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Assessment of Levels and Health Risk of Volatile Organic Compounds in Indoor Environments in Minna, Niger State, Nigeria

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Abstract
Indoor air quality (IAQ) is a growing public health concern in rapidly developing Nigerian cities, where residents spend most of their time indoors. Volatile organic compounds (VOCs) such as benzene, ethylbenzene, formaldehyde, toluene, and xylene (BTEX) are serious indoor pollutants due to their long stay in poorly ventilated spaces. They can cause severe and prolonged health effects. This study evaluated indoor VOC concentrations and associated health risks in residential buildings across the Minna metropolis, Niger State, using a cross-sectional environmental monitoring and risk assessment approach. Fifty residential buildings were carefully chosen through multistage sampling, and VOC determination was carried out using a portable real-time VOC monitor furnished with photoionization detectors (PID) at breathing height during ultimate occupancy periods. Exposure and health risks were assessed using the Average Daily Dose (ADD), Hazard Quotient (HQ) for non-carcinogenic effects, and Lifetime Cancer Risk (LCR) for carcinogenic compounds, following WHO and US EPA guidelines. The findings revealed that all the VOCs were present in quantifiable amounts across the sampled residential houses, with the levels of benzene remaining higher compared to the WHO permissible limits. This shows an LCR of 3.76×10^{-5} that indicates high long-term cancer risk. The higher HQ value (1.23) shown by formaldehyde for children signifies a possible non-carcinogenic effect among children. Meanwhile, other VOCs assessed (ethylbenzene, toluene, and xylene) were below permissible limits. Hence, this study offers evidence-based understandings of public health mediations and indoor air quality strategies in Nigerian cities.

Keywords: BTEX, VOCs, Indoor air quality, Minna, Nigeria.

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1. Introduction

In Minna, like in several fast-developing cities in Nigeria, people spend most of their time indoors in offices, homes, schools, and places of worship, making the quality of indoor air an important part of public health. While consideration has usually concentrated on outdoor air pollution in Nigerian cities, there is growing concern that indoor air can be seriously polluted, frequently with amounts of lethal pollutants that are above outdoor levels as a result of limited ventilation, heavy city traffic emissions, and indoor sources (cooking smoke and household products). Among the pollutants of major concern are indoor volatile organic compounds (VOCs) because of their persistence in poorly ventilated spaces and their potential to cause both acute and protracted health effects (Horvat, Pehnec, & Jakovljević, 2025).

VOCs include a wide-ranging group of carbon-based chemicals (benzene, formaldehyde, toluene, ethylbenzene, and xylenes) that freely vaporize at room temperature. These VOCs may result from common sources like cleaning agents, paints, cooking activities, furnishings, and tobacco smoke (Horvat, Pehnec, & Jakovljević, 2025). Other possible sources of VOCs include emissions from electric generators, kerosene stoves, open burning of waste, and outdoor vehicle exhaust (Abai, Ite, & Ibok, 2025).

Exposure to high amounts of VOCs has been associated with a range of health disorders. Exposure within a short time may irritate the eyes, nose, and throat, cause dizziness, headaches, and nausea, while long-term exposure to compounds such as benzene and formaldehyde is linked to respiratory diseases, neurological effects, and increased cancer risk (Ghobakhloo *et al*., 2023). Several studies carried out across the globe have shown that high indoor VOC concentrations pose both non-cancer and cancer risks to households. This emphasizes the urgent need for confined air quality assessments (Horvat, Pehnec, & Jakovljević, 2025; Nored *et al*., 2024; Zehra *et al*., 2025). To long-term indoor exposure to VOCs, the most vulnerable groups are children, the elderly, and individuals with health challenges resulting from their delicate physiological sensitivity (Nie *et al*., 2025).

Besides the determination of levels of VOCs, assessment of health risk incorporates toxicological levels to appraise the possibility for adverse health effects, offering a framework for selecting alleviation approaches (Horvat, Pehnec, & Jakovljević, 2025). By appraising hazard quotients for non-carcinogenic effects and lifetime excess cancer risks for carcinogenic compounds, risk assessment offers a better understanding of urban health plans, building design, and public awareness campaigns. Such methods are particularly appropriate in locations like Minna, where baseline data on indoor VOC pollution are rare and monitoring based on indoor air quality is still emerging (Demissie *et al*., 2024).

