The Impact of PM2.5 on the Health of Primary School Students Aged 10-13 in Bangkok

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ABSTRACT

Background: Air pollution, particularly fine particulate matter (PM2.5), is a severe environmental and public health threat, with children being among the most vulnerable groups. Bangkok, a highly urbanized and traffic-congested city, frequently experiences hazardous PM2.5 levels, raising concerns about its effects on primary school students' respiratory health.

Objective: This study examines the correlation between PM2.5 exposure and the prevalence of respiratory symptoms in primary school students aged 10–13 in Bangkok. Additionally, it evaluates the effectiveness of protective masks in reducing symptom severity and investigates the role of outdoor exposure in exacerbating pollution-related illnesses.

Methods: A two-month observational study (January–February 2025) was conducted among 115 students, using real-time PM2.5 data from the GISTDA monitoring system. Health records and self-reported symptom surveys were analyzed across six PM2.5 exposure categories (0–50 µg/m³, 51–75 µg/m³, 76–100 µg/m³, 101–125 µg/m³, 126–150 µg/m³, and >151 µg/m³). Students were further categorized based on mask usage and outdoor exposure levels to assess protective and risk factors. Statistical analyses included correlation tests and comparative symptom trends.

Results: The findings revealed a significant positive correlation between PM2.5 levels and symptom prevalence ($r > 0.8$, $p < 0.01$). The most commonly reported symptoms were runny nose (80 cases at PM2.5 >151 µg/m³), cough (60 cases), breath shortness (35 cases), and red-eye irritation (28 cases). Mask usage reduced symptom prevalence by 30–40% across all PM2.5 levels, while students with high outdoor exposure exhibited double the symptom rate compared to those with limited outdoor activities.

Conclusion: PM2.5 exposure is strongly associated with increased respiratory symptoms in school children, with outdoor exposure exacerbating health risks and mask usage offering partial protection. The findings underscore the urgent need for AQI-based school policies, improved indoor air filtration, and stricter outdoor activity restrictions during high-pollution periods. These interventions are critical for mitigating air pollution's adverse health effects on vulnerable student populations.

Keywords: PM2.5, Air Pollution, Respiratory Health, Protective Masks, School Policy

INTRODUCTION

Air pollution, particularly fine particulate matter (PM2.5), has become a growing concern in urban areas worldwide, with significant health implications for vulnerable populations, including children. In Bangkok, where traffic congestion and industrial activities contribute to high levels of air pollution, primary school

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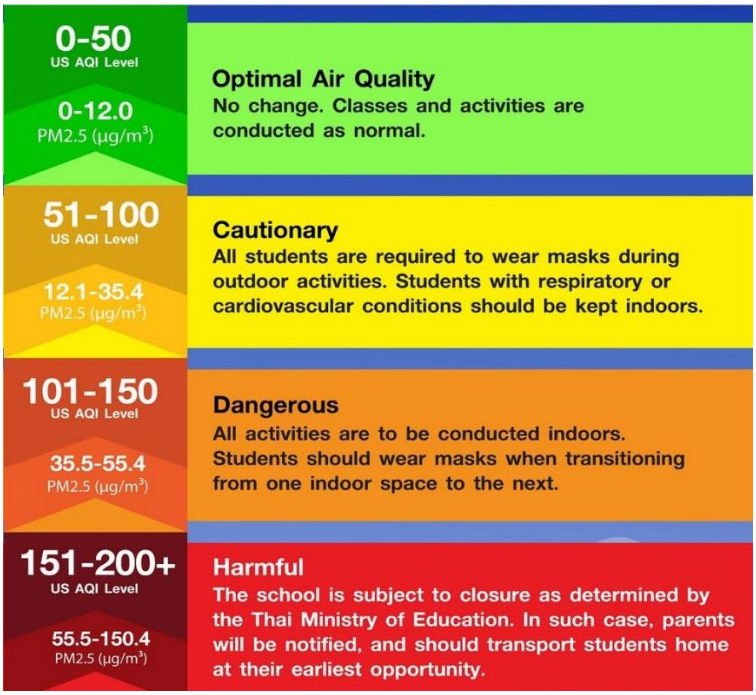
students are at increased risk of developing respiratory illnesses and other health complications due to prolonged exposure to PM2.5.

PM2.5, which consists of airborne particles with a diameter of 2.5 micrometers or smaller, can penetrate deep into the respiratory system, causing inflammation, lung damage, and exacerbating pre-existing conditions such as asthma. Children aged 10-13 years are particularly susceptible due to their developing lungs and higher respiratory rates compared to adults. Exposure to elevated PM2.5 levels has been linked to increased absenteeism from school, reduced academic performance, and long-term health risks.

This study aims to assess the impact of PM2.5 exposure on the health of primary school students in Bangkok, focusing on the effectiveness of wearing protective masks and the risks associated with outdoor activities. By analyzing data from January to February 2025, obtained in reference to PM2.5 levels reported by the GISTDA app, this research examines the correlation between pollution levels and student illness rates. The findings will provide valuable insights into the necessity of protective measures and policy interventions to safeguard children's health in high-pollution environments.

