보건학석사학위논문

Associations between hourly $PM_{2.5}$ chemical constituents and emergency department visits for cardiovascular and respiratory disease

시간 변화에 따른 초미세먼지($PM_{2.5}$) 구성 성분과
심혈관계 질환 및 호흡기계통 질환 발생의 상관성 연구:
실시간 응급실 방문 자료를 중심으로

2016년 08월

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지도교수 이 승 묵
이 논문을 보건학석사학위논문으로 제출함

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Abstract

Associations between hourly $PM_{2.5}$ chemical constituents and emergency department visits for cardiovascular and respiratory disease

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Introduction : Several epidemiological studies have investigated fine particulate matter (≤ 2.5 µm in aerodynamic diameter, $PM_{2.5}$) has a risk for adverse effects on human health. Previous studies have focused on the risk associated with the total mass of particles, without considering the chemical constituents of them. In this study, the hourly differences between $PM_{2.5}$ chemical constituents and emergency visits for cardiovascular disease and respiratory disease were estimated using time-stratified case-crossover design.
Methods: The study periods were from January 1 to December 31, 2013 in Seoul, Korea. Hourly health outcome data on emergency department visits for cardiovascular disease and respiratory disease were provided by National Emergency Department Information System (NEDIS). Emergency department

visits data were classified according to the discharge diagnosis for cardiovascular disease and respiratory disease (ICD-10, cardiovascular, I00-I99 and respiratory, J00-J99). Hourly data for $PM_{2.5}$ mass and chemical constituents were measured by real-time monitoring at one sampling site located at Bulgwang-dong, Seoul (37.36° N, 126.56° E). In this study, $PM_{2.5}$ mass and only 13 chemical constituents (OC, EC, Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, and Zn), were selected after QA/QC procedure. The meteorological data such as hourly mean temperature (℃), relative humidity (%), and air pressure (hPa) were adjusted as confounding variable. Time-stratified case-crossover analysis and conditional logistic regression analysis were used to estimate the adverse health effects of fine air particles and to estimate and adjusted odds ratio (ORs) and 95% confidence intervals (CIs), respectively. The short-term effects were estimated using moving averages in six periods (1-6(h), 7-12(h), 13-18(h), 19-24(h), 25-48(h), 49-72(h)) and adjustments of this association by age (≥ 65 years) and season.

Results and Discussion : The strongest adverse effects for cardiovascular disease exacerbations were associated with $PM_{2.5}$ mass, OC, EC, Cl^-, Ca, Fe and Zn after 19-24h lag period and NH_4^+, NO_3^-, and SO_4^{2-} after 25-48h lag period were estimated. The strongest adverse effects for respiratory disease exacerbations were associted with NO_3^-, K and Pb after short lag periods (0-6h and 7-12h) and $PM_{2.5}$, OC, EC, Cl^-, NH_4^+, SO_4^{2-}, Ca, Fe, and Zn after longer lag periods (19-24h and 25-48h). For those older than ≥ 65 years, the strongest adverse effects for cardiovascular disease exacerbations were shown with $PM_{2.5}$ mass, OC, EC, Cl^-, Ca, Fe, and Zn after 19-24h lag

period and NO_3^- after 25-48 h lag period and respiratory disease exacerbations of OC, EC, Fe and Zn after 19-24h lag period were observed. Especially, among $PM_{2.5}$ chemical constituents, EC showed the strongest association with cardiovascular disease and respiratory disease exacerbations. For all of seasons, significant positive associations for $PM_{2.5}$ mass and chemical constituents excluding Mg^{2+} were observed for cardiovascular and respiratory disease.

Conclusion : This study found major differences of associations between $PM_{2.5}$ constituents and emergency visits for cardiovascular and respiratory disease in Seoul. This study will provide robust evidences for the health impacts of $PM_{2.5}$ chemical constituents.

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Keywords : $PM_{2.5}$, Chemical constituents, Emergency department visits, Cardiovascular disease, Respiratory disease, Time-stratified case-crossover

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1. Introduction

1.1. Backgrounds

Several epidemiological studies have investigated that fine particulate matter (≤ 2.5 μm in aerodynamic diameter, $PM_{2.5}$) has a risk for adverse effects on human health. The studies have shown associations between short-term or long-term exposure to $PM_{2.5}$ and the risk of excess morbidity and premature mortality (peng et al., 2009). In these days, the adverse health impacts of $PM_{2.5}$ on humans and characteristics of $PM_{2.5}$ chemical constituents that contribute to public health has been interested (Zhou et al., 2011l; Ostro et al., 2007). However, previous studies have just focused on the risk associated with the total mass of particles, without considering the chemical constituents. Few studies investigated regarding biological multiple mechanism affecting human health associated with exposure to $PM_{2.5.}$

Studies using smaller time-scale data such as hourly data are required than daily because of the time-dependent characteristics of air pollutant and health outcome (Janes et al., 2005). However, due to the complexities in sampling and lack of available routine measurement, just few epidemiological studies have been investigated associations of health effects with specific $PM_{2.5}$ constituents and temporal resolution of them. Routine measurement generally conducted every 3 or 6 days, which limits their usefulness for studies of associations between daily variation and health outcomes in air pollutant concentration (Sarnat et al., 2015). For instance, a study which was analyzed associations between premature mortality and $PM_{2.5}$ chemical constituents in Seoul, Korea using positive matrix factorization (PMF) reported a limitation because of using $PM_{2.5}$ data measured every third days (Heo et al., 2009).

In this study, the hourly differences between $PM_{2.5}$ chemical constituents and emergency visits for cardiovascular disease and respiratory disease were estimated using times-stratified case-crossover design.

1.2. Objectives

This study was analyzed temporal associations between $PM_{2.5}$ chemical constituents and onset cardiovascular and respiratory disease exacerbations. The risk of each chemical constituent was estimated using real-time measurement data and emergency department visits data from January 1 to December 31, 2013 in Seoul, Korea.

To investigate adverse effects of $PM_{2.5}$ chemical constituents with health outcomes, a time-stratified case-crossover design was used in this study.

2. Methods

2.1. Study period

The study period was from January 1 to December 31, 2013 in Seoul, Korea. In this study, emergency department visits data was as health outcome and $PM_{2.5}$ mass concentration and chemical constituents of $PM_{2.5}$ were used as air pollution.

2.2. Emergency department visits data

Hourly health outcome data on emergency department visits for cardiovascular disease and respiratory disease were provided by National Emergency Department Information System (NEDIS). Emergency department visits data were collected from 31 hospitals in Seoul.

Emergency department visits data were classified according to the discharge diagnosis for cardiovascular disease and respiratory disease using International Classification of Disease 10th Revision from WHO (ICD-10, cardiovascular, I00-I99 and respiratory, J00-J99).

2.3. $PM_{2.5}$ measurement data

Hourly data for $PM_{2.5}$ mass and chemical constituents were measured by real-time monitoring system at the one of national monitoring site located on Bulgwang-dong, Seoul (37.36° N, 126.56° E). $PM_{2.5}$ chemical constituents included carbon constituents such as organic carbon (OC), elemental carbon (EC), ion constituents including Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-} and metal constituents(As, Ca, Cu, Ni, Fe, K, Mn, Pb, Ti, and Zn).

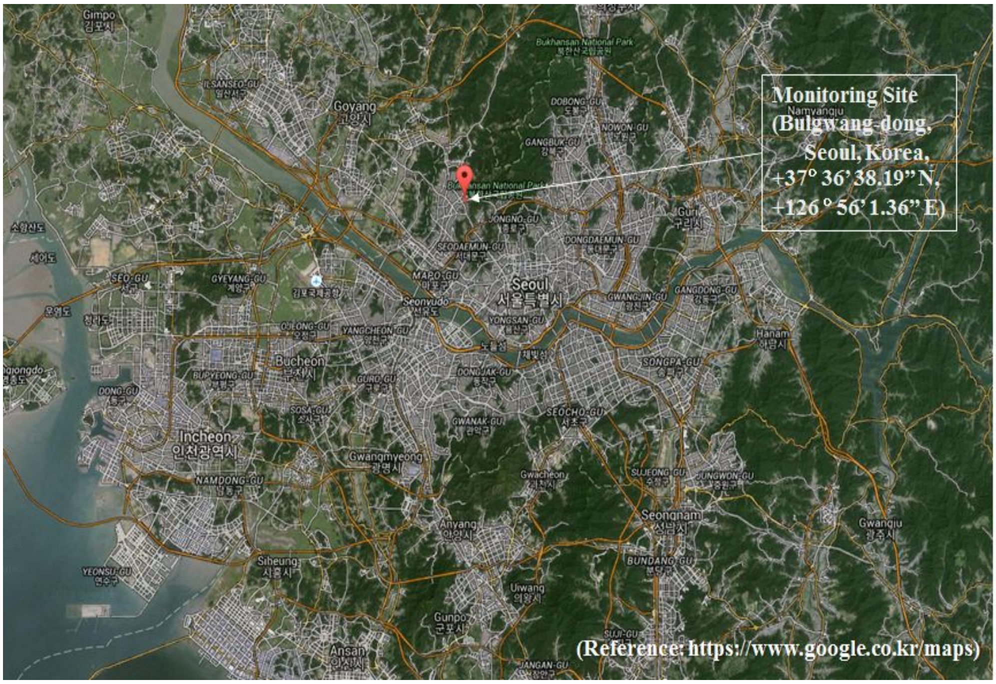

Figure 1. The location of monitoring site

$PM_{2.5}$ mass concentrations were analyzed by BAM-1020 (Met one, USA) using β-ray attenuation method, OC and EC constituents were analyzed by

Semi-continuous OC/EC carbon Aerosol Analyzer (SOCEC, USA) using thermal-optical transmission method, Ion constituents were analyzed by URG-9000D (USA) using ion chromatography method and metal constituents were analyzed using X-ray Flouorescence Spectroscopy (XRF) (Xact-620, USA). In this study, $PM_{2.5}$ mass and only 13 chemical constituents (OC, EC, Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, and Zn), which conducted QA/QC procedure, were used.

2.4. Confounding variable

The meteorological data such as hourly mean temperature (℃), realative humidity (%), and air pressure (hPa) were measured the same monitoring site of $PM_{2.5}$. A given day's rain was adjusted as a binary variable, and rainy time was identified with hourly precipitation > 0 mm. The day of week were also adjusted as confounding variable in this study.

2.5. Statistical analysis

This study was conducted by time-stratified case-crossover analysis to estimate the adverse health effect of air particle for Seoul, Korea. A case-crossover study can be regarded as a case-control design of a crossover study and this concept can adjust for time invariant confounder such as environmental variable (Temperature, relative humidity and air pressure) (Yorifuji et al., 2014).

The case-crossover study design has been used to study the association between short-term air pollution exposure and an adverse effects of health outcome. This design can use cases only; for each individual case only, exposure before the event (case period) is compared with exposure at other control period (Janes et al., 2005). Time-stratified period can ensure unbiased estimates from conditional logistic regression and avoid bias resulting from time trend. Control periods were selected from the same times on other days, on the same days of the week in the same months and years (Yorifuji et al., 2014). Air pollution and confounder variable for the hour of the onset of cardiovascular disease and respiratory disease exacerbations on the case period were compared with those at the same hour on control period. Also, The study design was adjusted in terms of moving averages in the 6 period which was stratified in time blocks as 1-6(h), 7-12(h), 13-18(h), 19-24(h), 25-48(h), and 49-72(h) defined as a multi-time average of exposures (J. Kim et al., 2015).
This study was conducted by conditional logistic regression analysis to

estimate adjusted odds ratio (ORs) and 95% confidence intervals (CIs) for the $PM_{2.5}$ exposure and each health outcome. The effect of units increase were considered by inter-quartile difference (IQR, between the 25th and the 75th percentile) of each chemical constituent concentration. For example, the effects of a 10 $\mu g/m^3$ increase in the concentration of $PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-}, the effects of a 1 $\mu g/m^3$ increase in the concentration of Cl-, the effects of a 0.1 $\mu g/m^3$ increase in the concentration of Mg^{2+}, Na^+, Ca, Fe, K, Zn and the effects of 0.01 $\mu g/m^3$ increase in the concentration of Pb were estimated for the onset of cardiovascular disease and respiratory disease exacerbations.

Especially, this study was focused on the elderly population (≥ 65 yaers) because they are considered to be greater risk of the adverse health effect of outdoor air pollution. Also, seasonal effects were considered in overall study period. The durations of the four seasons were identified as March-May for spring, June-August for summer, September-November for fall, and December-February for winter.

All statistical analyzes were performed using R 3.2.3 (The Comprehensive R Archive Network: http://cran.r-project.org) and SAS 9.4 (SAS Institute, Inc., Cary, North Carolina). All statistical tests were two-sided, and a *p*-value <0.05 indicated statistical significance.

3. Results

3.1. General characteristics

Demographic characteristics of patients who visited emergency department for cardiovascular disease and respiratory disease from January 1 to December 31, 2013 were shown in Table 1. A total of 52,263 cardiovascular disease-related emergency department visits and a total of 135,960 respiratory disease-related emergency department visits were registered in the 31 hospitals in Seoul. The average of cardiovascular disease-related emergency department visits per hour and respiratory disease-related emergency department visits pre hour were 5.97 and 15.52, respectively. 26,391 visits for cardiovascular disease (50.50%) by patients aged ≥ 65 years, 14,958 visits for respiratory disease (11.00%) by patients aged ≥ 65 years.

Figure 2 and Figure 3 show time-series plot of the number of hourly emergency department visits for cardiovascular disease and respiratory disease in Seoul, Korea (2013).

Table 1 Summary statistics of hourly emergency department visits of cardiovascular and respiratory disease in Seoul, Korea (2013)

		All-season					
		N (%)	Mean	SD	Min.	Median	Max.
Emergency department visits (2013)	Cardiovascular	52,263 (100)	5.97	3.62	0	5	28
	≥ 65 years	26,391 (50.5)	3.01	2.29	0	3	17
	Respiratory	135,960 (100)	15.52	12.52	0	13	151
	≥ 65 years	14,958 (11.00)	1.71	1.77	0	1	12

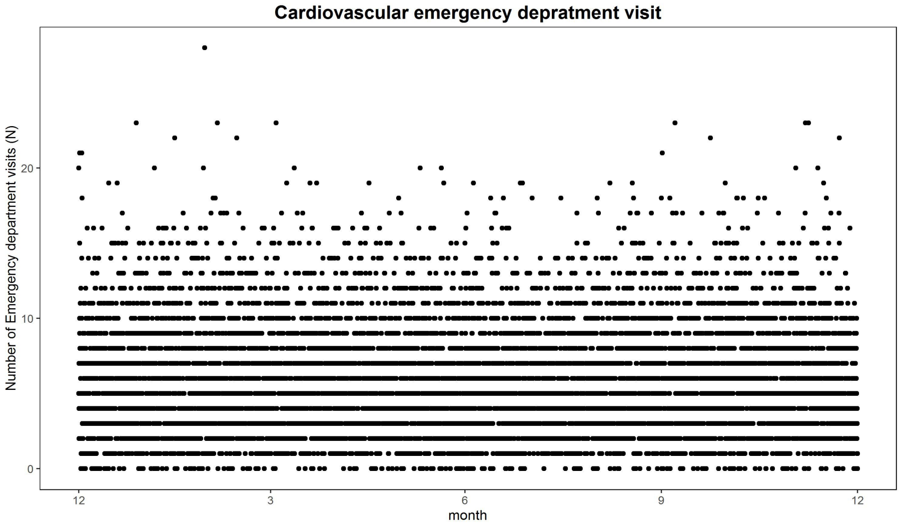

Figure 2. Time-series plot of the number of hourly emergency department visits for cardiovascular disease in Seoul, Korea (2013)

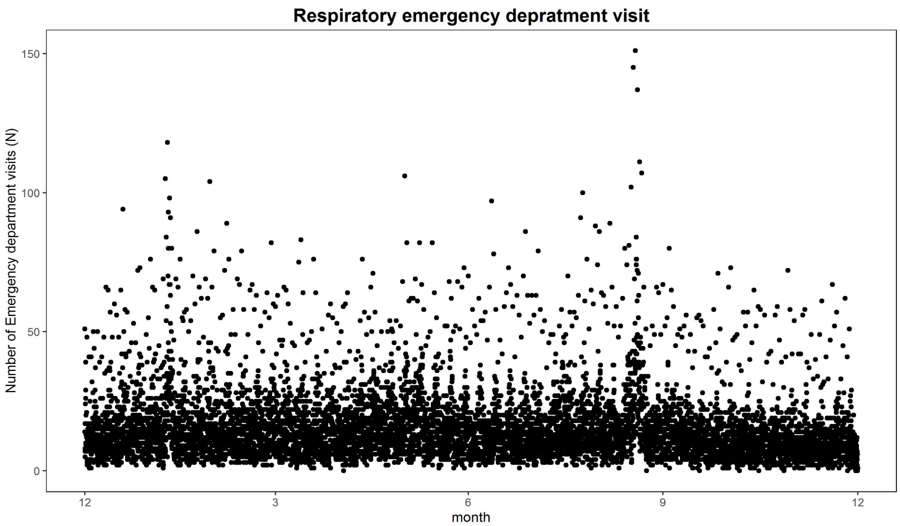

Figure 3. Time-series plot of the number of hourly emergency department visits for respiratory disease in Seoul, Korea (2013)

3.2. Environmental exposures

Summary statistics for all pollutants measured at the monitoring site are presented in Table 2. The mean of $PM_{2.5}$ mass concentration was 38.30 $\mu g/m^3$, which was higher than the annual $PM_{2.5}$ standard of National Ambient Air Quality Standards (NAAQS) in Korea as 25 $\mu g/m^3$. $PM_{2.5}$ constituents to total $PM_{2.5}$ included NO_3^- (24.30%), SO_4^{2-} (23.24%), NH_4^+ (13.29%), OC (9.92%) and EC (4.58%), respectively. The selected metals contributed a little to $PM_{2.5}$ (< 6%). Total $PM_{2.5}$ mass was most strongly correlated with NH_4^+ (r = 0.94) and NO_3^- (r = 0.86) (Table 3). Among the $PM_{2.5}$ chemical constituents, correlations were generally strong in the group of ion species, within chemical grouping: for example, NH_4^+ with NO_3^- (r = 0.89), NH4+ with SO_4^{2-} (r = 0.88) and elemental species groups such as Fe with Ca (r = 0.88), respectively.

Meteorological data such as temperature, relative humidity and air pressure were summarized in Table 4. A correlation between $PM_{2.5}$ mass and weather variable in Seoul were also presented in Table 5.

Appendix A shows the time-series plots of hourly concentration of $PM_{2.5}$ mass and each chemical constituents in Seoul, Korea (2013).

Table 2 Summary statistics of $PM_{2.5}$ mass and chemical constituents in Seoul, Korea (2013)

		All-season							
		N	Mean	SD	Min.	Median	Max.	IQR (Q1 − Q3)[1)]	Proportion (%)
Air Pollutants ($\mu g/m^3$)	$PM_{2.5}$	8,567	38.30	26.69	1.00	31.00	205.00	33.00 (18.00 - 51.00)	100
	SO_4^{2-}	7,335	8.90	7.67	0.49	6.39	73.70	8.62 (3.52 − 12.14)	23.24
	NO_3^-	7,335	9.31	8.98	0.05	6.23	86.12	10.26 (2.83 − 13.09)	24.30
	Cl^-	5,443	0.72	0.83	0.01	0.46	9.51	0.76 (0.17 − 0.93)	1.89
	Na^+	7,063	0.17	0.18	0.002	0.11	2.33	0.12 (0.07 − 0.19)	0.45
	NH_4^+	7,335	5.20	4.50	0.11	3.95	33.31	5.56 (1.78 − 7.34)	13.29
	Mg^{2+}	7,264	0.16	0.15	0.001	0.11	1.74	0.13 (0.07 − 0.20)	0.41
	OC	7,426	3.80	2.59	0.04	3.23	32.95	2.84 (1.99 − 4.83)	9.92
	EC	7,426	1.75	1.09	0.05	1.50	8.15	1.23 (1.00 − 2.23)	4.58
	K	8,058	0.42	0.54	0.0002	0.24	5.07	0.36 (0.11 − 0.47)	1.10
	Ca	8,026	0.13	0.37	0.00002	0.06	12.51	0.08 (0.03 − 0.12)	0.35
	Fe	8,102	0.29	0.36	0.0007	0.21	8.02	0.21 (0.12 − 0.33)	0.76
	Zn	8,095	0.10	0.09	0.00006	0.07	1.82	0.09 (0.04 − 0.13)	0.25
	Pb	8,086	0.04	0.04	0.00001	0.03	0.37	0.04 (0.05 − 0.01)	0.10

1) IQR : Inter-quartile Range

Table 3 Pearson correlations among $PM_{2.5}$ mass and chemical constituents in Seoul, Korea (2013)

	$PM_{2.5}$	SO_4^{2-}	NO_3^-	Cl^-	Na^+	NH_4^+	Mg^{2+}	OC	EC	K	Ca	Fe	Zn	Pb
$PM_{2.5}$		0.82	0.86	0.49	0.19	0.94	-0.10	0.83	0.81	0.57	0.20	0.46	0.76	0.79
SO_4^{2-}	0.82		0.59	0.24	0.22	0.88	-0.13	0.52	0.53	0.28	0.11	0.34	0.57	0.60
NO_3^-	0.86	0.59		0.51	0.13	0.89	-0.14	0.75	0.71	0.47	0.15	0.41	0.70	0.71
Cl^-	0.49	0.24	0.51		0.40	0.47	0.05	0.48	0.46	0.42	0.13	0.24	0.50	0.53
Na^+	0.19	0.22	0.13	0.40		0.18	0.23	0.16	0.17	0.10	0.07	0.12	0.21	0.22
NH_4^+	0.94	0.88	0.89	0.47	0.18		-0.16	0.71	0.69	0.42	0.15	0.42	0.70	0.72
Mg^{2+}	-0.10	-0.13	-0.14	0.05	0.23	-0.16		-0.08	-0.09	0.13	-0.01	-0.06	0.05	-0.02
OC	0.83	0.52	0.75	0.48	0.16	0.71	-0.08		0.87	0.64	0.20	0.41	0.68	0.65
EC	0.81	0.53	0.71	0.46	0.17	0.69	-0.09	0.87		0.57	0.21	0.44	0.69	0.65
K	0.57	0.28	0.47	0.42	0.10	0.42	0.13	0.64	0.57		0.37	0.43	0.52	0.63
Ca	0.20	0.11	0.15	0.13	0.07	0.15	-0.01	0.20	0.21	0.37		0.88	0.31	0.26
Fe	0.46	0.34	0.41	0.24	0.12	0.42	-0.06	0.41	0.44	0.43	0.88		0.57	0.52
Zn	0.76	0.57	0.70	0.50	0.21	0.70	0.05	0.68	0.69	0.52	0.31	0.57		0.75
Pb	0.79	0.60	0.71	0.53	0.22	0.72	-0.02	0.65	0.65	0.63	0.26	0.52	0.75	

Table 4 Summary statistics of weather variables Seoul, Korea (2013)

		Weather variable					
		N	Mean	SD	Min.	Median	Max.
All season	Temperature (℃)	8760	12.10	11.49	-16.77	12.48	34.10
	Relative Humidity (%)	8760	65.41	19.17	11.60	65.74	100.00
	Air pressure (hPa)	8760	1015.80	8.44	994.80	1016.20	1039.20
Spring (Mar. − May)	Temperature (℃)	2208	10.60	7.00	-4.97	10.04	30.80
	Relative Humidity (%)	2208	59.20	21.36	11.60	58.10	99.81
	Air pressure (hPa)	2208	1014.12	6.35	997.00	1013.90	1028.90
Summer (Jun. - Aug.)	Temperature (℃)	2208	25.38	3.15	15.12	25.34	34.10
	Relative Humidity (%)	2208	75.36	16.13	22.45	78.24	100.00
	Air pressure (hPa)	2208	1006.36	4.01	994.80	1006.50	1017.80
Fall (Sep. − Nov.)	Temperature (℃)	2184	14.07	7.84	-6.07	15.22	30.52
	Relative Humidity (%)	2184	64.52	17.57	21.70	63.75	98.48
	Air pressure (hPa)	2184	1018.42	4.97	997.80	1018.50	1030.90
Winter (Dec. − Feb.)	Temperature (℃)	2160	-1.96	5.38	-16.77	-1.72	12.99
	Relative Humidity (%)	2160	62.48	17.20	19.25	62.98	100.00
	Air pressure (hPa)	2160	1024.54	5.40	1007.20	1025.20	1039.20

Table 5 Pearson correlations among $PM_{2.5}$ and weather variable in Seoul, Korea (2013)

	$PM_{2.5}$ mass concentration (μg/m^3)	temperature (℃)	relative humidity (%)	air pressure (hPa)
$PM_{2.5}$ mass concentration (μg/m^3)		-0.08	0.14	0.05
temperature (℃)	-0.08		0.17	-0.08
relative humidity (%)	0.14	0.17		0.10
air pressure (hPa)	0.05	-0.08	0.10	

3.3. Associations between $PM_{2.5}$ and the onset of cardiovascular and respiratory disease

The adverse effect [OR, (95% CI)] on the moving average for lag periods with cardiovascular and respiratory disease exacerbations were estimated Table 6 and Table 7.

For cardiovascular disease, a 10 $\mu g/m^3$ increase in $PM_{2.5}$ mass, OC and EC were significantly associated at the lag period of 19-24(h) [1.0012, (1.0007-1.0018)], [1.0162 (1.0098-1.0227)] and [1.0946 (1.0779-1.1116)], respectively. A 1 $\mu g/m^3$ increase in Cl^- was significantly associated at the lag period of 19-24(h) [1.0066 (1.0041-1.0092)]. A 0.1 $\mu g/m^3$ increase in Ca, Fe and Zn was significantly associated at the lag period of 19-24(h) [1.0010 (1.0006-1.0015)], [1.0011 (1.0007-1.0016)] and [1.0048 (10031-1.0065), respectively. A 10 $\mu g/m^3$ increase in NH_4^+, NO_3^- and SO_4^{2-} were significantly associated at the lag period of 25-48(h) [1.0086 (1.0026-1.0147)], [1.0045 (1.0014-1.0077)] and [1.0047 (1.0012-1.0082), respectively.

For respiratory disease, a 10 $\mu g/m^3$ increase in NO_3^- and a 0.01 $\mu g/m^3$ increase in Pb were significantly associated at the lag period of 1-6(h) [1.0041, (1.0029-1.0053)] and [1.0003 (1.0001-1.0005)], respectively. A 0.1 $\mu g/m^3$ increase in K was significantly associated at the lag period of 7-12(h) [1.0003 (1.0001-1.0005)]. A 10 $\mu g/m^3$ increase in $PM_{2.5}$ mass, OC, EC and a 1 $\mu g/m^3$ increase in Cl- and a 0.1 $\mu g/m^3$ increase in Ca, Fe and Zn were significantly associated at the lag period 19-24(h) [1.0009, (1.0006-1.0012)], [1.0215 (1.0178-1.0252)], [1.1107 (1.1010-1.1205)], [1.0066 (1.0050-1.0082)], [1.0006 (1.0004-1.0009)], [1.0012 (1.0010-1.0015)] and [1.0043 (1.0033-1.0053), respectively.

