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The association between ambient fine particulate matter ($PM_{2.5}$) concentrations and air pollution-related respiratory disease at the pollution control zone of Rayong Province, Thailand

Keywords: $PM_{2.5}$, respiratory disease, air pollution, pollution control zone, time-lag analysis

Introduction

Airborne particles smaller than 2.5 μm in diameter ($PM_{2.5}$), known as fine particles, are among the most harmful air pollutants globally with substantial effects on human health. These small particles can penetrate extremely deep into pulmonary alveoli and result in extensive respiratory disease and premature death.

Traffic is heavy in industrial zones, such as the pollution control zone of Rayong Province in Thailand and biomass burning is common; therefore, $PM_{2.5}$ pollution is an important and long-term public health issue. Exposure to $PM_{2.5}$ causes millions of deaths annually and disproportionately affects the populations of low- and middle-income countries (World Health Organization [WHO], 2021). Thailand's industrial provinces also contain high concentrations of $PM_{2.5}$ that exceed surpass the WHO guideline annual average of 15 $\mu g \cdot m^{-3}$, highlighting the need for further research to better understand associated health effec ts and provide a basis for policy action (Kanchanasuta et al., 2020). This research focuses on the pollution control zone of Rayong Province, a major industrial cluster, to study how exposure to $PM_{2.5}$ relates to respiratory outcomes of health.

There has been considerable epidemiological research on the impact of $PM_{2.5}$ and lung health in recent years. Various studies have repeatedly shown that exposure to $PM_{2.5}$ is associated with an elevated risk of asthma, bronchitis, and other respiratory complications, especially in urban-industrial settings (Choo et al., 2023; Zhu et al., 2023). In Southeast Asia, industrial pollution and seasonal biomass burning have been identified as the predominant sources of elevated levels of $PM_{2.5}$, and short-term exposure has been linked with higher rates of hospital admissions due to respiratory illnesses (Phosri et al., 2019; Amnuaylojaroen et al., 2020). Time-lag analyses have revealed that $PM_{2.5}$ exposure can have immediate or delayed adverse health effects, with vulnerable subgroups such as the elderly and children being especially affected (Kim et al., 2012; Chantaraprachoom et al., 2024). These findings underscore the importance of regional analysis in order to better characterize local patterns of pollution and their associated health effects.

The literature suggests that the health impacts of $PM_{2.5}$ differ based on exposure duration, concentration levels, and population vulnerability. Research in Thailand suggests that industrial estates, such as Rayong, have higher levels of $PM_{2.5}$ than areas such as Bangkok, but data on the short-term adverse effects of $PM_{2.5}$ exposure in industrial environment remain limited (Vichit-Vadakan et al., 2008; Cheanklin et al., 2012). The "harvesting effect," whereby $PM_{2.5}$ exposure can cause morbidity in susceptible persons, has been observed in many studies illustrating the complex temporal patterns of exposure–response relationships (Anggraeni & Lestari, 2023; Suwanprapha et al., 2024). These gaps highlight the importance of local research that combines air quality and health information to assess the short-term impact of $PM_{2.5}$ exposure on respiratory morbidity in industrial environments (Pothirat et al., 2016; Muenmee & Bootdee, 2021). Despite the growing body of international

and national evidence regarding the health effects of $PM_{2.5}$ exposure, limited empirical research has specifically examined short-term temporal associations in designated industrial pollution control zones in Thailand. In particular, there remains insufficient integration of multi-station air quality monitoring data with hospital-based morbidity records at the provincial level. Therefore, this study aims to address this gap by systematically analyzing daily $PM_{2.5}$ concentrations and respiratory disease outcomes within the pollution control zone of Rayong Province using time-lag correlation analysis.

The objective of this research is to evaluate trends in $PM_{2.5}$ levels and respiratory disease morbidity in the pollution control zone of Rayong Province between 2020 and 2023. The study will investigate short-term associations between daily concentrations of $PM_{2.5}$ and respiratory diseases using time-lag analysis to explore immediate and delayed health outcomes. By integrating air pollution data from monitoring stations with hospital admission data, this article provides empirical evidence to support strategic air quality management and public health interventions in industrial areas.

Material and methods

Study design

This study employed a retrospective analytical design based on secondary data obtained from air quality monitoring stations and hospital patient record systems.

Study area and air quality monitoring stations

A geographical map illustrating the spatial distribution of air quality monitoring stations within the pollution control zone of Rayong Province is presented in Figure 1. The map provides context for understanding station locations in relation to industrial estates, residential zones, and transportation corridors.

A descriptive summary of each monitoring station, including land-use classification and proximity to major emission sources, is provided in Table 1. These additional details facilitate the interpretation of inter-station variability in $PM_{2.5}$ concentrations and allow for the assessment of potential location-specific influences.

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FIGURE 1. Geographic distribution of $PM_{2.5}$ monitoring stations and the hospital catchment area within the pollution control zone of Rayong Province

Source: own work.

TABLE 1. Characteristics of $PM_{2.5}$ monitoring stations included in the study

Station code	Monitoring site	Nearby sources
28T	Pluakdaeng District Health Office, Rayong, Thailand	industrial estate, port activities
29T	Health Promotion Hospital Maptaphut, Rayong, Thailand	petrochemical complex, traffic
30T	Rayong Provincial Agricultural Office, Rayong, Thailand	traffic, mixed land use
31T	Field Crop Research Center, Rayong, Thailand	agricultural activities, open areas
74T	Government Center, Rayong, Thailand	residential traffic, commercial area

Source: own work.