Thus, this study aims to measure some VOCs in indoor environments across selected locations in Minna and to assess the linked health risks to the households. By relating field measurements with well-known risk assessment models, this study seeks to fill rare data gaps, enlighten stakeholders, and support targeted interventions to improve indoor air quality and protect community health in Minna.

2. Materials and methods

This study embraced a cross-sectional environmental monitoring and health risk assessment design. This approach pooled both field measurement of indoor volatile organic compounds (VOCs) with quantitative exposure and health risk assessment models to appraise possible non-carcinogenic and carcinogenic risks associated with indoor VOC exposure. This approach is extensively employed in indoor air quality assessment due to its ability to simultaneously characterize both pollutant levels and health impacts under real-life exposure conditions (US EPA, 2023; WHO, 2024).

This study was carried out in Minna Metropolis, the capital of Niger State, Nigeria. Minna is described by rapid urban development, diverse types of residential buildings, and general reliance on electric generators due to a lack of a stable supply of electricity. Common household activities, including cooking using kerosene/gas stoves, the use of cleaning chemicals, and closeness to major roads, add to indoor air pollution in the study area. Minna city usually experiences a hot savanna climate with different dry and rainy seasons, which determines ventilation patterns and indoor pollutant buildup (Okobia & Abdul, 2020).

This study employed a multistage sampling technique such that Minna metropolis was first stratified into high-, medium-, and low-density areas. In each area, residential buildings were randomly selected. Indoor sampling positions included living rooms and bedrooms, as these spaces represent areas of persistent human use. The study sample size was determined using the Cochran (1977) formula for environmental exposure studies:

$$n = \frac{Z^2 6^2}{d^2}$$

Where n = required sample size, Z = standard normal deviate at 95% confidence level (1.96), σ = estimated standard deviation of indoor VOC concentrations from previous Nigerian studies, and d = acceptable margin of error. Logically, 50 residential buildings were sampled.

A portable real-time VOC monitor furnished with photoionization detectors (PID) was employed to measure the Indoor VOC (benzene, toluene, ethylbenzene, xylene (BTEX**),** and formaldehyde**)** concentrations. Meanwhile, VOC sampling was conducted for 45 minutes at a breathing height of 1.3 m above the floor during morning and evening, which are the ultimate occupancy periods for the households. The mean concentrations of the VOC were determined and recorded in µg/m³ following WHO and US EPA indoor air quality protocols (WHO, 2024; US EPA, 2023).

The questionnaire-maintained exposure assessment by providing a framework for detecting VOC levels and ascertaining possible emission sources. Inhalation exposure to VOCs was determined using the Average Daily Dose (ADD) model recommended by the US Environmental Protection Agency:

$$\mathrm{ADD} = \frac{\mathrm{C \times IR \times EF \times ED}}{\mathrm{BW \times AT}}$$

Where C = VOC concentration (µg/m³), IR = inhalation rate (m³/day), EF = exposure frequency (days/year), ED = exposure duration (years), BW = body weight (kg), and AT = averaging time (days)
Meanwhile, non-carcinogenic risk was assessed using the Hazard Quotient (HQ)**:**

$$\mathrm{HQ} = \frac{\mathrm{ADD}}{R_f}$$

Here, R_f = reference dose. An HQ > 1 indicates a possible health concern. Lifetime excess cancer risk (LCR) was measured for carcinogenic VOCs (benzene and formaldehyde) using:

$$\mathrm{LCR = ADD \times CSF}$$

Where *CSF* is the cancer slope factor. Acceptable cancer risk levels were assessed using the benchmark range of 1×10^{-6} to 1×10^{-4} (WHO, 2024).

Data were analysed using Statistical Packages for Social Sciences (SPSS, version 26)**.** Descriptive statistics were used to present mean concentrations of VOC, while inferential analyses were carried out at $p < 0.05$ to study differences in mean levels of VOC across residential areas and fuel types.

3. Results and discussion

3.1 Results

Figure 1 shows the mean indoor concentrations of some VOCs determined in residential buildings within Minna metropolis, in contrast to the World Health Organization (WHO) permissible limits.

