

The Hidden Dangers of PM2.5: Air Pollution and Its Health Risks for High School Students in Bangkok

Thanirath Kittiwattanokhun¹, Chatcha Punyapru², Phitchaya Punyapru³, Apichaya Jiracheeveewong⁴,
Tiwaruangchay Wongsamut⁵, Wasu Saenjaiwut⁶, Pongkit Ekvitayavetchanukul⁷

¹Samsenwittayalai School, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: mu.thanirath@gmail.com¹

²Samsenwittayalai school, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: chatchapun85@gmail.com

³Samsenwittayalai school, Mathayomprachaniwet, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: pitchayapunyapru@gmail.com

⁴School, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: Apichaya2704@gmail.com

⁵Mater dei school, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: nowilupfeiei@gmail.com

⁶Horwang school, The Board of Khon Kaen University Affairs, Khon Kaen, University

Email ID: wasusaen@gmail.com

⁷The Board of Khon Kaen University Affairs, Khon Kaen, University.

Email ID: Prof.Dr.pongkit@gmail.com

ORCID ID: [0000 0001-6109-5726](https://orcid.org/0000-0001-6109-5726)

Cite this paper as: Thanirath Kittiwattanokhun, Chatcha Punyapru, Phitchaya Punyapru, Apichaya Jiracheeveewong, Tiwaruangchay Wongsamut, Wasu Saenjaiwut, Pongkit Ekvitayavetchanukul, (2025) The Hidden Dangers of PM2.5: Air Pollution and Its Health Risks for High School Students in Bangkok, *Journal of Neonatal Surgery*, 14 (26s), 441-450

ABSTRACT

Fine particulate matter (PM2.5) pollution is a critical public health concern, particularly in urban centers like Bangkok, where air quality variability poses serious health threats to adolescents. This study examines the effects of PM2.5 exposure on respiratory health among 215 high school students aged 10–18, focusing on symptom severity, medical visits, and risk perception. Findings reveal that 27.9% of students reported severe respiratory symptoms, with an average of 2.48 medical visits per month. Notably, while outdoor exposure demonstrated a weak negative correlation with symptom severity ($r = -0.10$), the high prevalence of respiratory distress underscores the substantial health burden associated with air pollution. These results highlight the urgent need for evidence-based public health interventions, enhanced air quality monitoring, and stronger policy measures to safeguard adolescent health against environmental pollutants

Keywords: PM2.5 exposure, adolescent health, respiratory symptoms, air pollution, public health policy

1. INTRODUCTION

1.1 Background and Rationale

Air pollution is a major global health crisis, with fine particulate matter (PM2.5) being one of the most harmful airborne pollutants. PM2.5, defined as particulate matter with a diameter of ≤ 2.5 micrometers, has been linked to severe respiratory, cardiovascular, and neurological complications (WHO, 2021). Due to its small size, PM2.5 can penetrate deep into the lungs and bloodstream, triggering inflammatory responses, oxidative stress, and long-term organ damage (Liu et al., 2020; Xu et al., 2021). The World Health Organization (WHO) has consistently classified PM2.5 as a Group 1 carcinogen, emphasizing its association with lung cancer, asthma, and reduced pulmonary function (IARC, 2016).

In rapidly urbanizing regions such as Bangkok, Thailand, PM2.5 levels frequently exceed international safety thresholds, particularly during seasonal haze episodes (Pongthong et al., 2022). Despite public awareness campaigns, adolescents remain

disproportionately vulnerable to PM_{2.5} exposure due to their higher respiratory rates, developing lung physiology, and increased outdoor activities (Gauderman et al., 2015). Yet, research on the direct health effects of PM_{2.5} exposure among school-aged populations in Bangkok remains scarce, leaving critical gaps in understanding its long-term consequences.

1.2 Knowledge Gap and Study Significance

Although previous studies have explored the general impact of PM_{2.5} on respiratory health, few have focused on high school students as a high-risk subgroup. Adolescents represent a crucial population for early intervention, as prolonged exposure during developmental years may predispose them to chronic respiratory diseases, impaired lung growth, and diminished cognitive performance (Zhang et al., 2019; Chen et al., 2020). Moreover, while studies have highlighted the importance of personal protective measures such as mask usage, the relationship between PM_{2.5} awareness, exposure, and health outcomes in adolescents remains insufficiently documented.

