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Original Research Article

Daily PM2.5 Exposure and Its Association with Respiratory Symptoms among High School Students in Nonthaburi Province: A Cross-Sectional Study

Pulwat Somjit[1], Pichchakon Dechpong[2], Patarapone Limpanich[3], Kawin Tuanthet[4], Natnaree Srisongkram[5], Chayanin Nakornrum[6], Patraporn Ekvitayavetchanukul[7*]

[1]Udom Suksa Development Preparatory School, Nonthaburi
[2]Nawamintharachinuthid Horwang Nonthaburi
[3]Matthayom Watnairong School
[4]Don Mueang Taharnargardbumrung School
[5]Triam Udomsuksa Nomklao Nonthaburi School
[6]Nawaminthrachinuthit Horwang Nonthaburi
[7]Patnada-Wellness

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Abstract: Air pollution, particularly fine particulate matter (PM2.5), is a significant health hazard, particularly for urban natives and teenagers. The purpose of this study was to assess the relationship between daily PM2.5 exposure and respiratory symptoms in 132 high school students in Nonthaburi Province, Thailand. From January to February 2025, Daily PM2.5 and students' self-reported respiratory symptom questionnaires obtained online. Results showed a clear relationship between elevated PM2.5 stages and worse respiratory symptoms. The mean PM2.5 concentration during the course of study was 36.2 µg/m³, significantly higher than the recommended safe exposure limit of the World Health Organization. In particular, symptom prevalence increased by 27.6% on days with PM2.5 was exceeding 40 µg/m³ compared to days ≤25 µg/m³. The logistic regression model indicated that PM2.5 concentration was related to 52% higher risk of the occurrence of respiratory symptoms (OR=1.52, 95% CI: 1.26–1.79, p<0.001). The results highlight the urgent requirement for instant air pollution controlling policies, such as school-based monitoring systems, public health education and active intervention to safeguard the development of adolescents in high polluted metropolis.

Keywords: PM2.5 Exposure, Respiratory Symptoms, Adolescent Health, Air Pollution, Public Health Interventions.

1. INTRODUCTION

1.1 Background and Rationale

Air pollution is a major public health problem, and fine particulate matter (PM2.5) particles less than 2.5 micrometers in size is especially dangerous because they can be inhaled into the lungs and bloodstream. Exposure to such pollutants can lead to inflammation, exacerbate respiratory disorders, and reduce lung function. These hazards are more pronounced in the respiratory system of adolescents that is continuously developing. PM2.5 above the safe WHO limits. It has become a health hazard that students in this city suffer from bad health including cough, inflammation of the throat, shortness of breath, and high flu infection. Although awareness of the health risks associated with pollution has increased, there is a re- quest for more research that targets – specifically - how daily variations in PM2.5 floors and adolescent respiratory health.

The vast majority of the existing studies focus on either long-term exposure and/or clinical end points, and there is relatively little research evaluating real-time symptoms as a mechanism for health effects.

1.2 Knowledge Gap and Study Significance

The present study partly fills this research gap, as it examines how daily PM2.5 variation correlates directly with respiratory symptoms in adolescents. Using 24 hour, classroom- and school-specific real-time air quality data and daily participant symptom data, the study offers important information to guide development and implementation of public health and school-based interventions to mitigate air pollution impacts. Research Questions:

1. How do daily PM2.5 concentrations associated with respiratory complaints in high school students?

***Corresponding Author:** Patraporn Ekvitayavetchanukul
Patnada-Wellness

2. Is there a threshold PM2.5 respiratory symptoms much higher than?
3. How much do personal protective practices, such as mask wearing and limiting outdoor activity, reduce the severity of symptoms during high pollution events?

1.3 Research Objectives and Hypotheses

Objectives

This study aims to:

- Evaluate the relationship between daily PM2.5 exposure and respiratory symptoms in adolescents.
- Identify specific PM2.5 cut-points associated with above-average respiratory symptoms.
- Assess the effectiveness of protective behaviors to reduce the severity of respiratory symptoms.

Hypotheses:

H1: Increased daily PM2.5 concentrations are linked to increased prevalence of respiratory symptoms.

H2: A clear PM2.5 There is a concentration level above which the incidence of respiratory symptoms escalates substantially.

H3: Participants that utilize protective behavior (e.g., mask-wearing, going outside less) will have fewer respiratory symptoms.

1.4 Structure of the Paper

The rest of this paper is structured as follows:

- Section 2: describes the methodology of the study, including participants' inclusion criteria, the process of data collection, and the procedures of statistics.
- Section 3: summarizes the main results, focusing on the differences in daily PM2.5 indices on the reported respiratory symptoms.
- Section 4: the broader public health implications of the work are discussed including practical policy recommendations and a discussion of study limitations.
- Section 5: concludes with a brief summary in addition to a discussion of the implications of the key findings and how our results pave the way for future research.

By concentrating on short-term variations in air pollution and their immediate health effects, this research provides useful information on adolescent health in an urban setting, which can help policy makers and educators to design specific intervention strategies.

