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# Indoor Air Quality and Volatile Organic Compounds Exposure from Household Chemicals: A Comparative Study in Iraqi Homes

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## Abstract

Background: Growing evidence shows that household cleaning products, especially those containing volatile organic compounds (VOCs), represent a major source of indoor air contamination. These chemicals may also contribute to oxidative imbalance and heightened inflammatory responses, particularly among women who spend extended periods inside their homes. Objective: This study set out to examine how indoor air quality is influenced by household chemical use and to assess the impact of this exposure on oxidative stress and inflammatory biomarkers in women residing in Kirkuk. Methods: A total of 120 housewives from Kirkuk were enrolled in a comparative cross- sectional study , divided evenly into an exposed group (n= 60) and a control group (n=60) . Air samples were taken from each home and analyzed using gas chromatography- mass spectrometry to quantify (VOC) levrls. Result: Participants in the high -exposure group reported significantly greater use of household products ( (13.7 ± 3.9 vs 2.1 ± 0.8) products/day, p<0.001) and presented with notably elevated indoor (VOC) concentrations. Average formaldehyde levels reached (231.7 ± 65.4) µg/$m^3$ in high – exposure homes, compared with (89.4 ± 28.1) µg/$m^3$ in the control group (p<0.001, Cohen's d=2.78), exceeding WHO limits by more than double. Benzene concentrations followed the same pattern ((17.1 ± 4.7 vs 6.2 ± 2.4) µg/$m^3$, p<0.001, d=2.89), alongside similar increases in toluene, xylene, and other VOCs. Biological analyses revealed clear alterations in oxidative stress and inflammatory indicators- findings that align with our ealier work identifying oxidative disruption as a key factor in disease development. Conclusion: Heavy reliance on household cleaning products was found to significantly compromise indoor air quality, produsing VOC concentrations that surpass established international safety limits. These results highlight the immediate need to promoter better ventilation practices, encourage the use of safer product alternatives, and implement targeted public health measures. The associated biological effects are explored in detail in our companion study.

**Keywords:** Formaldehyde; Oxidative stress; Indoor air quality; Home chemicals

## 1. Introduction

Household chemicals have been used much more frequently worldwide in recent decades. A decline in indoor air quality is caused by the average family's daily use of over 40 chemical goods that contain volatile organic compounds such formaldehyde, benzene, toluene, and xylene, according to statistics [1]. Research has indicated that indoor air can include concentrations of these compounds that are two to five times higher that indoor air , particularly in houses with extensive cleaning product usage [2]. The group most exposed to these pollutants is women, particularly housewives, who are more vulnerable to the harmful health effects of chronic exposure since they spend more time indoors [3]. These consequences include severe medical disorders including oxidative stress, which is the disturbance of the body's oxidative balance, and persistent inflammatory reactions, which are significant pathological processes that contribute to the emergence of numerous chronic illnesses[4]. Prolonged exposure to VOCs has been shown to disrupt redox homeostasis and initiate inflammatory processes[5,6]. In a concurrent analysis, we investigate the specific biological

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pathways that may account for these effects in our study cohort [7,8]. Kirkuk and other Iraqi cities have experienced rapid urban and economic growth, which has altered people's lifestyles and increased the use of household chemicals[9]. Even though numerous studies have been done worldwide, these is a dearth of information in the literature regarding the impact of these products on public health in Iraq[10], particularly among women. Thus, the importance of this study resides in its effort to assess the relationship among Kirkuk women's oxidative stress and inflammation markers, household chemical use, and indoor air quality. Developing a scientific database to support the development of reasonable municipal environmental and health policies is the aim of this project. A detailed evaluation of the biological impacts of VOC exposure, including changes in oxidative stress markers and inflammation- related biomarkers, is presented in a separate companion paper based on analyses from the same participdnt group[11]. The findings of the present study are in agreement with earlier research from neighboring countries[12- 17].