$PM_{2.5}$ concentrations from fixed-site monitoring stations were used as proxies for ambient population-level exposure within the pollution control zone. These stations were assumed to reflect general air quality conditions across the hospital catchment area; however, spatial variability in pollutant distribution may result in exposure misclassification at the individual level.

The study did not include geocoded residential data; therefore, precise distances between individual patient residences and monitoring stations could not be calculated. Exposure was assigned at the ecological level rather than the individual level. Daily $PM_{2.5}$ concentrations were analyzed separately for each monitoring station to explore spatial heterogeneity. In addition, an area-level average

concentration across all five stations was calculated to represent general ambient exposure within the pollution control zone of Rayong Province. The monitoring stations are located approximately 3–18 km from the hospital catchment area.

Health data collection

Health data were obtained from Her Royal Highness Princess Maha Chakri Sirindhorn Memorial Hospital, which functions as a major tertiary care facility serving the Pollution Control Zone of Rayong Province. The hospital receives referrals for moderate to severe respiratory conditions from surrounding districts within the study area.

Although additional primary healthcare units operate in the region, inpatient respiratory admissions are predominantly managed at this center. Therefore, the hospitalization data are considered broadly representative of respiratory morbidity patterns within the study population.

The study utilized both daily-level and monthly aggregated datasets. Daily $PM_{2.5}$ concentrations and daily respiratory case counts were used for the short-term time-lag assessment. In parallel, monthly averages and monthly aggregated case counts were constructed for ecological correlation analysis across the study period.

Data collection

The study utilized both daily-level and monthly aggregated datasets. Daily $PM_{2.5}$ concentrations and daily respiratory case counts were used to evaluate short-term exposure–response relationships and time-lag associations. Monthly averages and aggregated case counts were additionally constructed to examine broader ecological temporal patterns across the study period.

Lag analysis was performed to explore temporal displacement patterns between $PM_{2.5}$ concentrations and respiratory morbidity within the aggregated monthly framework. These lag estimates do not represent true daily distributed lag effects but rather relative shifts in temporal association.

Daily 24-hour $PM_{2.5}$ concentrations were collected from five air pollution monitoring stations within the Rayong pollution control area, including Stations 28T, 29T, 30T, 31T, and 74T. The data were collected from January 1, 2017, to December 31, 2023, and were expressed as concentrations in micrograms per cubic meter [$\mu g \cdot m^{-3}$].

Health information on outpatients and inpatients was collected from Her Royal Highness Princess Maha Chakri Sirindhorn Memorial Hospital Siam Grand Palace, Rayong. It covered only patients with respiratory and air pollution diseases, as classified by the International Statistical Classification of Diseases and Related Health Problems 10th revision (ICD-10) codes J00–J99. Seven respiratory disease categories were selected based on their clinical relevance and prior epidemiological evidence indicating sensitivity to air pollution exposure. These conditions represent a combination of acute inflammatory diseases (e.g., pneumonia, bronchitis) and chronic respiratory disorders (e.g., asthma, COPD) that are commonly reported in regional health surveillance data. Other ICD-10 codes within J00–J99 were not included due to low case frequency or limited evidence of short-term air pollution sensitivity. The examination focused on seven general categories of diseases: (1) COPD, (2) asthma, (3) pneumonia, (4) influenza, (5) acute pharyngitis, (6) chronic rhinitis, and (7) bronchitis.

Monthly average $PM_{2.5}$ concentrations and monthly aggregated counts of respiratory disease cases were used in the analysis. This ecological design, based on monthly temporal resolution, limits the ability to evaluate short-term daily lag effects and should be interpreted accordingly.

Study period

Although air quality monitoring data were available from 2017 onward, complete and standardized hospital admission records were consistently accessible only from 2020. To ensure data completeness and comparability, the analytical period was therefore restricted to 2020–2023.

Data analysis

Descriptive statistics were calculated to summarize air pollution levels and respiratory morbidity.

Daily-level time-series assessment. Daily 24-hour $PM_{2.5}$ concentrations and daily counts of respiratory disease cases were analyzed to examine short-term exposure–response relationships. The Spearman rank correlation coefficient was applied due to the non-normal distribution of the data.

Time-lag analyses were conducted for lag days 0–7 to explore delayed associations following exposure. These analyses represent unadjusted exploratory correlations and do not constitute causal time-series modeling. The daily-level

dataset included approximately 1,461 observations (January 2020–December 2023). Days with incomplete $PM_{2.5}$ or hospital records were excluded from the daily-level correlation analyses. No imputation was performed. All statistical tests were two-tailed, and statistical significance was defined as $p < 0.05$.

Daily $PM_{2.5}$ concentrations were calculated as the average of the five fixed monitoring stations to represent population-level exposure within the study area. Both daily-level and monthly-level analyses were conducted to examine short-term exposure–response relationships as well as broader ecological temporal patterns.

