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Original Contribution

Association between ambient PM_{2.5} and emergency department visits for psychiatric emergency diseases☆

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ABSTRACT

Background: Whether or not short-term exposure to particulate matter <2.5 μm in diameter (PM_{2.5}) increases the risk of psychiatric emergency diseases is unclear.

Methods: The study was performed in a metropolis from January 2015 to December 2016. The exposure was PM_{2.5}, and the confounders were weather (temperature and humidity) and other pollutants (PM₁₀, SO₂, CO, O₃, and NO₂). The outcomes were emergency department (ED) visits with psychiatric disease codes (F00–F99 in ICD10 codes). General additive models were used for the statistical analysis to calculate the adjusted relative risks (ARRs) and 95% confidence intervals (95% CIs) for the daily number of ED visits with a lag of 1 to 3 days following a 10 μg/m³ increase in PM_{2.5}.

Results: During the study period, a total of 67,561 ED visits for psychiatric diseases were identified and tested for association with PM_{2.5}. Daily ED visits for all psychiatric diseases were not associated with PM_{2.5} in the model that was not adjusted for other pollutants. The ARR (95% CI) in the model adjusted for SO₂ was 1.011 (1.002–1.021) by 10 μg/m³ of PM_{2.5} on Lag 1 for all psychiatric diseases (F00–F99). The ARR (95% CI) in the model adjusted for O₃ was 1.015 (1.003–1.029) by 10 μg/m³ of PM_{2.5} on Lag 1 for F40–F49 (Neurotic, stress-related and somatoform disorders).

Conclusion: An increase in PM_{2.5} showed a significant association with an increase in ED visits for all psychiatric diseases (F00–F99) and for neurotic, stress-related and somatoform disorders (F40–F49) on lag day 1.

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1. Introduction

Psychiatric diseases account for approximately 6.2% of the global disease burden measured by disability adjusted life years (DALYs) and affected >400 million people globally in 2015 [1]. Approximately 4.3 million people visited emergency department for emergency psychiatric diseases in the USA, which accounted for 21 visits per 1000 adults in 2000 [2]. The risk factors must be identified to prevent acute exacerbation of psychiatric diseases.

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PM_{2.5}, which is the abbreviation for particulate matter 2.5 μm or less in diameter, is one of the most important potential environmental hazards for health conditions and mortality. Ambient PM_{2.5} exposure has been found to be a leading cause of death and disability worldwide [3]. A 10 μg/m³ increase in PM_{2.5} corresponds to a 0.68% increase in cardiovascular mortality [4]. Short-term exposure to PM_{2.5} induces respiratory hospital admissions [5,6], increases total cerebrovascular disease mortality [7], and even aggravates already diagnosed Parkinson's disease [8].

Although studies have investigated the relationship between emergency department visits for depression and ambient PM_{2.5} exposure [9–12], studies on other emergency psychiatric diseases and PM_{2.5} are rare. Air pollutants may cause activation of inflammatory processes, the immune system, oxidative stress, and alterations in cerebral neurotransmitter concentrations [13–15], which can lead to mental or behavioral alterations. Therefore, an increase in PM_{2.5} may exacerbate emergency psychiatric diseases. The purpose of this study is to determine the

association between ambient PM_{2.5} exposure and visits to the emergency department (ED) for emergency psychiatric diseases.

2. Methods

2.1. Study design and setting

This study is a cross-sectional observational study to evaluate the association between the number of patients visiting the ED for psychiatric diseases and the PM_{2.5} concentration in Seoul, Korea.

According to the National Statistical Office, the population of Seoul is 10 million people, which represents one-fifth of the Korean population. Seoul is one of the most highly populated cities in the world, with a population density of 16,492/km² reported in 2017. Seoul has an area of 605 km² and consists of 25 health and administrative districts. According to the Korea Meteorological Administration, the average annual temperature of Seoul is 12.5 °C (54.5 °F), but the temperature varies greatly depending on the season, with an average temperature in August of 25.7 °C (78.3 °F) and in January of −2.4 °C (27.7 °F). Seoul has a temperate climate with four distinct seasons. The annual average PM_{2.5} concentrations in Seoul were 23 µg/m³ and 26 µg/m³ in 2015 and 2016, respectively, according to the National Institute of Environmental Research.

According to statistics from the Ministry of Health and Welfare, there are 51 emergency departments in Seoul, which the national government has classified into three groups. These departments include 4 level 1 departments with a mission to provide a full range of emergency care services and disaster medical services that are staffed by emergency physicians 24 h per day and 7 days per week, 27 level 2 emergency departments where emergency physicians are on standby 24 h per day 365 days per year to provide general comprehensive emergency care services, and 20 level 3 emergency departments staffed by general physicians to provide general emergency care services. A total of 610 emergency medicine specialists, 217 residents, and 1290 nurses worked at the emergency departments in Seoul in 2016. A total of 1.8 million citizens visit the emergency departments annually in Seoul, including more than thirty thousand visits for psychiatric emergency diseases per year.

2.2. Data sources

We used four data sources for this study. The first data set for the Seoul population was collected from the National Statistical Office. The data set includes the population size, age distribution, gender distribution, and residence on a nationwide scale for policy making every year using family registry documents.