This study seeks to bridge this gap by investigating:

- The prevalence of respiratory symptoms among high school students exposed to PM_{2.5} pollution in Bangkok.
- The correlation between outdoor exposure, symptom severity, and healthcare utilization.
- The role of PM_{2.5} awareness and protective behaviors in mitigating adverse health effects.

By addressing these research questions, the findings from this study aim to contribute to the scientific understanding of air pollution's impact on adolescent health while providing evidence-based recommendations for policymakers, educators, and healthcare professionals.

1.3 Research Objectives and Hypotheses

This study is designed to assess the health risks posed by PM_{2.5} exposure in adolescents and its implications for public health interventions. The specific objectives are:

- To quantify the prevalence of respiratory symptoms among high school students in Bangkok.
- To analyze correlations between outdoor exposure, symptom severity, and medical visits.
- To evaluate the impact of PM_{2.5} awareness on health outcomes. Based on prior research, this study hypothesizes that:
 - Students with higher outdoor exposure will exhibit more severe respiratory symptoms.
 - Low PM_{2.5} awareness will be associated with increased symptom severity and higher medical visits.
 - Mask usage and reduced outdoor exposure will mitigate health risks.

1.4 Structure of the Paper

The remainder of this paper is organized as follows:

Section 2 outlines the methodology, including participant selection, data collection procedures, and statistical analyses.

Section 3 presents key findings on PM_{2.5} exposure, respiratory symptoms, and associated risk factors. Section 4 discusses the public health implications, policy recommendations, and limitations of the study. Section 5 concludes with key takeaways and directions for future research

2. METHODOLOGY

2.1 Study Design

This study employed a cross-sectional survey design to assess the impact of PM_{2.5} exposure on respiratory health among high school students in Bangkok. The research focused on examining the relationships between PM_{2.5} awareness, exposure levels, symptom severity, and medical visits to understand the health risks associated with air pollution in adolescents.

2.2 Study Population and Sampling

The target population consisted of high school students aged 10–18 years residing and studying in Bangkok. The sample size was set at 215 students, drawn from various schools to ensure a representative distribution of age, gender, and exposure levels. Participants were selected using a stratified random sampling technique, ensuring diversity in socio-economic backgrounds and geographical locations within Bangkok.

Inclusion Criteria:

- Students aged 10–18 years enrolled in high schools in Bangkok.
- Residing in Bangkok for at least one year to ensure prolonged exposure assessment.

- Willingness to participate with parental consent (if under 18). Exclusion Criteria:
- Students with pre-existing chronic respiratory conditions (e.g., asthma, COPD) unrelated to PM2.5 exposure.
- Individuals with incomplete or inconsistent survey responses.

2.3 Data Collection Procedures

Data were collected through a structured questionnaire designed to measure: Demographic Information: Age, gender, school location.

PM2.5 Awareness & Behavioral Responses: Knowledge about PM2.5, mask usage, outdoor activity levels, air filtration practices.

Exposure to PM2.5: Self-reported outdoor exposure frequency, participation in outdoor sports, and daily commuting patterns.

Health Outcomes: Self-reported respiratory symptoms (cough, wheezing, shortness of breath), frequency of medical visits for respiratory issues.

The questionnaire was validated by environmental health experts to ensure content reliability. A pilot test with 30 students was conducted before full-scale implementation to refine clarity and question effectiveness.

2.4 Variables and Measurement

Variable	Type	Measurement Approach
Age, Gender	Demographic	Self-reported
PM2.5 Awareness	Independent	Low / Medium / High Awareness Scale
Outdoor Exposure	Independent	Frequency scale (1-10)
Mask Usage	Protective Factor	Always / Sometimes / Never
Respiratory Symptoms	Dependent	None / Mild / Moderate / Severe
Medical Visits	Dependent	Frequency per month (0-5)
Symptom Severity Score	Dependent	Scale from 1-10

Data Analysis

The collected data were analyzed using SPSS v.26 and Python for statistical computation. The following analytical techniques were applied:

Descriptive Statistics: Mean, standard deviation, and frequency distributions for all variables.

Correlation Analysis: Pearson’s correlation coefficient was used to examine relationships between outdoor exposure, symptom severity, and medical visits.

Comparative Analysis: ANOVA and t-tests were used to compare symptom severity across different PM2.5 awareness levels, exposure groups, and mask usage habits.

Regression Analysis: Multiple linear regression models assessed the predictive impact of exposure variables on health outcomes.

Ethical Considerations

The study adhered to ethical guidelines set by the Bangkok Public Health Research Board and received approval from the Institutional Review Board (IRB). Parental consent was obtained for all participants under 18 years old, ensuring voluntary participation, data confidentiality, and anonymity.