Monthly-level ecological correlation. Monthly average $PM_{2.5}$ concentrations and monthly aggregated respiratory case counts were analyzed to assess broader ecological co-variation patterns. Spearman rank correlation coefficient was used to evaluate associations between each monitoring station and each respiratory disease category at the monthly level ($N \approx 48$ months). All analyses were performed using IBM SPSS Statistics, version 26.0.

Ethical approval

This research received ethical approval from the Research Ethics Review Committee, Rajamangala University of Technology Tawan-ok (RMUTTO REC Reference No. 033/2024) on July 15, 2024, based on the ethical guidelines described in the Declaration of Helsinki and Guidelines on Good Clinical Practice (ICH-GCP). No individual data was collected, and patient identifiers were anonymized to the extent possible. The analysis used aggregated data.

Results and discussion

$PM_{2.5}$ concentrations at pollution control zone of Rayong Province in Thailand

The trend analysis revealed an overall increase in $PM_{2.5}$ levels across Rayong's pollution control areas during the study period, as shown in Table 2, Figures 2 and 3. The mean overall concentration from all monitoring points rose from 18.19 $\mu g \cdot m^{-3}$ in 2020 to 20.55 $\mu g \cdot m^{-3}$ in 2023, representing a 13% increase. Station 29T recorded the highest mean $PM_{2.5}$ concentration at 19.42 $\mu g \cdot m^{-3}$ while Station 74T recorded the lowest concentration at 18.33 $\mu g \cdot m^{-3}$. The highest value was 21.93 $\mu g \cdot m^{-3}$, recorded at Station 29T in 2023. Although these values were

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still within Thailand's national air quality standard of 50 $\mu g \cdot m^{-3}$, they were above WHO guideline value of 15 $\mu g \cdot m^{-3}$ by about 37%. The ongoing rise in $PM_{2.5}$ concentrations, especially at Station 29T and Station 31T, emphasizes the necessity of ongoing monitoring and action towards safeguarding public health in Rayong's industrial estates.

TABLE 2. Average concentrations of $PM_{2.5}$ by monitoring station and year at the pollution control zone of Rayong Province in Thailand during 2020–2023 [$\mu g \cdot m^{-3}$]

Year	Station					Mean (all stations)	Max	Min
	28T	29T	30T	31T	74T			
2020	20.94	16.43	17.75	16.75	19.07	18.19	20.94	16.43
2021	20.02	19.42	16.49	17.51	17.41	18.17	20.02	16.49
2022	16.74	19.91	19.16	18.63	16.83	18.25	19.91	16.74
2023	18.79	21.93	20.30	21.72	19.99	20.55	21.93	18.79
Average	19.12	19.92	18.43	18.65	18.33	18.89	21.93	16.43

Source: own work.

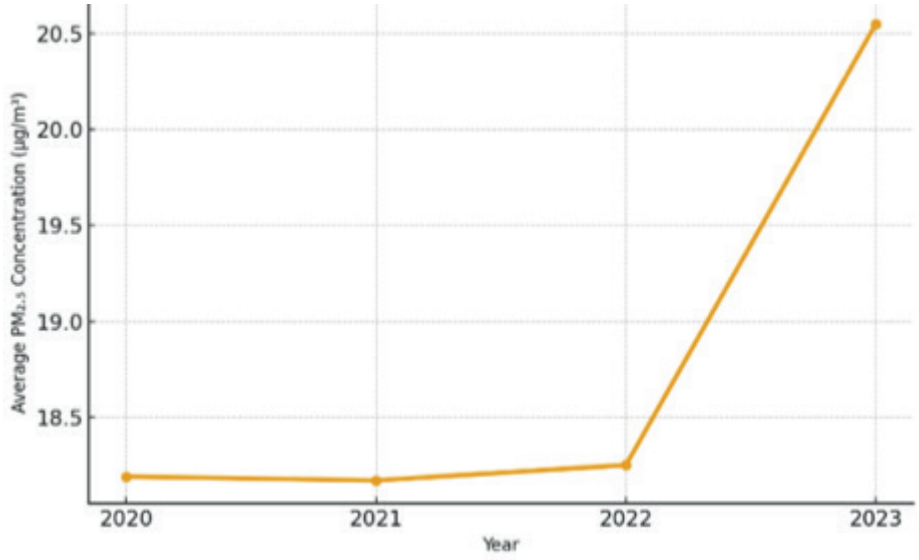

FIGURE 2. Annual trend of average $PM_{2.5}$ concentrations from all monitoring stations at the pollution control zone of Rayong Province in Thailand during 2020–2023

Source: own work.

