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Environmental Characteristics and Mixed Exposure Risks in Small-Scale Beauty Facilities in Vietnam

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Abstract

Small-scale beauty facilities constitute a distinctive occupational setting characterized by simultaneous exposure to multiple volatile organic compounds (VOCs) emitted from hairdressing, nail services, and solvent-based cleaning. This study aims to characterize workplace environmental conditions, quantify concentrations of priority VOCs, and assess non-carcinogenic health risks under different exposure scenarios in small-scale beauty facilities in Vietnam. A field-based design was applied across four facilities, integrating structured site surveys, air monitoring, and scenario-based risk assessment under baseline, task-based, and adverse conditions. Toluene and formaldehyde were measured in two sampling campaigns, while acetone was included as an indicator of mixed exposure. Real-time measurements of formaldehyde (HCHO) and total VOCs (TVOC) were conducted to capture short-term variability. Results show that all facilities were micro-scale (15–40 m²) with prolonged exposure duration and widespread open chemical handling practices. Toluene concentrations ranged from 0.014 to 0.024 mg/m³, formaldehyde from 0.005 to 0.027 mg/m³, and acetone up to 0.066 mg/m³. End-of-shift HCHO and TVOC reached 0.45 ppm and 0.47 ppm, respectively. Formaldehyde exhibited greater variability and dominated cumulative risk. One facility recorded a hazard index (HI) exceeding 1, increasing to 1.2872 under adverse conditions. The findings highlight that mixed VOC exposure is strongly influenced by ventilation, service intensity, exposure duration, and chemical handling practices.

Keywords

volatile organic compounds, mixed exposure, small-scale beauty facilities, formaldehyde, toluene, acetone, hcho, tvoc, hazard quotient, hazard index

1. Introduction

Small-scale beauty facilities, particularly hair salons and combined hair-nail service establishments, constitute a widespread service sector in Vietnam. Within these workplaces, workers are routinely exposed to a wide range of chemicals during activities such as hair dyeing, bleaching, perming, straightening, styling, and equipment cleaning. These facilities are typically characterized by limited floor space, open layouts, prolonged worker presence, and relatively simple ventilation systems, all of which facilitate the accumulation of chemical vapors in indoor air [1], [6].

International evidence indicates that hairdressers are concurrently exposed to multiple airborne chemicals, including volatile organic compounds (VOCs) and carbonyl compounds such as formaldehyde. A scoping review by Kezic et al. demonstrated that pollutant concentrations in salons vary substantially across studies and are strongly influenced by facility characteristics, service types, customer density, and ventilation effectiveness [7]. Similarly, Hadei et al., in a study of 20 beauty salons, reported considerable variability in concentrations of BTEX compounds, formaldehyde, and acetaldehyde, depending on service intensity and ventilation conditions [8].

Among the chemicals of concern, formaldehyde is of particular importance due to its well-documented health effects, including eye and respiratory irritation, and its regulatory significance in inhalation toxicity assessment. The National Institute for Occupational Safety and Health (NIOSH) recommends an exposure limit (REL) of 0.016 ppm as an 8-hour time-weighted average and a 15-minute ceiling value of 0.1 ppm. The U.S. Environmental Protection Agency (EPA) Integrated Risk Information System (IRIS) establishes an inhalation reference concentration (RfC) of 0.007 mg/m³, while the World Health Organization (WHO) recommends a 30-minute indoor air guideline of 0.1 mg/m³ [2], [4], [6].

In the hairdressing sector, formaldehyde warrants particular attention because certain hair smoothing and straightening products can release formaldehyde when heated. Both the Occupational Safety and Health Administration (OSHA) and the U.S. Food and Drug Administration (FDA) have issued warnings that such products may emit formaldehyde during use, thereby increasing inhalation risks for salon workers, particularly under inadequate ventilation conditions [10], [11]. Empirical studies by Pierce et al. and Pexe et al. further confirm that thermal hair-straightening processes can generate substantial formaldehyde concentrations within the breathing zone [12], [13].

