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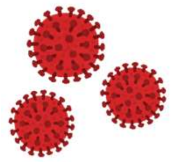
MDPI

Air Quality Variation in Wuhan, Daegu, and Tokyo during the Explosive Outbreak of COVID-19 and Its Health Effects



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INTRODUCTION

Since the initial report of cases in Wuhan, China, on 31 December 2019, the coronavirus disease 2019 (COVID-19) spread worldwide in a short period of time and is still in progress.

During the pandemic, 4,445,920 confirmed cases were reported in 213 countries and 298,440 people have died so far from the COVID-19 outbreak, as of 14 May 2020. In this study, the air quality variation with the trend of COVID-19 at Wuhan in China, Daegu in South Korea, and Tokyo in Japan experienced explosive outbreaks in a short period of time, which was estimated based on the actual measured data from air pollution monitoring stations (AQMS). The health effect of the reduced $PM_{2.5}$ dose due to COVID-19 on 10-year-old children in each city was also quantitatively assessed.

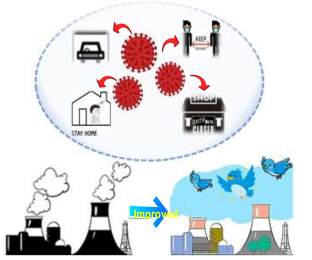

Figure 1. A pictorial concept of air quality improvement according to the COVID-19 measures.

TARGET CITIES & SITUATION

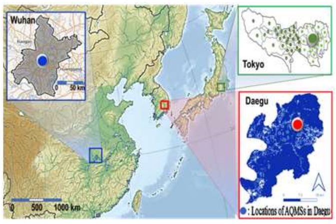

Figure 2. The maps of Wuhan, Daegu, and Tokyo and the locations of air pollution monitoring stations (AQMS) in each city.

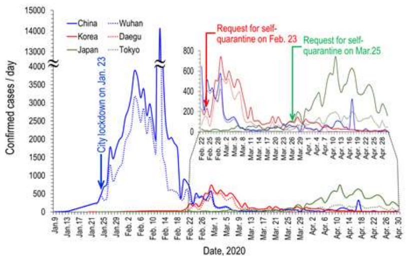

Figure 3. Timely variation of the confirmed cases of COVID-19 per day in Wuhan(China), Daegu(Korea), and Tokyo (Japan).

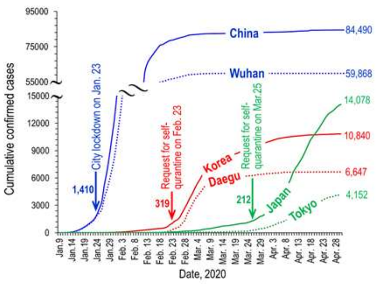

Figure 4. Timely variation of the cumulative status of COVID-19 in Wuhan, Daegu, and Tokyo.

In this study, the data of $PM_{2.5}$ and NO_2 measured continuously at one-hour intervals at the air quality monitoring stations (AQMSs) of three cities were studied. The data monitored at the AQMSs of three cities from 9 January to 29 April 2020 became the subjects of this study.

To better represent the time series trend of $PM_{2.5}$ concentration over the whole measurement period, all data were treated with the 5-day simple moving average (SMA) by the following equations:

$$\bar{C}_{d\,SMA} = \frac{C_d + C_{d-1} + \cdots + C_{d-(n-1)}}{n} = \frac{1}{n}\sum_{i=0}^{n-1} C_{d-i}$$

RESULTS

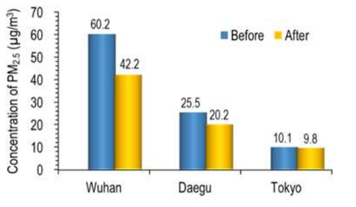

Figure.5 Comparison of $PM_{2.5}$ concentration before and after each city's self-quarantine.

The decreasing rate of $PM_{2.5}$ concentration in each city was 29.9, 20.9 and 3.6% in Wuhan, Daegu and Tokyo, respectively.

Xu et al. [19] reported that, during the defined 3-week lockdown period, Wuhan's PM2.5 level went down 44% from 2019. In the case of Tokyo, the decreasing rate was significantly lower compared to the two cities, probably because of usual low $PM_{2.5}$ concentration.

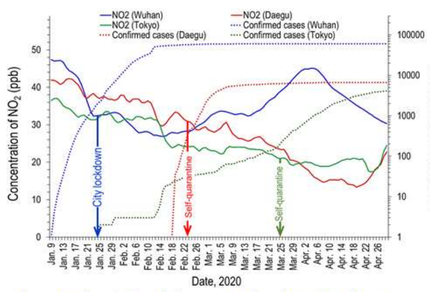

Figure 6. Daily variations of the concentration of $PM_{2.5}$ in Wuhan, Daegu, and Tokyo, with the cumulative confirmed cases of COVID-19.