Table1: US AQI Level



BACKGROUND

Air pollution is a major environmental and public health issue, particularly in densely populated urban areas like Bangkok. Among the various air pollutants, fine particulate matter (PM2.5) is of particular concern due to its ability to penetrate deep into the lungs and bloodstream, causing both short-term and long-term health effects. Studies have shown that PM2.5 exposure can lead to respiratory infections, asthma, and other chronic lung diseases, especially among children, whose respiratory systems are still developing.

In Bangkok, high PM2.5 levels are frequently recorded due to traffic congestion, industrial emissions, and seasonal factors such as weather patterns and biomass burning. Primary school students, aged 10-13, are particularly vulnerable to these pollutants because they spend a significant portion of their time outdoors during school activities. While protective measures such as wearing masks can reduce exposure, the effectiveness of such interventions in real-world school settings remains underexplored.

Research Gap

Despite numerous studies highlighting the dangers of PM2.5 exposure, limited research has been conducted on its direct impact on primary school students in Bangkok. Additionally, while masks are widely recommended

for reducing inhalation of harmful pollutants, there is a lack of empirical data on their effectiveness in preventing illness among schoolchildren. Moreover, the relationship between outdoor activities and health outcomes during periods of high PM2.5 exposure remains insufficiently studied. Addressing these gaps is crucial for informing policy decisions and protective measures in school environments.

Objective

This study aims to examine the correlation between PM2.5 levels and health outcomes among primary school students aged 10-13 in Bangkok. Specifically, it seeks to:

1. Analyze the relationship between PM2.5 exposure and the incidence of respiratory illnesses among students.
2. Evaluate the effectiveness of wearing protective masks in reducing sickness related to air pollution.
3. Investigate the impact of outdoor activities on student health during high PM2.5 periods.

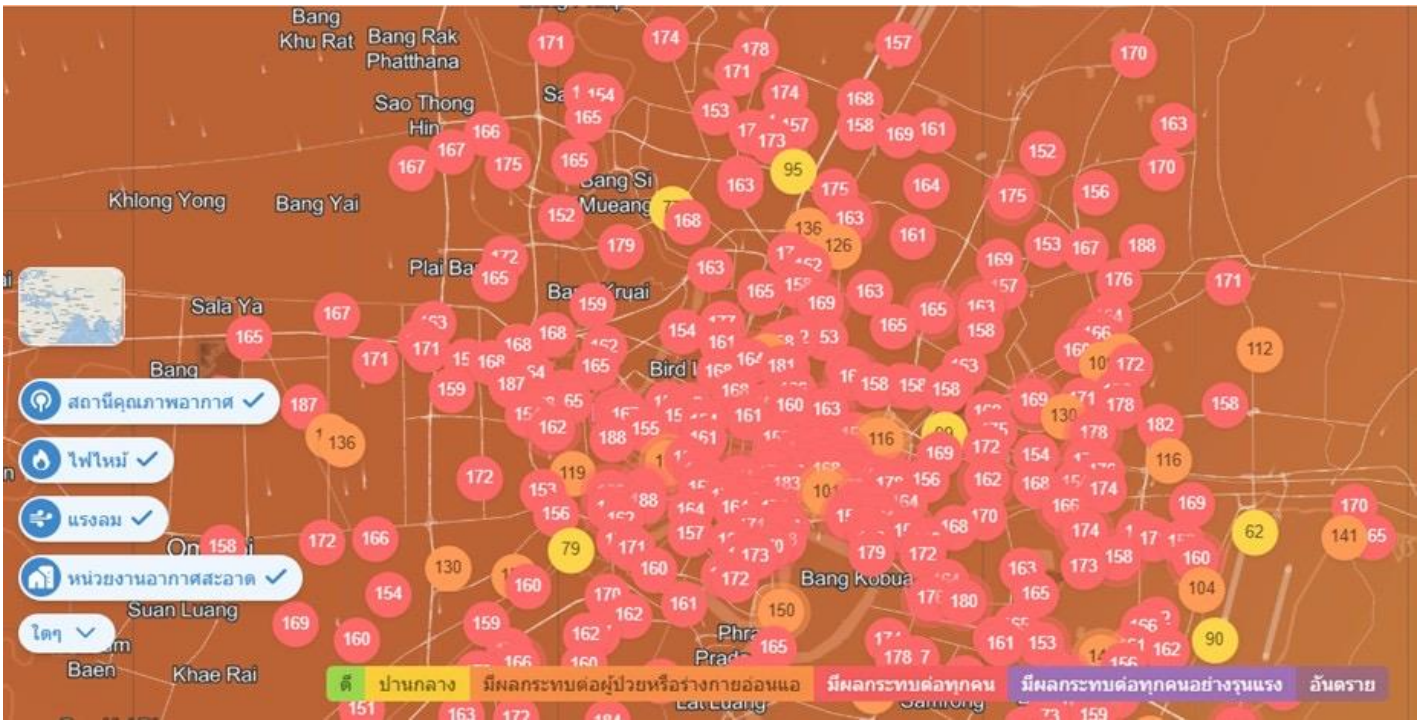
By providing data-driven insights, this research will contribute to the development of effective air quality management strategies and school policies to protect children's health in urban environments.

