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The Health Impact of Fine Dust[1] and Its Policy Implications

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Korea's particulate matter policies remain in need of continued scrutiny, as particulate matter concentrations in Korea, while having trended downward recently, may well increase as the world progresses into recovery from covid-19. Our analysis of particulate matter data and death statistics for the city of Seoul found associations between short-term exposure to low-level particulate matter concentrations and the risk of death in certain sensitive groups. In the United States and Canada, national agencies such as the US Centers for Disease Control and Prevention, the US Environmental Protection Agency, Health Canada, and Environment and Climate Change Canada have implemented policies on particulate matter and ambient air pollution and have provided action guidelines specifically tailored to sensitive and socially vulnerable groups in the event of high-level particulate matter concentrations. Assessments of the health hazards of particulate matter should be continuously updated, reflecting the latest findings. Monitoring of particulate matter concentrations needs to be strengthened, and such health services should be provided as to protect sensitive and socially vulnerable groups from exposure to high-level particulate matter concentrations. The system used for inspecting air quality in such public facilities as long-term care facilities and community elderly centers should undergo continuous examination for improvement.

1) Fine dust refers to particulate pollutants that are suspended in the air. Here, we use the terms PM_{10} and $PM_{2.5}$ to refer to particulate pollutants of a diameter of 10 micrometers or less and of 2.5 micrometers or less. We will more often use the term particulate matter to collectively refer to both PM_{10} and $PM_{2.5}$.

Introduction

Subsequent to the enactment in 2019 of the Special Act on the Reduction and Management of Fine Dust, the Korean government has taken various measures to reduce health hazards stemming from exposure to high-level concentrations of particulate matter. For example, with the latest Comprehensive Plan on Fine Dust Management, the government has presented the direction of policy measures and official programs by means of which to reduce and control particulate matter concentrations for the five years to 2024. The government also distributed the Manual on Coping with High-Level Particulate Matter Concentrations to the public with a view to protecting the health of such groups highly vulnerable to air pollution, such as infants, toddlers, and schoolchildren, as much as possible from exposure to particulate matter.

With efforts taken in and outside the country, particulate matter concentrations have declined in recent years in Korea. $PM_{2.5}$ concentrations for the months of March to May 2022 were recorded on average at 20 micrograms per cubic meter, the lowest since they were first measured, with no single day in the month of March accompanied by the execution of emergency particulate matter reduction measures. However, the progress did not go to such an extent as recommended by the World Health Organization. Moreover, air pollutant emissions might well increase both inside and outside the country as the world progresses farther into recovery from covid-19. Against this backdrop, this study explores the association between exposure to recent lower-level particulate matter concentrations and health outcomes, looks from a comparative perspective at policies taken in Korea and elsewhere to cope with exposure to particulate matter, and draws implications for policy for Korea.

Health impact of exposure to particulate matter

This study uses national data to examine how exposure to PM_{10} and $PM_{2.5}$ relates to the number of deaths that occurred in Seoul and whether the risks of death from exposure to particulate matter vary across demographic characteristics like sex and age.

The data on air pollution—daily concentration levels of PM_{10} and $PM_{2.5}$—on which this study draws comes from the Urban Air Monitoring Network dataset as uploaded on the Air Korea website of the National Institute of Environmental Research. The data we obtained from the Korea Meteorological Administration's Automated Synoptic Observing System, which contains average temperatures, average dew point temperatures, and average relative humidity by city and province, provided model adjustment variables for our analysis of the association of exposure to particulate matter with mortality. In addition, we used annual death data from Statistics Korea's Integrated Microdata Service, which furnished daily numbers of deaths for Seoul and such variables as the deceased's sex, age, education level, and pre-death occupation.

The period that this study covers spans the five years leading up to 2020. We classified the counts of deaths that occurred daily in Seoul by total, sex, and age range. We assumed a quasi-Poisson distribution for the death data. The adjustment variables used are date, average temperature by day, average dew point temperature, and day of the week. We used, in addition, a generalized additive model to allow for the nonlinearity of the relationship between temperature variables and mortality. This study looks to assess the lag effects of exposure to particulate matter, but only up to Lag 4 (in the four days prior to death), given that, as noted in a previous study[2], the health effects of particulate matter not only occur on the day of exposure but persist, if only for a few days, thereafter.

