Poll Res. 41 (4) : 1157-1163 (2022)

ISSN 0257–8050

DOI No.: http://doi.org/10.53550/PR.2022.v41i04.003

STATISTICALLY UPDATING PATTERN CHANGE OF NITROGEN DIOXIDE (NO_2) POLLUTION IN SEOUL

SEOK HO CHANG AND SOONHUI LEE

HUFS Business School, Hankuk University of Foreign Studies, Seoul Campus 107 Imun-ro, Dongdaemun-gu, Seoul, 02450, Republic of Korea

(Received 27 March, 2022; Accepted 24 May, 2022)

ABSTRACT

Our previous study (Chang and Lee, 2022) presented observations on the recent changes in nitrogen dioxide (NO_2) pollution of Seoul after the COVID-19 pandemic. This paper derives updated results by incorporating recent data, specifically data for the second half of 2021. In addition to confirming the extended results of the existing study (Chang and Lee, 2022), we derived more specific interpretations of the results. The results were as follows: (i) The average monthly NO_2 concentration in Seoul has decreased significantly in 2020 compared to that before the COVID-19 pandemic; and (ii) the average difference in the monthly concentration of NO_2 in Seoul between January 2021 to December 2021 period and that from January 2020 to December 2020 is not statistically significant. We also found the results originating partly from lifted restrictions on public transportation and non-road vehicles, and partly from resumption of suspended non-industrial combustion plants in Seoul after the first half of 2020, complementing our previous findings in Chang and Lee (2022). Our study shows statistically comprehensive results compared to the studies that limit their discussions to average values, as that presented in a report by the Ministry of Environment, Republic of Korea.

KEY WORDS : Nitrogen Dioxide (NO_2), COVID-19 pandemic, Pattern change in pollution, Statistical significance

INTRODUCTION

Our previous study (Chang and Lee, 2022a) presented observations on the recent changes in nitrogen dioxide (NO_2) pollution of Seoul after the COVID-19 pandemic. Note that NO_2 is widely recognized as a toxic air pollutant and is one of the causative substances producing secondary ultrafine dust such as particulate matter 2.5 (PM2.5). It must be remarked that the amount of secondary fine dust accounts for about two-thirds of the total amount of ultrafine dust generated in the metropolitan area such as Seoul (Atmospheric environment report [2010-2021]). The analysis presented by Chang and Lee (2022a) produced the following results: (i) The monthly NO_2 concentration in Seoul has reduced significantly in the first half of 2020 compared to that before the COVID-19 pandemic; and (ii) the average difference in the monthly NO_2 concentrations in Seoul between the period from October of 2020 to June 2021 and that from October of 2019 to June 2020 is not statistically significant.

This paper derives updated results for the pattern change of NO_2 pollution in Seoul after incorporating recent data, specifically the data for the second half of 2021. In addition to confirming the extended results of the existing study (Chang and Lee, 2022a), we derived more specific interpretations of the results. The results were as follows: (i) The average monthly NO_2 concentration in Seoul has decreased significantly in 2020 compared to that before the COVID-19 pandemic; and (ii) the average difference in the NO_2 monthly concentration in Seoul in the period between the January 2021 to December 2021 period and that from January 2020 to December 2020 is not statistically significant. We also found the results originating partly from lifted restrictions on public transportation and non-road vehicles, and partly from resumption of suspended non-industrial combustion plants in Seoul after the first half of 2020, complementing our previous findings in Chang and Lee (2022a). Our study shows statistically comprehensive results compared to the studies that limit their discussions to average values, as that presented in a report by the Ministry of Environment, Republic of Korea. See the Results and Discussion section of this paper for further details.

For the successful monitoring and solution of environmental-friendly pollution control technologies, continuous update of research findings on pattern change in pollution is of utmost importance. The updated information on pattern change in pollution promotes exchange of knowledge and communication between researchers, scientists, policy-makers, government agencies and professionals working in the field environmental sciences or other related areas. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) have homepages for monitoring monthly averages of global concentrations of NO_2 (see NASA 2022 and ESA 2020 for details). Whereas, Environmental Protection Agency (EPA) mentions that NO_2, SO_2, CO, particulate matter (PM), ozone (O_3), and lead as major health-damaging air pollutants and provided health-based guideline levels for each air pollutants. Since each air pollutant has different properties, hazards, and environmental standards, it is necessary to establish a monitoring and management system tailored to each air pollutant.