## 2. Materials and methods

### 2.1. Study Design and Ethical Approval

Between January and October of 2024, this comparative cross-sectional survey was carried out in Kirkuk, Iraq. The Scientific Research Ethics Committee of the University of Kirkuk's College of Science provided ethical clearance, and the Directorate of Health in Kirkuk also officially approved the project (Approval Letter No. 581, dated 22 July 2024). G*Power sample size calculations (independent t-test, effect size $d=0.75$, $\alpha=0.05$, power=0.80) showed that each group needed at least 57 participants. There were 120 participants in total, 60 women were recruited into each group to account for possible dropouts or missing data.

### 2.2. Participants

Eligible participants were housewives aged 25–55 years who had lived in the same household for at least five years. Women were included if they were not employed or worked fewer than four hours per day outside the home, and if they provided written informed consent. Exclusion criteria covered pregnancy or lactation, chronic illnesses such as diabetes, hypertension, cardiovascular or autoimmune disorders, current or past smoking, significant secondhand smoke exposure, occupational chemical exposure, alcohol use, and the use of anti-inflammatory drugs or antioxidant supplements. Women with acute infections within the two weeks prior to enrollment were also excluded.

### 2.3. Exposure Characterization and Confounding Control

A number of lifestyle and environmental factors were rigorously evaluated in order to reduce confounding.

- **Cooking and heating practices:** were meticulously documented, including stove usage, daily cooking time, and primary fuel type (natural gas, LPG, electricity, or kerosene). Households with gas or kerosene heaters were identified as perhaps more dangerous.
- **Group classification:** was improved with data on measured exposure. The first step involved grouping women according to the products they reported using: the high-exposure group was made up of women who frequently used cleaning and fragranced products (such as bleach, disinfectants, air fresheners, and bathroom and multi-surface cleaners), while the low-exposure group was made up of women who reported using natural alternatives like vinegar, lemon, or baking soda. However, the final assignment depended on measures of indoor air: individuals were classified as low exposure if formaldehyde was ($<100\ \mu g/m^3$) and benzene was ($<5\ \mu g/m^3$), and as high exposure if formaldehyde was ($>150\ \mu g/m^3$)or benzene ($>10\ \mu g/m^3$) in their houses. These objective metrics were used to reclassify three subjects.

### 2.4. Indoor Air Sampling and VOC Analysis

Tenax TA thermal desorption tubes coupled to calibrated pumps running at (100 mL/min) for eight hours were used to collect indoor air samples from the living room, kitchen, and bedroom. For four weeks in a row, sampling was done twice a week while regular household tasks continued. For quality control, duplicate samples, field blanks, and calibration checks were included. Using internal standards and calibration curves, gas chromatography–mass spectrometry (GC–MS, Agilent 7890B/5977A) was used to assess the VOC concentrations. DNPH (2,4-dinitrophenylhydrazine) cartridges (Waters Sep-Pak) running at 0.5 L/min for four hours were used to measure formaldehyde. Acetonitrile was used to extract the samples, and HPLC-UV was used to evaluate them at 360 nm. Cross-validation of a 20% subset of samples against Tenax TA results revealed a good correlation ($r=0.89$, $p<0.001$).

Tenax-derived results were adjusted using the following correction equation: $[HCHO]\{corrected\} = 1.15 \times [HCHO]\{Tenax\} + 12.3 \backslash, \mu g/m^3$ .

To guarantee accuracy, laboratory duplicates (RSD <8%), field blanks (<2.5 μg/m$^3$), and approved standards (Sigma-Aldrich) were employed. The results show corrected DNPH-validated measurements for all formaldehyde values.

### 2.5. Blood Collection and Biomarker Analysis

Fasting venous blood (10mL) was obtained from participants between 08:00 and 10:000 after at least eight hours of fasting. All samples were processed within 30 minutes of collection, centrifuged at 3000 xg for 15 minutes at 4°C , and aliquoted into 500 μL cryovials befor storage at -80 °C. Oxidative stress indicators- malondialdehyde (MDA), reduced glutathione (GSH), catalase activity, total antioxidant capacity (TAC), and nitric oxide (NO) – were assessed ^spectrophotometrically using validated commercial kits (Cayman Chemical, Sigma Aldrich, Invitrogen). Inflammatory markers, including interleukin-6 (IL-6) and tumor necrosis factor -α (TNF-α), were analyzed using ELISA provided by ELK Biotechnology. All laboratory measurements were carried out in duplicate, and intrrnal quality controls were applied in accordance with kit specifications. A full description of the analytical procedures, quality assurance steps, and the complete set of biomarter findings is provided in our related manuscript addressing the biological responses to VOC exposure in this same study group [11].