In Vietnam, however, empirical evidence on workplace environmental characteristics and mixed exposure risks in small-scale beauty facilities remains limited. Existing studies in the beauty service sector have primarily focused on occupational symptoms and VOC exposure among nail salon workers, while integrated studies combining field observation, VOC monitoring, and scenario-based risk assessment in small-scale beauty facilities are still scarce [9]. Addressing this gap, the present study

aims to: (i) characterize the environmental conditions of small-scale beauty facilities; (ii) determine concentrations of priority VOCs; (iii) analyze environmental and operational factors associated with VOC levels; and (iv) assess mixed exposure and associated health risks among workers under different exposure scenarios. The study adopts a field-centered approach, treating each facility as a distinct exposure unit with its own contextual configuration.

2. Methods

2.1 Study Design

This study employed a field-based descriptive design integrating workplace assessment, air monitoring of priority pollutants, and scenario-based health risk evaluation. This approach is suitable for small-scale service settings characterized by variable operations and limited standardization.

2.2 Study Sites and Selection Criteria

The study included four small-scale beauty facilities that were actively operating and using chemical products in hairdressing or related services. Facilities were purposively selected to capture variation in size, workforce, customer volume, working hours, and ventilation conditions. Sites were coded from 001 to 004.

2.3 Field Data Collection

Data were collected through structured observation, interviews with workers or managers, and standardized recording forms. Variables included workforce size, customer volume, facility area, working hours, chemical exposure duration, ventilation characteristics, service intensity, chemical handling practices, and end-of-day residual odors.

2.4 Air Sampling and VOC Analysis

Toluene and formaldehyde were measured across two sampling campaigns, while acetone was included to characterize mixed exposure. Real-time measurements of HCHO and TVOC were conducted mid-shift and end-of-shift to capture short-term variability. Occupational reference standards followed QCVN 03:2019/BYT, with analytical methods aligned with NIOSH Method 2016 (formaldehyde) and OSHA Method 111 (toluene) [1-3].

2.5 Data Processing and Quality Assurance

Data were processed by sampling campaign. Mean concentrations across two campaigns were used for baseline and task scenarios, while the higher value was applied for the adverse scenario. For values below the limit of detection, a substitution of LOD/2 (0.005 mg/m³) was consistently applied.

2.6 Exposure Scenarios

Three exposure scenarios were defined: (i) baseline (full-shift presence), (ii) task-based (direct chemical handling duration), and (iii) adverse (maximum observed concentration under less favorable conditions). This framework captures variability in real-world exposure patterns.

2.7 Risk Assessment (HQ and HI)

Exposure concentration (EC) was calculated as:

EC = C × (ET/24) × (EF/7), where C is pollutant concentration, ET is daily exposure time, and EF is exposure frequency (days/week).

Hazard quotient (HQ) was calculated as HQ = EC/RfC, and hazard index (HI) as the sum of HQs within each scenario. RfC values were 5 mg/m³ for toluene and 0.007 mg/m³ for formaldehyde [4], [5].

2.8 Data Analysis

Data were analyzed using descriptive statistics and case-based comparison. The analysis focused on four dimensions: workplace characteristics, VOC concentrations, environmental determinants, and mixed exposure risks. Given the small sample size, interpretation emphasized mechanistic plausibility rather than statistical generalization.

2.9 Ethical Considerations

Participation was voluntary. Facilities were anonymized using coded identifiers, and data were used solely for research purposes. Field activities were conducted to minimize disruption to normal operations.

3. Results

3.1 Workplace Environmental Characteristics

As shown in Table 1, all four surveyed facilities were micro-scale service establishments, with floor areas ranging from 15 to 40 m², workforce sizes of 1-4 workers, and daily customer volumes between 15 and 50. Direct chemical exposure duration ranged from 3 to 5 hours per day. These findings indicate that workers in small-scale beauty facilities are subject not only to task-based exposure but also to prolonged background exposure due to extended presence in semi-enclosed environments.

Regarding environmental configuration, only one facility had windows or natural ventilation openings that were occasionally used, while the remaining three relied primarily on air conditioning and fans. However, the presence of air conditioning does not necessarily ensure effective air exchange. All facilities reported the practice of leaving chemical products open during use, and residual chemical odors were detected at the end of the working day across all sites, ranging from mild to strong. These baseline characteristics are critical for interpreting subsequent differences in pollutant concentrations and associated risks.

