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Source-specific PM2.5 pollution and respiratory health impacts in an urban Asian district: a real-time monitoring study in Ho Chi Minh City, Vietnam

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Abstract

Introduction: Fine particulate matter (PM2.5) is a pressing public health challenge in rapidly urbanizing Asian cities. In District 5 of Ho Chi Minh City, Vietnam, localized PM2.5 pollution arises from diverse sources such as stationary street food vendors, religious temples, traffic congestion, and fuel stations. Understanding the relative contribution of these sources is critical for designing effective interventions. This study aims to identify and quantify the contributions of specific local PM2.5 sources to respiratory health outcomes among residents in District 5, Ho Chi Minh City.

Methods: We conducted a source-specific assessment of PM2.5 exposure and its association with respiratory health outcomes using a real-time sensor network (Airbeam3) deployed at seven sites representative of key emission sources. A total of 184 participants were recruited for the study, including residents living near various PM2.5 sources. Respiratory symptoms were evaluated through a locally adapted American Thoracic Society questionnaire (ATS-DLD-78). Multivariable regression models were used to quantify the impact of specific sources on reported symptoms.

Results: Stationary street-food vendors and traffic congestion were identified as dominant contributors to PM2.5 pollution. Residents living near continuous traffic and stationary street vendor areas experienced significantly higher rates of sputum production. Stationary street-food vendors exhibited the strongest association with adverse outcomes ($\beta=0.47$, $p<0.001$).

Conclusions: Our findings highlighted the urgent need for targeted air pollution control strategies in complex urban environments. Interventions such as cleaner cooking technologies and improved traffic management may significantly reduce PM2.5 exposure and its health burden. This study demonstrates the utility of low-cost, real-time monitoring for guiding public health policies in rapidly developing megacities.

Keywords: air pollution; environmental monitoring; environmental health

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1. INTRODUCTION

Air pollution, particularly by fine particulate matter (PM2.5), has become a pressing global health challenge, contributing significantly to the rising burden of respiratory and cardiovascular diseases. PM2.5 particles, due to their microscopic size, can penetrate deep into the respiratory tract, causing severe health effects and elevating mortality rates [1]. In rapidly urbanizing cities like Ho Chi Minh City, Vietnam, the combination of rapid economic growth, increasing population density and unregulated urban activities has exacerbated air pollution, posing critical health risks to the population.

District 5 in Ho Chi Minh City exemplifies this urban complexity, characterized by heavy traffic congestion, dense street food vending, numerous religious temples, and fuel stations, all of which contribute significantly to localized PM2.5 emissions. Despite growing concerns, there is a critical research gap in understanding how these diverse sources specifically impact air quality and public health. Previous studies in global megacities have emphasized the dominant role of traffic emissions, but the distinct urban fabric of Ho Chi Minh City, with its dense network of informal street economies and cultural practices, demands a more localized, source-specific analysis [2–6].

Traditional air quality monitoring systems, while accurate, are often costly and lack the spatial resolution to capture localized pollution variations. The advent of low-cost sensor technologies, such as the Airbeam3, offers a promising solution for continuous, real-time, and high-resolution air quality monitoring. This technological advancement enables researchers to precisely identify and quantify emissions from specific sources and assess their direct health impacts on nearby populations [7–11].

This study aimed to bridge the knowledge gap by conducting a source-specific analysis of PM2.5 emissions in District 5 and evaluating their association with respiratory health outcomes. By deploying Airbeam3 sensors across multiple strategic locations and integrating health survey data, this research provided critical insights into the localized dynamics of air pollution. The findings formed a basis to inform targeted, evidence-based policies to mitigate PM2.5 emissions and safeguard public health in Ho Chi Minh City and similar urban environments globally.

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted in District 5, Ho Chi Minh City (geographic coordinates: 10.762622, 106.660172), an area known for its dense population and diverse sources of air pollution. District 5 was specifically chosen due to its complex urban structure, characterized by heavy traffic congestion, a high concentration of stationary street food vendors, numerous religious temples, and fuel stations. Prior studies have identified this district as a significant air pollution hotspot, making it an ideal location to study localized PM2.5 exposure and its impact on respiratory health. The district's socio-economic diversity and proximity between residential areas and pollution sources further underscored its suitability for this investigation.

