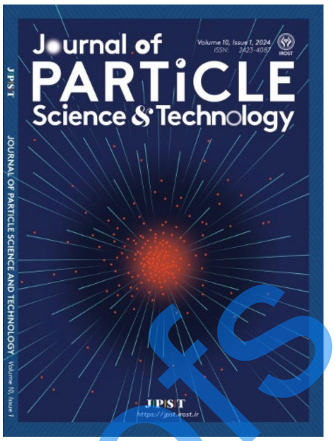

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Secondary Organic Aerosol And Ozone Formation Potentials From Diesel Engine Emissions At Isale-Koto, Ilorin,Kwara State, Nigeria

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Abstract

Secondary organic aerosols (SOAs) and tropospheric ozone (O_3) pose significant risks to air quality and public health in urban environments, particularly in developing regions reliant on diesel-powered machinery. This study investigates the aromatic volatile organic compounds (VOCs) benzene, toluene, ethylbenzene, and xylene isomers (BTEX) emitted from diesel grinding enginesat the Isale-Koto food processing market in, Ilorin, Nigeria. Passive sampling at ten locations (five indoor, five outdoor) over one month captured VOC concentrations, and then analyzed them via gas chromatography. Ozone formation potential (OFP) was estimated using maximum incremental reactivity (MIR) coefficients, while secondary organic aerosol potential (SOAP) employed reactivity-based metrics relative to toluene.Results revealed higher indoor VOC levels, with total OFP at 148.014 µgm^{-3}indoors versus 128.098 µgm^{-3} outdoors (15.5% increase), dominated by toluene (29-31%) and m-xylene (25%). Total SOAP at 4,076.82 µgm^{-3} (16.4% above outdoor levels). Toluene, m-xylene, and ethylbenzene were dominant contributors to OFP, while benzene, toluene, and ethylbenzene accounted for 84% of SOAP due to high concentrations and reactivity. These findings highlight diesel engine exhaust as a key precursor to ozone and SOA formation, with indoor accumulation due to poor ventilation amplifying photochemical pollution at ground-level and posing serious health risks, especially for workers exposed over long durations. The study emphasizes the urgent need for improved ventilation, cleaner energy alternatives, and emission regulations.

Keywords: exhaust emissions, photochemical smog, health effects, climate impacts on micro-environment

1. Introduction

Secondary organic aerosols (SOAs) and tropospheric ozone (O_3) are major components of urban air pollution, with profound implications for public health, climate change, and environmental quality [1]. In micro-urban food processing centers such as Isale-Koto, located at; Ilorin, Kwara State, Nigeria, diesel-powered grinding machines are extensively used and represent a significant source of volatile organic compounds (VOCs) [2,18]. These VOCs act as key precursors in the atmospheric formation of both SOAs and ground-level ozone [3].

Diesel engine exhaust is a complex mixture of gaseous and particulate pollutants, including alkanes, alkenes, aromatic hydrocarbons (e.g., benzene, toluene, ethylbenzene, xylenes—collectively known as BTEX), and oxygenated compounds [4]. Once emitted, these VOCs undergo photochemical reactions driven by sunlight and nitrogen oxides (NO_x), leading to the formation of secondary pollutants. The extent of SOA and O_3 formation depends on VOC composition, NO_x levels, solar radiation, temperature, and humidity [5].

Tropospheric (ground-level) ozone is not directly emitted but forms via photochemical oxidation of VOCs in the presence of NO_x and sunlight [6]. Unlike stratospheric ozone, which shields the Earth from ultraviolet radiation, ground-level ozone is a harmful pollutant [7]. Exposure to elevated concentrations is associated with respiratory tract inflammation, aggravated asthma,chronic obstructive pulmonary disease (COPD), reduced lung function, and an increased incidence of coughing, chest pain, and shortness of breath during physical activity. Long-term exposure contributes to accelerated lung aging and increased mortality from cardiovascular and respiratory diseases [5]. Secondary byproducts such as peroxyacetyl nitrate (PAN) and nitric acid (HNO_3) further contribute to photochemical smog and ecosystem damage [8]. While stratosphere-to-troposphere ozone transport contributes a global background flux (720-1,220 million metric tons annually), local photochemical production in urban areas with high VOC and NO_x emissions dominates ozone pollution [7].

