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# Characterization of Particulate Matter Exposure and Health Implications in Poorly Ventilated Chemical Retail Outlets: Evidence from Ogbo-Ogwu Market

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## ABSTRACT

This study investigated the impact of poor ventilation on air quality and health risks in chemical stores at Ogbo-Ogwu Market, Onitsha, Nigeria. Over a three-month period, particulate matter ($PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and TSP) was measured with an aerocet (531) particulate analyzer in six chemical stores of three storekeepers from each and compared their concentrations to those in control clothing stores located 1.1 km away. Biomarkers of chronic obstructive pulmonary disease were measured with enzyme-linked immunosorbent assay (ELISA) test kits. The results revealed that particulate concentrations in chemical stores were significantly higher than in control stores, indicating elevated pollutant concentrations due to inadequate ventilation. The Exposure Factor-Adjusted Air Concentration (EF-AAC) and Hazard Quotients (HQ) metrics further highlighted substantial health risks, with chemical store environments posing greater hazards compared to controls. Biomarker analysis of exhaled breath condensate (EBC) showed increased oxidative stress and inflammation among chemical storekeepers, as evidenced by higher concentrations of hydrogen peroxide ($H_2O_2$), thiobarbituric acid reactive substances (TBARS), and leukotriene B4 (LTB4). These biomarkers correlate with the physiological impacts of prolonged particulate exposure and suggest an elevated risk of respiratory conditions, including Chronic Obstructive Pulmonary Disease (COPD). This research underscores the critical need for improved ventilation in chemical stores to mitigate health risks. The findings provide valuable insights into occupational health challenges in developing regions and highlight the importance of enhancing air quality management to protect workers' health in similar environments worldwide.

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## INTRODUCTION

Indoor air quality (IAQ) plays a pivotal role in the health of individuals, particularly in occupational environments where prolonged exposure to airborne pollutants is common. In markets with high chemical usage, such as Ogbo-Ogwu Market in Onitsha, Nigeria, the challenge of managing IAQ becomes even more critical due to typically inadequate ventilation systems. Poor ventilation can lead to the accumulation of particulate matter (PM), which poses significant health risks to workers. This study investigates the concentrations of airborne particulates, evaluates health risks using Exposure Factor-Adjusted Air Concentration (EF-AAC) and Hazard Quotients (HQ), and examines biomarkers in exhaled breath condensate (EBC) to assess oxidative stress and inflammation among chemical storekeepers.

Particulate matter (PM) is a key component of air pollution and is categorized based on size into $PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and Total Suspended Particles (TSP). Each size fraction has different implications for human health. Recent studies underscore the significant health risks associated with elevated PM concentrations in indoor environments, especially in workplaces with poor ventilation. Lee et al. (2014) found that chemical storage areas often have high concentrations of airborne particulates, leading to increased respiratory and cardiovascular health risks. Zhu et al. (2020) similarly observed that indoor $PM_{2.5}$ concentrations, exacerbated by inadequate ventilation, correlate with a higher incidence of chronic respiratory conditions.

The health impacts of particulate matter exposure are well-documented, with various studies highlighting the association between PM exposure and adverse health outcomes. Boogaard et al. (2023) conducted a comprehensive review and reported that long-term exposure to $PM_{2.5}$ is linked to chronic obstructive pulmonary disease (COPD), asthma, and other respiratory ailments. The mechanisms through which particulate matter affects health include inflammation and oxidative stress, which can lead to exacerbation of existing health conditions and development of new health issues (Zhu et al., 2021). For instance, fine particulates can penetrate deep into the lungs, causing significant inflammation and systemic oxidative stress, which are precursors to respiratory and cardiovascular diseases (Thangavel et al., 2022).

Exhaled breath condensate (EBC) serves as a non-invasive tool to assess the impact of airborne pollutants on respiratory health. EBC analysis can reveal biomarkers related to oxidative stress and inflammation, such as hydrogen peroxide ($H_2O_2$), thiobarbituric acid reactive substances (TBARS), and glutathione (GSH). Recent studies have demonstrated that elevated concentrations of these biomarkers are indicative of oxidative damage and inflammatory responses due to particulate matter exposure. Casimirri et al. (2016) highlighted that increased $H_2O_2$ and TBARS concentrations, along with decreased GSH, are associated with oxidative stress in individuals exposed to high concentrations of particulate matter. Similarly, Zhu et al. (2021) found that higher concentrations of leukotriene B4 (LTB4) in EBC correlate with inflammation and can be used as an indicator of the health impacts of particulate exposure. The aim of this research was to investigate the impact of poor ventilation on air quality and health risks in chemical stores at Ogbo-Ogwu Market, Onitsha, Nigeria, by comparing particulate matter concentrations and biomarkers of chronic obstructive pulmonary disease (COPD) to those in control stores.