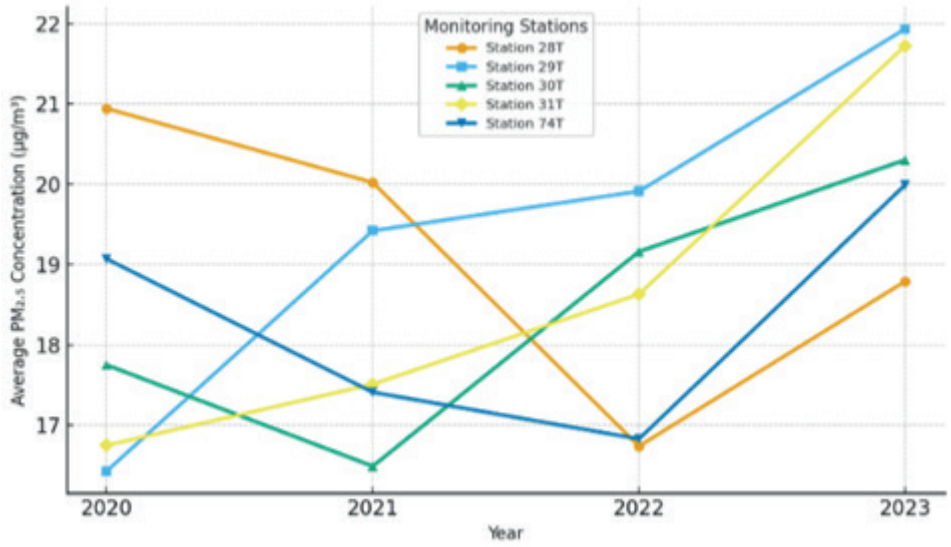

FIGURE 3. Temporal variation in $PM_{2.5}$ concentrations by station during 2020–2023

Source: own work.

Trends in the number of patients with respiratory diseases

As shown in Table 3, respiratory disease trends are summarized numerically through annual case counts across disease categories.

TABLE 3. Number of patients with respiratory diseases by category and year at the pollution control zone of Rayong Province in Thailand during 2020–2023

Disease	2020	2021	2022	2023	Total (4 years)	Mean (1 year)	Max	Min
Chronic obstructive pulmonary disease (COPD)	722	566	704	688	2,680	670.0	722	566
Asthma	1,384	1,222	1,360	1,784	5,750	1,437.5	1,784	1,222
Pneumonia	707	413	571	1,127	2,818	704.5	1,127	413
Influenza	274	6	194	2,530	3,004	751.0	2,530	6
Acute pharyngitis	1,255	578	1,554	2,235	5,622	1,405.5	2,235	578
Chronic rhinitis	31	27	21	22	101	25.3	31	21
Bronchitis	1,141	367	706	1,090	3,304	826.0	1,141	367
All diseases combined	5,514	3,179	5,110	9,476	23,279	5,819.8	–	–

Source: own work.

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Association between $PM_{2.5}$ concentrations and respiratory diseases over time

As presented in Table 4 and Figure 4, the correlation analysis revealed significant positive correlations between $PM_{2.5}$ concentrations and three respiratory diseases. Pneumonia incidence showed a strong positive correlation with $PM_{2.5}$ at Station 31T ($r = 0.276$, $p < 0.05$). (2) Bronchitis was also highly correlated with same-day $PM_{2.5}$ levels at Station 74T ($r = 0.276$, $p < 0.05$), whereas significant positive correlations were observed at Station 28T (lag 4: $r = -0.419$, $p < 0.01$) and Station 29T (lag 4: $r = -0.331$, $p < 0.05$). (3) Asthma also showed a positive correlation with $PM_{2.5}$ concentration at Station 31T at a lag of 1 day (lag 1: $r = 0.283$, $p < 0.05$).

Negative correlations were observed at lags 3–5 at certain stations, suggesting that acute exposure to elevated levels of $PM_{2.5}$ may result in increased respiratory morbidity among susceptible populations initially, followed by a subsequent reduction in morbidity as the susceptible population is diminished. There were no statistically significant correlations for the remaining categories of respiratory illness investigated in this research.

Correlation analysis revealed varying degrees of association between $PM_{2.5}$ concentrations and respiratory disease incidence across monitoring stations. Significant positive correlations were identified at Stations 31T and 74T ($r = 0.276$, $p = 0.012$), while weaker or non-significant associations were observed at other stations. However, the magnitude of the correlation was modest ($r < 0.30$), explaining less than 10% of the variance.

TABLE 4. Spearman correlation coefficients (r) between $PM_{2.5}$ concentrations and respiratory diseases by monitoring station at the pollution control zone of Rayong Province in Thailand during 2020–2023

Disease	Station					Mean (r)
	28T	29T	30T	31T	74T	
Chronic obstructive pulmonary disease (COPD)	0.072	−0.006	0.057	0.042	0.075	0.062
Asthma	0.052	0.208	0.153	0.255	0.259	0.206
Pneumonia	0.062	0.260	0.159	0.276*	0.242	0.223
Influenza	−0.023	0.203	0.129	0.256	0.204	0.170
Acute pharyngitis	−0.110	0.104	0.031	0.134	0.069	0.051
Chronic rhinitis	−0.041	−0.175	−0.099	−0.189	−0.151	−0.153
Bronchitis	0.153	0.199	0.166	0.258	0.276*	0.232
All diseases combined	0.024	0.186	0.110	0.239	0.212	0.169

Spearman rank correlation coefficients were calculated based on monthly aggregated data (N = 45–52 months depending on data completeness; *$p < 0.05$). Values represent contemporaneous monthly associations. No lag structure was applied at the monthly level.

Source: own work.

