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Influence of Particulate Matter on Asthma Control in Adult Asthma

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Abstract: No clear evidence shows the association between particulate matter (PM) with an aerodynamic diameter < 10 µm (PM_{10}) and asthma control. Therefore, the objective of this study was to determine the association between PM_{10} and asthma control. A retrospective observational study was conducted at the Airway Clinic, Chiang Mai University Hospital, Chiang Mai, Thailand, between January 2010 and April 2013. Various values of asthma control test (ACT) scores between high and low PM_{10} periods were analyzed. The association of an increased monthly average PM_{10} level and ACT score was analyzed using a time series analysis. There were a total of 1180 visits from 236 asthmatic patients. The monthly average ACT score was significantly lower in the high PM_{10} period compared with the low PM_{10} period. Every 10 µg/m^3 increment of monthly average PM_{10} resulted in a significantly decreased ACT score at lag zero and one month, with an adjusted coefficient of –0.101 (95% CI; –0.165, –0.037), *p*-value = 0.002 and –0.079 (95% CI; –0.147, –0.012), *p*-value = 0.021, respectively. Monthly average PM_{10} significantly affected asthma control in asthmatic patients. During the air pollution period, the serial assessments of ACT should be measured for early detection of worsening asthma control.

Keywords: air pollution; asthma; asthma control; asthma control test; particulate matter

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1. Introduction

Air pollution is one of the major problems in the northern part of Thailand, including Chiang Mai. Every year, air pollutant levels usually exceed the world health organization (WHO) safety threshold during pre-summer and summer seasons (January–April) in this region. The main sources of air pollutants in this area come from forest fires and the burning of post-harvesting agricultural residues [1]. The Pollution Control Department of Thailand reported that the particulate matter with a diameter less than 10 microns (PM_{10}) reached a peak concentration in mid-March 2010, at 383 micrograms per cubic meter (µg/m^3) [2]. Although the policy on controlling air pollution has been published by the Thai government since 1992, air pollution remains a serious problem in this region of Thailand annually [3].

Previous studies concluded that the exposure to daily air pollution ((PM_{10}, particulate matter with a diameter less than 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3)) and meteorological parameters were associated with asthma health [4,5]. However, the particular matter levels which usually exceed the WHO safety threshold are the main problem in Chiang Mai, Thailand [1]. Therefore, we focused on the association between PM_{10} and asthma control in this study.

Previous studies reported the negative short-term effect of air pollution exposure, both PM_{10} and $PM_{2.5}$, and health effects, including all-cause, cardiovascular, respiratory, and cerebrovascular mortality [6–11]. For chronic airway disease, air pollution was associated with occurrence of asthma, acute asthma, and chronic obstructive pulmonary disease

(COPD) exacerbation [12–16]. Pothirat et al. also found that short-term exposure to PM_{10} resulted in a short-term negative impact on the quality of life (QoL) in subjects with COPD [17]. In asthma patients, previous studies also demonstrated that exposure to PM_{10} caused a significant impact on symptoms, quality of life, extra hospital visits, and hospitalization due to asthma, as well as asthma control defined by the 2006–2009 Global Initiative for Asthma (GINA) guidelines [14,18,19].

According to GINA guidelines, the achievement and maintenance of asthma control is the goal of asthma care [20]. The Asthma Control Test (ACT) is a useful and popular tool for assessing asthma control [21]. The ACT questionnaire is designed for the self-assessment of asthma symptoms and perception of control [21]. This questionnaire consists of five questions, including daytime and nighttime asthma symptoms, the use of rescue medications used, the limitation of activity due to asthma, and the patient's perception of asthma control [21]. The Thai version of ACT has been validated and extensively used in many clinical settings [22]. However, data on the association between ACT scores and PM_{10} are still limited and controversial. A study reported a statistically insignificant trend of a decreased ACT score in association with an increase in PM_{10} in 32 asthmatic patients [20]. They found that 10 $\mu g/m^3$ of PM_{10} exposure was associated with a decrease in ACT score, with a coefficient of –0.022 (95% CI; –0.045, 0.001; p value = 0.060) [23]. Another study, published by Fernandez et al., also showed no correlation between ACT scores among 99 asthmatic patients and PM_{10} levels during a four-month study period [24]. More studies on the effect of PM_{10} on asthma control using ACT scores are still required. Therefore, the objective of this study was to determine the association between PM_{10} and asthma control using the ACT questionnaire in adults with asthma.