## MATERIALS AND METHODS

### *Study Area and Population*

The study was conducted over a period of three months (June to August 2024) at Ogbo-Ogwu Market, Onitsha, Nigeria (6.4377°N, 7.4878°E). This market, known for its high chemical activity, attracts approximately 15,000 visitors daily. The focus was on chemical stores with poor ventilation, typically having only one door and no windows, and control stores located about 1.1 km away in the same market but selling clothing, providing environmental consistency.

A total of 24 storekeepers (both male and female), aged between 18 and 55 years, from six chemical stores were recruited. All participants had worked in their respective stores for approximately four years and were non-smokers, which was a key inclusion criterion. Storekeepers reported respiratory symptoms such as shortness of breath, chest pain, and coughing, in the questionnaire given to them before sample collection. Control participants were selected from clothing stores to match the environmental conditions of the chemical stores as closely as possible.

*Air Quality Measurement*

Air quality measurements were taken using the Aerocet 531 Particulate Analyzer, which measures particulate matter (PM) concentrations. The concentration range of the equipment is 0-105945000μg/m$^3$ while its accuracy is ±10% to calibration aerosol. The analyzer recorded concentrations of $PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and Total Suspended Particles (TSP) in both chemical and control stores. Measurements were conducted for three consecutive months during the study period to capture variations across different months and times. The measurement was carried out as described by Madu *et al.* (2022).

*Health Risk Assessment*

Exposure Factor-Adjusted Air Concentration (EF-AAC)**:** EF-AAC values were calculated to estimate the exposure concentrations adjusted for various factors, using the formula:

EF-AAC = PM concentration × EF / ED (ATSDR, 2022)

Where:

EF (Exposure Frequency) = 312 days

ED (Exposure Duration) = 4 years

The adjustment factor EF / ED is 78 days/year.

Hazard Quotient (HQ): HQ was calculated for each particulate size using the formula:

HQ = EF- AAC / RfC (WHO, 2021).

Where:

EF-AAC is the Exposure Factor-Adjusted Air Concentration.

RfC (Reference Concentration) is 12 μg/m$^3$ for all particulates (WHO, 2021).

*Collection and Analysis of Exhaled Breath Condensate (EBC) from Storekeepers*

Exhaled Breath Condensate (EBC) samples were collected from storekeepers to evaluate biomarkers linked to chronic obstructive pulmonary disease (COPD) and oxidative stress. The biomarkers assessed included hydrogen peroxide ($H_2O_2$) as an oxidative stress indicator, thiobarbituric acid-reactive substances (TBARS) reflecting lipid peroxidation, glutathione (GSH) as a marker of antioxidant capacity, leukotriene B4 (LTB4) as an inflammation marker, and pH as a measure of airway acidity.

EBC was collected by having participants breathe tidally into a refrigerated condenser (R-tube) for 15 minutes. Before the procedure, subjects rinsed their mouths thoroughly and were instructed to breathe only through their mouths while using the R-tube mouthpiece. Collection was conducted between 8–11 AM, and participants were advised to avoid eating or drinking for at least one hour before sampling. Additionally, to prevent interference with biomarker concentrations, subjects were asked to refrain from taking anti-inflammatory medications for three days prior to the procedure. After collection, EBC samples were labeled and immediately stored at -70°C to preserve their integrity until analysis.

Biomarker concentrations in the EBC were measured using enzyme-linked immunosorbent assay (ELISA) test kits, following the manufacturer's protocols. ELISA was used to quantify $H_2O_2$, TBARS, LTB4, and GSH, while pH was determined using a calibrated pH meter.

*Statistical Analysis*

The mean, standard deviation, level of significance, and confidence intervals for each result were carefully calculated. A 5% significance level was applied to evaluate differences between the means of replicate values, ensuring comparisons with a 95% confidence level. Statistical analyses were conducted using both analysis of variance (ANOVA) and Student's t-test to assess relationships and differences among the data sets. Data analysis was performed with the Statistical Package for Social Sciences (SPSS), Version 22, enabling thorough statistical evaluation and ensuring accuracy in interpreting the results.