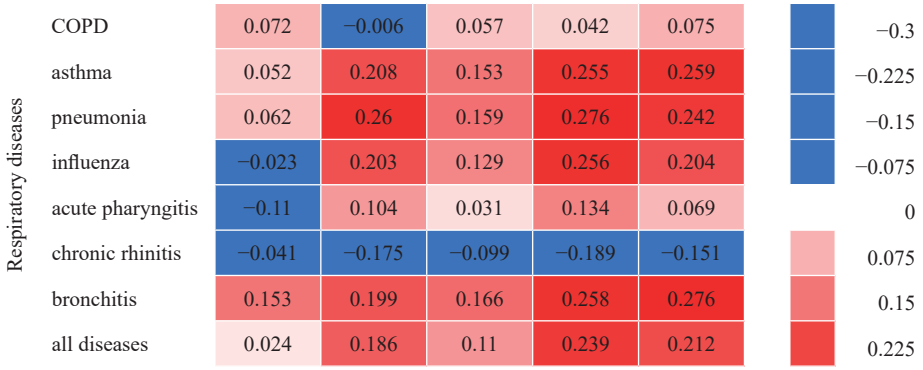

FIGURE 4. Correlation matrix illustrating relationships between $PM_{2.5}$ concentrations and respiratory disease categories across monitoring stations. All correlation coefficients are numerically presented in Table 4

Source: own work.

Lag analysis of $PM_{2.5}$ exposure and respiratory diseases (0–7 days) – evidence of an acute effect

As shown in Table 5 and Figure 5, a weak but statistically significant positive correlation was observed between $PM_{2.5}$ concentration and bronchitis cases at Station 74T on the same day ($r = 0.276$, $p = 0.048$).

TABLE 5. Statistically significant Spearman correlations (r) between daily $PM_{2.5}$ concentrations and respiratory diseases across lag periods (0–7 days) at pollution control zone of Rayong Province in Thailand during 2020–2023 (approximately 1,461 daily observations)

Disease	Station	lag	*r*	Significance
Chronic obstructive pulmonary disease (COPD)	28T	lag 7	−0.296	*
Asthma	28T	lag 4	−0.304	*
Asthma	31T	lag 1	0.283	*
Acute pharyngitis	28T	lag 2	−0.295	*
Acute pharyngitis	28T	lag 3	−0.337	*
Acute pharyngitis	28T	lag 4	−0.310	*
Bronchitis	28T	lag 3	−0.354	*
Bronchitis	28T	lag 5	−0.317	*
Bronchitis	28T	lag 4	−0.419	**
Bronchitis	29T	lag 4	−0.331	*
Bronchitis	29T	lag 5	−0.296	*
Bronchitis	74T	lag 0	0.276	*

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TABLE 5 (cont.)

Disease	Station	lag	*r*	Significance
Bronchitis	74T	lag 4	−0.303	*
All diseases combined	28T	lag 3	−0.333	*
All diseases combined	28T	lag 4	−0.349	*

*$p < 0.05$; **$p < 0.01$.

Source: own work.

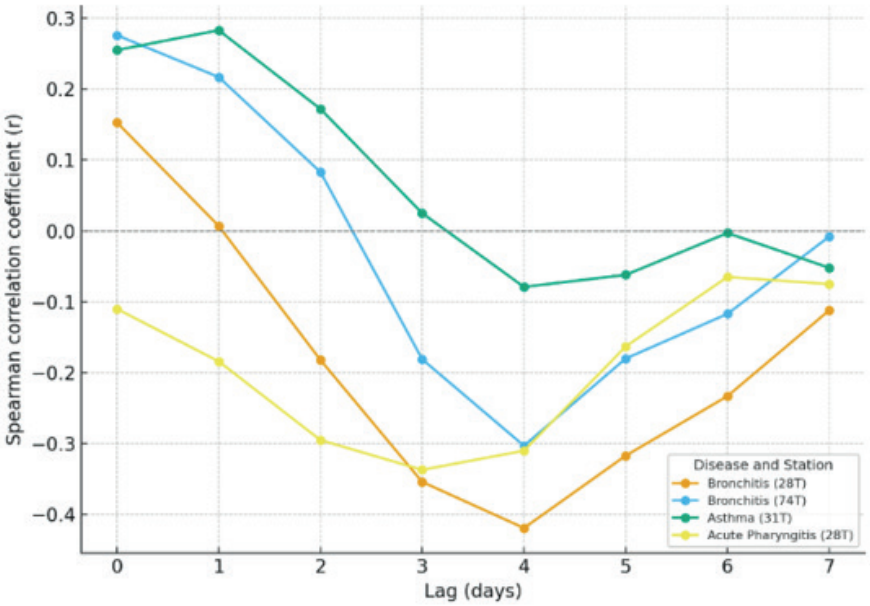

FIGURE 5. The Spearman correlation analysis between $PM_{2.5}$ exposure and selected respiratory diseases
Source: own work.

This finding suggests a modest temporal association between elevated ambient $PM_{2.5}$ levels and increased bronchitis visits. In contrast, negative correlations were observed at lag days 3–5 at Stations 28T and 29T, indicating possible short-term displacement patterns. Although the magnitude of the association was small, the same-day pattern is consistent with the hypothesis that short-term increases in $PM_{2.5}$ may contribute to acute bronchial irritation, particularly among susceptible populations such as children, older adults, and individuals with pre-existing respiratory conditions.