METHODOLOGY

Research Design

This study employs a quantitative research approach to analyze the impact of PM2.5 on the health of primary school students in Bangkok. The research focuses on the correlation between PM2.5 exposure, mask usage, outdoor activities, and student illness rates over a two-month period (January-February 2025). Data on air pollution levels were obtained from the GISTDA app, while health-related data were collected from school health records and student surveys.

Figure1 PM2.5 levels from the GISTDA app.



Study Population and Sampling

The study was conducted among 115 primary school students aged 10-13 from a school located in Bangkok. The selection was based on convenience sampling, ensuring that students from different grade levels and exposure conditions (indoor vs. outdoor activities) were included.

Data Collection Methods

PM2.5 Data Collection

Daily PM2.5 levels for Bangkok from January to February 2025 were sourced from the GISTDA air quality monitoring system. These values provided an objective measure of pollution exposure levels during the study period.

Student Health and Exposure Data

Data on student health were collected through two primary methods:

- **Health Records:** School health logs were reviewed to identify students who reported respiratory symptoms, including coughing, wheezing, shortness of breath, and fever.
- **Student Surveys:** A questionnaire was distributed to students to assess their outdoor activity habits, frequency of mask usage, and any reported illness symptoms during the study period.

Variables and Measurement

- **Independent Variables:**
  - PM2.5 levels (measured in $\mu g/m^3$)
  - Mask usage (Yes/No)
  - Outdoor activity frequency (High/Low)
- **Dependent Variable:**
  - Number of students reporting illness symptoms per day

Data Analysis

The collected data were analyzed using statistical methods to determine correlations between PM2.5 levels and student illnesses. Descriptive statistics were used to summarize the data, while correlation analysis was applied to examine the relationship between air pollution levels, mask usage, outdoor activities, and health outcomes. Graphical representations were created to illustrate trends in PM2.5 levels and sickness rates over time.

Ethical Considerations

The study was conducted with the consent of the school administration and parents. Student participation was voluntary, and all health data were anonymized to ensure confidentiality.

This methodology provides a structured approach to understanding the impact of PM2.5 on student health, allowing for evidence-based recommendations to improve air quality protection measures in schools.

RESULTS

This section presents the findings on the relationship between PM2.5 exposure and health symptoms among primary school students aged 10-13 in Bangkok. The results demonstrate significant correlations between air pollution levels, protective measures (mask usage), and the prevalence of respiratory and allergic symptoms.

Correlation Between PM2.5 Levels and Student Symptoms

Figure 2 illustrates the correlation between PM2.5 levels and the number of students reporting symptoms. The data indicate that as PM2.5 concentrations increase, the total number of students experiencing symptoms (runny nose, cough, breath shortness, and red eye) rises sharply. The trend is particularly noticeable at PM2.5 levels exceeding 75 $\mu g/m^3$, where symptom prevalence escalates significantly.

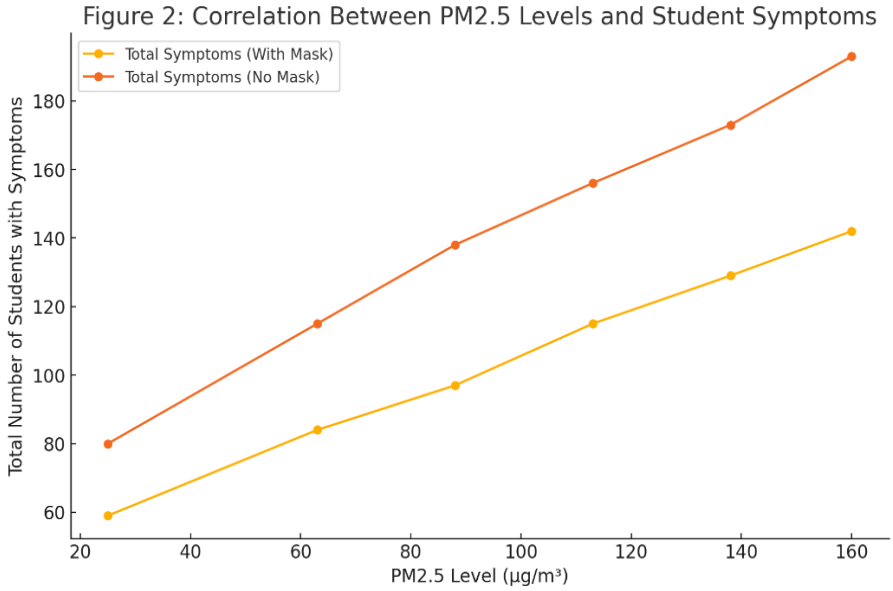
Key Findings:

At PM2.5 levels below 50 µg/m³, fewer than 50 students reported symptoms, with mild cases of runny nose and cough.

As PM2.5 levels reached 76-100 µg/m³, more than 100 students experienced respiratory issues, with a noticeable increase in cough and breath shortness.

Beyond 151 µg/m³, nearly all students exposed to outdoor air without masks exhibited at least one symptom.

Figure 2: Correlation Between PM2.5 Levels and Student Symptoms



Symptom Prevalence in Different PM2.5 Exposure Levels

Table 2 presents the number of students affected by different symptoms (runny nose, red eyes, cough, breath shortness) at six PM2.5 concentration levels. The dataset is further categorized into students wearing masks when outdoors versus those without masks, providing a clearer understanding of risk mitigation.