*Ethical Considerations*

The study protocol received approval from the Research and Ethics Committee of the University of Agriculture and Environmental Sciences, Umuagwo (Ethical Approval Certificate No. UAES/URC/EAC/0001/FoEvt) and the Anambra State Ministry of Health Research Ethics Committee (Certificate No. MH/COMM/523/VOL.47). All participants provided written informed consent before sample collection, ensuring full compliance with ethical standards.

## RESULTS AND DISCUSSIONS

The particulate matter concentrations ($PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and TSP) in chemical stores at Ogbo-Ogwu Market significantly exceed the World Health Organization (WHO) standards (table 1), particularly for $PM_1$ and $PM_{2.5}$, indicating alarming concentrations of air pollution. For example, the WHO standard for $PM_{2.5}$ is set at 5 µg/m³, whereas Store 4 records 3.3 ± 1.0 µg/m³ for $PM_{2.5}$ and 5.4 ± 1.5 µg/m³ for TSP, highlighting a direct health risk to storekeepers and residents. Among the stores, Store 4 exhibits the highest particulate concentrations, with $PM_{10}$ at 4.8 ± 1.1 µg/m³ and TSP at 5.4 ± 1.5 µg/m³. Although Stores 5 and 6 show moderately lower particulate values, they still surpass control concentrations and some WHO standards. The control environment registers significantly lower particulate concentrations, underscoring the disproportionate exposure faced by storekeepers. Overall, these findings reveal that chemical stores in Ogbo-Ogwu Market experience substantial particulate pollution, representing a serious health threat to individuals working or residing nearby.

Exposure Factor-Adjusted Air Concentration (EF-AAC) is a calculation used to estimate the concentration of a contaminant in the air after adjusting for exposure factors. This calculation aims to modify the air concentration based on factors like exposure duration, frequency, and

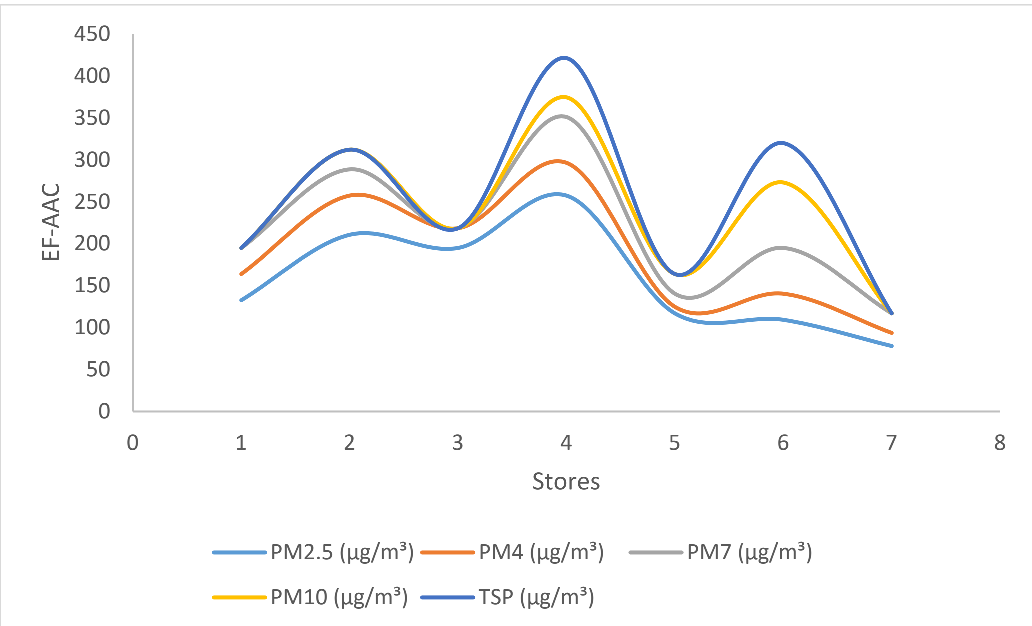
**Table 1.** Concentrations (µg/m³) of Particulates in Chemical Stores at Ogbo-Ogwu, Onitsha Main Market