The "harvesting effect" phenomenon

As Table 5 and Figure 5 illustrate, various respiratory illnesses were negatively correlated with $PM_{2.5}$ concentrations at lag times ranging from 3 to 5 days, which may suggest a possible harvesting effect. Of particular note, bronchitis at Station 28T (lag 4: $r = -0.419$, $p < 0.01$) and pharyngitis at Station 28T (lag 3: $r = -0.337$, $p < 0.05$) exhibited strong negative correlations. In contrast, pollution may trigger acute illness among susceptible individuals shortly after safe pollution levels peak. This may subsequently reduce the number of susceptible individuals in the short term, contributing to the decline in case numbers after the initial increase. This temporal pattern is consistent with the air pollution-morbidity research using time series analyses. Past investigations have confirmed that such patterns of pollution-related health effects are plausible.

Interstation variability suggesting different pollution sources

As shown in Table 5 and Figure 5, the correlations varied significantly across monitoring stations. Station 74T showed the strongest immediate effect ($r = 0.276$, $p < 0.05$) while Stations 28T and 29T displayed distinct negative lagged correlations, suggesting a possible harvesting effect. However, no statistically significant correlations were observed for data collected at Station 30T and Station 31T. These spatial variations may reflect differences in the structure and origin of $PM_{2.5}$. Some of these differences may be attributable to combustion sources, motor vehicle exhaust, and local site characteristics.

No observable association for certain disease groups

As shown in Table 5, no significant correlations were identified for chronic rhinitis or influenza across all stations. This finding is consistent with the understanding that these diseases are primarily caused by viral or bacterial infections rather than direct particulate exposure. Nonetheless, $PM_{2.5}$ may act as a co-factor that exacerbates symptoms or increases susceptibility in individuals with underlying conditions, warranting further investigation in future epidemiological studies.

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Conclusion and discussion

Short-term elevations in $PM_{2.5}$ in the pollution control zone of Rayong Province in Thailand were associated with increased respiratory morbidity, with the strongest signals observed for bronchitis (lag 0) and asthma (lag 1), and indications of harvesting at lags of 3–5 days. Significant positive correlations were observed for bronchitis ($r = 0.276$, $p < 0.05$) and asthma ($r = 0.283$, $p < 0.05$), with lag effects detected up to three days following exposure. Even where concentrations remained below the Thai standard, exceedance of the WHO guideline suggests that "moderate" pollution can still trigger clinically relevant events. Public health actions should include continuous monitoring, rapid risk communication, and targeted protection of susceptible groups, alongside emission controls tailored to industrial source profiles. Methodologically, future studies should adopt distributed lag (non-linear) and small-area designs and incorporate co-pollutants, meteorology, and chemical speciation to refine exposure–response estimates and causal interpretation.

This study provides exploratory evidence of a short-term temporal association between fine particulate matter ($PM_{2.5}$) and respiratory diseases in Rayong Province, an industrialized area of Thailand designated as a pollution control zone. The results indicated that elevated $PM_{2.5}$ concentrations were weak but significantly correlated with increased bronchitis and asthma cases on the same day and the following day. Negative correlations observed at lags of three to five days may reflect short-term temporal displacement, sometimes described as a harvesting effect. However, given the aggregated monthly design and the absence of distributed lag time-series modeling, this interpretation remains speculative. These findings are broadly consistent with previous time-series and multi-city studies reporting associations between short-term $PM_{2.5}$ exposure and respiratory hospital admissions, although differences in methodology limit direct comparability (Han et al., 2022; Wang et al., 2025).

The observed acute effects correspond to biological mechanisms reported in experimental and epidemiological literature, where $PM_{2.5}$ has been associated with oxidative stress and airway inflammation in experimental and epidemiological studies, airway inflammation, and reduced lung function (Atkinson et al., 2014; Mueller et al., 2021). Moreover, the pattern of negative correlations at lags of 3–5-day, also known as the "harvesting effect," has been widely documented in short-term mortality and morbidity studies across Asia and Europe (Gasparrini, 2022; Quijal-Zamorano et al., 2024). This phenomenon occurs when pollution events precipitate illness in vulnerable individuals, temporarily reducing the population at risk in subsequent days (Burnett et al., 2018). Spatial heterogeneity among

monitoring stations in Rayong suggests differences in emission sources and pollutant composition. Stations near petrochemical complexes (e.g., Station 74T) showed stronger acute effects, whereas those near mixed residential areas exhibited delayed responses consistent with findings from industrial regions where particle composition influences toxicity (Bootdee et al., 2023). A previous Thai study also reported significant associations between $PM_{2.5}$ and respiratory admissions in industrial areas of Eastern Thailand (Chatphuti & Jayathavaj, 2025), reinforcing the localized relevance of these findings. While the average $PM_{2.5}$ concentrations (18–21 $\mu g \cdot m^{-3}$) in this study remained below the Thai 24-hour standard (50 $\mu g \cdot m^{-3}$), they consistently exceeded the WHO, 2021 guideline of 15 $\mu g \cdot m^{-3}$. Global evidence indicates that adverse health effects can occur even at low-to-moderate concentrations of $PM_{2.5}$, suggesting that there is effectively no safe threshold for exposure (Health Effects Institute & Institute for Health Metrics and Evaluation [HEI & IHME], 2024; Parasin & Amnuaylojaroen, 2024). The stronger associations observed for pneumonia and bronchitis compared to COPD may reflect the acute inflammatory response triggered by short-term $PM_{2.5}$ exposure, which has been shown to increase airway inflammation and susceptibility to respiratory infections (Kyung & Jeong, 2020; Han et al., 2022; Teeranoraseth et al., 2024). Acute respiratory conditions are generally more sensitive to short-term environmental fluctuations, whereas chronic diseases such as COPD may demonstrate more heterogeneous or delayed responses across monitoring stations (Atkinson et al., 2014; Zhu et al., 2023). The magnitude of the associations observed in this study was relatively small. Such modest correlations are consistent with the multifactorial nature of respiratory diseases, in which air pollution represents one of several contributing environmental factors rather than a sole determinant.

