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Seasonal Dynamics and Structural Characteristics of Complex Odor Components in Urban Traditional Markets

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Abstract

Purpose: This study investigates the seasonal variation of odor components in traditional markets and examines the relationship between measured concentrations and public interest using both field monitoring and Google Trends data. The goal is to provide empirical and social evidence for developing effective odor management policies in urban commercial spaces. **Research Design, Data, and Methodology:** Field measurements of NH_3, H_2S, TVOC, and complex odor (D/T) were conducted in four traditional markets in Wonju, Korea, from 2021 to 2025. In parallel, Google Trends data for five related keywords were analyzed to capture patterns of public interest. Time-series analysis identified seasonal and annual trends, one-way ANOVA tested for seasonal differences, PCA determined the main contributors to complex odor, and correlation analysis compared field data with search volumes. Statistical analyses were performed using SPSS, R, and Python visualization tools. **Research Results:** NH_3, and H_2S displayed seasonal patterns consistent with search interest, indicating a strong link between environmental conditions and public perception. In contrast, TVOC concentrations increased by over 100% in 2025 without corresponding search interest, reflecting a management gap. Complex odor was consistently measured but rarely searched, revealing a terminology gap between experts and residents. **Conclusion:** Odor management policies appear effective for NH3, and H2S but insufficient for TVOC. Combining physical measurements with public awareness data offers a multidimensional understanding of urban odor issues and supports the need for tailored, long-term, and communication-sensitive management strategies.

Keywords : Traditional Markets, Complex Odor, Seasonal Variation, Google Trends, Odor Management Policy

JEL Classification Code : Q53, Q58, R11, R52, C38

1. Introduction

Traditional markets in urban areas function not only as spaces of commercial exchange but also as complex living environments where the unique culture and lifestyle of local communities are concentrated. However, due to rapid modernization and industrial restructuring, these markets have gradually aged, facing both the limitations of outdated infrastructure and the vulnerabilities of hygiene conditions (Capelli et al., 2013; Joo et al., 2022). Among these issues, odor has emerged as a critical sensory-environmental problem, directly influencing residents' satisfaction with their surroundings, the competitiveness of local businesses, and even the overall urban image (Sun & Peterson, 2012).

Previous studies on odor have primarily focused on large-scale emission sources or legally regulated facilities such as factories and waste treatment plants (Capelli et al., 2013; Senatore et al., 2021). In contrast, research on small-scale, community-oriented spaces like traditional markets has been extremely limited, particularly regarding chemical composition and long-term variation. In traditional markets, diverse odor sources coexist—including food preparation, wastewater discharge, and food waste accumulation—with odor complaints rising sharply in the summer season.

Odor is not a single chemical substance but a complex stimulus composed of multiple compounds, the impact of which varies depending on chemical composition, seasonal changes, and social perception factors (Han et al., 2024). Accordingly, odor analysis requires not only concentration measurements but also examinations of component contributions, seasonal dynamics, and links to public awareness indicators. Although some studies (Zahra & So, 2024; Szyłak-Szydłowski et al., 2025) have explored the association between major odor compounds such as NH_3 (ammonia), H_2S (hydrogen sulfide), TVOC (total volatile organic compounds), and the complex odor index (D/T), integrated analyses combining field measurements with public interest data have rarely been attempted.

This study examines four traditional markets in Wonju, Korea—Jayou Market, Jungang Market, Doraemi Market, and Sundae Alley—using five years (2021–2025) of field measurements for complex odor, NH_3, H_2S, and TVOC to analyze seasonal variation. Simultaneously, Google Trends data for related keywords (Wonju traditional market, TVOC, NH_3, H_2S and complex odor) were collected and analyzed during the same period to capture public search interest as a complementary dataset.

This dual approach extends beyond treating odors solely as environmental engineering indicators and provides a framework to assess how policy interventions are reflected in both residents' perceptions and societal attention. Ultimately, this study contributes empirical and social evidence from a sensory-environmental perspective, offering insights for customized odor mitigation policies in traditional markets and serving as a foundation for integrated strategies in future urban environmental management.

2. Theoretical Backgrounds and Literature Review

2.1. Definition and Major Components of Complex Odor

Odor is a chemical and simultaneously subjective sensory stimulus that induces discomfort in human perception. In particular, complex odor refers to the sensory response generated when two or more odor components are mixed. Compared to a single compound, complex odors often produce stronger olfactory stimuli, and the threshold, recognition rate, and avoidance behavior may vary depending on the interactions among components (Blanes-Vidal et al., 2012).