| Store | PM1 | PM2.5 | PM4 | PM7 | PM10 | TSP |
|---|---|---|---|---|---|---|
| 1 | $1.3\pm0.2^{f}$ | $1.7\pm0.5^{f}$ | $2.1\pm0.9^{g}$ | $2.5\pm1.0^{g}$ | $2.5\pm0.5^{f}$ | $2.5\pm0.9^{e}$ |
| 2 | $1.9\pm0.1^{e}$ | $2.7\pm0.9^{e}$ | $3.3\pm0.4^{f}$ | $3.7\pm0.7^{f}$ | $4.0\pm1.3^{e}$ | $4.0\pm1.4^{f}$ |
| 3 | $1.9\pm0.2^{d}$ | $2.5\pm0.7^{e}$ | $2.8\pm0.5^{e}$ | $2.8\pm0.9^{e}$ | $2.8\pm0.4^{b}$ | $2.8\pm0.7^{e}$ |
| 4 | $2.5\pm0.7^{c}$ | $3.3\pm1.0^{d}$ | $3.8\pm0.9^{d}$ | $4.5\pm1.0^{d}$ | $4.8\pm1.1^{d}$ | $5.4\pm1.5^{d}$ |
| 5 | $1.2\pm0.2^{b}$ | $1.5\pm0.8^{c}$ | $1.6\pm0.5^{c}$ | $1.8\pm0.6^{c}$ | $2.1\pm0.1^{c}$ | $2.1\pm0.9^{c}$ |
| 6 | $1.1\pm0.1^{b}$ | $1.4\pm0.00^{b}$ | $1.8\pm0.3^{b}$ | $2.5\pm0.8^{b}$ | $3.5\pm0.8^{b}$ | $4.1\pm1.0^{b}$ |
| Control | $0.7\pm0.00^{a}$ | $1.0\pm0.00^{a}$ | $1.2\pm0.2^{a}$ | $1.5\pm0.2^{a}$ | $1.5\pm0.1^{a}$ | $1.5\pm0.00^{a}$ |
| WHO Standard | 0.25 | 5.00 | - | - | 15.00 | - |

Values are means of triplicate measurements; means with the same superscript (a, b, c, etc.) in the same columns are statistically similar ($p \leq 0.05$). **PM1**: Particulate Matter 1 µm, **PM2.5**: Particulate Matter 2.5 µm, **PM4**: Particulate Matter 4 µm, **PM7**: Particulate Matter 7 µm, **PM10**: Particulate Matter 10 µm, **TSP**: Total Suspended Particulates timing. The adjustment allows for comparisons with health guidelines related to inhalation and non-cancer risks, as well as cancer-related inhalation risks (ATSDR, 2022). The EF-AAC values for particulates in chemical stores reflect the estimated exposure concentrations based on the time workers spend in these environments, with elevated EF-AAC values signifying increased health risks. Figure 1 shows that store 4 exhibits the highest EF-AAC values across all particulate sizes, with TSP reaching 421.2 µg/m³, which greatly exceeds acceptable exposure limits, aligning with its high direct measurements from Table 1. Store 2 also shows elevated EF-AAC values, particularly for TSP (312.0 µg/m³) and $PM_{10}$ (312.0 µg/m³), suggesting potential long-term adverse health effects for the storekeepers. In contrast, the control store demonstrates much lower EF-AAC values, indicative of a safer environment where workers face reduced exposure to harmful particulates. These elevated EF-AAC values reinforce the conclusion that storekeepers in Stores 4 and 2 are exposed to significantly higher concentrations of particulate matter, putting them at greater risk for health issues related to poor air quality, such as respiratory and cardiovascular problems.

