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NOTE ON THE COMPARISON OF AIR POLLUTION IN SEOUL BEFORE CORONAVIRUS (BC; BEFORE COVID-19) AND AFTER CORONAVIRUS (AC; AFTER COVID-19) VIA STATISTICAL REASONING

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Abstract: *The world is currently, facing a distinct new era between pre-coronavirus and post-coronavirus. Seoul is the capital of the Republic of Korea and is one of the most polluted cities in the Organization for Economic Cooperation and Development (OECD) member countries in terms of particulate matter (PM). According to recent research (Chang 2020), the data before corona (BC) does not provide enough evidence that the average density of PM10 and PM2.5 in Seoul during spring and winter 2018 or 2019 was reduced compared with 2012 or 2013.In this article, we compare the average concentration of fine dust during the first half of 2018 (BC) and that during the first half of 2020 (AC) via statistical reasoning. According to our analysis, there is significant evidence that the average density of the PM in Seoul AC is currently reduced, compared with that of BC. Our method has the advantage of providing statistically valid and reliable results compared to the simple average comparison which is available in National Institute of Environmental Research report in Republic of Korea. We also present brief comments on the implications of our results. Our analysis and results could be used to define the current situation related to fine dust in Seoul, and to establish related policies and evaluate their performance.*

Keywords: *post-coronavirus, particulate matter, fine dust air pollution, global environmental pollution, statistical comparison.*

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INTRODUCTION

The world is currently, facing a distinct new era between pre-coronavirus and post-coronavirus. There are significant societal and economic changes in many areas globally, and new terms, BC (Before COVID-19) and AC (After COVID-19), are often read in academic literature, newspapers, etc (Attiq-ur-Rehman et al. 2020, Bhaven Shah and Mehak Vohra 2020, Article in Deloitte Touche Tohmatsu India LLP. 2020, Friedman, T L. 2020, Financial Times 2020).

Although human economic activity has recently been limited due to the COVID-19 pandemic, there have been reports of improving air quality in the global village. Readers are referred to recent papers and reports published in the journals, newspapers, and books (see Section 2.)

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Seoul is the capital of Republic of Korea and is one of the most polluted cities in Organization for Economic Cooperation and Development (OECD) member countries in terms of particulate matter (PM) (2019 World Air Quality Report - IQAir). According to the 2019 World Air Quality Report, IQAir, the average annual concentration of ultrafine dust in the Republic of Korea is 24.8 **μg/m³**, which is the worst among 36 OECD member countries. According to a report published by OECD in 2019, the PM2.5 concentration in the Republic of Korea is about twice as high as the World Health Organization's guidelines, or the levels of other major cities in developed countries (Daniel Trnka 2020). According to recent research (Chang 2020), the data before corona (BC) does not provide enough evidence that the average density of PM10 and PM2.5 in Seoul during spring and winter 2018 or 2019 was reduced compared with 2012 or 2013. See OECD report (2020) for details on the issues related to air pollution.

In this article, we compare the air pollution in Seoul between BC and AC using statistical reasoning. Based on recent research (Chang 2020), the average concentration of fine dust in Seoul in 2018 was selected as pre-coronavirus data. We then compared the average concentration of particulate matter (PM10 and PM2.5) in Seoul during the first half of 2018 (BC) and that during the first half of 2020 (AC). According to our analysis, there is significant evidence that the average density of PM in Seoul AC has reduced compared with that in Seoul BC. Our method of comparison has the advantage of providing statistically valid and reliable results rather than the simple average comparison which is available in the National Institute of Environmental Research report in the Republic of Korea. We also present brief comments on the implication of our results.

The rest of this article is organized as follows. In Section 2, we summarize previous results, and their implications and limitations. In Section 3, this article compares the air pollution in Seoul between BC and AC vis statistical reasoning. In Section 4, this article presents a brief discussion of the implications of the results, including brief comments on the issues and prospects of the post-coronavirus era.

MATERIAL AND METHODS – REVIEW OF PREVIOUS RESULTS

Statistics from the Meteorological Agency in the Republic of Korea

According to the report in Meteorological Agency in the Republic of Korea, yellow dust is a type of dust haze. It is a phenomenon in which a large amount of loess dust, mainly from the loess area of the continent, floats over the entire sky and gradually descends. In severe conditions, the sky looks yellowish-brown, the sunlight is dim, and dirt may accumulate on the exposed ground or objects. The number of days of yellow dust is defined as the number of days that the yellow dust was reported, and dust concentration is the PM10 mass concentration observed with a floating dust analyzer (PM10).