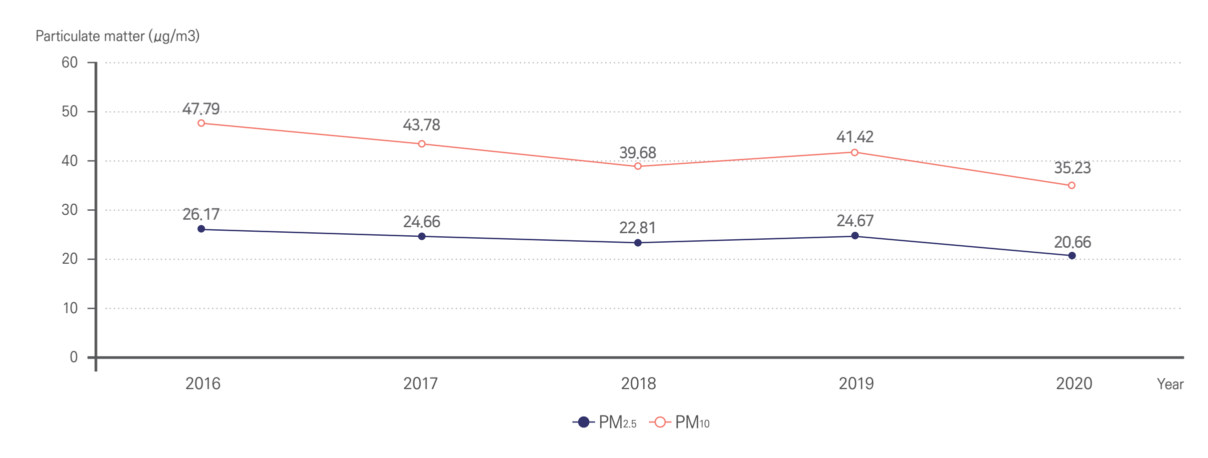
PM_{10} and $PM_{2.5}$ concentrations in Seoul overall have trended downward since 2016, with their average levels, despite having risen in 2019 above the 2018 level, falling in 2020 to their lowest in the preceding five years, as shown in Figure 1.

In an analysis we conducted of a sample of 221,042 deaths that occurred in the period 2016~2020 in Seoul, the relative risk of death from exposure to particulate matter was higher at Lag 0 than at Lag 1, 2, 3, or 4, but not by a statistically significant amount, as shown in Table 1, nor was there any statistically significant risk in the lagged effects. However, such an outcome may be due to the relatively short period this study covers, during which particulate matter concentrations, trending downward in general, have been lower than in the years preceding it.

Our age-group analysis found a significant association between same-day exposure to $PM_{2.5}$ concentrations and death for those aged 65 and older. Also, the relative risk of death from exposure to particulate matter was higher for groups 65 and older and 35~64 years of age than for younger groups (see Table 2). In addition, relative risks of death were higher with exposure to $PM_{2.5}$ than with exposure to PM_{10}. In addition, the relative risk of death from exposure to $PM_{2.5}$ concentrations for women at Lag 0, Lag 1, Lag 2, and Lag 3 increased statistically significantly with each inter-quartile range increase, with the association at its strongest at Lag 0 (see Table 3).

2) Zeka, A., Zanobetti, A., & Schwartz, J. (2005). Short term effects of particulate matter on cause specific mortality: effects of lags and modification by city characteristics. *Occupational and environmental medicine*, 62(10), 718–725.

[Figure 1] Annual average particulate matter concentrations in Seoul, 2016~2020



Source: Author's calculations based on Air Korea's Urban Air Monitoring Network dataset

[Table 1] Poisson regression analysis of the association between exposure to particulate matter and death[1)]

Lag	PM_{10}			$PM_{2.5}$		
	RR[2)]	95% CI	P value	RR[2)]	95% CI	P value
Lag 0	1.004	0.997-1.010	0.253	1.005	0.999-1.011	0.098
Lag 1	1.001	0.995-1.007	0.783	1.002	0.996-1.007	0.606
Lag 2	0.998	0.992-1.004	0.522	0.999	0.993-1.005	0.699
Lag 3	1.000	0.994-1.006	0.967	1.001	0.995-1.006	0.772

Note: 1) Independent variables are air pollutant (PM_{10} or $PM_{2.5}$), date, average temperature, average dew point temperature, average relative humidity, and day of the week.
2) Relative risk (RR) values for each interquartile range (IQR) increase in exposure to particulate matter

Source: Authors' calculations using Poisson regression analysis.

