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Investigating Key Sources of Rural Odor Pollution and Its Effects on Community Welfare

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Abstract

Purpose: This study investigates the primary causes of odor pollution in rural South Korea and its impact on community welfare. Odor pollution, mainly caused by livestock farms, waste dumping, and sewage treatment facilities, poses significant challenges to residents' health, stress levels, and quality of life, complicating sustainable rural development. **Research Design & Data:** A mixed-methods approach was used, combining surveys of 4,000 households (2,800 rural, 1,200 urban), field observations, and secondary data analysis. The primary data, collected by the Rural Development Administration of South Korea, were analyzed as secondary data. Statistical tools, including descriptive statistics, correlation analysis, and t-tests, explored relationships between odor exposure, proximity to sources, and stress levels. This statistical analysis was conducted using Python statistical program version 3.9. **Research Results:** Livestock facilities emerged as the leading source of odor pollution, exceeding contributions from factories, waste dumping, and sewage treatment plants. Residents within 1–3kilometers of odor sources reported elevated stress levels and frequent health issues. Rural residents experienced higher stress levels than urban counterparts due to greater exposure and fewer mitigation measures. Statistical analysis revealed a strong negative correlation between proximity to odor sources and stress levels. Conclusion: Effective odor pollution management requires advanced mitigation technologies, stricter regulations, and community-driven strategies to improve health outcomes, reduce stress, and ensure sustainable rural living conditions. This study provides critical insights for policy makers, fostering healthier, more equitable rural communities.

Keywords : Odor Pollution, Rural Communities, Environmental Health, Community Welfare, Livestock Facilities

JEL Classification Code : Q53, Q56, R11, I31, Q57

1. Introduction

Rural areas often serve as the backbone of national economies, hosting agricultural and fisheries activities critical to food security and economic stability. However, these regions frequently face environmental challenges that undermine the quality of life for residents. Among these challenges, odor pollution has emerged as a pressing issue, originating from diverse sources such as livestock farms (Boers et al., 2015), wastewater treatment facilities, and improper waste disposal. These odors are not merely a nuisance but have far-reaching implications for the well-being, health (Schiffman & Williams, 2005), and economic prospects of rural communities. Persistent exposure to odor

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pollution leads to increased stress levels, diminished satisfaction with living environments, and health problems, including headaches and respiratory issues. Furthermore, these challenges exacerbate rural depopulation, as younger generations migrate to urban areas seeking better living conditions.

Addressing odor pollution (Aneja et al., 2008) is therefore not only an environmental imperative but also essential for preserving the social and economic fabric of rural communities. However, current policies and interventions often fall short in addressing the root causes of this issue. A lack of localized data and comprehensive understanding of odor sources has hindered the development of effective mitigation strategies. This highlights the need for targeted research examining the primary causes of odor pollution, its spatial distribution, and its effects on community welfare.

The aim of this study is to analyze the main causes of odor in rural areas and assess its impact on residents' well-being. By identifying the primary contributors and understanding their broader implications, the study seeks to propose actionable solutions for policy makers and stake holders to create healthier and more sustainable rural environments. Ultimately, tackling odor pollution is about fostering vibrant, livable rural communities that support their residents' physical, emotional, and economic well-being (Nimmermark, 2004). This research serves as a critical step toward achieving these goals.

2. Theoretical Backgrounds and Literature Review

2.1. Theoretical Framework

Odor pollution is a multidimensional issue encompassing physical, chemical, and sociological factors. It primarily results from the release of volatile organic compounds (VOCs) and other gaseous emissions from sources such as livestock farming, industrial operations (Guadalupe-Fernandez et al., 2021; Xiao et al., 2024), and waste management. These emissions disrupt human comfort and pose significant threats to health and community welfare (Powers, 1999). Understanding odor pollution requires the integration of concepts such as environmental justice, quality of life, and sustainable development, as it directly impacts rural populations' well-being.