Table 1. Average number of dust day in Seoul by season

Year	Spring (Mar-May)	Summer (Jun-Aug)	Autumn (Sep-Nov)	Winter (Dec-next Feb)
2020	2	0	NA	NA
2015-2019	5.2	0	1.6	0.4
2010-2019	5.1	0	1.3	1.4

Table 2. Average number of yellow dust days per month in Seoul

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2020	0	1	0	1	1	0	0	NA	NA	NA	NA	NA
2015-2019	0.4	0.8	2	1.8	1.4	0	0	0	0	0.2	1.4	0
2010-2015	0.4	0.5	2.2	1	1.9	0	0	0	0	0.1	1.2	0.5

According to the report in the Meteorological Administration, the number of days in the east wind increased by 36% compared to the average of the past three years throughout the first half of 2020. The average monthly rainfall for six months was 506mm, which was 29% higher than the average for the past three years (391mm). Rain not only cleans up dust in the air, but also dissolves the causative substances that create ultrafine dust, such as ammonia and nitric acid.

Implications: As can be seen in Tables 1 and 2, most yellow dust days in Seoul are during the spring season. We thus make statistical comparisons during the first half (Jan -June) of 2020.

Statistics and reports in the Ministry of Environment in the Republic of Korea

According to the Ministry of Environment in the Republic of Korea, the average concentration of ultrafine dust (PM2.5) nationwide during the first half of 2020 (AC) was 21**μg/m³**, which is an 8μg/m³ μg decrease from the previous year's average (29μg/m³). It was 25% lower than the average for the same period in the last three years (28 μg/m³).

According to the Ministry of Environment in Republic of Korea, the reasons for the unusual drop in ultrafine dust concentration are complex. In addition to the special circumstances caused by the novel coronavirus infection COVID-19, the Ministry of Environment believes that the seasonal management system and weather conditions have been affected. Note that the seasonal management system in Republic of Korea was implemented from December 2019 to March, 2020, when the concentration of ultrafine dust increased. During this period, at least 7 units and up to 28 units out of 60 coal-fired power plants nationwide were suspended. Large business reduced pollutant emissions, and the government has tightened regulation. As a result, pollutant emissions decreased for four months by 19.5%

compared to the same period in previous years, and the concentration of ultrafine dust decreased by 27%. When announcing the results of the seasonal management system in May 2020, the Ministry of Environment noted that it had reduced the frequency and intensity of high concentrations of fine dust.

The National Institute of Environmental Research (NIER) in Republic of Korea made a comparison between January 17-20, 2019 and Jan 1-4, 2020 before the impact of Coronavirus 19 emerged. In both periods, pollutants from foreign countries such as China were introduced through the western wind, and the atmosphere was stagnant, so pollutants were likely accumulate. In 2019, the concentration of ultrafine dust in the metropolitan area soared to 106 µg at one point, showing a very bad level, but this year (2020) at the worst level was 69 µg.

Although it is difficult to calculate accurately, it is believed that the reduction in traffic volume and other social and economic activities due to COVID-19 also reduced ultrafine dust. According to the Ministry of Environment, the concentration of ultrafine dust generally drops in the rainy summer and in the autumn when the air spreads more smoothly due to greater winds. The monthly concentration of ultrafine dust from July to October has been around 14 to 18 µg for the past three years (2017, 2018, and 2019).

Implications: The Ministry of Environment's results in Republic of Korea are based on average comparison, which is a simple method and easy to understand, but they do not give us detailed information about whether the difference is statistically significant. The analytical method presented in this paper is not just the average comparison that is available in the NIER report in the Republic of Korea, and it has the advantage of providing statistically valid and reliable results.

Recent research based on the data BC.

According to recent research (Chang 2020), the data before corona (BC) does not provide enough evidence that the average density of PM10 and PM2.5 in Seoul during spring and winter 2018 or 2019 was reduced compared with 2012 or 2013.

Implication: Based on recent research (Chang 2020), we can select the average concentration of fine dust in Seoul in 2018 as pre-coronavirus data.