Table 6 Estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of cardiovascular disease in Seoul, Korea, 2013 (All)

Constituents	All age					
	Cardiovascular					
	lag 0-6(h)	lag 7-12(h)	lag 13-18(h)	lag 19-24(h)	lag 25-48(h)	lag 49h-72(h)
$PM_{2.5}$ 1)	0.9998 (0.9993-1.0004)	0.9998 (0.9992-1.0004)	0.9994 (0.9988-0.9999)	**1.0012 (1.0007-1.0018)**	1.0001 (0.9993-1.0008)	0.9999 (0.9992-1.0007)
OC 1)	0.9827 (0.9765-0.9890)	0.9858 (0.9790-0.9926)	1.0019 (0.9953-1.0086)	**1.0162 (1.0098-1.0227)**	0.9964 (0.9859-1.0070)	0.9879 (0.9771-0.9988)
EC 1)	0.9546 (0.9397-0.9697)	0.9721 (0.9566-0.9880)	0.9634 (0.9485-0.9785)	**1.0946 (1.0779-1.1116)**	0.9852 (0.9602-1.0109)	0.9687 (0.9428-0.9952)
Cl^- 2)	0.9994 (0.9969-1.0020)	0.9994 (0.9969-1.0020)	1.0067 (0.9982-1.0031)	**1.0066 (1.0041-1.0092)**	0.9981 (0.9934-1.0029)	0.9815 (0.9356-1.0296)
Mg^+ 3)	0.9994 (0.9982-1.0007)	1.0003 (0.9989-1.0018)	1.0005 (0.9992-1.0018)	1.0003 (0.9991-1.0015)	0.9996 (0.9974-1.0018)	1.0003 (0.9982-1.0024)
Na^+ 3)	0.9999 (0.9989-1.0009)	0.9999 (0.9989-1.0010)	0.9991 (0.9981-1.0000)	1.0004 (0.9994-1.0014)	0.9978 (0.9962-0.9994)	0.9992 (0.9976-1.0008)
NH_4^+ 1)	1.0014 (0.9973-1.0056)	0.9895 (0.9853-0.9937)	0.9958 (0.9917-0.9998)	1.0064 (1.0028-1.0100)	**1.0086 (1.0026-1.0147)**	1.0016 (0.9954-1.0077)
NO_3^- 1)	1.0030 (1.0009-1.0051)	0.9948 (0.9927-0.9970)	0.9953 (0.9932-0.9973)	1.0041 (1.0022-1.0059)	**1.0045 (1.0014-1.0077)**	1.0012 (0.9980-1.0045)
SO_4^{2-} 1)	0.9990 (0.9966-1.0014)	0.9942 (0.9918-0.9967)	1.0013 (0.9990-1.0037)	1.0031 (1.0010-1.0052)	**1.0047 (1.0012-1.0082)**	1.0010 (0.9973-1.0046)
Ca 3)	0.9999 (0.9995-1.0004)	0.9991 (0.9986-0.9996)	0.9997 (0.9992-1.0002)	**1.0010 (1.0006-1.0015)**	1.0003 (0.9995-1.0010)	0.9998 (0.9991-1.0006)
Fe 3)	0.9994 (0.9990-0.9999)	0.9992 (0.9987-0.9997)	1.0000 (0.9995-1.0005)	**1.0011 (1.0007-1.0016)**	0.9998 (0.9990-1.0006)	0.9995 (0.9987-1.0003)
K 3)	0.9999 (0.9995-1.0003)	1.0001 (0.9996-1.0005)	0.9999 (0.9995-1.0003)	1.0003 (0.9998-1.0007)	1.0001 (0.9995-1.0008)	1.0000 (0.9994-1.0007)
Pb 4)	1.0003 (0.9999-1.0007)	0.9998 (0.9994-1.0002)	0.9997 (0.9993-1.0001)	0.9999 (0.9995-1.0003)	1.0000 (0.9994-1.0006)	1.0002 (0.9996-1.0008)
Zn 3)	1.0000 (0.9982-1.0018)	0.9934 (0.9916-0.9952)	0.9992 (0.9973-1.0011)	**1.0048 (1.0031-1.0065)**	1.0004 (0.9972-1.0035)	0.9990 (0.9959-1.0021)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.

1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})

2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)

3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)

4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

Table 7 Estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of respiratory disease in Seoul, Korea, 2013 (All)

Constit-uents	All age					
	Respiratory					
	lag 0-6(h)	**lag 7-12(h)**	**lag 13-18(h)**	**lag 19-24(h)**	**lag 25-48(h)**	**lag 49-72(h)**
$PM_{2.5}$ 1)	0.9999 (0.9996-1.0002)	0.9996 (0.9993-0.9999)	0.9988 (0.9985-0.9991)	**1.0009 (1.0006-1.0012)**	0.9997 (0.9993-1.0001)	1.0004 (1.0000-1.0008)
OC 1)	0.9853 (0.9818-0.9887)	0.9864 (0.9826-0.9903)	1.0018 (0.9980-1.0056)	**1.0215 (1.0178-1.0252)**	1.0046 (0.9990-1.0102)	1.0014 (0.9954-1.0075)
EC 1)	0.9508 (0.9423-0.9593)	0.9736 (0.9647-0.9826)	0.9518 (0.9432-0.9604)	**1.1107 (1.1010-1.1205)**	0.9954 (0.9818-1.0091)	0.9925 (0.9779-1.0074)
Cl^- 2)	0.9992 (0.9976-1.0007)	1.0003 (0.9987-1.0018)	0.9991 (0.9977-1.0006)	**1.0066 (1.0050-1.0082)**	1.0008 (0.9982-1.0035)	1.0033 (1.0007-1.0059)
Mg^+ 3)	1.0001 (0.9993-1.0009)	1.0008 (0.9999-1.0016)	1.0006 (0.9998-1.0014)	1.0001 (0.9994-1.0008)	1.0009 (0.9997-1.0021)	1.0010 (0.9997-1.0022)
Na^+ 3)	0.9997 (0.9991-1.0003)	0.9999 (0.9993-1.0005)	0.9996 (0.9991-1.0002)	1.0005 (0.9999-1.0011)	0.9983 (0.9975-0.9992)	0.9999 (0.9991-1.0008)
NH_4^+ 1)	1.0032 (1.0009-1.0055)	0.9893 (0.9870-0.9917)	0.9940 (0.9917-0.9962)	1.0024 (1.0004-1.0044)	**1.0053 (1.0022-1.0085)**	1.0036 (1.0004-1.0069)
NO_3^- 1)	**1.0041 (1.0029-1.0053)**	0.9949 (0.9938-0.9961)	0.9939 (0.9928-0.9951)	1.0025 (1.0015-1.0036)	1.0033 (1.0016-1.0049)	1.0017 (0.9999-1.0034)
SO_4^{2-} 1)	1.0000 (0.9987-1.0013)	0.9940 (0.9927-0.9954)	1.0009 (0.9996-1.0022)	1.0013 (1.0001-1.0024)	**1.0026 (1.0007-1.0044)**	1.0022 (1.0003-1.0041)
Ca 3)	1.0002 (1.0000-1.0004)	0.9994 (0.9992-0.9996)	0.9993 (0.9990-0.9996)	**1.0006 (1.0004-1.0009)**	1.0005 (1.0001-1.0010)	1.0005 (1.0001-1.0009)
Fe 3)	0.9996 (0.9993-0.9998)	0.9991 (0.9989-0.9994)	0.9995 (0.9992-0.9998)	**1.0012 (1.0010-1.0015)**	1.0002 (0.9997-1.0006)	1.0004 (1.0000-1.0009)
K 3)	1.0001 (0.9998-1.0003)	**1.0003 (1.0001-1.0005)**	0.9997 (0.9995-0.9999)	1.0002 (0.9999-1.0004)	0.9999 (0.9996-1.0003)	1.0001 (0.9997-1.0005)
Pb 4)	**1.0003 (1.0001-1.0005)**	0.9997 (0.9995-0.9999)	0.9997 (0.9995-0.9999)	0.9997 (0.9995-1.0000)	0.9997 (0.9994-1.0001)	1.0000 (1.0000-1.0007)
Zn 3)	0.9999 (0.8994-1.0939)	0.9922 (0.9989-1.0009)	0.9988 (0.9912-0.9932)	**1.0043 (1.0033-1.0053)**	0.9997 (0.9980-1.0014)	1.0027 (1.0010-1.0044)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.

1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})

2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)

3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)

4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

3.4. Estimation by age (≥65 years of age)

The adverse effect [OR, (95% CI)] on the moving average for lag period with the onset of cardiovascular disease and respiratory disease influenced by aged (≥65 years) were estimated Table 8 and Table 9.

For cardiovascular disease, a 10 μg/m^3 increase in NO_3^- was significantly associated at the lag period of 1-6(h) [1.0034 (1.0004-1.0063)]. A 10 μg/m^3 increase in $PM_{2.5}$ mass, OC and EC, a 1 μg/m^3 increase in Cl^- and a 0.1 μg/m^3 increase in Ca, Fe and Zn were significantly associated at the lag period of 19-24h [1.0011(1.00031.0019], [1.0160 (1.0068-1.0253)], [1.0981 (1.0743-1.1225)], [1.0080 (1.0044-1.0116)], [1.0009 (1.0003-1.0016)], [1.0011 (1.0005-1.0017)] and [1.0049 (1.0024-1.0074), respectively. .

For respiratory disease, a 10 μg/m^3 increase in OC and EC, a 0.1 μg/m^3 increase in Fe, Zn were significantly associated at the lag period 19-24(h) [1.0190, (1.0071-1.0312)], [1.1024 (1.0716-1.1340)], [1.0001 (1.0001-1.0017)] and [1.0047 (1.0013-1.0081), respectively.

From Figure 4 to Figure 9 show the effect size of $PM_{2.5}$ mass, OC, EC. The effect size of other constituents such as Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, and Zn are showed in Appendix B.

Table 8 Estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of cardiovascular disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

Constit-uents	Aged (≥65 years)					
	Cardiovascular					
	lag 0-6(h)	lag 7-12(h)	lag 13-18(h)	lag 19-24(h)	lag 25-48(h)	lag 49-72(h)
$PM_{2.5}$ 1)	0.9996 (0.9988-1.0004)	0.9997 (0.9989-1.0005)	0.9993 (0.9986-1.0001)	**1.0011 (1.0003-1.0019)**	0.9997 (0.9987-1.0008)	0.9998 (0.9987-1.0009)
OC 1)	0.9801 (0.9712-0.9891)	0.9894 (0.9797-0.9993)	1.0032 (0.9936-1.0128)	**1.0160 (1.0068-1.0253)**	1.0012 (0.9862-1.0164)	0.9827 (0.9669-0.9987)
EC 1)	0.9528 (0.9316-0.9744)	0.9779 (0.9557-1.0006)	0.9686 (0.9473-0.9905)	**1.0981 (1.0743-1.1225)**	0.9974 (0.9612-1.0350)	0.9610 (0.9241-0.9994)
Cl^- 2)	0.9990 (0.9954-1.0026)	0.9998 (0.9962-1.0034)	1.0012 (0.9977-1.0048)	**1.0080 (1.0044-1.0116)**	1.0034 (0.9968-1.0101)	0.9985 (0.9917-1.0053)
Mg^+ 3)	0.9998 (0.9979-1.0017)	1.0006 (0.9986-1.0026)	1.0016 (0.9997-1.0035)	1.0011 (0.9994-1.0028)	1.0016 (0.9985-1.0048	0.9999 (0.9969-1.0030)
Na^+ 3)	0.9999 (0.8570-1.1429)	1.0003 (0.8890-1.1832)	0.9994 (0.8235-1.0709)	1.0012 (0.9762-1.2967)	0.9988 (0.7047-1.1078)	0.9997 (0.9975-1.0020)
NH_4^+ 1)	1.0016 (0.9957-1.0075)	0.9900 (0.9840-0.9961)	0.9944 (0.9887-1.0002)	1.0047 (0.9996-1.0099)	1.0080 (0.9995-1.0167)	1.0013 (0.9925-1.0102)
NO_3^- 1)	**1.0034 (1.0004-1.0063)**	0.9949 (0.9918-0.9979)	0.9948 (0.9919-0.9977)	1.0031 (1.0005-1.0058)	1.0043 (0.9997-1.0088)	1.0020 (0.9973-1.0067)
SO_4^{2-} 1)	0.9988 (0.9954-1.0022)	0.9946 (0.9910-0.9981)	1.0004 (0.9970-1.0039)	1.0025 (0.9994-1.0055)	1.0046 (0.9996-1.0096)	1.0002 (0.9949-1.0055)
Ca 3)	1.0001 (0.9995-1.0008)	0.9992 (0.9985-0.9999)	0.9997 (0.9990-1.0004)	**1.0009 (1.0003-1.0016)**	1.0000 (0.9989-1.0010)	0.9985 (0.9985-1.0007)
Fe 3)	0.9996 (0.9989-1.0002)	0.9993 (0.9986-1.0000)	0.9999 (0.9992-1.0006)	**1.0011 (1.0005-1.0017)**	0.9995 (0.9983-1.0006)	0.9989 (0.9977-1.0001)
K 3)	0.9999 (0.9993-1.0005)	1.0000 (0.9994-1.0006)	0.9998 (0.9998-1.0010)	1.0004 (0.9990-1.0008)	0.9999 (0.9990-1.0008)	1.0000 (0.9991-1.0009)
Pb 4)	1.0004 (0.9998-1.0009)	0.9998 (0.9993-1.0004)	0.9998 (0.9992-1.0003)	0.9999 (0.9993-1.0004)	0.9996 (0.9987-1.0005)	0.9998 (0.9989-1.0007)
Zn 3)	1.0002 (0.9977-1.0027)	0.9939 (0.9914-0.9965)	0.9991 (0.9964-1.0018)	**1.0049 (1.0024-1.0074)**	0.9998 (0.9954-1.0043)	0.9966 (0.9922-1.0011)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.

1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})

2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)

3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)

4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

Table 9 Estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

Constit-uents	Aged (≥65 years)					
	Respiratory					
	lag 0-6(h)	lag 7-12(h)	lag 13-18(h)	lag 19-24(h)	lag 25-48(h)	lag 49-72(h)
$PM_{2.5}$ 1)	0.9998 (0.9988-1.0009)	0.9997 (0.9986-1.0007)	0.9989 (0.9979-0.9999)	1.0009 (0.9999-1.0019)	0.9991 (0.9978-1.0004)	0.9993 (0.9980-1.0007)
OC 1)	0.9853 (0.9740-0.9967)	0.9877 (0.9749-1.0007)	1.0048 (0.9926-1.0171)	**1.0190 (1.0071-1.0312)**	1.0050 (0.9861-1.0242)	0.9834 (0.9644-1.0028)
EC 1)	0.9546 (0.9271-0.9829)	0.9673 (0.9383-0.9972)	0.9681 (0.9404-0.9966)	**1.1024 (1.0716-1.1340)**	0.9866 (0.9424-1.0329)	0.9405 (0.8961-0.9871)
Cl^- 2)	0.9998 (0.9951-1.0045)	0.9987 (0.9939-1.0035)	1.0009 (0.9961-1.0056)	1.0039 (0.9990-1.0088)	0.9945 (0.9862-1.0028)	0.9965 (0.9878-1.0053)
Mg^+ 3)	1.0008 (0.9982-1.0034)	1.0011 (0.9983-1.0038)	1.0009 (0.9983-1.0034)	1.0014 (0.9989-1.0038)	1.0006 (0.9964-1.0047)	1.0002 (0.9962-1.0043)
Na^+ 3)	1.0000 (0.9981-1.0019)	0.9997 (0.9978-1.0016)	0.9989 (0.9971-1.0007)	1.0004 (0.9985-1.0023)	0.9975 (0.9944-1.0006)	0.9990 (0.9959-1.0020)
NH_4^+ 1)	1.0008 (0.9932-1.0085)	0.9856 (0.9777-0.9935)	0.9908 (0.9833-0.9983)	1.0036 (0.9969-1.0104)	0.9981 (0.9873-1.0091)	0.9980 (0.9869-1.0092)
NO_3^- 1)	1.0027 (0.9988-1.0066)	0.9929 (0.9889-0.9970)	0.9922 (0.9883-0.9960)	1.0032 (0.9998-1.0067)	0.9986 (0.9930-1.0043)	0.9973 (0.9915-1.0031)
SO_4^{2-} 1)	0.9992 (0.9948-1.0036)	0.9925 (0.9879-0.9970)	0.9995 (0.9951-1.0040)	1.0021 (0.9981-1.0060)	0.9996 (0.9930-1.0063)	1.0005 (0.9939-1.0072)
Ca 3)	1.0000 (0.9992-1.0008)	0.9988 (0.9978-0.9998)	0.9986 (0.9977-0.9995)	1.0003 (0.9994-1.0011)	1.0005 (0.9992-1.0018)	1.0006 (0.9995-1.0017)
Fe 3)	0.9991 (0.9983-1.0000)	0.9988 (0.9978-0.9997)	0.9991 (0.9983-1.0000)	**1.0001 (1.0001-1.0017)**	0.9998 (0.9984-1.0013)	0.9997 (0.9984-1.0010)
K 3)	1.0000 (0.9992-1.0007)	1.0005 (0.9997-1.0013)	0.9998 (0.9990-1.0005)	1.0002 (0.9993-1.0010)	0.9997 (0.9986-1.0009)	0.9998 (0.9987-1.0010)
Pb 4)	1.0000 (0.9993-1.0007)	0.9995 (0.9988-1.0002)	0.9995 (0.9988-1.0002)	0.9997 (0.9990-1.0004)	0.9995 (0.9984-1.0006)	0.9994 (0.9983-1.0005)
Zn 3)	0.9983 (0.9949-1.0017)	0.9910 (0.9875-0.9946)	0.9980 (0.9944-1.0015)	**1.0047 (1.0013-1.0081)**	1.0000 (0.9942-1.0058)	0.9961 (0.9904-1.0018)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.
1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})
2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)
3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)
4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

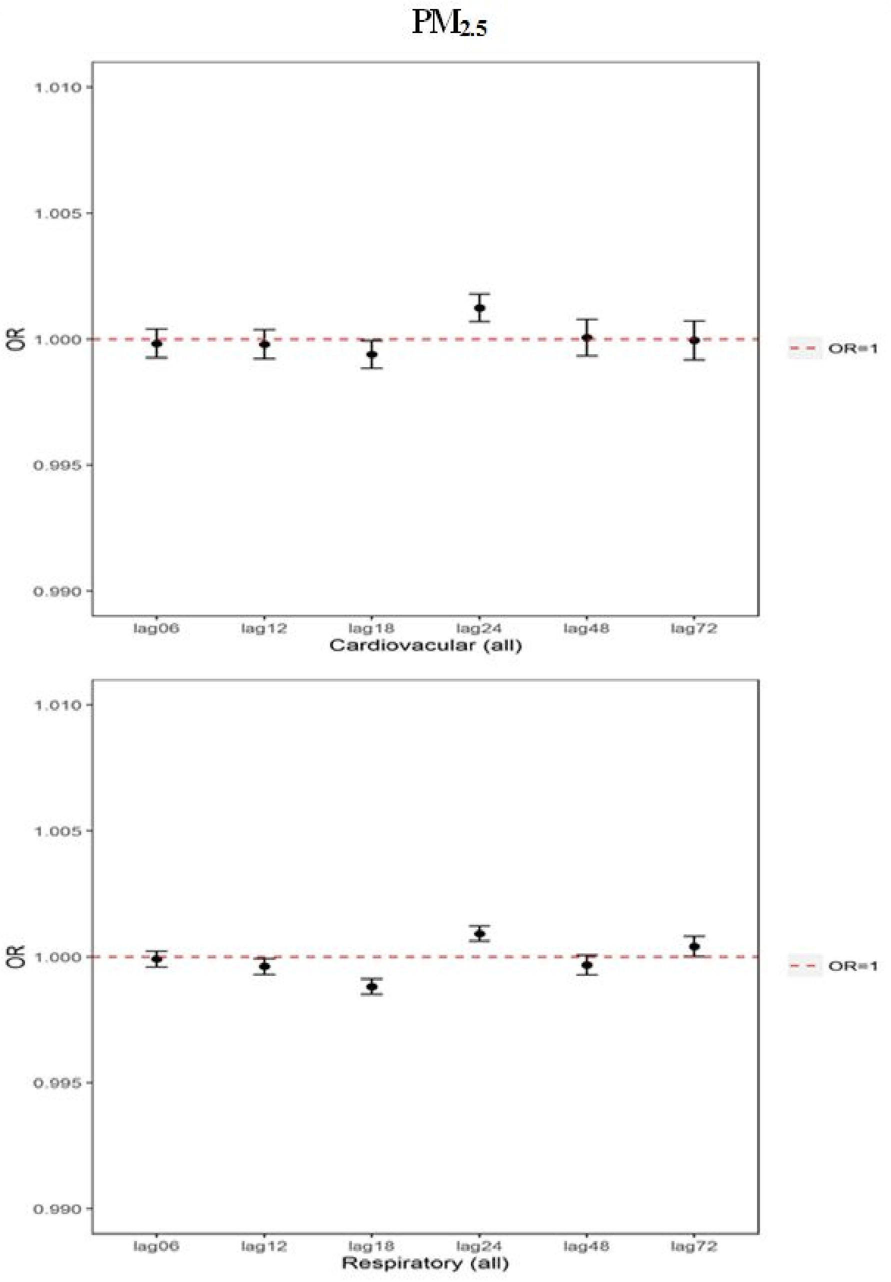

Figure 4. Estimated odds ratio (95% CI) between moving average levels of $PM_{2.5}$ mass and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

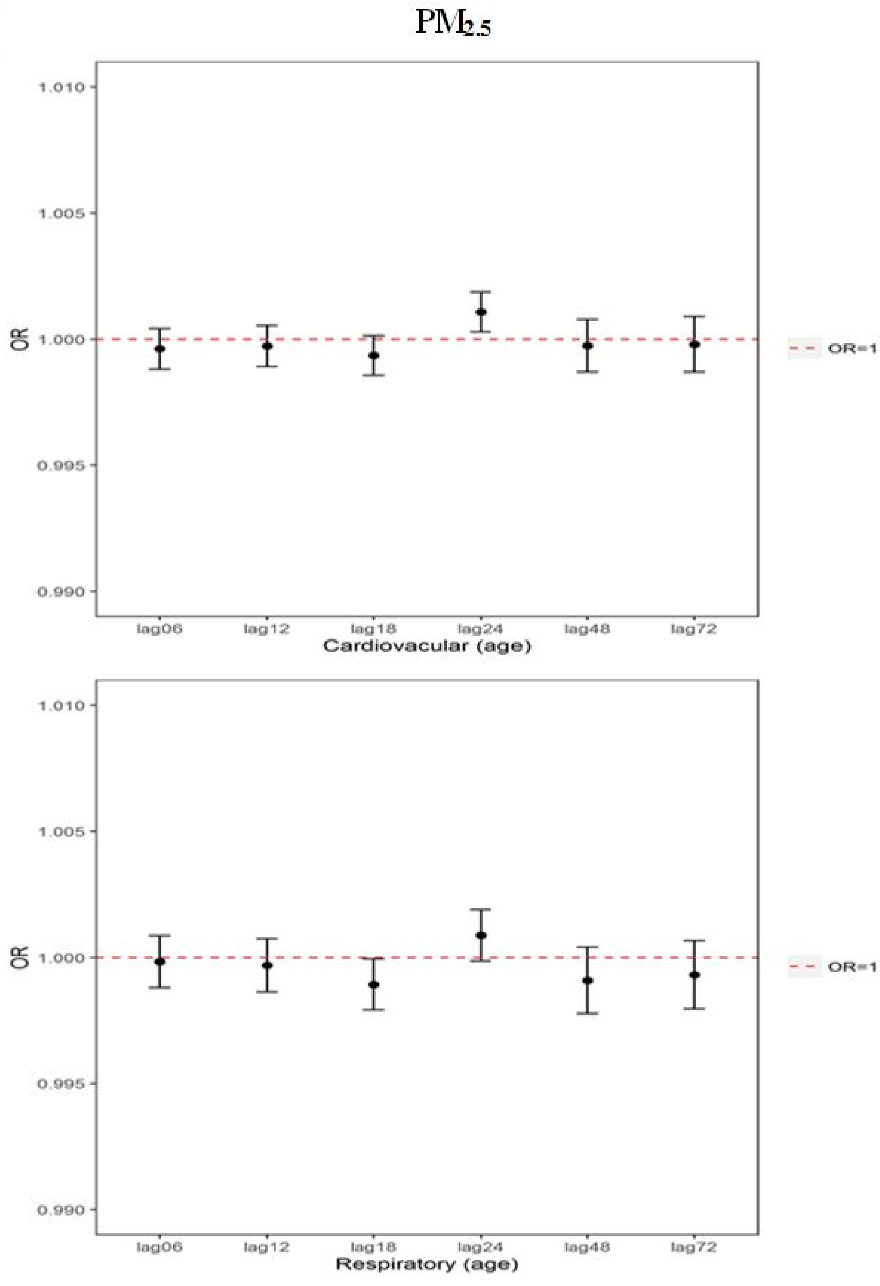

Figure 5. Estimated odds ratio (95% CI) between moving average levels of $PM_{2.5}$ mass and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

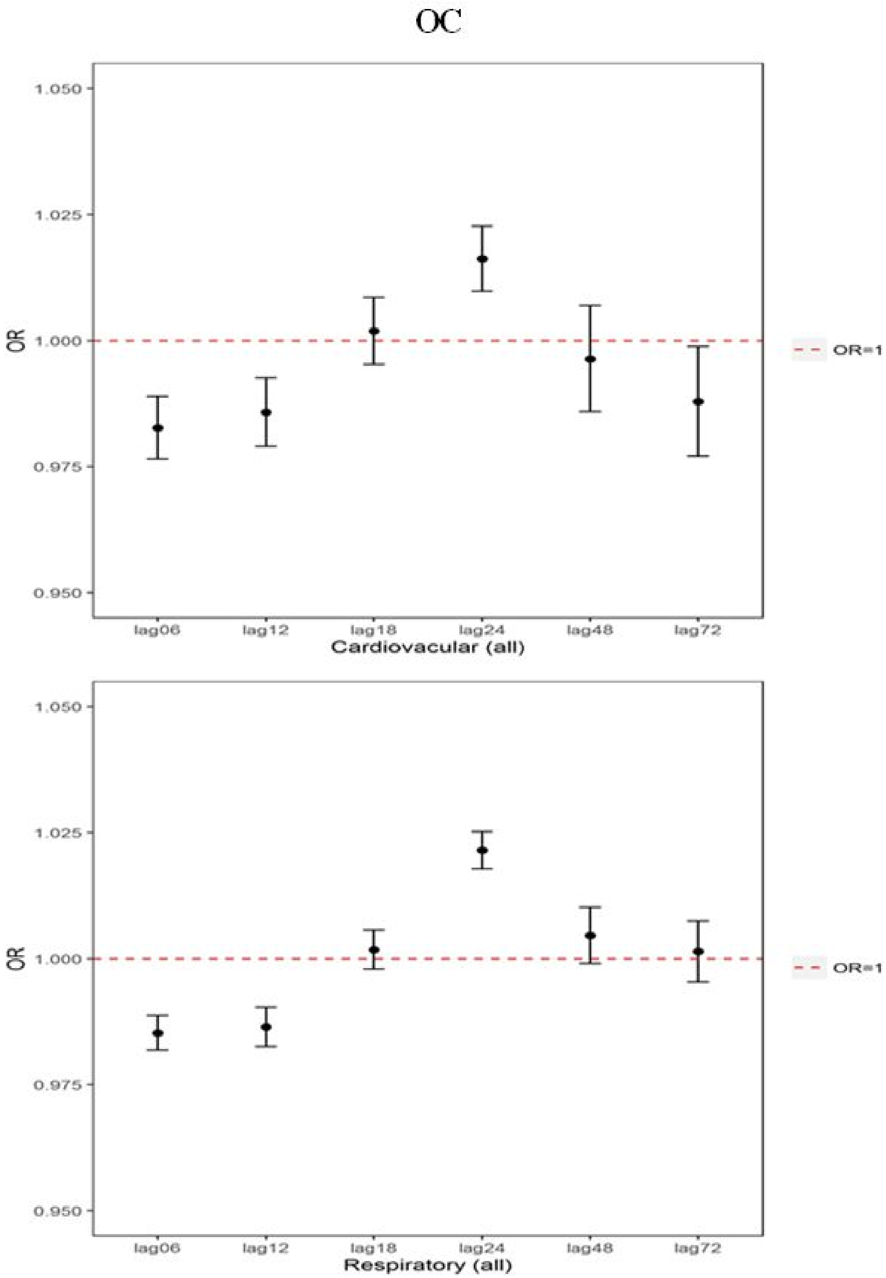

Figure 6. Estimated odds ratio (95% CI) between moving average levels of OC and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