2.2. Air quality monitoring

PM2.5 concentrations were continuously monitored using the Airbeam3 air quality sensor. AirBeam® is a low-cost, palm-sized air quality monitoring device (weighing 6 ounces) designed to measure fine particulate matter concentrations, including PM1, PM2.5, and PM10, as well as temperature and relative humidity (Fig. 1). Its robust and weather-resistant casing makes it suitable for both indoor and outdoor use, in either fixed or mobile applications. The device is equipped with GPS, a real-time clock, an SD card, and a rechargeable lithium battery (3.7 V, 3,350 mAh), allowing it to operate independently from Android or iOS devices once disconnected. According to the manufacturer, a fully charged battery can power the device for approximately 17 hours. Measured data are designed to store and transmit via Bluetooth, Wi-Fi, or 4G mobile networks. Users can access AirBeam3 measurement results through the AirCasting website or Android and iOS applications [12]. The performance of AirBeam has been evaluated by the South Coast Air Quality Management District's AQ-SPEC program in the United States. Comparing AirBeam3 data with the Federal

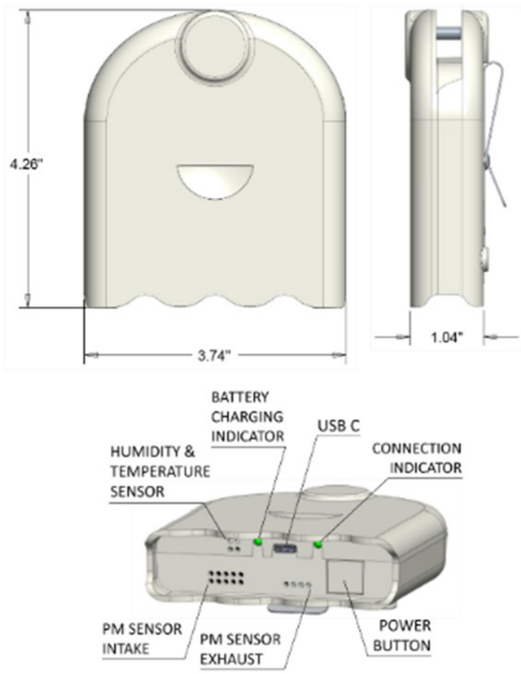
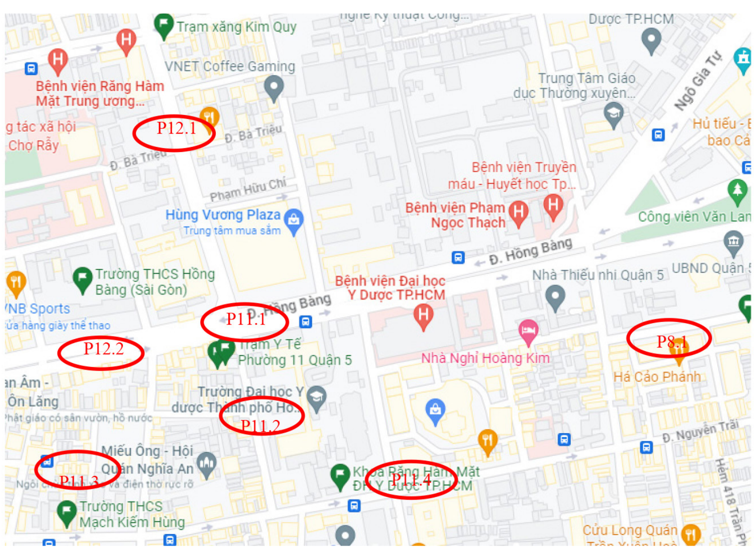


Fig. 1. **The low cost air sensor Airbeam 3.**

Equivalent Method (FEM), the results demonstrated a strong correlation for PM1 and PM2.5, with R^2 values ranging from 0.81 to 0.99 [13].