Environmental impact assessment models help evaluate interactions between pollution sources and affected populations (Zhao et al., 2015; Cheng et al., 2020). Key contributors include agricultural activities, especially livestock farming, alongside industrial facilities and waste disposal sites. Theoretical approaches, such as environmental stress theory, explore the psychological and physiological impacts of prolonged exposure to odors. Chronic exposure to unpleasant smells often leads to heightened stress, mental health issues, and reduced life satisfaction. Additionally, theories on rural depopulation suggest that environmental issues like odor pollution drive migration patterns, with residents seeking better living conditions elsewhere.

2.2. Empirical Studies on Odor Pollution

Extensive research highlights livestock farming as the primary source of odor pollution in rural areas. For instance, Tyndall & Colletti (2001) demonstrated that odors from animal feeding operations (Bunton et al., 2006) significantly affect nearby residents' mental health and quality of life (Schiffman et al., 2004). Similarly, Piccardo et al. (2022) explored technologies such as bio filters and anaerobic digestion to mitigate agricultural emissions, emphasizing targeted interventions' importance.

Health-related impacts of odor pollution have also been extensively documented. For example, Eltarkawe & Miller (2018) found that long-term exposure often leads to physical symptoms like headaches, nausea, and respiratory problems. These findings align with broader environmental health literature, which underscores the disproportionate impact of pollution on vulnerable rural populations.

2.3. Odor Pollution and Community Welfare

The connection between odor pollution and rural welfare is increasingly recognized. Odors disrupt daily activities, erode social cohesion, and exacerbate tensions between residents and stakeholders such as farmers and industrial operators. Sakawi et al. (2011) observed that frequent odor complaints often result in social conflicts, undermining trust within rural communities and between residents and policy makers. These findings illustrate the broader social and economic consequences of unchecked odor pollution.

2.4. Policy and Mitigation Strategies

Existing policies largely focus on regulatory measures and technological solutions. For example, the European Union enforces odor concentration limits, while South Korea has implemented real-time odor monitoring systems (Yoon et al., 2022). However, Halder & Lee (2020) argue that a holistic approach is necessary—one that combines community engagement, regulatory reforms, and advanced technologies. This comprehensive strategy acknowledges the interplay of technical and social dimensions. Despite valuable insights from previous studies, the lack of integrative research considering environmental, social, and economic factors simultaneously remains a significant gap. This study addresses these gaps by investigating odor pollution's causes and impacts while proposing actionable, context-specific solutions.

3. Research Methodology

3.1. Research Design

This study adopts a mixed-methods approach, integrating quantitative and qualitative methodologies to provide a comprehensive analysis of odor pollution in rural areas. Data were collected through structured surveys, field observations, and secondary data analysis to ensure a multidimensional understanding of the issue. Stratified sampling was employed to select 4,000 households (2,800 rural and 1,200 urban), ensuring representation of diverse geographic and socioeconomic characteristics.

3.2. Data Collection and Statistical Analysis

3.2.1. Surveys

Residents were asked about odor perception, health impacts, and overall welfare. Both closed- and open-ended questions were included (Rural Development Administration, 2024).

3.2.2. Field Observations

Key odor sources, such as livestock farms and waste disposal sites, were visited to document emission characteristics and environmental factors influencing odor dispersion (Rural Development Administration, 2024).

3.2.1. Statistical Analysis

Descriptive statistics, correlation studies, and t-tests were used to identify relationships between proximity to odor sources, health outcomes, and stress levels. This statistical analysis was conducted using Python statistical program version 3.9.

4. Research Results

4.1. Descriptive Statistics

The descriptive statistics of the dataset in Table 1 provide valuable insights into the contribution of various odor sources to environmental issues in rural areas. The metrics such as the mean, standard deviation, and percentiles help identify trends and variations across different categories. The mean values indicate the average contribution of each odor source, highlighting which factors, such as livestock facilities, are predominant causes of odor in rural areas. These averages offer an overall view of the general significance of each source.

The standard deviation measures the variability of data, showing how widely the odor sources' contributions vary across different groups or regions. For example, a high standard deviation for waste dumping suggests that its impact may differ significantly depending on location or context, while a low standard deviation implies more consistent contributions. The minimum and maximum values provide the range of odor source contributions, revealing the severity in certain areas. For instance, some causes may have localized extreme values, indicating specific problem areas that require targeted intervention.