The second set of data on emergency department visits from the 51 hospitals in Seoul was obtained from the National Emergency Department Information System (NEDIS) of the National Emergency Medical Center (NEMC). The NEMC is the central headquarters of the emergency care system for quality assurance, evaluation, and emergency care program grants. The NEMC has collected NEDIS data since 2004 from 16 level 1 EDs; the NEMC collected data from 408 of the 413 emergency departments in the country in 2016 and from 403 emergency departments out of 420 in 2015. All 51 emergency departments in Seoul were included in both years. The NEDIS data include sex, age, when the event occurred, the patient's main symptom, the diagnosis, which emergency department the patient visited, and the address of the patient. The data are verified by the automatic system; if modification or reexamination is necessary, each emergency department revises the data [16].

The third set of meteorological data, including the daily mean temperature, relative humidity, and air pressure, was obtained from the Korean Meteorological Administration. The administration was established in 1949 and has collected meteorological data since that time. In Seoul, 35 automatic weather systems (AWSs) measure weather

information every minute to inform citizens of weather situations and collect data for research. [17]

The fourth data source provided air pollutant monitoring data obtained from the Korean National Institute of Environmental Research. This data source provides the average concentrations of air pollutants, including PM_{2.5}, PM₁₀, carbon oxide (CO), nitric dioxide (NO₂), sulfur dioxide (SO₂), and ozone (O₃), every hour using monitoring stations. The institute collects data from 40 monitoring stations in Seoul to provide information to citizens and researchers as a pollution alarm. [18]

2.3. Study population

The population aged 15 years and older in 2015 and 2016 was included in this study. We excluded children (<15 years old) and individuals who were not registered as residents at the district office, such as temporary visiting foreigners and travelers.

2.4. Main exposure and variables

We used the daily average concentration of the hourly PM_{2.5} for each district as the main exposure. The daily average concentration was provided by the data source. The variables included the daily mean temperature, relative humidity, air pressure, age, gender, day of the week, season, and patient addresses. The Middle East respiratory syndrome (MERS) outbreak occurred over a two-month period in 2015 when several EDs were closed, and the number of ED visits decreased. Therefore, the MERS outbreak period was added as a variable. The PM_{2.5} concentration was measured using the beta-ray absorption method, the PM₁₀ concentration was measured using beta-ray absorption in µg/m³, CO was measured with the non-dispersive infrared method, NO₂ was measured using chemiluminescence, SO₂ with measured with ultraviolet fluorescence, and O₃ was measured using ultraviolet photometry.

2.5. Outcome measurements

The outcome was the daily number of people who visited the emergency departments in Seoul from 2015 to 2016 with a diagnostic code for psychiatric diseases (International Classification of Disease-10th version, Mental and Behavioral Disease, F00–F99, including F00–F09 (Organic, including symptomatic, mental disorders), F10–F19 (Mental and behavioral disorders due to psychoactive substance use), F20–F29 (Schizophrenia, schizotypal and delusional disorders), F30–F39 (Mood [affective] disorders), F40–F48 (Neurotic, stress-related and somatoform disorders), F50–F59 (Behavioral syndromes associated with physiological disturbances and physical factors), F60–F69 (Disorders of adult personality and behavior), F70–F79 (Mental retardation), F80–F89 (Disorders of psychological development), F90–F98 (Behavioral and emotional disorders with onset usually occurring in childhood and adolescence), and F99–F99 (Unspecified mental disorder)). The diagnostic codes for ED care were inputted by the emergency physicians when the patients were discharged to home, transferred to another hospital, or admitted to a ward. In addition to the ED diagnosis, the duty physicians inputted the diagnostic codes into the electronic medical records when the patients were discharged after admission. A maximum of 20 diagnostics codes can be uploaded to the NEDIS server. The NEDIS diagnostic codes are used for the National Emergency Department Evaluation Program, which is performed annually by the Ministry of Health and Welfare as a source of diagnostic codes, and are also used for the reimbursement program of the National Health Insurance Corporation. Therefore, most hospitals rigorously manage the diagnostic codes to ensure reliability and validity.

2.6. Statistical analysis

Demographic information was collected, including information for patients with emergency psychiatric diseases (age, gender, season,

month, day of the week, disease category, MERS period, and district), weather (daily temperature, humidity, and pressure), and pollutants (PM₁₀, CO, NO₂, SO₂, and O₃). We determined the correlations between the pollutants using the R package version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria).

A time-series analysis using a generalized additive model (GAM) was used to calculate adjusted relative risks (ARRs) with 95% confidence intervals (95% CIs), because most epidemiological air pollution studies (cited in the second paragraph of the article) used this approach. The model was controlled for daily mean temperature, relative humidity, and mean air pressure, which were treated as continuous variables, as well as for the day of the week. The basic model is as follows: $\text{Log}[E(Y)] = \beta_0 + S_1(X_1) + S_2(X_2) + \dots + S_p(X_p) + \beta(\text{PM}_{2.5})$, where Y is the daily number of emergency department visits for psychiatric diseases, X_1, \dots, X_p are covariates, $S_i(\cdot)$ is a nonparametric smoother, and $\text{PM}_{2.5}$ is the mean value for the corresponding day. A total of 4 degrees of freedom were selected to smooth the time trends. We examined the concentrations of the individual lag days 1 through 3 (lag 1 represents the PM_{2.5} level one day prior to the emergency room visit, lag 2 is the previous day, and so on). We tested the association between PM_{2.5} and all emergency psychiatric diseases and subgroups of emergency psychiatric diseases (F20 to F50) to calculate the ARR (95% CIs) using the GAM model described above. All statistical analyses for the GAM data processing were performed using the SAS software, version 9.4 (SAS institute Inc., Cary, NC, USA).