2. Materials and Methods

2.1. Study Design and Population

This retrospective observational study was conducted on asthmatic patients greater than 18 years old treated at the Airway Clinic, Chiang Mai University Hospital, Chiang Mai, Thailand, between January 2010 and April 2013. All included subjects lived in Chiang Mai for at least one year. All subjects were diagnosed with asthma on the basis of GINA guidelines [20]. Subjects with a history of asthma exacerbations or hospitalizations for lower respiratory tract infections within the past four weeks were excluded. Subjects with other coexisting pulmonary diseases, five or more pack-years of smoking history, or pregnancy were also excluded. This study protocol was approved by the Research Ethics Committee of the Faculty of Medicine, Chiang Mai University (Institutional Review Board (IRB) approval number: MED-2565-09244, date of approval: 28 October 2022).

2.2. Asthma Control Test (ACT)

The Thai version of the ACT questionnaire [22] was routinely serially measured during each visit (one to three months) in all subjects throughout the study period. The five-item ACT questionnaire is designed for the self-assessment of asthma symptoms and perception of control [21]. This questionnaire consists of five questions, including asthma symptoms (daytime and nocturnal), the use of rescue medications, the limitation of activity due to asthma, and the patient's perception of asthma control. Each item of ACT includes five degrees of responses ranging from one to five [21]. A higher score means better asthma control, where the summation score yields a score ranging from 5 (poor control of asthma) to 25 (complete control of asthma) [21].The monthly average of ACT scores of all subjects (each item and total score) was used for the analysis.

2.3. Air Pollution Data and Meteorological Parameters

The levels of air pollutants, including PM_{10}, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3), were measured at sampling stations of the Pollution Control Department, Ministry of National Resources and Environment located in municipal areas of the Muang Chiang Mai District, Chiang Mai Province, Thailand [2]. The pollution data were reported as a monthly average. The cut-off of the high and low monthly averages of PM_{10} in this study was based on the average 24 h PM_{10} level of 45 μg/m^3 published in the 2021 Air Quality Guidelines of the WHO [25]. The meteorological data, including pressure, temperature, humidity, rain, sun, and wind speed, were obtained from the Northern Meteorology Center, Chiang Mai Province. A sampling monitoring station of meteorological data was also located in the municipal area of Muang Chiang Mai District, Chiang Mai, Thailand.

2.4. Statistical Analysis

Results for numerical values were expressed as means ± standard deviation (SD) or median and IQR (interquartile range), and those for categorical data were expressed as absolute frequencies and percentages. Various values of pollutant data, meteorological data, and ACT scores between high and low PM_{10} periods were determined using independent sample t-tests. The correlations between the monthly average of all pollutants and all meteorological parameters and ACT were determined using Pearson's correlation coefficient analysis. The following cut-off parameters were used in this study: $0 < |r| < 0.3$ = weak correlation; $0.3 < |r| < 0.7$ = moderate correlation; and $|r| > 0.7$ = strong correlation [26]. The association between the monthly average of each item and the total score of ACT and a monthly average of PM_{10} concentrations was analyzed using general linear models (GLM) after adjustment for SO_2, NO_2, CO, O_3, and all meteorological parameters. Adjustments for SO_2, NO_2, CO, O_3, and all meteorological parameters were performed in the GLM using a multivariable linear regression. The associations between the monthly average concentrations of PM_{10} and changes in ACT score were examined for each lag from zero to five months by using time series analysis. GLM was used to fit the time series data. Lag time zero (lag0) is the month of an increase in monthly average PM_{10}. Results were displayed as adjusted coefficients, with 95% confidence intervals (CI). All tests were two-tailed, and *p*-values below 0.05 were considered statistically significant. Statistical analysis was performed using a software package (StataCorp version 16, College Station, TX, USA).

3. Results

There were a total of 1180 visits from 236 asthmatic patients from January 2010 to April 2013. The monthly averages of all pollutants data and meteorological parameters are shown in Table 1. All pollutant data between the high PM_{10} period (≥45 μg/m^3) and the low PM_{10} periods (<45 μg/m^3) are shown in Table 2. During the study period, there were 15 and 25 months of high and low PM_{10}, respectively. The PM_{10} concentration in the high PM_{10} months was significantly higher compared with the low PM_{10} months (73.6 ± 23.9 μg/m^3 vs. 27.4 ± 8.3 μg/m^3, $p < 0.001$, respectively). The monthly average concentrations of other pollutants were also significantly higher in the high PM_{10} months. Additional data are shown in Table 2.