This device was selected for its high accuracy, affordability, and real-time data recording capability, making it suitable for dense urban environments. Seven Airbeam3 devices were strategically installed at key locations representing various pollution sources: continuous traffic, stop-and-go traffic, stationary street food vendors, temples, fuel stations, schools, and a background control site elevated 10 meters above ground (Fig. 2). PM2.5 monitoring was conducted during the rainy season in Ho Chi Minh City. Throughout the data collection period, no extreme weather events such as typhoons, severe flooding, or prolonged heavy rainfall were recorded. Moderate rainfall was typical during the season when the research took place. To ensure reliable measurements and minimize direct weather impacts, Airbeam3 devices were installed approximately 5 meters away from the



Types of PM2.5 sources (geographic coordinates: latitude and longitude):

P8.1- Stationary street food vendor, continuous traffic
P11.1- Stop and go traffic (10.755136, 106.662382)
P11.2- Background control 10.754912, 106.662440)
P11.3- School, temples (10.753711, 106.662156)
P11.4- Continuous traffic (10.753457, 106.663510)
P12.1- Stop and go traffic, fuel station (10.758051, 106.661753)
P12.2- School (10.753136, 106.660620)

Fig. 2. **Air monitoring sensors set up at district 5, Ho Chi Minh City.**

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road surface and elevated 2 meters above ground level. Each sensor was protected by a fixed cover to shield against rain and environmental disturbances, thereby maintaining measurement consistency. Each sensor was calibrated and tested before deployment to ensure data reliability. Data collection spanned seven consecutive days, with measurements recorded every minute. Regular maintenance and data validation checks were conducted twice daily to ensure the consistency and integrity of the data.

The monitoring period was carefully chosen to capture typical daily activities and pollution patterns, accounting for both weekdays and weekends.

2.3. Respiratory health assessment

Respiratory health outcomes were assessed using a modified version of the American Thoracic Society Division of Lung Disease (ATS-DLD-78) questionnaire, adapted to the local context. The questionnaire covered chronic respiratory symptoms such as cough, sputum production, wheezing, and shortness of breath [14]. Additional questions were added to capture participant's exposure to specific PM2.5 emission sources relevant to the study context (e.g., proximity to street food vendors, traffic congestion areas, gas stations). We also conducted a pilot study on 40 participants who met the inclusion criteria. Face-to-face interviews were conducted using the draft questionnaire to test clarity, relevance, and comprehensibility. Based on participant feedback, minor wording adjustments were made to finalize the questionnaire before it was used in the primary study. The final version of questionnaire can be found at the Supplementary Table S1. Data collected during the pilot phase were not included in the final analysis. The sample size was calculated based on the formula for estimating a proportion. Using an expected proportion of 37.5% (p=0.375), derived from a study on respiratory symptoms in urban Pakistani populations, we set a margin of error (d) at 0.07 [15]. Participants were required to be at least 18 years old, to reside within a 10-meter radius of identified PM2.5 emission sources. Residents who had lived and worked continuously in the study area for less than three years were excluded. A stratified random sampling method was employed to ensure diverse representation across all pollution sources. Ethical approval was obtained, and written informed consent was collected from all participants. This study's ethics was approved by the Biomedical Research Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, No.253/HĐĐĐ-ĐHYD.

2.4. Statistical analysis

Continuous variables were presented as means and SD. Categorical variables were reported as frequency and percentage.