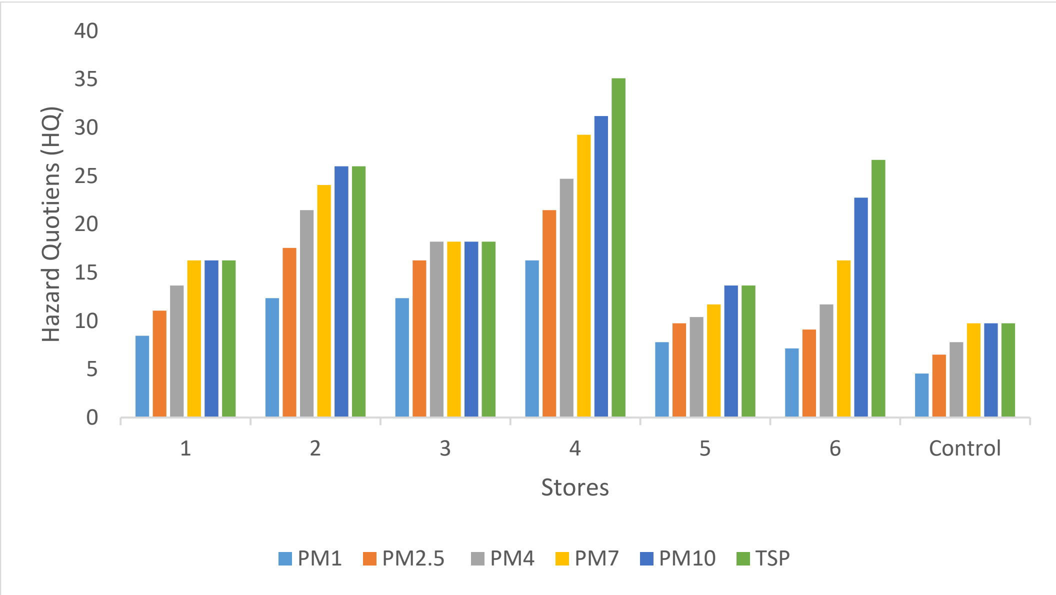
The hazard quotient (HQ) values (figure 2) assess non-carcinogenic risks, where values above 1 suggest potential health hazards. Store 4 registers the highest HQ across all particulate sizes, with TSP reaching 35.10 and $PM_{10}$ at 31.20, indicating that workers in this store are at the highest risk of developing health issues from prolonged exposure. Stores 2 and 3 also show concerning HQ values, with Store 2 recording an HQ of 26.00 for both TSP and PM10, further emphasizing the heightened risk of adverse health effects. In contrast, control stores have HQ values below 10.00 across all particulate sizes, demonstrating minimal health risks in areas without direct chemical exposure. The significantly elevated HQ values in Stores 4, 2, and 3 underscore that chemical storekeepers are exposed to substantial non-carcinogenic health risks due to the high concentrations of particulate matter in their work environments.

Table 2 presents biomarkers related to chronic obstructive pulmonary disease (COPD) among chemical storekeepers, emphasizing respiratory distress and oxidative stress due to particulate




Stores 1 – 6 are the various chemical stores at the market. Store 7 is a clothing store (control) located about 1.1 km from the chemical stores. **$PM_1$**: Particulate Matter 1 µm, **$PM_{2.5}$**: Particulate Matter 2.5 µm, **$PM_4$**: Particulate Matter 4 µm, **$PM_7$**: Particulate Matter 7 µm, **$PM_{10}$**: Particulate Matter 10 µm, **TSP**: Total Suspended Particulates.

**Fig. 1.** EF-AAC Results for Particulates in Chemical Stores at Ogbo-Ogwu Market




Stores 1 – 6 are the various chemical stores at the market. Store 7 is a clothing store (control) located about 1.1 km from the chemical stores. **$PM_1$**: Particulate Matter 1 µm, **$PM_{2.5}$**: Particulate Matter 2.5 µm, **$PM_4$**: Particulate Matter 4 µm, **$PM_7$**: Particulate Matter 7 µm, **$PM_{10}$**: Particulate Matter 10 µm, **TSP**: Total Suspended Particulates.

**Fig. 2.** Hazard Quotients (HQ) for Chemical Storekeepers at Ogbo-Ogwu Market

**Table 2.** EBC Biomarkers of COPD in Chemical Storekeepers at Ogbo-Ogwu Market

| Store | pH | $H_2O_2$ (µM) | TBARS (µM) | GSH (µM) | LTB4 (pg/mL) |
|---|---|---|---|---|---|
| 1 | $7.0\pm1.0^b$ | $0.8\pm0.1^f$ | $0.9\pm0.2^b$ | $2.1\pm1.0^b$ | $50\pm5.0^b$ |
| 2 | $6.9\pm1.5^d$ | $1.0\pm0.2^e$ | $1.1\pm0.1^e$ | $1.8\pm0.2^f$ | $60\pm10.0^e$ |
| 3 | $7.1\pm1.8^b$ | $0.6\pm0.1^b$ | $0.7\pm0.1^d$ | $2.6\pm0.9^e$ | $45\pm12.0^b$ |
| 4 | $6.8\pm1.0^c$ | $1.2\pm0.4^d$ | $1.3\pm0.5^a$ | $1.5\pm0.7^d$ | $65\pm17.0^d$ |
| 5 | $7.2\pm1.1^b$ | $0.5\pm0.1^c$ | $0.6\pm0.1^c$ | $2.8\pm0.9^c$ | $40\pm10.0^c$ |
| 6 | $7.1\pm1.7^b$ | $0.7\pm0.1^b$ | $0.8\pm0.1^b$ | $2.4\pm0.3^b$ | $48\pm14.0^b$ |
| Control | $7.5\pm2.0^a$ | $0.2\pm0.00^a$ | $0.3\pm0.00^a$ | $4.5\pm1.0^a$ | $25\pm5.0^a$ |