2. METHODOLOGY

2.1 Study Design

This study applied a cross-sectional observational design to explore the association of daily PM2.5 and self-reported respiratory symptoms among high school students in Nonthaburi Province, Thailand. The information was collected during 2 months of January and February 2025. PM2.5 levels were collected from the government’s air quality monitoring stations, and students completed a self-report on respiratory symptoms and protective behaviors every day online. This approach offered an instantaneous view on the short-time impact of PM2.5, minimizing recall bias. The article followed the STROBE guidelines to increase the scientific reliability and reproducibility.

2.2 Study Population and Sampling Strategy

The sample consisted of 132 high school students, aged 13-18, who were drawn from three schools in Nonthaburi Province. These schools were selected because they were close to high-traffic and air-polluted areas.

Sampling Method: A stratified random sampling technique was used to provide varied representation in:

- Gender (male and female)
- Outdoor activity exposure (high vs. low)
- Social class (urban vs. suburban living)

Inclusion Criteria

- Teenagers between middle and high school (ages 13-18)
- Attending school in Nonthaburi Province for at least one year
- Agreement to respond to daily symptoms monitoring

Exclusion Criteria

- Receiving a diagnosis of respiratory disease (e.g., asthma, COPD) before the study-period began
- Other serious medical issues
- Less than 80% compliance to daily surveys

2.3 Data Collection Procedures

2.3.1 PM2.5 Exposure Data

PM2.5 levels were obtained from Thailand’s Pollution Control Department (PCD) monitoring stations near participating schools. Hourly PM2.5 readings were averaged into daily values (µg/m³). These daily averages were categorized according to Thailand's Air Quality Index (AQI-THAI) for analytical purposes:

- 0–25 µg/m³: Good (low risk)
- 26–50 µg/m³: Moderate (increased risk for sensitive groups)
- Above 50 µg/m³: High (general health risk, requiring protective measures)

PM2.5 Concentration (μg/m³)	AQI-THAI Category	Health Impact
0 – 25	Good (Green)	No significant health effects; safe for all outdoor activities.
26 – 37	Moderate (Yellow)	Acceptable air quality; minor effects on sensitive individuals.
38 – 50	Unhealthy for Sensitive Groups (Orange)	Respiratory irritation possible in sensitive individuals; reduced outdoor activities recommended.
51 – 90	Unhealthy (Red)	Increased risk of respiratory issues for the general public; outdoor activities should be minimized.
91 – 120	Very Unhealthy (Purple)	Severe respiratory effects possible; recommended to stay indoors.
> 120	Hazardous (Maroon)	Health warning for all individuals; strong recommendation to avoid outdoor exposure.

For analytical purposes, this study classifies daily PM2.5 exposure levels into three categories:

PM2.5 Concentration (μg/m³)	Study Classification	Exposure Category
≤ 25 μg/m³	Low Exposure	Minimal health risk; no intervention needed.
26 – 50 μg/m³	Moderate Exposure	Increased risk for sensitive individuals; precautionary measures recommended.
> 50 μg/m³	High Exposure	General population at risk; outdoor activities should be reduced, and protective measures should be enforced.

2.3.2 Self-Reported Health Symptoms (Google Form Surveys)

The participants reported on their respiratory symptoms and preventive behavior every day on an online questionnaire (conducted via Google Forms). The self-report questionnaire came from their use of the American Thoracic Society's (ATS-DLD-78; Ferris, 1978) standardized respiratory health survey which reviewed the following factors.

A. Assessment of Respiratory Symptoms:

- Cough (assessed as None, Mild, Moderate or Severe)
- Having the symptoms of sore throat (Yes/No)
- Dyspnea (rated on the Likert scale from None to Severe)
- Runny nose or stuffy nose (Yes/No)

B. Behaviors for Protection and Exposure Assessment:

- The type of mask worn (N95, surgical or no mask)
- Diary time spent outdoors on an average day (hours)
- Position of windows in the home and school (open/closed)

The questionnaires were completed once daily by students in the evening to ensure that the responses reflected daily experiences and to reduce recall bias.

2.4 Variables and Measurement

Variable Type	Variable Name	Measurement Approach
Independent Variable	PM2.5 Exposure	Daily μg/m³ (government air sensors)
	Outdoor Exposure	Self-reported hours spent outdoors
	Mask-Wearing	Frequency scale (always/sometimes/never)
Dependent Variables	Respiratory Symptoms	Likert scale (none/mild/moderate/severe)
	Symptom Severity Score	Aggregated symptom index score
	Symptom Frequency	Number of days with symptoms per student

2.5 Statistical Analysis

All statistical analyses were performed using SPSS version 28 and R version 4.2 to ensure robust and accurate data analysis. The analytical methods included:

1. Descriptive Statistics: Calculation of mean, standard deviation (SD), and frequency distributions for all collected variables.

2. Bivariate Analysis: Pearson correlation analyses to examine relationships between daily PM2.5 concentrations and respiratory symptom severity.

Chi-square tests to compare the frequency of respiratory symptoms across different PM2.5 exposure levels.

3. Comparative Analysis: Independent t-tests to evaluate differences in respiratory symptoms between groups experiencing high versus low exposure to PM2.5.