PM2.5 emission sources on ambient PM2.5 concentrations in the community was assessed following a modelling approach similar to previous studies [16,17]. The model was defined as follows:

$$P_{local} = \beta_0 + \gamma_1 (P_{background}) + \gamma_2 (temperature) + \gamma_3 (humidity) + \sum \beta_i X_i + \varepsilon$$

where:

- P_{local} (μg/m^3) represented the local mean PM2.5 concentration, measured at a 5-minute resolution within a 5-meter radius from potential emission sources.
- $P_{background}$ (μg/m^3) denoted the background PM2.5 concentration, measured at a 5-minute resolution at a height of 10 meters above the ground, serving as the reference concentration.
- *Temperature* (°C) and humidity (%) were recorded at the same 5-minute resolution.
- β_0 was the intercept, and γ_1, γ_2, γ_3, β_i were the regression coefficients.
- ε represented the error term.
- X_i was a binary variable indicating the presence of a specific PM2.5 emission source within the 5-meter radius of the measurement site.

The variable X_i was assigned a value of 1 if an emission source is present within the 5-meter radius; otherwise, it was set to 0. For example, if a traffic signal is located within this radius, X_i=1; otherwise, X_i=0. If a stationary street food vendor is present, but only operates within a specific time window (e.g., from 1:00 PM to 6:00 PM), then X_i=1 during these hours and X_i=0 otherwise. The regression model included only emission sources with active operations during the measurement period.

The normality of residuals of the data was assessed through visual inspection of Q-Q plots and/or by using the Shapiro-Wilk test. In addition, the regression model was built using hypothesis driven approach rather than determine the best fit model using statistical indices, such as Akaike Information Criteria (AIC), Bayesian information criterion (BIC). The Variance Inflation Factor (VIF) of the final model was conducted to examine the multicollinearity. Statistical analyses were conducted using R software (version 4.4.2), and the analytical process aimed to provide robust and replicable results. Regression coefficients (β) and their confidence intervals (CI) were calculated to quantify the strength of associations, for which the statistical significance was set at 95%. A logistic regression analysis was conducted to examine the association between area-level PM2.5 concentration and respiratory symptoms, including odds ratios (OR) and 95% CI.

3. RESULTS

3.1. PM2.5 concentration levels

The PM2.5 monitoring data collected over seven consecutive days revealed significant variations across different emission sources. The highest 24-hour average PM2.5 concentration was recorded near stationary street food vendor areas, with a mean of 41.7 μg/m^3, and the peak level reached 598.0 μg/m^3 (Fig. 3). This was followed by stop-and-go traffic zones (16.4 μg/m^3) and continuous traffic areas (14.8 μg/m^3). In contrast, the background control site elevated 10 meters above ground level reported the lowest concentration at 14.0 μg/m^3. Notably, PM2.5 levels spiked at temple sites on the Buddhist Vesak holiday, reflecting ritual incense burning activities (19.1 μg/m^3) (Fig. 3).

Daily average PM2.5 concentrations generally met the QCVN 05:2023 standards (50 μg/m^3), except for the location near continuous traffic and stationary street food vendors (P8.1), which exceeded the limit on May 30th (52 μg/m^3). However, when compared to WHO's 2021 standard for 24-hour PM2.5 levels (15 μg/m^3), nearly 50% of the daily measurements did not meet the guideline (Fig. 4).

The multivariable regression model examining factors associated with community PM2.5 concentrations included continuous traffic, stop-and-go traffic, religious temples, stationary street food vendors, fuel stations, traffic near schools, background levels, temperature, and humidity. This model explained 34% of the variance in the 5-minute average PM2.5 concentration in the community. Table 1 presents the emission sources in descending order of their partial R^2 values.

In the multivariable regression model, among various PM2.5 emission sources, areas with stationary street food vendors exhibited a 53.22 μg/m^3 higher 5-minute average PM2.5 concentration compared to areas without stationary street food vendors, with statistical significance ($p<0.001$). This emission source contributed the most to the variation in PM2.5 concentrations within the study area, with a partial R^2 of 21.15%.