OC

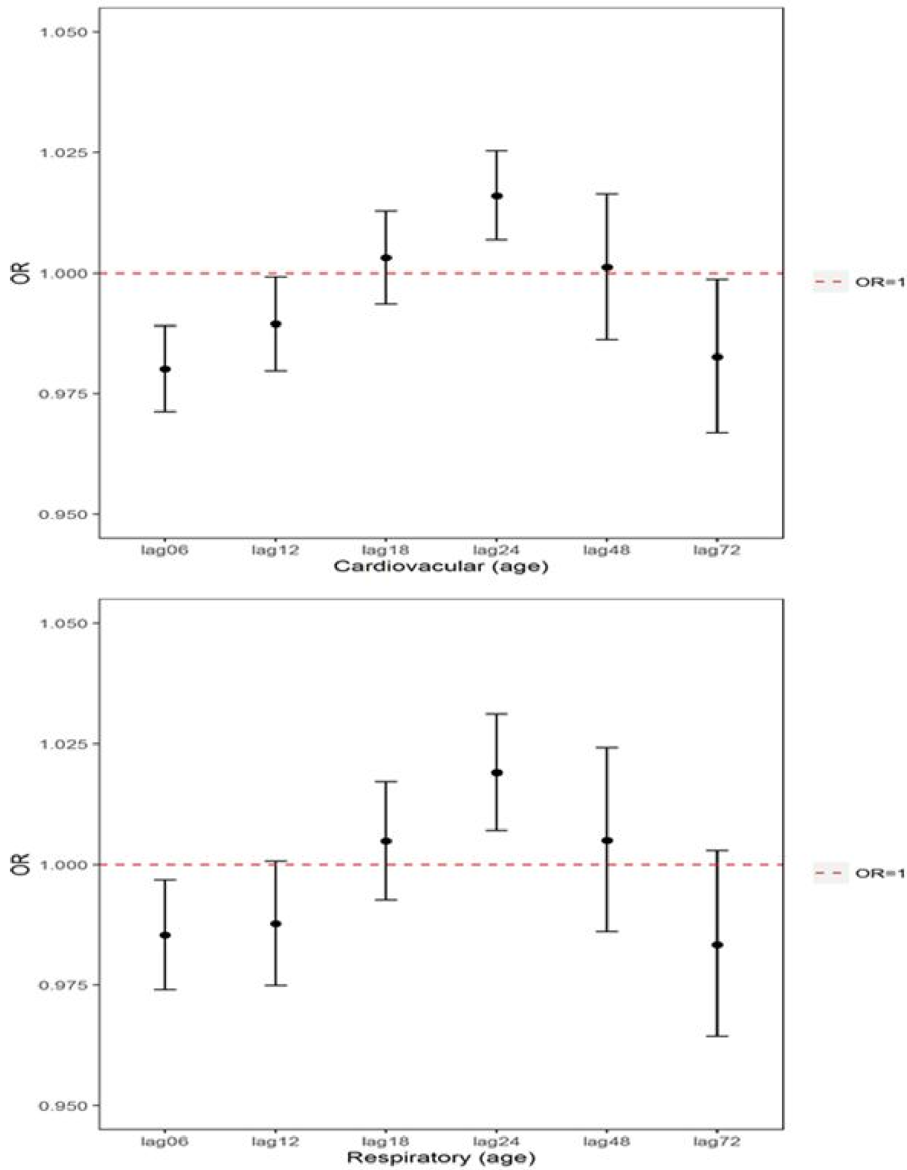

Figure 7. Estimated odds ratio (95% CI) between moving average levels of OC and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

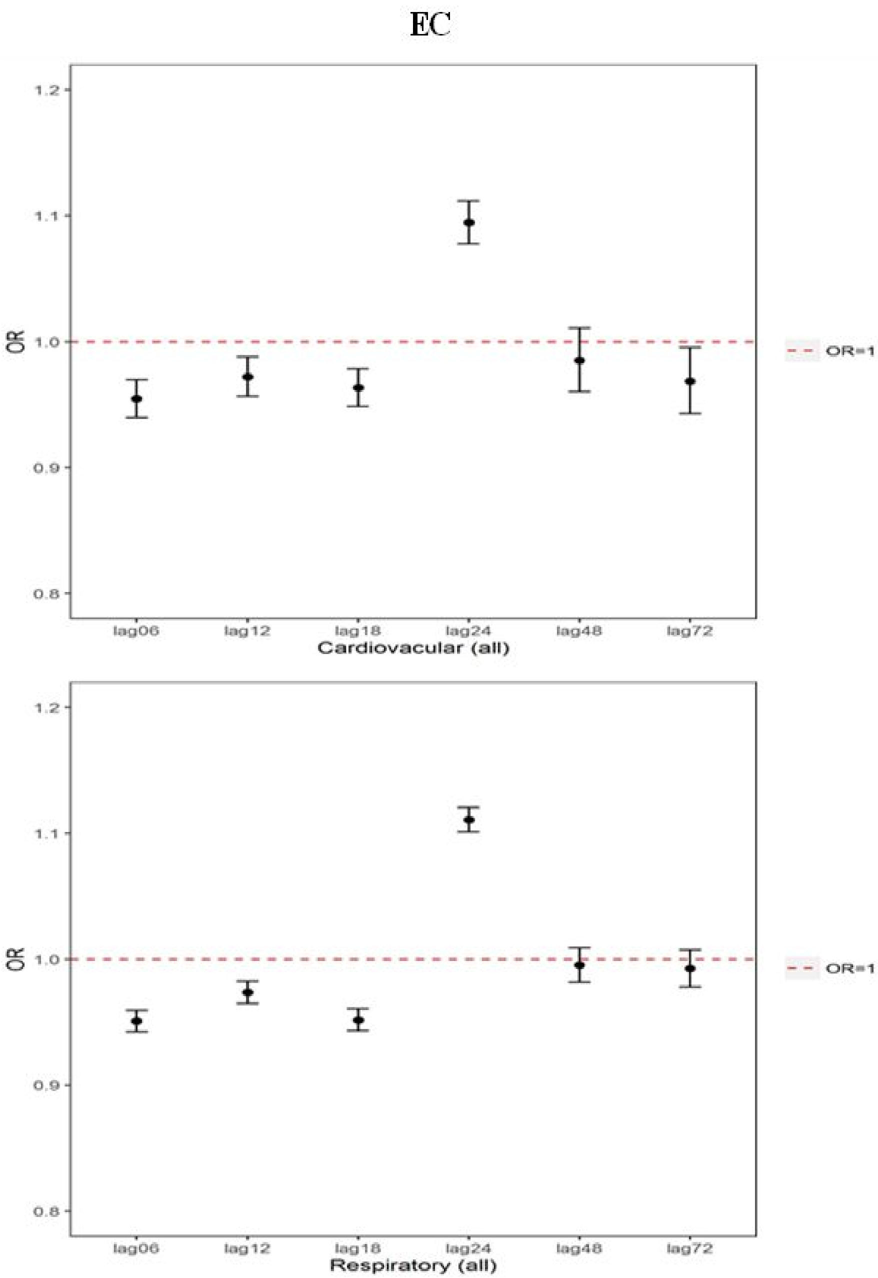

Figure 8. Estimated odds ratio (95% CI) between moving average levels of EC and the onset of cardiovascular and respiratory disease in Seoul, Korea (2013)

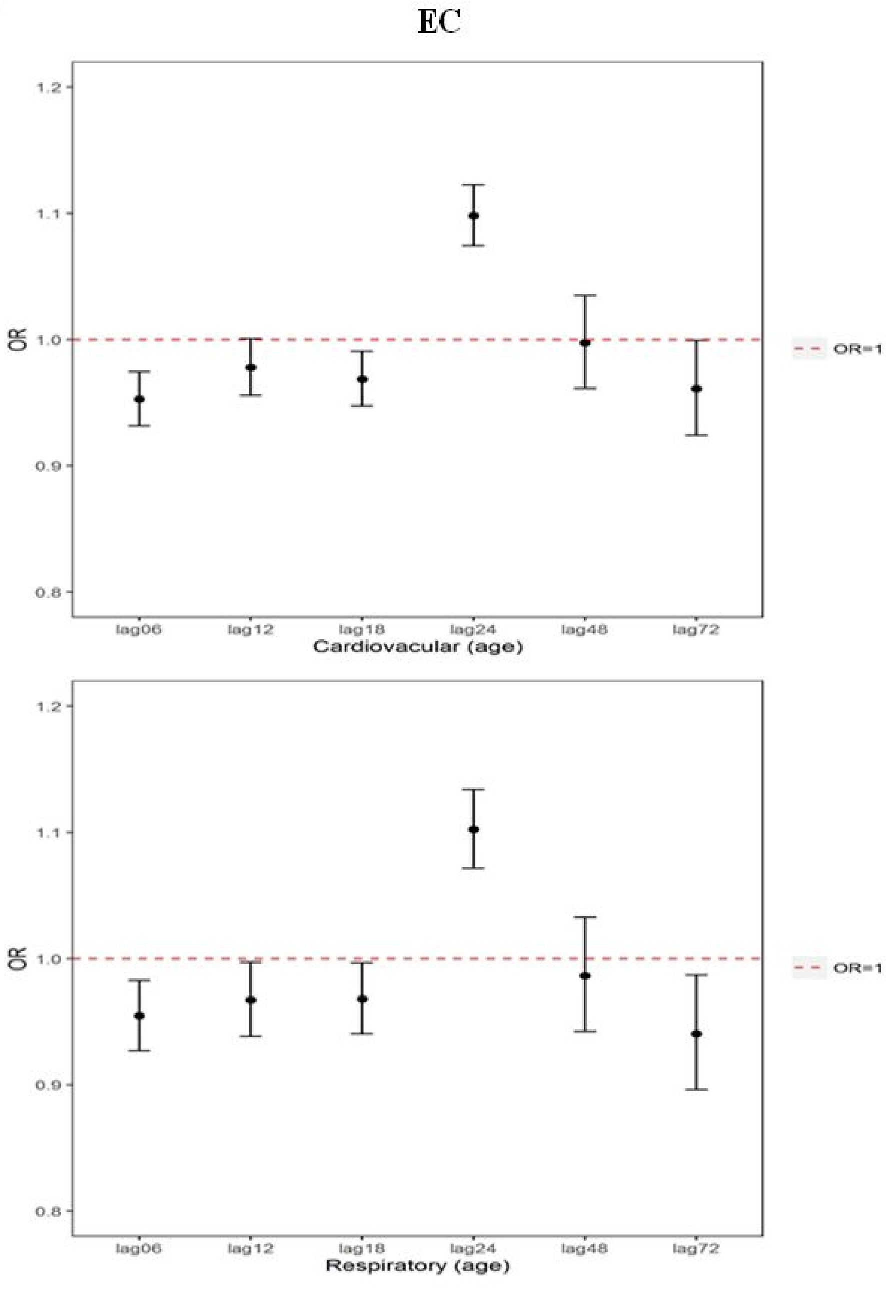

Figure 9. Estimated odds ratio (95% CI) between moving average levels of EC and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

3.5. Estimation by season

Seasonal effects on the onset of cardiovascular disease with emergency department visits for $PM_{2.5}$ mass, OC, EC, Cl^-, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, and Zn were showed in Table 10 (Appendix C). In summer, fall and winter, a 10 μg/m^3 increase in $PM_{2.5}$ mass was significantly associated with the largest effect size at the lag period of 19-24(h) [1.0023 (1.0010-1.0036)], [1.0029 (1.0014-1.0044)] and [1.0010 (1.0000-1.0020)], respectively. The effect of OC showed a positive association with the largest effect size at the lag period of 13-18(h) [1.0226 (1.0091-1.0363)] in spring, at the lag period of 19-24(h) [1.0395 (1.0194-1.0601)] in summer and [1.0177 (1.0066-1.0289)] in winter and at the lag period of 7-12(h) [1.0341 (1.0116-1.0572)] in fall. The effect of EC showed a positive association with the largest effect size at the lag period of 19-24(h) [1.1430 (1.1061-1.1810)] in spring, [1.2156 (1.1520-1.2826)] in summer, [1.1815 (1.1353-1.2295)] in fall and [1.0609 (1.0364-1.0860)] in winter.

A 1 μg/m^3 increase in Cl^- was significantly associated with the largest effect size at the lag period of 19-24(h) [1.0068 (1.0026-1.0109)] in spring and [1.0076 (1.0021-1.0130)] in winter, at the lag period of 7-12(h) [1.0130 (1.0031-1.0229)] in fall.

A 0.1 μg/m^3 increase in Na^+ was significantly associated with the largest effect size at the lag period of 19-24(h) [1.0021 (1.0004-1.0038)] in spring.

A 10 μg/m^3 increase in NH_4^+ showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0187 (1.0107-1.0268)] in summer and [1.0073 (1.0002-1.0144)] in winter. The effect of NO_3^- showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0034 (1.0002-1.0065)] in spring, [1.0109 (1.0062-1.0157)] in summer and [1.0044 (1.0009-1.0079)] in winter. The effect of SO_4^{2-} showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0084 (1.0044-1.0124)] in fall.

A 0.1 µg/m^3 increase in Ca showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0008 (1.0004-1.0013)] in spring, [1.0547 (1.0458-1.0637)] in summer, [1.0164 (1.0114-1.0215)] in fall and [1.0046 (1.0022-1.0070)] in winter. The effect of Fe showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0007 (1.0002-1.0012)] in spring, [1.0110 (1.0085-1.0135)] in summer, [1.0052 (1.0031-1.0072)] in fall and [1.0017 (1.0001-1.0033)] in winter. The effect of K showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0057 (1.0021-1.0094)] in summer and at the lag period of 7-12(h) [1.0024 (1.0008-1.0041)] in fall. The effect of Zn showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0069 (1.0036-1.0103)] in summer and [1.0074 (1.0029-1.0119)] in fall and at the lag period of 0-6(h) [1.0049 (1.0012-1.0086)] in winter.

A 0.01 µg/m^3 increase in Pb showed a positive association with the largest effect size at the lag period of 7-12(h) [1.0008 (1.0000-1.0016)] in spring, at the lag period of 49-72(h) [1.0035 (1.0016-1.0053)] in summer and at the lag period of 13-18(h) [1.0013 (1.0001-1.0025)] in fall.

Table 11 (Appendix C) shows seasonal effects on the onset of respiratory disease with emergency department visits for $PM_{2.5}$ mass, OC, EC, Cl^-, Na^+,

NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb and Zn.

A 10 µg/m^3 increase in $PM_{2.5}$ mass was significantly associated with the largest effect size at the lag period of 49-72(h) [1.0010 (1.0003-1.0017)] in spring, at the lag period of 19-24(h) [1.0026 (1.0019-1.0033)], [1.0034 (1.0025-1.0042)] and [1.0009 (1.0003-1.0014)] in summer, fall and winter, respectively. The effect of OC showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0206 (1.0143-1.0269)] in spring and [1.0223 (1.0155-1.0291) in winter and at the lag period of 7-12(h) [1.0410 (1.0278-1.0544)] in summer and [1.0410 (1.0278-1.0544)] in fall. The effect of EC showed a positive association with the largest effect size at the lag period of 19-24(h) [1.1566 (1.1360-1.1776)] in spring, [1.2422 (1.2074-1.2779)] in summer, [1.2707 (1.2398-1.3022)] in fall and [1.0743 (1.0596-1.0892)] in winter.

A 1 µg/m^3 increase in Cl^- showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0076 (1.0051-1.0101)] in spring and [1.0091 (1.0066-1.0117)] in winter, at the lag period of 7-12(h) [1.0142 (1.0079-1.0205)] in fall.

A 1 µg/m^3 increase in Mg^{2+} showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0048 (1.0024-1.0073)] in winter. The effect of Na^+ showed a positive association with the largest effect size at the lag period of 19-24(h) [1.0029 (1.0019-1.0039)] in spring and at the lag period of 13-18(h) [1.0013 (1.0004-1.0023)].

A 10 µg/m^3 increase in NH_4^+ showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0039 (1.0009-1.0069)] in spring and [1.0252 (1.0174-1.0331)] in winter, at the lag period 19-24(h) [1.0128

(1.0048-1.0208)] in fall and at the lag period 25-48(h) [1.0148 (1.0087-1.0210)] in winter. The effect of NO_3^- showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0039 (1.0009-1.0069)] in spring, at the lag period 19-24(h) [1.0127 (1.0101-1.0153)] in summer and [1.0077 (1.0039-1.0114)] in fall and at the lag period 0-6(h) [1.0076 (1.0054-1.0098)] in winter. The effect of SO_4^{2-} showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0085 (1.0045-1.0126)] in spring, at the lag period of 13-18(h) [1.0062 (1.0032-1.0091)] in summer and at the lag period of 19-24(h) [1.0091 (1.0069-1.0113)] in fall and [1.0066 (1.0017-1.0115)] in winter. A 0.1 $\mu g/m^3$ increase in Ca showed a positive association with the largest effect size at the lag period of 25-48(h) [1.0011 (1.0007-1.0015)] in spring and at the lag period of 19-24(h) [1.0644 (1.0594-1.0694)] in summer, [1.0215 (1.0183-1.0246)] in fall and [1.0069 (1.0052-1.0086)] in winter. The effect of Fe showed a positive association with the largest effect size at the lag period of 25-48(h) [1.0011 (1.0006-1.0016)] in spring and at the lag period of 19-24(h) [1.0128 (1.0114-1.0142)] in summer, [1.0089 (1.0077-1.0102)] in fall and [1.0023 (1.0013-1.0032)] in winter. The effect of K showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0024 (1.0015-1.0032)] in spring and [1.0064 (1.0046-1.0083)] in summer, at the lag period of 19-24(h) [1.0039 (1.0029-1.0049)] in fall and at the lag period of 1-6(h) [1.0005 (1.0001-1.0009)] in winter. The effect of Zn showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0055 (1.0022-1.0088)] in spring and [1.0080 (1.0043-1.0118)] in summer, at the lag period of 13-18(h) [1.0024 (1.0017-1.0031)] in fall and at the lag period of 0-6(h) [1.0008 (1.0004-1.0012)] in winter.

A 0.01 $\mu g/m^3$ increase in Pb showed a positive association with the largest effect size at the lag period of 49-72(h) [1.0010 (1.0003-1.0017)] in spring and [1.0045 (1.0036-1.0054)] in summer, at the lag period of 19-24(h) [1.0130 (1.0102-1.0159)] in fall and at the lag period of 0-6(h) [1.0084 (1.0062-1.0106)] in winter.

4. Discussion

In this study, significant associations between the onset of cardiovascular disease and respiratory disease exacerbations and hourly levels of exposure to $PM_{2.5}$ mass and chemical constituents (OC, EC, Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb and Zn) in Seoul, Korea (2013) was estimated by time-stratified case-crossover design. The short-term effects were estimated in terms of moving averages in the 6 periods (1-6(h), 7-12(h), 13-18(h), 19-24(h), 25-48(h), 49-72(h)) and adjustments of this association by age ($\geq$ 65 years) and season.

Most epidemiological studies of $PM_{2.5}$ chemical constituents have been conducted in the U.S. and Europe. Relatively few studies have been conducted in Korea, where characteristics of study contexts are different such as $PM_{2.5}$ chemical constituents, age structure and toxicity (Yang et al., 2012). Moreover, few time-stratified case-crossover studies have been able to examine the extended lag structure of short-term exposure to $PM_{2.5}$ chemical constituents using hourly concentration measurement in Korea (Kim et al., 2012). The time-stratified case-crossover design ensures unbias conditional logistic regression estimates, avoids bias resulting from time trend in the exposure series, and can be tailored to match on specific time-varying confounder (Janes et al., 2005).

$PM_{2.5}$ mass had strong correlations with NH_4^+ (0.94), NO_3^- (0.86), OC (0.83), SO_4^{2-} (0.82), and EC (0.81), respectively. NH_4^+ was most strongly correlated with NO_3^- (0.89) and SO_4^{2-} (0.88). A previous study showed similar result which $PM_{2.5}$ total mass had a strongest correlations with NH_4^+, OC, NO_3^- and SO_4^{2-}, especially more strong with NH_4^+, SO_4^{2-} and NO_3^- (Michelle L. Bell et al. 2007).

Time-stratified case-crossover study was conducted to identify chemical constituents of $PM_{2.5}$ that were strongly associated with risk hospitalization and found evidence of differing health risks across the chemical constituents. Among the chemical constituents, the strongest adverse effects for cardiovascular disease exacerbations of $PM_{2.5}$ mass, OC, EC, Cl^-, Ca, Fe and Zn after 19-24h lag period and of NH_4^+, NO_3^- and SO_4^{2-} after 25-48h lag period were observed. The estimated short-term effects of OC and EC were larger than were other chemical constituents. Several studies have been investigated the associations among air pollutants and onset of cardiovascular disease. Peng et al. (2009) found that risk of daily emergency admissions for cardiovascular disease increased by 0.46% (95% posterior interval (PI), 0.17-0.75%) for a 1.64 $\mu g/m^3$ increase in nitrate, 0.72% (95% PI, 0.43-1.01%) for a 0.40 $\mu g/m^3$ increase in EC, 0.66% (95% PI, 0.29-1.02%) for a 3.18 $\mu g/m^3$ increase in organic carbon matter (OCM) and 0.68% (95% PI, 0.31-1.06%) for a 1.35 $\mu g/m^3$ increase in ammonium at a same-day in a study of 119 urban communities U.S.

The strongest adverse effects for respiratory disease exacerbations of NO_3^-, K and Pb after short lag periods (0-6h and 7-12h) and of $PM_{2.5}$, OC, EC, Cl^-, NH_4^+, SO_4^{2-}, Ca, Fe and Zn after longer lag periods (19-24h and

25-48h) were estimated. In previous study, Sarnat et al. (2015) found that 24-hour average concentration of $PM_{2.5}$ mass, SO_4^{2-} and Ca were significantly associated with asthma and wheeze disease exacerbations in the St. Louis, Missouri-Illinois, the U.S. The risk of daily emergency admissions for respiratory disease increased by 1.01% (95% PI, 0.04-1.98%) for a 3.18 $\mu g/m^3$ increase in OCM at a same-day in Peng et al. (2009).

For cardiovascular and respiratory disease among those ≥ 65 years of age, the strongest adverse effects for cardiovascular disease exacerbations of $PM_{2.5}$ mass, OC, EC, Cl^-, Ca, Fe and Zn after 19-24h lag period and of NO_3^- after 25-48h lag period and for respiratory disease exacerbations of OC, EC, Fe and Zn after 19-24h lag period were observed in this study. Prior study (Franklin et al., 2007) found that the percent increase in cardiovascular and respiratory related mortality in 27 U.S communities between 1997 and 2002 with a 10- $\mu g/m^3$ increase in lag 1-day $PM_{2.5}$ mass was significant for the elderly (aged ≥ 75 years).

Among $PM_{2.5}$ chemical constituents, EC showed the strongest association with cardiovascular disease and respiratory disease exacerbations. EC was significantly associated at the lag period 19-24(h) [1.0946 (1.0779-1.1116)] for cardiovascular disease and [1.1107 (1.1010-1.1205)] for respiratory disease in all-age population. Also, EC was significantly associated at the lag period 19-24(h) [1.0981 (1.0743-1.1225)] for cardiovascular disease and [1.1024 (1.0716-1.1340)] for respiratory disease in the elderly population (≥ 65 years of age).

Many epidemiological studies reported that EC in $PM_{2.5,}$ which was emitted by oil combustion, traffic emissions and biomass burning (Bell, Ebisu, Peng et al., 2009), showed statistically significant association with health outcomes than other constituents (Kim et al., 2012; Peng et al., 2009; Ostro et al., 2009; Merzer et al., 2004; Lall et al. 2011). For example, associations of emergency department visits for cariovascular disease and EC showed in Sarnet et al. (2015). The study found 24-hr average EC was statistically significant with cardiovascular outcomes [relative risk = 1.016 (95% CI: 1.002-1.030) per IQR (0.42 $\mu g/m^{3)}$ increase] in the St. Louis, U.S. Heo et al. (2014) found tha an IQR (2.05 $\mu g/m^3$) increase in EC at a 2-day lag was associated with a 9.5% (95 CI: 0.8-19.0) increase in respiratory disease mortality in Seoul, Korea. Ostro et al. (2007) reported that exposures to EC is associated with indicators that could contribute to risk of daily cardiovascular disease mortality in a study of six California counties.

Sarnat et al. 2015 found negative association between Zn and respiratory disease, but in this study, Zn showed significant positive association with onset of respiratory disease. Ostro et al. (2007) and Heo et al. (2014) reported that respiratory mortality was significantly associated with Zn.

In the all season, significant positive associations for $PM_{2.5}$ mass and chemical constituents excluding Mg^{2+} for onset of cardiovascular and respiratory disease were examined. In the spring season, $PM_{2.5}$ mass, NH_4^+, NO_3^-, SO_4^{2-} and metal constituents such as Fe, K, Pb and Zn for respiratory showed significant positive associations at 49-72(h) lag period. Zhou et al.

(2011) found significant positive associations for $PM_{2.5}$ for cardiovascular mortality in the warm season and EC showed significant positive associations at sing-day lags in Detroit, the U.S. Also, $PM_{2.5}$, EC, K and Zn were significantly positively associated with cardiovascular mortality in the cold season and Fe for respiratory mortality at the lag 1-day showed positively significant associations in the cold season in Seattle, the U.S.

This Study has several limitations. Firstly, data of $PM_{2.5}$ mass and chemical constituents were used in this study had some missing data and some chemical constituents could not use for this study because they had not conducted QA/QC procedure. Missing data may have led to make a bias in this study. In addition, this study was conducted by only 1 years data. If study period was longer than one year, the result may be more clearly examined.

Secondly, air pollution data of $PM_{2.5}$ mass concentration and chemical constituents was from a single monitoring site in Seoul. This limitation may have led to misclassification of some cases because of variability at individual residence (J. Kim et al., 2015).

Thirdly, emergency department visits data from NEDIS had no information of exact times of cardiovascular disease and respiratory onset, and hence this study was used the time of emergency call as the disease onset for each case. If a person who onset of cardiovascular disease at midnight can visit emergency department in morning because it is tough to visit emergency department at midnight, this may have also led to make a bias in this study.

Lastly, association between $PM_{2.5}$ and health outcome were estimated in a single city in this study. To understand the effect of $PM_{2.5}$ on the onset of cardiovascular disease and respiratory disease in further detail, multi-city studies are required (J. Kim et al., 2015).

5. Conclusions

In summary, this study examined the associations between hourly $PM_{2.5}$ chemical constituents and emergency visits for cardiovascular and respiratory disease. Short-term effect of $PM_{2.5}$ chemical constituents varied by season and age group. The lag effect periods were used and estimated in this study. For example, according to the OR values and the 95% confidence intervals, 19-24(h) and 25-48(h) after exposure were the adverse effect period for $PM_{2.5}$ mass, OC, EC, Cl^-, NH_4^+, SO_4^{2-}, Ca, Fe, and Zn. In the elderly group (≥ 65 years), 19-24(h) and just after exposure were the adverse effect period for OC, EC, Fe and Zn. Major differences in seasonal pattern of association between $PM_{2.5}$ constituents and emergency visits for cardiovascular and respiratory disease in Seoul were also found. Associations between health outcomes and $PM_{2.5}$ in epidemiological studies may be result of multiple constituents acting on different physiological mechanism. Therefore, this study will provide robust evidences for the health impacts of $PM_{2.5}$ chemical constituents.