Secondary organic aerosols (SOAs) form through the atmospheric oxidation of VOCs, yielding low-volatility organic compounds that condense onto existing particles or nucleate new ones [9]. Unlike primary particulate matter (PM), SOAs are not directly emitted but arise from secondary chemical processes and can constitute 20-50% of fine particulate matter ($PM_{2.5}$) in urban environments. Aromatic hydrocarbons are among the most potent SOA precursors. Upon reaction with hydroxyl (OH) and nitrate (NO_3) radicals, they form multifunctional oxidation products such as dicarbonyls and organic acids that readily partition into the aerosol phase [9]. SOA formation efficiency depends on precursor type and concentration, oxidant levels, temperature, relative humidity, solar radiation, and the presence of co-pollutants like NO_x and SO_2.

SOAs contribute to $PM_{2.5}$, which penetrates deep into the respiratory system and may enter the bloodstream [10]. Health effects include premature mortality in individuals with cardiopulmonary conditions, exacerbation of asthma and bronchitis, and potential systemic inflammation [1]. Moreover, SOAs can carry toxic constituents such as polycyclic aromatic hydrocarbons (PAHs), enhancing their carcinogenic potential. Environmentally, SOAs reduce visibility through light scattering, damage ecosystems, alter cloud formation and radiative balance, and contribute to material degradation [11].

Notably, diesel emissions are up to seven times more efficient at forming SOAs than gasoline emissions [12], primarily due to higher emissions of aromatic and semi-volatile organic compounds (SVOCs). In developing countries like Nigeria, older diesel engines, often poorly maintained and operating on low-quality fuel, lack modern emission controls (e.g., diesel particulate filters, selective catalytic reduction). This results in elevated, more reactive VOC emissions, particularly BTEX compounds, which are highly effective in generating both ozone and SOAs under high-NO_x conditions [11].

Despite their significance, the secondary pollutant formation potential of VOCs from micro-scale diesel operations in urban markets remains poorly characterized. The enclosed nature of many market shops, combined with limited ventilation and continuous engine operation, likely enhances VOC accumulation and photochemical activity.

Understanding the emission profiles and atmospheric reactivity of diesel-derived VOCs in such settings is critical for developing effective air quality management strategies. This study investigates the concentration and composition of aromatic VOCs emitted at Isale-Koto, estimates their ozone formation potential (OFP), and evaluates their contribution to SOA formation using the Specific Reactivity-Based Ozone and Aerosol Potential (SOAP) approach. The findings will provide essential data to inform public health policies and emission control measures in rapidly urbanizing communities across Nigeria.

2. Materials and Methods

2.1. Study Site Description

The study was conducted in Isale-Koto, a densely populated micro-urban food processing hub located within the Ago Market in Ilorin, the capital of Kwara State, Nigeria. Situated in the Ilorin South Local Government Area, the site lies at the geographic coordinate's 8°29′33.36″N latitude and 4°33′05.11″E longitude. As a major commercial center in north-central Nigeria, the market hosts over 300 individuals daily, with high human activity concentrated around small-scale food processing units that rely on diesel-powered grinding machines.

2.2. Sampling Design and Site Selection

Ten sampling locations were strategically selected to represent key microenvironments influenced by diesel engine emissions. Five sites were established indoorswithin enclosed processing shops, while five were positioned outdoors in open-air market areas adjacent to high-emission sources. Sites were chosen based on proximity to operational diesel engines used for milling and food processing, ensuring representative exposure to equipment-related volatile organic compounds (VOCs).

Sampling units were deployed at a height of 1.5 meters above ground level to approximate the human breathing zone, in accordance with standard occupational exposure assessment protocols [13]. Sampling was conducted continuously over a one-month period to capture time-integrated VOC concentrations under typical operational conditions.