Unlike Tokyo, where the concentration was not high before the self-restraint regulation, there was a clear reduction in the $PM_{2.5}$ concentration in Wuhan and Daegu. Although it was not a continuous reduction, the concentration of $PM_{2.5}$ in Wuhan showed a significant decrease. It is necessary to assess whether this is a simple seasonal variation or a change due to the city lockdown. In Daegu, the concentration of $PM_{2.5}$ shows a temporary increase or decrease, but the trend of decline was evident in the overall period.

The overall decline of the $PM_{2.5}$ in Tokyo is not seen, but it is clearly decreasing after request for self-quarantine on 25 March.

Apart from the overall pattern of decline, several short reduction intervals due to rainfall were also clearly found in all three cities.

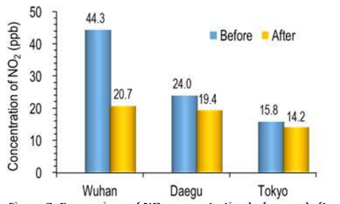

Figure 7. Comparison of NO_2 concentration before and after each .

Wuhan, Daegu, and Tokyo recorded 53.2, 19.0, and 10.4% fall of NO_2, respectively. Although it is a short-term decline, it can be said that this result is very meaningful for the citizens' health of three cities, especially Wuhan citizens. The model calculation by Dutheil et al. [2020] suggested that the reduction of NO_2 in China due to COVID-19 epidemic during a time period of two months saved around 100,000 lives in China.

Exposure Assessment

$$Reduced\ Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}\ (\mu g) = Reduced\ C_{PM2.5} \times I/O\ ratio \times F_{dep.} \times T_{exp.} \times R_{bre.}$$

Table 1. The variables for calculation of the reduced Dose$PM_{2.5}$ (μg) for the 10-year-old children per day and over two months after the self-quarantine of each city.

	Behavioral patterns of 10-year-old children in the day	Activity time (h)	Total exposure period ($T_{exp.}$, day)	$C_{PM2.5}$ (μg/m³) reduced in 2020	I/O ratio	$F_{dep.}$ Br.	$F_{dep.}$ A.I.	$R_{bre.}$ (m³/h)
Wuhan	Sleep	9	60	18	0.94	0.209	0.355	0.246
	Sitting/Rest	4	60	18	0.94	0.218	0.370	0.301
	Light activity	10	60	18	0.94	0.270	0.459	0.888
	Heavy activity	1	60	18	0.94	0.300	0.510	1.610
Daegu	Sleep	9	60	5.3	0.66	0.123	0.355	0.246
	Sitting/Rest	4	60	5.3	0.66	0.128	0.370	0.301
	Light activity	10	60	5.3	0.66	0.159	0.459	0.888
	Heavy activity	1	60	5.3	0.66	0.176	0.510	1.610
Tokyo	Sleep	9	60	0.36	0.39	0.123	0.355	0.246
	Sitting/Rest	4	60	0.36	0.39	0.128	0.370	0.301
	Light activity	10	60	0.36	0.39	0.159	0.459	0.888
	Heavy activity	1	60	0.36	0.39	0.176	0.510	1.610

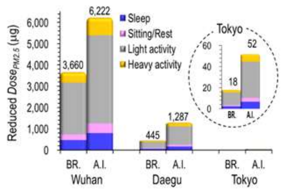

Figure 8. The reduced $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (μg) at bronchiolar and alveolar-interstitial (AI) region over two months after the self-quarantine of each city.

Wuhan, which had the largest decrease of $PM_{2.5}$ concentration (18 μg/m³), also showed the largest reduced $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (3,660 μg at Br. and 6,222 μg at AI), followed by Daegu (445 μg at Br. and 1,287 μg at AI) and Tokyo (18 μg at Br. and 52 μg at AI). Additionally, the reduced $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (μg) varied greatly depending on the children's behavior patterns. In all three cities, the reduced $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (μg) was high, in order of light activity > heavy activity > sleep > sitting/rest.

Airway Inflammation Delay Effect

$$Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}\ (mg/kg) = Dose_{Mouse}(mg/kg) \times K_m\ ratio$$

where K_m ratio = $\frac{K_{m\ Mouse}}{K_{m\ 10-year-old\ children}}$.