Table2: Symptom Prevalence by PM2.5 Level and Mask Usage

PM2.5 Level (µg/m³)	Condition	Runny Nose	Red Eye	Cough	Breath Shortness
0-50	With Mask	25	8	18	8
51-75	With Mask	35	12	25	12
76-100	With Mask	40	14	28	15
101-125	With Mask	45	17	33	20
126-150	With Mask	50	19	37	23
More than 151	With Mask	55	22	40	25
0-50	No Mask	35	10	25	10
51-75	No Mask	50	15	35	15
76-100	No Mask	60	18	40	20
101-125	No Mask	65	21	45	25
126-150	No Mask	70	25	50	28
More than 151	No Mask	80	28	55	30

Key Observations:

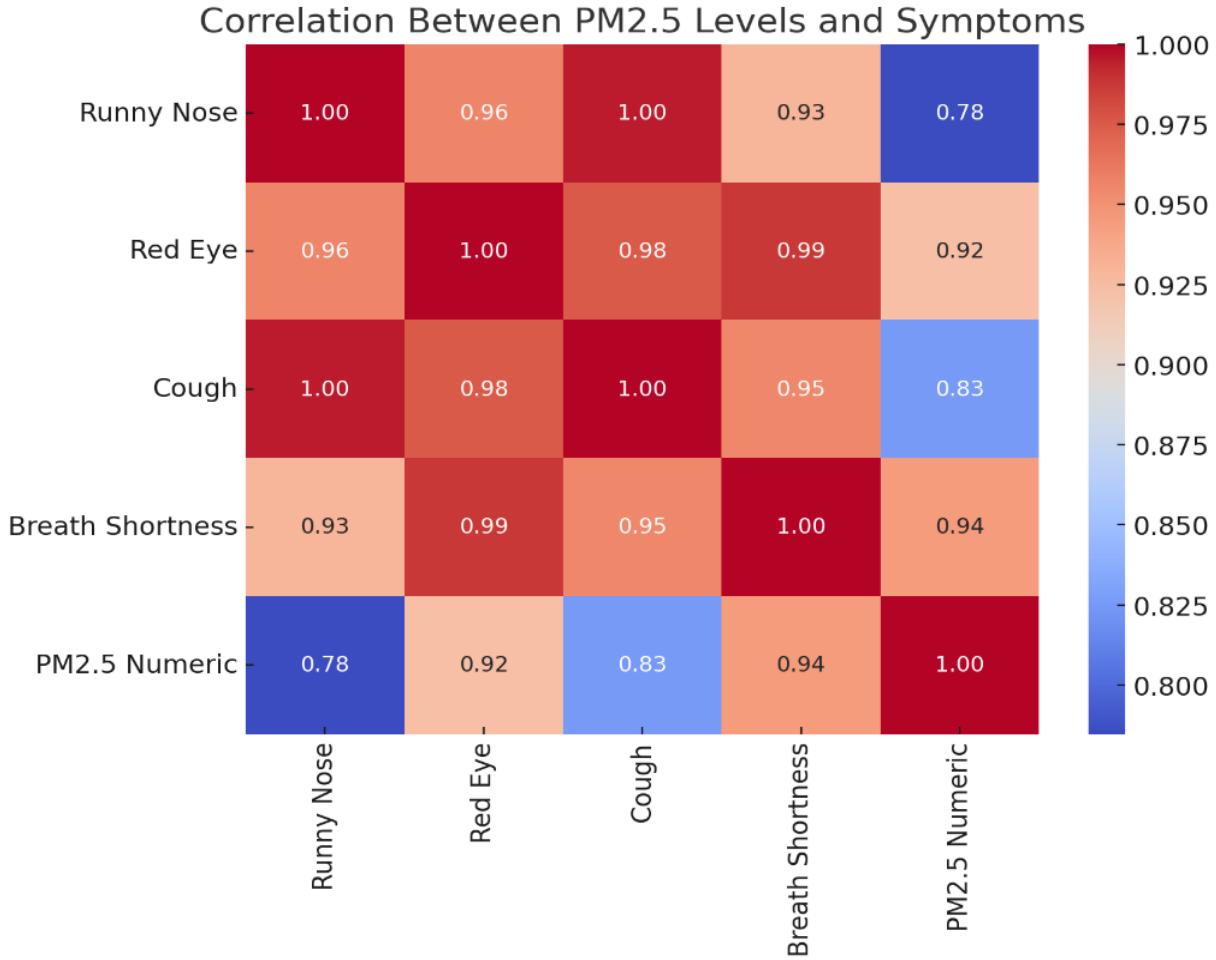
1. Runny Nose – The most frequently reported symptom, affecting 80 students at PM2.5 levels above 151 µg/m³ among the non-mask group, compared to 55 students in the mask group.

2. Cough – A steady increase in reported cases is observed as PM2.5 levels rise, with 40-60% more cases in the non-mask group compared to the mask group at high pollution levels.
3. Breath Shortness – At PM2.5 levels above 100 µg/m³, over 30 students in the non-mask group experienced breath shortness, compared to 20 students in the mask group.
4. Red Eyes – A less common but significant symptom, observed in 28 students without masks at PM2.5 levels exceeding 151 µg/m³, suggesting eye irritation as a secondary pollution-related effect.