Recent research and reports on air pollution based on the data AC

Countries all over the world implemented some sort of lockdown to slow the spread of the infection of Coronavirus. Air quality has also started to improve and there are positive signs that the environment has begun to restore itself (Zambrano-Monserrate et al 2020). According to the Ministry of Ecology and Environment in China (Report in China Ministry of Ecology and Environment, 2020), the concentration of pollutants in China during the first quarter of 2020 decreased significantly compared to the same period in 2019, as production and transportation activities were halted due to coronavirus virus. The nitrogen dioxide concentration was at level last seen in the 1990s, and the average concentration of ultrafine dust across China decreased by 14.8% year-on-year (Report in China Ministry of Ecology and Environment, 2020, Guojun He et al. 2020). According to local media in India(JasjeevGandhiok 2020), the air quality in New Delhi was good enough to see the constellations at the end of March 2020 and had improved to normal levels. Analysis suggested that the air had cleared as most industrial facilities and vehicles had stopped operation due to the national coronavirus containment policies In this connection, see see Susanta Mahato et al. (2020) and Prashant Kumar et al. (2020). In Italy, the government took extraordinary measures, including a national lockdown, to prevent the spread of COVID-19 (European Space Agency 2020). Camelaetti (2020) reports that the extraordinary situation led to a reduction in air pollution levels measured across the whole Po Valley in Italy, usually known as one of the most polluted areas in Europe in terms of PM and nitrogen dioxide concentration. Sulaman Muhammad and Xingle Long (2020) report that lockdown due to COVID-19 had positive effects on the natural environment. Recent data released by NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) indicates that pollution in some of the epicenters of COVID-19 such as Wuhan, Italy, Spain and the USA reduced up to 30%. Lokhandwala and Gautam (2020) present evidence-based insights into the improvement of air quality and environment pre- and post-lockdown. They demonstrate the improvement in air quality using tools such as satellite images of the Indian atmosphere and the air quality index (AQI) calculated by the Central Pollution Control Board of India.

Implications: As mentioned in the introduction, although human economic activity has recently been limited due to Corona 19, there have been reports of improving air quality in the global village.

Recent reportsof Corona-19 in Republic of Korea

On February 23, 2020, the Korean government upgraded the infectious disease crisis warning to 'severe' and opened the Coronavirus Infectious Disease-19 Central Disaster Safety Countermeasure Headquarters headed by the Prime Minister. The Ministry of Health and Welfare in Republic of Korea conducts briefings on COVID-19 infection every day around 11 am and 2 pm. As a result of intensive social distancing and the reinforcement of quarantine for immigrants, the number of new confirmed cases each day in April 2020 became more stable than in other countries. Many Koreans are still tense, however, because it is not over, and a large-scale population infection may recur. Eventually, the number of new confirmed cases increased to 79 on May 28, 2020 due to a group infection outbreak at the distribution center. As a result, concerns persist that the coronavirus epidemic may recur at any time if we are not vigilant. In August 2020, the number of new confirmed cases continued to be in three digits (103 ▯166 ▯ 279 ▯ 197 ▯ 246 ▯ 297▯ 288 ▯ 324 ▯266), from the 14th August when group infection began increasing. The Head of the Central Defense Countermeasure Headquarters defined the recent spread of the coronavirus infection as an early stage of a second wave of the pandemic. She warned that if the current spread wasnot properly controlled, it would cause enormous damage in various fields such as healthcare and the economy. Readers are referred to the report by the Ministry of Health and Welfare in the Republic of Korea for details.

Implications: To prevent the spread of corona-19, the government needs to respond quickly and build infrastructure accordingly.

MATERIAL AND METHODS–STATISTICAL COMPARISON, EXPERIMENTAL RESULTS, AND INTERPRETATIONS

This section provides a concise and precise description of the method, experimental results, their interpretation, and the experimental conclusions that can be drawn.

We make statistical comparisons of PM10 and PM2.5 between 2018 (BC) and 2020 (AC). As mentioned in Section 2, particulate matters mainly occur during the spring and winter seasons in the Republic of Korea (Report in Korea Meteorological Administration, 2015-2020), and most dust days in Seoul occur between January and May. For this reason, we make statistical comparisons between 2018 (BC) and 2020 (AC) during the first half period (Jan -June) of the year to obtain more precise conclusions.