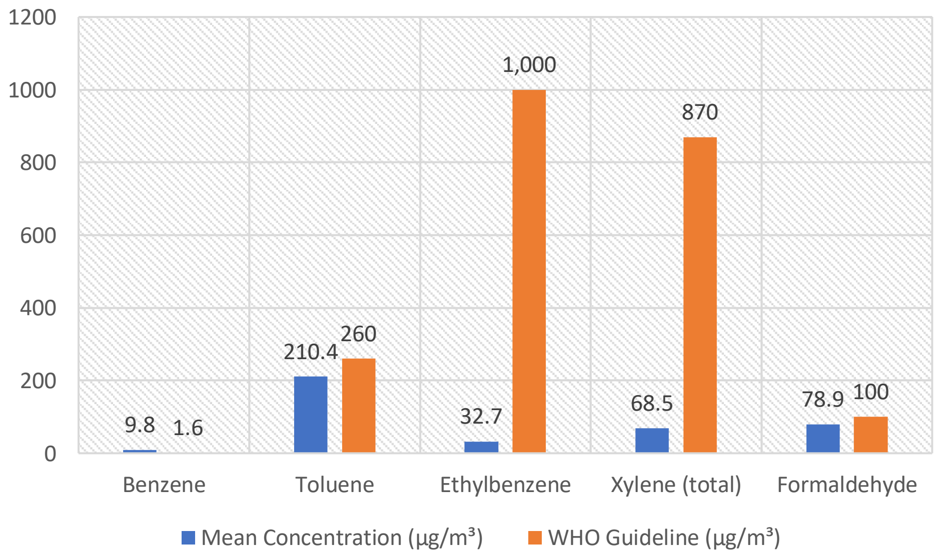

Figure 1: Mean Indoor VOC Concentrations in Residential Buildings in Minna Metropolis

Figure 2 presents the non-carcinogenic health risk assessment of some indoor VOCs in residential buildings within Minna metropolis, expressed as Hazard Quotients (HQ) for adults and children, showing differences in susceptibility and potential health implications across age groups.

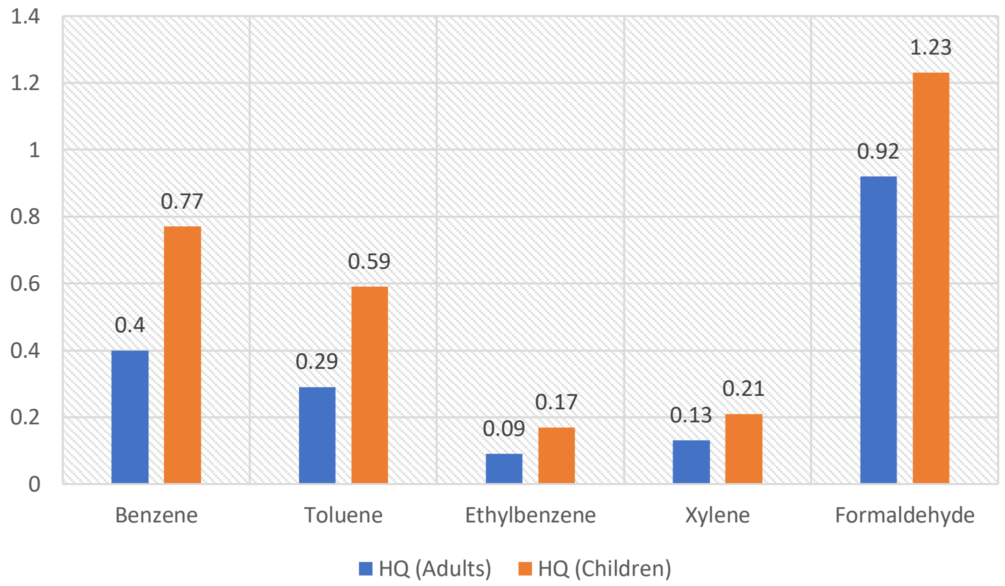

Figure 2: Non-Carcinogenic Health Risk Assessment (Hazard Quotient, HQ)

Table 1 presents the assessed lifetime excess cancer risk (LCR) linked with indoor exposure to some carcinogenic VOCs in residential buildings within Minna metropolis. From the results, benzene and formaldehyde show a high cancer risk and moderate risk, respectively, although both values fall within the acceptable regulatory range, yet necessitate public health concern due to continuous indoor exposure.