[Table 2] Poisson regression analysis of the association between exposure to particulate matter and death, by age group[1)]

Age	Lag	PM_{10}			$PM_{2.5}$		
		RR[2)]	95% CI	P value	RR[2)]	95% CI	P value
0~19	Lag 0	0.997	0.937-1.060	0.914	1.006	0.949-1.067	0.833
	Lag 1	0.997	0.936-1.061	0.920	0.987	0.930-1.047	0.663
	Lag 2	1.003	0.942-1.067	0.938	0.998	0.941-1.059	0.950
20~34	Lag 0	1.007	0.968-1.048	0.740	1.004	0.967-1.042	0.830
	Lag 1	0.990	0.951-1.030	0.613	0.993	0.957-1.031	0.720
	Lag 2	1.012	0.973-1.052	0.565	1.005	0.968-1.042	0.812
35~64	Lag 0	1.010	0.999-1.022	0.074	1.009	0.998-1.019	0.108
	Lag 1	1.009	0.998-1.021	0.110	1.010	0.999-1.020	0.070
	Lag 2	1.009	0.997-1.020	0.132	1.007	0.997-1.018	0.185
65 and older	Lag 0	1.006	0.998-1.013	0.129	1.008	1.001-1.015	0.035
	Lag 1	1.002	0.995-1.010	0.537	1.002	0.995-1.009	0.537
	Lag 2	0.997	0.990-1.005	0.467	0.998	0.992-1.005	0.636

Note: 1) Independent variables are air pollutant (PM_{10} or $PM_{2.5}$), date, average temperature, average dew point temperature, average relative humidity, and day of the week.
2) Relative risk (RR) values for each interquartile range (IQR) increase in exposure to particulate matter.

Source: Authors' calculations using Poisson regression analysis.

[Table 3] Poisson regression analysis of the association between exposure to particulate matter and death, by sex[1)]

Sex	Lag	PM_{10}			$PM_{2.5}$		
		RR[2)]	95% CI	P value	RR[2)]	95% CI	P value
Men	Lag 0	1.004	0.996-1.012	0.299	1.005	0.998-1.012	0.195
	Lag 1	1.003	0.996-1.011	0.436	1.001	0.994-1.008	0.719
	Lag 2	0.999	0992-1.007	0.814	0.999	0.992-1.006	0.789
	Lag 3	0.999	0.992-1.007	0.863	1.001	0.995-1.008	0.694
	Lag 4	1.005	0.998-1.013	0.169	1.004	0.997-1.010	0.326

Women	Lag 0	1.020	1.012-1.029	<0.001	1.015	1.006-1.024	<0.001
	Lag 1	1.014	1.005-1.023	0.002	1.009	1.001-1.018	0.032
	Lag 2	1.003	0.994-1.012	0.496	1.010	1.002-1.018	0.019
	Lag 3	1.012	1.003-1.020	0.009	1.008	1.000-1.016	0.046
	Lag 4	1.003	0.995-1.012	0.462	1.003	0.995-1.011	0.471

Note: 1) Independent variables are air pollutant (PM_{10} or $PM_{2.5}$), date, average temperature, average dew point temperature, average relative humidity, and day of the week.
2) Relative risk (RR) values for each interquartile range (IQR) increase in exposure to particulate matter.

Source: Authors' calculations using Poisson regression analysis.

Trends in health policies in response to particulate matter concentrations

The US first enacted the Clean Air Act in 1963[3] and, with it as a legal basis, put in place measures such as the National Ambient Air Quality Standard (NAAQS) and Air Quality Index (AQI) to proactively cope with exposure to air pollution. The US Centers for Disease Control and Prevention provide, via the National Center for Environmental Health, educational resources on ambient air pollution and particulate matter. The CDC's air pollution education resources define what particulate matter is and where it mainly comes from, discuss the health impact and risks of particulate matter, and recommend specific actions to take to cope with days of high fine dust concentrations. Additionally, the US has sub-federal programs in place in response to high-level particulate matter concentrations. For example, the state of California requires all indoor air cleaning devices sold in the state to be certified by the California Air Resources Board. The board also provides information resources based on which users can choose air cleaners that best fit their needs for improving indoor air quality. As the ambient air quality turned severely hazardous in Portland, Oregon, with an Air Quality Index of above 500, following the devastating wildfires that had erupted in September 2020, the city government deployed community centers to provide emergency shelter against exposure to ambient air pollutants and distributed KN95 masks to homeless people. Also, the Joint Office of Homeless Services of Multnomah County, Oregon, set up and ran additional emergency shelters in collaboration with local volunteer organizations.