Correlations between the monthly average of weather data, including pollutants and meteorological parameters and the monthly average of ACT score, are shown in Table 3. There were significant correlations between the monthly average of all pollutants and the ACT score. The monthly average of all meteorological parameters was also significantly correlated with a monthly average of ACT scores, except for temperature and wind speed. Among all the air pollutants, PM_{10} was demonstrated to have the strongest negative correlation, with a monthly average of ACT score, r = –0.70, $p < 0.001$. Additional data are shown in Table 3.

The monthly average scores of each item and the total score of ACT were significantly lower in the high PM_{10} period when compared with the low PM_{10} period. The monthly average of total ACT scores in the high PM_{10} period and the low PM_{10} period were 21.49 ± 0.48 and 22.14 ± 0.49, $p < 0.001$, respectively. The differences in the monthly average of each item score of ACT between the months of high PM_{10} versus low PM_{10} are also shown in Table 4.

Table 1. Monthly Average of All Pollutants Data and Meteorological Parameters (from January 2010 to April 2013).

Pollutants	Mean ± SD	Min–Max
Pollutant data		
PM_{10} (μg/m^3)	44.7 ± 27.6	17.7–119.4
SO_2 (ppb)	0.9 ± 0.5	0.0–2.0
NO_2 (ppb)	10.9 ± 4.3	6–22
CO (ppb)	0.5 ± 0.2	0.2–0.9
O_3 (ppb)	24.2 ± 10.1	8–47
Meteorological parameters		
Pressure (millibars)	1009.3 ± 3.0	1004.3–1014.9
Temperature (Celsius)	26.9 ± 2.3	22.8–31.6
Humidity (%)	70.1 ± 9.6	47.8–83.0
Rain (millimeters)	3.1 ± 3.6	0–15.2
Sun (hours)	6.9 ± 1.9	3.4–9.8
Wind speed (kilometer/hour)	21.6 ± 4.7	12.5–31.5

Note: Data are mean ± SD and range.

Table 2. Pollutant Data between High PM_{10} Period (≥45 μg/m^3) and Low PM_{10} Periods (<45 μg/m^3) Recommended by WHO Air Quality Guidelines 2021.

Pollutants	High PM_{10} (n = 15 Months)	Low PM_{10} (n = 25 Months)	*p*-Value
Pollutants			
PM_{10} (μg/m^3)	73.6 ± 23.9	27.4 ± 8.3	<0.001
SO_2 (ppb)	1.2 ± 0.4	0.7 ± 0.5	0.005
NO_2 (ppb)	15.1 ± 3.6	8.3 ± 2.1	<0.001
CO (ppm)	0.7 ± 0.2	0.4 ± 0.1	<0.001
O_3 (ppb)	32.5 ± 9.2	19.2 ± 6.9	<0.001
Meteorological parameters			
Pressure (millibars)	1010.5 ± 2.2	1008.8 ± 3.2	0.099
Temperature (Celsius)	26.8 ± 2.9	26.9 ± 1.9	0.887
Humidity (%)	59.5 ± 7.6	75.2 ± 5.4	<0.001
Rain (millimeters)	0.7 ± 1.1	4.3 ± 3.8	0.003
Sun (hours)	8.5 ± 1.2	6.1 ± 1.8	<0.001
Wind speed (kilometer/hour)	21.7 ± 3.7	21.5 ± 5.1	0.897

Note: Data are mean ± standard deviation (SD).

Table 3. Correlation between Weather Data (Pollutants and Meteorological parameters) and Asthma Control Test (ACT) Score.

Weather Data	Correlation (r)	*p*-Value
Pollutants		
Average PM_{10} (ug/m^3)	–0.70	<0.001
Average SO_2 (ppb)	–0.31	0.048
Average NO_2 (ppb)	–0.54	<0.001
Average CO (ppm)	–0.58	<0.001
Average O_3 (ppb)	–0.48	0.002
Meteorological parameters		
Average pressure (millibars)	–0.37	0.025
Average temperature (Celsius)	0.19	0.251
Average humidity (%)	0.49	0.002
Average rainfall (millimeters)	0.37	0.024
Average sunshine (hours)	–0.44	0.007
Average wind speed (kilometer/hour)	0.02	0.926

Table 4. Monthly Average of Asthma Control Test (ACT) Score in High PM_{10} Periods (≥45 μg/m^3) and Low PM_{10} Periods (<45 μg/m^3).