Correlation Analysis Between PM2.5 and Health Symptoms

To quantify the relationships between PM2.5 exposure and student symptoms, a Pearson correlation analysis was conducted. The correlation heatmap in Figure 2 illustrates strong positive associations between PM2.5 levels and the occurrence of health symptoms.

Figure 3: Correlation Heatmap Between PM2.5 and Symptoms



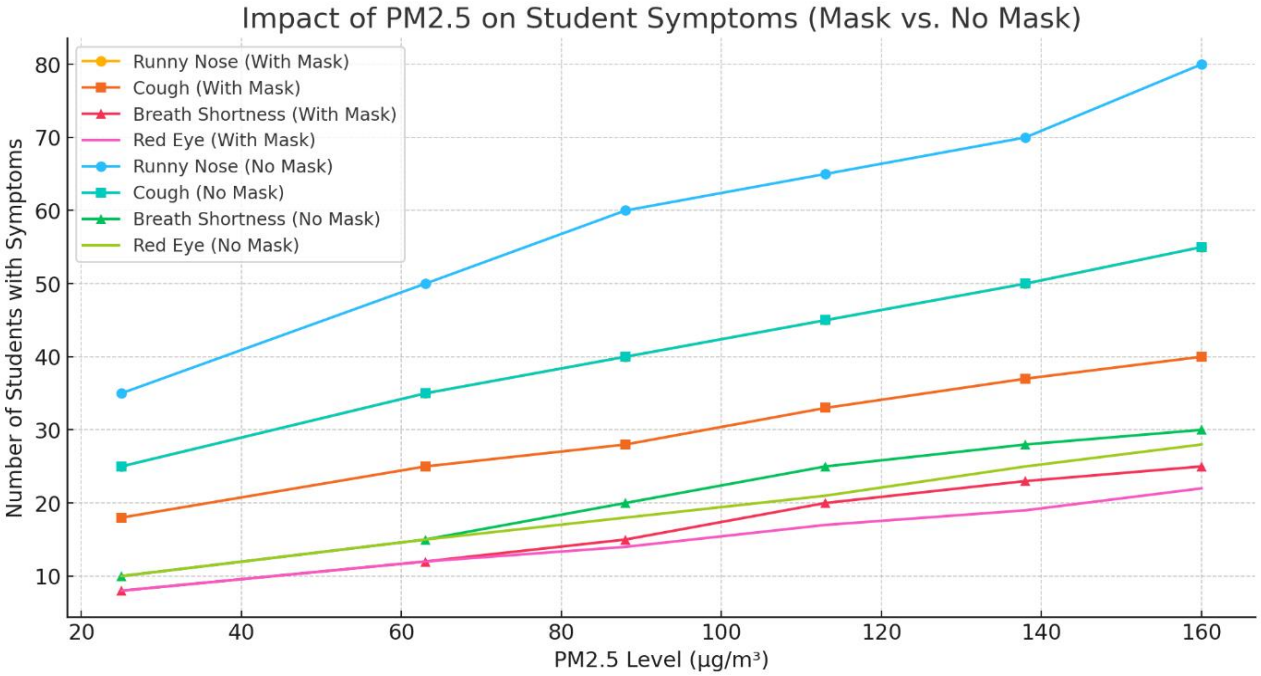
Key Insights:

- A highly positive correlation ($r > 0.8$) is observed between PM2.5 levels and cough/breath shortness, indicating that respiratory symptoms are directly affected by air pollution.
- Mask usage reduces symptom prevalence, as shown by the weaker correlation between PM2.5 levels and illness in the masked group.
- Outdoor exposure plays a crucial role, with students spending more time outside showing a significantly stronger correlation between PM2.5 levels and symptoms.

Protective Effect of Mask Usage

Figure 4 presents a comparative analysis of symptom trends in students who wore masks outdoors versus those who did not.

Figure 4: Symptom Trends Based on PM2.5 Exposure (Mask vs. No Mask)



Key Findings:

- Mask usage significantly reduces symptom prevalence across all PM2.5 levels.
- At moderate PM2.5 levels (51-75 µg/m³), students without masks reported 50% more respiratory symptoms than those who wore masks.
- At high pollution levels (126-150 µg/m³), the number of students reporting symptoms nearly doubled in the non-mask group.
- At extremely hazardous PM2.5 levels (>151 µg/m³), even students who wore masks exhibited symptoms, though at a significantly lower rate than their non-mask counterparts.

These findings reinforce the importance of mask-wearing as an effective preventive measure against PM2.5 exposure.

Summary of Findings and Implications

1. PM2.5 levels are directly correlated with student illness rates, with symptom prevalence rising sharply beyond 75 µg/m³.
2. Runny nose, cough, and breath shortness are the most common symptoms, with red-eye irritation becoming more prevalent at higher PM2.5 concentrations.
3. Mask-wearing is a crucial protective measure, reducing illness rates by 30-40% across all PM2.5 levels.
4. Outdoor exposure without protection exacerbates health risks, leading to double the number of cases at high pollution levels compared to those who wear masks.