3. Results

3.1. Basic characteristics

The study population over 15 years of age in Seoul included 8,734,321 citizens in 2015 and 8,675,108 citizens in 2016. In total, 67,561 patients with psychiatric emergencies (33,041 in 2015 and 34,520 in 2016) were analyzed (Fig. 1).

Table 1 shows the study population and the numbers of ED visits. A total of 67,561 emergency department visits were identified in Seoul from January 2015 to December 2016 (731 days). Emergency department visits for ICD codes F10–F19 (Mental and behavioral disorders due to psychoactive substance use) represented the largest subgroup, because alcohol abuse was included. Generally, the total ED visits were higher in women than in men, although this trend was not

observed in some subgroups. More visits occurred in the summer than in the winter.

Table 2 summarizes the key variables. The mean ED (standard deviation) visits for psychiatric diseases and the mean PM_{2.5} level was 92 (12) and 24.8 (15.2) $\mu\text{g}/\text{m}^3$. On 121 days corresponding to the 17th percentile, the daily mean PM_{2.5} was below 15 $\mu\text{g}/\text{m}^3$, which was a level classified as “good” by the Korean Meteorological Administration. The daily mean PM_{2.5} was above 50 $\mu\text{g}/\text{m}^3$, which was a “bad” level, on 11 days. Fig. 2 shows the number of ED visits for psychiatric diseases and the daily mean PM_{2.5} concentrations for each date. Fig. 3 shows correlations among the pollutants and ED visits. The ED visits for psychiatric disease were not significantly correlated with the daily PM_{2.5} concentrations ($p = 0.149$).

Table 3 shows the associations between pollutants (SO₃, CO, O₃, and NO₂) and ED visits for psychiatric diseases in the GAM models. SO₂ was significantly associated with decreased ED visits for all psychiatric diseases on lag day 1 (0.991, 0.982–0.999). CO was also significantly associated with a decrease in ED visit due to F20–F29 (0.966, 0.944–0.989), whereas O₃ was associated with increased ED visits (1.039, 1.001–1.079). Codes F40–F49 were significantly increased on lag day 1 by an increase in NO₂ (1.015, 1.001–1.031).

3.2. Main analysis

Table 4 shows the associations between PM_{2.5} and ED visits for psychiatric diseases. ED visits for all psychiatric diseases were not associated with PM_{2.5} in the analyses that were not adjusted for the other pollutants. The ARR (95% CI) in the model adjusted for SO₂ was 1.011 (1.002–1.021) for a 10 $\mu\text{g}/\text{m}^3$ increment of PM_{2.5} on lag day 1 for all psychiatric diseases (F00–F99). The ARR (95% CI) in the model adjusted for O₃ was 1.015 (1.003–1.029) for a 10 $\mu\text{g}/\text{m}^3$ increment of PM_{2.5} on lag day 1 for F40–F49 (Neurotic, stress-related and somatoform disorders). The other models did not show any significant associations between PM_{2.5} and ED visits due to psychiatric diseases.

4. Discussion

We found a significant association between the PM_{2.5} concentration and emergency department visits for psychiatric diseases on lag 1 day in the adjusted models. ED visits due to all types of psychiatric diseases following an increase in PM_{2.5} were increased on lag day 1 after

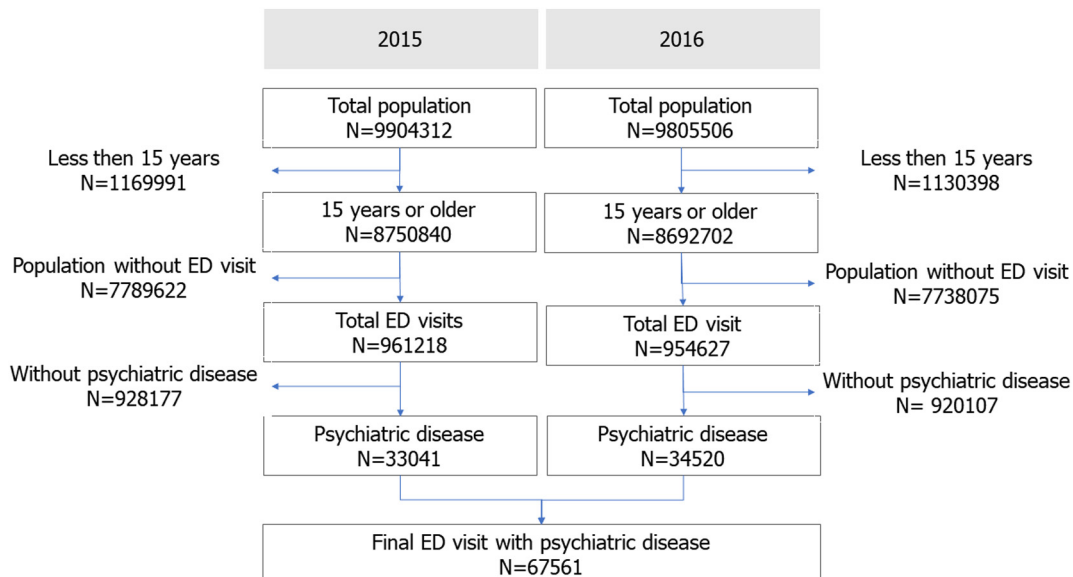


Fig. 1. Study population. ED, emergency department.

Table 1
Demographic characteristics of emergency department patients with psychiatric diseases.