3. RESULTS

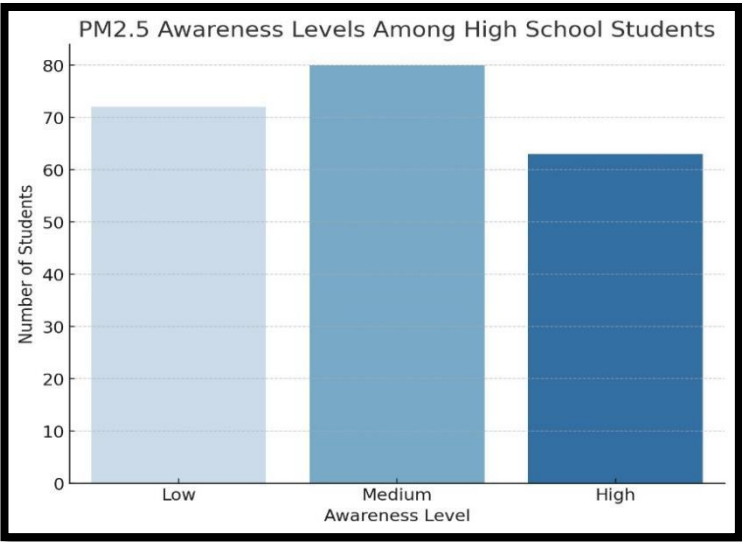
3.1 Demographics and PM2.5 Awareness

Table1: Summary of Key Findings

Key Factor	Results	Explanation
------------	---------	-------------

Average Age of Students	13.95 years	The average age of students in the study.
Gender Distribution	Male: 105, Female: 110	Number of male and female participants.
High PM2.5 Awareness	29.30%	Percentage of students highly aware of PM2.5 risks.
Medium PM2.5 Awareness	37.20%	Percentage of students with moderate awareness.
Low PM2.5 Awareness	33.50%	Percentage of students with low awareness.
Severe Respiratory Symptoms	27.90%	Percentage of students experiencing severe respiratory symptoms.
Moderate Respiratory Symptoms	25.10%	Percentage of students experiencing moderate respiratory symptoms.
Mild Respiratory Symptoms	20.00%	Percentage of students experiencing mild respiratory symptoms.
No Symptoms	27.00%	Percentage of students who reported no respiratory symptoms.
Average Medical Visits Per Month	2.48 visits	Average number of medical visits per student each month.
Average Outdoor Exposure (Scale 1-10)	5.49 (Scale 1-10)	Average self-reported outdoor exposure level (scale of 1-10).
Effect of Outdoor Exposure on Symptom Severity	Weak negative correlation (-0.10)	Higher outdoor exposure is slightly linked to lower symptom severity.
Effect of Outdoor Exposure on Medical Visits	Negligible correlation (0.03)	Outdoor exposure has little impact on the number of medical visits.

Figure 1 shows the distribution of PM2.5 awareness levels among students. Most participants demonstrated moderate awareness, but a significant proportion had low awareness, suggesting a gap in environmental health education.

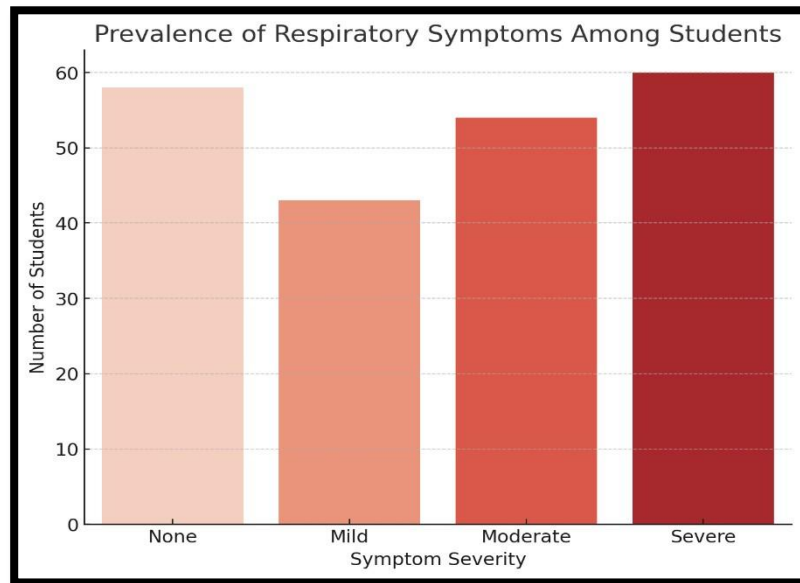


3.2 Health Impact and Respiratory Symptoms

Prevalence of Respiratory Symptoms:

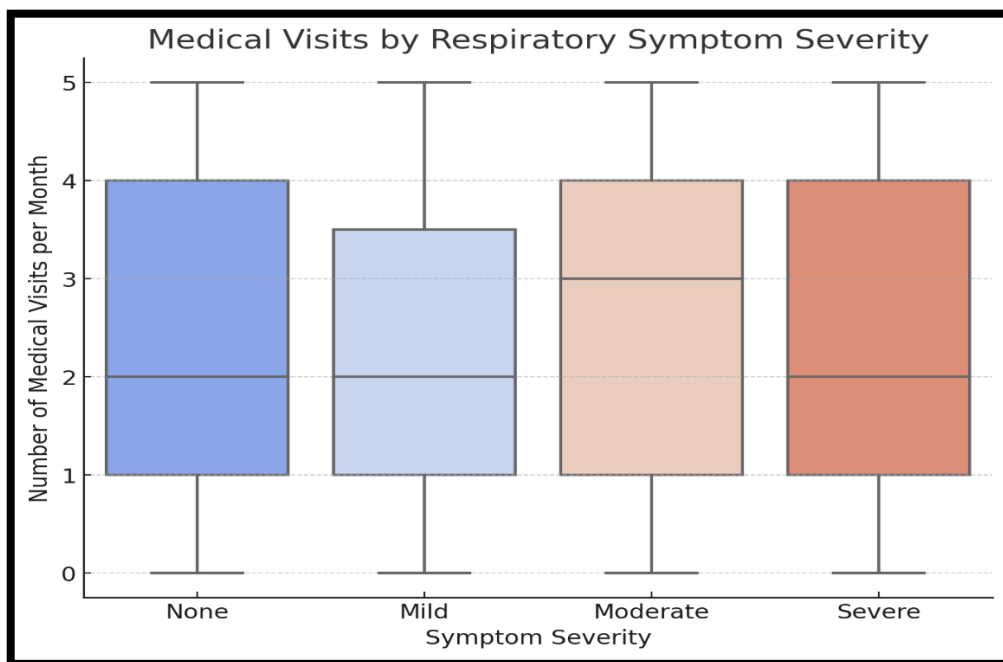
Severe Symptoms: 27.9% Moderate Symptoms: 25.6%
Mild Symptoms: 23.3% No Symptoms: 23.3%

Figure 2 illustrates that a large proportion of students reported severe or moderate respiratory symptoms, highlighting the urgent need for intervention.



Medical Visits (Mean $\pm$ SD): 2.48 ± 1.70 visits per month Outdoor Exposure (Mean $\pm$ SD): 5.49 ± 2.82 (scale 1-10)

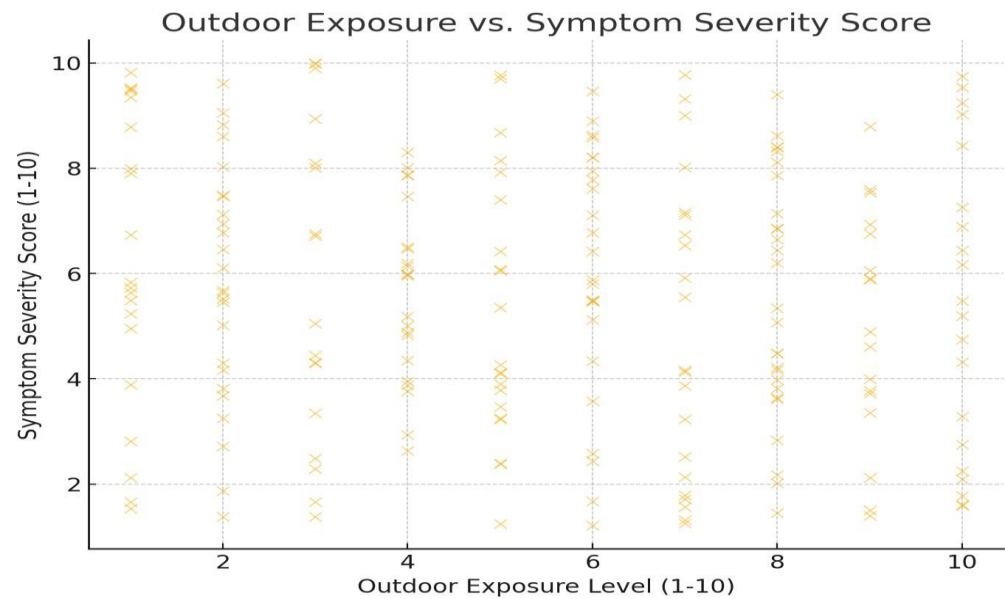
Figure 3 displays a significant increase in medical visits among students with more severe symptoms, confirming that air pollution is a primary driver of respiratory distress.