3.2. Respiratory health outcomes

A total of 220 individuals were approached, with 36 excluded due to incomplete responses or ineligibility, resulting in a final sample of 184 and a response rate of 83.6%. Table 2 shows the characteristics of participants in the study. Among the 184 study participants, the largest age group was over 37 years old, accounting for 63.6%. The gender distribution was relatively balanced between males and females. The most common occupation was business/trade (37.5%), while homemakers had the lowest proportion (16.9%). The majority of participants had lived and worked in the study area for 3 to 10 years (44.6%). The prevalence of participants with a history of respiratory-related diseases (including asthma, tuberculosis, etc.) was 13.0%. Most participants were non-smokers (78.8%) and did not live with a smoker (72.3%). Incense use was reported by 73.4% of participants. Among environmental exposures, the highest proportion of participants lived near continuous traffic (35.3%), while the lowest proportion lived near fuel stations (7.6%).

Table 3 shows the association between living near PM2.5 sources and respiratory symptoms measured by ATS-DLD-78. There was a statistically significant association between sputum production and living near continuous traffic. Participants with sputum production had 5.54 times

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Fig. 3. Average PM2.5 concentrations across various pollution sources in district 5.

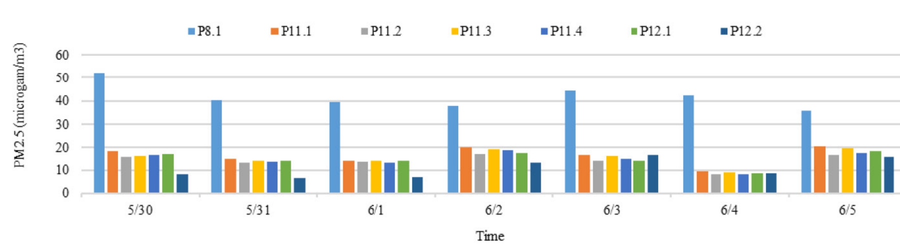

Fig. 4. Daily average PM2.5 concentration across different monitoring sites. Types of PM2.5 sources: P8.1: stationary street food vendor, continuous traffic; P11.1: stop and go traffic; P11.2: background control; P11.3: school, Temples; P11.4: continuous traffic; P12.1: stop and go traffic, fuel station; P12.2: school.

higher odds of living near continuous traffic areas compared to those without sputum production (OR=5.54, 95% CI: 1.95–18.4). Similarly, participants with sputum production had 3.45 times higher odds of living near stationary street food vendor areas compared to those without this symptom (OR=3.45, 95% CI: 1.08–10.1). However, the study did not

Table 1. Multivariable regression analysis of PM2.5 exposure and respiratory symptoms

Pollution source	Regression coefficient (β)	p-value	Partial R^2
Stationary street food vendors	53.22	<0.001	0.2115
Stop-and-go yraffic	4.52	<0.001	0.0028
Continuous yraffic	7.47	<0.001	0.0093
Temples	3.67	<0.001	0.0024
Fuel stations	–1.52	0.024	0.0004
Background site (10 m)	1.03	<0.001	0.1180
Temperature	0.34	0.120	0.0002
Humidity	0.28	0.002	0.0008

Table 2. Baseline characteristics of study participants (n=184)

Characteristic	Frequency	Percentage (%)	Characteristic	Frequency	Percentage (%)
Age group			Incense use		
18–27 years	23	12.5	No	49	26.6
28–37 years	44	23.9	Yes	135	73.4
>37 years	117	63.6	Living with a smoker		
Gender			No	133	72.3
Male	96	52.2	Yes	51	27.7
Female	88	47.8	Living near stop-and-go traffic		
Current occupation			No	126	68.5
Homemaker	31	16.9	Yes	58	31.5
Office worker	32	17.4	Living near continuous traffic		
Business/trade	69	37.5	No	119	64.7
Other	52	28.3	Yes	65	35.3
Duration of residence in the area			Living near school traffic		
3–10 years	82	44.6	No	129	70.1
11–20 years	44	23.9	Yes	55	29.9
>20 years	58	31.5	Living near a fuel station		
History of respiratory diseases			No	170	92.4
No	160	87.0	Yes	14	7.6
Yes	24	13.0	Living near street food vendors		
Smoking status			No	157	85.3
Never	145	78.8	Yes	27	14.7
Current smoker	31	16.9	Living near a temple		
Former smoker	8	4.4	No	152	82.6
			Yes	32	17.4

find a statistically significant association between living near PM2.5 emission sources and other respiratory symptoms, including cough, wheezing, and shortness of breath among the study participants.