Variables	Total		2015		2016	
	N	%	N	%	N	%
All	67,561	100.0	30,472	100.0	32,997	100.0
Sex						
Male	30,193	44.7	14,481	47.5	15,712	47.6
Female	33,276	49.3	15,991	52.5	17,285	52.4
Age group, years						
15–29	9747	14.4	4624	15.2	5123	15.5
30–44	12,069	17.9	5743	18.8	6326	19.2
45–59	16,756	24.8	8087	26.5	8669	26.3
60–74	12,056	17.8	5899	19.4	6157	18.7
75+	12,841	19.0	6119	20.1	6722	20.4
Season						
Spring (March–May)	16,973	25.1	7873	25.8	8378	25.4
Summer (June–August)	17,767	26.3	7670	25.2	8853	26.8
Autumn (September–November)	16,867	25.0	7687	25.2	8285	25.1
Winter (December–February)	15,954	23.6	7242	23.8	7481	22.7
Day of week						
Sun	12,011	17.8	5664	18.6	6347	19.2
Mon	8920	13.2	4383	14.4	4537	13.7
Tue	8557	12.7	4168	13.7	4389	13.3
Wed	8136	12.0	4048	13.3	4088	12.4
Thu	8524	12.6	4145	13.6	4379	13.3
Fri	8500	12.6	4032	13.2	4468	13.5
Sat	8821	13.1	4032	13.2	4789	14.5
Disease category						
F00–F09	13,092	19.4	6348	20.8	6744	20.4
F10–F19	19,218	28.4	9050	29.7	10,168	30.8
F20–F29	4011	5.9	1889	6.2	2122	6.4
F30–F39	11,453	17.0	5608	18.4	5845	17.7
F40–F49	18,772	27.8	9105	29.9	9667	29.3
F50–F59	2164	3.2	978	3.2	1186	3.6
F60–F69	395	0.6	187	0.6	208	0.6
F70–F79	206	0.3	111	0.4	95	0.3
F80–F89	110	0.2	51	0.2	59	0.2
F90–F99	1504	2.2	702	2.3	802	2.4
MERS outbreak						
No	58,995	87.3	25,998	85.3	32,997	100.0
Yes	4474	6.6	4474	14.7	0	0.0
District						
Gangnam	3121	4.6	1506	4.9	1615	4.9
Gangdong	2549	3.8	1218	4.0	1331	4.0
Gangbuk	2113	3.1	1068	3.5	1045	3.2
Gangseo	2341	3.5	1158	3.8	1183	3.6
Gwanak	3498	5.2	1718	5.6	1780	5.4
Gwangjin	1671	2.5	726	2.4	945	2.9
Guro	2415	3.6	1209	4.0	1206	3.7
Geumcheon	1475	2.2	715	2.3	760	2.3
Nowon	4021	6.0	1816	6.0	2205	6.7
Dobong	2312	3.4	1071	3.5	1241	3.8
Dongdaemun	4088	6.1	1844	6.1	2244	6.8
Dongjak	2383	3.5	1060	3.5	1323	4.0
Mapo	2143	3.2	1086	3.6	1057	3.2
Seodaemun	2287	3.4	1158	3.8	1129	3.4
Seocho	2151	3.2	1052	3.5	1099	3.3
Seongdong	2023	3.0	944	3.1	1079	3.3
Seongbuk	3303	4.9	1605	5.3	1698	5.1
Songpa	2662	3.9	1271	4.2	1391	4.2
Yangcheon	2052	3.0	1075	3.5	977	3.0
Yeongdeungpo	2800	4.1	1327	4.4	1473	4.5
Yongsan	1895	2.8	928	3.0	967	2.9
Eunpyeong	2489	3.7	1274	4.2	1215	3.7
Jongro	1786	2.6	927	3.0	859	2.6
Jung	1543	2.3	788	2.6	755	2.3
Jungnang	4348	6.4	1928	6.3	2420	7.3

MERS, Middle East respiratory syndrome; F00–F99, Mental and Behavioral Disease, F00–F99; F00–F09, Organic, including symptomatic, mental disorders; F10–F19, Mental and behavioral disorders due to psychoactive substance use; F20–F29, Schizophrenia, schizotypal and delusional disorders; F30–F39, Mood [affective] disorders; F40–F48, Neurotic, stress-related and somatoform disorders; F50–F59, Behavioral syndromes associated with physiological disturbances and physical factors; F60–F69, Disorders of adult personality and behavior; F70–F79, Mental retardation; F80–F89, Disorders of psychological development; F90–F98, Behavioral and emotional disorders with onset usually occurring in childhood and adolescence; F99–F99, Unspecified mental disorder.

adjustment for SO₂. ED visits with codes F40–F49 were also increased on lag day 1 by an increase in PM_{2.5} after adjustment for O₃.

Our study did not show consistent effects due to increases in pollutants, as reported in previous studies. One possible reason is the relatively low PM_{2.5} levels in Seoul in this study setting compared with other studies. The mean (standard deviation) of PM_{2.5} was 24.8 (15.2), and only 31 days had PM_{2.5} concentrations >50 µg/m³.

Among the 40 air pollutant monitoring stations, 25 are located in each district of Seoul at community service centers or other public buildings,

such as high schools or museums. Their average height from the ground is 14.6 m. Because these buildings and centers are located in residential areas and are highly accessible, measurements from these stations represent the air that the citizens breathe. A total of 15 stations are located at road sides, such as main intersections or public transport stations, where the floating population is very high. Because data from the roadside stations might show different trends than the data from the residential area stations and the roadside stations were not located in all districts, data from the roadside stations were excluded.

Table 2
Daily statistics for weather factors and ambient pollutants.