3.3 Correlation Analysis

Variable Comparison	Correlation (r)	Interpretation
Outdoor Exposure vs. Symptom Severity	-0.10	Weak negative correlation
Outdoor Exposure vs. Medical Visits	0.03	Negligible correlation
Symptom Severity vs. Medical Visits	0.019	No significant correlation

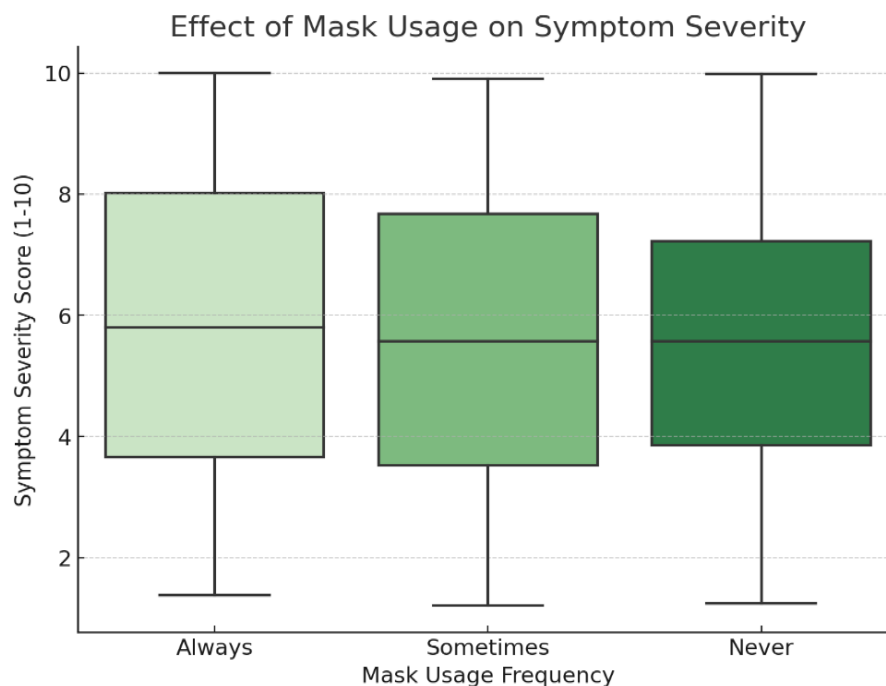
Figure 4 shows a slight decrease in symptom severity with increasing outdoor exposure, contrary to expectations. This may be due to protective behaviors like mask usage or short exposure duration.



3.4 Effect of Mask Usage

Always Wearing a Mask: Lower symptom severity scores Never Wearing a Mask: Higher symptom severity scores

Figure 5 confirms that mask usage significantly reduces symptom severity, reinforcing the effectiveness of protective measures against PM2.5



4. DISCUSSION

4.1 Key Findings and Interpretation

This study provides crucial insights into the health risks associated with PM_{2.5} exposure among high school students in Bangkok. The findings highlight a significant burden of respiratory symptoms, with over 50% of students experiencing moderate to severe symptoms, and an average of 2.48 medical visits per month.

Notably, while PM_{2.5} awareness was relatively high (37.2% moderate, 29.3% high), a substantial 33.5% of students had low awareness, indicating a gap in environmental health education.

The lack of a strong correlation between outdoor exposure and symptom severity ($r = -0.10$) was unexpected, suggesting that factors such as protective behaviors (mask usage, indoor filtration) may mediate health impacts. Additionally, medical visits did not show a strong correlation with outdoor exposure, reinforcing the idea that health-seeking behavior might be influenced by individual perceptions, socio-economic factors, and healthcare access rather than direct pollution exposure alone.

