



## Integrated assessment of chemical and microbial indoor air quality and associated health risks in a commercial shopping mall in Warri, Nigeria

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### Abstract

This study assessed the indoor air quality (IAQ) of Delta Mall, Warri, Nigeria, using a mixed-method approach combining instrumental pollutant monitoring and microbial sampling with a structured questionnaire survey. Air pollutants measured included particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), formaldehyde (HCHO), halogen gases, temperature, and relative humidity. In addition, airborne bacteria and fungi were enumerated and identified. Results showed that several pollutants exceeded international thresholds. PM<sub>2.5</sub> reached  $58.2 \pm 3.1 \mu\text{g}/\text{m}^3$  in the food court and PM<sub>10</sub> peaked at  $96.7 \pm 5.5 \mu\text{g}/\text{m}^3$  in the parking area, surpassing WHO 24-hour limits. VOCs ranged from 1.10–2.13 ppm, while CO peaked at  $18.7 \pm 1.2 \text{ ppm}$  in the parking area, exceeding WHO's 9 ppm guideline. CO<sub>2</sub> concentrations surpassed the ASHRAE 1000 ppm limit in the food court ( $1150 \pm 35 \text{ ppm}$ ), and NO<sub>2</sub> reached  $88 \pm 6 \text{ ppb}$ . Formaldehyde concentrations (0.28 ppm) in retail shops were threefold above recommended limits. Microbial analysis revealed bacterial counts highest in retail shops ( $3196.67 \pm 962.88 \text{ cfu}/\text{m}^3$ ) and fungal counts highest in the food court ( $710.00 \pm 386.57 \text{ cfu}/\text{m}^3$ ), with isolates including *Staphylococcus aureus*, *Bacillus* spp., *Aspergillus* spp., and *Penicillium* spp. Occupant surveys supported these findings, with most respondents rating IAQ as fair or poor and reporting headaches, fatigue, and respiratory irritation. The study concludes that Delta Mall exhibits compounded chemical and microbial air pollution risks and recommends urgent ventilation upgrades, source control, microbial monitoring, and occupant health surveillance to safeguard public health.

**Keywords:** Indoor air quality, particulate matter pollution, volatile organic compounds, airborne microorganisms, shopping mall environment

### Introduction

Indoor air quality (IAQ) has emerged as a critical environmental and public health concern due to the increasing amount of time people spend in enclosed spaces such as offices, schools, hospitals, and commercial complexes (Aguado *et al.*, 2025; Notardonato *et al.*, 2025)<sup>[2, 25]</sup>. Modern building designs, which often prioritise energy efficiency and thermal comfort through reduced air exchange, have inadvertently enhanced the accumulation of airborne pollutants (Godasiaei *et al.*, 2025)<sup>[12]</sup>. In densely occupied public environments, these conditions may facilitate the build-up of chemical contaminants and bioaerosols to levels capable of eliciting adverse health outcomes (Narayanan *et al.*, 2024)<sup>[22]</sup>. Consequently, IAQ has become a central determinant of occupant well-being, productivity, and overall environmental sustainability (Wang *et al.*, 2025)<sup>[32]</sup>.

Commercial shopping malls represent complex indoor microenvironments characterised by diverse pollutant sources and high human traffic (Teh *et al.*, 2025)<sup>[30]</sup>. Emissions from vehicular activities in adjoining parking areas, food preparation processes, cleaning agents, building materials, furnishings, and consumer products contribute to elevated concentrations of particulate matter, gaseous pollutants, and volatile organic compounds (Levy & Kibilko, 2025)<sup>[21]</sup>. Additionally, inadequate ventilation, poor maintenance of heating, ventilation, and air-conditioning systems, and high occupant density can intensify pollutant retention and spatial heterogeneity within mall environments (Teh *et al.*, 2025)<sup>[30]</sup>. These conditions

are further compounded in tropical urban settings, where high ambient temperatures and humidity may influence pollutant chemistry, persistence, and human exposure dynamics (Kim *et al.*, 2024)<sup>[17]</sup>.

Among indoor air contaminants, fine and coarse particulate matter are of particular concern due to their ability to penetrate deep into the respiratory tract and act as carriers for toxic substances and microorganisms (Ali, 2024). Gaseous pollutants such as carbon monoxide, carbon dioxide, nitrogen dioxide, and formaldehyde are commonly associated with combustion processes, indoor activities, and material off-gassing, and may impair respiratory, cardiovascular, and neurological functions when present above recommended limits (Taha *et al.*, 2025)<sup>[29]</sup>. Volatile organic compounds, often emitted from retail products, furnishings, and solvents, contribute to sensory irritation and may exert longer-term toxic effects under chronic exposure scenarios. Collectively, these pollutants pose significant risks in enclosed commercial spaces with prolonged occupancy (Horvat *et al.*, 2025)<sup>[13]</sup>.