According to Korea's Odor Prevention Act, representative designated odorants include H_2S, NH_3 and TVOC. These substances frequently arise from the accumulation of food waste, cooking activities, and wastewater treatment processes.

2.2. Relationship between Urban Odor and Environmental Displeasure

Odor in urban environments is not merely a hygiene issue but also a socio-economic factor that affects residents' quality of life, the competitiveness of local businesses, and consumer behavior. Traditional markets, in particular, are highly vulnerable to odor problems due to aging infrastructure, dense spatial structures, and limited ventilation, which allow odors to persist for long periods (Zahra & So, 2024).

Such conditions often lead to environmental displeasure, triggering resident complaints and reducing visitor numbers to the markets. Therefore, the issue of urban odor requires not only physical measurements but also a multidimensional approach that incorporates social perception indicators.

2.3. Seasonal Variation of Odor Components and Time-Series Analysis

Odor components vary in concentration depending on seasonal and climatic factors. For example, NH_3 tends to volatilize more readily under hot and humid summer conditions, whereas H_2S typically increases during autumn due to accelerated organic decomposition. TVOC is closely associated with cooking activities and ventilation conditions (Han et al., 2024).

Recent studies (Capelli et al., 2013; Cruz et al., 2022; Szyłak-Szydłowski et al., 2025) have increasingly applied statistical methods such as principal component analysis (PCA), analysis of variance (ANOVA), and regression models to quantify the seasonal contributions of odor components. However, most of these studies have focused on regulated sites such as industrial complexes and waste facilities, while time-series analyses based on field measurements in community-oriented commercial spaces like traditional markets remain rare.

2.4. Distinction from Previous Studies

Although domestic and international studies on odor analysis have achieved considerable precision in identifying chemical components, most research has focused on industrial complexes and livestock facilities. For instance, Joo et al. (2022) monitored the concentrations of NH_3, H_2S and TVOC in environmental treatment facilities, while Han et al. (2024) reviewed odor control strategies applied in livestock and poultry farms.

However, these studies in Table 1 did not adequately reflect odor issues as experienced in the everyday living spaces of urban residents. For example, Huang et al. (2024) analyzed the seasonal variation of NH_3, H_2S and TVOC in pig houses, focusing primarily on health and environmental risks, while Zahra and So (2024) investigated odor issues in Wonju's traditional market but did not incorporate time-series or statistical methods. Similarly, Langford et al. (2023) emphasized VOC/TVOC monitoring in South Korea, and Oh et al. (2024) concentrated on bench-scale odor removal technologies, but these approaches offered limited integration of long-term field measurements and social perception data.

Table 1: Distinctions of This Study Compared to Previous Research

Previous Studies	Summary of Contents	Distinction from This Study
Joo et al. (2022)	Measurement of NH_3, H_2S, and TVOC concentrations in industrial and environmental treatment facilities	Did not include small-scale urban living spaces such as traditional markets
Langford et al. (2023)	Real-time monitoring of VOC/TVOC in South Korea	Lacked contextual analysis of community-based spaces
Han et al. (2024)	Odor control research in livestock and poultry farms	Did not address community-oriented spaces such as traditional markets
Huang et al. (2024)	Seasonal variation of NH_3, H_2S and TVOC in pig houses	Lacked integration of residents' perceptions or social awareness indicators
Zahra & So (2024)	Case study on odor issues in Wonju traditional market	Did not apply time-series analysis or integrate social data
Oh et al. (2024)	Bench-scale experimental removal of NH_3, H_2S, and TVOC	Did not include long-term field measurements or socio-environmental indicators

In contrast, this study analyzed five years of field measurements of NH_3, H_2S, TVOC and complex odor in traditional markets in Wonju, while simultaneously incorporating Google Trends search data from the same period as a supplementary dataset. This combined approach allowed us to examine the correlation between environmental measurements and social interest. Thus, unlike previous research, this study extends odor analysis beyond physical concentration data to a composite socio-environmental indicator that reflects both citizen perception and policy effects.

3. Research Methodology

3.1. Study Sites

This study focused on four traditional markets in Wonju, Korea: Jayou Market, Jungang Market, Doraemi Market, and Sundae Alley. These markets are located in the central urban area of Wonju and represent typical small-scale commercial spaces where diverse odor sources coexist, including food preparation facilities, sewer outlets, and areas for food waste accumulation.

Survey points within each market were selected based on spatial balance and accessibility. Priority was given to locations with a high frequency of odor-related complaints, particularly cooking zones, areas adjacent to sewers, and main pedestrian pathways. Prior field inspections were conducted to ensure that the selected measurement sites accurately reflected the major odor-prone areas of the markets.