Table 1. Workplace Characteristics and Core Operational Conditions

Code	Facility	Location	Area (m²)	Workers	Customers/day	Exposure time (h/day)	Ventilation (window/opening)	Air conditioning	Open chemical handling	End-of-day odor
001	Tuan Anh Barbershop	Ninh So, Thuong Tin	15	1	20	5	Yes (seasonal)	Yes	Yes	Noticeable

002	Thang Barbershop	Soc Son	28	4	50	5	No	Yes	Yes	Strong
003	Manh Hai	Dong Da	40	2	15	3	No	Yes	Yes	Mild
004	Huy Salon	Dong Da	35	2	15	5	No			

3.2 VOC Concentrations and Exposure Profiles

As presented in Table 2, all three monitored compounds: toluene, formaldehyde, and acetone, were detected in the indoor air of the surveyed facilities, although their occurrence patterns and relative contributions differed. Toluene and formaldehyde were consistently detected across all facilities in both sampling campaigns, whereas acetone was identified in three out of four facilities; one non-detect value was interpreted as below the limit of quantification. These findings confirm that the studied environments are characterized by mixed exposure rather than single-compound exposure.

Toluene concentrations ranged from 0.014 to 0.024 mg/m³, with two-campaign averages between 0.0175 and 0.0205 mg/m³. The relatively narrow variability across sites suggests that toluene represents a stable background component of the VOC mixture. In contrast, formaldehyde exhibited a wider range (0.005-0.027 mg/m³) and greater inter-site variability, with Facility 003 showing the highest mean concentration. Acetone was more prominent in Facilities 002 and 004, indicating variability in service-specific emission sources.

End-of-shift indicators (HCHO and TVOC) further highlight the dynamic nature of indoor air conditions. Notably, Facility 001 recorded the highest end-of-shift levels for both HCHO and TVOC, suggesting combined effects of emission intensity and limited ventilation efficiency.

Table 2. VOC Concentrations Across Two Sampling Campaigns and End-of-shift Indicators (mg/m³; ppm)

Code	Facility	Toluene (S1)	Toluene (S2)	Toluene (Mean)	Formaldehyde (S1)	Formaldehyde (S2)	Formaldehyde (Mean)	Acetone	HCHO (end-shift, ppm)	TVOC (end-shift, ppm)
001	Tuan Anh Barbershop	0.014	0.024	0.0190	0.015	0.018	0.0165	0.000	0.45	0.47
002	Thang Barbershop	0.020	0.015	0.0175	0.005	0.005	0.0050	0.058	0.08	0.39
003	Manh Hai	0.022	0.019	0.0205	0.021	0.027	0.0240	0.047	0.00	0.12

004	Huy Salon	0.016	0.021	0.0185	0.005	0.005	0.0050	0.066	0.00	0.18

Table 2 highlights both inter-site variability and within-site consistency, with formaldehyde showing greater variability compared to toluene, and end-of-shift indicators capturing short-term accumulation patterns.

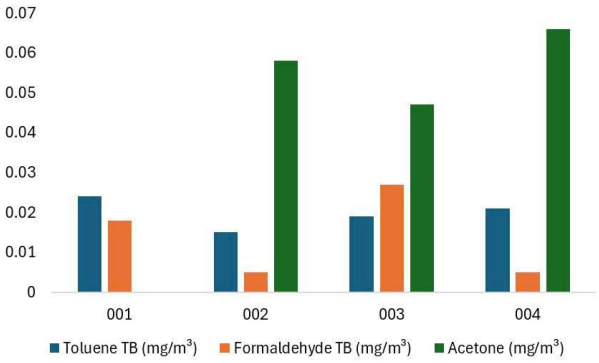

Figure 1. Comparison of Mean or Single-point VOC Concentrations Across Facilities

3.3 Environmental Determinants of VOC Levels

Table 3 summarizes key environmental and operational factors potentially associated with variations in VOC concentrations across facilities. Given the small sample size, the analysis does not aim to establish statistical causality but rather to identify mechanistically plausible determinants of exposure variability.

Three main factor groups were identified. First, service intensity: facilities with higher customer volumes and more frequent chemical treatments (e.g., dyeing and perming) tended to exhibit stronger residual odors and higher end-of-shift TVOC levels. Second, ventilation configuration: the presence of windows or air conditioning does not necessarily ensure effective air exchange, highlighting the importance of actual airflow patterns rather than nominal infrastructure. Third, on-site chemical practices: all facilities reported leaving chemical products open during use, a practice that likely promotes continuous emission at the source.