Results are means of triplicate values. Means with the same superscript (a, b, c, etc.) in the columns are statistically the same at $p \leq 0.05$. **$H_2O_2$**: Hydrogen Peroxide, **TBARS**: Thiobarbituric Acid Reactive Substances, **GSH**: Glutathione, **LTB4**: Leukotriene B4

matter exposure. Notable findings include slightly lower pH levels in exhaled breath condensate (EBC) from Store 4 (6.8 ± 1.0), reflecting more acidic conditions often linked to respiratory impairment. Elevated $H_2O_2$ concentrations in Store 4 (1.2 ± 0.4 µM) and Store 2 (1.0 ± 0.2 µM) suggest higher oxidative stress, a known contributor to COPD. Thiobarbituric Acid Reactive Substances (TBARS) concentrations, indicating lipid peroxidation and oxidative damage, are highest in Store 4 (1.3 ± 0.5 µM) and Store 2 (1.1 ± 0.1 µM), pointing to significant oxidative stress in these workers. Furthermore, glutathione (GSH), a critical antioxidant, is lowest in Store 4 (1.5 ± 0.7 µM) and Store 2 (1.8 ± 0.2 µM), indicating a reduced ability to counteract oxidative damage. Additionally, elevated Leukotriene B4 (LTB4) concentrations in Store 4 (65 ± 17 pg/mL) and Store 2 (60 ± 10 pg/mL) suggest heightened inflammation, which is another key indicator of COPD progression. Collectively, these biomarkers show that workers in Stores 2 and 4 are exposed to considerable oxidative stress and inflammation, which may increase their risk of developing long-term respiratory conditions like COPD.

This study provides a comprehensive evaluation of particulate matter (PM) exposure in chemical stores at Ogbo-Ogwu Market, Onitsha, with an emphasis on health risks posed to storekeepers. The findings, which indicate significant deviations from World Health Organization (WHO) air quality standards, underscore the urgent need for occupational health interventions.

Not only do the data quantify particulate concentrations, but they also contextualize the exposure within the framework of adjusted air concentrations (EF-AAC), hazard quotients (HQ), and biological markers of chronic obstructive pulmonary disease (COPD). This multi-dimensional approach is particularly innovative as it integrates environmental data with biomarker-based evidence of health effects, thus offering a robust assessment of both exposure and outcome.

*Elevated Particulate Matter and Health Implications*

The recorded particulate concentrations, especially $PM_{10}$ and TSP, exceeded WHO limits, particularly in Stores 4 and 2, where $PM_{10}$ reached 4.8 ± 1.1 μg/m³ and TSP climbed to 5.4 ± 1.5 μg/m³. These concentrations are significantly higher than the control and WHO's safe limits, indicating poor air quality in these chemical stores. The results are consistent with previous studies demonstrating that markets and urban areas with limited ventilation are prone to high concentrations of air pollutants due to dust, chemicals, and human activity (Jiang et al., 2016; Madu et al., 2022). The elevated concentrations of particulate matter across multiple size categories, from $PM_1$ to TSP, pose a clear risk to respiratory health. $PM_{2.5}$, in particular, has been linked to the development of respiratory diseases, cardiovascular problems, and even premature death (WHO, 2021; Guo et al., 2023).

The use of EF-AAC to adjust particulate concentrations based on exposure time provides a more accurate reflection of the actual health risks for storekeepers. In Stores 4 and 2, the EF-AAC for TSP is 421.2 μg/m³ and 312.0 μg/m³, respectively, far exceeding safe occupational exposure limits. Previous studies highlight that long-term exposure to such concentrations of particulate matter can lead to chronic respiratory illnesses and other systemic health problems (Pope and Dockery, 2006; Yamineva et al., 2017). This study's incorporation of EF-AAC highlights the innovative aspect of this research, making the findings more relevant for occupational health assessments, a gap noted in the literature (Liu et al., 2022).