Health Canada, together with Environment and Climate Change Canada, developed the Air Quality Health Index (AQHI) in 2008, with a view to keeping the public informed of daily air quality conditions and the precautionary actions they should take in response. The AQHI, constructed based on time series analysis, measures excess mortality risks associated with ground-level ozone, ultra-fine dust, and nitrogen dioxide on a scale of 1 to 10.

The Canadian government further classifies the strategies it recommends people take in response

3) Heinzerling, L. (2001). The Clean Air Act and the Constitution. *Louis U. Pub. L. Rev.*, 20, 121.

to certain AQHI levels into those for the general population and those for at-risk groups such as young children, people with underlying conditions, and older adults. Health Canada informs the public at large of the importance of ventilation in indoor spaces and of how they should ventilate as per the guidance tied to AQHI levels, emphasizing the usefulness of indoor air cleaners. The Canadian health ministry also runs podcasts where panels of experts in health and environment are invited to discuss the health impacts of ambient air pollution and particulate matter, socio-environmental determinants of health, and what people can do on their own to mitigate the effects of particulate matter on their health.

There are several previous studies that have pointed out how effective individual-level actions can be in reducing exposure to ambient air pollutants and particulate matter[4),5)] . However, some other studies have raised concerns that these personal-level approaches, effective though they might be in the short-term, can cause unintended consequences and, by placing too much responsibility on individuals for their health, may not be as effective in the long-term[6)]. This skepticism was also evident in the American Thoracic Society's recent workshop report, where "personal interventions" were looked on as secondary to policies, which are deemed to be of primary importance, aimed at reducing the health risks of ambient air pollution by driving "reductions in pollution emissions."[7)]

Korea's policy response to particulate matter: achievements and limitations

Since the announcement in 2017 of the Comprehensive Plan on Fine Dust Management, various pieces of legislation have been enacted, notable among them the Clean Air Conservation Act and the Special Act on the Reduction and Management of Fine Dust, laying the legal groundwork on which to cope with exposure to particulate matter. The Climate Change Health Risk Assessment was conducted following the Framework Act on Health and Medical Services and a health risk assessment has been conducted on a national scale as regards air quality.

However, while the law requires that the Comprehensive Plan on Fine Dust Management be updated every five years and the Climate Change Health Risk Assessment be conducted on a regular basis, most particulate matter regulations that are in place remain but as recommendations that lack binding force. One reason for such a situation might be that there is not enough research evidence to establish precisely how much exposure to fine dust constitutes a health risk. The setting up of precise regulations on fine dust concentrations should be predicated on a precise understanding of the level of fine dust concentrations that can pose a health risk.

4) Chen, C., & Zhao, B. (2011). Review of relationship between indoor and outdoor particles: I/O ratio, infiltration factor and penetration factor. *Atmospheric Environment*, 45, 275-288.

5) Cui, X., Li, F., Xiang, J., Fang, L., & Chung, M. K. (2018). Cardiopulmonary effects of overnight indoor air filtration in healthy non-smoking adults: a double-blind randomized crossover study. *Environment International*, 114, 27-36.

6) Laumbach, R., & Cromar, K, (2022). Personal interventions to reduce exposure to outdoor air pollution. *Annals Review of Public Health*, 43, 293-309.

7) American Thoracic Society. (2021). Personal interventions for reducing exposure and risk for outdoor air pollution: An official American Thoracic Society Workshop Report. *Annals of the American Thoracic Society*, 18(9), 1435-1443.

For this reason, further research studies should be encouraged to advance the state of knowledge about the health impact of exposure to fine dust. Also important is to keep updated on the latest developments in research conducted abroad pertaining to relevant subjects. Korea's ambient air quality standards are not as stringent as the World Health Organization's. Whether to adjust Korea's air quality standards in line with the WHO guidelines should be determined based on further deliberation and research evidence.

In recent years, air quality guidelines have been developed in Korea, including the "Rules of Thumb for Protecting Health from Fine Dust" and the "Healthy Tips Against Fine Dust, For Individuals with Underlying Conditions," as well as outreach materials in the form of videos and news cards.