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Appendix A. The time-series plots of hourly concentration of $PM_{2.5}$ mass and each chemical constituents in Seoul, Korea (2013)

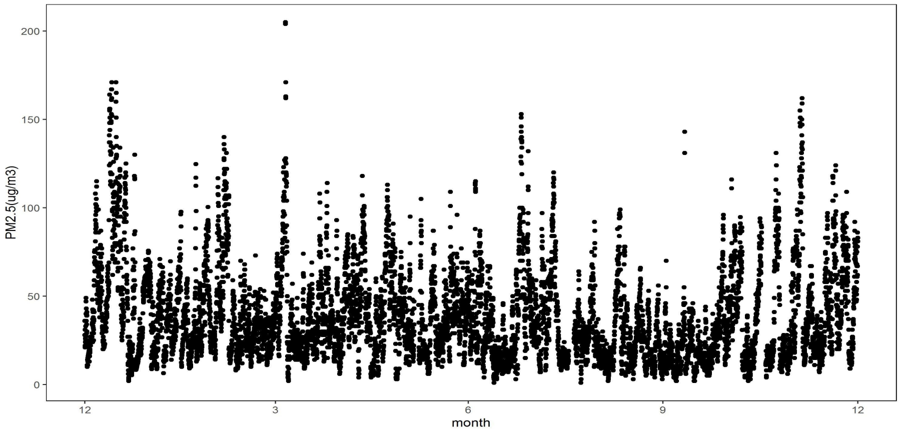


Figure 10. Time-series plot of hourly concentration of $PM_{2.5}$ mass in Seoul, Korea (2013)

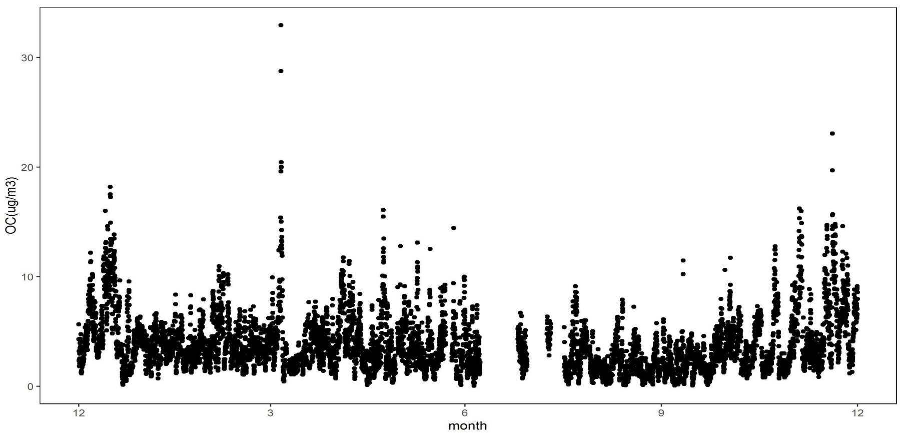


Figure 11. Time-series plot of hourly concentration of OC in Seoul, Korea (2013)

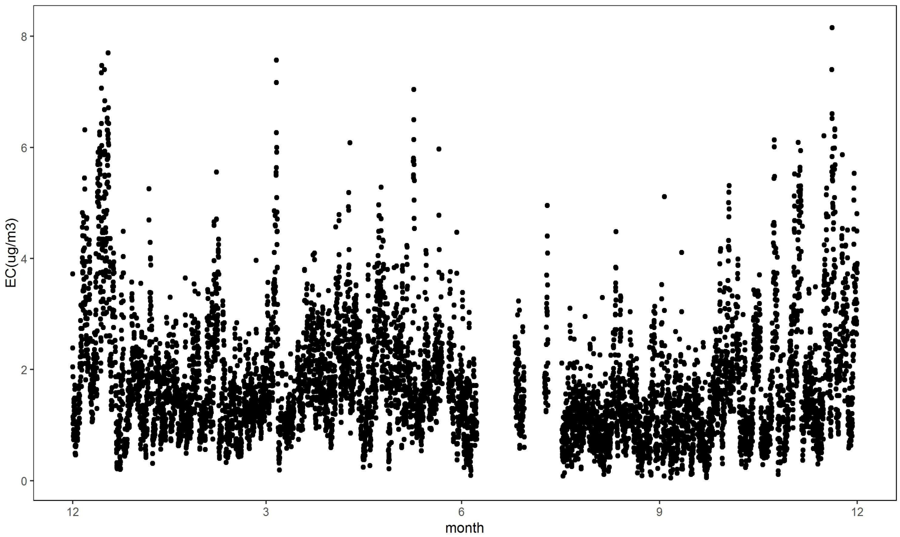


Figure 12. Time-series plot of hourly concentration of EC in Seoul, Korea (2013)

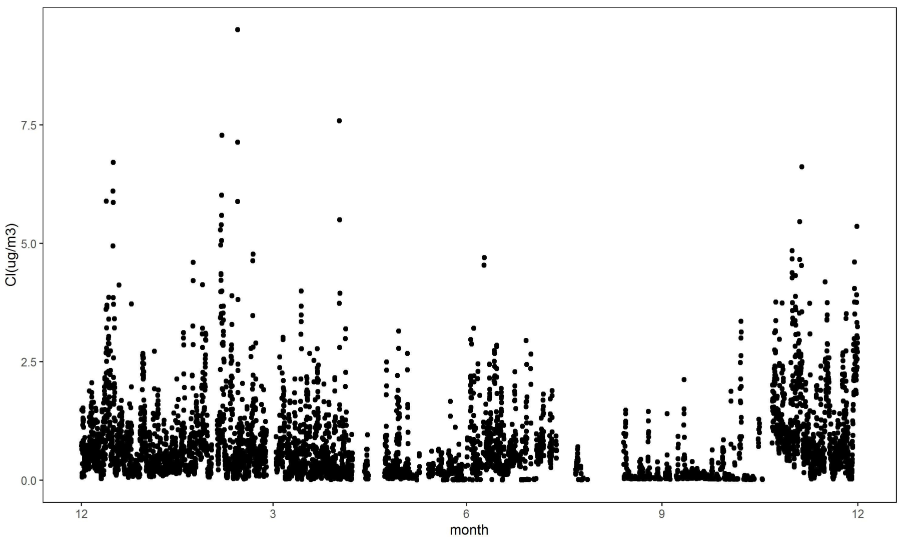


Figure 13. Time-series plot of hourly concentration of Cl^- in Seoul, Korea (2013)

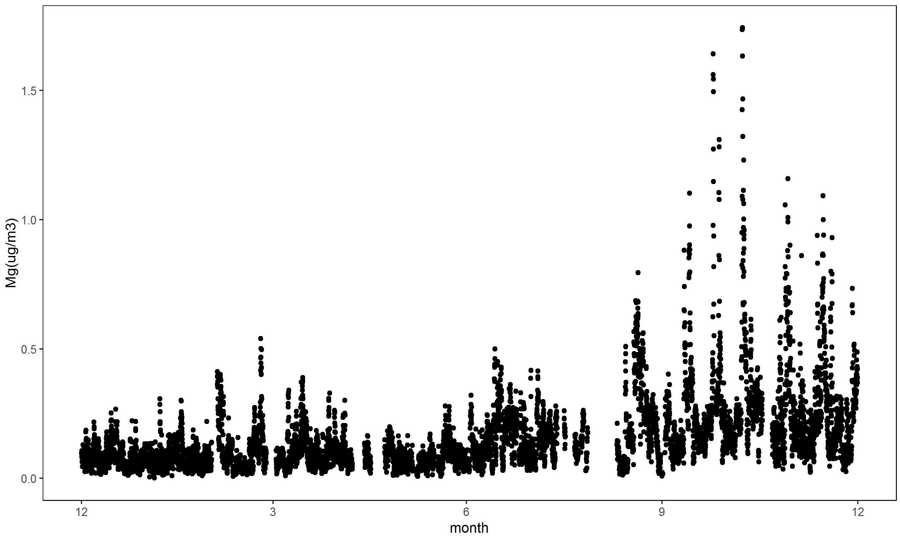


Figure 14. Time-series plot of hourly concentration of Mg^{2+} in Seoul, Korea (2013)

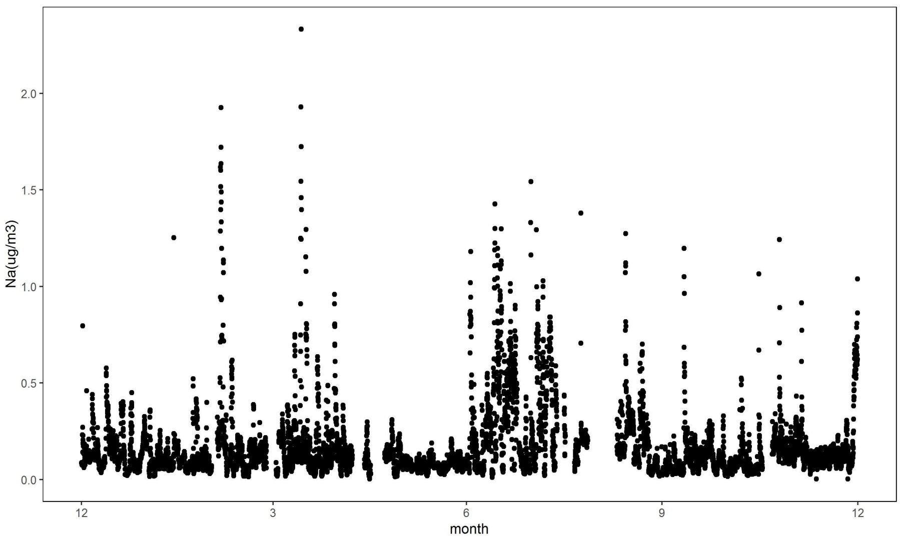


Figure 15. Time-series plot of hourly concentration of Na^{+} in Seoul, Korea (2013)

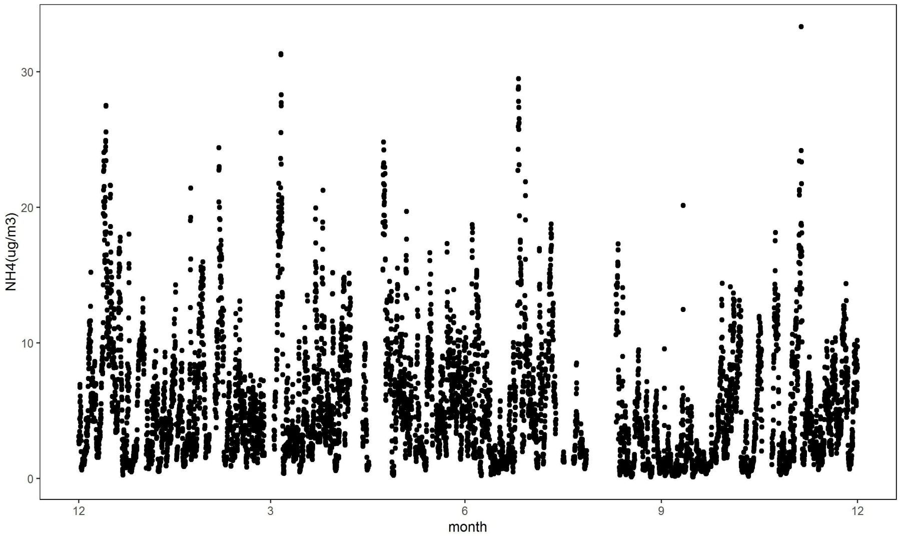


Figure 16. Time-series plot of hourly concentration of NH_4^+ in Seoul, Korea (2013)

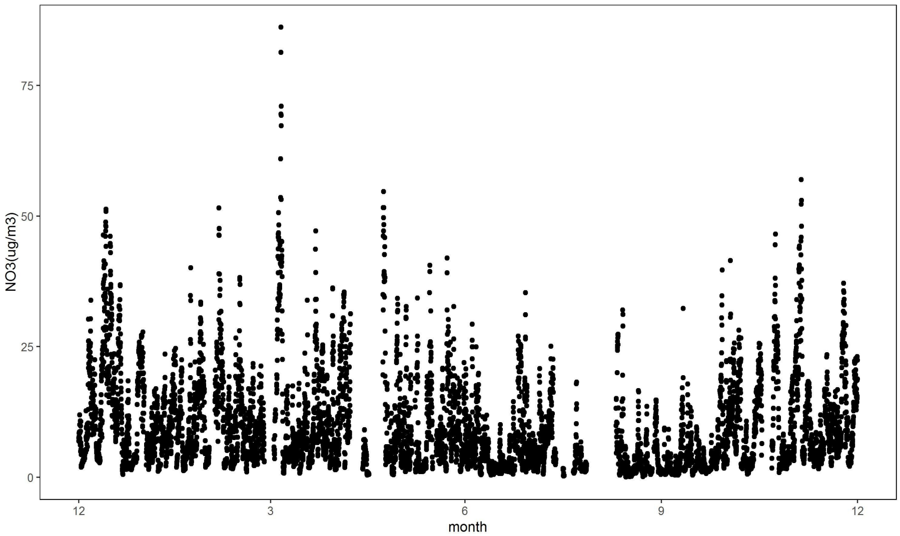


Figure 17. Time-series plot of hourly concentration of NO_3^- in Seoul, Korea (2013)

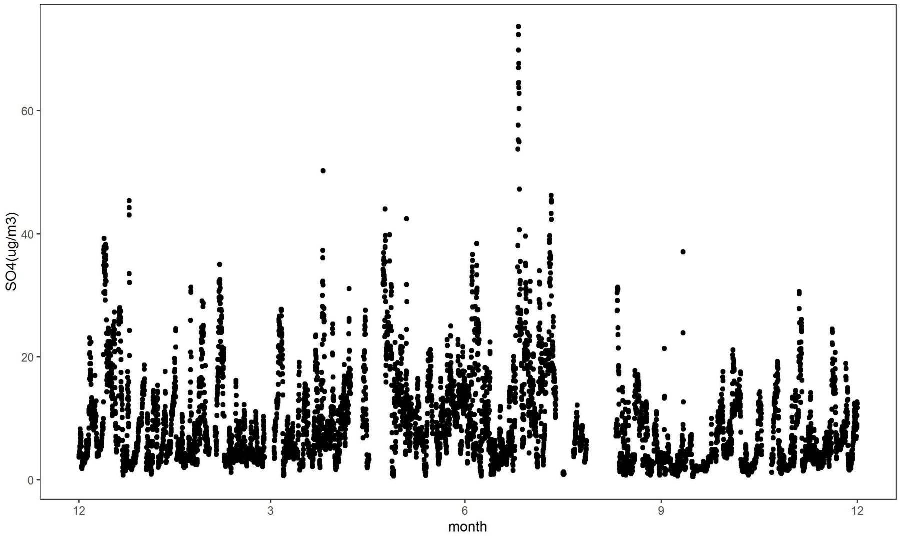


Figure 18. Time-series plot of hourly concentration of SO_4^{2-} in Seoul, Korea (2013)

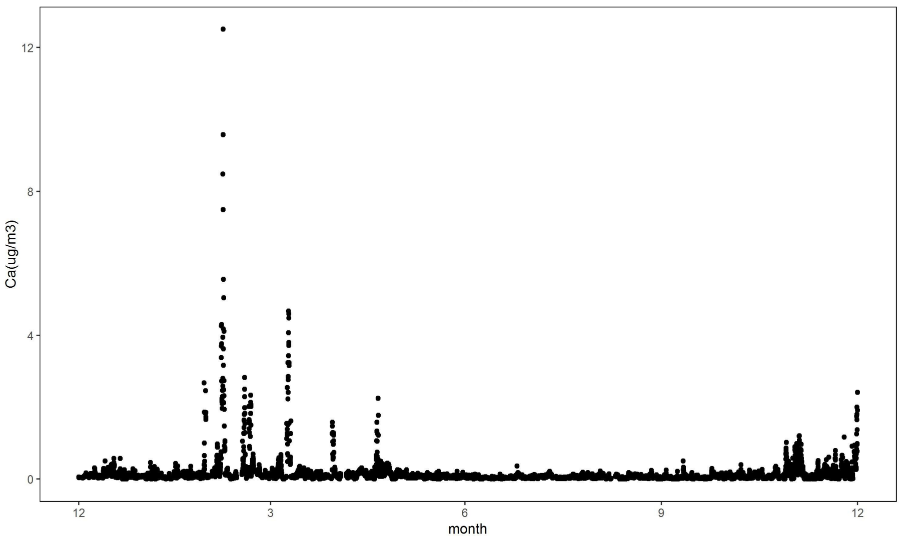


Figure 19. Time-series plot of hourly concentration of Ca in Seoul, Korea (2013)

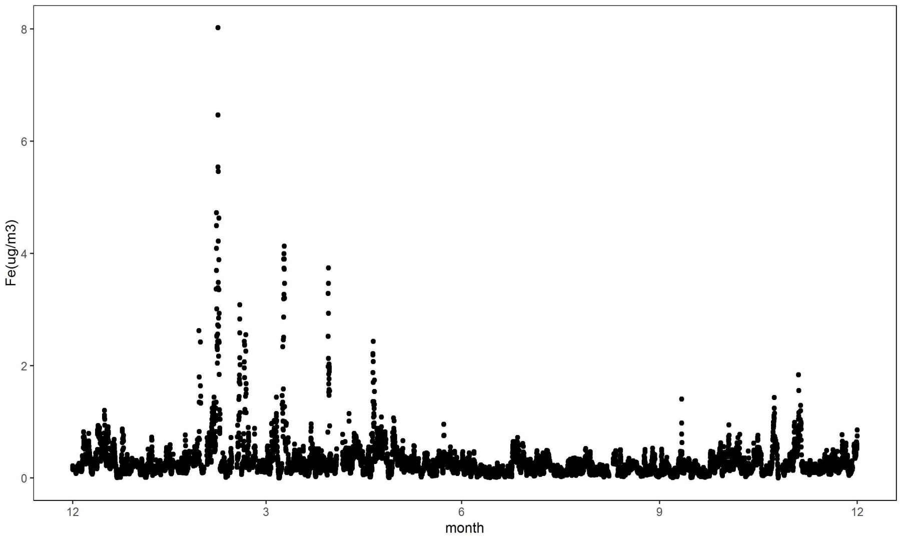


Figure 20. Time-series plot of hourly concentration of Fe in Seoul, Korea (2013)

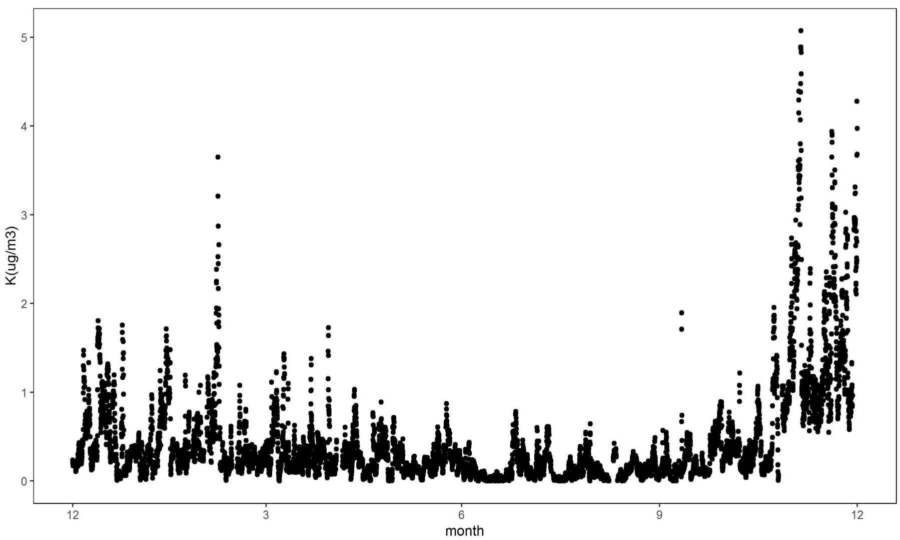


Figure 21. Time-series plot of hourly concentration of K in Seoul, Korea (2013)

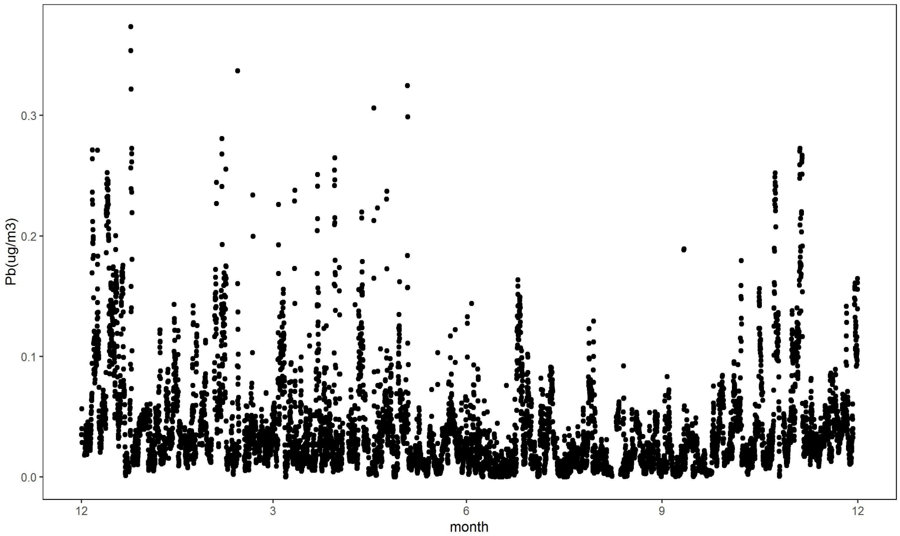


Figure 22. Time-series plot of hourly concentration of Pb in Seoul, Korea (2013)

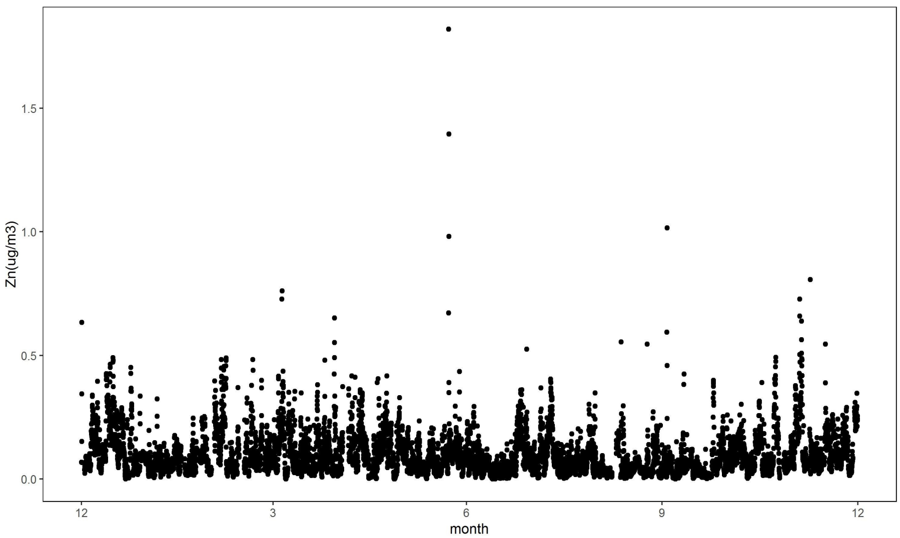


Figure 23. Time-series plot of hourly concentration of Zn in Seoul, Korea (2013)

Appendix B. The lag effect size of $PM_{2.5}$ chemical constituents (Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, and Zn)

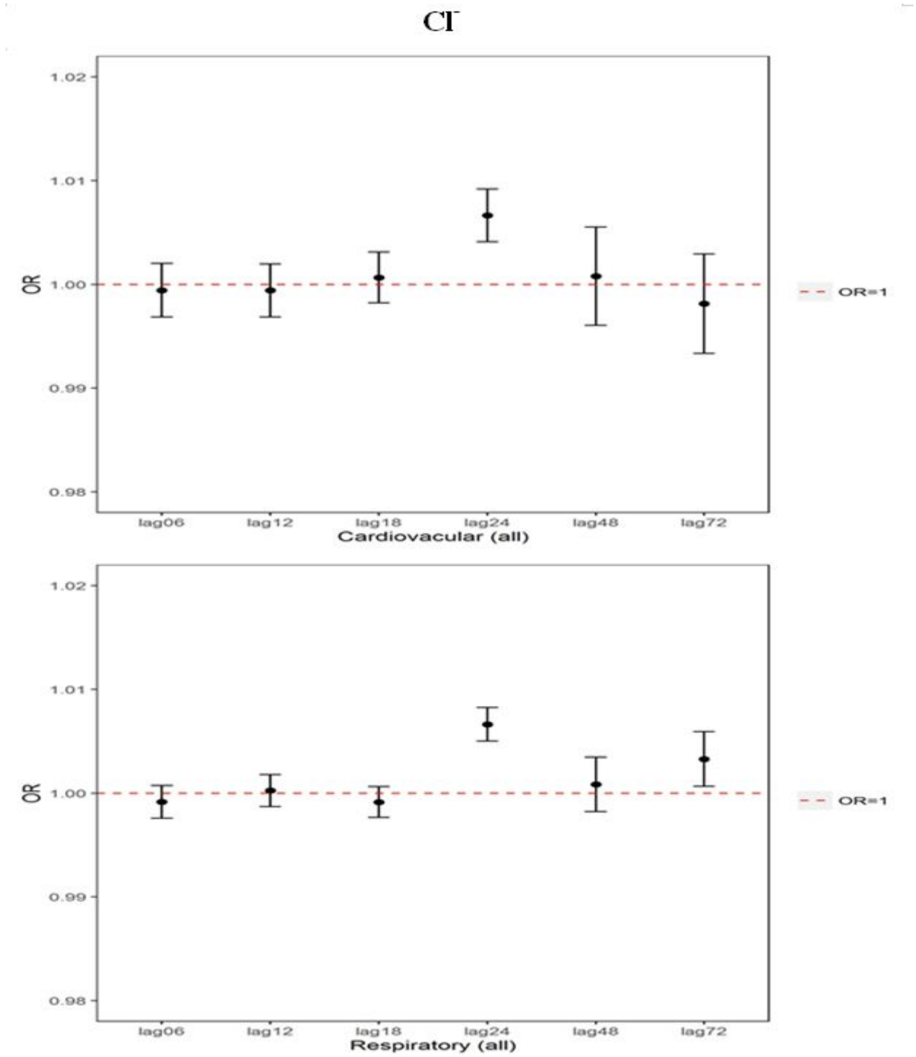


Figure 24. Estimated odds ratio (95% CI) between moving average levels of Cl^- and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

