doi.org/10.1007/s11356-023-29919-8.

National Institute for Occupational Safety and Health (NIOSH) (2023). NIOSH pocket guide to chemical hazards. Centers for Disease Control and Prevention. https://www.cdc.gov/niosh/npg/.

Nduka, C.O., Okafor, J.N., & Nwachukwu, E.O. (2020). Hydrogen sulfide exposure and upper airway irritation among oil depot workers. Toxicology Reports, 7: 1151–1159.

NIOSH (2020). Occupational exposure to carbon monoxide: Safety and health topic. National Institute for Occupational Safety and Health.

Nwaichi, E.O., Ajaero, C.K., & Ndimas, H.O. (2021). Biomarkers of oxidative stress among gasoline station attendants exposed to VOCs. Biomarkers in Occupational Health, 5(2): 77–89.

Nwaogazie, I.L., & Onuorah, A.A. (2021). Air quality assessment of petroleum retail stations in Port Harcourt metropolis, Nigeria. Environmental Forensics, 22(1–2): 87–98. https://doi.org/10.1080/15275922.2020.1827395.

Nwaokocha, C.N., Okonkwo, E.U., & Adebayo, M.A. (2020). Emissions and safety concerns in Nigerian fuel depots and forecourts: Implications for occupational health. Journal of Petroleum and Environmental Biotechnology, 11(2): 405. https://doi.org/10.4172/2157-7463.1000405.

Occupational Safety and Health Administration (OSHA) (2024). Permissible exposure limits (PELs) for airborne contaminants. U.S. Department of Labor. https://www.osha.gov/annotated-pels.

Ogunkunle, C.O., Adebusoye, S.O., & Fasakin, S.O. (2020). BTEX and TVOC levels in filling stations: Implications for worker health. Environmental Monitoring and Assessment, 192(11): 715.

Oguntoke, O., Adekola, P.O., & Bankole, A.M. (2020). Urban heat island and microclimate modification in tropical cities: Implications for environmental sustainability. Urban Climate, 34: 100682. https://doi.org/10.1016/j.uclim.2020.100682.

Oketola, A.A., & Akpotu, S.O. (2022). Airborne volatile organic compounds from petroleum product handling: Sources, concentrations, and exposure assessment. Environmental Science and Pollution Research, 29(5): 7031–7043. https://doi.org/10.1007/s11356-021-15808-4.

Okonkwo, F.C., Ubani, U.C., & Obialor, V.A. (2023). Comparative air quality evaluation between major and independent petrol stations in Nigeria. Journal of Environmental Management, 64(2): 112–122.

Onah, E.E., Agbo, A., & Etim, J. (2023). Respiratory impairments among petrol station workers: A survey-based study. International Journal of Environmental Health Research, 33(1): 12–25.

Patel, D.S., Thombre, B.S., & Jain, M. (2023). Elevated indoor CO_2 levels and cognitive performance in occupational settings. Indoor Air Quality Insights, 14(4): 221–228.

Pope, C.A., Dockery, D.W., & Turner, M.C. (2019). Interactions of climate change, air pollution, and human health. New England Journal of Medicine, 381(7): 664–672. https://doi.org/10.1056/nejmra1807873.

Prockop, L.D., & Chichkova, R.I. (2007). Carbon monoxide intoxication: An updated review. Journal of the Neurological Sciences, 262(1–2): 122–130. https://doi.org/10.1016/j.jns.2007.06.037.

Seinfeld, J.H., & Pandis, S.N. (2016). Atmospheric chemistry and physics: From air pollution to climate change (3rd Edition). John Wiley & Sons.

Sundell, J. (2011). On the history of indoor air quality and health. Indoor Air, 21(6): 442–452. https://doi.org/10.1111/j.1600-0668.2011.00718.x.

World Health Organization (WHO) (2021). WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329.

Zhang, L., Liu, G., & Chen, Y. (2022). Formaldehyde exposure and cancer risk: A meta-analysis. Cancer Epidemiology, 78: 102–110.

Zhang, Y., Mu, Y., Liu, J., & Mellouki, A. (2021). The impact of meteorological conditions and atmospheric stability on air pollution in China. Science of the Total Environment, 761: 143265. https://doi.org/10.1016/j.scitotenv.2020.143265.