2.3. Sample Retrieval and Preparation

Following the one-month sampling period, the activated charcoal was carefully retrieved from each column and transferred into pre-cleaned, airtight glass sampling bottles to prevent contamination or volatilization losses. Samples were promptly transported to the laboratory under controlled storage conditions for subsequent extraction and analysis.

2.4. Analytical Procedure

In the laboratory, VOCs were extracted from the activated charcoal using a suitable organic solvent (e.g., carbon disulfide or methanol) via Soxhlet or ultrasonic extraction. The resulting extracts were concentrated and analyzed using gas chromatography–mass spectrometry (GC-MS) for the identification and quantification of target aromatic hydrocarbons, including benzene, toluene, ethylbenzene, and xylene isomers (BTEX), which are key precursors to secondary organic aerosols (SOAs) and ozone formation.

3. Results and Discussion

3.1. VOC Emission Inventory and Area Profile for the Ago Market in Isale-Koto, Ilorin

A previous study [13] investigated aromatic volatile organic compound (VOC) emissions from diesel-powered equipment used in a local food processing market in Isale-Koto, Ago, Ilorin, Nigeria. This research provides critical site-specific data on ambient concentrations of key aromatic hydrocarbons, i.e., benzene, toluene, ethylbenzene, and xylene isomers (collectively known as BTEX), emitted during routine market operations. Their findings were used to develop a localized VOC emission inventory and spatial profile for the market environment.

Air sampling was conducted using passive diffusion samplers packed with activated charcoal, deployed at ten strategic locations, five indoors and five outdoors,within and around food processing shops utilizing diesel engines for grinding and milling operations. Sampling was performed during peak operational hours (09:00–17:00) to capture representative exposure levels under typical working conditions. The passive sampling method allowed for time-integrated VOC collection, reflecting average concentrations over the exposure period.

Following sample collection, the extracted VOCs were analyzed using gas chromatography with flame ionization detection (GC-FID, Hewlett-Packard Model HP 6890), enabling precise quantification of individual aromatic compounds. The analytical procedures adhered to established environmental monitoring standards, including ANSI/ASTM protocols for VOC measurement, ensuring accuracy, reproducibility, and comparability with other urban emission studies.

The resulting data were compiled into a spatially resolved emission profile that reflects variations in VOC concentrations associated with indoor versus outdoor microenvironments and differing levels of source proximity and ventilation. This profile forms the basis of the aromatic VOC inventory presented in Table 1, which summarizes measured concentrations (in µgm^{-3}) across the five paired sampling locations (A-E).

Table 1. Aromatic VOC Concentrations in the Isale-Koto Food Processing Market (µgm^{-3})

S/N	Location	Setting	Benzene	Toluene	Ethylbenzene	P-Xylene	M-Xylene	O-Xylene	Xylene
1	A	Outdoor	2.1	1.7	0.9	0.6	0.4	0.01	1.01
2	B	Outdoor	2.6	2.0	1.6	1.1	0.8	0.02	1.92
3	C	Outdoor	2.4	2.3	1.3	0.9	0.8	0.02	1.72
4	D	Outdoor	2.3	1.9	1.7	1.0	0.7	0.01	1.77
5	E	Outdoor	2.6	2.1	1.4	0.8	0.6	0.02	1.42
6	A	Indoor	3.1	2.3	2.3	1.4	0.8	0.02	2.22
7	B	Indoor	2.4	1.8	1.3	0.9	0.6	0.01	1.51
8	C	Indoor	2.8	2.3	2.1	1.3	0.8	0.02	2.12
9	D	Indoor	2.7	2.2	1.9	1.1	0.9	0.01	2.01
10	E	Indoor	2.5	2.3	1.6	0.11	0.8	0.02	0.93

This emission inventory highlights the influence of microenvironmental conditions on VOC distribution, with generally higher concentrations observed indoors due to limited ventilation and proximity to diesel engine sources. The dataset provides a foundational basis for assessing secondary pollutant formation potential, including ozone and secondary organic aerosol (SOA) generation, and supports the development of targeted air quality management strategies in informal urban market settings.