ACT Score	High PM_{10} (15 Months)	Low PM_{10} (25 Months)	*p*-Value
Question 1, limited activity (5)	4.78 ± 0.09	4.87 ± 0.08	0.004
Question 2, shortness of breath (5)	4.26 ± 0.11	4.34 ± 0.13	0.049
Question 3, nighttime symptom (5)	4.42 ± 0.15	4.59 ± 0.12	<0.001
Question 4, rescuer used (5)	4.15 ± 0.15	4.32 ± 0.16	0.002
Question 5, self-rating of asthma control (5)	3.89 ± 0.09	4.00 ± 0.11	0.002
Total score (25)	21.49 ± 0.48	22.14 ± 0.49	<0.001

Note: Data are mean ± standard deviation (SD).

Variations of the monthly average PM_{10} and the monthly average of total ACT scores throughout the study period are shown in Figure 1. After adjustment for the other pollutants (CO, SO_2, NO_2, and O_3) and all meteorological data, we found an association between PM_{10} and asthma control. The total score of ACT and all of the items, except for the shortness of breath item, significantly decreased in correlation with an increase of every 10 μg/m^3 of PM_{10}. The effect of every 10 μg/m^3 increment of PM_{10} on the decrement of total ACT score was significant, with an adjusted coefficient of –0.101 (95% CI; –0.165, –0.037), *p*-value = 0.002. Additional data are shown in Table 5.

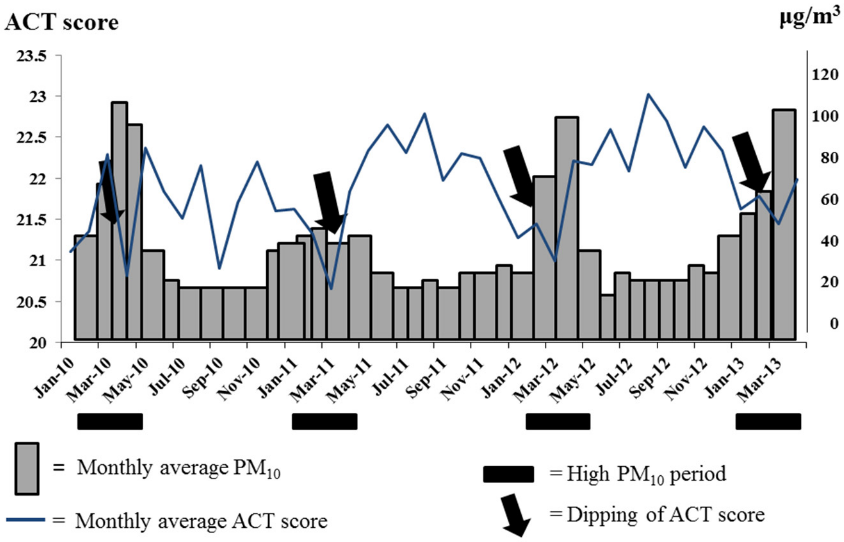

Figure 1. Variation of Monthly Average PM_{10} and Monthly Average of ACT Scores Throughout the Study Period. (Abbreviations: ACT, Asthma Control Test; PM10, particulate matters with diameter less than 10 microns).

Table 5. Associations between Every 10 μg/m^3 Increase in Monthly Average of PM_{10} and Monthly Average of Total Asthma Control Test (ACT) Score and Sub-domains.

ACT Score	Adjusted Coefficient *	95% CI	*p*-Value
Question 1, limited activity	–0.019	–0.029, –0.009	<0.001
Question 2, shortness of breath	–0.012	–0.028, 0.004	0.137
Question 3, nighttime symptom	–0.024	–0.041, –0.007	0.005
Question 4, rescuer used	–0.030	–0.050, –0.009	0.004
Question 5, self-rating of asthma control	–0.016	–0.027, –0.004	0.008
Total score	–0.101	–0.165, –0.037	0.002

Note: *, adjusted for other pollutants (CO, SO_2, NO_2, and O_3) and meteorological parameters.

The associations of every 10 $\mu g/m^3$ increase in the monthly average of PM_{10} on the monthly average of ACT score are displayed in Table 6. After adjustment for the other pollutants and all meteorological data, the monthly average ACT score decreased significantly at lag zero and one month, with an adjusted coefficient of –0.101 (95% CI; –0.165, –0.037), *p*-value = 0.002 and –0.079 (95% CI; –0.147, –0.012), *p*-value = 0.021, respectively. Additional data are shown in Table 6.