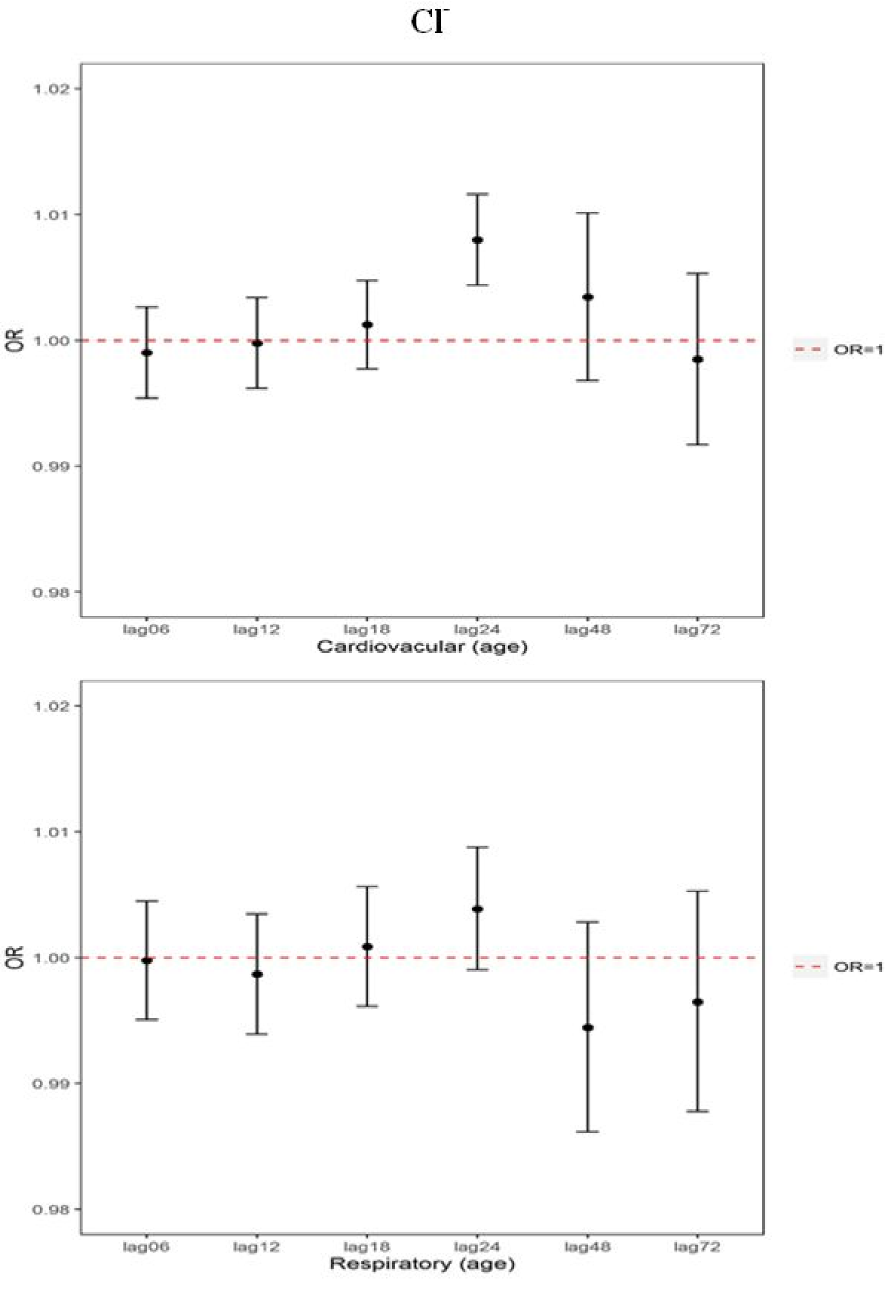
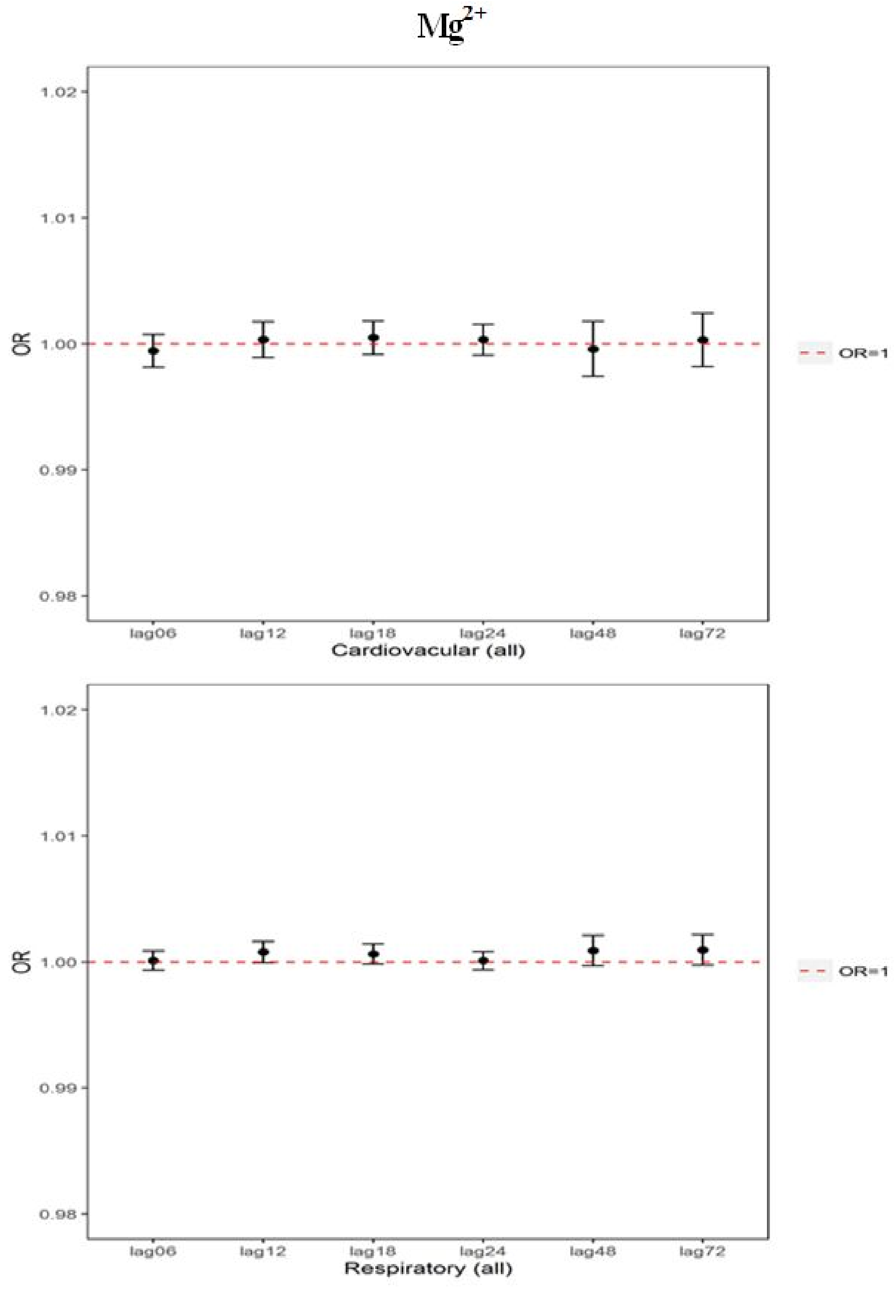
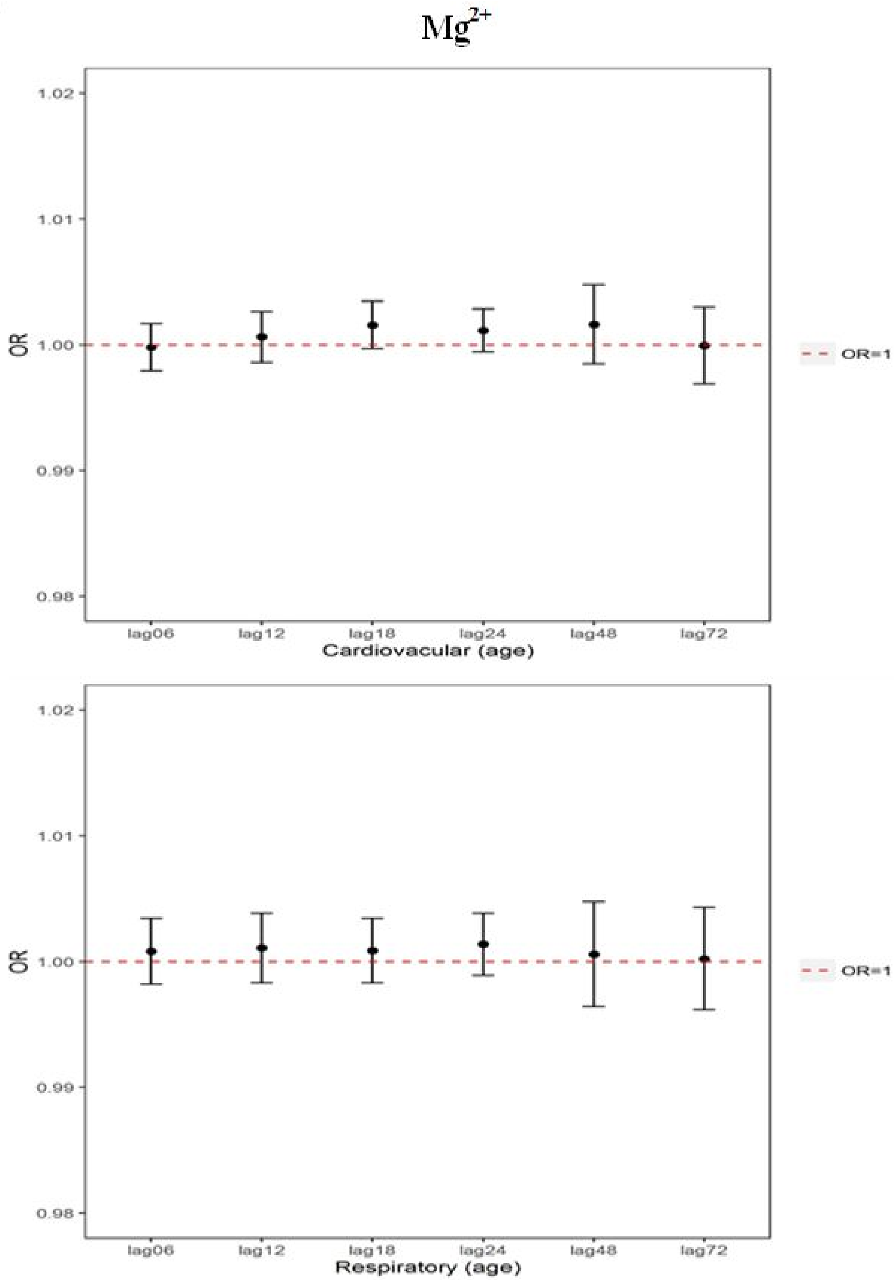


Figure 25. Estimated odds ratio (95% CI) between moving average levels of Cl^- and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)



Fifure 26. Estimated odds ratio (95% CI) between moving average levels of Mg^{2+} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)



Fifure 27. Estimated odds ratio (95% CI) between moving average levels of Mg^{2+} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

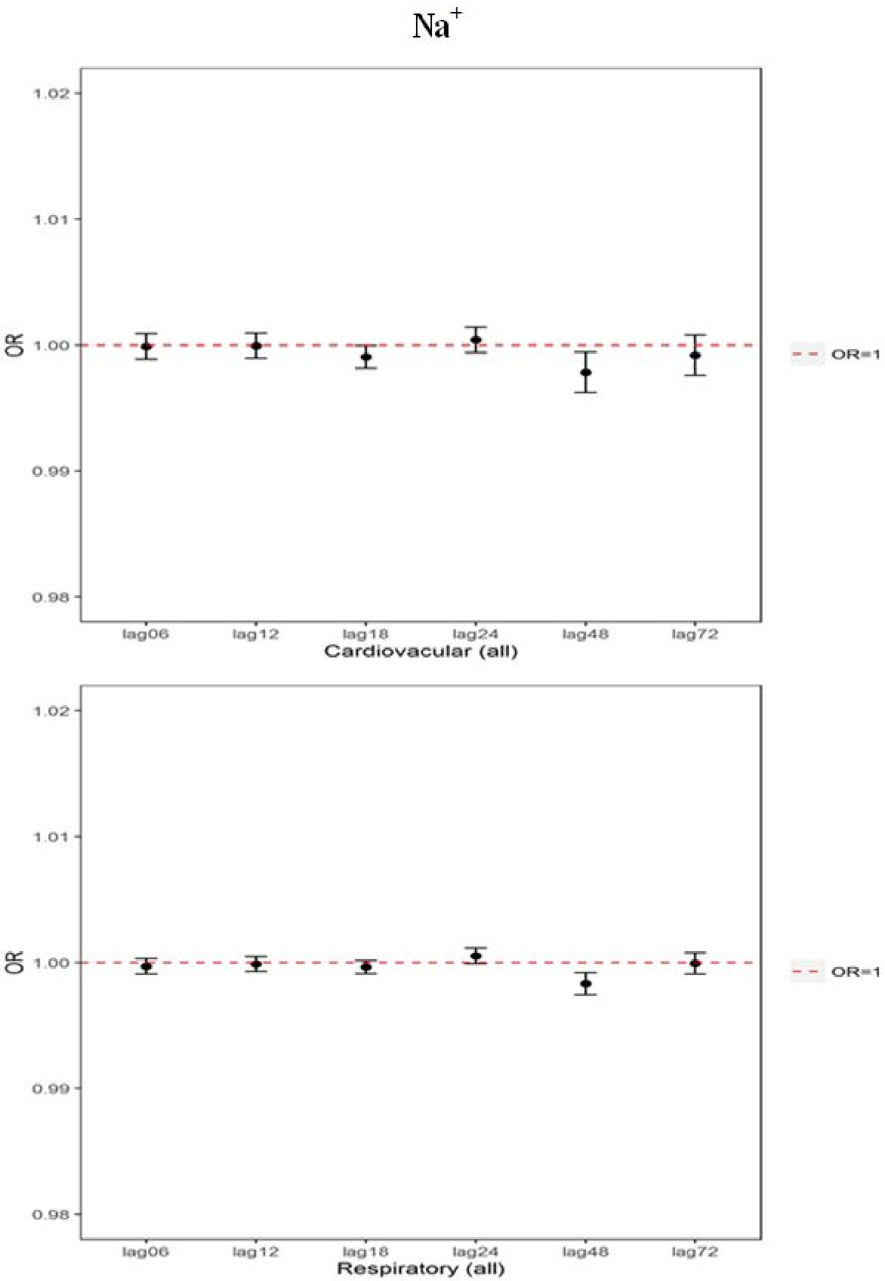


Figure 28. Estimated odds ratio (95% CI) between moving average levels of Na^{+} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

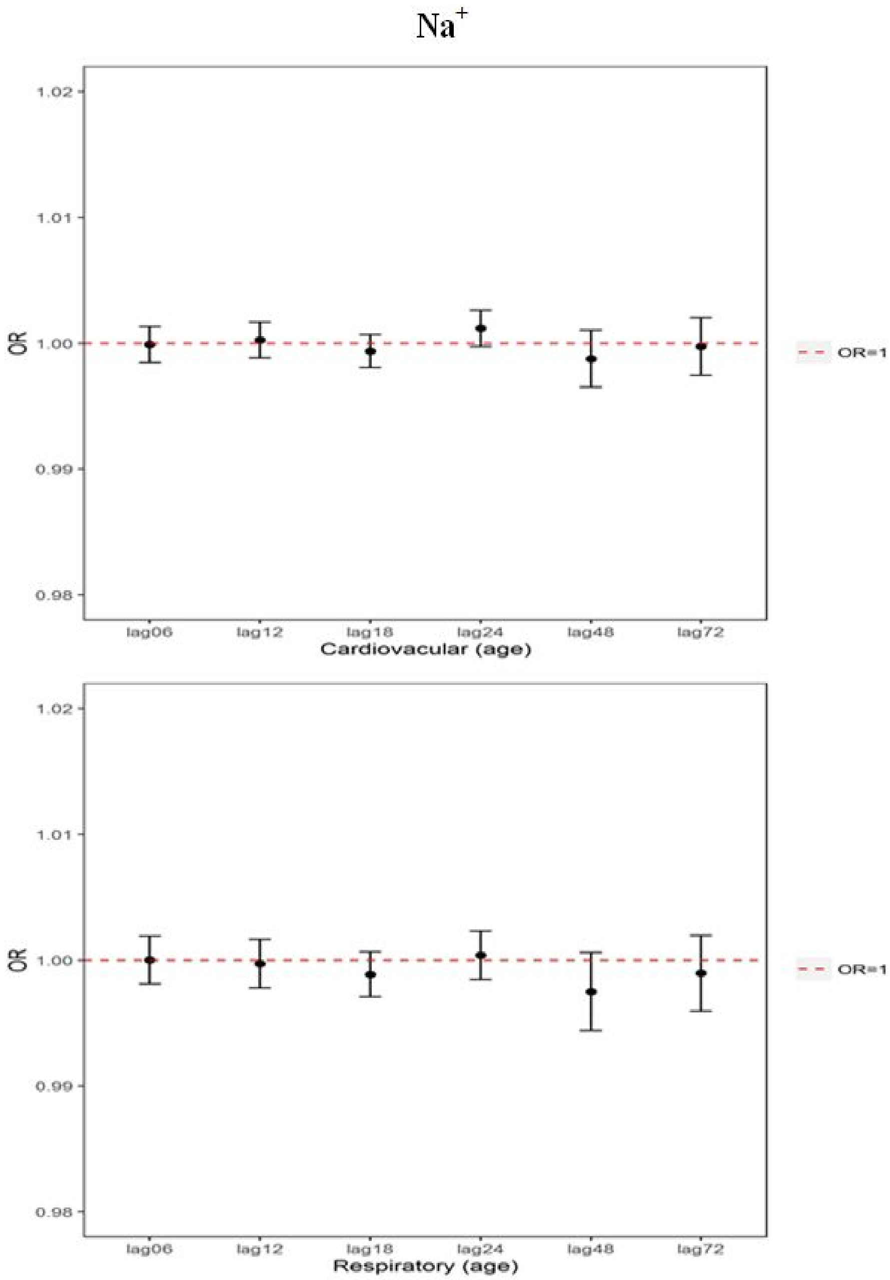


Figure 29. Estimated odds ratio (95% CI) between moving average levels of Na^{+} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

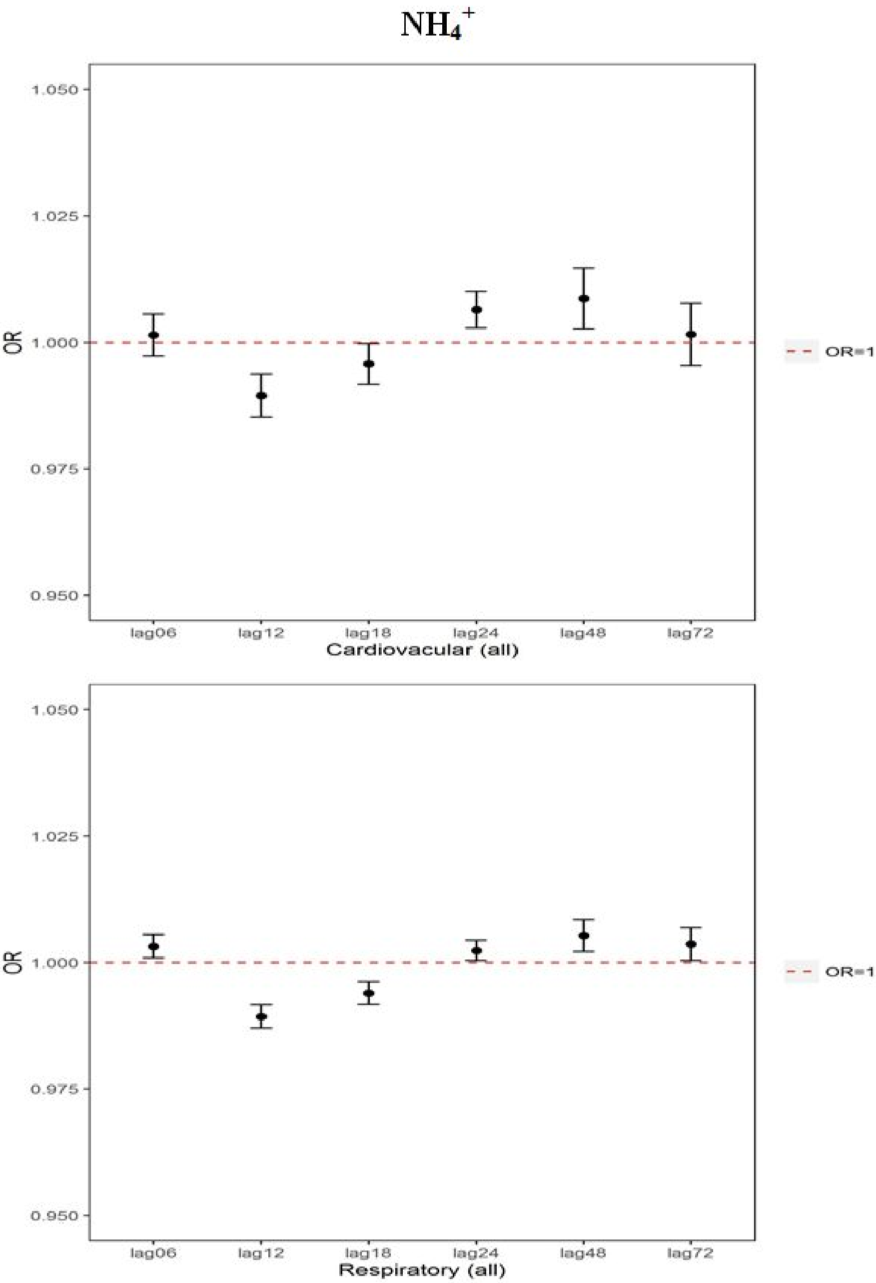


Figure 30. Estimated odds ratio (95% CI) between moving average levels of NH_4^+ and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

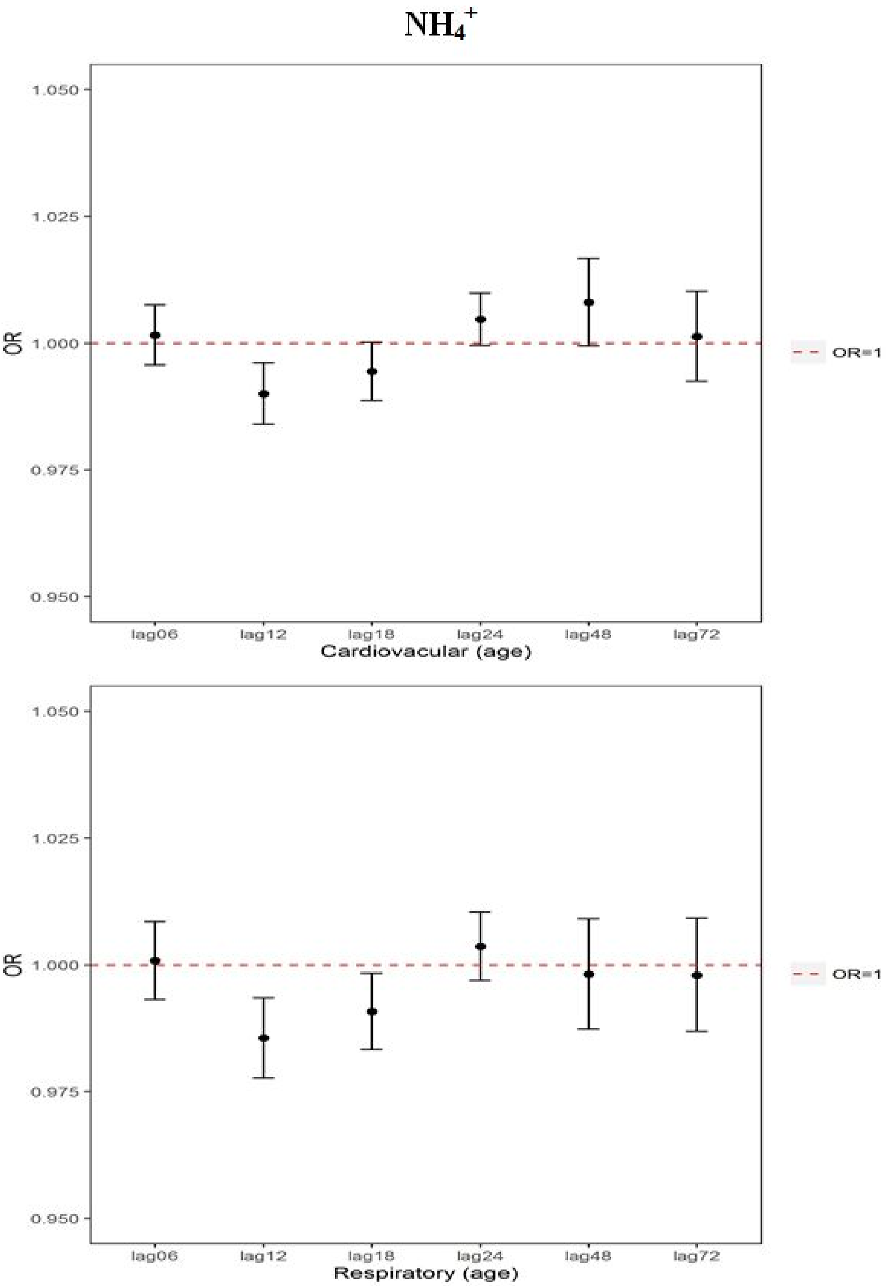


Figure 31. Estimated odds ratio (95% CI) between moving average levels of NH_4^+ and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

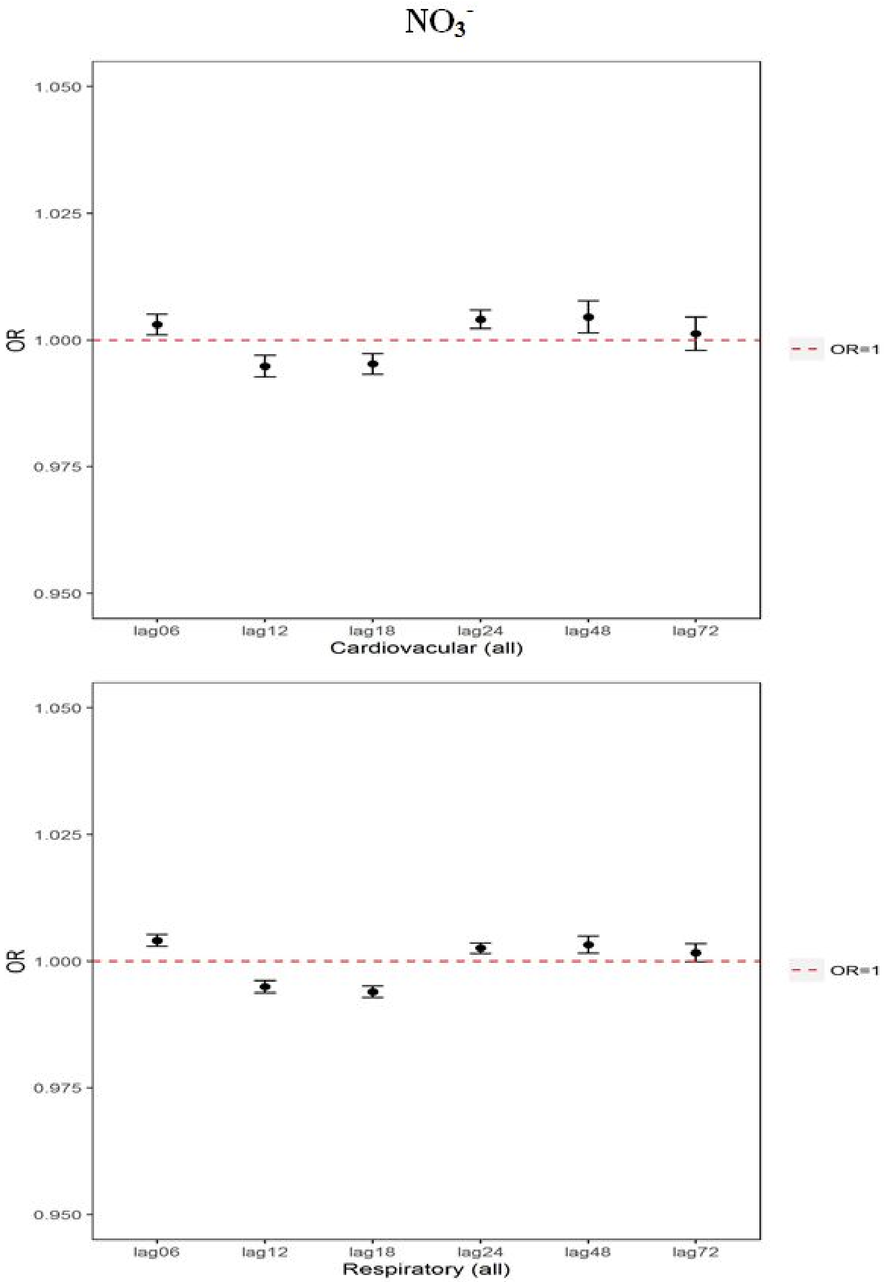


Figure 32. Estimated odds ratio (95% CI) between moving average levels of NO_3^- and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