3.2. Ozone Formation Potential (OFP) of VOC Emissions from Diesel Engines in Isale-Koto, Ilorin

The Ozone Formation Potential (OFP) is a key metric used to assess the contribution of volatile organic compounds (VOCs) to the formation of ground-level (tropospheric) ozone, a major component of photochemical smog with significant implications for human health and environmental quality. In this study, OFP was calculated using the Maximum Incremental Reactivity (MIR) scale, a widely accepted method developed in [14] that quantifies the amount of ozone (in grams) produced per gram of VOC emitted under high-NO_x conditions, which are typical of urban environments.

The MIR values for individual aromatic VOCs were applied to the measured concentration data from the Isale-Koto food processing market to estimate their respective OFPs. The calculation follows the standard formula [14]:

$$OFPi = Ci \times MIRi \tag{1}$$

where O is the ozone formation potential of VOC species i (µg/m^3), Ci = Ambient concentration of VOC species i (µgm^{-3}), and $MIRi$ is the = Maximum Incremental Reactivity of species i (g O_3(g VOC$^{)-1}$).

The MIR coefficients used in this study are as follows: benzene has a MIR of 0.72 g O_3/g VOC, toluene 4.00 g O_3 (g VOC)$^{-1}$, ethylbenzene 3.04 g O_3 (g VOC)$^{-1}$, *p*-xylene 5.84 g O_3 (g VOC)$^{-1}$,*m*-xylene 9.75 g O_3 (g VOC)$^{-1}$, and *o*-xylene 7.64 g O_3 (g VOC)$^{-1}$. These coefficients reflect the relative photochemical reactivity of each volatile organic compound (VOC) in ozone formation under high-NO_x conditions,

Table 2. Ozone Formation Potential (OFP) in Isale-Koto Food Processing Market (µgm^{-3}).

S/N	Location	Setting	Benzene	Toluene	Ethylbenzene	P-Xylene	M-Xylene	O-Xylene	Total OFP
1	A	Outdoor	1.512	6.800	2.736	3.504	3.900	0.076	18.528
2	B	Outdoor	1.872	8.000	4.864	6.424	7.800	0.153	29.113
3	C	Outdoor	1.728	9.200	3.952	5.256	7.800	0.153	28.089
4	D	Outdoor	1.656	7.600	5.168	5.840	6.825	0.076	27.165
5	E	Outdoor	1.872	8.400	4.256	4.672	5.850	0.153	25.203
6	A	Indoor	2.232	9.200	6.992	8.176	7.800	0.153	34.553
7	B	Indoor	1.728	7.200	3.952	5.256	5.850	0.076	24.062
8	C	Indoor	2.016	9.200	6.384	7.592	7.800	0.153	33.145
9	D	Indoor	1.944	8.800	5.776	6.424	8.775	0.076	31.795
10	E	Indoor	1.800	9.200	4.864	0.642	7.800	0.153	24.459

Totals by Setting:

Outdoor: Benzene is 8.640 (6.74%), Toluene is 40.000 (31.23 %), Ethylbenzene is 20.976 (16.39%), P-Xylene is 25.696 (20.06 %), M-Xylene is 32.175 (25.12%), O-Xylene is 0.611(0.48 %), and Total OFP is 128.098

Indoor: Benzene is 9.720(6.57%), Toluene is 43.600(29.46%), Ethylbenzene is 27.968(18.90%), P-Xylene is 28.090 (18.98 %), M-Xylene is 38.025 (25.69%), O-Xylene is 0.611(0.41%), and Total OFP is 148.014

3.3. Secondary Organic Aerosol Formation Potential (Soap)

The Secondary Organic Aerosol Potential (SOAP) is a reactivity-based metric used to estimate the contribution of volatile organic compounds (VOCs) to the formation of secondary organic aerosols (SOAs) in the atmosphere. It is expressed on a mass-emitted basis relative to toluene, which is assigned a reference SOAP value of 100.0 [15]. SOAs constitute a significant fraction of fine particulate matter ($PM_{2.5}$) in urban environments and are associated with adverse impacts on air quality, visibility, climate, and human health.