Known Statistics (NIER report 2018-June 2020): Tables 3-4

The average densities of fine dust in Seoul from January to June in 2018 (BC) and 2020 are presented in Tables 3 and 4, based on the data available for the atmospheric environment of Seoul (NIER report 2018-June 2020):

Table 3: Fine dust (PM10) Monthly air pollution in Seoul during spring and winter in 2018 and 2020(unit: μg/m³)

	2018	2020
Jan	52	42.41935
Feb	53	40.89655
Mar	53	45
Apr	53	43.76667
May	42	34.67742
Jun	37	36.26667

Table 4: Fine dust (PM2.5) Monthly air pollution in Seoul during spring and winter in 2018 and 2020 (unit: μg/m³)

	2018	2020
Jan	33	28.70968
Feb	30	28.03448
Mar	35	25.09677
Apr	26	20.46667
May	23	18.89097
Jun	24	20.56667

Statistical reasoning and analysis

In this section, we present statistical comparisons between 2018 and 2020 based on statistical reasoning and comparison. The following hypotheses are set for the average density of PM 10 in Seoul:

H_0 (Null hypothesis): Average density of fine dust (PM10) in Seoul during the first half period (Jan -June) of 2018= average density of fine dust (PM10) in Seoul during the first half period (Jan-June)of 2020.

H_1 (Alternative hypothesis): Average density of fine dust (PM10) in Seoul during the first half period (Jan -June) of 2018 > average density of fine dust in Seoul during the first half period (Jan -June) of 2020.

Since two time series are correlated, and each month's data is paired with each other, a pairwise test was used to compare the differences between the two populations (Chang 2018, Chang and Lee 2018). Under the assumption that the null hypothesis is true, the average densities of fine dust (PM10) in Seoul are compared between 2018 and 2020. The following is the result of the pairwise comparison test (significant level of test = 0.01) using Excel (2016):

Table 5: Pairwise comparison (2018 vs 2020) test result (significant level of test = 0.01) t-test results: Pairwise comparison test

	Density of PM10 in 2018	Density of PM10 in 2020
Average	48.33333333	40.50444333
Sample variance	49.46666667	17.3171383
No. of observations	6	6
Pearson's correlation coefficient	0.888248752	
Difference between two means	0	
d.f.	5	

t statistics	4.986602081	
P(T<=t) one-sided	0.002076063	
t statistics one-sided	3.364929999	
P(T<=t) two-sided	0.004152125	
t statistics two-sided	4.032142984	

As can be seen from the above table, the null hypothesis that the two population groups (2018 and 2020) have the same mean is rejected because the p-value is 0.002076063, which is less than the 0.01 significance level. There is significant evidence that the average density of fine dust (PM10) in Seoul in 2020was less than that in Seoul in 2018, and the reliability of this conclusion is 0.99.

We carry out a similar analysis, and obtain the following table for the average density of PM 2.5 in Seoul:

Table 6: Pairwise comparison (2018 vs 2020) test result (significant level of test = 0.01) t-test results: Pairwise comparison test

	Density of PM2.5 in 2020	Density of PM2.5 in 2020
Average	28.5	23.62754
Sample variance	24.3	17.84060472
No. of observations	6	6
Pearson's correlation coefficient	0.833350885	
Differences between two means	0	
d.f.	5	
T statistics	4.376274529	
P(T<=t) one-sided	0.003589826	
t statistics one-sided	3.364929999	
P(T<=t) two-sided	0.007179652	
t statistics two-sided	4.032142984	

As can be seen from the above table, the null hypothesis that the two population groups (2018 and 2020) have the same mean is rejected because the p-value is 0.00358926, which is less than the 0.01 significance level. The assertion of the alternative hypothesis that the average density of fine dust (PM10) in Seoul in 2020 was less than that of Seoul on 2018 is statistically significant, and the reliability of this conclusion is 0.99.

RESULTS AND DISCUSSION

We compared the average concentration of fine dust in the first half of 2018 (BC) with that in the first half of 2020(AC) via statistical reasoning. According to our analysis (with significance level = 0.01), there is significant evidence that the average density of the PM in Seoul AC was reduced compared with that in Seoul BC. The analytical method presented in this paper is not just the average comparison that is available in the NIER report in the Republic of Korea, and it has the advantage of providing statistically valid and reliable results. Note that our analysis is based on the statistics in Seoul for the first half of the 2020. The conclusion presented in this article is thus likely to be a temporary change. The resumption of economic activities and emission of pollutants may mean that conditions deteriorate to pre-lockdown levels. Note that our conclusion will always be the same because it is based on static data. It is the situation that might change, which would require new analysis and conclusions. Our analysis and results could be used to define the current situation related to fine dust in Seoul, and to establish related policies and evaluate their performance.

It is expected that the post-COVID-19 era will intensify the policy response of each country regarding the transition to a low-carbon economy and the Green New Deal, a comprehensive reform policy that pursues the transformation of the environment, economy and industrial systems. Effective, practical, and detailed strategies are required in the Green New Deal policy.

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