Variables	Mean	SD	Minimum	25%	50%	75%	Maximum	IQR
ED visits for PD, N	92	12	58	84	93	100	140	56
Temperature, °C	13.6	10.6	−14.4	3.7	14.9	23.2	31.2	19.5
Humidity, %	59.5	14.4	36.6	48.4	60.1	69.5	97.3	21.1
Pressure, hPa	1016.4	8.5	1004.2	1009.3	1016.7	1023.1	1035.3	13.8
PM _{2.5} , µg/m ³	24.8	15.2	0.0	14.0	22.0	32.0	168.0	18.0
PM ₁₀ , µg/m ³	46.7	38.4	1.0	27.0	40.0	57.0	1160.0	30.0
O ₃ , ppm	0.023	0.019	0.000	0.008	0.020	0.033	0.168	0.0
NO ₂ , ppm	0.032	0.016	0.000	0.019	0.029	0.042	0.145	0.0
CO, ppm	0.523	0.242	0.000	0.400	0.500	0.600	3.400	0.2
SO ₂ , ppm	0.005	0.002	0.000	0.004	0.005	0.006	0.030	0.0

SD, standard deviation; IQR, interquartile range; ED, emergency department; PD, psychiatric disease; PM_{2.5}, particulate mass <2.5 µm; PM₁₀, particulate mass <10 µm; O₃, trioxide (ozone); NO₂, nitric dioxide; CO, carbon oxide; SO₂, sulfur dioxide.

Air pollutants are hypothesized to affect the mental status through activation of inflammatory processes, the alteration of immune system, influence on oxidative stress, and alterations in cerebral neurotransmitter concentrations. Because absorption and chemical reactions take time, using the daily mean concentrations of pollutants rather than other values, such as the maximum, is a reasonable approach. Although most studies use daily mean concentrations of air pollutants except for O₃, one journal uses the standard deviations of air pollutants (PM₁₀) as well as the daily mean concentrations [19]. Because air pollutants increase and decrease through chemical reactions, the air pollutant concentrations are expected to increase or decrease faster when the daily mean concentration is higher. Because the daily mean concentration and standard deviation were positively associated, as mentioned in one article [19], we only used the daily mean concentration. In most studies, researchers use daily maximal 8-hour averages [20,21] or the daily maximum values between 0900 and 1800 h in the case of O₃ [22]. This approach is reasonable, because the main cause of O₃ is ultraviolet waves generated by the sun. However, the pollution ozone can be produced by traffic exhaust which may be increased in the evening to night time in a metropolis. [23]

Nonetheless, in our data, the O₃ concentrations were sometimes higher during the night than during the day. Because using the daily

maximal 8-hour average of O₃ would represent a time bias, we used the daily mean O₃ concentration.

Three time-series analyses in China investigated the associations between air pollution and hospital admissions for psychiatric diseases. The study in Tianjin reported that an increase of 10 µg/m³ in the 2-day average concentrations of PM₁₀, SO₂, and NO₂ corresponded to increases in daily hospital admissions of 0.15%, 0.49%, and 0.57%, respectively [24]. According to a study in Shanghai, increases in PM₁₀, SO₂, and CO increased hospital admissions for psychiatric diseases by 1.27%, 6.88%, and 0.16% per 10 µg/m³ increase, respectively [25]. The study in Beijing reported that PM₁₀ showed a significant association with hospital admissions for psychiatric diseases [26]. Although the results of the three studies were different, PM₁₀ was commonly associated with hospital admissions for psychiatric diseases. The types of pollutants that showed significant associations with emergency room visits varied by study, as did the extent to which air pollutants affected hospital visits. These inconsistent outcomes may be due to the different climatic environments of different cities. Unlike Korea, the reason for the significant results in China may be that the PM_{2.5} concentration in China is 203 times higher than the concentration. Although PM_{2.5} had a significant effect over a time span longer than 3 days, we only evaluated the association between PM_{2.5} and ED visits for a lag of 1 to 3 days. Previous studies have included longer lags for mortality outcomes due to pollutants.