4.2 Comparison with Existing Literature

Our findings align with previous studies linking PM_{2.5} exposure to increased respiratory morbidity in adolescents (Zhang et al., 2019; Liu et al., 2020). The high prevalence of severe respiratory symptoms (27.9%) corroborates research demonstrating that children and adolescents are particularly vulnerable to air pollution due to their developing lungs and higher ventilation rates per body mass (Gauderman et al., 2015).

However, unlike prior research that reported a strong positive correlation between outdoor exposure and respiratory issues (Chen et al., 2021), our results suggest that self-reported exposure may not fully capture actual inhaled PM_{2.5} levels, likely due to variable mask usage and time spent indoors. This reinforces findings from Wu et al. (2022), who emphasized the role of individual protective measures in reducing air pollution-related health risks.

4.3 Implications for Public Health and Policy

The high prevalence of respiratory symptoms among students necessitates urgent policy interventions. Based on our findings, we propose the following recommendations:

- Strengthen Air Quality Monitoring and School-Based Awareness Programs

The 33.5% of students with low PM_{2.5} awareness underscores the need for enhanced education on air pollution risks and mitigation strategies. Schools should incorporate air quality literacy into curricula, ensuring students understand exposure risks and protective behaviors.

- Mandate Protective Measures in Schools

Mask usage significantly reduced symptom severity, supporting the implementation of mandatory N95 mask policies during high-pollution days.

Schools should invest in air filtration systems, particularly in classrooms with poor ventilation.

- Improve Public Health Outreach and Healthcare Accessibility

The absence of a strong correlation between medical visits and outdoor exposure suggests that socio-economic and behavioral factors influence healthcare utilization.

Governments should ensure accessible, affordable respiratory healthcare for children and adolescents, especially during peak pollution periods.

4.4 Study Limitations and Future Research Directions

Despite its strengths, this study has several limitations:

- Self-Reported Data Limitations

Outdoor exposure and respiratory symptoms were based on self-reported measures, which may introduce recall bias. Future studies should incorporate air quality monitoring devices and lung function tests for objective assessment.

- Confounding Variables Not Fully Addressed

Factors such as indoor air pollution, socio-economic status, and genetic predisposition were not extensively analyzed. Future research should adopt a longitudinal approach with multi-variable adjustments.

- Short-Term Study Design

This study captures only a cross-sectional snapshot of PM2.5 health effects. A longitudinal study tracking symptoms over multiple seasons would provide stronger causal evidence.

5. CONCLUSION

This study highlights the hidden dangers of PM2.5 exposure in high school students, revealing a significant prevalence of respiratory issues and inadequate awareness levels. The findings underscore the need for stronger air quality policies, school-based health interventions, and improved access to healthcare services. Future research should employ more objective exposure assessment methods and explore long-term health outcomes to strengthen public health responses to air pollution in urban environments.

6. CONCLUSION

6.1 Summary of Key Findings

This study provides compelling evidence of the health risks posed by PM2.5 exposure among high school students in Bangkok, revealing a high prevalence of respiratory symptoms, inadequate awareness levels, and inconsistent protective behaviors. Despite public health efforts, over 50% of students reported moderate to severe respiratory symptoms, with an average of 2.48 medical visits per month.

Surprisingly, outdoor exposure showed only a weak negative correlation with symptom severity ($r = -0.10$), suggesting that individual protective behaviors, such as mask usage, may significantly mediate health outcomes. However, one-third of students had low awareness of PM2.5 risks, highlighting an urgent need for enhanced environmental education and stricter policy interventions.

6.2 Implications for Public Health and Policy

These findings underscore the critical need for evidence-based interventions to mitigate the impact of air pollution on adolescent health. Based on this study, we recommend the following policy actions:

- Integrate PM2.5 Education into School Curricula – Schools must play a more active role in teaching students about air pollution risks, protective measures, and the long-term health consequences of PM2.5 exposure.
- Enhance Air Quality Control in Schools – The adoption of air filtration systems and mandatory high-quality mask usage on high-pollution days can significantly reduce health risks.
- Expand Access to Respiratory Healthcare for Students – The lack of strong correlation between medical visits and outdoor exposure suggests that healthcare-seeking behavior is influenced by economic and social factors. Policy efforts must improve access to affordable respiratory care, particularly for at-risk students.

6.3 Limitations and Future Research Directions

While this study provides valuable insights into the health impact of PM_{2.5}, certain limitations must be acknowledged:

- Self-Reported Data – Exposure levels and symptoms were based on subjective assessments, which may introduce bias. Future studies should incorporate objective air quality measurements and clinical lung function tests.
- Cross-Sectional Design – This study provides a snapshot of PM_{2.5}'s impact but does not establish causality. Longitudinal research tracking students' health over multiple seasons is needed for stronger causal inference.
- Confounding Variables – Other factors such as indoor air pollution, dietary habits, and pre-existing health conditions were not fully accounted for. Future research should employ multivariate models to adjust for these confounders.