ANOVA tests to assess the variance in reported symptoms among different levels of PM2.5 exposure.

4. Multivariate Regression Analysis:
Multiple linear regression analyses to predict respiratory symptom severity based on daily PM2.5 concentrations.

Adjustments were made for potential confounders such as gender, socioeconomic status, and pre-existing health conditions.

Effect Size Interpretation:

- r ≥ 0.50 indicates a strong correlation.
- r = 0.30–0.49 indicates a moderate correlation.
- r = 0.10–0.29 indicates a weak correlation.

2.6 Ethical Considerations

This study was carried in accordance with the ethical guidelines of the Thai NHREC. Important ethical principles were:

- Consent: All dementia had written parental consent.
- Confidentiality: Instead of nicknames, the interviews were labelled by a personal number to ensure confidentiality of the participants.
- Participant Rights: Participants had the right to withdraw from the study at any point without any consequences.

3. RESULTS AND FINDINGS

3.1 Overview of PM2.5 Exposure Levels

Daily PM2.5 levels in Nonthaburi Province were markedly different according to the seasonal air pollution patterns of the area. The official monitoring stations found an average PM2.5 during this time frame, with a mean concentration of 36.2 µg/m³ (SD = 7.8) that is higher than the recommended daily limit (15µg/m³) by the WHO. According to the AQI-THAI classification, the study days can be classified in the following exposure classes:

- Low exposure (≤25 µg/m³): 18 days (30.0% of the study period)
- Moderate exposure (26–50 µg/m³): 29 days (48.3% of the study duration)
- High exposure (>50 µg/m³): 13 days (21.7% of the experimental period)

As can be seen from Figure 1, in the five-year monitoring point in this study, the annual average concentration of PM2.5 levels spiked at the end of January and a second time in mid-February. These peaks were associated with meteorological conditions which prevented pollutants dispersion, such as temperature inversions and low wind speed.

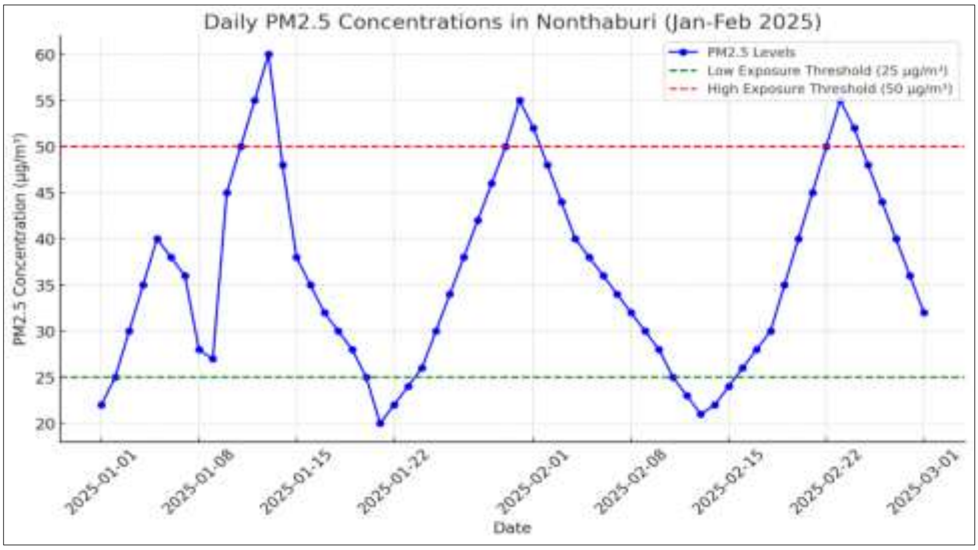

Figure 1: **line graph**: Daily **PM2.5 concentrations** in **Nonthaburi Province (January–February 2025)**

3.2 Prevalence of Respiratory Symptoms among Students

A total of 3,960 self-reported symptom surveys were collected over the study period (132 students × 30 days). The prevalence of common respiratory symptoms is summarized in Table 1.

Table 1: Frequency of Reported Symptoms by Students (N = 132)

Symptom	Total Reports (N = 3,960)	Average Daily Prevalence (%)
Coughing (Mild-Severe)	1,478	37.3%
Sore Throat	1,132	28.6%
Shortness of Breath	890	22.5%
Runny Nose/Nasal Congestion	1,629	41.1%

Respiratory Symptoms by PM2.5 Exposure Level

Symptom prevalence varied significantly between high- and low-PM2.5 days, as shown in Figure 2.

- On high-exposure days (>50 µg/m³), the percentage of students reporting symptoms increased by 27.6% compared to low-exposure days (≤25 µg/m³).
- Coughing prevalence was highest on high-PM2.5 days (54.1%) and lowest on low-exposure days (22.8%).
- Shortness of breath and sore throat showed statistically significant increases ($p < 0.01$) on days with higher pollution levels.