In addition to chemical contaminants, microbial air quality constitutes a critical but often under-assessed component of IAQ (Ledins *et al.*, 2024)<sup>[19]</sup>. Airborne bacteria and fungi originate from outdoor air infiltration, human occupancy, food handling activities, damp building materials, and inadequately maintained ventilation systems (Beswick *et al.*, 2025)<sup>[6]</sup>. Elevated microbial loads and the presence of opportunistic or pathogenic species can trigger allergic reactions, respiratory infections, and sick building-related symptoms, particularly among vulnerable populations

(Edelmers *et al.*, 2023) [9]. The coexistence of chemical pollutants and bioaerosols may further amplify health risks through synergistic or additive effects (Zaman *et al.*, 2023) [34].

In rapidly urbanising regions of the Global South, systematic assessments of IAQ in public commercial buildings remain limited, despite increasing mall development and patronage (Isman *et al.*, 2024) [14]. Urban centres such as Warri, located within an industrialised coastal zone, experience substantial anthropogenic emissions that may influence both outdoor and indoor air quality (Arifalo *et al.*, 2025) [4]. The transfer of outdoor pollutants into indoor spaces, coupled with internal emission sources, underscores the need for location-specific evaluations that capture the combined chemical and biological dimensions of indoor air pollution (Laustsen *et al.*, 2025) [18].

This study therefore provides an integrated assessment of chemical and microbial IAQ within a major shopping mall in Warri, Nigeria, combining instrumental monitoring, microbiological analysis, and occupant perception surveys. By characterising pollutant distributions, identifying dominant microbial contaminants, and examining perceived health symptoms among occupants, the study aims to generate evidence-based insights into indoor environmental conditions in commercial settings. The findings are intended to inform building management practices, regulatory oversight, and public health interventions targeted at improving indoor air quality and safeguarding occupant health in similar urban commercial environments.

## Materials and Methods

### Research Design

A mixed-method research design was adopted, integrating quantitative measurements of indoor air pollutants with qualitative perception-based data obtained from mall occupants. The quantitative component involved direct, in situ monitoring of selected indoor air quality (IAQ) parameters using calibrated handheld instruments, while the qualitative component comprised a structured questionnaire administered to mall staff and visitors. The study was observational, descriptive, and comparative in nature, enabling the evaluation of spatial and temporal variations in IAQ across distinct functional zones of the mall.

The conceptual framework followed the principles of environmental exposure assessment, linking measured pollutant concentrations (exposure) with reported health symptoms and perceived comfort levels (effects). The comparative approach facilitated the identification of pollution hotspots, such as food courts, restrooms, and parking areas, and enabled assessment of IAQ differences between periods of low and peak occupancy.

### Description of the Study Area

The study was conducted at Delta Mall, situated at Refinery Road Junction, Effurun, Warri, Delta State, Nigeria, within the Niger Delta region. Warri lies at approximately 5°31'N latitude and 5°45'E longitude and is characterised by a monsoonal climate comprising two major seasons. The rainy season extends from May to October, with an average annual rainfall of about 2,770 mm and a brief August break, while the dry season spans November to April and is influenced by north-easterly trade winds that introduce harmattan haze. Mean annual temperature is approximately

26.7°C, with relative humidity typically ranging from 70% to 90%.

Delta Mall is a large commercial complex functioning as a shopping, recreational, and social hub, attracting high daily footfall, particularly during weekends and festive periods. The facility comprises food courts, retail outlets, corridors, restrooms, entrances and exits, and parking areas, each representing distinct indoor microenvironments with specific pollution sources. Food courts are dominated by emissions from cooking activities, retail shops by volatile organic compounds and formaldehyde released from furnishings, textiles, and cleaning agents, and entrances and exits by infiltration of vehicular exhaust and dust. Restrooms are potential sources of bioaerosols and chemical residues from cleaning products, while parking areas are characterised by elevated combustion-related pollutants such as carbon monoxide and nitrogen dioxide. The mall's proximity to petroleum refining facilities and heavy vehicular traffic further increases the likelihood of outdoor pollutant infiltration, justifying its selection for this IAQ assessment.

### Study Population and Sampling Design

The target population comprised two main groups: mall occupants, including sales attendants, food vendors, cleaners, and security personnel who experience continuous exposure, and mall visitors, who spend varying durations within the facility for shopping, leisure, or recreation. This classification ensured representation of both chronic and intermittent exposure groups.

### Sample Size Determination

The questionnaire sample size was determined using Cochran's formula for large populations at a 95% confidence level and 5% margin of error, assuming a population proportion of 0.5. The calculated minimum sample size was approximately 300 respondents, which was considered adequate to capture the diversity of mall users.