**Table 1** C-MS Analytical Parameters and Method Performance

| Compound | Retention Time (min) | Quantifier Ion (m/z) | Qualifier Ions (m/z) | LOD (μg/m$^3$) | LOQ (μg/m$^3$) | Recovery (%) |
|---|---|---|---|---|---|---|
| Formaldehyde | 5.23 ± 0.05 | 30 | 29, 31 | 2.5 | 8.3 | 92 ± 7 |
| Benzene | 8.45 ± 0.08 | 78 | 77, 51 | 0.8 | 2.6 | 95 ± 5 |
| Toluene | 12.67 ± 0.10 | 91 | 92, 65 | 1.2 | 4.0 | 88 ± 8 |
| Xylene | 15.32 ± 0.12 | 106 | 91, 77 | 1.5 | 5.0 | 91 ± 6 |
| Ethylbenzene | 14.89 ± 0.11 | 91 | 106, 77 | 1.0 | 3.3 | 89 ± 7 |
| Acetone | 4.12 ± 0.03 | 43 | 58, 42 | 2.0 | 6.7 | 85 ± 9 |
| Methyl chloride | 3.85 ± 0.02 | 50 | 52, 49 | 1.8 | 6.0 | 87 ± 8 |

LOD: Limit of Detection; LOQ: Limit of Quantification. Calibration linearity ($R^2$) ranged from 0.995 to 0.999 for all compounds.

### 2.6. Statistical Analysis

R version 4.3.1 and SPSS version 26.0 were used for all analyses. Q-Q plots and Shapiro-Wilk tests were used to evaluate normality. Using Levene's test, homogeneity of variance was confirmed. Univariate Comparisons: For continuously distributed variables with a normal distribution, independent t-tests were employed. Non-normal distributions were tested using the Mann-Whitney U test. For categorical variables, Fisher's exact tests or chi-square tests were employed. Effect sizes are expressed as r (for Mann-Whitney) or Cohen's d (for t-tests). For every difference between groups, 95 percent confidence intervals were computed.

#### *2.6.1. Modeling Regression:*

Variance Inflation Factors (VIF) were computed for each VOC predictor in order to assess multicollinearity. In joint models, variables with a VIF higher than five were not included. Separate models were created for formaldehyde and benzene (VIF=6.8).

#### *2.6.2. Model Structure*

- Model 1 (MDA): MDA = $\beta_0 + \beta_1$(Formaldehyde) + $\beta_2$(Age) + $\beta_3$(BMI) + $\beta_4$(ACH) + $\beta_5$(Season) + $\varepsilon$
- Model 2 (GSH): GSH = $\beta_0 + \beta_1$(Formaldehyde) + $\beta_2$(Toluene) + $\beta_3$(Age) + $\beta_4$(BMI) + $\beta_5$(Cooking fuel) + $\varepsilon$
- Model 3 (IL-6): IL-6 = $\beta_0 + \beta_1$(Formaldehyde) + $\beta_2$(Xylene) + $\beta_3$(Age) + $\beta_4$(BMI) + $\beta_5$(ACH) + $\varepsilon$

Age (years), BMI (kilograms per square meter), ventilation rate (ACH), cooking fuel type, season, years in residence.

*2.6.3. Reporting*

**t**-statistics, p-values, standard errors, and 95 percent confidence ranges for standardized beta coefficients. F-statistics and adjusted R-squared for overall model fit. Normality and heteroscedasticity tests were conducted as residual diagnostics.

*2.6.4. Sensitivity Analyses*

Sensitivity analyses excluding extreme outliers (greater than 3 standard deviations from mean) confirmed the robustness of these findings, with all statistically significant associations remaining unchanged. Regression diagnostics confirmed that all models met standard assumptions including normality of residuals, homoscedasticity, and independence of errors.