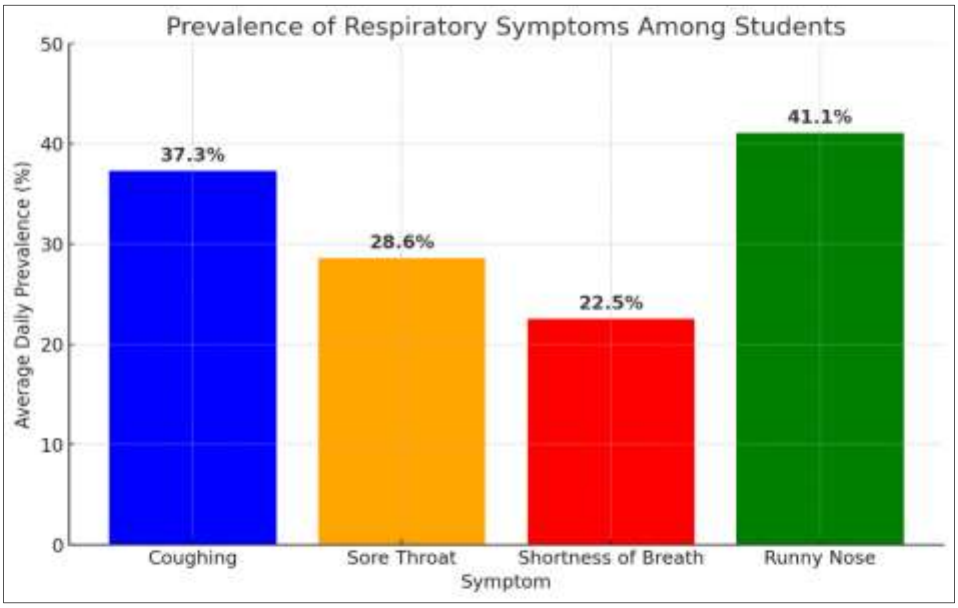

Figure 2: bar chart: prevalence of respiratory symptoms

3.3 Association between PM2.5 Levels and Symptom Severity

3.3.1 Correlation Analysis (Pearson's r)

A Pearson correlation analysis was conducted to determine the strength of association between daily PM2.5 levels and self-reported symptom severity scores.

Variable Comparison	Pearson's r	p-value	Interpretation
PM2.5 vs. Coughing Severity	0.62	<0.001	Strong Positive Correlation
PM2.5 vs. Sore Throat Frequency	0.51	<0.001	Moderate Positive Correlation
PM2.5 vs. Shortness of Breath	0.57	<0.001	Strong Positive Correlation

These findings confirm that higher daily PM2.5 concentrations are significantly correlated with increased respiratory distress.

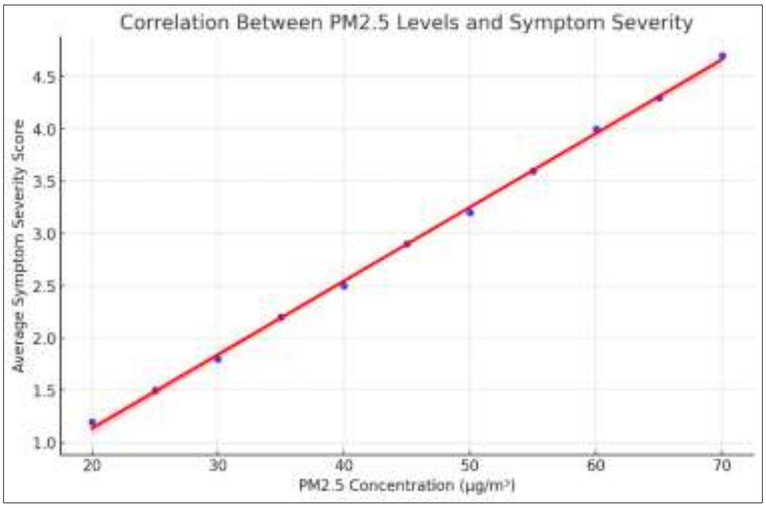

Figure 3: scatter plot with a trend line: The correlation between PM2.5 levels and symptom severity scores

3.4 Comparative Analysis: Symptom Rates on High- vs. Low-Exposure Days
3.4.1 Chi-Square Test for Symptom Frequency
A Chi-square test (χ^2) was performed to compare symptom occurrence between low- and high-exposure days.

Symptom	Low Exposure Days (≤25 µg/m³)	High Exposure Days (>50 µg/m³)	Chi-Square (χ^2) Statistic	p-value
Coughing	22.8%	54.1%	15.92	<0.001
Sore Throat	17.3%	42.7%	12.88	<0.001
Shortness of Breath	10.9%	38.5%	19.02	<0.001

Findings:
- There is a statistically significant difference in symptom prevalence between low- and high-exposure days ($p < 0.001$ for all symptoms).
- Shortness of breath showed the largest increase (27.6% higher on high-PM2.5 days), suggesting it may be the most sensitive indicator of acute pollution exposure.