Multicollinearity diagnostics indicated high VIF values for temperature and relative humidity, suggesting a strong correlation between these two meteorological variables. To assess their individual contributions and potential collinearity effects, we compared the full model (including both variables) with two reduced models: one excluding temperature and one excluding relative humidity. The regression coefficients remained stable across models, indicating that multicollinearity did not substantially bias the estimates (Supplement ary Table S2). Nonetheless, this limitation should be considered when interpreting the influence of environmental variables on PM2.5 concentrations.

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Table 3. Association between living near PM2.5 emission sources and respiratory symptoms among study participants (n=184)

Characteristic	Cough OR (95% CI)	Sputum production OR (95% CI)	Wheezing OR (95% CI)	Shortness of breath OR (95% CI)
Living near stop-and-go traffic				
No	1	1	1	1
Yes	1.03 (0.39–2.51)	1.60 (0.54–4.46)	0.84 (0.25–2.37)	1.27 (0.50–3.05)
Living near continuous traffic				
No	1	1	1	1
Yes	1.26 (0.51–3.00)	5.54 (1.95–18.4)*	2.50 (0.92–7.00)	0.85 (0.33–2.06)
Living near school traffic				
No	1	NA	1	1
Yes	0.56 (0.17–1.48)		0.28 (0.04–1.06)	0.72 (0.25–1.84)
Living near fuel stations				
No	1	1		1
Yes	1.89 (0.38–6.76)	0.78 (0.03–4.36)	0.78 (0.03–4.36)	2.87 (0.71–9.66)
Living near stationary street food vendors				
No	1	1	1	1
Yes	0.50 (0.07–1.85)	3.45 (1.08–10.1)*	0.75 (0.10–2.90)	0.50 (0.07–1.85)
Living near temples				
No	1	NA	NA	1
Yes	0.40 (0.06–1.47)			0.64 (0.14–2.02)

* $p<0.05$.
OR, odds ratio; CI, confidence interval; NA, not applicable.

4. DISCUSSION

4.1. Air quality standards and PM2.5 concentrations

The daily average PM2.5 concentrations on most study days met the Vietnamese National Technical Regulation on Ambient Air Quality (QCVN 05:2023). However, when compared to the 2021 WHO Air Quality Guidelines, which set a 24-hour PM2.5 standard of 15 μg/m^3, the proportion of days exceeding this threshold was relatively high (57.1%).

4.2. Impact of street food cooking on PM2.5 levels

In our study, the nearest stationary street food vendor to the PM2.5 monitoring device operated only between 6:00 AM and 1:00 PM daily. During these hours, PM2.5 concentrations spiked significantly, exceeding the Vietnamese standard multiple times and at certain moments, reaching levels ten times higher than the allowable limit. This suggested that cooking activities at street food stalls directly influence the 24-hour average PM2.5 concentration, resulting in substantial variations across monitoring locations.

Previous studies worldwide have also identified cooking activities as a major contributor to urban PM pollution. In Taiwan, 24% of study participants lived within 15 meters of smoke-emitting restaurants [18]. Additionally, studies have shown that cooking with charcoal produced the highest PM2.5 emissions compared to other fuel types [19]. The level of PM2.5 emissions is also influenced by the type of cooking oil used and the cooking method applied [20,21]. In our study area, stationary street food vendors primarily used gas stoves for frying and stir-frying, with an average PM2.5 concentration of 41.7 μg/m^3 during the monitoring period, peaking at 598.0 μg/m^3, with the lowest recorded concentration at 3.8 μg/m^3.

4.3. Influence of incense burning in temples on PM2.5 concentrations

One notable observation was on June 2nd, corresponding to the full moon of the fourth lunar month, a significant religious day. On this date, the 24-hour average PM2.5 concentration at site P11.3 increased to 19.1 μg/m^3, the highest level recorded at this location during the study period. A similar study conducted at temples in Vietnam and Taiwan reported comparable findings, where PM1 and PM2.5 levels on religious event days (1st and 15th in the lunar calendar) were approximately twice as high as on non-event days, highlighting the impact of incense burning on PM levels [22].