## 3. Results

134 women in all were tested ; 14 were disqualified (7 were using antioxidant supplements, 6 were pregnant, and 7 had chronic illnesses). There were 120 participants in the final sample, 60 in each group. Without any dropouts, every participant finished the trial program.

**Table 2** Demographic Characteristics of the Sample

| Variable | Control group (n=60) | Experimental group (n=60) | p-value |
|---|---|---|---|
| Age (years) | 36.8 ± 7.9 | 38.2 ± 8.4 | 0.327 |
| Body Mass Index (BMI) | 25.9 ± 3.8 | 26.8 ± 4.2 | 0.211 |
| Number of children | 2.9 ± 1.1 | 3.1 ± 1.2 | 0.369 |
| House area ($m^2$) | 138.7 ± 26.1 | 142.5 ± 28.3 | 0.435 |
| Educational level - university (%) | 35.0 | 31.7 | 0.694 |
| Monthly income - average (%) | 58.3 | 61.7 | 0.712 |
| Ventilation (ACH) | 0.8± 0.31 | 0.75 | 0.267 |
| Gas cooking (%) | 71.7 | 75.0 | 0.682 |
| Winter sampling(%) | 50.0 | 50.0 | 1.00 |
| Home age (years) | 18.2 | 19.6± 10.2 | 0.428 |

Note: No statistically significant differences were found between the two groups, reflecting acceptable homogeneity in basic characteristics.

The results of the statistical analysis showed no statistically significant differences between the two groups in terms of age (38.2 ± 8.4 years for the experimental group versus 36.8 ± 7.9 years for the control group, p = 0.326), or in body mass index (26.8 ± 4.2 kg/$m^2$ versus 25.9 ± 3.8 kg/$m^2$, p = 0.214). Regarding educational level and economic status, no significant differences were recorded (p > 0.05), with slight variations in the proportions of university education and low-income status between the two groups, reflecting similar societal composition.

**Table 3** Represents the patterns of use of household chemicals

| Variable | Control | Experimental | p-value |
|---|---|---|---|
| Number of products used | 2.1 ± 0.8 | 13.7 ± 3.9 | <0.001 |
| Daily usage hours | 0.8 ± 0.3 | 4.1 ± 1.3 | <0.001 |
| Years of use | 8.4 ± 3.1 | 12.1 ± 4.4 | <0.001 |
| Use of bathroom cleaners(%) | 25.0 | 88.3 | <0.001 |
| Use of kitchen cleaners(%) | 30.0 | 90.0 | <0.001 |
| Use of floor cleaners(%) | 35.0 | 83.3 | <0.001 |

The results clearly demonstrate substantial variation between the two groups in both the number of products used and the amount of time spent using them, highlighting distinct differences in household habits.

Analysis of the data showed that the experimental group relied on a far greater number of cleaning products, averaging (13.7 ± 3.9 )items per day , compared with only ( 2.1 ± 0.8 ) products in the control group ($p < 0.001$). A comparable trend was observed in daily usage duration, with participants in the experimental group reporting an average of 4.1 ± 1.3 hours per day, while the control group averaged only 0.8 ± 0.3 hours. The total length of product use also demonstrated a marked difference, with the exposed group averaging 12.1 ± 4.4years compared to 8.4 ± 3.1 years in the control group. Among women in the experimental group, floor cleaners, kitchen detergents, and bathroom cleaning products were the most commonly used, with usage rates surpassing 85%. Conversely, the control group had considerably lower usage rates, highlighting clear differences in household behaviors and cleaning routines between the two groups.