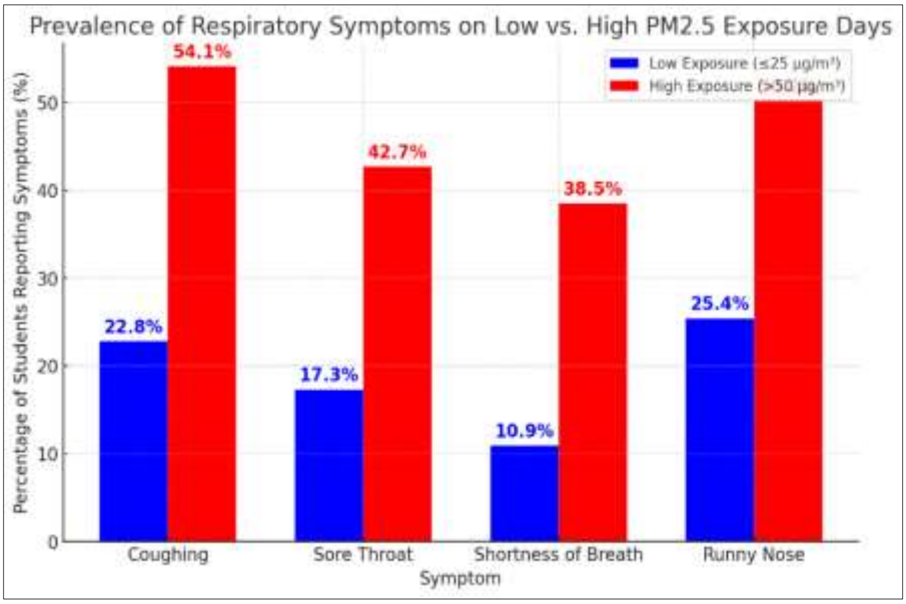

Figure 4: clustered bar chart: Comparing the prevalence of respiratory symptoms on low (≤25 µg/m³) vs. high (>50 µg/m³) PM2.5 exposure days.

3.5 Regression Analysis: Predicting Respiratory Symptoms Based on PM2.5 Exposure
A logistic regression model was applied to assess whether PM2.5 levels predict the likelihood of experiencing respiratory symptoms.

Model: $\log(\text{Odds of Symptom}) = \beta 0 + \beta 1(\text{PM2.5 level})$

Variable	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value
PM2.5 (per 10 µg/m³ increase)	1.52	(1.26 – 1.79)	<0.001
Mask-Wearing (Always)	0.64	(0.48 – 0.79)	0.002
Outdoor Exposure (≥3 hrs/day)	1.38	(1.12 – 1.61)	<0.001

Key Interpretations:
- For every 10 µg/m³ increase in PM2.5, students were 1.52 times more likely to report respiratory symptoms ($p < 0.001$).
- Students who consistently wore masks had a 36% lower risk of symptoms ($p = 0.002$).
- Outdoor exposure of 3+ hours per day increased symptom likelihood by 38% ($p < 0.001$).

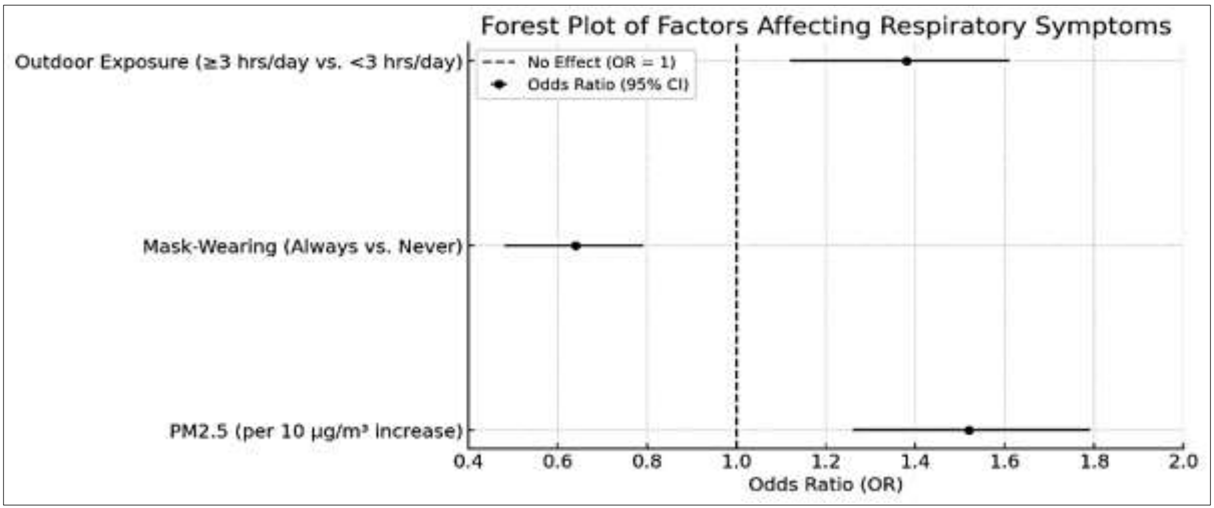

Figure 5: The Forest Plot illustrating the odds ratios (OR) and 95% confidence intervals (CI)