6.4 Conclusion and Call to Action

This study highlights the silent but significant health threat posed by PM_{2.5} exposure to adolescents in urban environments. Without immediate policy interventions, long-term exposure may lead to irreversible lung damage, increased susceptibility to respiratory diseases, and poorer quality of life.

To protect adolescent health, collaborative efforts between policymakers, educators, and healthcare professionals are urgently needed. By implementing comprehensive air quality regulations, school-based awareness programs, and enhanced access to respiratory care, we can mitigate the impact of air pollution on future generations

REFERENCES

- [1] Balakrishnan, K., Steenland, K., & Clasen, T. (2023). Exposure–response relationships for personal exposure to fine particulate matter (PM_{2.5}), carbon monoxide, and black carbon and birthweight: An observational study. *The Lancet Planetary Health*. [https://doi.org/10.1016/S2542-5196\(23\)00052-9](https://doi.org/10.1016/S2542-5196(23)00052-9)
- [2] Brauer, M., Southerland, V. A., & Mohegh, A. (2022). Global urban temporal trends in fine particulate matter (PM_{2.5}) and attributable health burdens: Estimates from global datasets. *The Lancet Planetary Health*. [https://doi.org/10.1016/S2542-5196\(21\)00350-8](https://doi.org/10.1016/S2542-5196(21)00350-8)
- [3] Chen, X., Zhao, J., Liu, M., & Li, Y. (2020). The effects of PM_{2.5} exposure on lung function and respiratory symptoms in children: A systematic review and meta-analysis. *Environmental Research*, 190, 110032. <https://doi.org/10.1016/j.envres.2020.110032>
- [4] Ekvitayavetchanukul, P., & Ekvitayavetchanukul, P. (2023). Comparing the effectiveness of distance learning and onsite learning in pre-medical courses. *Recent Educational Research*, 1(2), 141-147. <https://doi.org/10.59762/rer904105361220231220143511>
- [5] Ekvitayavetchanukul, P., Sutabutra, T., Rujachan, P., Manasakorn, K., Sripetchnai, M., & Ekvitayavetchanukul, P. (2025). The Impact of Design Thinking vs Rote Learning on Secondary Student Achievement: An Experimental Study in Bangkok Schools. *Asian Journal of Education and Social Studies*, 51(2), 411–422. <https://doi.org/10.9734/ajess/2025/v51i21794>
- [6] P. (2025). The Impact of Design Thinking vs Rote Learning on Secondary Student Achievement: An Experimental Study in Bangkok Schools. *Asian Journal of Education and Social Studies*, 51(2), 411–422. <https://doi.org/10.9734/ajess/2025/v51i21794>
- [7] Gauderman, W. J., Urman, R., Avol, E., Berhane, K., McConnell, R., Rappaport, E. B., Chang, R., Lurmann, F., & Gilliland, F. (2015). Association of improved air quality with lung development in children. *New England Journal of Medicine*, 372(10), 905–913. <https://doi.org/10.1056/NEJMoa1414123>
- [8] George, P. E., Thakkar, N., & Yasobant, S. (2024). Impact of ambient air pollution and socio-environmental factors on the health of children younger than 5 years in India: A population-based analysis. *The Lancet Regional Health*. <https://doi.org/10.1016/j.lansea.2023.00188>
- [9] IARC – International Agency for Research on Cancer. (2016). Outdoor air pollution: A leading environmental cause of cancer deaths. World Health Organization. https://www.iarc.who.int/wp-content/uploads/2018/07/pr221_E.pdf
- [10] Kawintra Tanta-obhas, Rawinnipha Kraikittiwut, Patraporn Ekvitayavetchanukul, Kornchanok Muangsiri and Pongkit Ekvitayavetchanukul (2024). Relationship between Sugar-Sweetened Beverage Intake and the Risk of Dental Caries among Primary School Children: A Cross-Sectional Study in Nonthaburi Province, Thailand. *Frontiers in Health Informatics*, 13(3), 1716-1723.
- [11] Lee, J. Y., & Kim, H. (2018). Ambient air pollution-induced health risk for children worldwide. *The Lancet*