3.2. Data Collection Period and Method

Odor measurements were conducted regularly over a five-year period, from March 2021 to February 2025, with four surveys carried out in each season. The seasonal classification followed spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Measurements were taken between 10:00 and 14:00, corresponding to peak hours of pedestrian activity within the markets.

In parallel with the field measurements, Google Trends data were collected over the same period to provide a social indicator of online interest. Five keywords — "Wonju Traditional Market," "TVOC," "NH_3," "H_2S," and "Complex Odor"— were selected to capture temporal variations in regional and social awareness. These data were used as a supplementary dataset for comparison with the measured odor concentrations.

3.3. Measurement Items and Instruments

This study quantified in Table 2 four odor-related pollutants: NH_3, H_2S, TVOC (Joo et al., 2022), and complex odor (D/T). Odor measurements were carried out using the AOMS-1000(Zahra & So, 2024), a sensor array-based portable device (Capelli et al., 2013). Its primary advantage is the ability to measure H_2S, NH_3, TVOC, and complex odor in real time in a mobile and efficient manner. The device employs a forced-air sampling method, incorporates Teflon-based sensor modules, and includes an LCD display. Its response linearity has been validated ($R^2 > 0.98$), ensuring measurement reliability.

Table 2: Major Odorous Pollutants Investigated in This Study

Pollutant	Measurement Unit	Major Sources
NH_3	ppm	Food waste decomposition, sewage
H_2S	ppm	Sewage, organic matter decomposition
TVOC	ppb	Cooking activities, cleaning agents
Complex Odor (D/T)	Dilution-to-threshold (D/T)	Measurement of mixed odor intensity

3.4. Analytical Methods

This study combined field measurement data with Google Trends data to simultaneously explore the physical reality of odor and its linkage with public interest.

First, time-series analysis (line plots) was employed to visualize seasonal and annual variations in NH_3, H_2S, TVOC and complex odor (D/T) (Wysocka & Dębowski, 2025). These patterns were compared with Google Trends search volumes collected during the same periods to examine the extent to which measured concentrations aligned with or diverged from public interest trends.

4. Research Results and Discussions

4.1. Analysis of Field Measurement Data

4.1.1. Time-Series Analysis of Odor Substances by Market (2021–2025)

In Figure 1 this study analyzed the annual average concentration trends of four major odor components (complex odor (D/T), TVOC, H2S and NH3) across traditional markets in Wonju from 2021 to 2025.

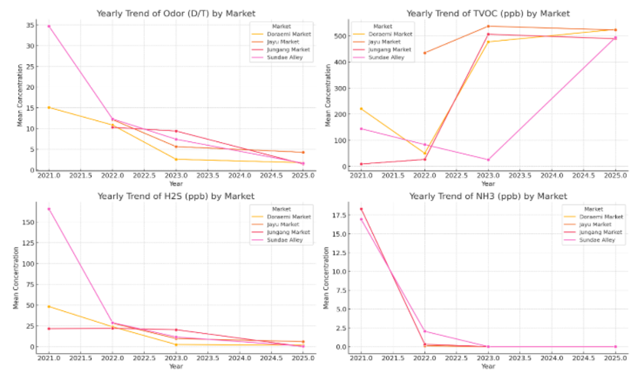

Figure 1: Yearly Trend of Odor (ppb) by Market

1) Complex Odor (D/T)
The concentration of complex odor (D/T) showed a gradual decline across most markets, with a visible reduction in 2025, likely attributable to policy interventions and the introduction of technical measures such as enhanced ventilation systems and odor control devices. Jungang Market and Sundae Alley exhibited a steady downward trend beginning in 2023, which may be associated with improvements in cooking practices, sewer maintenance, and the design of ventilation systems in cooking zones.

2) TVOC
TVOC levels displayed greater variability across markets. In Jayou Market and Sundae Alley, concentrations temporarily increased in 2025, potentially due to extended cooking hours, external air inflow, or inadequate ventilation. By contrast, Jungang Market and Doraemi Market maintained relatively stable TVOC concentrations throughout the study period.

3) H_2S
H_2S showed a consistent decline in all markets, reflecting the effectiveness of basic environmental improvement measures such as sewer maintenance, enhanced corridor ventilation, and regular cleaning. In particular, Jungang Market and Sundae Alley maintained very low H_2S concentrations by 2025.