The rest of this article is organized as follows: In Material and Methods, we summarize our review of related works and their implications. In Results, we derive updated results in Chang and Lee (2022) and compare the average differences in the monthly NO_2 concentration in Seoul between that before and that after the COVID-19 pandemic. In the Conclusion, we discuss and comment on the implications of the results, which complements Chang and Lee (2022).

MATERIALS AND METHODS

In Material and Methods, we present air quality criteria of NO_2, the main source of NO_2 emissions, and classification of the sources of NO_2 emission in Seoul and their interpretations, which are not discussed in Chang and Lee (2022a).

Nitrogen dioxide (NO_2) is a reddish-brown, highly reactive gas that is generated by oxidation of nitrogen monoxide in the atmosphere (U.S. Environmental Protection Agency (EPA), 2018; UK Air Pollution Information System, 2019; Greenpeace India Report, 2021; Indoor Quality Air [IQAIR]). Studies suggest that NO_2 could be harmful to human health and associated with several diseases. See Table 1 in Chang and Lee (2022a) for the summary of the properties, hazards, derivation, and environmental effects of NO_2.

Air Quality Criteria of Nitrogen Dioxide (NO_2)

We summarize the air quality criteria of NO_2 stated in the US EPA, WHO, US CDC, and Ministry of Environment in Republic of Korea in Tables 2-5.

Table 3. Recommended Air quality levels (AQC) of NO_2 established in WHO (2022)

Pollutant	AQG level
Nitrogen Dioxide (NO_2)	1 hour average 200 mg/m^3 24-hour average 25 mg/m^3 Annual average 10 mg/m^3

Remark: Conversion factors: 1 ppm = 1.145 mg/m^3,

Table 4. Permissible Exposure Limit (PEL) of NO_2 established in CDC, US (2022)

Pollutant	PEL
Nitrogen Dioxdie (NO_2)	Occupational Safety and Health Administration (OSHA) standard - 8-hour TWA (ST) STEL (C) Ceiling Peak PEL-C = 5 ppm (9 mg/m^3)

Table 5. Air quality criteria of NO_2 established in Ministry of Environment, Republic of Korea

Pollutant	National Standard
Nitrogen dioxide (NO_2)	1 hour average 0.10 ppm 24 hour average 0.06 ppm Yearly average 0.03 ppm

Table 2. Air quality criteria of NO_2 established by EPA

Pollutant	Type	Standard
Nitrogen Dioxide (NO_2)	Primary Primary and secondary	1 hour average = 100 parts per billion (ppb) 1 year average = 53 ppb

1 mg/m^3 = 0.873 ppm

As the pollution prevention technologies improve, air quality criteria should be more stringent than those presented in Table 5.

Main source of NO_2 emissions and classification of NO_2 emission sources in Seoul

We summarize the main source of NO_2 emissions in Table 6 (WHO).

Tables 7 summarize the classification of NO_2 emission sources in Seoul (ministry of environment in Republic of Korea).

We can see that the findings in Table 7 suggest that the primary source (40.104%) of NO_x emissions source in Seoul was road transport pollutant, such as pollutant emitted from diesel vehicle, and automobile exhaust gas. It was followed by non-road transport pollution source, which amounted to 35.783%. It should be remarked that the primary source of NO_2 emission source differs by region and city in Republic of Korea.

NASA and ESA pollution monitoring satellites detected significant decreases in NO_2 concentrations worldwide in the first half of 2020. However, as the economic activities of countries gradually resumed in the second half of 2020, some changes in air quality around the world, including China and the Republic of Korea, have been observed (see the literature review in Chang and Lee (2022a, 2022b)). Readers are referred to the EPA report, Greenpeace report, International (2022), Greenpeace report, India (2022), Greenpeace report, UK (2017), OECD report (2021), WHO, and Material and Methods in Chang and Lee (2022) for details on the seriousness of NO_2 air pollution.

RESULTS

In this section, we present the main results and their interpretations.