*Health Risk Assessment and Innovation in Approach*

The Hazard Quotient (HQ) is used to assess the likelihood of non-cancer health risks arising from exposure to a contaminant, based on established health guidelines such as Minimum Risk Levels (MRLs), Reference Doses (RfDs), or Reference Concentrations (RfCs). The calculation of Hazard Quotients (HQ) provides further insight into the health risks posed by the exposure to particulates. An HQ greater than 1 indicates a potential for adverse health effects which include rise in respiratory and heart-related conditions such as rhinitis, asthma, chronic obstructive pulmonary disease (COPD), high blood pressure, atherosclerosis, and lung cancer. These health issues are primarily caused by systemic inflammation and oxidative stress (Madu et al., 2022). In this study, Store 4 had an HQ of 35.10 for TSP and 31.20 for $PM_{10}$, while Store 2 had an HQ of 26.00 for both $PM_{10}$ and TSP. These high HQ values suggest significant non-carcinogenic risks to storekeepers. The use of HQ for multiple particulate sizes ($PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and TSP) represents a methodological innovation, allowing for a more granular understanding of health risks (Cincinelli and Martellini, 2017; Madu et al., 2022).

The significant risk highlighted in Stores 4 and 2 echoes findings from global studies on indoor air pollution and occupational exposure in high-particulate environments (Kampa and Castanas, 2008; Vardoulakis et al., 2020). However, this study builds on existing literature by considering multiple particulate sizes and integrating them into a holistic risk model. Moreover, the results emphasize that while larger particulate sizes (e.g., TSP and $PM_{10}$) pose serious health risks, smaller particles ($PM_1$ and $PM_{2.5}$) are equally dangerous due to their ability to penetrate deeper into the respiratory system and cause systemic damage (Xing et al., 2016).

*Biomarkers of COPD: A Novel Insight into Occupational Health Risks*

One of the most innovative aspects of this research is the inclusion of exhaled breath condensate (EBC) biomarkers to assess the early onset of COPD among storekeepers. This is a relatively new approach in environmental health studies, where the emphasis has traditionally been on external air quality measurements rather than internal biomarkers of disease progression (Horváth et al., 2017). Biomarkers such as hydrogen peroxide ($H_2O_2$), thiobarbituric acid reactive substances (TBARS), glutathione (GSH), and leukotriene B4 (LTB4) provide a direct link between environmental exposure and physiological responses, specifically oxidative stress and inflammation.

The significant increase in $H_2O_2$ and TBARS concentrations in storekeepers from Stores 4 and 2 indicates higher oxidative stress, while the reduction in GSH suggests diminished antioxidant defenses. Elevated LTB4 concentrations, particularly in Store 4, further indicate inflammation, which is a hallmark of respiratory conditions like COPD (MacNee, 2005; Barnes, 2022). These findings are consistent with previous studies linking PM exposure to oxidative stress and inflammation (Brauer et al., 2001; Kelly and Fussell, 2015). However, the novel use of EBC biomarkers in this study provides a more direct assessment of health effects in real-time occupational settings, setting this research apart from traditional air quality studies.

*Comparison to Global and Local Standards*

The study's findings are consistent with global trends regarding the health impacts of particulate matter exposure. The WHO 2021 Global Air Quality Guidelines suggest that $PM_{2.5}$ concentrations should not exceed 5 µg/m³, and $PM_{10}$ concentrations should remain below 15 µg/m³. The data from Ogbo-Ogwu Market show that $PM_{10}$ concentrations in some stores are approaching and even exceeding these thresholds, placing workers at significant risk (WHO, 2021). In developing countries, where regulatory oversight is limited, and indoor air quality is often neglected, these findings provide valuable evidence for policymakers to implement stricter air quality standards (Gall et al., 2013; Yamineva et al., 2017).

Locally, this study extends the work of Madu et al**.** (2022), who highlighted poor air quality in Nigerian market. The current study's innovation lies in its holistic approach, integrating EF-AAC, HQ, and biomarkers, providing a comprehensive view of both environmental and health data in chemical stores. These novel additions add to the body of work on occupational health in developing countries, where environmental hazards are often understudied (Jiang et al., 2016).