4.4. Contribution of traffic-related PM2.5 emissions

Traffic-related PM2.5 sources in our study included continuous traffic (P11.4), stop-and-go traffic (P11.1), and school traffic (P12.2). These locations were selected as they had only one primary traffic-related emission source within a 5-meter radius. Other locations, such as P8.1, P11.3, and P12.1, had additional emission sources (e.g., temples, fuel stations, or stationary street food vendors) within the 5-meter range. Although the association between living near continuous traffic and sputum production was statistically significant, the 95% CI was relatively wide (OR=5.54, 95% CI: 1.95–18.4), indicating a high degree of uncertainty around the point estimate. This may be attributed to the limited sample size in certain exposure groups, which reduced the precision of the estimated OR. Therefore, this result should be interpreted with caution. Future studies with larger sample sizes are needed to confirm this association and provide more stable estimates.

In Vietnam, traffic emissions are a dominant source of air pollution. According to 2018 statistics, Ho Chi Minh City had a total population of 8.8 million, while the number of registered vehicles was 8,658,087 - including 762,581 cars and 7,895,506 motorcycles - not accounting for vehicles entering the city from neighbouring provinces [23]. With most vehicles relying on gasoline and diesel fuels, combustion emissions are the primary source of air pollutants. At intersections and road junctions, air pollution levels tend to be higher due to vehicles accelerating and restarting. Similarly, fuel stations and school traffic zones experience increased pollution levels due to vehicle idling and stopping. Additionally, narrow roads, aging infrastructure, and frequent traffic congestion further exacerbate urban air pollution, particularly in high-density cities like Ho Chi Minh City.

4.5. Multivariate regression model for PM2.5 sources

The multivariate regression model assessing community PM2.5 sources in our study included continuous traffic, stop-and-go traffic, temples, stationary street food vendors, fuel stations, school traffic, temperature, and humidity, explaining 34% of the variance in the 5-minute average PM2.5 concentration. Among these sources, stationary street food vendors contributed the most, with a partial R^2 of 21.1%.

A similar study by S.C.C. Lung et al. [17] assessed community-level PM2.5 sources, incorporating multiple emission sources. Their model explained 57% of PM2.5 variance, with background PM2.5 levels contributing the most (partial R^2=54.3%), followed by seasonal effects (0.16%) [17]. In contrast, in our study area, stationary street food vendors were the dominant contributor, with higher PM2.5 concentrations (53.22 $\mu g/m^3$) than areas without food stalls. Moreover, continuous traffic contributed more to PM2.5 levels than stop-and-go traffic, likely due to differences in fuel types, cooking materials, and the characteristics of the residential area. The negative regression coefficient associated with the gas station variable may be attributed to several factors. Many gas stations are located on open lots set with lower traffic density and better natural ventilation, which may reduce PM2.5 accumulation. Alternatively, this result may reflect confounding factors or sample limitations and should be interpreted with caution.

4.6. Limited research on PM2.5 source contributions in Vietnam

In Vietnam, there is limited research on PM2.5 source contributions using low-cost sensors, while emission inventories are more commonly used. A PM2.5 emission inventory study in Ho Chi Minh City reported that restaurants and food stalls accounted for 29.56% of total PM2.5 emissions from area sources [24], highlighting their significant contribution to urban air pollution.

4.7. Comparison with other Asian urban environments

Living near traffic and other PM2.5 sources has been extensively studied in Asian cities. In Taiwan, 30% of residents lived within 15 meters of major roads, and 24% lived near smoke-emitting restaurants. Additionally, 13% lived near night markets, and 40% resided within 50 meters of temples

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where incense burning occurred [18]. A separate survey found that 54.3% of Taipei's urban population lived within 10 meters of a major road [16].