Each K_m i.e., $K_{m\ Mouse}$ and $K_{m\ 10\text{-}year\text{-}old\ children}$ can be calculated with the following equation:

$$K_m = \frac{Weight\ (kg)}{BSA(m^2)}$$

The $K_{m\ 10\text{-}year\text{-}old\ children}$ for the Chinese, Korean, and Japanese were calculated by the average weight and body surface area (*BSA*) of boys and girls in each country. Their *BSA* were also calculated from following:

$$\begin{aligned} BSA_{10\text{-}year\text{-}old\ children} &= 0.008883 \times Weight^{0.444} \times Height^{0.663} \\ &= 0.007331 \times Weight^{0.425} \times Height^{0.725} \\ &= 0.00713989 \times Weight^{0.427} \times Height^{0.516} \end{aligned}$$

Then, the $Dose_{PM2.5}$ for the AAI of 10-year-old children, i.e., the *AAI* $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (mg), can be calculated by following:

$$AAI\ Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}\ (mg) = Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}\ (mg/kg) \times Weight_{10\text{-}year\text{-}old\ children}\ (kg)$$

In this study, the *AAI* $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ (mg) was calculated by the $Dose_{Mouse}$ (mg/kg), with 1.58 mg/kg (31.6 μg per mouse), on the assumption of medium air quality.

Additionally, the time (day) to reaching the *AAI* $Dose_{PM2.5\ 10\text{-}year\text{-}old\ children}$ can be calculated by the following:

$$Day\ to\ reaching\ AAI\ Dose_{PM2.5\ 10-year-old\ children} = \frac{AAI\ Dose_{PM2.5\ 10-year-old\ children}}{Daily\ Dose_{PM2.5\ 10-year-old\ children}}$$

Table 2. Reduced $Dose_{PM2.5}$ (μg) at the bronchiolar and AI regions of the 10-year-old children per day and over two months after the city lockdown/self-quarantine of each city.

	Behavioral patterns of 10-year-old children in the day	Activity time (h)	Reduced $Dose_{PM2.5}$ (μg) at Br. 1 day	Reduced $Dose_{PM2.5}$ (μg) at Br. 2-month	Reduced $Dose_{PM2.5}$ (μg) at A.I. 1 day	Reduced $Dose_{PM2.5}$ (μg) at A.I. 2-month
Wuhan	Sleep	9	7.82	469	13	798
	Sitting/Rest	4	4.43	266	8	452
	Light activity	10	40.57	2434	69	4138
	Heavy activity	1	8.17	490	14	834
	Total reduced $Dose_{PM2.5}$ (μg)		***61***	***3660***	***104***	***6222***
Daegu	Sleep	9	0.95	57	3	165
	Sitting/Rest	4	0.54	32	2	93
	Light activity	10	4.93	296	14	855
	Heavy activity	1	0.99	60	3	172
	Total reduced $Dose_{PM2.5}$ (μg)		***7***	***445***	***21***	***1286***
Tokyo	Sleep	9	0.04	2.3	0.1	7
	Sitting/Rest	4	0.02	1.3	0.1	4
	Light activity	10	0.20	11.9	0.6	34
	Heavy activity	1	0.04	2.4	0.1	7
	Total reduced $Dose_{PM2.5}$ (μg)		***0.30***	***17.9***	***0.9***	**52**

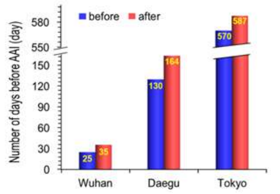

Figure 9. The number of days it takes to cause AAI by $PM_{2.5}$ exposure, before and after the city lockdown/self-quarantine at each city.

In the case of Wuhan, it took 25 days before the city lockdown, but 35 days after the city lockdown. Meanwhile, it was calculated that it took 130 to 164 days in Daegu and 570 to 587 days in Tokyo.

While it is easy to predict that inhaling clean air is good for children's health, this study was able to quantitatively evaluate that the temporarily reduced $PM_{2.5}$ concentration due to COVID-19 was effective for the delaying the AAI in three cities of Asia.

Meanwhile, there is still a possibility that much more harmful household air pollutants may have been exposed by staying indoors during the city lockdown/self-quarantine periods.

SUMMARY

According to the study of Cohen et al. [2015], 4.6 million people are dying annually because of the diseases and illnesses directly related to poor air quality. Therefore, the delay effect of AAI estimated in this study is limited only by the effects of the reduced $PM_{2.5}$. According to the study of Cohen et al. [2015], 4.6 million people are dying annually because of the diseases and illnesses directly related to poor air quality. Therefore, in terms of long-term human health hazards, the threat of air pollution can be much greater than that of COVID-19. Therefore, we should not only try to overcome the current situation of the COVID-19 pandemic, but at the same time seriously consider the new eco-lifestyle that we have to pursue after the end of COVID-19 pandemic..