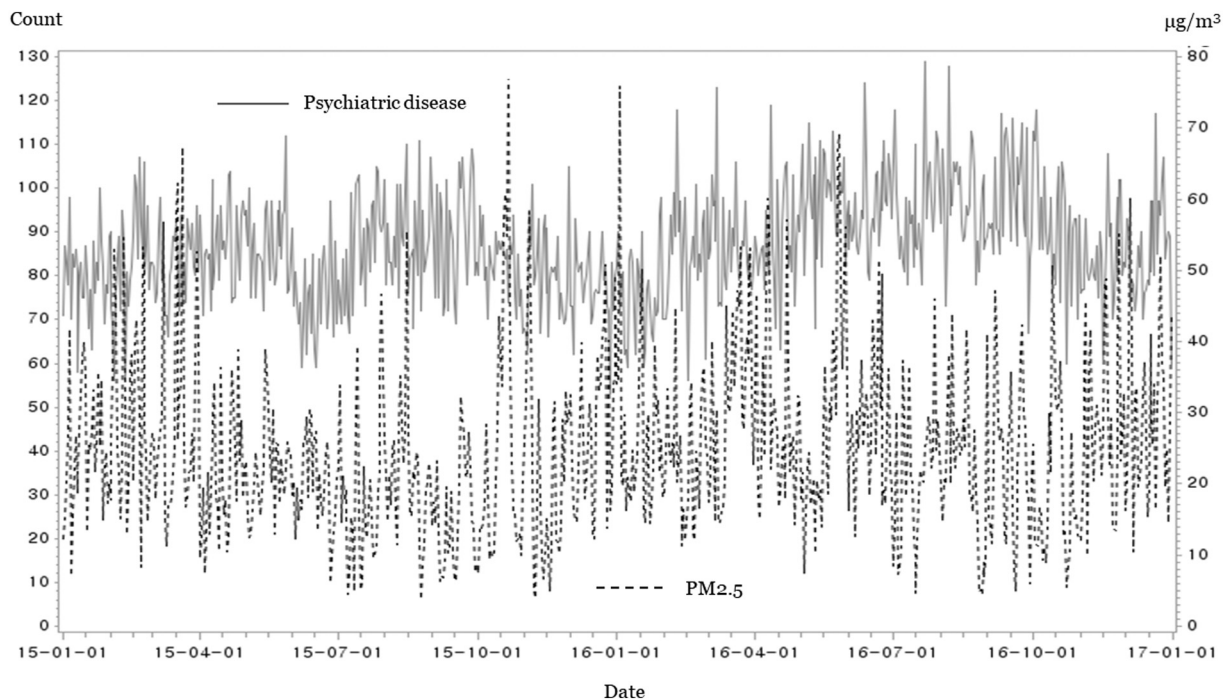


Fig. 2. Daily mean emergency department visits for psychiatric disease and the daily mean PM_{2.5} concentrations.

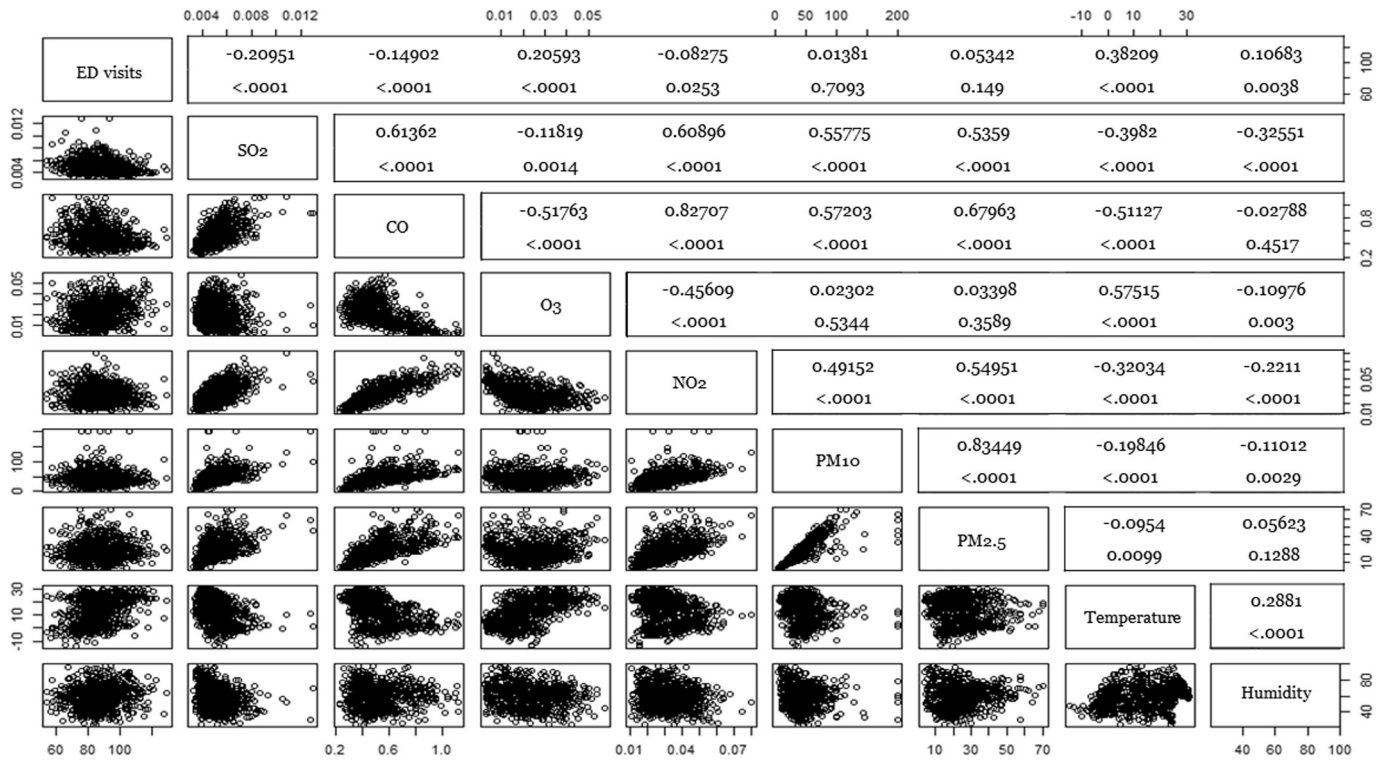


Fig. 3. Correlation analysis between ED visits, pollutants, and weather. ED, emergency department PM_{2.5}, particulate mass <2.5 μm PM₁₀, particulate mass <10 μm O₃, trioxide (ozone) NO₂, nitric dioxide CO, carbon oxide SO₂, sulfur dioxide.

However, a maximum lag of three days was used in the GAM model in this study to test the abrupt association between exposure and outcomes.