*Innovation and Future Implications*

The primary innovation of this study is the combined use of environmental monitoring (PM concentrations), exposure-adjusted air concentrations (EF-AAC), health risk assessments (HQ), and biomarkers of disease (EBC analysis). This comprehensive framework offers a clearer picture of the real-time health effects of particulate exposure in occupational settings. The integration of biomarker data into traditional air quality analysis represents a methodological advance that could be replicated in future studies to assess the early stages of respiratory diseases in other high-risk occupations (MacNee, 2005; Suhaimi and Jalaludin, 2015). Through an innovative approach combining traditional air quality analysis with biomarker assessments, the study provides comprehensive insights into both the extent of exposure and its health effects. The findings highlight the urgent need for regulatory actions, enhanced occupational health standards, and continued research to protect vulnerable workers in similar environments. Therefore, the research underscores the significant health risks posed by particulate matter exposure in chemical outlets at Ogbo-Ogwu Market, Onitsha. The study lays a crucial groundwork for future interventions aimed at reducing particulate exposure and its associated health risks in chemical retail outlets. Key recommendations include improving ventilation systems to lower particulate concentrations and worker exposure, equipping storekeepers with personal protective equipment (PPE) to reduce the inhalation of fine particles, and instituting regular health monitoring using the biomarkers identified in this research. This would enable early detection of respiratory issues and prompt intervention.

*Recommendations*

Further research should focus on long-term monitoring of air quality and health outcomes in chemical stores to assess chronic impacts. Studies evaluating the effectiveness of ventilation improvements in reducing particulate matter and health risks would be valuable. Expanding biomarker analysis to include other respiratory diseases and assessing specific chemicals' risks can enhance understanding of health threats. Research on workplace health interventions, such as PPE and health education, could inform preventive measures for workers. Finally, examining air quality impacts on surrounding communities and comparing regulatory environments could help develop effective air quality policies in developing regions.

## CONCLUSION

This study offers a crucial and novel perspective on indoor air quality and health risks associated with poorly ventilated chemical stores in Ogbo-Ogwu Market, Onitsha, Nigeria. The research reveals significantly elevated concentrations of particulate matter ($PM_1$, $PM_{2.5}$, $PM_4$, $PM_7$, $PM_{10}$, and TSP) in these environments compared to control stores, highlighting the severe impact of inadequate ventilation on air quality. The application of Exposure Factor-Adjusted Air Concentration (EF-AAC) and Hazard Quotients (HQ) underscores the heightened health risks for storekeepers, while biomarker analysis in exhaled breath condensate (EBC) confirms increased oxidative stress and inflammation. This study not only fills a gap in understanding the specific challenges faced in poorly ventilated, high-chemical environments but also provides valuable, context-specific insights relevant to developing countries. The findings advocate for urgent improvements in ventilation systems and air quality management to mitigate the adverse health effects identified. By bridging gaps in existing literature and offering actionable recommendations, this research advances our understanding of occupational health risks and supports the development of effective strategies to enhance worker safety and public health in similar settings worldwide.

*Abbreviations*

**AAC**: Adjusted Air Concentration
**ANOVA**: Analysis of Variance
**COMM**: Committee
**COPD**: Chronic Obstructive Pulmonary Disease
**ED**: Exposure Duration
**EF**: Exposure Frequency
**EF-AAC**: Exposure Factor-Adjusted Air Concentration
**EBC**: Exhaled Breathe Condensate
**ELISA**: Enzyme-Linked Immunosorbent Assay
**GSH**: Glutathione
**HQ**: Hazard Quotient
**$H_2O_2$**: Hydrogen Peroxide
**IAQ**: Indoor Air Quality

**LTB4**: Leukotriene B4
**MH**: Ministry of Health
**PM1**: Particulate Matter 1 µm
**PM2.5**: Particulate Matter 2.5 µm
**PM4**: Particulate Matter 4 µm
**PM7**: Particulate Matter 7 µm
**PM10**: Particulate Matter 10 µm
**PM**: Particulate Matter
**PPE**: Personal Protective Equipment
**RfC**: Reference Concentration
**SPSS**: Statistical Package for the Social Sciences
**TSP**: Total Suspended Particulates
**TBARS**: Thiobarbituric Acid Reactive Substances
**UAES**: University of Agriculture and Environmental Sciences
**URC**: University Research Committee
**WHO**: World Health Organization

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## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors

## LIFE SCIENCE REPORTING

The study protocol received approval from the Research and Ethics Committee of the University of Agriculture and Environmental Sciences, Umuagwo (Ethical Approval Certificate No. UAES/URC/EAC/0001/FoEvt) and the Anambra State Ministry of Health Research Ethics Committee (Certificate No. MH/COMM/523/VOL.47). All participants provided written informed consent before sample collection, ensuring full compliance with ethical standards.

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