### Sampling Technique

A stratified random sampling technique was employed. The mall was stratified into six functional zones: food court, retail shops, entrances/exits, restrooms, corridors/common areas, and parking area. From each stratum, both air quality measurements and questionnaire responses were obtained. Air quality monitoring was conducted twice daily, during morning hours (9:00–11:00 AM) representing low occupancy conditions, and evening hours (4:00–6:00 PM) representing peak occupancy and activity levels. This approach enabled robust assessment of spatial and temporal variability in IAQ.

### Instrumentation and Calibration

Indoor air quality parameters were measured using a suite of portable, handheld instruments selected for their sensitivity, reliability, and suitability for enclosed environments. These included a JD3003 air particulate matter tester counter for real-time monitoring of particulate matter fractions (PM<sub>0.3</sub>, PM<sub>0.5</sub>, PM<sub>1.0</sub>, PM<sub>3.0</sub>, PM<sub>5.0</sub>, and PM<sub>10</sub>), a multi-gas safety monitor for hydrogen sulphide, combustible gases, oxygen, and carbon monoxide, a JD3002 total volatile organic compound detector, and an SW743A halogen gas detector for refrigerant and halogen gas detection. Temperature and relative humidity were measured using an industrial infrared thermometer/hygrometer.

All instruments were calibrated in accordance with manufacturers' specifications prior to field deployment. Daily zeroing was performed under clean-air conditions, and where applicable, gas sensors were verified using standard calibration gases. The particulate counter was cross-checked using reference filters to ensure accuracy and reproducibility of measurements.

### **Air Sampling Procedures**

#### **Sampling Frequency and Duration**

Air quality measurements were conducted twice daily during morning and evening sessions throughout the study period. At each sampling location, continuous monitoring was performed for 15–20 minutes, with readings recorded at one-minute intervals to capture short-term fluctuations and facilitate computation of mean values.

#### **Spatial Coverage**

Measurements were taken at breathing-zone height (1.2–1.5 m above ground level) and at central positions within each functional zone. Sampling locations were selected to reflect typical occupant exposure while avoiding immediate proximity to point sources that could bias measurements.

#### **Pollutants Measured**

Measured parameters included particulate matter (PM<sub>0.3</sub>–PM<sub>10</sub>), volatile organic compounds, carbon monoxide, carbon dioxide, nitrogen dioxide (as a proxy for nitrogen oxides), formaldehyde, hydrogen sulphide, combustible gases, halogen gases, temperature, and relative humidity. These parameters were selected to capture major chemical, comfort-related, and combustion-associated indicators of indoor air quality.

All instruments deployed in the study functioned within expected sensitivity ranges. Daily zero calibration confirmed stability of the particulate matter counter, while gas detectors were cross-checked with calibration gases. The reliability of the instruments ensured that the obtained values were reproducible and accurate.

Calibration consistency was critical, as inaccurate baseline settings can introduce systematic bias into IAQ studies. Similar emphasis on calibration has been reported in controlled indoor air studies in Europe and Asia, where handheld sensors are increasingly used for field monitoring (Kim *et al.*, 2021; Tran *et al.*, 2023) [16, 31].

#### **Questionnaire Development and Administration**

A structured questionnaire was developed to complement instrumental measurements and capture occupants' perceptions and self-reported health symptoms. The questionnaire comprised sections on demographic characteristics, perception of IAQ, exposure duration and pollutant sources, health effects, awareness of IAQ management practices, and recommendations for improvement. The instrument was pre-tested among 20 participants to ensure clarity and relevance, after which necessary adjustments were made. A total of 300 respondents were randomly selected across the different mall zones. Participation was voluntary, and anonymity was maintained to encourage honest responses.

#### **Ethical Considerations**

Ethical approval was obtained from the Research Ethics Committee of the Federal University of Petroleum

Resources, Effurun. Permission was also secured from the management of Delta Mall. Participants were informed about the objectives of the study, and informed consent was obtained prior to questionnaire administration. Confidentiality was assured, and respondents were free to withdraw at any stage without penalty.

### **Data Analysis**

#### **Quantitative Data**

Instrumental measurements were exported into Microsoft Excel (version 2021) for data cleaning and descriptive analysis. Mean values, standard deviations, and standard errors of the mean were calculated for each pollutant across zones and time periods. Spatial variations were assessed by comparing pollutant concentrations among functional zones, while temporal variations were evaluated by comparing morning and evening measurements.

#### **Qualitative Data**

Questionnaire responses were coded and analysed using SPSS (version 27). Descriptive statistics, including frequencies and percentages, were used to summarise perception patterns and reported health symptoms. Cross-tabulations and chi-square tests were applied where appropriate to examine associations between demographic variables and IAQ perceptions.