This observation is consistent with international evidence demonstrating that both chronic and acute exposure to $PM_{2.5}$ are associated with increased mortality and morbidity, particularly from respiratory and cardiovascular diseases (Burnett et al., 2018). From a methodological perspective, this study employed a retrospective design utilizing Spearman correlation and lag analyses to identify short-term temporal associations. This approach is consistent with recent Thai studies that have successfully applied time-series and correlation methods to forecast pollution-related health outcomes (Li et al., 2023; Choocheep et al., 2024; Chumnicherngka et al., 2024). While this approach offers an accessible means of interpreting lagged effects, future investigations should incorporate distributed lag non-linear models (DLNMs) and Bayesian spatial frameworks to more comprehensively capture complex exposure–response relationships and spatial dependencies (Gasparrini, 2022; Quijal-Zamorano et al., 2024).

Integrating meteorological variables, co-pollutants, and source-specific emission data will further enhance the precision of exposure assessments and strengthen causal inference in future research. In the context of Thailand's environmental health management, the results indicate a need to strengthen local air quality surveillance, integrate environmental monitoring data with hospital admission and health surveillance systems, and enforce industrial emission regulations within designated pollution control zones (Chumnicherngka et al., 2024; Tanasirirak et al., 2024). These measures align with national strategies outlined in the Ministry of Natural Resources and Environment's Air Quality Action Plan and are reinforced by recent evidence linking $PM_{2.5}$ exposure to increased mortality from non-communicable diseases across Thailand (Yan, 2023; Parasin & Amnuaylojaroen, 2024).

This study provides additional evidence supporting a short-term association between $PM_{2.5}$ exposure and respiratory morbidity in an industrialized region of Thailand.

Finally, this study reinforces that short-term elevations in $PM_{2.5}$ concentrations, even at moderate levels, may contribute to increased respiratory health risk, particularly among vulnerable populations. These findings emphasize the necessity of continuous air quality monitoring, stricter emission control measures, and targeted preventive health policies to mitigate the growing burden of air pollution-related diseases in industrialized regions.

Continuous air quality monitoring, early warning systems, and the integration of environmental data into public health planning are recommended to reduce respiratory health risks in industrial regions.

Future studies incorporating meteorological variables and multivariate statistical models are warranted to better clarify potential causal pathways.

In conclusion, the present study demonstrated statistically significant but modest short-term associations between ambient $PM_{2.5}$ concentrations and respiratory morbidity in the pollution control zone of Rayong Province during 2020–2023. The strongest associations were observed for bronchitis on the same day of exposure and for asthma with a one-day lag, with evidence suggestive of short-term temporal displacement at lags of three to five days. Although effect sizes were small, $PM_{2.5}$ concentrations consistently exceeded WHO guideline levels, indicating that even moderate pollution may contribute to measurable respiratory health impacts in industrialized settings. These findings represent exploratory ecological evidence derived directly from the study analysis and underscore the public health relevance of continued air quality monitoring and targeted prevention strategies in pollution-affected regions.

Limitations

This study utilized hospitalization data from a single tertiary care hospital. While this institution serves as a major referral center in the region, the absence of data from smaller healthcare facilities may limit the complete capture of mild respiratory cases.

The absence of pre-pandemic morbidity data limits long-term comparisons of respiratory disease trends and constrains the interpretation of COVID-19-related behavioral effects within a broader historical context.

The absence of adjustment for potential confounders, including meteorological factors and co-pollutants, represents an important limitation. Seasonal patterns shared by air pollution and respiratory diseases may partially explain the observed correlations. Future research should apply time-series regression models or DLNMs to better isolate the independent short-term effects of $PM_{2.5}$ exposure.

The use of monthly aggregated data substantially reduces temporal resolution and limits the ability to evaluate true short-term daily exposure–response relationships. Daily-level time-series analyses would provide greater statistical power and conceptual consistency for distributed lag assessment. Therefore, the current findings should be interpreted as exploratory ecological associations rather than definitive short-term causal effects.

The use of fixed monitoring stations as exposure proxies and the absence of residential-level linkage may introduce exposure misclassification, potentially attenuating observed associations.

The analysis combined outpatient and inpatient visits within each diagnostic category. Differences in disease severity and healthcare utilization patterns may influence sensitivity to air pollution exposure. This aggregation could potentially dilute effect estimates, and future studies should consider stratified analyses by care setting.