Some studies reported significant associations of specific subtypes of psychiatric diseases with air pollutants. Both the study conducted in Seoul, Korea, and the study conducted in Canada reported that SO₂, PM₁₀, NO₂, and CO were positively associated with emergency department visits for depression [11,12]. The study in Beijing also reported that an increase in the PM₁₀ concentration of 10 μg/m³ corresponded

to an increase in hospital admissions for schizophrenia of 1.74% [26]. In the study conducted in Seoul, Korea, the association was more significant when the patients were older and had background illnesses, such as cardiovascular diseases and diabetes mellitus.

4.1. Limitations

In the GAM models, we adjusted for weather factors, such as the daily mean temperature and humidity. Those weather factors were

Table 3 Effects of SO₂, CO, O₃, and NO₂ on emergency department visits for psychiatric diseases.

Exposure	All (F00-F99)		F20-F29		F30-F39		F40-F49		F50-F59						
	ARR	95% CI	ARR	95% CI	ARR	95% CI	ARR	95% CI	ARR	95% CI					
SO ₂ , ppm															
Lag 1	0.991	0.982	0.999	0.981	0.948	1.015	0.981	0.961	1.001	1.004	0.988	1.020	0.994	0.948	1.042
Lag 2	1.000	0.992	1.009	1.003	0.970	1.038	1.000	0.980	1.020	1.002	0.986	1.017	1.000	0.952	1.051
Lag 3	0.999	0.990	1.007	1.000	0.968	1.033	1.003	0.983	1.023	0.997	0.981	1.012	1.025	0.978	1.074
CO, ppm															
Lag 1	0.998	0.992	1.004	0.966	0.944	0.989	0.992	0.978	1.005	1.003	0.992	1.014	0.989	0.958	1.021
Lag 2	1.000	0.994	1.006	0.991	0.968	1.015	1.008	0.994	1.022	0.999	0.988	1.010	1.003	0.973	1.035
Lag 3	0.999	0.993	1.005	0.982	0.959	1.005	1.009	0.995	1.023	0.999	0.988	1.010	1.001	0.969	1.034
O ₃ , ppm															
Lag 1	1.001	0.992	1.011	1.039	1.001	1.079	1.003	0.980	1.025	1.006	0.989	1.024	1.011	0.961	1.064
Lag 2	0.998	0.988	1.007	1.037	0.999	1.077	1.006	0.984	1.029	1.005	0.988	1.022	0.992	0.943	1.043
Lag 3	0.995	0.986	1.005	1.034	0.996	1.074	0.994	0.972	1.016	0.994	0.977	1.012	0.995	0.945	1.047
NO ₂ , ppm															
Lag 1	1.000	0.992	1.008	0.996	0.965	1.028	0.993	0.975	1.012	1.015	1.001	1.031	0.990	0.949	1.032
Lag 2	0.998	0.990	1.006	0.976	0.946	1.007	0.995	0.977	1.014	1.004	0.990	1.019	0.989	0.948	1.032
Lag 3	0.998	0.990	1.006	0.991	0.961	1.022	1.010	0.991	1.029	0.994	0.980	1.009	0.992	0.951	1.034

Adjusted relative risks (ARRs) with 95 confidence intervals (95 CIs) were calculated using general additive models: $\text{Log}[E(Y)] = \beta_0 + \beta(\text{pollutants}) + S_1(\text{Temperature}) + S_2(\text{humidity}) + S_p(\text{number} + \text{parameters (week, season, middle east respiratory syndrome period)})$ (degree of freedom = 3). The beta coefficients of pollutants were calculated with relative risks with 95% confidence intervals. O₃, trioxide (ozone) (ppm, pulse per minute); NO₂, nitric dioxide (ppm, pulse per minute); CO, carbon oxide (ppm, pulse per minute); SO₂, sulfur dioxide (ppm, pulse per minute); F00-F99, Mental and Behavioral Disease, F00-F99; F00-F09, Organic, including symptomatic, mental disorders; F10-F19, Mental and behavioral disorders due to psychoactive substance use; F20-F29, Schizophrenia, schizotypal and delusional disorders; F30-F39, Mood [affective] disorders; F40-F48, Neurotic, stress-related and somatoform disorders; F50-F59, Behavioral syndromes associated with physiological disturbances and physical factors; F60-F69, Disorders of adult personality and behavior; F70-F79, Mental retardation; F80-F89, Disorders of psychological development; F90-F98, Behavioral and emotional disorders with onset usually occurring in childhood and adolescence; F99-F99, Unspecified mental disorder.

Table 4
Effect of PM_{2.5} on emergency department visits for psychiatric diseases.