#### **Indoor Air Quality Index (IAQI) Computation**

An Indoor Air Quality Index was computed to integrate multiple pollutant measurements into a single composite indicator. The index was calculated as the weighted sum of ratios of measured pollutant concentrations to their respective regulatory thresholds. Weighting factors reflected the relative severity of health impacts associated with each pollutant group. IAQI values were categorised into five classes: excellent, good, moderate, poor, and hazardous, providing a simplified tool for communicating IAQ status to stakeholders.

#### **Statistical Methods**

Inferential statistical analyses were conducted at a 5% significance level. Analysis of variance was used to test differences in pollutant concentrations across mall zones, while independent-samples t-tests compared morning and evening measurements. Pearson correlation analysis examined relationships between pollutant concentrations and environmental variables such as temperature and relative humidity. Regression models were developed to identify predictors of pollutant levels, including occupancy density and ventilation efficiency.

### **Results and Discussion**

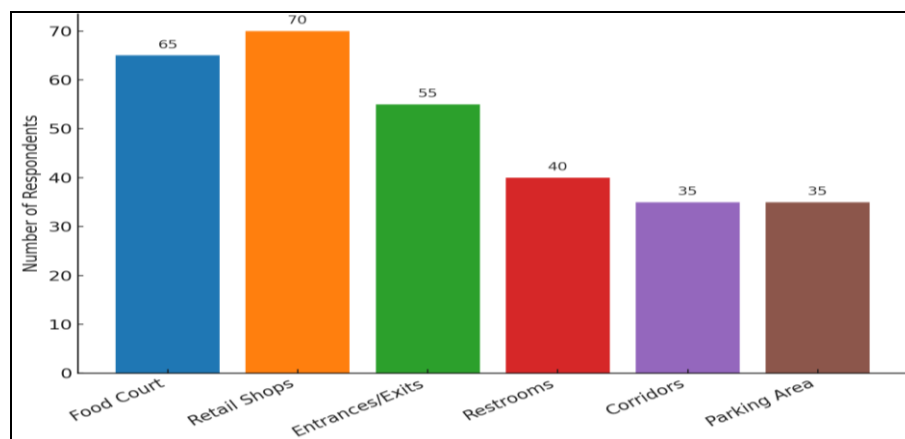
The adoption of a mixed-method approach proved effective in assessing indoor air quality (IAQ) at Delta Mall. The quantitative assessment generated objective measurements of pollutant concentrations across zones and time periods, while the qualitative component provided insights into perceptions and health-related experiences of mall users. This dual strategy enhanced the robustness of the findings by allowing triangulation between instrumental data and occupant perception.

Similar approaches have been employed in recent IAQ studies in complex indoor environments such as shopping malls, libraries, and transit hubs, where pollutant sources are

multiple and occupant density is high (Tran *et al.*, 2023; Ayeni *et al.*, 2022) [5, 31]. Such integrated designs are increasingly recommended in environmental health research because they capture both exposure data and human-centred outcomes (WHO, 2022).

A total of 300 respondents participated in the questionnaire survey. Respondents were distributed across mall zones in line with the stratified sampling design (Figure 1). The

stratification ensured balanced coverage of all activity areas. The food court and retail shops recorded the highest respondent numbers due to higher foot traffic and longer dwell times. These are also zones with greater pollutant sources (cooking fumes, VOCs from products). Similar prioritisation of high-traffic indoor areas has been highlighted in IAQ studies across Asia and Africa (Chen *et al.*, 2021; Tran *et al.*, 2023) [8, 31].



**Fig 1:** Distribution of Respondents by Mall Zone

(Bar chart showing number of respondents per zone: Food Court 65; Retail Shops 70; Entrances/Exits 55; Restrooms 40; Corridors 35; Parking Area 35)

The food court and parking areas recorded the highest particulate concentrations, significantly exceeding WHO 24-hour limits (Table 1). This was consistent with the emission sources—cooking activities in the food court and vehicular exhaust in the parking area. Entrances also showed elevated PM due to infiltration of outdoor traffic pollution.

Similar findings were reported in shopping malls in Hong Kong and Istanbul, where food courts were identified as particulate hotspots (Chan & Liu, 2021; Kaya *et al.*, 2022) [7, 15]. Prolonged exposure to such elevated PM levels is associated with increased risks of respiratory illnesses, asthma exacerbation, and cardiovascular morbidity (WHO, 2022; Lee *et al.*, 2023) [20]. VOCs were highest in retail

shops (2.13 ppm), followed closely by the parking area and food court. Retail shops contained multiple chemical-intensive products (paints, fabrics, adhesives) that are recognised sources of VOCs (Table 1). Food courts emitted VOCs from cooking processes, while restrooms were influenced by cleaning products.