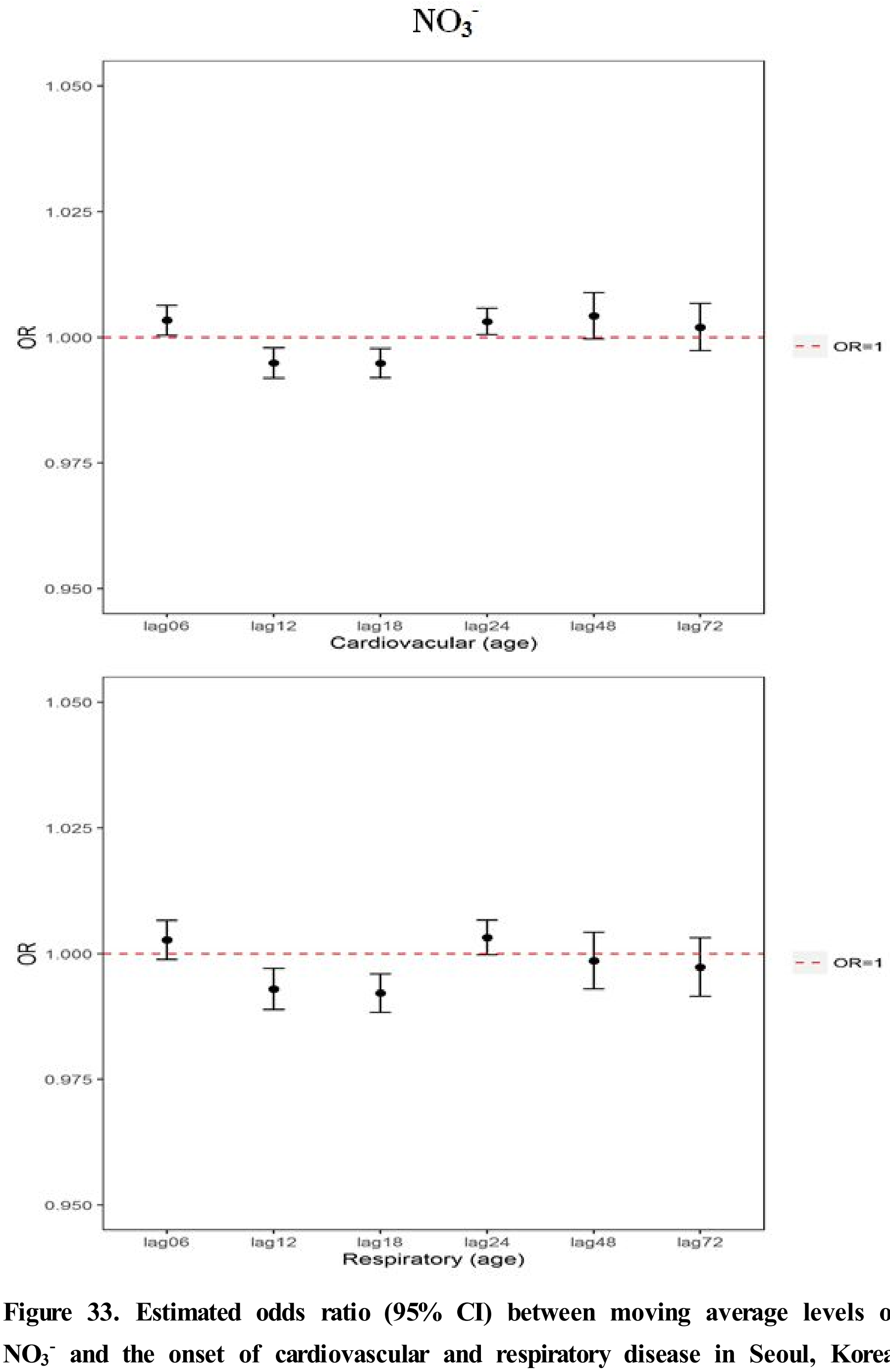


Figure 33. Estimated odds ratio (95% CI) between moving average levels of NO_3^- and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

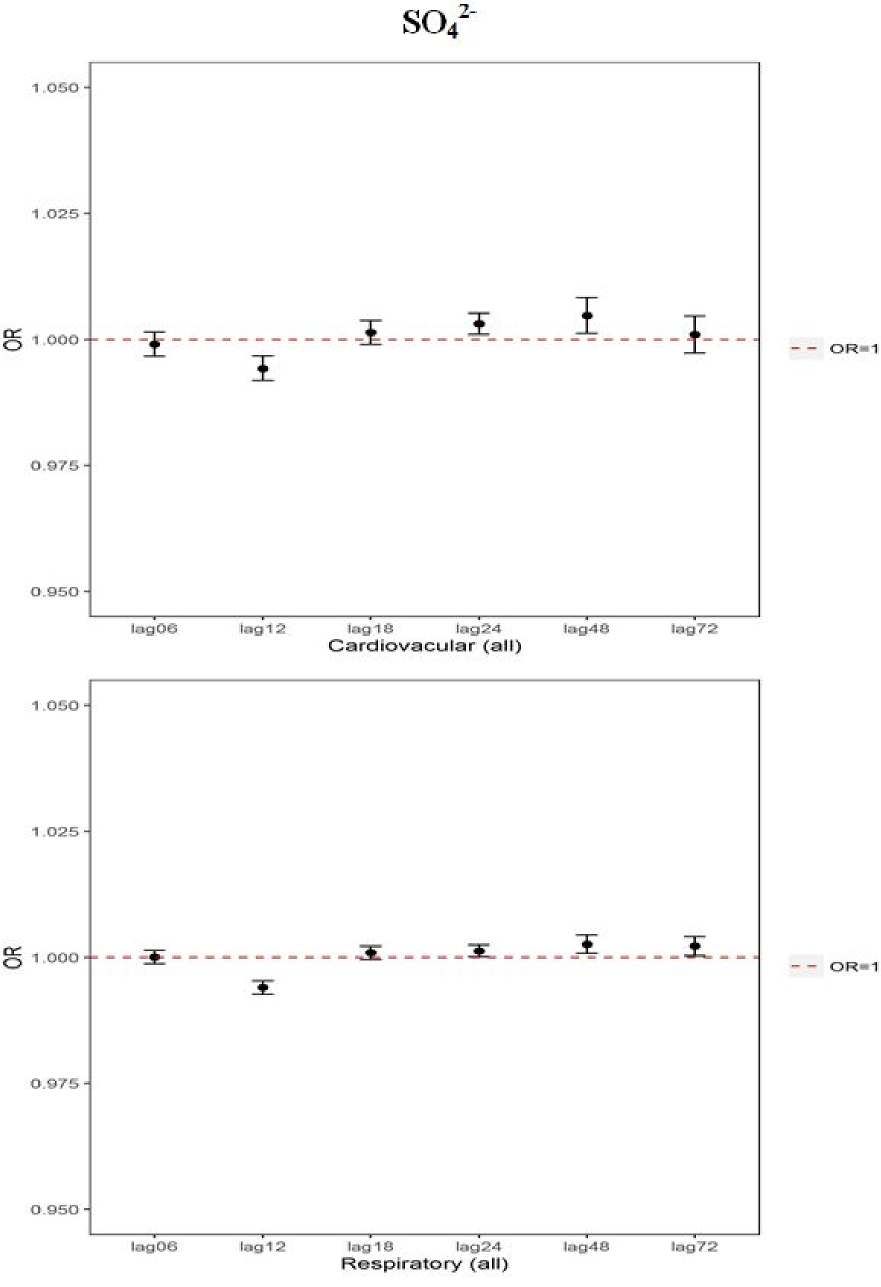


Figure 34. Estimated odds ratio (95% CI) between moving average levels of SO_4^{2-} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

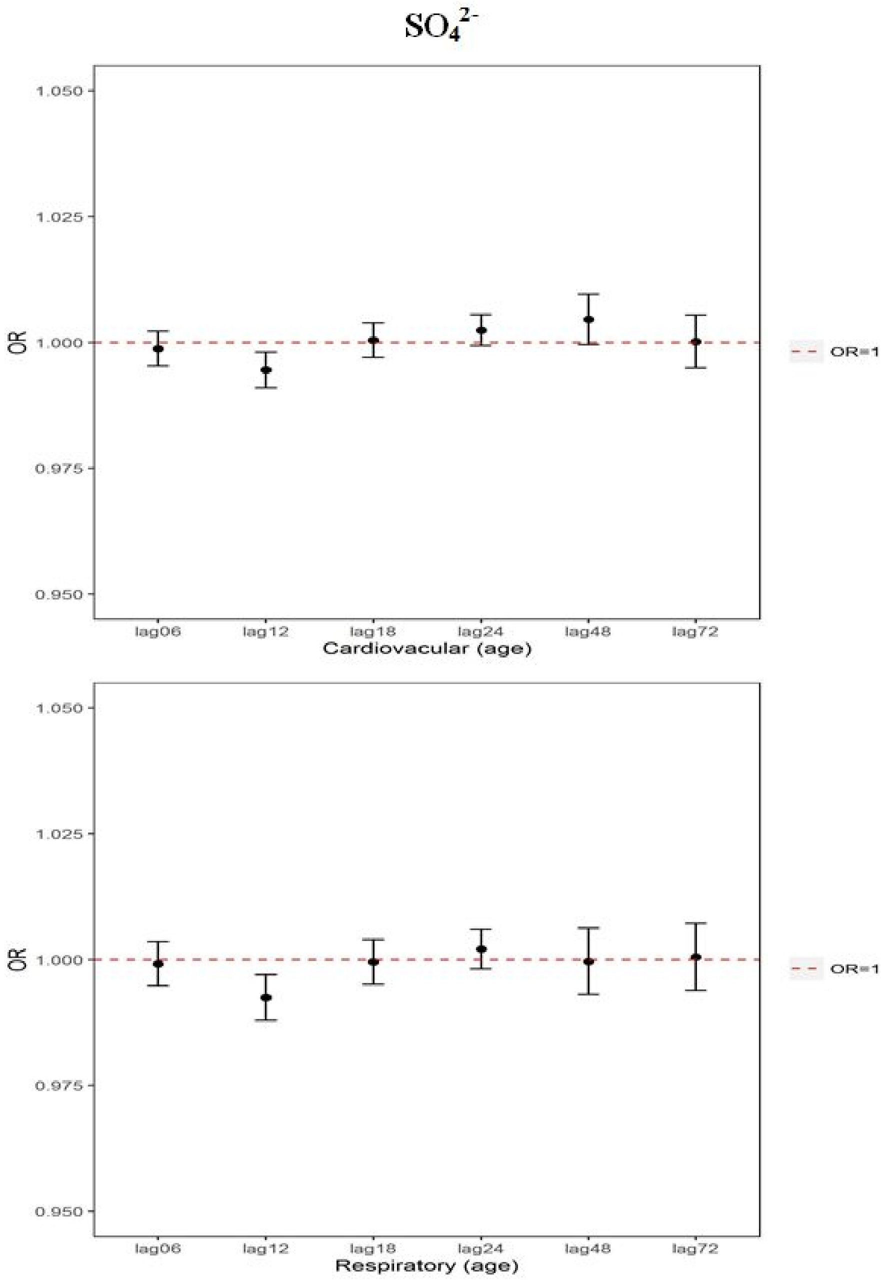


Figure 35. Estimated odds ratio (95% CI) between moving average levels of SO_4^{2-} and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

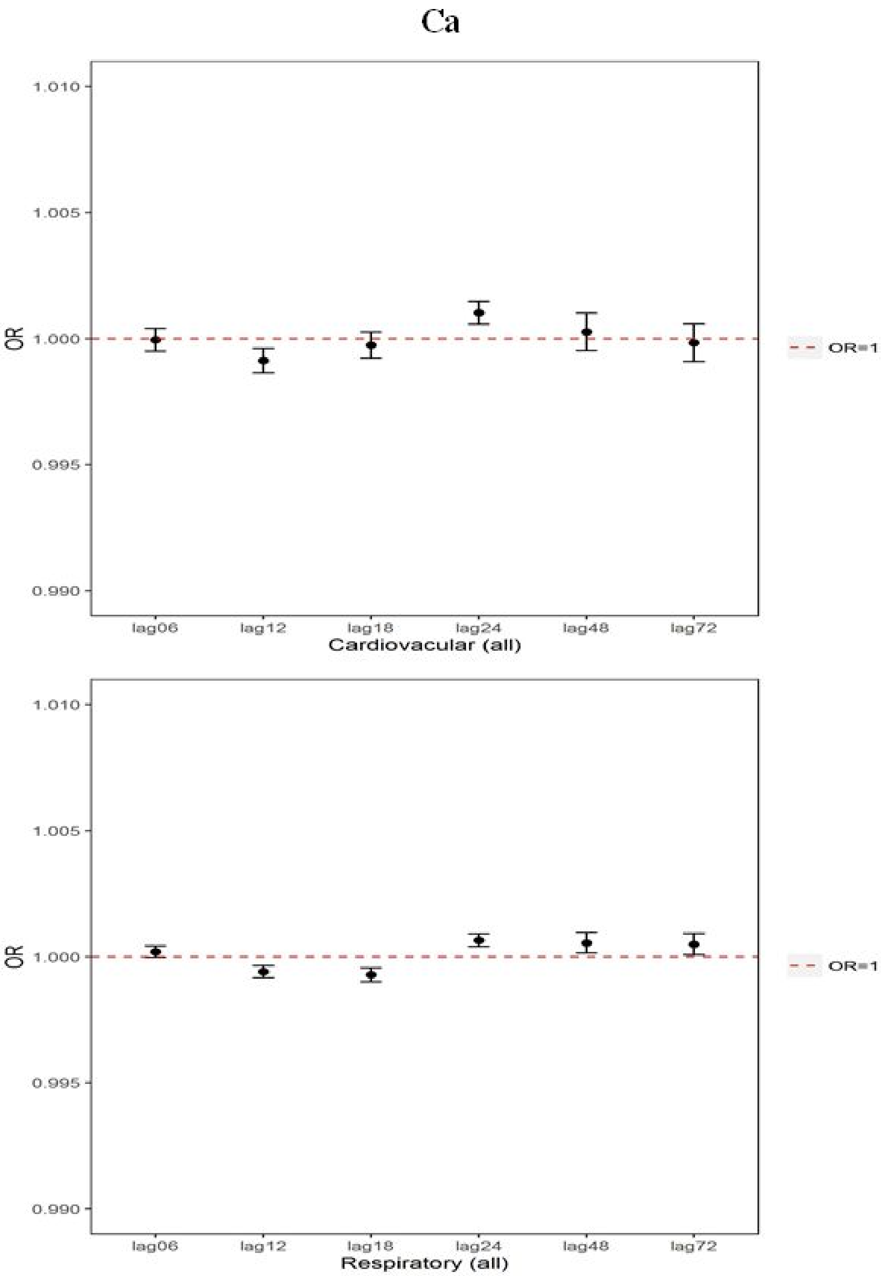


Figure 36. Estimated odds ratio (95% CI) between moving average levels of Ca and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

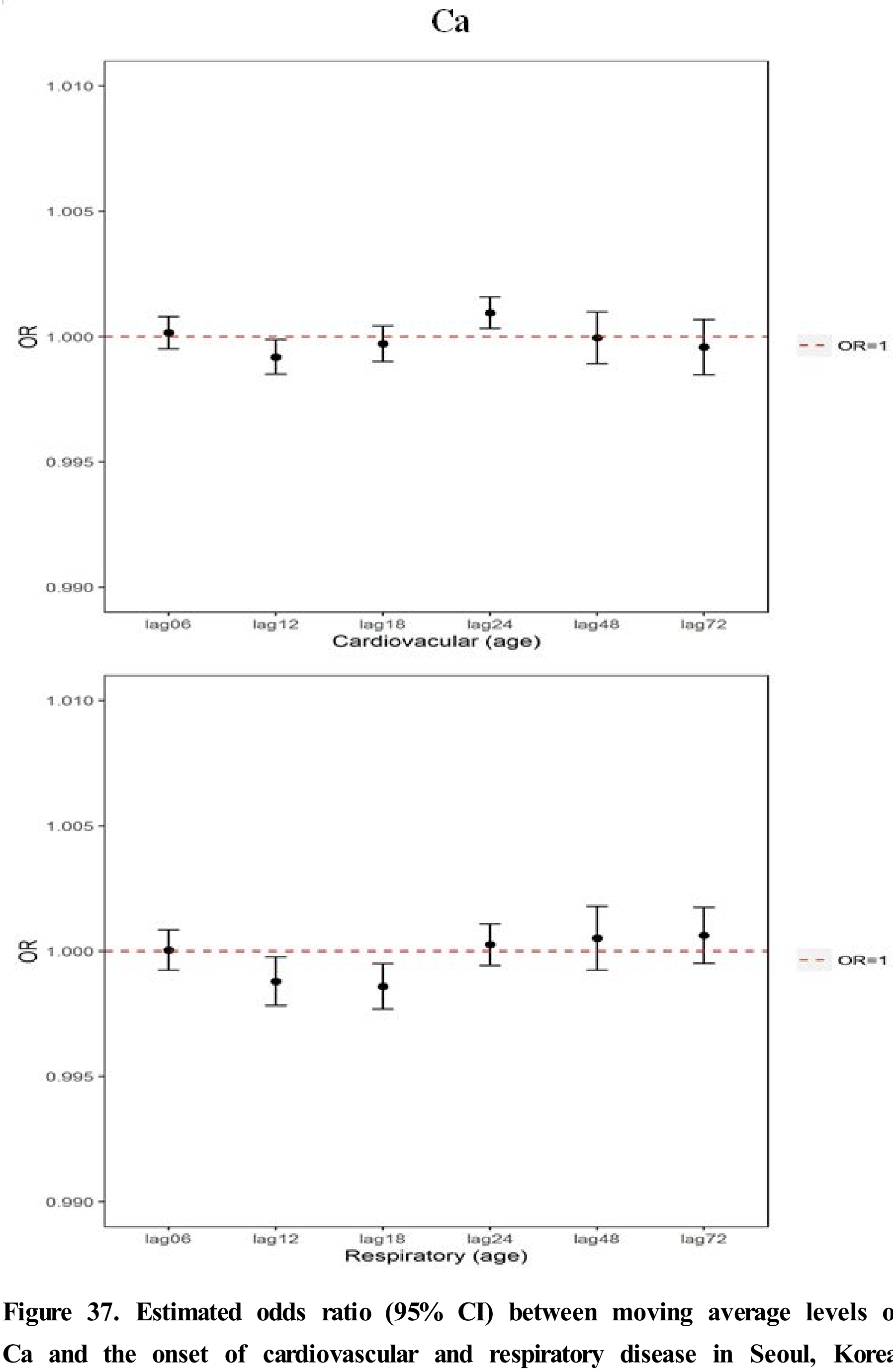


Figure 37. Estimated odds ratio (95% CI) between moving average levels of Ca and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

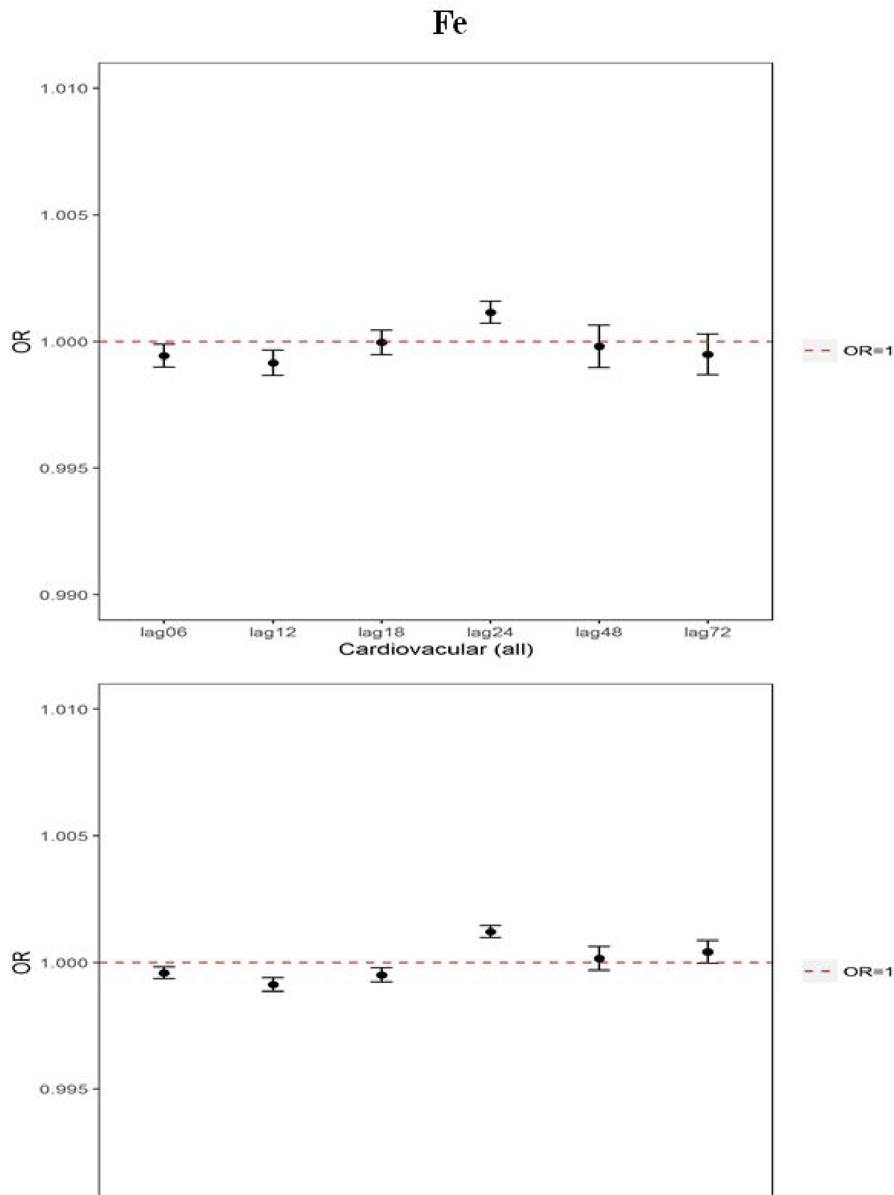


Figure 38. Estimated odds ratio (95% CI) between moving average levels of Fe and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

Fe

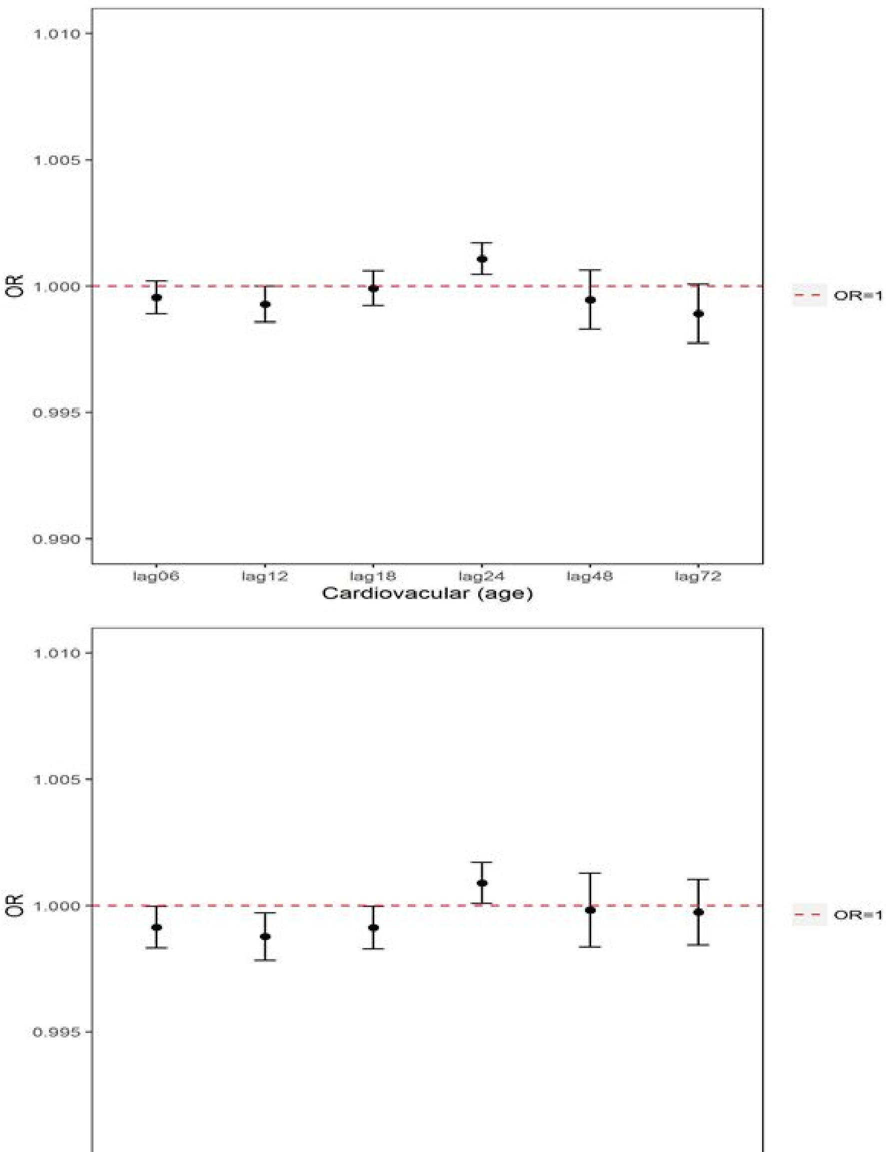


Figure 39. Estimated odds ratio (95% CI) between moving average levels of Fe and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

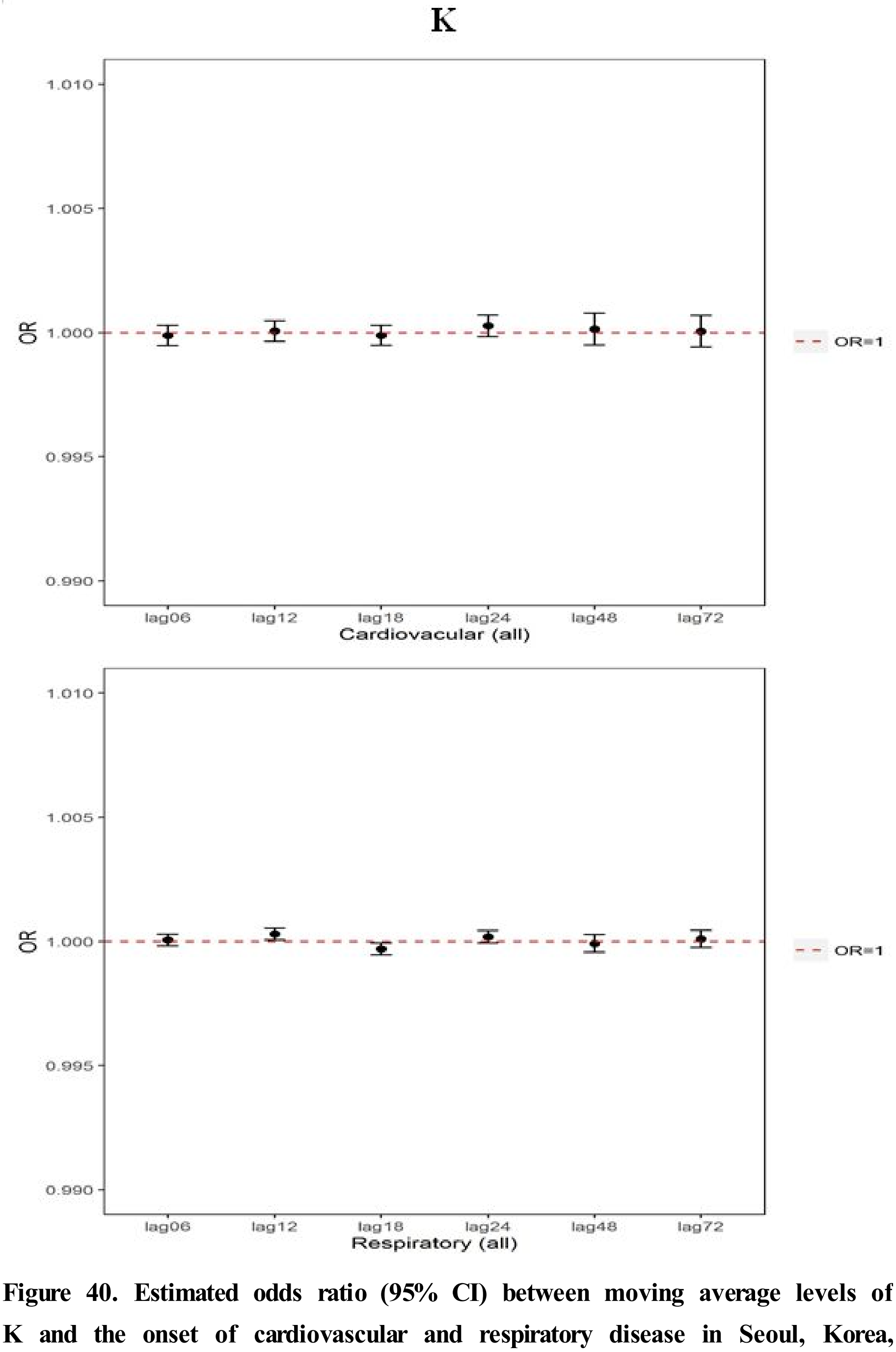


Figure 40. Estimated odds ratio (95% CI) between moving average levels of K and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