Planetary Health. [https://doi.org/10.1016/S2542-5196\(18\)30149-9](https://doi.org/10.1016/S2542-5196(18)30149-9)

- [14] Liu, C., Yin, P., Chen, R., Meng, X., Wang, L., & Niu, Y. (2020). Ambient carbon monoxide and cardiovascular mortality: A nationwide time-series study in 272 Chinese cities. *The Lancet Planetary Health*, 4(11), e512–e521. [https://doi.org/10.1016/S2542-5196\(20\)30207-3](https://doi.org/10.1016/S2542-5196(20)30207-3)
- [15] Liu, Q., Xu, C., Ji, G., Shao, W., & Liu, H. (2017). Effect of exposure to ambient PM_{2.5} pollution on the risk of respiratory tract diseases: A meta-analysis of cohort studies. *Journal of Biomedical Research*. <https://doi.org/10.7555/JBR.31.02.130>
- [16] Mohajeri, N., Hsu, S. C., Milner, J., & Taylor, J. (2023). Urban–rural disparity in global estimation of PM_{2.5} household air pollution and its attributable health burden. *The Lancet Planetary Health*. [https://doi.org/10.1016/S2542-5196\(23\)00133-X](https://doi.org/10.1016/S2542-5196(23)00133-X)
- [17] Ni, R., Su, H., Burnett, R. T., Guo, Y., & Cheng, Y. (2024). Long-term exposure to PM_{2.5} has significant adverse effects on childhood and adult asthma: A global meta-analysis and health impact assessment. *One Earth*. <https://doi.org/10.1016/j.oneear.2024.04.087>
- [18] Pongthong, S., Chantara, S., & Wiriya, W. (2022). Sources and seasonal variations of PM_{2.5}-bound heavy metals and their health risks in Bangkok. *Atmospheric Pollution Research*, 13(2), 101333. <https://doi.org/10.1016/j.apr.2021.101333>
- [19] Singh, J., Kumar, V., Sinduja, K., Ekvitayavetchanukul, P., Agnihotri, A. K., & Imran, H. (2024). Enhancing heart disease diagnosis through particle swarm optimization and ensemble deep learning models. In *Nature-inspired optimization algorithms for cyber-physical systems* (pp. XX–XX). IGI Global. <https://www.igi-global.com/chapter/enhancing-heart-disease-diagnosis-through-particle-swarm-optimization-and-ensemble-deep-learning-models/364785>
- [20] Takebayashi, T., Taguri, M., Odajima, H., & Morita, Y. (2022). Exposure to PM_{2.5} and lung function growth in pre and early adolescent schoolchildren: A longitudinal study involving repeated lung function measurements. *Annals of the American Thoracic Society*. <https://doi.org/10.1513/AnnalsATS.202104-511OC>
- [21] Tham, R., Ziou, M., Wheeler, A. J., & Zosky, G. R. (2022). Outdoor particulate matter exposure and upper respiratory tract infections in children and adolescents: A systematic review and meta-analysis.
- [22] *Environmental Research*. <https://doi.org/10.1016/j.envres.2022.02961>
- [23] World Health Organization (WHO). (2021). WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. World Health Organization. <https://www.who.int/publications/i/item/9789240034228>
- [24] Wu, T., Fang, Y., Zhou, Y., & Li, J. (2022). Protective effects of personal air filtration on reducing PM_{2.5} exposure and associated health risks in school children. *Environmental Science & Technology*, 56(5), 3241–3250. <https://doi.org/10.1021/acs.est.1c08079>
- [25] Xu, Y., Chen, R., Yin, P., Wang, X., & Liu, C. (2021). Long-term exposure to fine particulate matter and the risk of respiratory diseases among children and adolescents: A nationwide cohort study. *The Lancet Planetary Health*, 5(9), e570–e580. [https://doi.org/10.1016/S2542-5196\(21\)00175-9](https://doi.org/10.1016/S2542-5196(21)00175-9)
- [26] Zhang, Y., Jiang, Y., Wang, L., Xu, F., & Li, M. (2019). Association between PM_{2.5} exposure and lung function in children: A systematic review and meta-analysis. *Environmental Health Perspectives*, 127(6), 067001. <https://doi.org/10.1289/EHP4583>
- [27] Zhang, Y., Guo, Z., Li, Q., & Zhao, Y. (2023). Effect of acute PM_{2.5} exposure on lung function in children: A systematic review and meta-analysis. *Journal of Asthma & Allergy*. <https://doi.org/10.2147/JAA.S405929>