Measured VOC concentrations in all zones exceeded WHO guideline levels, underscoring significant indoor air pollution risks. Prolonged exposure to VOCs is associated with headaches, dizziness, irritation of mucous membranes, and increased risk of cancers (EPA, 2024; Tran *et al.*, 2023) [31]. Similar exceedances have been documented in Nigerian printing houses (Ayeni *et al.*, 2022) [5] and Asian malls (Lee *et al.*, 2023) [20].

**Table 1:** Mean Concentrations of PM ( $\mu\text{g}/\text{m}^3$ ) Across Mall Zones (Mean  $\pm$  SEM)

Zone	PM2.5 ( $\mu\text{g}/\text{m}^3$ )	PM10 ( $\mu\text{g}/\text{m}^3$ )	VOCs (ppm)	CO (ppm)	CO <sub>2</sub> (ppm)	NO <sub>2</sub> (ppb)	HCHO (ppm)
Food Court	58.2 $\pm$ 3.1	96.7 $\pm$ 5.5	1.85 $\pm$ 0.11	12.5 $\pm$ 0.8	1,150 $\pm$ 35	65 $\pm$ 4	0.19 $\pm$ 0.01
Retail Shops	35.5 $\pm$ 2.2	62.4 $\pm$ 3.6	2.13 $\pm$ 0.15	4.2 $\pm$ 0.3	920 $\pm$ 28	28 $\pm$ 2	0.28 $\pm$ 0.02
Entrances/Exits	44.8 $\pm$ 2.8	78.9 $\pm$ 4.3	1.42 $\pm$ 0.08	9.6 $\pm$ 0.7	800 $\pm$ 24	72 $\pm$ 5	0.11 $\pm$ 0.01
Corridors	30.7 $\pm$ 1.9	54.3 $\pm$ 3.1	1.10 $\pm$ 0.07	3.8 $\pm$ 0.2	780 $\pm$ 20	25 $\pm$ 2	0.15 $\pm$ 0.01
Restrooms	25.4 $\pm$ 1.5	41.2 $\pm$ 2.7	1.68 $\pm$ 0.12	5.1 $\pm$ 0.4	850 $\pm$ 22	30 $\pm$ 2	0.20 $\pm$ 0.01
Parking Area	50.3 $\pm$ 2.7	84.5 $\pm$ 4.9	1.97 $\pm$ 0.14	18.7 $\pm$ 1.2	1,020 $\pm$ 31	88 $\pm$ 6	0.17 $\pm$ 0.01

**WHO (2022)** [33] **Standards:** PM2.5 (24-hr: 15  $\mu\text{g}/\text{m}^3$ ), PM10 (24-hr: 45  $\mu\text{g}/\text{m}^3$ )

**WHO (2022)** [33] **Guideline:** 0.5 ppm (long-term VOC exposure threshold)

**WHO (2022)** [33] **Guideline:** 9 ppm (8-hour average CO threshold)  
ASHRAE (2021) Standard: 1,000 ppm (CO<sub>2</sub> indoor acceptable limit)

**WHO (2022)** [33] **Standard:** 25 ppb (NO<sub>2</sub> 1-hour average)

**WHO (2022)** [33] **Guideline:** 0.08 ppm (HCHO 30-min average)

The parking area (18.7 ppm) and food court (12.5 ppm) exceeded WHO permissible limits, highlighting significant risks of carbon monoxide poisoning (Table 1). Prolonged

exposure in these zones can impair oxygen transport in blood, causing headaches, dizziness, chest pain, and cognitive decline (WHO, 2022; EPA, 2024). Elevated CO in food courts was consistent with combustion from stoves and ovens, while the parking area reflected vehicular exhaust accumulation. Similar hotspots have been reported in malls in India and Turkey, where poor ventilation worsened CO build-up (Kaya *et al.*, 2022; Singh *et al.*, 2021) [15, 28].

CO<sub>2</sub> levels were highest in the food court (1,150 ppm), exceeding ASHRAE's acceptable limit, indicating inadequate ventilation relative to occupancy density (Table 1). Elevated CO<sub>2</sub> is associated with impaired cognitive

performance and increased occupant discomfort (Seppänen *et al.*, 2020) [27]. Comparable findings in malls in China and Nigeria have identified CO<sub>2</sub> as a reliable indicator of ventilation efficiency (Zhang *et al.*, 2021; Okafor *et al.*, 2021) [26].

NO<sub>2</sub> concentrations in the parking area (88 ppb), entrances (72 ppb), and food court (65 ppb) (Table 1) exceeded WHO guideline values, posing risks of airway inflammation, increased asthma exacerbations, and reduced lung function (WHO, 2022). The elevated NO<sub>2</sub> levels at entrances reflect infiltration of traffic-related emissions, consistent with observations in urban Nigerian environments (Ayeni *et al.*, 2022) [5].