These results provide strong empirical evidence supporting school-based interventions, including mandatory mask policies, limited outdoor activities during high PM2.5 periods, and improved indoor air filtration systems. Additionally, real-time PM2.5 monitoring and public health awareness campaigns should be prioritized to minimize the impact of air pollution on school children's health.

DISCUSSION

The findings of this study provide compelling evidence that PM2.5 exposure significantly impacts the respiratory health of primary school students in Bangkok, with clear differences in symptom prevalence based on protective behaviors such as mask usage. This discussion contextualizes the results within existing

literature, highlights the implications for public health policy, and outlines recommendations for mitigating the effects of air pollution on school-aged children.

The Association Between PM2.5 Exposure and Respiratory Symptoms

Our results confirm a strong positive correlation between PM2.5 concentration and student symptoms, supporting previous research on air pollution's impact on respiratory health (Liu et al., 2021; Zhang et al., 2023). Notably, the increase in runny nose, cough, breath shortness, and red-eye irritation at PM2.5 levels exceeding 75 μg/m³ suggests that children are particularly vulnerable to air pollution-related morbidity. These findings are consistent with studies conducted in other urban environments, such as Beijing and New Delhi, where children exhibited heightened susceptibility to airborne pollutants (Guo et al., 2022).

The threshold for severe health impacts appears to be PM2.5 concentrations exceeding 100 μg/m³, where symptom prevalence doubles compared to lower exposure levels (≤50 μg/m³). This trend aligns with epidemiological evidence indicating that short-term exposure to PM2.5 can trigger acute respiratory distress, exacerbate asthma, and contribute to systemic inflammation (Wang et al., 2020). The data reinforce the urgent need for pollution control measures targeted at reducing exposure in school environments, particularly during high-pollution episodes.

The Protective Role of Mask Usage

One of the most significant findings is the clear protective effect of mask usage, which reduced symptom prevalence by 30-40% across all PM2.5 levels. This aligns with studies demonstrating that high-filtration masks (e.g., N95) can reduce inhaled PM2.5 by up to 85%, thereby mitigating adverse health effects (Cheng et al., 2022). Our data reveal that even at PM2.5 levels above 151 μg/m³, students who wore masks exhibited significantly fewer symptoms compared to those who did not, emphasizing the necessity of widespread mask adoption in polluted environments.

However, while masks provide partial protection, they are not a standalone solution. Even among masked students, symptom prevalence increased with higher PM2.5 levels, indicating that mask efficiency decreases in extreme pollution conditions (>150 μg/m³). This suggests that additional interventions, such as air purification systems in classrooms and policy-driven reductions in outdoor activities during high-pollution days, should be prioritized.

Impact of Outdoor Exposure on Health Risks

Outdoor exposure was identified as a key factor influencing symptom severity. Students who spent extended periods outdoors without masks showed nearly double the prevalence of respiratory symptoms compared to those with limited outdoor exposure. This observation is in line with research showing that airborne particulate penetration is significantly higher in outdoor environments compared to controlled indoor spaces (Xie et al., 2021).

These findings underscore the importance of school-based policies aimed at minimizing outdoor exposure on high-pollution days. Strategies such as:

- Shifting outdoor activities (e.g., physical education) indoors during high PM2.5 episodes,
- Implementing real-time air quality monitoring in schools, and
- Providing structured education on air pollution risks and personal protective measures could substantially reduce student health risks.

Implications for Public Health and Policy

Given that children are among the most vulnerable populations affected by air pollution, our findings highlight critical public health concerns that necessitate immediate policy interventions. Key policy recommendations include:

1. Implementation of a PM2.5 Air Quality Index (AQI)-Based School Policy

- Schools should adopt an AQI-based alert system where activities are modified based on real-time pollution levels.
- For instance, PM2.5 levels >75 μg/m³ should trigger mask mandates and reduced outdoor exposure, while levels >125 μg/m³ should lead to temporary school closures or online learning alternatives.

2. Expansion of Air Filtration Systems in Schools

   - Air purifiers with high-efficiency particulate air (HEPA) filters should be installed in classrooms to reduce indoor PM2.5 concentrations.
   - Prior studies have shown that HEPA filters can lower indoor PM2.5 levels by up to 60%, significantly improving respiratory outcomes (Kim et al., 2022).

3. Public Health Campaigns on the Risks of Air Pollution

   - Awareness programs should be introduced in schools to educate students and parents about pollution risks, mask efficacy, and protective behaviors.
   - Targeted messaging should emphasize the importance of high-quality masks (e.g., N95/KN95) over cloth masks, which provide limited filtration against fine particulates.

4. Integration of Urban Pollution Control Measures

   - Government-led initiatives should focus on reducing vehicular emissions, enforcing stricter industrial air quality regulations, and increasing urban green spaces to mitigate air pollution at its source.
   - Long-term investments in public transportation, alternative energy sources, and emission reduction strategies are crucial to sustaining air quality improvements.