Table 8. Monthly average NO_2 concentration in Seoul in 2021, 2020 and 2019 (unit: ppm)

	Year 2021	Year 2020	Year 2019
Jan	0.031	0.034	0.039
Feb	0.030	0.032	0.036
Mar	0.032	0.028	0.034
Apr	0.022	0.021	0.029
May	0.019	0.020	0.028
Jun	0.018	0.019	0.020
Jul	0.016	0.016	0.018
Aug	0.015	0.014	0.018
Sep	0.014	0.015	0.021
Oct	0.022	0.025	0.025
Nov	0.031	0.030	0.034
Dec	0.031	0.032	0.035

Table 6. Main sources of NO_2 emissions (WHO)

Type of Sources	Examples
Anthropogenic sources	Combustion of fossil fuels in stationary sources (heating, power generation) and motor vehicle (internal combustion engines).
Natural sources	Intrusion of stratospheric nitrogen oxides, bacterial and volcanic action, and lighting, etc.
Indoor environment	Specific noncombustion industrial processes, such as the manufacture of nitric acid, the use of explosives and welding, tobacco smoking and use of gas-fired appliances and oil stoves etc.

Table 7. NO_x emission source classification in Seoul (2018)

Emission source classification	Emissions (ton/year)
Energy industry combustion	431651 ton/year
Non-road transport pollution source (e.g, Heavy construction equipment (fork cranes, bulldozers, etc), agricultural machinery, ships, etc)	31602916 ton/year
Manufacturing combustion	199601 ton/year
Road transport pollution source(e.g., Diesel vehicle, Automobile exhaust gas)	35419425 ton/year
Biocombustion	6684 ton/year
Waste disposal	434093 ton/year
Non-industrial combustion	20201938 ton/year
Other crossing-contaminant	22305 ton/year
Sum	88318613 ton/year

Known Statistics in Air Korea and Air Visual: Tables 8

We present the monthly average NO_2 concentrations in Seoul in 2021, 2020, and 2019 in Table 8 (Air Korea, Seoul Metropolitan Air Quality Information):

Statistical Reasoning and Analysis

We first make statistical comparisons of two data sets: (i) monthly average NO_2 concentration in Seoul between January 2020 to December 2020 period and (ii) monthly average NO_2 concentration in Seoul between January 2019 to December 2019. The following hypotheses are set for the monthly average NO_2 concentration in Seoul:

H_0 (Null hypothesis): Monthly average NO_2 concentration in Seoul between January 2020 to December 2020 period e" Monthly average NO_2 concentration in Seoul from January 2019 to December 2019

H_1 (Alternative hypothesis): Monthly Average NO_2 concentration in Seoul between January 2020 to December 2020 period < Monthly average NO_2 concentration in Seoul from January 2019 to December 2019

The basic principle of the analysis presented in this paper is same as that of the statistical control chart. We define the difference between monthly average of NO_2 concentration in Seoul between January 2019 to December 2019 period and monthly average of NO_2 concentration in Seoul from January 2020 to December 2020 as the error (or natural variability or the chance causes of variation). Under the assumption that the null hypothesis is true, the error (natural variability) follows normal distribution with mean 0 and a finite variance which is greater than 0, which is an implicit assumptions of our study.

Since two time series are correlated, and each month's data is paired with the other's, a pairwise test was used to compare the differences between the two populations (Chang and Lee, 2021, 2022a, 2022b). Under the assumption that the null hypothesis is true, we made statistical comparisons between data during the period from January 2019 to December 2019 and data during the period from January 2020 to December 2020. Table 9 summarizes the result of the pairwise comparison test (significance level of test = 0.01) using Excel (2016):

As can be seen from Table 9, we have drawn the following conclusion: The null hypothesis that the two population groups have the same mean is rejected because the p-value is 0.0000574401758878465, which is less than 0.01 significance level. There is strong evidence that the monthly average NO2 concentration in Seoul in 2020 from January 2020 to December 2020 was less than that in Seoul in 2019 from January 2019 to December 2019, and the reliability of this conclusion is 0.99.

We carried out a similar analysis and obtained Table 10 for the statistical comparisons between data during the period from January, 2021 to December, 2021 and data during the period from January, 2020 to December, 2020.