4) NH_3
NH_3 concentrations declined sharply across markets in 2022. Doraemi Market and Sundae Alley, where dense cooking areas and food waste storage were concentrated, stabilized after 2023. This trend highlights the role of market structure and operational practices in odor generation. Overall, the post-policy period (2023–2025) demonstrated clear reductions in complex odor and H2S, providing empirical evidence that targeted interventions and

quantitative component analysis contributed to environmental improvements. However, given the market-specific variation observed in TVOC and complex odor, future strategies should focus on component-specific and market-tailored control measures.

4.1.2. Changes in Odor Components in 2025 Compared to the 2021–2023 Average

In Figure 2 to evaluate the quantitative effects of policy interventions and environmental management, the 2025 measurement results were compared with the average concentrations from 2021 to 2023, and the rate of change for each odor component was calculated.

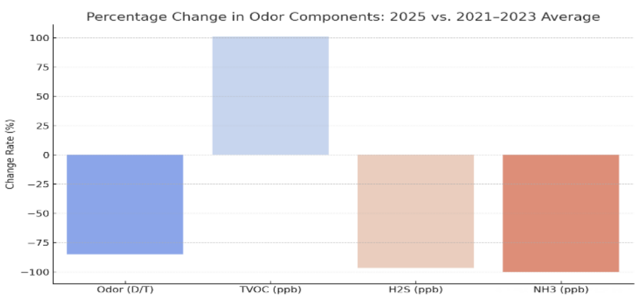

Figure 2: Percentage Change in Odor Components

1) Complex Odor (D/T): –84.81% decrease

In 2025, the average concentration of complex odor decreased by approximately 85% compared to the 2021–2023 average. This decline can be attributed to the implementation of AIoT-based odor detection and control systems, enhanced exhaust facilities in cooking areas, and sewer sealing measures. Complex odor thus serves as a representative indicator of policy effectiveness and improvements in overall environmental quality.

2) TVOC: +101.21% increase

Contrary to expectations, TVOC levels more than doubled in 2025, showing an increase of about 101%. This rise was particularly notable in markets with concentrated cooking activities, such as Doraemi Market and Sundae Alley, and may have been caused by poor ventilation or the accumulation of volatile compounds due to outdated equipment. The increase in TVOC highlights potential blind spots in policy interventions and the influence of uncontrolled environmental variables, suggesting the need for additional monitoring and micro environment-specific strategies.

3) H_2S: –96.70% decrease

H_2S concentrations decreased by about 97% in 2025, reaching near elimination levels. This result provides strong empirical evidence of the effectiveness of odor management policies targeting sewer-based sources, including sewer maintenance, structural improvements to block odor inflows, and upgrades to ventilation systems. As H_2S is a representative indicator of sewer-related odor, it can serve as a core metric for evaluating policy impact.

4) NH_3: –100.00% decrease

NH_3 was not detected in the 2025 measurements, reflecting a complete (100%) reduction. This result indicates the effectiveness of improved sanitation practices, including post-cooking residue management, household waste control, and stricter cleaning cycles. The case of NH_3 demonstrates that policies linked to cleaning and waste separation programs were highly effective and may serve as a foundation for establishing sustainable cleaning and waste management systems.

In 2025, the changes in odor components demonstrated the quantitative effectiveness of policy interventions, with reductions in complex odor (D/T), H_2S, and NH_3 being positively evaluated. However, the increase in TVOC appears to reflect limitations in cooking environments and ventilation management, or the influence of specific measurement periods such as peak cooking times. Therefore, future management strategies should incorporate micro environment-focused control technologies and periodic inspection systems, with particular emphasis on TVOC.

4.1.3. Changes in Odor Components in 2025 Compared to the 2021–2023 Average Across Market

This analysis compared the average odor component concentrations from 2021 to 2023 with those of 2025 for four traditional markets in Wonju, thereby quantitatively assessing the policy effects and the degree of odor reduction at each market (Figure 3).

1) Complex Odor (D/T)

In all markets, complex odor concentrations decreased in 2025. Notably, Jungang Market and Sundae Alley recorded reductions of over 50%, indicating that policy measures such as AIoT sensor installation, reinforcement of local exhaust systems, and routine inspections were effectively implemented in alignment with market structures and on-site conditions. Doraemi Market and Jayou Market also showed declines, albeit to a lesser degree, reflecting an overall positive outcome.

2) TVOC

TVOC exhibited increases in certain markets, highlighting the need for careful attention. In Jayou Market and Sundae Alley, average concentrations rose in 2025, suggesting potential influences of enclosed cooking environments, poor ventilation, and micro environmental variability. By contrast, Jungang Market and Doraemi Market maintained relatively stable TVOC levels throughout the period.