In micro-urban settings such as Isale-Koto, where diesel-powered grinding machines are extensively used for food processing,aromatic VOCs, including benzene, toluene, ethylbenzene, and xylene isomers (BTEX), are emitted in substantial quantities. These compounds are known precursors to SOA formation via atmospheric oxidation pathways involving hydroxyl (OH) radicals and nitrate (NO_3) radicals, particularly under high-NO_x conditions typical of diesel exhaust environments.

SOAP values are influenced by several factors, including ambient NO_x levels, photochemical aging, and the chemical speciation of VOC emissions. The method assumes incremental addition of VOCs to the existing atmospheric mixture and accounts for co-emitted primary pollutants (6). Given the complexity and non-linearity of SOA formation mechanisms, direct measurement remains challenging. Therefore, indirect modeling approaches such as SOAP are widely employed to assess the relative SOA-formation potential of different VOCs in urban emission inventories [15].

In this study, the SOAP for each VOC species was calculated by multiplying its measured concentration (Ci , in $\mu g/m^3$) by its respective SOAP coefficient (SOAPi), as follows (6):

$$SOAP = \sum Ci \times SOAPi \tag{2}$$

Where Ci is the ambient concentration of VOC species i and $SOAPi$ is the unit minus the unit. SOA formation potential coefficient derived from chamber studies and atmospheric modeling [8].

The coefficients applied in this study are Benzene: 92.9, Toluene: 100.0 (reference), *p*-Xylene: 67.1, *m*-Xylene: 84.5, *o*-Xylene: 95.5, and Ethyl Benzene: 116.6.

Table 3. Secondary Organic Aerosol Potential (SOAP) in Isale-Koto Food Processing Market (µgm^{-3}).

S/N	Location	Setting	Benzene	Toluene	Ethylbenzene	p-Xylene	m-Xylene	o-Xylene	Total SOAP
1	A	Outdoor	195.09	170.00	104.94	40.26	33.80	0.96	545.05
2	B	Outdoor	241.54	200.00	186.56	73.81	67.60	1.91	771.42
3	C	Outdoor	222.96	230.00	151.58	60.39	67.60	1.91	734.44
4	D	Outdoor	213.67	190.00	198.22	67.10	59.15	0.96	729.10
5	E	Outdoor	241.54	210.00	163.24	53.68	50.70	1.91	721.07
6	A	Indoor	287.99	230.00	268.18	93.94	67.60	1.91	949.62
7	B	Indoor	222.96	180.00	151.58	60.39	50.70	0.96	666.59
8	C	Indoor	260.12	230.00	244.86	87.23	67.60	1.91	891.72
9	D	Indoor	250.83	220.00	221.54	73.81	76.05	0.96	843.19
10	E	Indoor	232.25	230.00	186.56	7.38	67.60	1.91	725.70

Totals by Setting:

Outdoor: Benzene is 1114.80 (31.84%),Toluene is 1000.00 (28.56%), Ethylbenzene is 804.54 (22.98%), p-Xyleneis 295.24 (8.43%), m-Xyleneis 278.85 (7.96%), o-Xylene is7.65 (0.22%), and Total SOAP is 3501.08

Indoor: Benzene is 1254.15 (30.76%), Toluene is 1090.00 (26.74%),Ethylbenzene is 1072.72 (26.31%), p-Xyleneis 322.75 (7.92%), m-Xyleneis 329.55 (8.08%), o-Xylene is 7.65 (0.19%), and Total SOAP is 4076.82.

As presented in Table 2, the outdoor ozone formation potential (OFP) of 128.098 µgm^{-3}and the indoor OFP of 148.014 µgm-^{3}indicate a moderate to high potential for photochemical ozone generation, significantly exceeding typical urban background levels (for instance,50 µgm^{-3} in less polluted environments). These elevated OFP values reflect substantial photochemical activity within the study area.