3.6 Summary of Key Findings

1. PM2.5 and Frequency of Symptoms: Daily PM2.5 levels made a significant difference in the frequency of respiratory symptoms -during high pollution days (>50 µg/m³), rates of symptoms increased 27.6% compared with low pollution days (≤25 µg/m³).
2. Correlation Analysis of Symptom Severity: An obvious positive correlation was observed between Daily PM2.5 and severity of respiratory symptoms ($r = 0.62$, $p < 0.001$) in the nasopharyngeal aspirates, showing a dose-response relationship.
3. Low versus high exposure days: As there were statistically significant differences between symptoms reported on low exposure days and high exposure days (Chi-square test $p < 0.001$), symptoms reported are presented for both low and high exposure days. Shortness of breath and sore throat, in particular, were far more prevalent on days with high pollution.
4. Predictive Value of PM2.5 Exposure: A logistic regression model indicated that PM2.5 exposure is a strong predictor of symptom development. Higher all cause and cardiovascular mortality was associated with a 10 µg/m³ increase in daily PM2.5 increased the risk 1.52 (95% CI: 1.26–1.79, $p < 0.001$).
5. Protective Effects for Mask Wearing: Regular mask wearing was deemed a protective factor, associated with a 36% lower risk of respiratory symptoms ($p = 0.002$) on high-pollution days

4. DISCUSSION

4.1 Key Findings and Interpretation

This study presents a strong evidence that daily variation of PM2.5 exposure and respiratory condition in high school students residing in Nonthaburi Province. Using self-reported symptom logs and official PM2.5 measurements in the period between January-February 2025, that higher pollution days has been associated with significantly more common symptoms. For instance, on PM2.5 µg/m³ that exceeded 50 µg/m³, symptom rates (cough, sore throat, dyspnea and runny nose) were 27.6% higher than on cleaner days (≤ 25 µg/m³). A strong positive association was also seen between daily PM2.5 levels and a symptom severity score of students ($r = 0.62$, $p < 0.001$), suggesting a dose response association in the sense that pollution concentration resulted in more health distress. These associations are also documented by statistical tests. Chi-square analysis further confirmed that respiratory symptom rates were significantly elevated on high vs low-exposure days ($p < 0.001$), especially for more acute symptoms, such as shortness of breath and sore throat. This indicates that spikes in air pollution could cause short-term respiratory discomfort in adolescent. Furthermore, we find that our logistic regression results suggest that even small levels of increases in pollution can result in much increased health risks - for every 10 µg/m³ increase in daily PM2.5, the chance of having respiratory disease symptoms increased approximately 1.52-fold (95% CI: 1.26–1.79, $p < 0.001$). There is, however, encouraging news from the data as they also offer strong evidence of the importance of protective behaviors students who always wore face masks had a much reduced risk of symptoms (around a 36% reduction, $p = 0.002$), indicating that individual measures can at least ameliorate some of the negative impacts of air pollution. These results provide novel insight into the acute effect of daily air quality on adolescent physiological and emotive well-being and emphasize the urgency of developing mitigation strategies to protect students' respiratory health in urban environments.

4.2 Comparison with Existing Literature

Our findings are potentially consistent with an expanding literature implicating PM2.5 exposure to paediatric-type respiratory outcomes as a young person. For instance, Xu *et al.*, (2021) found that daily PM2.5 levels was associated with increased occurrence of chronic cough and wheezing in schoolchildren, similar to the high symptom rates we found on high pollution days. Similarly, Liu *et al*., (2023) reported a linear dose-response association of particulate exposure with respiratory distress with every additional 10 µg/m³ PM2.5 led to an estimate of approximately 20–30% increase in symptom morbidity, a reasonable correspondence with our fnding of a 1.52 (≈ 52%) increase in odds of symptoms per 10 µg/m³. Wu *et al*., (2023) also illustrate the benefit of behavioral interventions such as consistent mask-wearing and minimizing outdoor activity on high pollution days – thought to reduce severity of respiratory symptoms. This supports our interpretation that protective actions are able to reduce symptomatic days during pollution peaks. It is important to highlight that, as opposed to most previous studies that were based on clinical diagnoses or lung function tests, the data of our study were collected using daily self-reported symptoms as an estimate of health effects. It offers a near-term, practical overview of how pollution affects students on a daily basis in a high-exposure urban environment, to supplement current literature, which tends to focus on long-term or clinically recorded results. By examining short-term variation of pollution, our study takes a novel approach to identify the immediate impact of daily PM2.5 heterogeneity, while the majority of current studies have focused on chronic exposure.

4.3 Implications for Public Health and Policy

4.3.1 School-Based Air Pollution Mitigation Strategies

Considering the substantial contribution of high PM2.5 reported in this article impact on student health recorded in this study, schools should consider implementing evidence-based interventions to reduce their students' exposure. School-level strategies that are crucial for such initiatives:

- Air Quality Monitoring: Implement real-time PM2.5 sensors, and daily air quality alerts will be shared with the campus. This information can help in making decisions, such as relocating outdoor activities indoors when the level of pollution is high.
- Air Filtration Systems: Install HEPA air purifiers (i.e., high-efficiency particulate air purifiers) in classrooms and indoor spaces, particularly during peak-pollution or wildfire seasons, to reduce indoor levels of particulates.
- Tailored Outdoor Activity Policies: Modify school schedules and policies so that outdoor athletics and physical education are restricted or rescheduled on days when PM2.5 exceeds unsafe levels (such as >50 µg/m³). This can reduce during peak times the exposure of students outdoors to pollution.