3) H_2S

Hydrogen sulfide concentrations sharply declined across all markets in 2025. Jungang Market and Doraemi Market achieved reductions close to elimination levels, reflecting the effectiveness of sewer rehabilitation, rainwater pipe sealing, and odor-blocking structural improvements. Jayou Market and Sundae Alley also demonstrated notable reductions, confirming the impact of policy interventions.

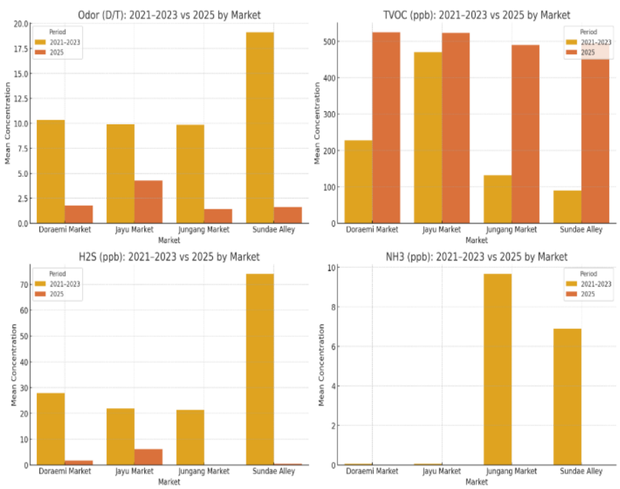

Figure 3: Comparative Analysis of Odor Component Concentrations

4) NH_3

Ammonia concentrations were virtually reduced to zero in all markets, indicating the successful application of improved food waste management, enhanced cleaning systems, and revised waste storage practices. The disappearance of NH_3 in cooking-intensive markets such as Doraemi Market and Sundae Alley particularly demonstrates that the policy impact reached a perceptible level for residents.

Overall, these findings suggest that policy interventions have made a substantial contribution to structural improvements in odor management within traditional markets (Atari et al., 2009), while also revealing differences in sensitivity and effectiveness by market and odor component. Clear reductions were observed for complex odor, H_2S, and NH_3, whereas TVOC increased in certain markets, underscoring the necessity of market-specific and component-sensitive follow-up strategies.

4.1.4. Principal Component Contribution Analysis

In this study, principal component analysis (PCA) was conducted on the four major odor components measured in traditional markets in Wonju: complex odor (D/T), TVOC, H_2S and NH_3. The PCA procedure (Table 3) involves data standardization, computation of the covariance matrix, calculation of eigenvalues and eigenvectors, and determination of principal components based on the proportion of variance explained by each eigenvalue.

Table 3: Formula for PCA Derivation

Standardization	Covariance Matrix	Eigenvector	Contribution Rate
$Z_i = \frac{X_i - \bar{X}_i}{S_i}$	$\Sigma = \begin{pmatrix} Var(Z_1) & Cov(Z_1 Z_2) & \cdots \\ Cov(Z_2 Z_1) & Var(Z_2) & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix}$	$\Sigma v = \lambda v$	$Z = \tilde{X} W$
Zi: Standardized value X_i: Original data $\bar{X}_i$: variable Mean s_i : Standard deviation	Calculate the covariance matrix (Σ) using standardized data	Eigenvalue v: Eigenvector	Where W is the matrix of selected eigenvectors (columns: w1, w2, …).

The cumulative contribution of these components must equal 100%.

For example, when the first principal component (PC1) accounts for 61.8%, this indicates that 61.8% of the total variance in the dataset is explained along the first axis (PC1) (Table 4). Thus, PC1 represents the dominant dimension summarizing the variability among odor components, while subsequent principal components (PC2, PC3, etc.) capture additional but smaller proportions of the variance.

Table 4: PCA Component Contribution and Explained Variance

Component	PC1	PC2	PC3	PC4	Explained Variance (%)
Odor (D/T)	0.605	–0.017	–0.354	–0.713	61.8
TVOC (ppb)	–0.323	0.833	–0.443	–0.073	22.6
H_2S (ppb)	0.599	0.089	–0.384	0.697	14.5
NH_3 (ppb)	0.413	0.546	0.729	–0.024	1.1

1) PC1 (Complex Odor– H_2S Structural Factor, 61.8%)

The first principal component explains approximately 61.8% of the total variance, with complex odor (D/T) and H_2S contributing the most. This indicates that the dominant sources of odor in traditional markets stem from structural systems such as sewers, storm drains, and drainage facilities, as well as cleaning and waste discharge practices. The results suggest that odor H_2S integrated control systems should serve as the core framework for detection and policy response.