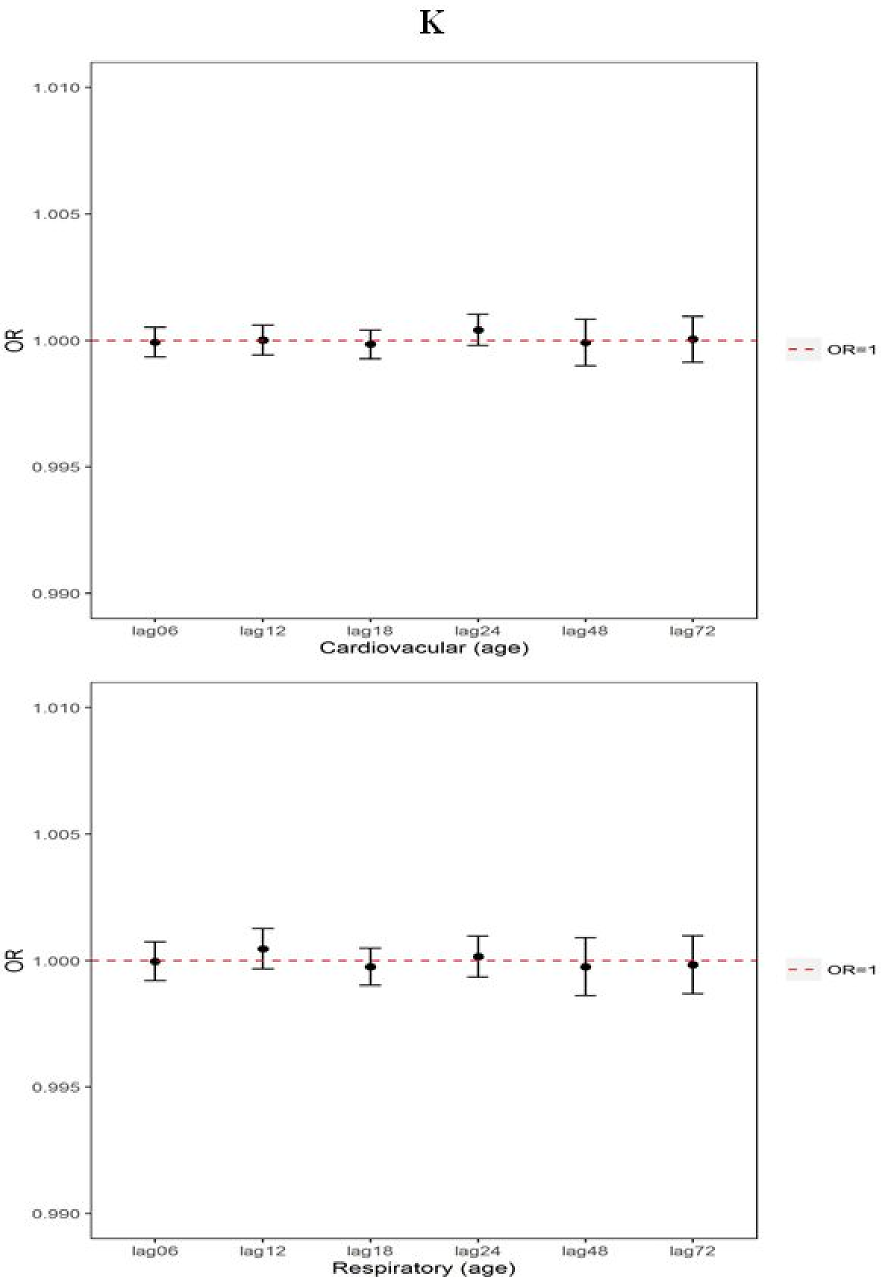


Figure 41. Estimated odds ratio (95% CI) between moving average levels of K and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

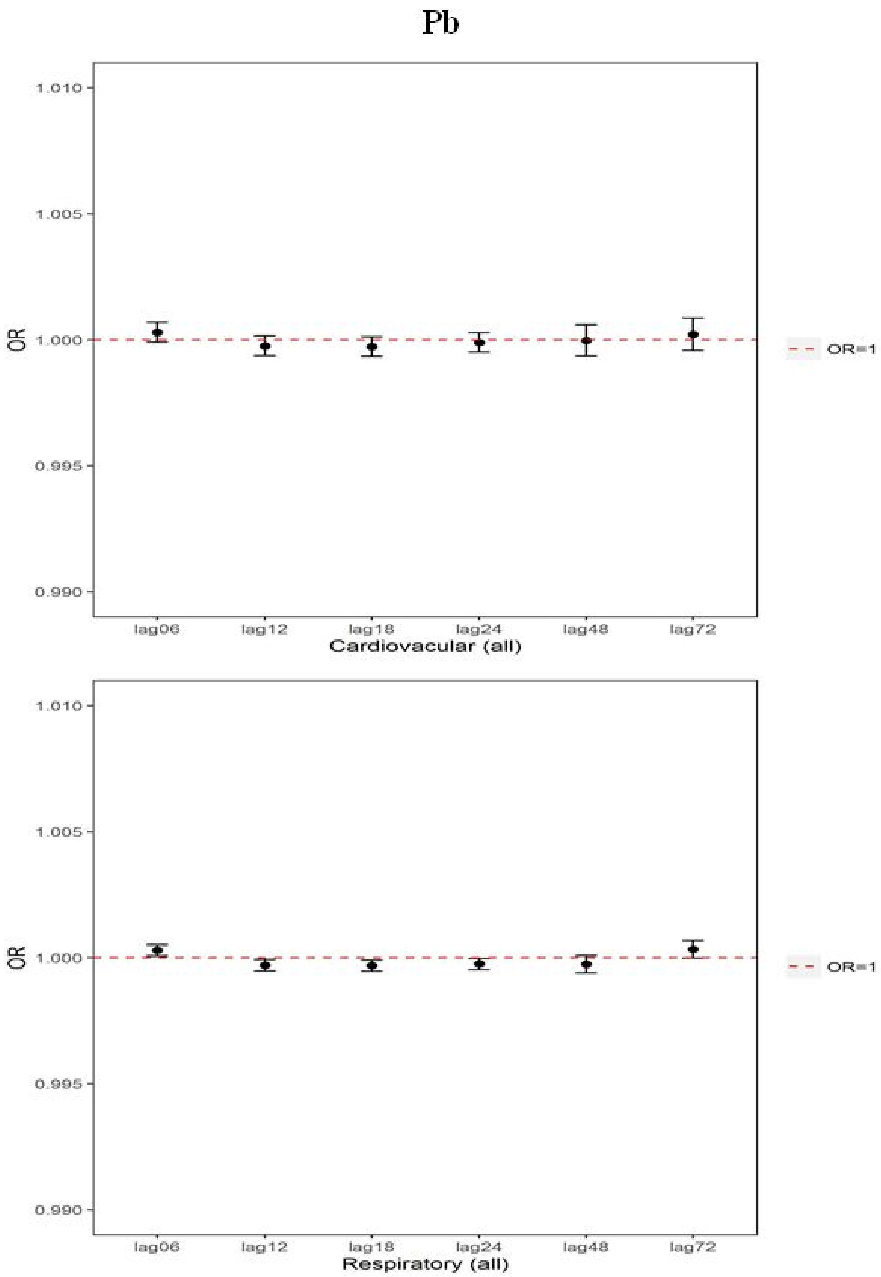


Figure 42. Estimated odds ratio (95% CI) between moving average levels of Pb and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

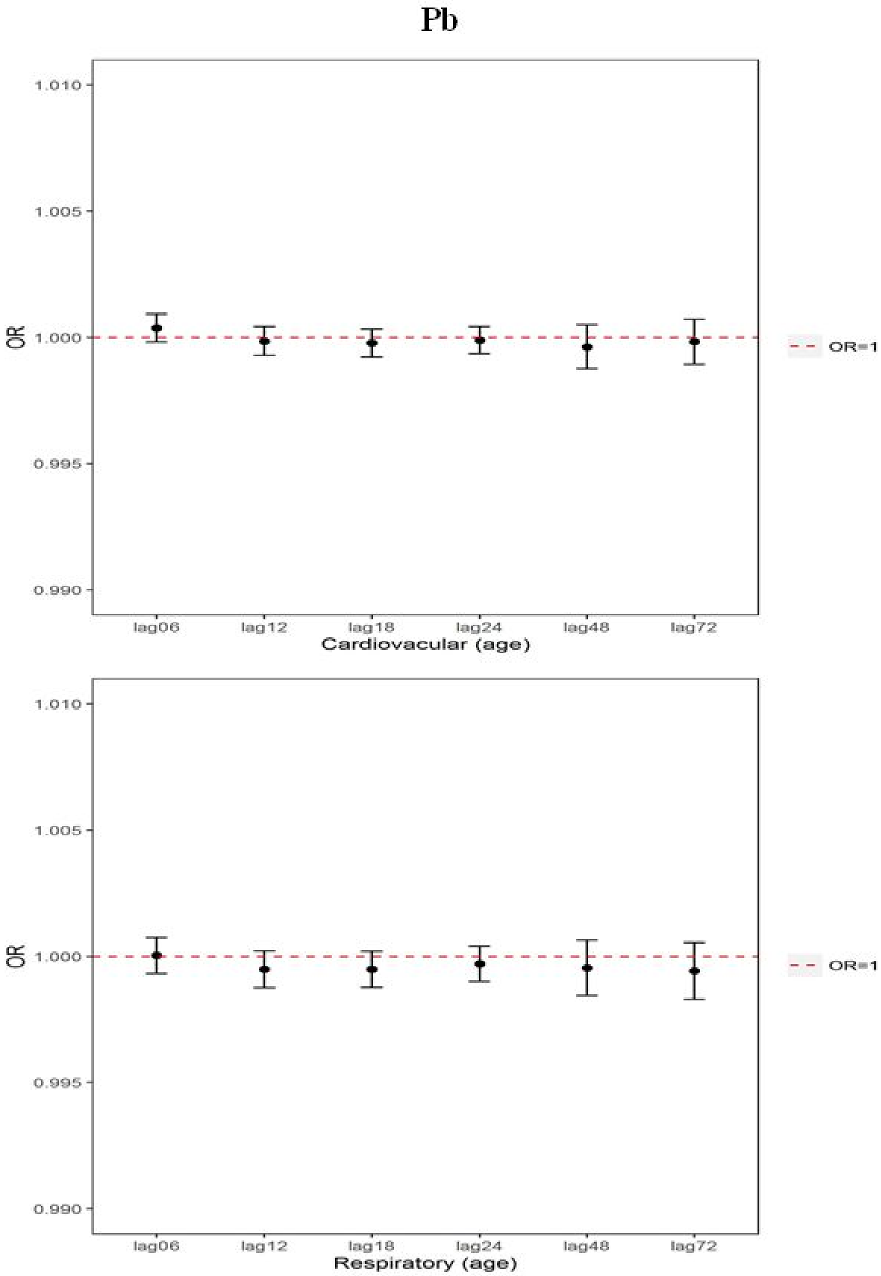


Figure 43. Estimated odds ratio (95% CI) between moving average levels of Pb and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

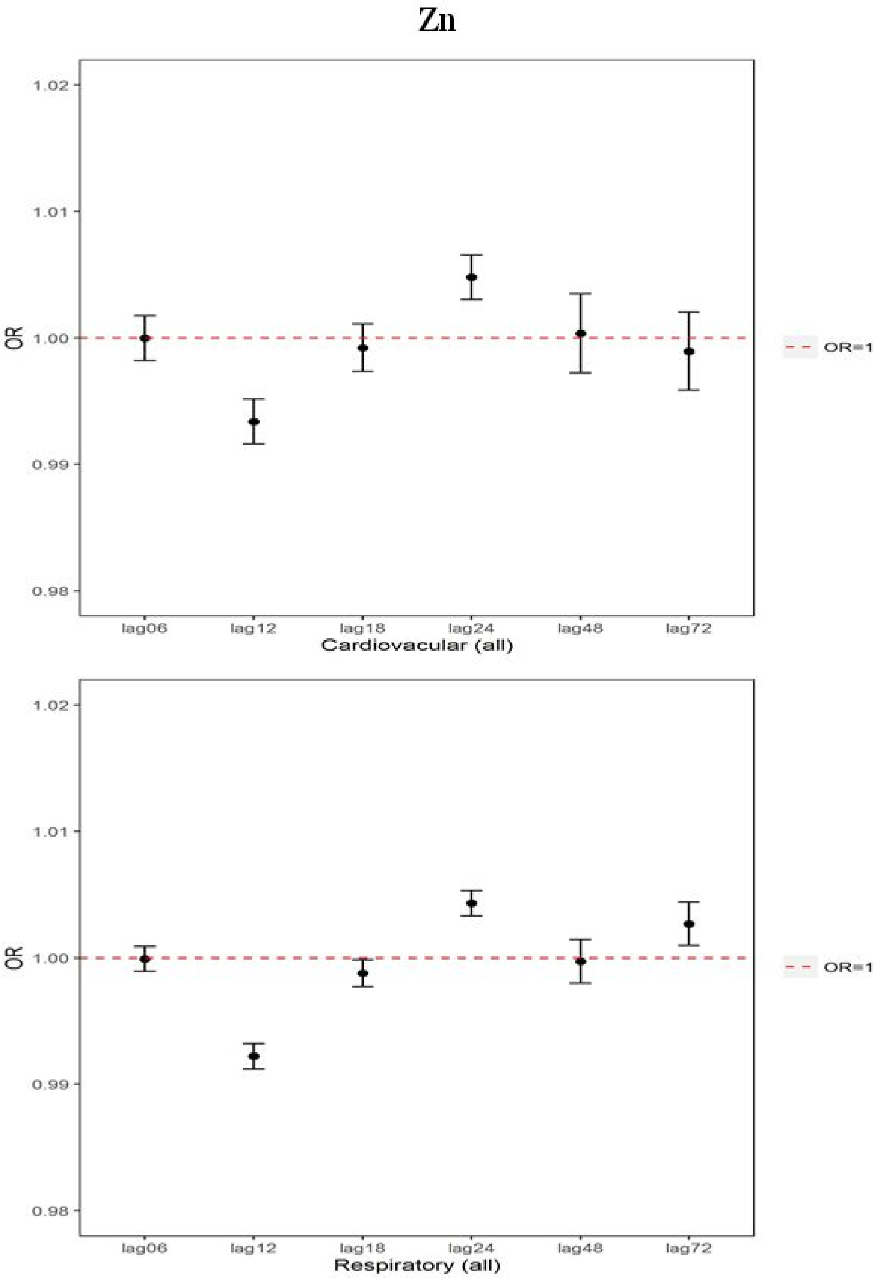


Figure 44. Estimated odds ratio (95% CI) between moving average levels of Zn and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (All)

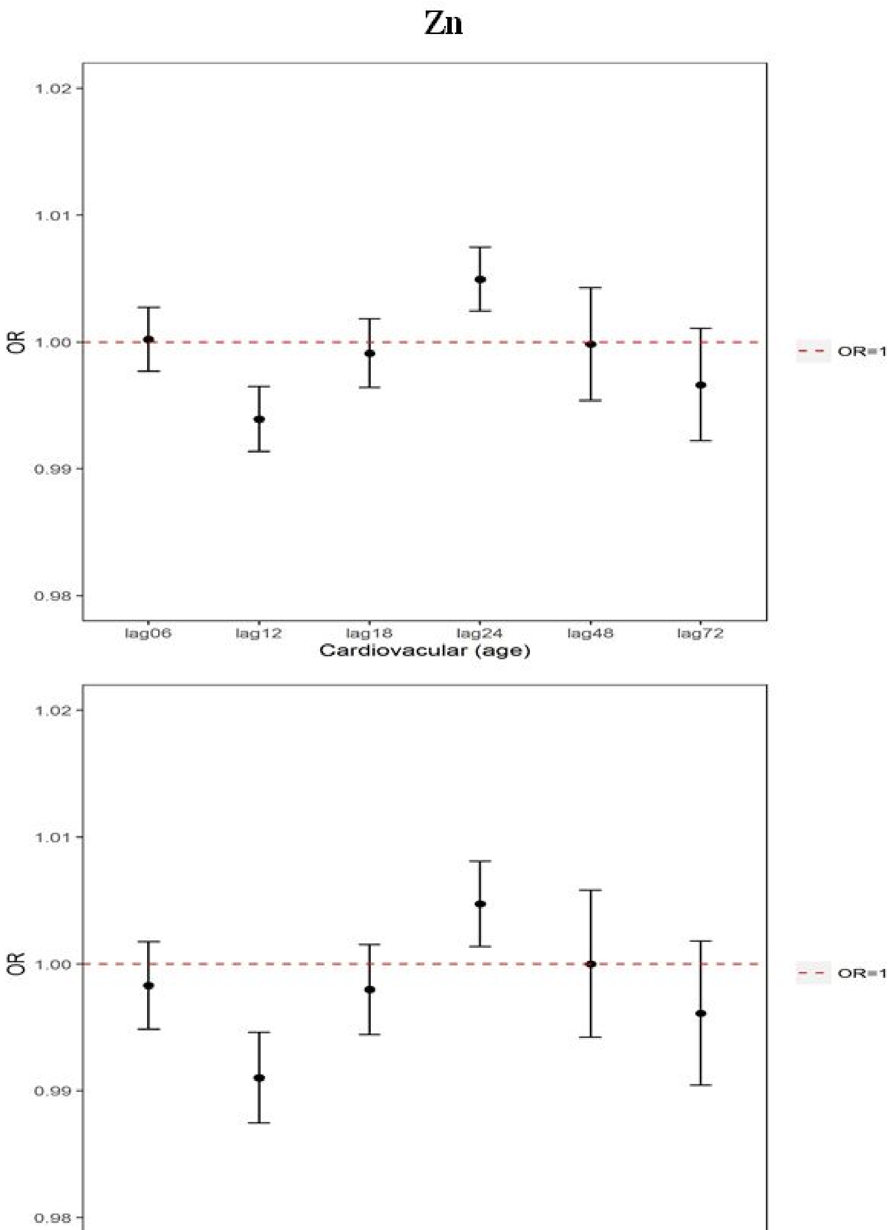


Figure 45. Estimated odds ratio (95% CI) between moving average levels of Zn and the onset of cardiovascular and respiratory disease in Seoul, Korea, 2013 (Aged ≥ 65 years)

Appendix C. Seasonal effects on respiratory disease-related emergency department visits for $PM_{2.5}$ mass and chemical constituents

Table 10 Seasonal estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of cardiovascular disease in Seoul, Korea, 2013

Constituents	Moving average lag (hour)	Cardiovascular			
		Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
$PM_{2.5}$ mass 1)	0-6h	0.9979 (0.9969-0.9989)	0.9996 (0.9983-1.0008)	1.0005 (0.9989-1.0021)	1.0001 (0.9991-1.0012)
	7-12h	0.9997 (0.9986-1.0008)	0.9989 (0.9975-1.0002)	1.0021 (1.0006-1.0037)	0.9994 (0.9984-1.0003)
	13-18h	0.9995 (0.9989-1.0006)	0.9990 (0.9977-1.0003)	0.9998 (0.9983-1.0013)	0.9997 (0.9988-1.0007)
	19-24h	0.9999 (0.9989-1.0008)	**1.0023 (1.0010-1.0036)**	**1.0029 (1.0014-1.0044)**	**1.0010 (1.0000-1.0020)**
	25-48h	1.0001 (0.9989-1.0014)	0.9996 (0.9976-1.0016)	1.0018 (0.9999-1.0036)	1.0002 (0.9989-1.0015)
	49-72h	1.0002 (0.9989-1.0015)	0.9989 (0.9970-1.0009)	1.0002 (0.9984-1.0020)	0.9996 (0.9981-1.0010)
OC 1)	0-6h	0.9655 (0.9552-0.9759)	0.9967 (0.9765-1.0172)	0.9621 (0.9417-0.9828)	1.0007 (0.9899-1.0117)
	7-12h	1.0001 (0.9862-1.0141)	0.9498 (0.9316-0.9683)	**1.0341 (1.0116-1.0572)**	0.9931 (0.9818-1.0046)
	13-18h	**1.0226 (1.0091-1.0363)**	1.0143 (0.9930-1.0362)	1.0114 (0.9917-1.0316)	1.0085 (0.9978-1.0194)
	19-24h	1.0161 (1.0046-1.0277)	**1.0395 (1.0194-1.0601)**	1.0182 (0.9985-1.0383)	**1.0177 (1.0066-1.0289)**
	25-48h	0.9910 (0.9704-1.0121)	1.0298 (0.9935-1.0675)	1.0146 (0.9809-1.0494)	0.9997 (0.9837-1.0160)
	49-72h	0.9775 (0.9571-0.9984)	0.9967 (0.9592-1.0356)	1.0046 (0.9712-1.0391)	0.9907 (0.9728-1.0091)
EC 1)	0-6h	0.8848 (0.8579-0.9125)	0.9450 (0.8989-0.9935)	0.8973 (0.8583-0.9380)	0.9953 (0.9711-1.0201)
	7-12h	0.9872 (0.9524-1.0232)	0.9634 (0.9216-1.0071)	1.0338 (0.9882-1.0814)	0.9695 (0.9458-0.9937)
	13-18h	0.9825 (0.9489-1.0173)	0.9372 (0.8915-0.9853)	0.8969 (0.8591-0.9363)	1.0159 (0.9925-1.0398)
	19-24h	**1.1430 (1.1061-1.1810)**	**1.2156 (1.1520-1.2826)**	**1.1815 (1.1353-1.2295)**	**1.0609 (1.0364-1.0860)**
	25-48h	0.9869 (0.9338-1.0430)	1.0662 (0.9709-1.1709)	1.0307 (0.9567-1.1103)	0.9870 (0.9529-1.0224)
	49-72h	0.9464 (0.8947-1.0011)	0.9830 (0.8867-1.0897)	0.9884 (0.9195-1.0625)	0.9659 (0.9265-1.0070)

Table 10 (continued)

Constituents	Moving average lag (hour)	Cardiovascular Spring (Mar.-May)	Cardiovascular Summer (Jun.-Aug.)	Cardiovascular Fall (Sep.-Nov.)	Cardiovascular Winter (Dec.-Feb.)
Cl^- 2)	0-6h	0.9965 (0.9926-1.0003)	0.9919 (0.9826-1.0013)	1.0034 (0.9936-1.0133)	0.9942 (0.9887-0.9998)
	7-12h	0.9991 (0.9955-1.0028)	0.9918 (0.9810-1.0026)	**1.0130 (1.0031-1.0229)**	0.9980 (0.9920-1.0040)
	13-18h	0.9966 (0.9933-1.0000)	0.9891 (0.9789-0.9994)	1.0025 (0.9901-1.0151)	1.0016 (0.9960-1.0072)
	19-24h	**1.0068 (1.0026-1.0109)**	1.0028 (0.9928-1.0129)	0.9979 (0.9835-1.0125)	**1.0076 (1.0021-1.0130)**
	25-48h	1.0004 (0.9939-1.0069)	0.9539 (0.9125-0.9971)	1.0000 (0.9601-1.0416)	0.9959 (0.9857-1.0062)
	49-72h	0.9983 (0.9921-1.0044)	0.9801 (0.9403-1.0215)	1.0000 (0.9570-1.0449)	0.9976 (0.9866-1.0087)
Mg^{2+} 3)	0-6h	1.0015 (0.9966-1.0063)	0.9970 (0.9923-1.0018)	0.9996 (0.9980-1.0011)	0.9979 (0.9944-1.0015)
	7-12h	1.0007 (0.9963-1.0052)	0.9981 (0.9932-1.0029)	0.9995 (0.9977-1.0012)	0.9979 (0.9945-1.0013)
	13-18h	0.9961 (0.9918-1.0005)	1.0012 (0.9968-1.0056)	1.0015 (0.9999-1.0031)	1.0011 (0.9976-1.0046)
	19-24h	0.9959 (0.9912-1.0007)	0.9997 (0.9953-1.0041)	1.0009 (0.9994-1.0024)	1.0027 (0.9990-1.0064)
	25-48h	0.9953 (0.9883-1.0023)	0.9952 (0.9859-1.0045)	1.0000 (0.9975-1.0024)	0.9964 (0.9905-1.0023)
	49-72h	0.9990 (0.9923-1.0058)	1.0060 (0.9972-1.0149)	1.0017 (0.9991-1.0042)	0.9980 (0.9925-1.0035)
Na^+ 3)	0-6h	1.0010 (0.9994-1.0027)	0.9975 (0.9958-0.9991)	0.9997 (0.9970-1.0023)	1.0028 (0.9987-1.0069)
	7-12h	0.9996 (0.9983-1.0010)	0.9979 (0.9962-0.9996)	1.0003 (0.9976-1.0030)	0.9973 (0.9936-1.0009)
	13-18h	0.9992 (0.9977-1.0006)	1.0010 (0.9993-1.0026)	0.9996 (0.9969-1.0024)	0.9947 (0.9911-0.9984)
	19-24h	**1.0021 (1.0004-1.0038)**	1.0005 (0.9989-1.0021)	1.0017 (0.9987-1.0047)	0.9985 (0.9951-1.0019)
	25-48h	0.9979 (0.9956-1.0002)	0.9979 (0.9947-1.0012)	0.9969 (0.9912-1.0026)	0.9910 (0.9841-0.9979)
	49-72h	0.9980 (0.9957-1.0004)	1.0008 (0.9976-1.0040)	1.0004 (0.9945-1.0063)	0.9884 (0.9803-0.9966)
NH_4^+ 1)	0-6h	0.9938 (0.9857-1.0020)	0.9996 (0.9920-1.0072)	1.0025 (0.9884-1.0169)	1.0025 (0.9949-1.0101)
	7-12h	0.9866 (0.9781-0.9952)	0.9907 (0.9820-0.9996)	0.9969 (0.9824-1.0117)	0.9915 (0.9843-0.9988)
	13-18h	1.0012 (0.9931-1.0093)	1.0051 (0.9968-1.0135)	0.9963 (0.9825-1.0103)	0.9970 (0.9901-1.0038)
	19-24h	1.0042 (0.9974-1.0112)	**1.0187 (1.0107-1.0268)**	1.0062 (0.9930-1.0195)	**1.0073 (1.0002-1.0144)**
	25-48h	1.0063 (0.9945-1.0182)	1.0001 (0.9848-1.0156)	0.9997 (0.9820-1.0177)	1.0097 (0.9989-1.0207)
	49-72h	0.9996 (0.9889-1.0105)	1.0101 (0.9956-1.0248)	0.9866 (0.9694-1.0041)	1.0090 (0.9970-1.0210)

Table 10 (continued)