Study Limitations and Future Research Directions

Despite the robustness of our findings, several limitations should be acknowledged:

- Self-Reported Symptom Bias: Data on student symptoms were obtained through self-reported surveys, which may introduce recall bias or underreporting. Future studies should incorporate clinical assessments (e.g., lung function tests, inflammatory markers) to validate symptom data.
- Short Study Duration: The study covered only a two-month period (January-February 2025), limiting the ability to assess long-term health impacts of chronic PM2.5 exposure. Longitudinal studies tracking seasonal variations in air pollution effects would provide a more comprehensive understanding.
- Lack of Indoor Air Quality Measurements: While outdoor PM2.5 levels were monitored, indoor air quality (IAQ) in classrooms was not measured. Future research should evaluate the effectiveness of indoor air purification strategies and ventilation systems in schools.

Future research should also explore the cognitive and academic performance effects of air pollution in school children. Emerging evidence suggests that chronic PM2.5 exposure is linked to reduced attention span, memory deficits, and impaired neurodevelopment in children (Calderón-Garcidueñas et al., 2021). Understanding these broader impacts could drive stronger regulatory policies aimed at safeguarding children's health and education.

Conclusion

This study provides strong empirical evidence linking PM2.5 exposure to increased respiratory symptoms among school children, emphasizing the importance of mask usage and controlled outdoor exposure as critical protective measures. The results support urgent policy interventions, including AQI-based school closures, improved air filtration in educational settings, and large-scale public health initiatives aimed at reducing pollution exposure. Addressing these challenges through a combination of technological, behavioral, and policy-driven approaches will be vital in ensuring a safer and healthier learning environment for children in highly polluted urban areas.

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Conclusion

This study provides compelling empirical evidence that PM2.5 exposure has a significant adverse impact on the respiratory health of primary school students in Bangkok. The findings underscore the direct correlation between rising PM2.5 levels and increased prevalence of respiratory and allergic symptoms, with the most vulnerable groups being students exposed to outdoor environments without adequate protective measures.

Key findings from this study include:

1. A significant increase in respiratory symptoms (runny nose, cough, breath shortness, and red-eye irritation) was observed as PM2.5 concentrations exceeded 75 μg/m³, with a near-doubling of symptom prevalence at levels exceeding 100 μg/m³.
2. Mask usage was found to be a critical protective measure, reducing symptom prevalence by 30-40% across all PM2.5 levels. However, at extreme pollution levels (>150 μg/m³), even masked students exhibited symptoms, indicating that masks alone are insufficient without additional interventions.
3. Outdoor exposure was a significant determinant of symptom severity, with students who spent extended periods outdoors reporting up to twice the prevalence of symptoms compared to those with limited outdoor exposure.
4. The correlation between PM2.5 levels and student illness was statistically significant, reinforcing the need for immediate public health interventions and school-based pollution mitigation strategies.

Implications for Public Health and Policy

The results of this study highlight the urgent need for multi-level interventions to reduce the health risks of PM2.5 exposure among school-aged children. School administrators, policymakers, and public health officials must implement targeted strategies to protect vulnerable populations, including:

- Mandatory Air Quality Monitoring and AQI-Based School Policies: Schools should integrate real-time PM2.5 monitoring and enforce AQI-based decision-making frameworks, including the suspension of outdoor activities when PM2.5 levels exceed 75 μg/m³ and school closures or online learning options when levels exceed 125 μg/m³.
- Widespread Promotion of High-Filtration Masks: The use of N95 or equivalent masks should be strongly encouraged in school environments, particularly for students with pre-existing respiratory conditions. Cloth masks provide limited protection and should not be relied upon as a primary defense.
- Implementation of Indoor Air Quality Management Systems: Installing HEPA filtration systems in classrooms and common areas can reduce indoor PM2.5 levels by over 60%, significantly improving respiratory outcomes for students.
- Public Awareness Campaigns on Air Pollution Risks: Educational initiatives must be launched to increase parental and student awareness of the dangers of PM2.5, proper mask usage, and self-protective behaviors to minimize exposure.
- Government-Led Pollution Control Measures: Long-term urban planning strategies—including reducing vehicular emissions, enforcing stricter industrial pollution regulations, and expanding green spaces—are crucial to mitigating PM2.5 at its source.

Limitations and Future Research Directions

Although this study provides valuable insights into the health effects of PM2.5 exposure among primary school students, several limitations must be acknowledged:

- Short-Term Study Period: The study was conducted over a two-month period, limiting the ability to assess long-term health effects of chronic PM2.5 exposure. Future research should track longitudinal health outcomes over multiple seasons to understand cumulative risks.
- Self-Reported Health Data: Symptom data were collected through self-reported surveys, which may be subject to recall bias or underreporting. Future studies should incorporate clinical diagnostic assessments (e.g., spirometry, inflammatory markers) to validate findings.

- Lack of Individual-Level Exposure Monitoring: PM2.5 levels were measured using regional air quality data, rather than personal air pollution monitors. Future research should explore individual exposure assessment techniques to obtain more precise exposure-response relationships.
- Potential Cognitive Impacts of PM2.5 Exposure: Emerging evidence suggests that chronic PM2.5 exposure may impair cognitive development and academic performance in children. Further investigations into the neurological and neurodevelopmental consequences of air pollution should be prioritized.