### 3.1. Volatile organic compound (VOC) concentrations indoor air

**Table 4** Indoor air VOC concentrations (μg/m$^3$)

| Compound | Control | Experimental | p-value | Cohen's d | WHO/EPA Guideline |
|---|---|---|---|---|---|
| Formaldehyde | 89.4 ± 28.1 | 231.7 ± 65.4 | <0.001 | 2.78 | 100 μg/m$^3$ (WHO, 30-min) |
| Benzene | 6.2 ± 2.4 | 17.1 ± 4.7 | <0.001 | 2.89 | No safe level (WHO) |
| Toluene | 42.1 ± 15.6 | 149.8 ± 41.5 | <0.001 | 3.44 | 260 μg/m$^3$ (WHO, weekly) |
| Xylene | 28.9 ± 11.3 | 94.2 ± 25.3 | <0.001 | 3.24 | 4800 μg/m$^3$ (EPA, chronic) |
| Methyl chloride | 18.2 ± 6.7 | 62.5 ± 17.8 | <0.001 | 3.44 | 22000 μg/m$^3$ (EPA, chronic) |
| Acetone | 45.7 ± 12.3 | 128.9 ± 36.2 | 0.012 | 3.26 | 35000 μg/m$^3$ (EPA, chronic) |
| Ethylbenzene | 12.4 ± 4.1 | 39.5 ± 10.7 | 0.033 | 3.26 | 90 μg/m$^3$ (EAA, chronic) |

The findings exhibit that the levels of major volatile organic compounds-especially formaldehyde, benzene, and toluene, were significantly elevated in the homes of the experimental group compared to the control group. This pattern supports the link between frequent use of cleaning products and the existence of intense indoor emission sources, which in turn leads to diminished indoor air quality.

### 3.2. Biochemical Analysis

Evalution of blood biomarkers showed significant differences between the groups across all measured indicators of oxidative stress and inflammation ( $p<0.01$). Women in the high- exposure group displayed elevated levels of lipid peroxidation and pro-inflammatory cytokines, alongside marked reductions in antioxidant defense markers. Detailed results for all biomarkers- including MDA, GSH, catalase ,TAC, NO, IL-6, TNF-α, 8-isoprostane, protein carbonyls, and SOD- as well as regression models, correlation analyses, and mechanistic insights, are presented in our companion manuscript examining the biological impact of VOC exposure [11].

Fegression analysis identified formaldehyde as the strongest predictor of adverse biological responses, which toluene and xylene also demonstrated significant independent effects after adjusting for age,BMI, ventilation,dnd other potential confounders.

## 4. Discussion

This study offers strong mechanistic proof that household cleaning solutions significantly raise indoor levels of carcinogenic volatile organic compounds (VOCs), especially formaldehyde and benzene, much above (WHO) WHO-recommended thresholds. While formaldehyde levels (231.7 ± 65.4 μg/m$^3$) more than doubled the allowable threshold (100 μg/m$^3$), the average benzene concentration (17.1 ± 4.7 μg/m$^3$) was (3.4 times) the (WHO) recommendation (5 μg/m$^3$) [18]. Both oxidative stress and inflammatory markers demonstrated a strong correlation with these exposures, highlighting an important yet often overlooked aspect of environmental health within homes. The volatile organic compound (VOC) levels measured in this study-particularly formaldehyde, which exceeded WHO limits by 2,3 times-raise significant health concerns [19,20]. The related biological effects, such as oxidative stress, decreased antioxidant levels, and increased inflammatory responses, are explored in detail in our companion study that provides a comprehensive biomarker analysis from the same participant group [11]. This research offers mechanistic evidence connecting exposure to specific VOCs with the observed biological changes, underlining their potential role in chronic disease development [21.22]. by presenting the first biomonitoring-based evidence from Iraq that integrates exposure assessment with mechanistic biomarkers, the study addresses a regional knowledge gap and complements global research. Comparable associations have been documented in studies from the US, China, and South Korea; however, data from the Middle East remain limited. strong correlation between VOC concentration and oxidative biomarkers-for instance, $r=0.78$ between formaldehyde and MDA ( $p< 0.01$)-provide quantitative backing for findings from other areas and stress the urgent need for region-specefic policy interventions [23]. The prevalent use of scented cleaning products along with poor ventilation in Kirkuk homes further exacerbates these health risks [24].

### 4.1. Clinical and Public Health Implications

The VOC concentrations identified in this study surpass international safety limits, highlighting a pressing need for public health actions. Indoor exposure to VOCs from household cleaning products represents an avoidable risk factor that has been largely neglected in clinical settings and regulatory policies.