Although there are seven months (January, February, May, June, September, October and December) when the average NO_2 concentration decreased, and four months (March, April, August, November) when the average NO_2 concentration increased (see Table 8), the average change is not large enough to lead to the rejection of the null

Table 9. Pairwise comparison test result (significance level = 0.01)
- Comparison period: Jan 2020 to Dec 2020 vs Jan 2019 to Dec 2019
t-test results
Pairwise comparison test

	Concentration of NO_2 JAN 2020 to DEC 2020	Concentration of NO_2 JAN 2019 to DEC 2019
Average	0.0238333333333333	0.0280833333333333
Sample variance	5.23333333333332E-5	5.71742424242427E-5
No. of observations	12	12
Pearson's correlation coefficient	0.942602539158222	
Difference between two means	0	
d.f.	11	
t statistics	-5.8257619054815	
P(T<=t) one-sided	5.74401758878465E-5	
t statistics	2.71807918381386	
P(T<=t) two-sided	0.000114880351775693	

Table 10. Pairwise comparison test result (significance level = 0.01)
- Comparison period: Jan 2021 to Dec 2021 vs Jan 2020 to Dec 2020
t-test results
Pairwise comparison test

	Concentration of NO_2 JAN 2021 to DEC 2021	Concentration of NO_2 JAN 2020 to DEC 2020
Average	0.0234166666666667	0.0238333333333333
Sample variance	5.06287878787878E-5	5.23333333333332E-5
No. of observations	12	12
Pearson's correlation coefficient	0.962239146567888	
Difference between two means	0	
d.f.	11	
t statistics	-0.730739750201311	
P(T<=t) one-sided	0.240106791064874	
t statistics	2.71807918381386	
P(T<=t) two-sided	0.480213582129749	
t statistics two-sided	3.10580651553928	

hypothesis. That is, the null hypothesis that the two population groups have the same mean is not rejected because the p-value is 0.24010679106487, which is greater than 0.01 significance level. There is not enough evidence that the monthly average NO_2 concentration of Seoul in Seoul in 2021 was less than that in Seoul in 2020 and the reliability of this conclusion is 0.99.

DISCUSSION

This paper derives updated results for pattern change of NO_2 pollution in Seoul after incorporating recent data, specifically data for the second half of 2021. The analysis produced the following updated results (with significance level = 0.01): (i) The average monthly NO_2 concentration in Seoul decreased significantly in 2020 compared to that before the COVID-19 pandemic; and (ii) the average difference in the monthly NO_2 concentration in Seoul during the period between January 2021 to December 2021 period and that from January 2020 to December 2020 is not statistically significant.

In contrast to the studies that limit their discussions to average values, as that presented in a report by the Ministry of Environment, Republic of Korea, our analyses produced statistically valid results. Based on our interpretation on the main source of NO_2 emissions and the classification of the sources of NO_2 emission in Seoul (Table 7), we found the results originating partly lifted restrictions on public transportation and non-road vehicles, and partly from resumption of suspended non-industrial combustion plants in Seoul after the first half of 2020, complementing Chang and Lee [2022a].

Based on our findings, the following suggestions, which are not discussed in our previous work (Chang and Lee 2022a), can be recommended:

- As the primary source of NO_2 emission differ by region and city, it is necessary to establish a monitoring and management system tailored to each region and city. Sources that contribute significantly to the NO_x emissions (e.g., road transport pollutant, such as pollutant emitted from diesel vehicle, and automobile exhaust gas, non-road transport pollution source such as heavy construction equipment (fork cranes, bulldozers, etc), agricultural machinery and ships, and non-industrial combustion plants) in Seoul (Table 7) must be prioritized. Economical and practical measures should be developed and implemented to prevent the disproportionate emission of NO_2 from such sources in Seoul. We provide the following suggestions to mitigate NO_2 pollution in Seoul:

1) Reinforcement of emission standards for road vehicles and stricter follow-up management
2) Strict tightening of motorcycle emission standards
3) Reinforcement of standards for environmental pollution prevention facilities
4) Development and supply of clean fuel at an economical price
5) Reinforcement of the certification of eco-friendly gas boilers used in homes and industries
6) Reinforcement of emission standards for household and industrial waste incineration facilities

7) Development of economical and commercially available catalytic converter technology for internal combustion engine cars, and establishment of infrastructure necessary for supplying eco-friendly vehicle power sources.
8) Enhanced international environmental cooperation.

ACKNOWLEDGMENT

This research was supported by Hankuk University of Foreign Studies Research Fund.