2) PC2 (TVOC Cooking-Environment Factor, 22.6%)

The second principal component, explaining 22.6% of the variance, is predominantly influenced by TVOC. This factor reflects cooking-related odor structures, especially those associated with high-temperature enclosed cooking and the release of oil combustion byproducts. Unlike PC1, PC2 captures a distinct dimension of odor, identifying TVOC as a cooking-specific odor group that differs spatially and temporally from sewer-related odors.

3) PC3 (NH_3 Waste-Based Residential Odor Factor, 14.5%)
The third principal component, accounting for 14.5% of the variance, is mainly driven by NH_3. This represents odor generated from food waste, waste storage, and insufficient cleaning in localized areas, characterizing a micro-scale, residential odor source. Unlike complex odor or TVOC, NH_3 requires targeted and localized management strategies.

4) PC4 (Residual/Noise Component, 1.1%)
The fourth principal component contributes only 1.1% of the variance, a negligible explanatory power, and is considered noise or a non-critical variable. Together, PC1 and PC2 explain approximately 84% of the total odor structure, highlighting two primary axes: sewer/drainage-based odor (PC1) and cooking/ventilation-based odor (PC2).

These results confirm that odor composition in traditional markets can be effectively summarized along two main axes (structural vs. cooking). This provides a structured framework for designing sensor-based monitoring systems, developing policy intervention models, and prioritizing odor management strategies.

For cross-validation, the PCA findings were compared with seasonal data from a parallel living lab project conducted in the same markets. For example, the maximum H_2S concentration measured in Doraemi Market during summer was 77.1 ppb, closely matching the concurrent average value of 72.4 ppb in this study. This consistency reinforces the reliability of PCA-based factorization and supports its application as a foundational tool for linking spatial and temporal factors in future analyses.

4.2. Google Trends Analysis

4.2.1. Time-Series Analysis by Keyword

The Google Trends in Figure 4 analysis revealed distinct temporal variability across the five selected keywords (Nuti et al., 2014; Mavragani et al., 2018). The search volume for "Wonju Traditional Market" tended to increase during traditional holidays such as Lunar New Year and Chuseok, as well as during the summer vacation period. This reflects heightened public interest associated with seasonal increases in market visitors. Overall, search volumes were relatively high in 2021–2022 but showed a gradual decline after 2023.

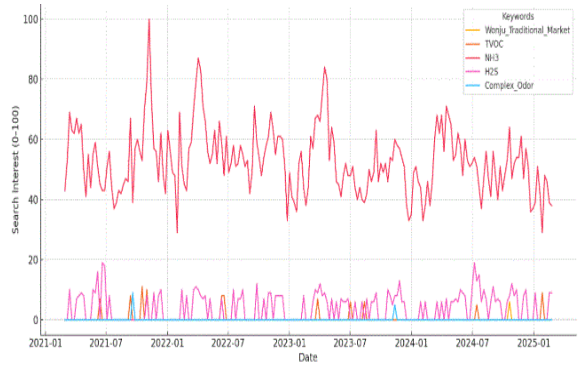

Figure 4: Google Trends: Time Series Changes by Keyword (2021–2025)

Among the odor-related keywords, NH_3 searches were particularly high during the summer months (July–August), partially aligning with field measurements that showed increased volatilization under hot and humid conditions. H_2S searches peaked in autumn (September–October), corresponding to periods of active sewage and organic matter decomposition. In contrast, TVOC did not display clear seasonal patterns but exhibited sporadic spikes, which appear to be linked to social events, public health concerns, or media coverage related to indoor air quality and ventilation.

Finally, the "Complex Odor" keyword showed consistently low search volumes compared to the others but exhibited a gradual decline after 2023. This trend suggests that strengthened odor management policies may have been partially reflected in reduced public attention to the issue.

In summary, the time-series patterns of Google Trends data partially mirrored the seasonality of field measurements, while also revealing distinctive fluctuations associated with social events and policy effects. This demonstrates that odor issues should be analyzed not only in terms of physical concentrations but also through a multidimensional lens that incorporates public awareness and perception.

4.2.2. Seasonal Search Patterns

A comparison between Google Trends data and field measurement results revealed that for certain odor components, environmental changes and public interest exhibited similar seasonal patterns. For NH_3, field concentrations were higher in the summer, and search volumes also increased during the same period, indicating partial alignment between environmental seasonality and social sensitivity. Likewise, H_2S showed elevated concentrations in autumn, and corresponding search volumes also increased, suggesting that changes in environmental concentrations of specific odorants can be directly reflected in public awareness in Figure 5.