Table 1: Lifetime Cancer Risk (LCR) related to exposure to Indoor VOC

VOC	Mean LCR	Acceptable Range	Risk Level
Benzene	3.76×10^{-5}	$1 \times 10^{-6} – 1 \times 10^{-4}$	High
Formaldehyde	8.1×10^{-6}	$1 \times 10^{-6} – 1 \times 10^{-4}$	Moderate

3.2 Discussion

To have an in-depth understanding of how indoor air quality conditions result in health challenges, there is a need to compare levels of selected volatile organic compounds (VOCs) with World Health Organization (WHO) permissible limits with respect to non-carcinogenic and carcinogenic risk evaluations. VOCs are among the most critical indoor air pollutants due to their long-term stay in enclosed environments and potential link with acute and chronic health effects (Jin *et al.*, 2023).

Benzene turned out to be the most concerning pollutant reported by all assessment metrics. Its mean indoor level above the WHO permissible limit indicates a serious indoor air quality deterioration.

Benzene is a Group 1 human carcinogen with no safe exposure threshold, and high indoor levels are usually linked to combustion-related activities, including environmental tobacco smoke, kerosene/biomass cooking, and penetration of traffic emissions (Kumari, Soni, & Aggarwal, 2024). Similarly, benzene showed somewhat high hazard quotient (HQ) values for both adults (0.40) and children (0.77), with children close to the safety threshold, showing their greater susceptibility due to higher intake rates and developing physiological systems (Ungureanu, Mustatea, & Popa, 2022). The lifetime excess cancer risk (LCR) for benzene of 3.76×10^{-5} is within the tolerable regulatory range but very close to the upper limit, which signifies a higher long-term cancer risk and highlights the need for targeted alleviation (Sanda *et al*., 2023).

The fact that formaldehyde is of health concern and at the same time has its mean concentration close to the threshold is an indicator that, under poor ventilation, irritation and other injurious effects may take place even below permissible levels (Zehra *et al*., 2025). Formaldehyde has the highest HQ values among all VOCs determined. This signifies a likely non-carcinogenic health challenge in children. The LCR for formaldehyde (8.1×10^{-6}) showed a moderate cancer risk within acceptable limits, agrees with its grouping as a human carcinogen, and its prevalent indoor emission from furnishings, household chemicals, and wood products (Khoshakhlagh *et al*., 2023).

The amounts of toluene were found to be below WHO permissible limits, yet go on quite high, signifying continuing indoor emission sources, including solvents, paints, cleaning agents, among others. HQ values showed tolerable non-carcinogenic risk for adults (0.29) and infants (0.59), though the elevated values noticed in teenagers indicate increased vulnerability to neurotoxic effects linked with chronic exposure. Ethylbenzene and xylene showed mean levels well below permissible limits and low HQ values for both age groups, showing negligible instant health risk (Kamani *et al*., 2023). However, these compounds add to the total VOC mixture, and increasing exposure may increase sensory irritation and other health challenges even when individual amounts are low (Malakan *et al*., 2025; Husaini *et al*., 2026).

Hence, the findings show a mixed indoor VOC composition characterized by universal agreement with recommended values but serious concerns associated with benzene and formaldehyde, mostly in infants. Findings showed that most specific HQ and LCR values were within acceptable limits, yet ignoring the possible synergistic effects resulting from collective exposure to the VOCs is dangerous (Alford & Kumar, 2021).

Hence, the common non-carcinogenic and carcinogenic health threats faced by infants can be linked to both benzene and formaldehyde as potential indoor pollutants. These outcomes indicate the need for urgent attention to indoor air quality management.

Conclusion

In this study, the indoor volatile organic compounds (VOCs) pollution with respect to environmental health challenges in residential buildings across Minna metropolis was assessed. It was found that in all the sampled residential houses, Quantifiable amounts of VOCs (benzene, ethylbenzene, toluene, formaldehyde, and xylene) were present. This shows that the exposure of the assessed homes to indoor chemicals is prevalent. Given the high proportion of time residents spend indoors, prolonged exposure to elevated VOC levels may contribute to respiratory symptoms, neurological effects, and long-term cancer risks. Thus, the study reveals that indoor air pollution needs equal policy consideration as outdoor air quality, chiefly in fast-developing Nigerian cities where there is persistent use of informal energy.

Conflict of Interest

The authors declare that the research was conducted without conflict of interest.

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