Table 3. Summary of Environmental and Operational Factors Associated with VOC Variability

Factor domain	Observed variables	Evidence from data	Occupational hygiene interpretation
Ventilation / air exchange	Windows, air conditioning, fans, local exhaust	Facility 001 had windows but showed the highest end-of-shift HCHO and TVOC; none of the	Ventilation effectiveness depends on airflow patterns and emission load, not merely the presence of ventilation

		facilities had local exhaust systems	devices
Service intensity	Customers/day; frequency of dyeing, perming, nail services	Facility 002 had the highest customer volume (50/day), with strong end-of-day odor and relatively high TVOC	Total emission load increases with service frequency and customer volume, contributing to higher overall VOC burden
Exposure duration	Chemical exposure hours/day	Three facilities reported 5 h/day compared to one facility with 3 h/day	Longer exposure duration increases cumulative exposure, even when absolute concentrations remain moderate
Chemical handling practices	Open chemical use; residual odors; waste management	All facilities reported open chemical handling and detectable end-of-day odors	Open handling enhances source emission; residual odor serves as a field indicator of suboptimal exposure control

3.4 Mixed Exposure and Health Risk Assessment

The mixed exposure profiles across the four facilities indicate that toluene and formaldehyde were consistently co-present in all sites, while acetone was detected in three facilities. This confirms that exposure in small-scale beauty facilities is inherently characterized by mixed chemical exposure, although the dominant contributors vary across sites.

Tables 4 and 5 facilitate the transition from concentration-based description to an integrated exposure-risk interpretation, allowing for a more comprehensive understanding of site-specific risk profiles.

Table 4. Co-occurrence Matrix of Pollutants and End-of-shift Indicators (1 = detected / exceeds indicative threshold)

Facility	Toluene	Formaldehyde	Acetone	HCHO end-shift > 0.1 ppm	TVOC end-shift > 0.4 ppm
Tuan Anh Barbershop	1	1	0	1	1
Thang Barbershop	1	1	1	0	0

Manh Hai	1	1	1	0	0
Huy Salon	1	1	1	0	0

Table 5. Mixed Exposure Profiles and Supporting Risk Indicators

Facility	No. of detected compounds	Dominant pollutant (by HQ)	HI (QCVN-based)	HQ (formaldehyde, NIOSH)	HI (RfC-based)	End-of-shift indicators	Exposure-risk interpretation
Tuan Anh Barbershop	2	Formaldehyde	0.033	0.84	2.36	High TVOC & HCHO	End-of-shift accumulation profile, suggesting combined effects of emission load and limited ventilation efficiency
Thang Barbershop	3	Formaldehyde (low)	0.010	0.25	0.72	Relatively high TVOC; low HCHO	High service intensity profile with acetone contribution; notable overall VOC burden despite low HI
Manh Hai	3	Formaldehyde (high)	0.048	1.22	3.43	Low TVOC/HCHO	Formaldehyde-dominant profile; prominent under conservative or screening-based reference frameworks
Huy Salon	3	Formaldehyde (low)	0.010	0.25	0.72	Low TVOC/HCHO	Acetone-relevant profile with lower formaldehyde contribution;

reduced cumulative risk

Tables 6-8 demonstrate that hazard levels vary markedly across exposure scenarios. Under the baseline scenario, HI ranged from 0.1709 to 1.1442, with Facility 003 being the only site exceeding the threshold of 1. In the task-based scenario, HI values were consistently lower due to reduced exposure duration. In contrast, under the adverse scenario, HI increased across all facilities, reaching a maximum of 1.2872 at Facility 003.

These results indicate that, even with the same concentration dataset, risk characterization can differ substantially when accounting for exposure duration and work patterns. This highlights the importance of integrating temporal factors into exposure assessment rather than relying solely on concentration-based comparisons.