Urban residential areas in Asia differ significantly from Western cities, partly due to historical development patterns, high population density, and a lack of strict urban planning. Over time, food stalls, traffic, temples, and schools have become interwoven into residential areas, exposing communities to multi-source air pollution. Importantly, this localized pollution is not always reflected in data from fixed air quality monitoring stations.

4.8. Health impacts of living near PM2.5 emission sources

The association between residential proximity to traffic and respiratory health has been extensively studied. One study found that individuals living within 100 meters of a major road had a 2.54-fold higher odds of chronic cough than those living beyond 200 meters [25]. Another study found that individuals living within 20 meters of major roads had a 15% higher risk of frequent sputum production, a 34% higher risk of wheezing and other respiratory issues, even among non-smokers [26].

Street food is a distinctive feature of Asian cities, with vendors typically located near traffic-heavy areas for convenience and accessibility. However, stationary street food vendors are among the most affected by air pollution, with 86.2% reporting respiratory symptoms in the past 12 months. Their forced expiratory volume in 1 second (FEV1) and forced vital capacity values were significantly lower than predicted values, indicating adverse respiratory effects [27].

In our study, we identified a statistically significant association between living near stationary street food vendors and sputum production (OR=3.45, p=0.03). This may be due to the fact that sputum production is a more immediate and sensitive response to airway irritation caused by particulate matter, particularly in environments with prolonged or repeated exposure.

4.9. Study limitations and future research directions

Our study successfully utilized low-cost sensors for community-level PM2.5 monitoring, offering high-resolution (1-minute) continuous measurements. However, data collection was conducted only during the rainy season, limiting our ability to account for seasonal variations. In Ho Chi Minh City, PM2.5 level peaks in the dry season (February) and declines during the rainy season (August) [24]. Future studies should incorporate seasonal and precipitation effects into regression models.

Additionally, outdoor sensor placement and power supply constraints during the rainy season resulted in fewer valid monitoring days than anticipated. Although limited to seven days, the monitoring period included a significant local event—the Buddhist Vesak holiday—allowing the study to assess the impact of religious activities on PM2.5 levels. Future studies should consider longer monitoring periods to capture seasonal variations in air pollution. Moreover, respiratory symptoms were self-reported, potentially introducing recall bias.

This study employed a hypothesis-driven regression approach and did not use model selection criteria such as AIC or BIC. Multicollinearity was assessed using VIF, which revealed high values for temperature and relative humidity. We addressed this by comparing models with and without these variables and found consistent estimates. However, other aspects of model fit were not fully evaluated. In addition, repeated measurements may have introduced temporal autocorrelation, which was reduced through daily averaging but not completely eliminated. Future studies should consider larger datasets and more advanced modelling strategies.

5. CONCLUSION

This study successfully achieved its objectives of identifying and quantifying the contributions of various localized PM2.5 pollution sources and their direct impact on respiratory health in densely populated areas of Ho Chi Minh City. Notably, emissions from stationary street food vendors and traffic congestion were identified as the most significant contributors to elevated PM2.5 concentrations, with a strong correlation to the symptom of sputum production. This finding fills a critical research gap in Vietnam, highlighting the urgent need for source-specific mitigation strategies to protect public health.

SUPPLEMENTARY MATERIALS

Supplementary materials are only available online from: https://doi.org/10.32895/MPR.25.00026

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Conflict of interest

No potential conflict of interest relevant to this article was reported.

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Authors' contributions

Conceptualization: DN Tran.
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Formal analysis: TTT Phan, DN Tran.
Methodology: TTA Tran, LTH Bui, DN Tran.
Writing - original draft: TTT Phan, QM Lam, TTH Huynh.
Writing - review & editing: TTT Phan, TTA Tran, QM Lam, TTH Huynh, LTH Bui, DN Tran.

Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval

This study's ethics was approved by the Biomedical Research Ethics Committee of The university of Medicine and Pharmacy at Ho Chi Minh City, No. 253/HĐĐĐ-ĐHYD.

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