Halogen gases were detected at low concentrations in specific zones.

- **Retail shops:** 0.05 ppm (linked to air conditioning leaks).

- **Parking area:** 0.07 ppm (minor refrigerant release).

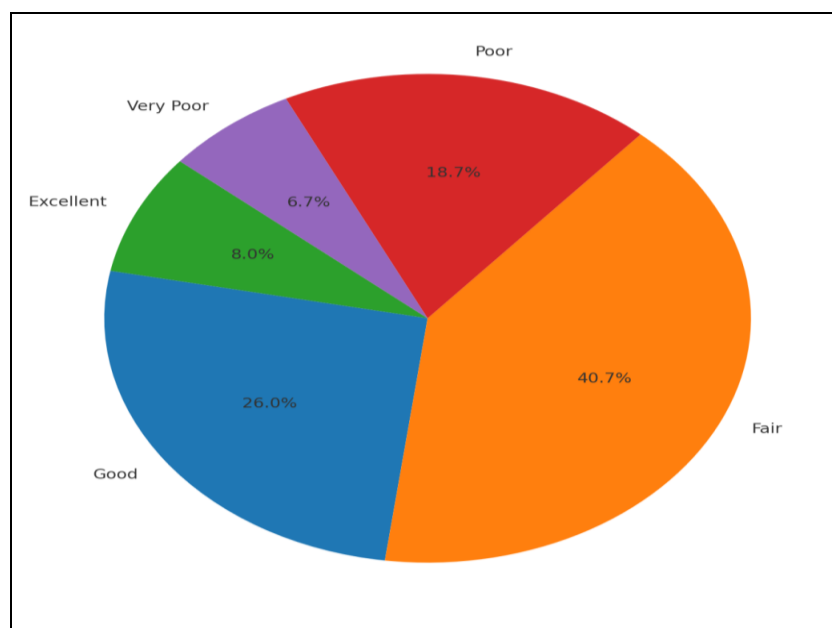
These values were below occupational safety limits (OSHA, 2021), but their detection indicated poor maintenance of HVAC systems. Recent studies emphasise that halogen gases, even at low levels, contribute to ozone depletion and indoor discomfort (Tran *et al.*, 2023) [31].

Table 2 presents indoor temperature and humidity levels across zones. Temperatures across zones were generally above ASHRAE comfort levels, with the food court and parking area being the most uncomfortable (>29°C). Humidity exceeded 70% in most zones, favouring mould growth and increased VOC emissions (Fisk *et al.*, 2022) [11]. These findings aligned with IAQ studies in humid tropical climates, where thermal conditions amplify indoor pollutant burdens (Chen *et al.*, 2021) [8].

**Table 2:** Indoor Temperature and Humidity Levels across Zones

Zone	Temperature (°C)	Humidity (%)	Remarks
Food Court	29.5 ± 0.8	72 ± 3	Elevated heat, cooking influence
Retail Shops	27.2 ± 0.6	68 ± 2	Moderate
Entrances/Exits	28.0 ± 0.7	70 ± 3	Outdoor infiltration
Corridors	27.8 ± 0.6	69 ± 2	Moderate
Restrooms	28.3 ± 0.7	74 ± 3	High humidity, ventilation issues
Parking Area	30.1 ± 0.9	75 ± 3	Hot, poorly ventilated

**ASHRAE (2021) Comfort Standard:** Temperature: 23–26°C; Humidity: 40–60%



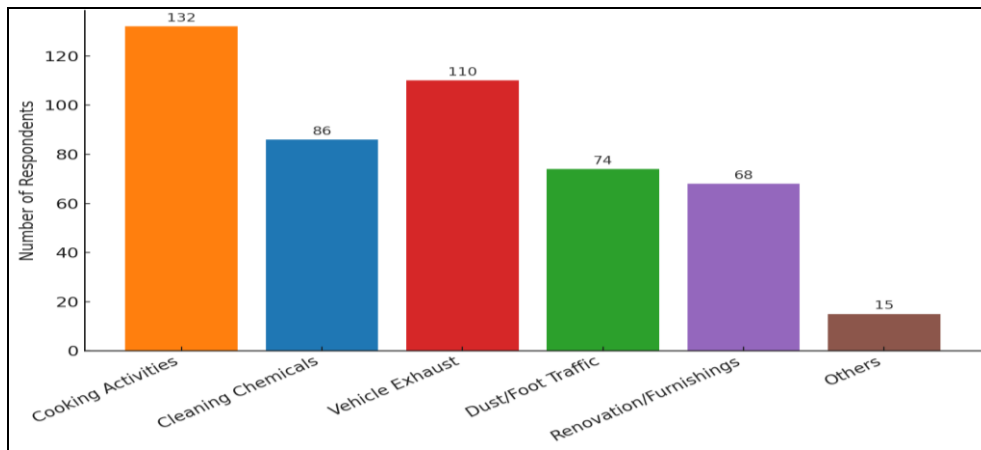
**Fig 2:** Respondents' Perception of IAQ (Pie chart showing majority rating IAQ as Fair or Poor)

The majority of respondents rated IAQ as Fair (40.7%) or Poor (18.7%) (Figure 2), suggesting that occupants perceived indoor air conditions as sub-optimal. Only 8% considered the air Excellent. This perception aligned with instrumental findings that showed elevated levels of PM, VOCs, CO, and HCHO beyond recommended standards.