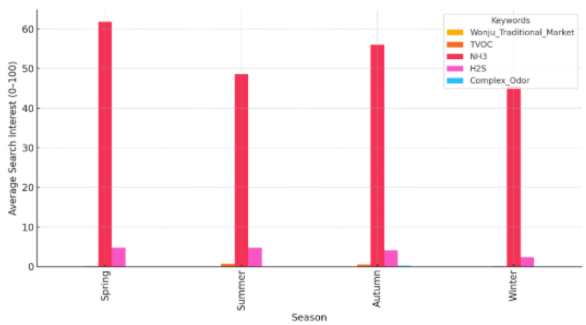

Figure 5: Google Trends: Seasonal Average Search Interest (2021–2025)

In contrast, TVOC displayed a divergence between the two datasets. While field measurements indicated increased concentrations during periods of intense cooking activity, Google Trends searches showed less seasonality and were instead marked by sporadic spikes linked to social issues or media reports.

This suggests that TVOC exhibited relatively low correlation between measured values and search interest. For the "Complex Odor" keyword, search volumes remained consistently low, showing little direct correlation with measured complex odor concentrations.

In conclusion, the degree of correlation between Google Trends data and field measurements varied by component. NH_3 and H_2S demonstrated relatively strong associations, while TVOC and complex odor showed noticeable discrepancies between public awareness and actual concentrations. These findings indicate that Google Trends analysis can complement field measurements by capturing the social dimension of odor perception. At the same time, they provide valuable insights into how changes in the actual concentration of specific odorants translate into residents' perceived discomfort and corresponding social responses.

4.2.3. Correlation Between Field Data and Google Trends Analysis

Table 5 presents a comparison of the average values of field-measured odor components and Google Trends search volumes from 2021 to 2025. This comparison highlights how the correlation between physical environmental data and social interest data varies depending on the component (Ryu & Min, 2020).

Table 5: Comparison between Field Measurement Averages and Google Trends Search Averages (2021-2025)

Pollutant	Field Measurement Mean	Google Trends Mean
NH_3	5.03 ppb	52.95 (index)
H_2S	48.58 ppb	4.04 (index)
TVOC	260.63 ppb	0.41 (index)
Complex Odor (D/T)	12.59 D/T	0.07 (index)

The correlation analysis revealed different patterns across odor components, requiring a distinction between seasonal patterns and absolute levels. For NH_3, seasonal increases were observed in the field data during hot and humid summer months, and Google Trends search volumes also rose in the same period. Thus, the seasonal fluctuation patterns matched across both datasets.

However, the absolute levels diverged significantly: the field average of NH_3 was only 5.03 ppb, while the search average was 52.95, the highest among all keywords. This suggests that NH_3, as a common odor source linked to sewage and food waste, was strongly perceived by residents (Blanes-Vidal et al., 2012), leading to heightened search activity despite its relatively low physical concentration. In other words, NH_3 is a component where social perception exceeds physical presence.

For H_2S, seasonal alignment was also observed, with field concentrations peaking in autumn and search volumes showing corresponding increases. However, the absolute relationship was the opposite of NH_3. Although H_2S had the highest field average concentration (48.58 ppb), its search average was only 4.04. This indicates that while residents experience H_2S odors, they may not search using the technical term "hydrogen sulfide." Thus, H_2S emerges as an environmentally significant but socially under recognized component.

TVOC displayed clear seasonal variability in field measurements, especially during intensive cooking activities, but only sporadic search spikes in Google Trends, often associated with public issues like ventilation or indoor air quality. Since the term "TVOC" is unfamiliar to the general public, searches may have been redirected to broader terms such as "air quality" or "ventilation." Accordingly, TVOC showed the lowest correlation between measured concentrations and search volumes.

For Complex Odor, the field data averaged 12.59 D/T, whereas Google Trends searches averaged only 0.07, indicating minimal search activity and almost no seasonal patterns. This underscores that the academic term "complex odor" does not resonate with public awareness. Nevertheless, the slight decrease in search volumes after 2023 paralleled the downward trend in field data, suggesting a limited reflection of policy effects.

In summary, while Google Trends and field data exhibited some similarities in seasonal patterns, they showed significant discrepancies in absolute levels (Ryu & Min, 2020). NH_3 and H_2S provided meaningful alignment in seasonal dynamics, linking environmental changes with public perception, but differed in absolute magnitudes due to perception bias and terminology gaps. TVOC and complex odor revealed much weaker associations, emphasizing that physical measurements alone cannot fully explain perceived odor problems. The overall correlation coefficient between field averages and search averages was –0.44, confirming that the relationship is not linear but component-specific.