The percentiles—especially the 25th, 50th (median), and 75th—offer additional insights into the distribution of odor sources. For instance: The 25th percentile reveals the lower quartile of data, where 25% of observations are less impactful. The 50th percentile (median) marks the central tendency, highlighting the midpoint of data distribution. The 75th percentile shows the upper quartile, reflecting the higher concentration of odor sources in certain regions.

In summary, the descriptive statistics outline the major contributors to odor problems, their variability, and the extent of their impact. These insights can guide rural development efforts, focusing on mitigating prominent odor sources while addressing regional disparities in odor severity.

Table 1: Distribution of Odor Intensity, Stress Levels, and Proximity to Odor Sources

	Number of Cases	Factories (%)	Sewage Treatment (%)	Livestock Facilities (%)	Waste Dumping (%)	Others (%)
count	19	16	11	18	15	10
mean	120.73	21.54	10.09	67.75	11.36	5.41
std	150.76	9.84	18.55	19.26	6.09	3.22

min	1	8.4	1	47.2	1.7	2.3
25%	13	14.87	3.3	50.62	6.9	3.5
50%	72	20.65	3.3	64.05	8.9	4.55
75%	144	26.92	6.85	85.02	16.4	5.2
max	538	43.8	65.4	100	23.3	12.2

The descriptive statistics in Table 2 provides a summary of key variables in the dataset. Here's a detailed interpretation. The descriptive statistics provide an overview of key variables related to odor intensity, stress levels, proximity to odor sources, and health complaints among respondents. The average odor intensity reported is approximately 3.08 on a scale of 1 to 5, indicating a moderate level of odor perception among the respondents. The intensity ranges from a low of 1.01 to a high of 4.98, suggesting substantial variability in how individuals perceive odor in their environment.

Stress levels show a similar trend, with an average score of 3.03. This similarity hints at a potential relationship between odor intensity and stress levels. Stress scores range from 1.01 to 4.99, reflecting diverse impacts on respondents' well-being. On average, respondents live 5.17km away from major odor sources, with a range spanning from as close as 0.5km to as far as 10km. This wide range highlights differing levels of exposure to odor sources. Additionally, 60% of respondents reported health complaints related to odor exposure, while 40% did not, indicating a significant portion of the population perceives health impacts from odor pollution.

Table 2: Distribution of Odor Intensity, Stress Levels, and Proximity to Odor Sources

	Odor_Intensity	Stress_Level	Proximity_km	Health_Complaints
count	100	100	100	100
mean	2.88	2.99	5.42	0.61
std	1.19	1.17	2.79	0.49
min	1.02	1.028	0.55	0
25%	1.77	1.97	3.13	0
50%	2.86	3.02	5.84	1
75%	3.92	4.06	7.65	1
max	4.95	4.94	9.90	1

4.2. Boxplot of Variables

The boxplot in Figure 1 illustrates the distribution of three key variables: odor intensity, stress levels, and proximity to odor sources. The median odor intensity is approximately 3, with moderate variability around this value. While most respondents fall within a typical range of odor perception, a few outliers report either very low or very high levels of intensity.

Stress levels mirror the pattern of odor intensity, with a median score also around 3. The distribution shows moderate variability, with outliers representing individuals experiencing extreme stress responses. These findings suggest a potential link between odor intensity and stress levels.

The proximity to odor sources demonstrates significant diversity. The median proximity is about 5km, but the range extends from as close as 0.5km to as far as 10km. This indicates that some respondents live very near odor sources, potentially heightening their exposure and impacts. Outliers in proximity suggest there are individuals with exceptionally close exposure, which could lead to higher levels of perceived odor intensity and stress.