The air quality guidelines developed in Korea target various groups, including the general public, specific organizations, and sensitive groups. However, the information provided about fine dust can be hard to access for those groups for whom it is intended, unless they are interested enough to go the length of visiting the source website and actively seek it out.

Korea's policies on particulate matter distinguish their target groups mostly into infants and toddlers, older adults, and those with underlying conditions. Of people with underlying conditions, those with asthma and chronic obstructive pulmonary disease are especially susceptible to exposure to particulate matter, as are such socially vulnerable groups as homeless people, foreigners, and people with disabilities. There is a need for efforts from the government and hospitals to disseminate particulate matter coping guidelines and find effective ways to do so to people with underlying conditions in the event of high-level particulate matter concentrations. Policy interventions on particulate matter should also consider socially vulnerable groups.

The examples of policies on particulate matter abroad discussed above also suggest that Korea needs to have policy strategies in place at municipal levels for coping with high-level fine dust concentrations occurring in certain localities.

Concluding remarks

Our analysis of several years of data found that, despite the downward trends in recent years in fine dust concentrations, there were associations in certain population groups between short-term exposure to low-level fine dust concentrations and death risks.

Given that the levels of fine particulate matter concentrations recorded in Korea on the whole remain above the latest ceiling—lowered in 2021—set by the World Health Organization, Korea's health policies concerning allowable concentrations of fine dust will need an overhaul informed by new research assessments of the health hazards of fine particulate matter concentrations. Considering that the health impact of exposure to fine dust is greater in older adults than in people of other age groups, the priority of fine dust policies may, in the years to come, be determined by the changing proportion of those aged 65 and over in the population.

Particulate matter concentration levels recorded in Korea in the recent past, as indicated in a recent study[8], remained among the highest in the world, an outcome that has drawn public attention and, as a result, led to relevant legislation and guidelines. Whereas in the US and Canada, where policies on particulate matter are integrated into a broader set of policies concerning ambient pollution, some of Korea's regulations on ambient pollution focus exclusively on particulate matter. As its socioenvironmental circumstances differ from other countries', Korea will need to take into account, in the process of improving its policies on particulate matter, the socioenvironmental features that are specific to the country, drawing on precise assessments of the status of its own particulate matter concentrations and of the exposure to particulate matter among sensitive groups and socially vulnerable groups.

There are various guidelines and practice strategies developed to help users better cope with exposure to particulate matter. However, there is a need to come up with effective means of delivery by which to provide existing information to those who need it. This would require budgetary backing to support efforts to promote access to information on particulate matter and ambient air pollution. Guidelines and strategies for coping with exposure to particulate matter can be delivered via such means as television channels, social media, or public transit advertising, whichever works best for a given target group.

While Korea has in place master plans and legal frameworks by which to cope with fine dust concentrations, the current situation requires additional efforts to improve guidelines for sensitive and socially vulnerable groups and to keep relevant policies under scrutiny to ensure that nothing goes awry in their implementation.

As for groups that are especially sensitive to exposure to fine dust, such as newborns, toddlers, and older adults, and socially vulnerable groups, for whom getting information online can be difficult, education programs about ambient air pollution need to be provided to their guardians and, where applicable, to their responsible facilities. Also, public-use facilities like long-term care facilities and community elderly centers should undergo regular inspections of their indoor air quality, and the methods used for such inspections should be subject to continuous review for improvement. Policies concerning particulate matter should move in the direction of enhancing intra-community education and expanding the range of means of information delivery regarding particulate matter. In addition, Korea should consider having a system ready, as in the US case seen earlier, so as to be able, in the event of high-level fine dust concentrations, to provide emergency health services, including shelters and facial masks, to vulnerable groups.

Lastly, Korea will need to set up guidelines and coping strategies that commonly cover both particulate matter and other air pollutants such as ozone and volatile organic compounds, which in recent years have emerged as sources of health hazards and whose control has become an issue of growing importance.

8) Yu, W., Ye, T., Zhang, Y., Xu, R., Lei, Y., Chen, Z., ... & Guo, Y. (2023). Global estimates of daily ambient fine particulate matter concentrations and unequal spatiotemporal distribution of population exposure: a machine learning modelling study. *The Lancet Planetary Health*, 7(3), e209–e218.