Table 6. Associations between Every 10 $\mu g/m^3$ Increase in Monthly Average of PM_{10} and Monthly Average Asthma Control Test (ACT) Scores.

ACT Score	Adjusted Coefficient *	95% CI	*p*-Value
Lag 0 month	–0.101	–0.165, –0.037	0.002
Lag 1 month	–0.079	–0.147, –0.012	0.021
Lag 2 months	–0.026	–0.098, 0.046	0.481
Lag 3 months	–0.012	–0.085, 0.062	0.759
Lag 4 months	0.010	–0.061, 0.081	0.780
Lag 5 months	0.018	–0.054, 0.089	0.628

Note: *, adjusted for other pollutants (CO, SO_2, NO_2, and O_3) and meteorological parameters.

4. Discussion

For more than ten years, air pollution has been a major problem in Northern Thailand, including Chiang Mai, due to the mass burning of agricultural waste and forest fires in the dry season during January through April [1]. Our study found that the monthly average of each item and total score of ACT were significantly lower in the high PM_{10} period when compared with the low PM_{10} period. Moreover, we found a significant effect of every 10 $\mu g/m^3$ increase in PM_{10} on the reduction of the total ACT and sub-elements of ACT scores, except for the shortness of breath item. For time series analysis, we also found that the monthly average ACT score decreased significantly at lag zero and one month.

Previous evidence suggested the negative effect of PM_{10} exposure and health effects, including cardiovascular, respiratory, cerebrovascular, and all-cause mortality [6–11]. In Northern Thailand, we found associations between increased concentrations of daily PM_{10}, with daily non-accidental mortality and causes of death, including COPD, coronary artery disease (CAD), and sepsis [10]. In chronic airway disease, PM_{10} was associated with acute asthma and COPD exacerbation [12–15]. We also found that every 10 $\mu g/m^3$ increase in PM_{10} concentration increased the risk of asthma and COPD exacerbations with a lag time of six to seven days (adjusted relative risk (RR) ranged from 1.02 to 1.03) [13]. Moreover, we demonstrated that short-term exposure to PM_{10} harmed QoL in patients with COPD [17]. In asthma subjects, previous studies showed that PM_{10} affected patients' quality of life and asthma control [14,18,19]. Ścibor et al. [19] revealed the effect of an increased exposure to PM_{10} on reduced scores in QoL measured by the Asthma Quality of Life Questionnaire (AQLQ). Another study by Maestrelli et al. [23] demonstrated a trend of poor QoL measured by St. George's Respiratory Questionnaire (SGRQ) in association with exposure to PM_{10} (coefficient = 0.22; 95% CI; –0.005, 4.451; p = 0.055).

For the association between PM_{10} and asthma control, Jacquemin et al., using the 2006–2009 GINA criteria, found that living in areas with high PM_{10} increased the risks of uncontrolled asthma, with the OR of 1.50 (95% CI; 1.19, 1.89) [18]. Another study, although its result was not statistically significant, displayed a tendency of poorer asthma control by lower ACT scores in asthmatic patients exposed to high PM_{10} (coefficient = –0.022; 95% CI, –0.045, 0.001; p = 0.060) [23]. However, this study included only 32 asthmatic subjects. Furthermore, the relatively short-term study in 99 asthmatic patients by Fernandez et al. [24] also showed no association between PM_{10} and ACT score. The non-correlation result of this study might be due to the non-significant difference in the monthly average of PM_{10} during the four months of the two-year study period (27.6 $\pm$ 5.3 vs. 25.8 $\pm$ 9.5) [24]. Thus, the influence of air pollution, particularly PM_{10}, on asthma control is still unclear. Our study focused on the association between PM_{10} levels during 40 consecutive months and asthma control measured by ACT in adult asthmatic patients living only in Chiang Mai province. Our result supported the effect of PM_{10} on asthma control by showing that the monthly average ACT score decreased significantly at lag zero and one month, with an adjusted coefficient of –0.101 (95% CI; –0.165, –0.037), p-value = 0.002 and –0.079 (95% CI; –0.147, –0.012), p-value = 0.021, respectively. Additionally, we demonstrated that four out of five items of the ACT questionnaire, including the nighttime symptoms, numbers of rescuers used, limitation of activity, and self-rating of asthma control were significantly influenced by PM_{10}. Our findings were consistent with the previous study indicating that symptoms and limitation of activity were the most affected domains of the quality of life in asthma subjects [19].