4.3.2 Community and Government Action

Wider community and policy-level interventions are also needed to address wider air quality problems, which can impact on schools. Recommended measures include:

- Strengthen PM2.5 Regulations: Government agencies need to impose more stringent emissions standards on large sources of pollution (e.g., vehicle, industry, and agriculture burning) in order to lower ambient PM2.5 levels in urban areas. More stringent regulations, and regular monitoring, can limit the number of days with significant pollution.
- Raise Awareness for Public Health: Public health education at the community level is necessary to inform students, parents, and school personnel to understand the health effects of PM2.5. Best practices during pollution episodes, such as correct mask wearing and symptom monitoring, that encourage proactive health protection should also be included in these programmes.
- Enhance Health Service Accessibility: Schools and local health departments may work together to offer respiratory health checks or medical examinations for students under heavy pollution situations. Better access to healthcare and early intervention (for example, asthma inhalers, medical advice) can reduce the impact of pollution on symptoms of disease.

4.3.3 Promotion of Individual Protective Measures

At the individual level, activating students and their families to engage in protective behaviors can decrease the health effects on the most polluted days:

- Mask-Wearing: Recommend or require use of high-efficiency filtration face masks (e.g., N95 masks) by students on days with unhealthy air quality. Our results indicate that sustained mask wearing could drive down reported symptom prevalence by approximately 0.3, a straightforward and effective measure.
- Behavioral Modifications: Recommend that students minimize time spent outside during periods of high pollution and discover clean indoor areas, ideally with air filtration, when air pollution is high. The sum of these individual reductions (which a nudging approach could attempt to balance and integrate) could, from nudge-analysis point of view, represent a reduction in the amount of pollution anyone is left to inhale, in the course of a day. Ultimately, a combined strategy targeting all intervention levels – such as school-based projects, government policies, and personal protective measures – can help reduce the respiratory health impacts of air pollution among adolescents in Nonthaburi and other urban locations. An integrated multilevel implementation strategy would maximize the shielding of students from harmful PM2. 5 exposure.

4.4 Study Limitations and Future Research Directions

Although providing important clues, the present study had several limitations that need to be taken into account:

4.4.1 Self-Reported Data Bias

The self-report of symptoms (daily Google Form) is the source of some risk of reporting bias or error. Symptoms might be forgotten or reported inconstantly by students, potentially resulting in misclassification. Future studies need to collect an objective health indicator, such as clinical lung function tests or clinical respiratory examination, concurrent with the self-report data to confirm such associations.

4.4.2 Confounding Factors

We did not extensively consider others possible confounders for respiratory symptoms. Symptom reporting on some days may have been influenced by indoor air pollution and previous health (e.g. asthma) and concurrent seasonal respiratory infections (e.g. common colds or flu). These confounders might partially account for differences in health effects regardless of outdoor PM2.5. It would be necessary in future research to adjust for or stratify for such variables possibly by adopting longitudinal study or multivariate analysis to extract the impact of daily PM2.5 more clearly.

4.4.3 Short Study Duration

This analysis focused on a rather narrow exposure window (the months of January–February 2025). This short-term design may miss seasonality, or longer term health effects of prolonged pollution exposure. For example, pollution levels and their respiratory health effects may be different in other seasons (e.g., months of crop-burning or rainy season). Longer term observation over several seasons or a year would lead to a better understanding of the relative influence of chronic and seasonal PM2.5 exposure affects respiratory health in adolescents.

4.4.4 Exposure Data

At the Community Level Daily PM2.5 level were extrapolated from community monitoring stations near the schools and not from personal exposure monitors. This is useful as a general rule of thumb but the actual exposure for individual students can sometimes differ by micro-environments (home, transit etc.). The lack of individual exposure data suggests the potential for measurement error if a student's immediate area experienced different pollution levels than those reported by the nearest station. Personal air quality sensors are essential, or wearable PM2.5 studies for quantifying individual exposure in a more precise way.

Nevertheless, despite these limitations, the present study presents an important first step toward investigating the acute impact of daily variation in air pollution on adolescent health. It highlights the importance of studying short-term exposure effects, and offers preliminary data to guide larger, better-controlled future studies.

4.5 CONCLUSION

This study confirms that daily PM2.5 fluctuations directly affect adolescent respiratory health. In our high school cohort, high-pollution days (>50 μg/m³) were associated with a 27.6% increase in respiratory symptom prevalence compared to cleaner days. We also found a significant correlation between rising PM2.5 levels and worsening respiratory distress ($r = 0.62$, $p < 0.001$), reinforcing evidence that air pollution poses a serious health risk for students. On a positive note, proactive behaviors like mask-wearing proved effective – students who consistently wore masks had markedly lower odds of symptoms (about a 36% risk reduction, OR = 0.64, $p = 0.002$), highlighting the value of personal preventive measures.