Toluene emerged as the dominant contributor to OFP in environments, accounting for 31.23% (40.000 µg/m³) outdoors and 29.46% (43.600 µgm^{-3}) indoors. *m*-Xylene ranked second, contributing 25.12% (32.175 µgm^{-3}) outdoors and 25.69% (38.025 µgm^{-3}) indoors, followed by *p*-xylene with 20.06% (25.696 µgm^{-3}) outdoors and 18.98% (28.090 µgm^{-3}) indoors, indicating comparable reactivity between the two xylene isomers. Ethylbenzene contributed 16.39% (20.976 µgm^{-3}) outdoors and 18.90% (27.968 µgm^{-3}) indoors, reflecting its high reactivity and significant role in ozone formation. Benzene contributed relatively modestly to OFP (6.74% outdoors, 6.57% indoors; 8.640 and 9.720 µgm^{-3}, respectively), though its presence remains a critical health concern due to its classification as a known human carcinogen. *o*-Xylene showed a negligible contribution in both settings (<0.5%; 0.611 µgm^{-3}), suggesting lower emission rates or faster atmospheric removal compared to other xylene isomers. Collectively, aromatic hydrocarbonstoluene, xylenes, and ethylbenzeneaccounted for approximately 73–74% of the total OFP, a distribution pattern consistent with emission profiles associated with diesel exhaust, which is rich in reactive aromatic compounds. This is consistent with previous studies indicating that aromatics can account for up to 40% of ozone formation in urban environments dominated by vehicular emissions [12,16].

Notably, the indoor OFP was 15.5% higher than the outdoor value (148.014 vs. 128.098 µgm^{-3}), primarily due to elevated concentrations of most measured VOCs. This increase is likely attributable to poor ventilation in enclosed market shops, leading to the accumulation of emissions from diesel-powered grinding machinery,a common source in such microenvironments. These findings align with prior research highlighting the role of confined urban spaces in amplifying VOC concentrations and associated photochemical risks [9]. The elevated OFP levels, particularly indoors, suggest a significant potential for ground-level ozone formation, with concentrations approaching or exceeding health-based thresholds. The enclosed nature of these indoor workspaces, combined with the continuous operation of diesel engines in poorly ventilated areas, exacerbates VOC accumulation and enhances ozone formation potential. The high OFP, especially in indoor settings, poses increased health risks for market workers and vendors, who may experience prolonged exposure (8-12 hours per day). Chronic exposure to elevated ozone levels is associated with respiratory effects, including asthma exacerbation and airway inflammation, as well as cardiovascular complications. Although benzene contributes modestly to OFP, its carcinogenic properties necessitate careful monitoring and exposure mitigation. Vulnerable populations, such as children and the elderly, are particularly susceptible to the adverse health effects of ozone and co-pollutants, underscoring the need for improved ventilation and emission-control strategies in these occupational microenvironments.

Table 3 presents the Secondary Organic Aerosol Potential (SOAP) across indoor and outdoor microenvironments in the Isale-Koto food processing market. The total indoor SOAP (4,076.82 μgm^{-3}) exceeds the outdoor total (3,501.08 μgm^{-3}) by 16.4%, indicating significantly higher SOA formation potential within enclosed spaces. This elevation is attributed to the nature of indoor microenvironments,typically poorly ventilated grinding sheds,where the continuous operation of diesel engines in confined areas leads to limited dispersion and dilution of emissions, resulting in the accumulation of volatile organic compounds (VOCs). Additionally, the potential for pollutant recirculation further increases indoor VOC concentrations. Consequently, workers and vendors who spend prolonged periods in these indoor settings are subjected to elevated exposure levels of SOA precursors and secondary aerosols, posing increased health risks.