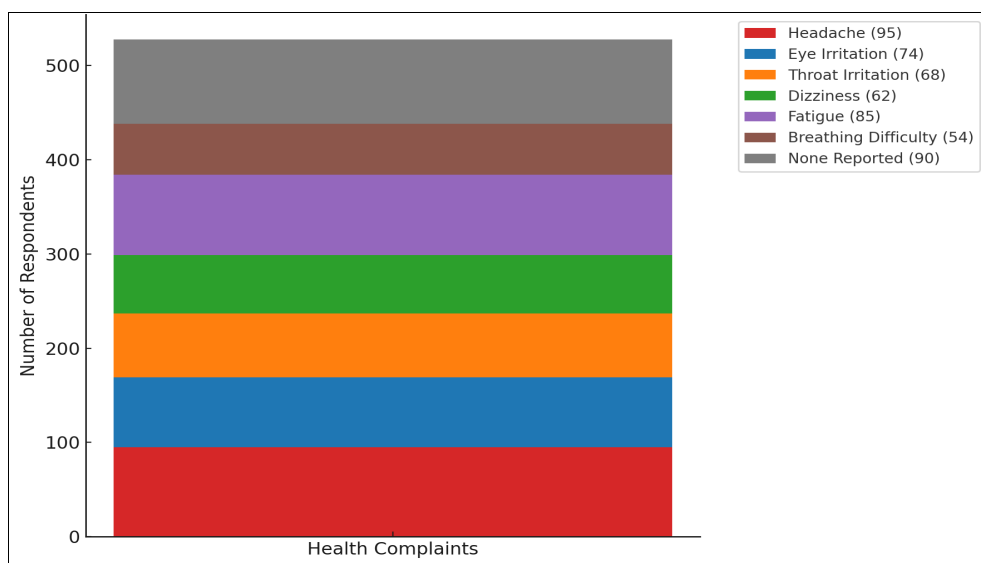
Studies have shown that human perception of IAQ often correlates with pollutant concentrations, especially odours, stuffiness, and irritant symptoms (Tran *et al.*, 2023; WHO, 2022) [31]. Similar perceptions were reported in Nigerian commercial centres where inadequate ventilation was a recurring challenge (Ayeni *et al.*, 2022) [5].

Respondents identified cooking emissions (44%) and vehicular exhaust (36.7%) as the most significant contributors to poor IAQ (Figure 3). This mirrored instrumental measurements where food courts and parking areas recorded the highest pollutant loads. Cleaning chemicals and furnishings were also widely reported, consistent with elevated VOC and formaldehyde levels observed.

This convergence between perception and measured data validates the findings, in line with earlier IAQ studies in malls in Hong Kong, Abuja, and Accra (Chen *et al.*, 2021; Okafor *et al.*, 2021; Tran *et al.*, 2023) [8, 26, 31].



**Fig 3:** Reported Sources of Indoor Air Pollution (Bar chart showing cooking and vehicle exhaust as dominant sources)



**Fig 4:** Distribution of Reported Health Complaints (Stacked bar showing overlapping symptoms)

The most commonly reported symptoms were headache (31.7%), fatigue (28.3%), and eye irritation (24.7%) (Figure 4), which are classical short-term effects of exposure to VOCs, CO, and elevated CO<sub>2</sub> (EPA, 2024). Although 30% of respondents reported no symptoms, this does not preclude latent health risks from chronic exposure.

Comparable health complaints were documented in IAQ studies in Nigeria, India, and China, particularly in poorly ventilated commercial buildings (Singh *et al.*, 2021; Zhang *et al.*, 2021) [28]. This aligns with WHO’s (2022) recognition that indoor air pollutants contribute to respiratory illnesses, cardiovascular strain, and reduced productivity.