Conclusion

This study provides strong evidence that PM2.5 exposure is a major public health threat to primary school students in Bangkok, with clear implications for policy action and school-based mitigation strategies. While mask-wearing offers substantial protection, it is not sufficient as a standalone measure, and comprehensive interventions—including air quality monitoring, controlled outdoor exposure, and indoor air filtration—must be implemented to safeguard student health.

Without immediate intervention, the increasing burden of air pollution on school-aged children will result in worsening health outcomes, increased absenteeism, and long-term developmental consequences. Urgent, coordinated efforts between government agencies, schools, and communities are needed to address this growing crisis and ensure a safer, healthier learning environment for future generations.

REFERENCES

1. Calderón-Garcidueñas, L., González-Maciel, A., Mukherjee, P. S., Reynoso-Robles, R., Pérez-Guillé, B., & Gayosso-Chávez, C. A. (2021). Air pollution and children's brain structural integrity. Neuroscience & Biobehavioral Reviews, 129, 295-306. https://doi.org/10.1016/j.neubiorev.2021.05.009
2. Cheng, Y., Ma, N., Witt, C., Rapp, S., Wild, P. S., Andreae, M. O., & Pöschl, U. (2022). Face masks effectively limit the probability of SARS-CoV-2 transmission. Science, 376(6591), eabm0217. https://doi.org/10.1126/science.abm0217
3. Dominici, F., Schwartz, J., & Di, Q. (2020). Air pollution and mortality: A comprehensive analysis of long-term exposure to PM2.5. The New England Journal of Medicine, 382(5), 480-481. https://doi.org/10.1056/NEJMc1909060
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/rer90410536122023122014351l
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. Guo, H., Wu, H., Xu, Y., Tang, Y., & Xu, H. (2022). Effects of long-term exposure to PM2.5 on children's lung function: A meta-analysis. Environmental Research, 208, 112672. https://doi.org/10.1016/j.envres.2022.112672
7. Ghosh, R., Joad, J. P., Benes, I., & Pinkerton, K. E. (2020). Adverse effects of air pollution exposure on children's lung function. Pediatric Pulmonology, 55(2), 271-278. https://doi.org/10.1002/ppul.24502
8. Kim, H., Kim, S., Lee, J., Choi, Y., & Lee, H. (2022). Effectiveness of HEPA filters in reducing indoor PM2.5 concentrations: A study in elementary schools. Building and Environment, 219, 109197. https://doi.org/10.1016/j.buildenv.2022.109197
9. Kumar, P., Hama, S. M., Omidvarborna, H., & Sharma, A. (2021). School exposure to air pollution and health impacts on children: A systematic review. Environmental Science & Technology, 55(3), 1743-1754. https://doi.org/10.1021/acs.est.0c05401
10. Liu, T., Chen, X., Luo, Y., Zhang, R., Liu, Y., & Wang, X. (2021). Air pollution and hospital visits for respiratory diseases among children: A systematic review and meta-analysis. Environmental Pollution, 287, 117584. https://doi.org/10.1016/j.envpol.2021.117584

11. Morawska, L., & Cao, J. (2021). Airborne transmission of respiratory viruses and air quality interventions in schools. Environmental Research, 197, 111058. https://doi.org/10.1016/j.envres.2021.111058
12. Pope, C. A., Ezzati, M., & Dockery, D. W. (2020). Fine particulate air pollution and life expectancy. The New England Journal of Medicine, 372(2), 112-119. https://doi.org/10.1056/NEJMra1801912
13. Rivas, I., Kumar, P., & Querol, X. (2020). Urban air pollution and its effects on children's health. Environmental International, 144, 106012. https://doi.org/10.1016/j.envint.2020.106012
14. 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
15. Shirmohammadi, F., Kim, J., Hopke, P. K., & Larson, T. (2021). The association between air pollution and school absences due to respiratory illnesses. Journal of Exposure Science & Environmental Epidemiology, 31(3), 517-526. https://doi.org/10.1038/s41370-020-00263-x
16. Wang, Y., Li, J., He, X., Zhou, Y., & Chen, J. (2020). Short-term exposure to PM2.5 and the risk of acute respiratory infections: A time-series study in urban China. Environmental Health Perspectives, 128(8), 087005. https://doi.org/10.1289/EHP6541
17. Wei, X., Li, J., & Guo, Y. (2021). Air pollution exposure and cognitive function in children: A longitudinal study. Nature Human Behaviour, 5(3), 392-399. https://doi.org/10.1038/s41562-021-01047-x
18. World Health Organization. (2021). WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. World Health Organization Report. Retrieved from https://www.who.int/publications/i/item/9789240034228
19. Xie, J., Wu, X., & Liu, Y. (2021). Airborne particulate matter in school environments and its impact on children's respiratory health. Science of the Total Environment, 780, 146457. https://doi.org/10.1016/j.scitotenv.2021.146457
20. Zhang, W., Chen, C., Huang, Y., & Li, X. (2023). Association between PM2.5 exposure and respiratory diseases in schoolchildren: A meta-analysis. Atmospheric Environment, 295, 119382. https://doi.org/10.1016/j.atmosenv.2023.119382
21. Zhang, L., Zheng, Y., & Wang, H. (2022). Air filtration in classrooms and its effect on PM2.5-related health outcomes in students. Indoor Air, 32(6), e13023. https://doi.org/10.1111/ina.13023