Exposure	All (F00-F99)		F20-F29		F30-F39		F40-F49		F50-F59						
	ARR	95% CI	ARR	95% CI	ARR	95% CI	ARR	95% CI	ARR	95% CI					
PM _{2.5}															
Lag 1	1.000	0.994	1.007	0.984	0.958	1.012	0.999	0.983	1.016	1.008	0.995	1.021	0.982	0.946	1.019
Lag 2	1.002	0.995	1.008	1.000	0.973	1.027	1.010	0.994	1.026	1.002	0.990	1.015	0.985	0.949	1.023
Lag 3	0.998	0.991	1.005	0.983	0.957	1.010	1.005	0.989	1.022	1.001	0.988	1.013	1.004	0.966	1.044
PM _{2.5} + SO ₂															
Lag 1	1.011	1.002	1.021	0.991	0.956	1.028	1.018	0.996	1.039	1.010	0.993	1.026	0.975	0.928	1.025
Lag 2	1.003	0.994	1.013	0.998	0.963	1.035	1.018	0.996	1.039	1.002	0.986	1.019	0.979	0.932	1.028
Lag 3	0.998	0.989	1.007	0.982	0.947	1.018	1.008	0.987	1.030	1.002	0.985	1.019	0.974	0.925	1.025
PM _{2.5} + CO															
Lag 1	1.005	0.995	1.015	1.034	0.993	1.077	1.019	0.995	1.044	1.007	0.988	1.026	0.985	0.932	1.042
Lag 2	1.004	0.994	1.014	1.021	0.980	1.063	1.005	0.982	1.030	1.005	0.986	1.024	0.962	0.909	1.017
Lag 3	0.998	0.988	1.009	1.000	0.960	1.042	0.991	0.967	1.016	0.998	0.979	1.017	1.013	0.956	1.074
PM _{2.5} + O ₃															
Lag 1	1.003	0.996	1.010	0.986	0.959	1.013	1.003	0.987	1.019	1.015	1.003	1.029	0.980	0.944	1.018
Lag 2	1.001	0.994	1.008	0.999	0.972	1.027	1.009	0.993	1.025	1.003	0.990	1.016	0.980	0.944	1.018
Lag 3	0.998	0.992	1.005	0.980	0.954	1.007	1.006	0.990	1.023	1.003	0.990	1.016	1.013	0.974	1.053
PM _{2.5} + NO ₂															
Lag 1	1.002	0.994	1.010	0.997	0.964	1.030	1.004	0.985	1.024	1.009	0.994	1.025	0.984	0.941	1.030
Lag 2	1.004	0.996	1.012	1.009	0.976	1.043	1.008	0.989	1.028	1.007	0.992	1.023	0.985	0.941	1.031
Lag 3	0.999	0.991	1.007	0.988	0.956	1.021	1.001	0.982	1.021	1.000	0.985	1.016	1.015	0.968	1.063
PM _{2.5} + PM ₁₀															
Lag 1	1.000	0.999	1.000	0.998	0.995	1.001	1.000	0.999	1.002	0.998	0.994	1.003	1.001	0.998	1.003
Lag 2	1.000	0.999	1.001	1.000	0.997	1.003	1.001	0.999	1.003	1.000	0.996	1.004	1.001	0.999	1.003
Lag 3	1.000	0.999	1.000	0.998	0.996	1.001	0.999	0.998	1.001	0.997	0.993	1.001	1.000	0.997	1.002

Adjusted relative risks (ARRs) with 95 confidence intervals (95% CIs) were calculated using general additive models: $\text{Log}[E(Y)] = \beta_0 + \beta(\text{pollutants}) + S1(\text{pollutants}) + S1(\text{Temperature}) + S2(\text{humidity}) + Sp(\text{number}) + \beta(\text{pollutants}) + \text{parameters (week, season, middle east respiratory syndrome period)}$ (degree of freedom = 3). The beta coefficients of PM_{2.5} were calculated with relative risks with 95% confidence intervals; PM_{2.5}, particulate mass <2.5 μm (μg/m³); PM₁₀, particulate mass <10 μm (μg/m³); O₃, trioxide (ozone) (ppm, pulse per minute); NO₂, nitric dioxide (ppm, pulse per minute); CO, carbon oxide (ppm, pulse per minute); SO₂, sulfur dioxide (ppm, pulse per minute); F00-F09, Mental and Behavioral Disease; F10-F19, Organic, including symptomatic, mental disorders; F20-F29, Schizophrenia, schizotypal and delusional disorders; F30-F39, Mood [affective] disorders; F40-F48, Neurotic, stress-related and somatoform disorders; F50-F59, Behavioral syndromes associated with physiological disturbances and physical factors; F60-F69, Disorders of adult personality and behavior; F70-F79, Mental retardation; F80-F89, Disorders of psychological development; F90-F98, Behavioral and emotional disorders with onset usually occurring in childhood and adolescence; F99-F99, Unspecified mental disorder.

correlated with ED visits for psychiatric diseases ($p < 0.001$, and $p = 0.0038$, respectively). Although 35 AWSs in Seoul measure weather factors, not all 35 AWSs measure relative humidity and air pressure. Therefore, we used data from one of the central station named 'Seoul' located in Jongro district. The Korean Meteorological Administration also uses the measurement values from this 'Seoul' station as representative weather values for Seoul.

We measured the numbers of ED visits for psychiatric disease. The NEDIS database was started to collect basic, clinical, diagnostic, and prognostic information for all emergency department patients in 2004. The data are used for ED evaluation programs by the Ministry of Health and Welfare and for reimbursement of the national health insurance program. Although the diagnostic codes in usual claims data may be incorrect in number of patients, NEDIS is required to include the exact diagnostic codes for the annual national evaluation program for all EDs.

The study was performed in Seoul, which is located in East Asia with four distinguishable seasons. These study findings may not be generalizable to other cities and climates.

5. Conclusion

Based on a two-year observational study in a metropolis, an increase in PM_{2.5} shows significant associations with emergency department visits for all psychiatric diseases (F00-F99) and neurotic, stress-related and somatoform disorders (F40-F49) after a lag of one day. However, PM_{2.5} did not increase the risk of or exacerbate other psychiatric diseases, such as major depression (mood disorder) or psychosis (schizophrenia). Additional research could develop a public health alert system for specific air pollutants associated with psychiatric emergencies, which could be used to prevent psychiatric emergencies in vulnerable populations.

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Ethical approval

The study was approved by the institutional review board of the study institution and informed consent was waived. The all databases were opened to public to be used in researches and did not have any individual private information.

Consent for publication

This manuscript is an original article, all of the authors have agreed to the submission and the manuscript is not under consideration by any other journal.

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