Recommended interventions include [15]:

- Product regulation: enforce enhanced surveillance and require clear labeling volatile organic compounds (VOCs), especially formaldehyde, benzene, in household cleaning products.
- Safer alternatives: encourage the adoption of products with low or VOC content, along with natural cleaning agents such as vinegar, baking soda, and lemon.
- Ventilation practices: inform the public about the importance of ensuring proper ventilation during and after cleaning to reduce exposure risks.
- Protection of vulnerable groups: target preventive measures toward high-risk populations such as pregnant women, children, and individuals with pre-existing respiratory or cardiovascular conditions. The biological and mechanistic effects of these exposures-including oxidative stress, depletion of antioxidants, and inflammation-are thoroughly discussed in our related biomarker study[11].

## 5. Conclusion

The analysis examines VOC exposure in LEAQI homes It finds that the use of traditional cleaning products regularly increases the amount of formaldehyde and benzene that is present in the homes' air. In one of the homes analysed, the amount of formaldehyde that is present in the air of the home is (231.7 $\mu g/m^3$) which is more than double the safe amount that is present in the home, and the amount of benzene that is present in the home is ( 17.1 $\mu g / m^3$ ), which is also more than the amount that is deemed safe by international guidelines. These findings show that cleaning and housekeeping practices that are employed within the house are a significant, but overlooked, source of exposure to toxic substances and gases in the home. Having formaldehyde and benzene present in the air within the home is especially concerning from a health perspective. This is further illustrated in the supplementary study that provides data on the same participants and which analyzes some important biological processes, such as oxidative stress and changes to the inflammatory system, involving disruption of the normal functioning of the system, that result from exposure to these toxic substances. The study findings indicate that some participants may have more toxic exposure than others participants. [11].

These findings have important implications for the public's health and show that there is a significant need for more comprehensive regulations on and clearer labelling of cleaning and household products, the need for the use and promotion of safer cleaning products with little or no toxic components, and the need for individuals to be more aware of the need for proper airflow and ventilation. The monitoring of certain people may also be needed to assess their exposure to the cleaning products and the indoor air pollutants. The analysis also highlights the need for further studies on the same participants and the need to use longitudinal studies in research in order to improve understanding of the exposure-response relationship.

### *Recommendations*

Based on the study results, we recommend the following:

- Promote the use of natural, non-toxic cleaning alternatives in households, particularly in indoor areas with limited ventilation.
- Enhance everyday home ventilation practices and minimize the use of perfumes and industrial solvents.

- Increase awareness among women and housewives about the health impacts of volatile organic compounds (VOCs) through community health initiatives.
- Monitor the levels of formaldehyde and benzene in household products available in Iraqi markets through environmental surveillance.
- Undertake future longitudinal studies that consider genetic and immunological factors in women, along with a comprehensive analysis of other compounds that could contribute to oxidative stress.

### 5.1. Study limitations

This study has some limitations that should be acknowledged:

- Cross-sectional design: Like most observational studies, this design requires cautious interpretation of associations, as it limits the ability to draw causal conclusions.
- Geographic scope: while the findings may apply to similar contexts in the Middle East, the study's focus on Kirkuk may limit how broadly the results can be generalized across all of Iraq.
- Temporal coverage: although exposure was monitored over four weeks during two different seasons, this period may not fully represent variations throughout the entire year.
- Self-reported data and sample size: A modest sample size limited subgroup analyses, and participant reports served as the basis for data on product use. These results will be confirmed by larger, multi-city research.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclsoed.

### *Statement of ethical approval*

Ethical approval for this study was obtained from the Scientific Committee, College of Science, University of Kirkuk. In addition, official approval was granted by the Directorate of Health in Kirkuk under letter No. 581, dated 22/7/2024.

### *Statement of informed consent*

Verbal informed consent was obtained from all participants before their inclusion in the study, after providing them with sufficient information regarding the objectives, procedures, and their right to withdraw at any time without consequences. This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The reporting of this work followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) protocol to ensure clarity, transparency, and totality of methodological and analytical details.

### *Author contributions*

Daroon Essam Raffik led all stages of the research, including conceptualization, data collection, statistical analysis, and manuscript writing. Zainab and Batool contributed to the development of this research according to their respective roles and approved the final version of the manuscript.

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