Table 6. HQ and HI under the Baseline Scenario

Code	Facility	Toluene (mean)	Formaldehyde (mean)	ET	EF	EC (toluene)	EC (formaldehyde)	HQ (toluene)	HQ (formaldehyde)	HI
001	Tuan Anh Barbershop	0.0190	0.0165	8	7	0.0063	0.0055	0.0013	0.7857	0.7870
002	Thang Barbershop	0.0175	0.0050	8	7	0.0058	0.0017	0.0012	0.2381	0.2393
003	Manh Hai	0.0205	0.0240	8	7	0.0068	0.0080	0.0014	1.1429	1.1442
004	Huy Salon	0.0185	0.0050	8	5	0.0044	0.0012	0.0009	0.1701	0.1709

Table 7. HQ and HI under the Task-based Scenario

Code	Facility	Toluene (mean)	Formaldehyde (mean)	ET	EF	EC (toluene)	EC (formaldehyde)	HQ (toluene)	HQ (formaldehyde)	HI
001	Tuan Anh Barbershop	0.0190	0.0165	5	7	0.0040	0.0034	0.0008	0.4911	0.4919
002	Thang Barbershop	0.0175	0.0050	5	7	0.0036	0.0010	0.0007	0.1488	0.1495

003	Manh Hai	0.0205	0.0240	3	7	0.0026	0.0030	0.0005	0.4286	0.4291
004	Huy Salon	0.0185	0.0050	5	5	0.0028	0.0007	0.0006	0.1063	0.1068

Table 8. HQ and HI under the Adverse Scenario

Code	Facility	Toluene (max)	Formaldehyde (max)	ET	EF	EC (toluene)	EC (formaldehyde)	HQ (toluene)	HQ (formaldehyde)	HI
001	Tuan Anh Barbershop	0.024	0.018	8	7	0.0080	0.0060	0.0016	0.8571	0.8587
002	Thang Barbershop	0.020	0.005	8	7	0.0067	0.0017	0.0013	0.2381	0.2394
003	Manh Hai	0.022	0.027	8	7	0.0073	0.0090	0.0015	1.2857	1.2872
004	Huy Salon	0.021	0.005	8	5	0.0050	0.0012	0.0010	0.1701	0.1711

Table 9. Comparison of HI across Exposure Scenarios

Code	Facility	HI (baseline)	HI (task)	HI (adverse)	ΔHI (task-baseline)	%	ΔHI (adverse-baseline)	%	ΔHI (adverse-task)	%
001	Tuan Anh Barbershop	0.7870	0.4919	0.8587	-0.2951	-37.5	+0.0718	+9.1	+0.3669	+74.6
002	Thang Barbershop	0.2393	0.1495	0.2394	-0.0897	-37.5	+0.0002	+0.1	+0.0899	+60.1
003	Manh Hai	1.1442	0.4291	1.2872	-0.7151	-62.5	+0.1430	+12.5	+0.8581	+200.0
004	Huy Salon	0.1709	0.1068	0.1711	-0.0641	-37.5	+0.0001	+0.1	+0.0642	+60.1

Table 10. Contribution of Toluene and Formaldehyde to HI (%)

Code	Facility	Toluene (baseline)	Formaldehyde (baseline)	Toluene (task)	Formaldehyde (task)	Toluene (adverse)	Formaldehyde (adverse)

001	Tuan Anh Barbershop	0.16	99.84	0.16	99.84	0.19	99.81
002	Thang Barbershop	0.49	99.51	0.49	99.51	0.56	99.44
003	Manh Hai	0.12	99.88	0.12	99.88	0.11	99.89
004	Huy Salon	0.53	99.47	0.56	99.44	0.58	99.42

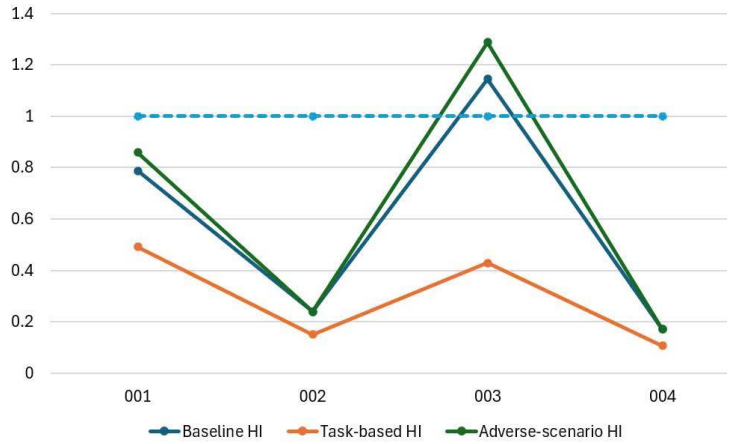

Figure 2. Comparison of Hazard Index (HI) Across Exposure Scenarios

4. Discussion

The findings indicate that small-scale beauty facilities are not merely workplaces where chemicals are used, but structurally distinct mixed-exposure environments in which spatial characteristics, ventilation conditions, service intensity, and on-site chemical practices interact to shape workers' exposure levels. This aligns with the review by Kezic et al., which highlights that hairdressers are simultaneously exposed to multiple airborne chemicals, with concentrations strongly influenced by salon characteristics, customer volume, and ventilation conditions [7].