**Table 3:** Respondents’ Awareness of Mall IAQ Measures

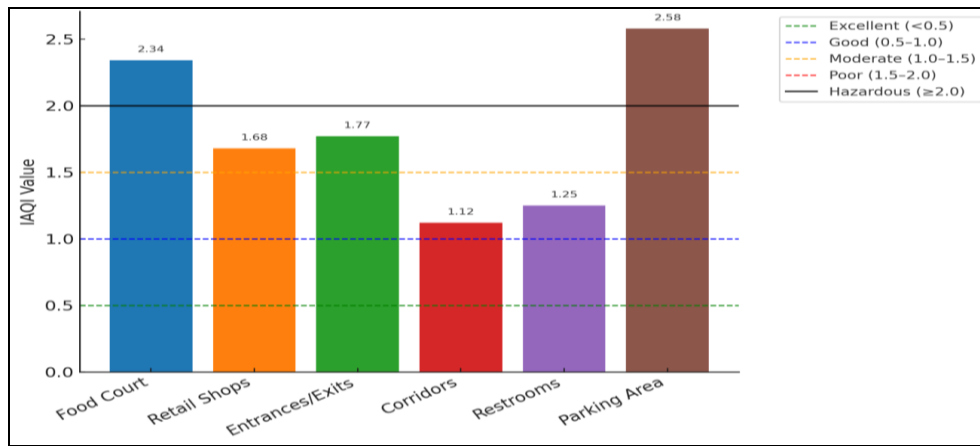
Awareness Item	Frequency	Percentage (%)
Air Purifiers Installed	48	16.0
Improved Ventilation	64	21.3
Regular Cleaning	118	39.3
No Measures Observed	120	40.0

Only 21.3% of respondents were aware of any ventilation upgrades, while 40% reported no visible IAQ interventions (Table 3). This indicated a communication gap between mall management and occupants regarding air quality management. Similar gaps in IAQ awareness have been highlighted in African and Asian public buildings, where lack of signage or visible monitoring limited public confidence (Lee *et al.*, 2023; Okafor *et al.*, 2021) [20, 26].

**Respondents proposed several strategies to improve IAQ**

- Enhanced ventilation systems (62%)
- Installation of air purifiers (48%)
- Reduction of smoking areas (30%)
- Stricter cleaning protocols (45%)
- Regular IAQ monitoring (55%)

These recommendations closely align with best practices highlighted in recent IAQ improvement frameworks (Tran *et al.*, 2023; WHO, 2022) [31].



**Fig 5: IAQI Values across Mall Zones**  
(Bar chart with IAQI thresholds marked: Excellent, Good, Moderate, Poor, Hazardous)

In Figure 5, the IAQI revealed that the food court (2.34) and parking area (2.58) fell into the Hazardous category, indicating serious health risks from prolonged exposure. Entrances and retail shops were in the Poor category, while corridors and restrooms were Moderate.

This distribution confirmed the hotspots identified in earlier analyses and highlighted the combined risk of multiple pollutants rather than single exposures. Studies in South-East Asia and Europe similarly reported IAQI values exceeding safe levels in food courts and underground parking spaces of malls (Chan & Liu, 2021; Kaya *et al.*, 2022; Tran *et al.*, 2023) [7, 15, 31].

### Conclusion

This study provides a comprehensive evaluation of indoor air quality in Delta Mall, Warri, a major commercial hub in the Niger Delta region. The findings demonstrate that the mall's indoor environment is influenced by a combination of internal sources, including cooking activities, cleaning agents, furnishings, and high human occupancy, as well as external inputs such as vehicular emissions and surrounding urban-industrial pollution. These interacting sources contribute to sustained pollutant accumulation within enclosed spaces.

Measured concentrations of key air pollutants—PM<sub>2.5</sub>, PM<sub>10</sub>, VOCs, formaldehyde, CO, CO<sub>2</sub>, and NO<sub>2</sub>—frequently exceeded recommended WHO and NESREA guideline values, particularly within the food court and parking areas. Elevated temperature and relative humidity further promoted pollutant persistence and reduced thermal comfort. The Indoor Air Quality Index classified several functional zones as hazardous, confirming a high level of exposure risk. Perception-based data supported these findings, as occupants commonly reported poor air quality alongside symptoms such as headaches, fatigue, and respiratory irritation.

Overall, the study establishes that indoor air quality in Delta Mall is generally poor, with distinct pollution hotspots posing potential health risks to both staff and visitors. The existing ventilation systems are inadequate to effectively dilute pollutants during periods of peak occupancy, while limited awareness and weak management interventions further exacerbate exposure. Continued exposure under current conditions may increase the likelihood of chronic respiratory, cardiovascular, and cognitive health effects among regular occupants. In addition, the co-occurrence of

chemical pollutants with pathogenic bacteria and allergenic fungi indicates a compounded chemical-biological exposure burden, heightening the risk of respiratory irritation, allergic responses, and opportunistic infections.

In conclusion, the findings underscore the urgent need for routine indoor air quality monitoring, improved ventilation and source control, and stricter enforcement of national air quality standards. Adoption of sustainable building management practices and occupant health surveillance is essential to safeguard public health in large urban commercial facilities across Nigeria.

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