To the best of our knowledge, this is the first time series analysis on the effect of PM_{10} on asthma control. Our previous study showed that every 10 $\mu g/m^3$ increment in PM_{10} concentration increased the risk of asthma exacerbations within one week [13]. However, after exposure to air pollution, some patients might present with worsening asthma control instead of exacerbation. Therefore, our study showed more evidence, other than asthma exacerbation, that PM_{10} had more deteriorating effects on nighttime symptoms, numbers of rescuer use, limitation of activity, and self-rating of asthma control. In addition, we also demonstrated the immediate and delayed effects of PM_{10} which affected asthma control not only during the month of high PM_{10} exposure but also one month later.

Achievement and maintenance of asthma control is the goal of asthma care [20], and ACT is an easy and useful tool for assessing asthma control [21]. A subjective self-assessment of patients suffering from asthma, including asthma symptoms (daytime and nocturnal), the use of rescue medications, the asthma-related limitation of activity, and the patient's perception of asthma control has a great benefit in the long-term evaluation of disease control. The significant difference in ACT scores during the high and low PM_{10} period confirmed that this tool was beneficial in the demonstration of worsening asthma control during high pollution season.

The major strength of our study was the inclusion of asthma patients who were treated by pulmonologists at a special asthma clinic of the university hospital. In addition to ACT assessment and spirometry, our clinic routinely checks the inhalation technique, treatment adherence, patients' comorbidities, and non-respiratory medications. In addition, we provide patient education for long-term asthma care focused on individualized patient environment control, including avoidance of exposure to specific aeroallergens, extreme climate change, and air pollution avoidance. A few studies showed that asthma management by specialists, rather than general practitioners, resulted in fewer symptoms, more appropriate use of asthma controllers, fewer emergency room visits, and better quality of life [27,28]. Thus, the effects of inappropriate management by physicians were likely to be minimal in our study. The factors which affected asthma control would be the disease factor itself. Another strength of our study was the duration of the data collection. We collected the air pollution data of Chiang Mai province for 40 months, which can be divided into the high and the low PM_{10} period according to the daily WHO threshold of 45 $\mu g/m^3$. In addition, we included only the asthma patients who lived in Chiang Mai for at least one year, which was long enough to expose them to both low and high PM_{10} periods. This might be the reason why the results of our study on the correlation between PM_{10} and ACT score was different from the previous negative studies. However, our study had some limitations. Firstly, although the inclusion of patients treated by asthma specialists was considered to be the strength of this study, as mentioned above, in other ways our results might not be generally applicable to asthmatic patients treated by internists or general practitioners in real-world practice. As mentioned above, outcomes of asthma management by specialists proved to be better than outcomes by generalists. Consequently, the effects of air pollution on asthma control in patients not treated by the experts were expected to be more obvious. Further studies to discover the effects of air pollution on asthma control in general practice are required. Secondly, the evidence of pollution-induced airway inflammation demonstrated by fractional exhaled nitric oxide (FeNO) was not measured in this study. Previous studies showed some associations between FeNO and air pollution in asthma [23,29]. Future studies focusing on the effects of air pollution on inflammatory biomarkers in association with outcomes of asthma, including asthma control, should be performed. Thirdly, because our clinic provided education for the protection of air pollution to our patients, we did not collect data on personal protection against air pollution, including the use of an N-95 mask and home air purifier, which might account for confounding factors in this study. Therefore, these factors should be included for analysis in future studies.

5. Conclusions

Every 10 $\mu g/m^3$ increase in monthly average PM_{10} resulted in a reduction in the ACT score. PM_{10} had a significantly negative impact on asthma control in asthmatic patients. In the period of air pollution, assessment of asthma control by ACT should be serially measured for early detection of worsening of asthma control before progression to asthma exacerbation. A worldwide policy for tighter control of air pollution is needed to reduce the impact of air pollutants on people's health, especially asthma subjects.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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Abbreviations

PM_{10}, particulate matters with diameter of less than 10 microns; $PM_{2.5}$, particulate matters with diameter of less than 2.5 microns; CO, carbon monoxide; SO_2, sulfur dioxide; NO_2, nitrogen dioxide; O_3, ozone.

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