Therefore, Google Trends data should not be seen as a substitute for field measurements but rather as a complementary indicator, highlighting the gap between "physical concentrations" and "social perception intensity."

4.3. Discussion – Limitations of the "Complex Odor" Concept and Policy Implications

In this study, the indicator of "complex odor" was consistently observed at measurable concentrations in field data, but it appeared almost absent in Google Trends search volumes. This discrepancy illustrates that while the term "complex odor" is used primarily in academic and policy contexts, it is rarely employed in residents' everyday language or search behavior (De Feo et al., 2013). Such a gap highlights the divergence between scientific terminology and public perception, which must be carefully considered when interpreting both physical measurements and social data together (De Vries, 2020).

Thus, although complex odor remains a necessary indicator for scientific analysis, it is limited in studies of public awareness. Residents tend to perceive and describe odors not as an abstract "complex odor," but rather as specific stimuli such as "sewer smell," "food waste odor," or "cooking smell." Therefore, future research and policies should continue to use complex odor as a technical metric while supplementing it with more concrete indicators such as NH_3, H_2S and TVOC or with general terms like "air quality" and "odor" when analyzing public perception (Henshaw, 2013).

From a policy communication perspective, it is essential to provide a resident-friendly definition, for example, explaining "complex odor" as 'an unpleasant smell perceived when multiple odors are mixed.' Such dual framing would help residents better understand the concept, narrowing the gap between expert terminology and lived experience. This twofold approach ensures that odor management policies reflect both scientific rigor and social relevance, enabling a more precise evaluation of policy effectiveness in terms of both resident communication and environmental improvement.

5. Conclusions and Research Limitations

5.1. Conclusion

This This study compared and analyzed field measurement data of NH_3, H_2S, TVOC and complex odor (D/T) collected from traditional markets in Wonju between 2021 and 2025 with Google Trends search data, in order to explore the relationship between environmental conditions and public interest.

The results showed that NH_3 and H_2S exhibited partial alignment between seasonal variations in concentrations and fluctuations in public search interest. Moreover, their measured concentrations declined markedly after 2023, coinciding with policy interventions. This suggests that targeted policies achieved measurable improvements in managing everyday odor sources. However, these changes may also have been influenced by external factors such as meteorological conditions, seasonal variations, and site-specific characteristics, raising the need for further verification to determine whether the downward trend will persist in the long term.

In contrast, TVOC concentrations increased by approximately 101% in 2025 compared to the previous year, showing almost no effect of policy interventions. Since TVOC largely originates from cooking activities, cleaning agents, and inadequate ventilation within markets, its rise highlights a management blind spot resulting from existing policies that primarily focused on sewer and waste-related odor sources. Therefore, TVOC should be prioritized in future odor management policies, with strategies emphasizing improved market ventilation systems and strengthened sanitation practices.

For complex odor (D/T), measurable levels were consistently present in field data, but Google Trends searches were nearly absent, revealing that the academic term "complex odor" is not reflected in residents' perception.

This underscores the gap between policy/scientific terminology and public awareness, and suggests the need for improved communication strategies to bridge this divide.

In summary, this study provided a multi-dimensional assessment of odor management by integrating environmental measurements with social data. While NH_3 and H_2S showed short-term improvements attributable to policy interventions, TVOC emerged as the most vulnerable and under-managed component. These findings imply that future odor reduction policies in traditional markets should adopt component-specific strategies, account for external factors, establish continuous monitoring systems, and enhance communication efforts to improve public understanding and engagement.

5.1. Research Limitations

Despite its contributions, this study has several limitations that should be acknowledged.

First, the correlation analysis between field measurements and Google Trends data was limited to descriptive statistics and a simple correlation coefficient. Although the overall correlation was –0.44, further statistical verification, such as significance testing or regression modeling, was not conducted. This restricts the robustness of the findings regarding the relationship between environmental data and public interest.

Second, the observed policy effects were derived from data covering a relatively short period (2023–2025). While reductions in NH_3 and H_2S concentrations were evident during this time, it remains uncertain whether such improvements can be sustained in the long term. Extended monitoring and follow-up studies are required to confirm the durability of these effects.

Third, Google Trends data, while useful as a proxy for public awareness, is influenced not only by actual odor perception but also by external factors such as media coverage, government campaigns, and public discourse. Therefore, the interpretation of Google Trends as a direct indicator of resident perception should be approached with caution.

Lastly, the term complex odor (D/T), though appropriate in academic and policy contexts, does not fully capture how residents perceive and search for odor-related experiences. This discrepancy suggests that future studies should combine technical measurements with more resident-friendly terminology in surveys or communication strategies.

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