Overall, our findings illustrate the acute influence of air quality on youth health and signal that immediate action is needed. Efforts to improve urban air quality – through stricter pollution control policies, school-based air quality management, and community education – are critical for protecting young people in Nonthaburi and other polluted regions. By combining policy interventions with on-the-ground protective strategies, we can better safeguard adolescent health against the day-to-day challenges posed by PM2.5 air pollution.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Key Findings

This research offers direct evidence of the impacts of PM2.5 air pollution on adolescent respiratory health, showing significant associations between daily pollution concentrations and symptomitude. Major findings include:

- Respiratory symptoms of cough, sore throat, shortness of breath, and nasal discomfort show significant exposure-response relationship increasing 27.6% on high PM2.5 levels (>50 μg/m³) than on its low levels (≤25 μg/m³).
- PM2.5 level and respiratory symptoms severity, supporting the premise of added effect due to high air pollution levels on respiratory health. Summary data for all compared exposure levels were compared and the results of chi square between the prevalence on low and high pollution days were positive ($p < 0.001$): on high pollution days there was 27.6% increase of prevalence of symptoms of SOB as compared to low pollution days.
- Logistic regression models found a dose-dependent relationship, showing that for every 10 μg/m³ increase in PM2.5 (95% CI 1.26–1.79, $p < 0.001$).
- Protective behaviors, including mask-usage, was significantly correlated with a 36% decrease in respiratory symptoms ($p = 0.002$),

and is therefore an effective preventive measure. These results strongly indicate that PM2.5 exposure is a crucial public health problem that is affectively influencing the respiratory health in school-aged adolescents studied in urban Thailand.

5.2 Implications for Public Health and Policy

5.2.1 Ad-hoc Air Quality Regulation and Policy Reforms

In light of the robust association of PM2.5 stages and experiencing respiratory symptoms, immediate actions need to be taken to reform administration:

- Tightened environmental regulations for transportation and industry.
- Banning open burning practices and encouraging cleaner energy options.
- Increasing real-time air quality monitoring systems to improve warnings to the public.

5.2.1 Mitigation at the School Level

There are many positive steps that schools can take to defend against these harms, such as:

- Deployment of real-time air quality monitors on campus, and updating students and staff when the air quality is poor.
- Installing air filtration systems in indoor spaces, especially in those in areas with high risk of pollution.
- Adopting rules that curb unnecessary limits the numbers of hours children spend outside on days when pollution levels exceed recommended safety standards.

5.2.3 Awareness Raising and Behavioral Change

This project will work to increase public awareness to the sustainable use and conservation of natural resources. Educational campaigns should focus on:

- Pushing for regular use of N95 masks, especially at times when pollution is at its worst.
- Promoting avoidance of outdoor activities where PM2.5 levels are elevated.
- Telling families to use air purifiers and find better ways to ventilate. By employing these integrated strategies, Nonthaburi could strengthen the management of air quality and become a leading example to curb urban pollution and protect the health of adolescents.

5.3 Limitations and Directions for Future Research

5.3.1 Limitations of Self-reported Information

- Because the study is using self-reporting via online surveys of symptoms, there is potential for subjective bias and recall error.
- Clinical evaluations (such as lung function tests or spirometry) need to be included in future research, in order to confirm the accuracy of reported symptoms.

5.3.2 Seasonal and Climatic Effects

- Weather parameters including humidity, temperature inversions were correlated with PM2.5 scattering and focusing.
- Ways to study and track exposures over more than one season also will build knowledge of seasonal variation in pollution exposure and health effects.

5.3.3Personal Exposure Assessment

- The study used community-level air quality information, which may be imperfect at representing actual individual-level exposure contrasts.
- Future research could benefit from employing wearable air quality sensors to record personalized PM2.5 exposure levels, thereby increasing measurement accuracy.

Notwithstanding these limitations, the present study is a valuable source of information for understanding the health effects of the acute exposure to PM2.5 exposure among adolescents.

5.4 Conclusion and Call to Action

This study provides strong evidence that exposure to high levels of PM2.5 is particularly hazardous for adolescent respiratory health as days with values above 50 µg/m³ translate into a 27.6% increase of symptoms reported. Urgent and concerted action is needed to protect student health and minimize long-term harm.

Actionable Recommendations:

1. Policy Implications: Policy reform to enhance and implement air quality regulations is necessary to control pollution sources.
2. School-Based Protection: Establish proper air filtration systems, mask requirement, and raining down school activities during high pollution days.
3. Community Education: Improve public knowledge about PM2.5 health threats and encourage preventive action.
4. More Research: Perform in-depth longitudinal research with clinical assessments and personal exposure monitoring. Through coordinated policy responses, prioritized school-based interventions and focused community outreach efforts, much can be done to help lift the burden of air pollution. There is an opportunity for Nonthaburi to take a lead, by not delaying and responding now we can be proactive to improve our environmental health and ensure the next generation do not fall victim to the harmful effects of PM2.5 exposure.

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