Compared with international studies, the absolute concentration levels observed in this study are generally lower than those reported in larger salons or high-intensity chemical service settings. However, the key insight lies not in absolute values but in exposure patterns. Hadei et al. demonstrated that concentrations of benzene, toluene, ethylbenzene, xylene, formaldehyde, and acetaldehyde are significantly affected by concurrent service activities and ventilation conditions, with improved ventilation substantially reducing indoor pollutant levels [8]. A similar pattern is evident in the present study, where facilities with higher service intensity or less effective air exchange exhibited elevated TVOC, HCHO, or persistent residual odors.

A central finding is that formaldehyde shows greater variability than toluene across facilities and dominates the hazard index (HI) across all exposure scenarios. This observation extends beyond a simple comparison of concentration levels, indicating that formaldehyde is not merely present but acts

as the primary driver of the risk profile in small-scale beauty facilities. This interpretation is consistent with international evidence showing that formaldehyde can be released during the heating of certain hair smoothing and straightening products. Regulatory agencies such as OSHA and FDA have warned that these products may emit formaldehyde at levels of concern, particularly under inadequate ventilation conditions [10], [11].

Studies by Pierce et al. and Pexe et al. further support this interpretation, demonstrating substantial formaldehyde exposure during thermal hair-straightening processes [12], [13]. These findings suggest that reliance on aggregate indicators such as TVOC or residual odor may underestimate health risks if the dominant role of formaldehyde is not explicitly considered. Notably, in this study, one facility exhibited the highest HI despite not having the highest end-of-shift TVOC or HCHO levels, due to elevated average formaldehyde concentrations.

Methodologically, the scenario-based approach represents a key strength of the study. If exposure assessment were limited to comparisons with occupational exposure limits, the results might suggest relatively low risk levels. However, when exposure duration and work patterns are incorporated, risk estimates increase substantially and may exceed acceptable thresholds under certain conditions. This demonstrates that risk is not a static function of concentration at a single time point, but rather an outcome of the interaction between concentration, exposure duration, and work organization [4], [5].

Several limitations should be acknowledged. First, the small number of facilities limits generalizability and positions the findings more as an analytical framework and trend identification rather than population-level inference. Second, exposure data were based primarily on area measurements rather than full-shift personal monitoring in the breathing zone. Third, acetone was included as a supplementary component of the mixed exposure profile but was not fully integrated into the HQ/HI risk model. Nevertheless, given the limited availability of field-based studies in small-scale beauty facilities in Vietnam, these limitations do not diminish the study's contribution; rather, they highlight the need for future research with larger samples and improved personal exposure assessment designs.

6. Mitigation Strategies

Based on the findings, the first priority should be source control. This includes reviewing chemical products used in dyeing, straightening, smoothing, and hair treatment processes; limiting the use of products that may release formaldehyde when heated; closing containers immediately after use; and avoiding prolonged open handling of chemicals. These measures provide the most direct and effective reduction of VOC emissions at the source [10], [11].

The second group of measures focuses on ventilation and spatial organization. For small facilities with limited capacity to install full local exhaust systems, natural ventilation should be optimized. Exhaust fans should be arranged to promote airflow from clean areas toward chemical handling zones, and chemical processing areas should be spatially separated where feasible. For heat-based or high-odor services, local exhaust ventilation at the emission source should be considered.

The third group involves work organization controls. Continuous exposure duration should be reduced through task rotation, scheduled breaks, and avoiding consecutive high-intensity chemical services performed by a single worker in confined spaces. In addition, end-of-shift cleaning, proper disposal of contaminated materials in sealed containers, and control of residual odors are simple yet essential practices.

The fourth group emphasizes risk communication and basic monitoring. Small-scale facilities often lack access to comprehensive chemical management systems. Therefore, practical and user-friendly guidance should be developed on product risk identification, label interpretation, safe handling, ventilation practices, and recognition of poor indoor air quality indicators. Monitoring should begin with simple indicators and progressively incorporate targeted measurements when necessary.