Constituents	Moving average lag (hour)	Cardiovascular Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
NO_3^- 1)	0-6h	0.9989 (0.9953-1.0025)	1.0051 (1.0002-1.0100)	1.0031 (0.9968-1.0095)	1.0029 (0.9991-1.0067)
	7-12h	0.9922 (0.9884-0.9961)	0.9939 (0.9889-0.9990)	0.9992 (0.9927-1.0057)	0.9966 (0.9929-1.0002)
	13-18h	0.9985 (0.9948-1.0021)	0.9968 (0.9918-1.0019)	0.9955 (0.9895-1.0016)	0.9967 (0.9932-1.0002)
	19-24h	**1.0034 (1.0002-1.0065)**	**1.0109 (1.0062-1.0157)**	1.0053 (0.9994-1.0112)	**1.0044 (1.0009-1.0079)**
	25-48h	1.0032 (0.9966-1.0098)	0.9992 (0.9897-1.0087)	1.0007 (0.9919-1.0095)	1.0053 (0.9997-1.0108)
	49-72h	0.9980 (0.9925-1.0036)	1.0061 (0.9973-1.0150)	0.9955 (0.9869-1.0041)	1.0039 (0.9979-1.0100)
SO_4^{2-} 1)	0-6h	1.0037 (0.9989-1.0086)	0.9949 (0.9896-1.0002)	0.9970 (0.9933-1.0008)	0.9984 (0.9894-1.0076)
	7-12h	0.9938 (0.9894-0.9982)	0.9959 (0.9904-1.0014)	0.9959 (0.9914-1.0005)	0.9963 (0.9869-1.0057)
	13-18h	1.0008 (0.9966-1.0051)	1.0049 (0.9997-1.0101)	1.0066 (1.0023-1.0108)	1.0044 (0.9948-1.0142)
	19-24h	1.0034 (0.9990-1.0077)	0.9997 (0.9951-1.0044)	**1.0084 (1.0044-1.0124)**	1.0022 (0.9934-1.0111)
	25-48h	1.0050 (0.9983-1.0117)	1.0020 (0.9954-1.0087)	1.0008 (0.9930-1.0085)	0.9990 (0.9867-1.0116)
	49-72h	1.0064 (0.9990-1.0139)	1.0013 (0.9948-1.0079)	1.0051 (0.9975-1.0127)	0.9895 (0.9774-1.0018)
Ca 3)	0-6h	0.9998 (0.9993-1.0003)	0.9910 (0.9823-0.9998)	1.0072 (1.0016-1.0128)	1.0020 (1.0000-1.0041)
	7-12h	0.9998 (0.9994-1.0002)	0.9681 (0.9594-0.9769)	0.9928 (0.9880-0.9977)	0.9966 (0.9942-0.9990)
	13-18h	1.0006 (1.0001-1.0012)	0.9933 (0.9840-1.0027)	0.9943 (0.9893-0.9993)	0.9954 (0.9928-0.9981)
	19-24h	**1.0008 (1.0004-1.0013)**	**1.0547 (1.0458-1.0637)**	**1.0164 (1.0114-1.0215)**	**1.0046 (1.0022-1.0070)**
	25-48h	1.0006 (0.9998-1.0013)	0.9943 (0.9752-1.0137)	1.0078 (0.9964-1.0194)	0.9997 (0.9943-1.0051)
	49-72h	1.0003 (0.9995-1.0011)	1.0175 (0.9993-1.0361)	0.9940 (0.9807-1.0074)	0.9989 (0.9934-1.0045)
Fe 3)	0-6h	0.9995 (0.9990-1.0000)	0.9948 (0.9924-0.9972)	0.9970 (0.9949-0.9992)	1.0002 (0.9986-1.0017)
	7-12h	1.0000 (0.9994-1.0005)	0.9947 (0.9919-0.9974)	0.9998 (0.9973-1.0023)	0.9979 (0.9962-0.9995)
	13-18h	1.0006 (1.0001-1.0012)	1.0031 (1.0005-1.0057)	1.0010 (0.9989-1.0031)	0.9997 (0.9981-1.0013)
	19-24h	**1.0007 (1.0002-1.0012)**	**1.0110 (1.0085-1.0135)**	**1.0052 (1.0031-1.0072)**	**1.0017 (1.0001-1.0033)**
	25-48h	1.0006 (0.9997-1.0015)	0.9985 (0.9941-1.0030)	1.0027 (0.9985-1.0069)	0.9984 (0.9959-1.0010)
	49-72h	1.0003 (0.9994-1.0013)	1.0025 (0.9984-1.0066)	0.9977 (0.9936-1.0019)	0.9985 (0.9955-1.0015)

Table 10 (continued)

Constituents	Moving average lag (hour)	Cardiovascular			
		Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
K 3)	0-6h	0.9994 (0.9985-1.0003)	0.9979 (0.9959-1.0000)	1.0015 (1.0001-1.0030)	1.0002 (0.9996-1.0009)
	7-12h	1.0005 (0.9995-1.0016)	1.0022 (0.9994-1.0049)	**1.0024 (1.0008-1.0041)**	0.9999 (0.9993-1.0005)
	13-18h	1.0008 (0.9997-1.0018)	1.0018 (0.9994-1.0041)	1.0011 (0.9995-1.0027)	0.9999 (0.9994-1.0005)
	19-24h	1.0009 (0.9999-1.0019)	1.0029 (1.0005-1.0052)	1.0019 (1.0003-1.0035)	1.0001 (0.9995-1.0007)
	25-48h	1.0009 (0.9994-1.0024)	1.0029 (0.9992-1.0067)	1.0028 (0.9998-1.0058)	0.9995 (0.9986-1.0005)
	49-72h	1.0010 (0.9994-1.0025)	**1.0057 (1.0021-1.0094)**	0.9996 (0.9966-1.0027)	0.9997 (0.9987-1.0008)
Pb 4)	0-6h	0.9999 (0.9992-1.0006)	1.0004 (0.9993-1.0014)	1.0010 (1.0000-1.0021)	1.0004 (0.9997-1.0011)
	7-12h	**1.0008 (1.0000-1.0016)**	1.0000 (0.9988-1.0013)	1.0008 (0.9996-1.0021)	0.9996 (0.9989-1.0002)
	13-18h	0.9995 (0.9987-1.0002)	0.9999 (0.9988-1.0010)	**1.0013 (1.0001-1.0025)**	1.0000 (0.9993-1.0006)
	19-24h	0.9998 (0.9991-1.0005)	1.0017 (1.0006-1.0028)	1.0005 (0.9995-1.0016)	0.9996 (0.9990-1.0002)
	25-48h	0.9998 (0.9985-1.0012)	1.0023 (1.0005-1.0041)	1.0012 (0.9989-1.0034)	0.9989 (0.9980-0.9999)
	49-72h	1.0004 (0.9991-1.0017)	**1.0035 (1.0016-1.0053)**	0.9988 (0.9965-1.0011)	0.9992 (0.9981-1.0003)
Zn 3)	0-6h	0.9967 (0.9935-0.9999)	1.0014 (0.9980-1.0048)	0.9996 (0.9952-1.0040)	**1.0049 (1.0012-1.0086)**
	7-12h	0.9991 (0.9955-1.0027)	0.9942 (0.9907-0.9977)	0.9967 (0.9918-1.0016)	0.9935 (0.9897-0.9973)
	13-18h	1.0000 (0.9964-1.0036)	1.0017 (0.9979-1.0055)	1.0026 (0.9979-1.0073)	0.9966 (0.9929-1.0003)
	19-24h	1.0031 (0.9996-1.0066)	**1.0069 (1.0036-1.0103)**	**1.0074 (1.0029-1.0119)**	1.0041 (1.0006-1.0077)
	25-48h	1.0019 (0.9956-1.0082)	1.0006 (0.9933-1.0079)	1.0065 (0.9965-1.0166)	0.9964 (0.9902-1.0026)
	49-72h	1.0012 (0.9951-1.0074)	1.0062 (0.9992-1.0132)	0.9912 (0.9815-1.0011)	0.9975 (0.9905-1.0046)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.
1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})
2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)
3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)
4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

Table 11 Seasonal estimated odds ratio (95% CI) on the lag effects of $PM_{2.5}$ with the onset of respiratory disease in Seoul, Korea, 2013

Constituents	Moving average lag (hour)	Respiratory			
		Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
$PM_{2.5}$ mass [1)]	0-6h	0.9972 (0.9966-0.9977)	0.9997 (0.9990-1.0003)	1.0000 (0.9990-1.0009)	1.0009 (1.0004-1.0015)
	7-12h	0.9995 (0.9989-1.0001)	0.9982 (0.9975-0.9989)	1.0025 (1.0016-1.0034)	0.9997 (0.9991-1.0003)
	13-18h	0.9993 (0.9987-0.9999)	0.9986 (0.9979-0.9993)	1.0000 (0.9992-1.0008)	0.9995 (0.9989-1.0000)
	19-24h	0.9996 (0.9990-1.0001)	**1.0026 (1.0019-1.0033)**	**1.0034 (1.0025-1.0042)**	**1.0009 (1.0003-1.0014)**
	25-48h	0.9998 (0.9991-1.0004)	0.9989 (0.9979-0.9999)	1.0007 (0.9996-1.0017)	1.0002 (0.9995-1.0009)
	49-72h	**1.0010 (1.0003-1.0017)**	0.9997 (0.9987-1.0007)	0.9992 (0.9982-1.0002)	0.9997 (0.9990-1.0005)
OC [1)]	0-6h	0.9655 (0.9600-0.9711)	0.9615 (0.9498-0.9734)	0.9615 (0.9498-0.9734)	1.0101 (1.0036-1.0166)
	7-12h	0.9961 (0.9885-1.0038)	**1.0410 (1.0278-1.0544)**	**1.0410 (1.0278-1.0544)**	0.9988 (0.9920-1.0057)
	13-18h	1.0169 (1.0094-1.0244)	1.0268 (1.0155-1.0381)	1.0268 (1.0155-1.0381)	1.0111 (1.0045-1.0177)
	19-24h	**1.0206 (1.0143-1.0269)**	1.0360 (1.0241-1.0482)	1.0360 (1.0241-1.0482)	**1.0223 (1.0155-1.0291)**
	25-48h	1.0018 (0.9912-1.0126)	1.0376 (1.0182-1.0575)	1.0376 (1.0182-1.0575)	1.0081 (0.9990-1.0173)
	49-72h	0.9971 (0.9858-1.0085)	1.0032 (0.9844-1.0224)	1.0032 (0.9844-1.0224)	0.9998 (0.9899-1.0097)
EC [1)]	0-6h	0.8760 (0.8614-0.8909)	0.9257 (0.9020-0.9500)	0.8856 (0.8622-0.9095)	1.0086 (0.9941-1.0233)
	7-12h	0.9829 (0.9634-1.0028)	0.9592 (0.9389-0.9799)	1.0479 (1.0211-1.0755)	0.9748 (0.9605-0.9893)
	13-18h	0.9587 (0.9401-0.9777)	0.9267 (0.9029-0.9510)	0.8959 (0.8739-0.9185)	1.0183 (1.0043-1.0326)
	19-24h	**1.1566 (1.1360-1.1776)**	**1.2422 (1.2074-1.2779)**	**1.2707 (1.2398-1.3022)**	**1.0743 (1.0596-1.0892)**
	25-48h	0.9966 (0.9681-1.0259)	1.0117 (0.9620-1.0639)	1.0894 (1.0440-1.1368)	1.0088 (0.9892-1.0288)
	49-72h	0.9893 (0.9595-1.0201)	0.9827 (0.9311-1.0373)	1.0329 (0.9917-1.0758)	0.9864 (0.9647-1.0086)
Cl^- [2)]	0-6h	0.9956 (0.9933-0.9980)	1.0024 (0.9967-1.0082)	1.0026 (0.9965-1.0088)	0.9940 (0.9916-0.9964)
	7-12h	0.9982 (0.9960-1.0003)	0.9947 (0.9880-1.0015)	**1.0142 (1.0079-1.0205)**	0.9982 (0.9956-1.0008)
	13-18h	0.9952 (0.9932-0.9971)	0.9832 (0.9771-0.9894)	1.0037 (0.9959-1.0115)	1.0022 (0.9998-1.0047)
	19-24h	**1.0076 (1.0051-1.0101)**	0.9964 (0.9902-1.0027)	0.9983 (0.9886-1.0081)	**1.0091 (1.0066-1.0117)**
	25-48h	0.9996 (0.9961-1.0031)	0.9835 (0.9605-1.0071)	1.0000 (0.9726-1.0282)	1.0058 (1.0014-1.0102)
	49-72h	1.0046 (1.0013-1.0079)	0.9864 (0.9650-1.0083)	1.0000 (0.9684-1.0326)	1.0017 (0.9972-1.0062)

Table 11 (continued)

Constituents	Moving average lag (hour)	Respiratory Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
Mg^{2+} 3)	0-6h	1.0002 (0.9973-1.0030)	0.9959 (0.9932-0.9986)	0.9996 (0.9986-1.0005)	0.9978 (0.9957-1.0000)
	7-12h	1.0012 (0.9987-1.0037)	0.9965 (0.9938-0.9993)	0.9989 (0.9979-1.0000)	0.9967 (0.9943-0.9990)
	13-18h	0.9976 (0.9951-1.0001)	1.0006 (0.9981-1.0031)	1.0007 (0.9997-1.0017)	1.0019 (0.9995-1.0042)
	19-24h	0.9956 (0.9928-0.9983)	1.0000 (0.9975-1.0025)	1.0005 (0.9996-1.0014)	**1.0048 (1.0024-1.0073)**
	25-48h	1.0008 (0.9970-1.0045)	0.9953 (0.9904-1.0002)	0.9993 (0.9979-1.0007)	0.9994 (0.9956-1.0032)
	49-72h	1.0023 (0.9987-1.0059)	1.0031 (0.9984-1.0077)	1.0006 (0.9991-1.0021)	0.9984 (0.9947-1.0020)
Na^{+} 3)	0-6h	1.0003 (0.9993-1.0014)	0.9973 (0.9963-0.9983)	0.9995 (0.9981-1.0010)	**1.0039 (1.0016-1.0062)**
	7-12h	0.9992 (0.9984-1.0000)	0.9978 (0.9968-0.9988)	0.9994 (0.9978-1.0011)	0.9994 (0.9973-1.0015)
	13-18h	0.9993 (0.9985-1.0001)	**1.0013 (1.0004-1.0023)**	0.9992 (0.9976-1.0007)	0.9932 (0.9909-0.9954)
	19-24h	**1.0029 (1.0019-1.0039)**	1.0011 (1.0001-1.0020)	1.0013 (0.9996-1.0030)	0.9983 (0.9962-1.0004)
	25-48h	0.9992 (0.9980-1.0004)	0.9970 (0.9953-0.9987)	0.9965 (0.9933-0.9996)	0.9919 (0.9878-0.9960)
	49-72h	0.9999 (0.9987-1.0011)	0.9992 (0.9976-1.0008)	0.9985 (0.9950-1.0020)	0.9908 (0.9863-0.9954)
NH_4^{+} 1)	0-6h	0.9917 (0.9871-0.9964)	1.0041 (0.9999-1.0083)	1.0036 (0.9951-1.0122)	1.0099 (1.0056-1.0142)
	7-12h	0.9868 (0.9820-0.9916)	0.9924 (0.9877-0.9971)	1.0076 (0.9985-1.0168)	0.9973 (0.9932-1.0014)
	13-18h	1.0012 (0.9966-1.0059)	1.0076 (1.0030-1.0121)	0.9942 (0.9860-1.0024)	0.9998 (0.9958-1.0039)
	19-24h	1.0035 (0.9997-1.0073)	1.0217 (1.0172-1.0261)	**1.0128 (1.0048-1.0208)**	1.0070 (1.0028-1.0112)
	25-48h	1.0033 (0.9971-1.0095)	1.0077 (0.9994-1.0161)	0.9803 (0.9699-0.9909)	**1.0148 (1.0087-1.0210)**
	49-72h	**1.0096 (1.0038-1.0154)**	**1.0252 (1.0174-1.0331)**	0.9821 (0.9717-0.9926)	1.0116 (1.0049-1.0183)
NO_3^{-} 1)	0-6h	0.9978 (0.9958-0.9999)	1.0065 (1.0038-1.0091)	1.0024 (0.9985-1.0064)	**1.0076 (1.0054-1.0098)**
	7-12h	0.9911 (0.9889-0.9933)	0.9945 (0.9918-0.9971)	1.0018 (0.9978-1.0059)	1.0003 (0.9982-1.0025)
	13-18h	0.9977 (0.9957-0.9998)	0.9982 (0.9956-1.0009)	0.9926 (0.9889-0.9962)	0.9981 (0.9960-1.0002)
	19-24h	1.0028 (1.0010-1.0045)	**1.0127 (1.0101-1.0153)**	**1.0077 (1.0039-1.0114)**	1.0045 (1.0024-1.0066)
	25-48h	1.0004 (0.9970-1.0039)	1.0016 (0.9966-1.0067)	0.9917 (0.9864-0.9970)	1.0073 (1.0042-1.0105)
	49-72h	**1.0039 (1.0009-1.0069)**	1.0127 (1.0080-1.0175)	0.9925 (0.9872-0.9977)	1.0032 (0.9999-1.0066)

Table 11 (continued)

Constituents	Moving average lag (hour)	Respiratory Spring (Mar.-May)	Respiratory Summer (Jun.-Aug.)	Respiratory Fall (Sep.-Nov.)	Respiratory Winter (Dec.-Feb.)
SO_4^{2-} 1)	0-6h	1.0079 (1.0052-1.0106)	0.9936 (0.9906-0.9967)	0.9991 (0.9970-1.0012)	1.0013 (0.9962-1.0065)
	7-12h	0.9965 (0.9941-0.9989)	0.9972 (0.9942-1.0003)	0.9961 (0.9937-0.9986)	1.0041 (0.9986-1.0097)
	13-18h	1.0032 (1.0007-1.0056)	**1.0062 (1.0032-1.0091)**	1.0069 (1.0047-1.0092)	1.0051 (0.9996-1.0106)
	19-24h	1.0038 (1.0013-1.0064)	1.0002 (0.9977-1.0027)	**1.0091 (1.0069-1.0113)**	**1.0066 (1.0017-1.0115)**
	25-48h	1.0081 (1.0044-1.0118)	1.0021 (0.9986-1.0056)	1.0047 (1.0005-1.0089)	0.9861 (0.9790-0.9933)
	49-72h	**1.0085 (1.0045-1.0126)**	1.0057 (1.0023-1.0092)	1.0130 (1.0089-1.0171)	0.9877 (0.9806-0.9948)
Ca 3)	0-6h	1.0000 (0.9997-1.0002)	0.9929 (0.9882-0.9977)	1.0128 (1.0093-1.0163)	1.0027 (1.0014-1.0040)
	7-12h	0.9998 (0.9995-1.0000)	0.9626 (0.9579-0.9674)	0.9968 (0.9939-0.9997)	0.9949 (0.9934-0.9965)
	13-18h	1.0007 (1.0004-1.0010)	0.9850 (0.9799-0.9901)	0.9967 (0.9937-0.9997)	0.9911 (0.9892-0.9929)
	19-24h	1.0009 (1.0006-1.0012)	**1.0644 (1.0594-1.0694)**	**1.0215 (1.0183-1.0246)**	**1.0069 (1.0052-1.0086)**
	25-48h	**1.0011 (1.0007-1.0015)**	1.0021 (0.9921-1.0123)	1.0049 (0.9984-1.0116)	0.9973 (0.9943-1.0004)
	49-72h	1.0009 (1.0005-1.0014)	1.0322 (1.0228-1.0417)	0.9880 (0.9804-0.9956)	0.9986 (0.9957-1.0015)
Fe 3)	0-6h	0.9996 (0.9993-0.9999)	0.9953 (0.9940-0.9966)	0.9968 (0.9956-0.9981)	1.0009 (1.0000-1.0018)
	7-12h	0.9999 (0.9996-1.0001)	0.9932 (0.9917-0.9946)	1.0006 (0.9991-1.0020)	0.9979 (0.9969-0.9989)
	13-18h	1.0007 (1.0004-1.0010)	1.0022 (1.0007-1.0036)	1.0023 (1.0010-1.0035)	0.9990 (0.9980-0.9999)
	19-24h	1.0008 (1.0005-1.0011)	**1.0128 (1.0114-1.0142)**	**1.0089 (1.0077-1.0102)**	**1.0023 (1.0013-1.0032)**
	25-48h	**1.0011 (1.0006-1.0016)**	1.0019 (0.9996-1.0042)	1.0033 (1.0008-1.0057)	0.9981 (0.9967-0.9995)
	49-72h	**1.0011 (1.0006-1.0016)**	1.0063 (1.0042-1.0084)	0.9963 (0.9939-0.9988)	0.9986 (0.9970-1.0002)
K 3)	0-6h	0.9993 (0.9988-0.9998)	0.9978 (0.9966-0.9989)	1.0018 (1.0009-1.0026)	**1.0005 (1.0001-1.0009)**
	7-12h	1.0004 (0.9998-1.0009)	1.0005 (0.9989-1.0020)	1.0032 (1.0022-1.0042)	0.9999 (0.9996-1.0003)
	13-18h	1.0010 (1.0004-1.0016)	1.0003 (0.9990-1.0016)	1.0024 (1.0015-1.0033)	0.9996 (0.9992-0.9999)
	19-24h	1.0006 (1.0001-1.0011)	1.0030 (1.0017-1.0043)	**1.0039 (1.0029-1.0049)**	0.9999 (0.9995-1.0003)
	25-48h	1.0015 (1.0007-1.0023)	1.0013 (0.9994-1.0032)	1.0023 (1.0006-1.0041)	0.9989 (0.9984-0.9994)
	49-72h	**1.0024 (1.0015-1.0032)**	**1.0064 (1.0046-1.0083)**	0.9970 (0.9951-0.9989)	0.9988 (0.9982-0.9994)

Table 11 (continued)

Constituents	Moving average lag (hour)	Respiratory			
		Spring (Mar.-May)	Summer (Jun.-Aug.)	Fall (Sep.-Nov.)	Winter (Dec.-Feb.)
Pb [4)]	0-6h	0.9997 (0.9993-1.0001)	1.0006 (1.0000-1.0012)	1.0014 (1.0008-1.0020)	**1.0008 (1.0004-1.0012)**
	7-12h	1.0008 (1.0003-1.0012)	0.9994 (0.9987-1.0001)	1.0011 (1.0003-1.0018)	0.9997 (0.9994-1.0001)
	13-18h	0.9993 (0.9988-0.9997)	1.0004 (0.9998-1.0010)	**1.0024 (1.0017-1.0031)**	0.9999 (0.9995-1.0002)
	19-24h	0.9995 (0.9991-0.9999)	1.0021 (1.0014-1.0027)	1.0017 (1.0011-1.0023)	0.9995 (0.9991-0.9999)
	25-48h	0.9999 (0.9992-1.0006)	1.0027 (1.0018-1.0037)	1.0003 (0.9990-1.0016)	0.9988 (0.9983-0.9993)
	49-72h	**1.0010 (1.0003-1.0017)**	**1.0045 (1.0036-1.0054)**	0.9969 (0.9955-0.9983)	0.9990 (0.9984-0.9996)
Zn [3)]	0-6h	0.9960 (0.9942-0.9978)	1.0025 (1.0008-1.0042)	0.9963 (0.9937-0.9990)	**1.0084 (1.0062-1.0106)**
	7-12h	0.9980 (0.9960-1.0001)	0.9926 (0.9909-0.9942)	0.9946 (0.9915-0.9977)	0.9929 (0.9906-0.9951)
	13-18h	1.0000 (0.9980-1.0021)	1.0020 (1.0000-1.0041)	1.0045 (1.0017-1.0073)	0.9961 (0.9939-0.9984)
	19-24h	1.0018 (0.9998-1.0038)	1.0076 (1.0058-1.0095)	**1.0130 (1.0102-1.0159)**	1.0059 (1.0037-1.0082)
	25-48h	1.0013 (0.9980-1.0047)	1.0070 (1.0031-1.0110)	1.0039 (0.9980-1.0098)	0.9952 (0.9917-0.9988)
	49-72h	**1.0055 (1.0022-1.0088)**	**1.0080 (1.0043-1.0118)**	0.9925 (0.9868-0.9984)	0.9974 (0.9934-1.0014)

Bold face indicates statistical significance (p-value < 0.05) and shows the strongest positive association between each chemical constituent and health outcome.

1) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 10 $\mu g/m^3$ increase of each chemical constituent ($PM_{2.5}$ mass, OC, EC, NH_4^+, NO_3^- and SO_4^{2-})

2) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 1 $\mu g/m^3$ increase of each chemical constituent (Cl^-)

3) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.1 $\mu g/m^3$ increase of each chemical constituent (Mg^{2+}, Na^+, Ca, Fe, K, Zn)

4) Estimated odds ratio (OR) and 95% confidence interval (CI) are presented as 0.01 $\mu g/m^3$ increase of each chemical constituent (Zn)

초 록

시간 변화에 따른 초미세먼지($PM_{2.5}$) 구성 성분과 심혈관계 질환 및 호흡기계통 질환 발생의 상관성 연구: 실시간 응급실 방문 자료를 중심으로

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다양한 역학 연구에서 초미세먼지(공기 역학적 직경이 2.5 μm 보다 작은 미세먼지, $PM_{2.5}$)가 인간의 건강에 유해한 영향을 주는 것으로 밝혀졌다. 하지만, $PM_{2.5}$의 화학적 구성 성분에 대한 역학 연구 및 시간 변화에 따른 상관성 연구는 다양하게 진행되고 있지 않은 상황이다. 따라서 본 연구에서는 시간-층화 환자-교차(time-stratified case-crossover) 연구를 활용하여 $PM_{2.5}$의 화학적 구성 성분과 심혈관계 질환 및 호흡기계통 질환으로 인해 응급실을 방문한 환자들 간의 시간적 변화를 연구하고자 한다.

본 연구의 연구 기간은 2013년 1월 1일부터 12월 31일까지이며, 대한민국 서울을 연구 대상으로 연구를 실시하였다. 건강 자료는 국가응급환자진료정보망(National Emergency Department Information System, NEDIS)의 심혈관계 질환 및 호흡기계통 질환 발생으로 인한 응급실 방문 자료를 사용하였다 (분류 코드: ICD-10, 심혈관계 질환, I00-I99, 호흡기 계통 질환, J00-J99). $PM_{2.5}$ 질량농도 및 화학적 구성 성분 농도의 시

간별 측정 자료는 서울시 불광동(37.36° N, 126.56° E)에 위치한 실시간 모니터링 사이트에서 측정된 자료를 사용하였다. 실시간 측정 자료 중 QA/QC가 수행되어 측정된 $PM_{2.5}$ 질량농도 및 13개의 화학적 구성 성분(OC, EC, Cl^-, Mg^{2+}, Na^+, NH_4^+, NO_3^-, SO_4^{2-}, Ca, Fe, K, Pb, Zn)의 농도 자료를 사용하였다. 온도(°C), 상대습도(%)와 기압(hPa) 등의 기상 변수들이 혼란 변수로 적용되었다. 본 연구에서는 $PM_{2.5}$가 건강에 미치는 영향을 측정하기 위해, 시간-층화 환자 교차연구 방법을 사용하였고, 95% 신뢰 수준에서 odds ratio (ORs)를 구하기 위해 조건부 로지스틱 회귀분석을 실시하였다. 또한, 지연 효과를 고려하여 이동 평균(moving average)이 적용된 6개의 지연 구간을 설정하였다 (1-6(h), 7-12(h), 13-18(h), 19-24(h), 25-48(h), 49-72(h)). 또한, 본 연구에서는 65세 이상 인구 집단에 대한 영향과 계절 변화에 따른 영향도 함께 살펴보았다.

연구 결과, 전체 인구 집단에서 심혈관계 질환 발생에 가장 큰 영향을 준 지연 구간은 19-24(h) 구간($PM_{2.5}$ 중량농도, OC, EC, Cl^-, Ca, Fe, Zn)과 25-48(h) 구간(NH_4^+, NO_3^-, SO_4^{2-})으로 밝혀졌고, 호흡기계통 질환 발생에 가장 큰 영향을 준 지연 구간으로는 0-6(h) 구간(NO_3^-, Pb), 7-12(h) 구간(K), 19-24(h) 구간($PM_{2.5}$ 중량농도, OC, EC, Cl^-, Ca, Fe, Zn), 25-48(h) 구간(NH_4^+, SO_4^{2-})으로 밝혀졌다. 65세 이상 인구 집단은 19-24(h) 구간($PM_{2.5}$ 질량농도, OC, EC, Cl^-, Ca, Fe, Zn), 25-48(h) 구간(NO_3^-)에서 심혈관계 질환 발생에 가장 큰 영향을 받는 것으로 밝혀졌고, 19-24(h) 구간(OC, EC, Fe, Zn)에서 호흡기계통 질환 발생에 가장 큰 영향을 받는 것으로 밝혀졌다. 특히, EC는 모든 화학적 구성 성분 중 질환 발생에 가장 큰 영향을 주는 것으로 밝혀졌다.

모든 계절에 대해서, $PM_{2.5}$ 질량 농도 및 Mg^{2+}를 제외한 모든 화학적 구성 성분이 심혈관계 질환 및 호흡기계통 질환 발생에 유의한 영향을

주는 것으로 분석되었다.

본 연구의 결과는 $PM_{2.5}$ 화학적 구성성분이 건강에 미치는 영향을 밝히는데 주요한 근거로 사용될 것이다.

주요어 : $PM_{2.5}$, $PM_{2.5}$ 구성 성분, 응급실 방문 자료, 심혈관계 질환, 호흡기계통 질환

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