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Appendix

TABLE S1. Full Spearman correlation matrix across all lag periods (N = 45–52)

Disease	Station	lag 0	lag 1	lag 2	lag 3	lag 4	lag 5	lag 6	lag 7	Strongest correlation
Chronic obstructive pulmonary disease (COPD)	28T	0.072	0.098	−0.009	−0.107	−0.142	−0.130	−0.268	−0.296*	−0.296* (lag 7)
	29T	−0.006	0.194	0.067	−0.029	−0.039	0.017	−0.227	−0.241	NS
	30T	0.057	0.240	0.080	−0.102	−0.019	−0.004	−0.209	−0.209	NS
	31T	0.042	0.195	0.125	0.013	−0.006	0.050	−0.172	−0.233	NS
	74T	0.075	0.206	0.095	−0.020	−0.068	−0.001	−0.210	−0.245	NS
Asthma	28T	0.052	−0.016	−0.145	−0.240	−0.304*	−0.278	−0.252	−0.230	−0.304* (lag 4)
	29T	0.208	0.252	0.153	−0.024	−0.125	−0.140	−0.027	−0.087	NS
	30T	0.153	0.160	0.072	−0.019	−0.047	0.002	0.050	0.056	NS
	31T	0.255	0.283*	0.172	0.025	−0.079	−0.062	−0.003	−0.052	0.283* (lag 1)
	74T	0.259	0.230	0.101	−0.042	−0.151	−0.078	−0.050	−0.073	NS
Influenza	28T	−0.023	−0.080	−0.215	−0.268	−0.259	−0.189	−0.164	−0.101	NS
	29T	0.203	0.225	0.116	−0.019	−0.033	0.030	0.062	0.102	NS
	30T	0.129	0.141	0.012	−0.043	−0.055	0.043	0.100	0.157	NS
	31T	0.256	0.262	0.155	0.025	0.007	0.094	0.092	0.086	NS
	74T	0.204	0.172	0.083	−0.060	−0.074	0.024	0.019	0.027	NS
Acute pharyngitis	28T	−0.110	−0.184	−0.295*	−0.337*	−0.310*	−0.163	−0.065	−0.075	−0.337* (lag 3)
	29T	0.104	0.146	0.077	−0.044	−0.078	0.048	0.186	0.172	NS
	30T	0.031	0.069	−0.003	−0.077	−0.100	0.039	0.159	0.156	NS
	31T	0.134	0.168	0.087	−0.041	−0.062	0.101	0.210	0.140	NS
	74T	0.069	0.085	0.007	−0.158	−0.184	−0.005	0.099	0.060	NS
Chronic rhinitis	28T	−0.041	0.121	0.127	0.149	0.097	0.055	0.011	−0.118	NS
	29T	−0.175	0.059	0.152	0.060	0.016	0.090	0.043	−0.059	NS
	30T	−0.099	0.137	0.167	0.082	0.119	0.075	0.066	−0.091	NS
	31T	−0.189	0.048	0.106	0.038	0.017	0.113	0.057	−0.089	NS
	74T	−0.151	0.110	0.107	0.043	−0.010	0.122	0.078	−0.071	NS
Bronchitis	28T	0.153	0.007	−0.182	−0.354*	−0.419	−0.317*	−0.233	−0.112	−0.419** (lag 4)
	29T	0.199	0.160	0.066	−0.211	−0.331*	−0.296*	−0.194	−0.077	−0.331* (lag 4)
	30T	0.166	0.135	−0.020	−0.206	−0.229	−0.099	−0.005	0.063	NS
	31T	0.258	0.240	0.122	−0.152	−0.273	−0.193	−0.117	−0.038	NS
	74T	0.276*	0.217	0.083	−0.181	−0.303*	−0.180	−0.117	−0.008	0.276* (lag 0)
All diseases combine	28T	0.024	−0.067	−0.224	−0.333*	−0.349*	−0.242	−0.164	−0.117	−0.349* (lag 4)
	29T	0.186	0.207	0.094	−0.110	−0.183	−0.096	0.016	0.061	NS
	30T	0.110	0.140	0.023	−0.098	−0.121	−0.007	0.109	0.158	NS
	31T	0.239	0.260	0.142	−0.061	−0.128	−0.010	0.071	0.070	NS
	74T	0.212	0.203	0.074	−0.126	−0.200	−0.057	0.011	0.029	NS

*$p < 0.05$; **$p < 0.01$; NS – not statistically significant; lag 0 – same-day exposure.

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Summary

The association between ambient fine particulate matter ($PM_{2.5}$) concentrations and air pollution-related respiratory disease at the pollution control zone of Rayong Province, Thailand. This study investigated the association between ambient $PM_{2.5}$ concentrations and respiratory diseases at the pollution control zone of Rayong Province in Thailand during 2020–2023. Daily $PM_{2.5}$ data were obtained from air quality monitoring stations, and hospital records of pneumonia, bronchitis, asthma, and chronic obstructive pulmonary disease (COPD) were analyzed. Spearman rank correlation and time-lag analyses (lags 0–7 days) were performed using IBM SPSS Statistics version 26.0. Significant positive correlations were observed between $PM_{2.5}$ concentrations and bronchitis ($r = 0.276$, $p < 0.05$) and asthma ($r = 0.283$, $p < 0.05$), with lag effects detected up to three days following exposure. Weaker or non-significant associations were found for COPD. These findings suggest that short-term exposure to elevated $PM_{2.5}$ levels may increase the risk of acute respiratory conditions. Continuous air quality monitoring and early warning systems are therefore essential to mitigate health impacts in industrial regions.