Across all strategies, formaldehyde control should be prioritized. Given its dominant contribution to the hazard index (HI) in this study, risk management efforts in small-scale beauty facilities should focus on reducing formaldehyde emissions rather than distributing resources evenly across all VOCs.

7. Conclusion

This study demonstrates that small-scale beauty facilities in Vietnam constitute occupational environments with potential for mixed VOC exposure, driven by the combined effects of limited space, constrained ventilation, high service intensity, and suboptimal chemical handling practices. Toluene, formaldehyde, and acetone were consistently detected, with formaldehyde showing the greatest variability across sites and acting as the primary contributor to cumulative risk.

The scenario-based approach indicates that even when absolute concentrations are relatively low, non-carcinogenic health risks may become significant once exposure duration and operational conditions are considered. This suggests that occupational exposure assessment in small-scale beauty facilities should not rely solely on comparisons with exposure limits, but should be contextualized within real-world working conditions and task organization.

In terms of risk management, priority should be given to source control, reduction of formaldehyde emissions, improvement of ventilation, and standardization of on-site chemical handling practices.

References

[1] Ministry of Health. (2019). *QCVN 03:2019/BYT - National technical regulation on permissible exposure limits of 50 chemical factors in the workplace*. https://luatvietnam.vn/y-te/quy-chuan-qcvn-03-2019-byt-gia-tri-gioi-han-tiep-xuc-cho-phep-50-yeu-to-hoa-hoc-noi-lam-viec-176200-d3.html

[2] National Institute for Occupational Safety and Health (NIOSH). (2003). *NIOSH Method 2016: Formaldehyde.* https://www.epa.gov/sites/default/files/2015-07/documents/niosh-2016.pdf

[3] Occupational Safety and Health Administration (OSHA). (1998). *OSHA Method 111: Toluene.* https://www.osha.gov/sites/default/files/methods/osha-111.pdf

[4] U.S. Environmental Protection Agency (EPA). IRIS. *Formaldehyde - inhalation reference concentration (RfC)*. https://iris.epa.gov/ChemicalLanding/&substance_nmbr=419

[5] U.S. Environmental Protection Agency (EPA). *Toluene hazard summary / RfC 5 mg/m³.* https://www.epa.gov/sites/default/files/2016-09/documents/toluene.pdf

[6] World Health Organization. (2010). *WHO guidelines for indoor air quality: selected pollutants.* https://www.afro.who.int/sites/default/files/2017-06/e94535.pdf

[7] Kezic, S., Nunez, R., Babić, Ž. et al. (2022). *Occupational Exposure of Hairdressers to Airborne Hazardous Chemicals: A Scoping Review.* International Journal of Environmental Research and Public Health, *19*(7), 4176. https://pubmed.ncbi.nlm.nih.gov/35409860/

[8] Hadei, M., Hopke, P. K., Shahsavani, A. et al. (2018). Indoor concentrations of VOCs in beauty salons. *Atmospheric Environment*, *187*, 76-83. https://pubmed.ncbi.nlm.nih.gov/30275872/

[9] Tran, H. M., Lee, B. K. et al. (2020). *Occupational symptoms due to exposure to volatile organic compounds among female Vietnamese nail salon workers in Danang city.* https://pmc.ncbi.nlm.nih.gov/articles/PMC7507489/

[10] Occupational Safety and Health Administration (OSHA). *Hair salons: facts about formaldehyde in hair products.* https://www.osha.gov/hair-salons

[11] U.S. Food and Drug Administration (FDA). *Hair smoothing products release formaldehyde when heated.*
https://www.fda.gov/cosmetics/cosmetic-products/hair-smoothing-products-release-formaldehyde-when-heated

[12] Pierce, J. S., Abelmann, A., Spicer, L. J. et al. (2011). *Characterization of formaldehyde exposure resulting from the use of four professional hair straightening products.* https://pubmed.ncbi.nlm.nih.gov/22035353/

[13] Pexe, M. E., Marcante, A., Luz, M. S. et al. (2019). *Hairdressers are exposed to high concentrations of formaldehyde during the hair straightening procedure.* https://pubmed.ncbi.nlm.nih.gov/31321727/