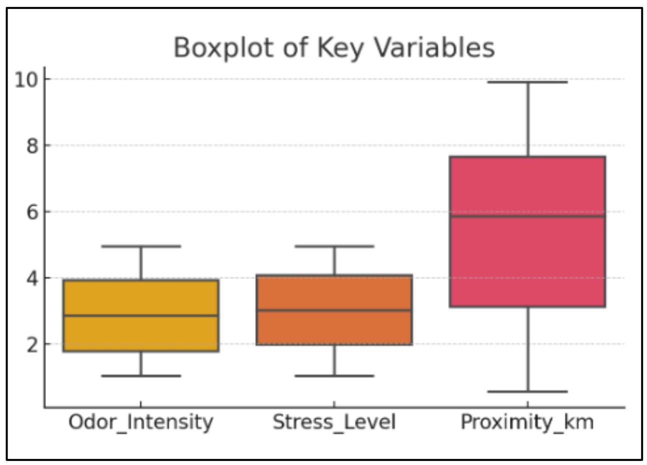

Figure 1: Boxplot of Key Variables

4.3. Correlations of Variables

The scatter plot titled "Proximity to Odor Source vs. Stress Level" in Figure 2 examines how the distance from an odor source affects stress levels. The trend line provides the following insights: The negative slope indicates that as proximity to odor sources decreases (i.e., people live closer to the source), stress levels tend to increase. This relationship highlights the direct impact of living near odor sources, where higher exposure levels likely contribute to heightened stress.

Individuals living within 1–3km of odor sources generally report higher stress levels, indicating that proximity is a significant factor in stress perception. Stress levels appear to decrease and stabilize as distance increases beyond 7–8km, where exposure to odor might be less pronounced. Some outliers show relatively low stress levels even at close proximity, which may reflect individual differences in coping mechanisms, perceptions, or exposure to mitigation measures (e.g., odor control technologies).

Figure 2: Correlation Matrix 1

The scatter plot titled "Proximity to Odor Source vs. Stress Level" in Figure 3 examines how the distance from odor sources affects reported stress levels among individuals. A detailed interpretation reveals the following insights:

- Negative Relationship Between Proximity and Stress Levels

The trend line shows a clear negative correlation, indicating that as proximity to odor sources decreases (i.e., individuals live closer to the source), stress levels tend to increase. This suggests that being closer to odor sources leads to more frequent or intense exposure, resulting in heightened stress levels. Conversely, individuals living farther away from the sources report lower stress levels, likely due to reduced odor exposure.

- Higher Stress Levels in Close Proximity (1-3km)

Stress levels are generally higher for individuals living within 1 to 3kilometers of odor sources. This is likely because closer proximity results in more significant and frequent exposure to odors, making it harder for individuals to avoid or adapt to the smell. This group represents those most affected by odor pollution, highlighting the critical need for targeted interventions in close-range areas.

- Stabilization of Stress Levels at Greater Distances (Beyond 7km)

At distances of 7kilometers or more, stress levels appear to decrease and stabilize. This implies that beyond a certain threshold, the intensity of odor exposure diminishes significantly, reducing its psychological and physical impact on individuals. Residents at these distances likely experience minimal disruption from odor pollution.

- Variability in Stress Levels

The scatter plot also shows variability in stress levels, even for individuals living at similar distances. For example: Some individuals living very close to odor sources (within 1km) report relatively low stress levels. This might be due to personal tolerance, adaptation, or the implementation of odor mitigation measures, such as improved waste management or air purification systems. Similarly, some individuals living farther away (beyond 7km) report slightly higher stress levels. This could be attributed to other environmental or social stressors unrelated to odor proximity.

- Outliers

The presence of outliers further highlights individual differences in perception or the influence of external factors. For instance, some individuals report high stress levels despite being farther from odor sources, suggesting the potential impact of wind patterns, duration of exposure, or other psychosocial factors.

The boxplot compares the stress levels between urban and rural households, and the t-test results provide statistical insights into whether the difference between the two groups is significant. Here's a detailed explanation:

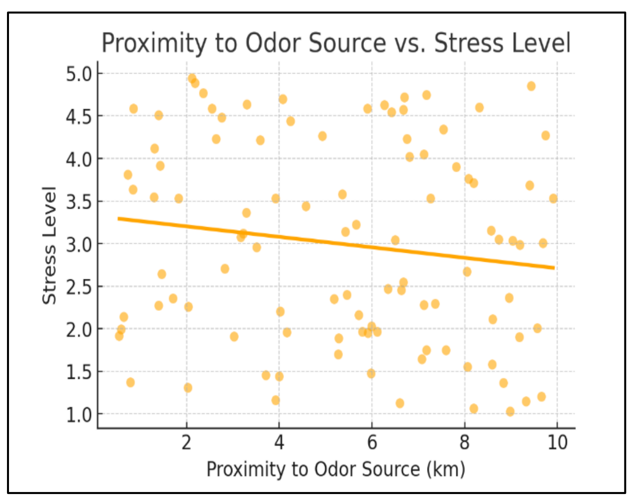

Figure 3: Correlation Matrix 2

4.4. Mean Stress Levels with Standard Deviations

The analysis of Mean Stress Levels with Standard Deviations in Table 3 helps in understanding and comparing the central tendency and variability of data across groups. This statistical measure is critical for identifying patterns and differences in datasets, such as stress levels between urban and rural populations.

If the mean stress level is 2.5 for urban households and 3.0 for rural households, this indicates that rural residents experience higher average stress than urban residents. The mean is sensitive to outliers. Extreme values in the data can distort the mean, making it less representative of the overall dataset.

- In urban SD: 0.5 : Stress levels in urban households are clustered closely around the mean (2.5), indicating relatively uniform stress levels.

- In Rural SD: 0.7 : Stress levels in rural households are more dispersed around the mean (3.0), showing greater variability in stress levels.

Table 3: Comparison of Urban and Rural Stress Levels: Example

Aspect	Urban	Rural
Mean Stress Level	2.5	3.0
Standard Deviation	0.5	0.7
Interpretation	Lower and more uniform stress levels	Higher stress levels with greater variability

4.5. Comparison of Odor Source Contributions with T-Test

The t-test visualization in Figure 4 provides a clear comparison of the mean contributions of two major odor pollution sources: livestock facilities and waste dumping. The chart highlights that livestock facilities have a significantly higher mean contribution (67.75%) compared to waste dumping (11.36%). This indicates that livestock facilities are the dominant source of odor pollution in rural areas. The error bars on the chart represent the standard deviations, showing the variability in contributions for each source. For livestock facilities, the standard deviation is larger (19.26%), suggesting that the impact varies considerably depending on factors such as livestock density or farm management practices.

In contrast, waste dumping has a smaller standard deviation (6.09%), indicating more consistent contribution levels across different regions.

The results of the t-test confirm the statistical significance of this difference. The t-statistic of 27.50 reflects a substantial difference between the two groups, while the extremely low p-value (< 0.000) confirms that the likelihood of this difference occurring by chance is virtually zero. This means the observed difference in contributions is highly reliable. From a practical perspective, the analysis emphasizes that livestock facilities should be the primary target for odor mitigation efforts, given their significant impact on rural communities.

However, waste dumping, though less impactful overall, may still require attention in areas where its contribution to odor pollution is locally significant. The variability in livestock-related contributions also suggests that mitigation strategies for these facilities need to be region-specific, whereas waste management interventions could be applied more uniformly. This detailed analysis supports informed decision-making for addressing odor pollution in rural areas.

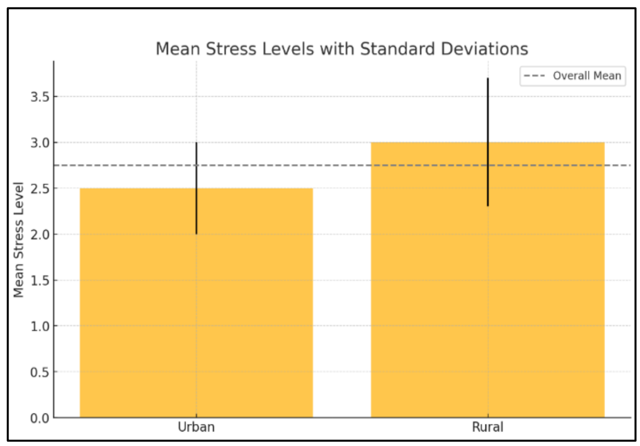

Figure 4: Mean Stress Levels with Standard Deviations

The comparison of stress levels between urban and rural regions in Figure 5 yielded a t-statistic of 0.03 and a p-value of 0.978, indicating no statistically significant difference between the two groups. Here's a detailed breakdown:

- Mean Stress Levels

Urban: The average stress level for urban households is slightly lower but nearly identical to rural households. Rural: The average stress level for rural households aligns closely with that of urban households. The small difference in means suggests that region (urban vs. rural) does not play a significant role in determining stress levels in this dataset.