Across both indoor and outdoor environments, benzene (31% of total SOAP), toluene (28%), and ethylbenzene (25%) emerge as the dominant contributors, collectively accounting for approximately 84% of the total SOAP. Despite their moderate SOA yields, benzene and toluene exert a substantial influence due to their high ambient concentrations and reactivity. Ethylbenzene, which exhibits a relatively high SOA mass yield per unit mass, is particularly elevated indoors (e.g., 268.18 μgm^{-3} at Location A), suggesting emissions from incomplete combustion or unburned fuel, likely associated with aging or poorly maintained engines.

Xylenes collectively account for about 17% of the total SOAP, with *m*-xylene and *p*-xylene being the primary contributors due to their higher emission rates and atmospheric reactivity. In contrast, *o*-xylene contributes negligibly (<0.3%) owing to its low ambient concentrations. Notably, while benzene has a lower SOA yield compared to the xylene isomers, its high concentration results in a disproportionately large contribution to the overall SOAP.

Spatial analysis reveals that Location A (indoor) exhibits the highest total SOAP (949.62 μgm^{-3}), driven primarily by exceptionally high levels of benzene (287.99 $\mu g/m^3$) and ethylbenzene (268.18 $\mu g/m^3$), potentially indicating proximity to older or malfunctioning diesel units. Conversely, Location E shows a marked reduction in *p*-xylene concentration indoors (7.38 $\mu g/m^3$), which may reflect temporal variability in engine activity, fuel composition, or operational practices. Indoor-to-outdoor comparisons further confirm pollutant accumulation: benzene, toluene, and ethylbenzene show increases of 12.5%, 9.0%, and 33.3% indoors, respectively. These elevated indoor concentrations underscore the inadequacy of ventilation and the resulting buildup of diesel-derived VOCs in enclosed workspaces, emphasizing the need for improved emission control and workplace air quality management in such micro-urban settings. Elevated indoor SOAP levels (16.2% higher than outdoor levels) increase $PM_{2.5}$ exposure, which is linked to respiratory and cardiovascular diseases, and premature death. Workers in poorly ventilated areas face prolonged risks, worsened by benzene (31–32% of SOAP), a known carcinogen. Vulnerable groups are especially at risk. These findings highlight the need for improved ventilation, cleaner technologies, and emission controls in informal urban markets to reduce health burdens.

The predominance of benzene, toluene, and ethylbenzene in the SOAP profile strongly implicates diesel engine exhaust, particularly from poorly maintained or unregulated grinding equipment, as the primary source of reactive VOCs. Diesel emissions are known to be rich in semi-volatile organic compounds (SVOCs) and aromatic species, which exhibit high SOA yields under photochemical aging in NO_x-rich atmospheres.

4. Conclusions

This study demonstrates that diesel-powered grinding operations at the Isale-Koto market significantly contribute to secondary pollutant formation, with aromatic VOCs exhibiting elevated ozone formation potential (OFP) and secondary organic aerosol potential (SOAP) indoors compared to outdoors. The 15.5% higher indoor OFP (148.014 μgm^{-3}) and 16.4% higher SOAP (4076.82 μgm^{-3}) reflect pollutant accumulation in poorly ventilated spaces, primarily from toluene, m-xylene, benzene, and ethylbenzene compounds prevalent in diesel exhaust. These results align with the inefficiencies of unregulated engines in developing contexts, exacerbating photochemical smog and, $PM_{2.5}$ levels, and the associated health burdens such as respiratory diseases, cardiovascular issues, and increased cancer risks for exposed populations.The dominance of these compounds in both OFP and SOAP profiles points to inefficient combustion in aging, poorly maintained diesel engines operating on substandard fuel.

Given the widespread reliance on similar micro-industrial operations across urban Nigeria, these findings call for targeted interventions, including the adoption of cleaner technologies, enforcement of emission standards, and structural improvements such as enhanced ventilation. Addressing this localized pollution source is critical for improving urban air quality and safeguarding public health in rapidly growing informal economic sectors.

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Authors' contributions

Muhibbu-din Ismail worked on primary data obtained in the field to develop OFP and SOAP.

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