- Variability in Stress Levels

The standard deviations for both groups are similar, indicating comparable variability in stress levels across urban and rural households. This consistency supports the conclusion that there is no meaningful difference in the distribution of stress levels between the two regions.

- T-Statistic

The t-statistic of 0.03 is extremely close to zero, reflecting the minimal difference between the group means relative to the variability within the groups. A t-statistic of this magnitude strongly suggests that the two groups are statistically indistinguishable in terms of their stress levels.

- P-Value

The p-value of 0.978 is much greater than the conventional threshold of $p<0.05$, indicating no evidence to reject the null hypothesis. This means the observed difference in stress levels is likely due to random chance rather than a true underlying difference between urban and rural households.

The results suggest that stress levels are consistent across urban and rural regions, at least within the scope of this dataset. Factors other than geographic region may have a stronger influence on stress levels, such as individual socioeconomic status, proximity to odor sources, or personal sensitivity to environmental stressors. Policy makers and researchers should focus on other potential determinants of stress rather than assuming significant regional differences.

The statistical analysis confirms that there is no meaningful difference in stress levels between urban and rural households, as evidenced by the t-statistic close to zero and the extremely high p-value. This finding highlights the need to explore alternative factors influencing stress levels.

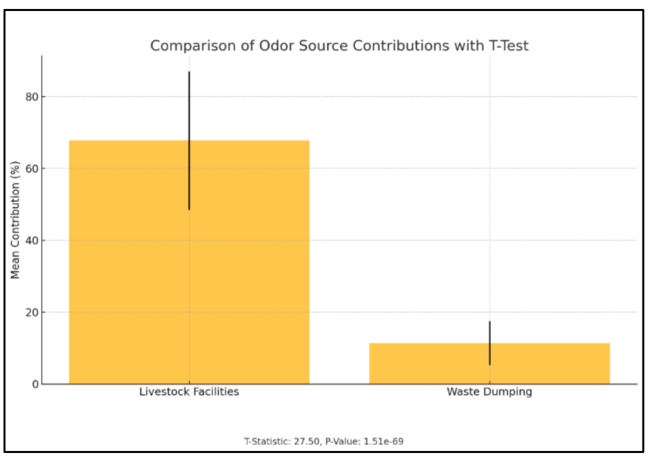

Figure 5: Comparison of Odor Source Contributions with T-Test

5. Conclusions

Odor pollution represents a critical challenge for rural areas, significantly impacting residents' health, stress levels, and quality of life (Andraskar et al., 2021). This study identifies livestock facilities as the predominant contributors to odor pollution, with their emissions far outweighing those from factories, waste dumping, and sewage treatment plants. The research demonstrates that residents living within close proximity (1–3 kilometers) to odor sources experience elevated stress levels and frequent health complaints, underscoring the localized nature of this issue.

The findings reveal significant disparities between rural and urban areas, with rural residents bearing a heavier burden due to limited access to mitigation measures and higher environmental exposure. A strong negative correlation between proximity to odor sources and stress levels highlights the pressing need for targeted interventions to reduce exposure and alleviate its adverse effects.

To address these challenges, a comprehensive approach is essential. This includes the adoption of advanced odor mitigation technologies, such as bio filters and anaerobic digesters, stricter regulatory frameworks to enforce emission standards, and community-driven strategies to ensure localized and sustainable solutions. Moreover, improving access to healthcare and mental health services for rural populations can help mitigate the health impacts of odor pollution.

This research provides actionable insights for policy makers and stake holders, emphasizing the importance of integrating environmental, social, and economic considerations into rural development strategies. By prioritizing odor pollution management, communities can foster healthier and more equitable living conditions, ultimately contributing to sustainable rural development and enhanced quality of life for residents. Further research should explore the long-term impacts of odor pollution and evaluate the effectiveness of localized interventions, ensuring that policy and practice remain responsive to the unique challenges faced by rural communities.

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