REFERENCES

Air quality criteria in Republic of Korea, Ministry of Environment, Republic of Korea, 2021, Available online: https://www.me.go.kr/mamo/web/index.do?menuId=586

Air quality criteria in Seoul (in Korean), Available online: https://cleanair.seoul.go.kr/information/info2

Air Korea, https://www.airkorea.or.kr/eng

AirVisual, https://www.airvisual.com

Ambient Air Quality Criteria (AAQC), Available online: https://en.wikipedia.org/wiki/Ambient_air_quality_criteria

American Lung·Association, Nitrogen Dioxide, Feb 12, 2020, Available online: https://www.lung.org/clean-air/outdoors/what-makes-air-unhealthy/nitrogen-dioxide

Atmospheric environment report (in Korean) (2010-2022), Ministry of Environment, Republic of Korea. Available online: http://www.me.go.kr/home/web/index.do?menuId=12 https://library.me.go.kr/#/search/org-statistical/si?all=0&rq=PUBLISHER%3D(*%ED%99%98%EA%B2%BD%EB%B6%80*%20OR%20*%ED%99%98%EA%B2%BD%EC%B2%98*%20OR%20*%ED%99%98% EA%B2%BD%EC%B2%AD*)%7CPCRC_C% 3DJ3

Chang, S.H. and Lee, S. 2021. Tracing the recent density of air pollution in Seoul via statistical reasoning. *Pollution Research.* 40(4) : 1553-1560.

Chang, S.H. and Lee, S. 2022. Statistically identifying the patter change of Nitrogen Dioxide (NO_2) pollution in Seoul after COVID-19 pandemic. *Pollution Research.* 41(1): 30-37.

Chang, S.H. and Lee, S. 2022. Comparison studies of pattern changes in Sulfur Dioxide (SO_2) Pollution in Seoul after the COVID-19 pandemic via statistical reasoning (written in English), accepted for publication in *Journal of the Korean Society for Environmental Technology,* March, 2022.

Greenpeace India Report, Hyderabad's NO_2 pollution increased by 69% in one year Report, India Today, 2022, Available online: https://www.indiatoday.in/science/story/hyderabad-delhi-mumbai-no2-pollution-lockdown-greenpeace-report-1825148-2021-07-07

Greenpeace report, International, New satellite data analysis reveals word's biggest NO_2 emissions hotspots, Available online: https://www.greenpeace.org/international/press-release/19072/greenpeace-analysis-of-new-satellite-data-reveals-worlds-biggest-no2-emissions-hotspots/

Greenpeace report, UK, The impacts of NO_2 on human health, 2017, Available online: https://storage.googleapis.com/gpuk-old-wp-site/wp-content/uploads/2017/09/Every-Breath-Health-Report-FINAL.pdf

Environmental Protection Agency (EPA), Nitrogen Dioxide (NO_2) Pollution, Available online: https://www.epa.gov/no2-pollution

EPA, NAAQS Table, Available online: https://www.epa.gov/criteria-air-pollutants/naaqs-table

European Space Agency (ESA), March 27, 2020. Coronavirus lockdown leading to drop in pollution across Europe, Report in ESA, Available online: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe

ESA, NO_2 concentrations over India, April 24, 2020, Available online: https://www.esa.int/ESA_Multimedia/Images/2020/04/NO2_concentrations_over_India

ESA, NO_2 concentrations over Europe, April 16, 2020, Available online: https://www.esa.int/ESA_Multimedia/Images/2020/04/NO2_concentrations_over_Europe

ESA, March 15, 2021, Air pollution returnning to pre-COVID levles: Available online: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Air_pollution_returning_to_pre-COVID_levels

Indoor Quality Air (IQAIR), Nitrogen-dioxide, Available online: https://www.iqair.com/blog/air-quality/nitrogen-dioxide

Korea Meteorological Administration (KMA) report (in Korean), Republic of Korea, 2019-2021, Available online : http://www.climate.go.kr/home/bbs/list.php?code=25&bname=report

Ministry of Environment report (in Korean), Republic of Korea, 2019-2021, Available online: https://www.me.go.kr/mamo/web/index.do?menuId=587

National Ambient Air Quality Standards (NAAQS) Table, 2021, Available online: https://www.epa.gov/criteria-air-pollutants/naaqs-table

National Aeronautics and Space Administration (NASA), COVID-19 Impact on Asian Emissions: Insight from Space Observations, March 26, 2020: Available online: https://www2.acom.ucar.edu/news/covid-19-impact-asian-emissions-insight-space-observations

NASA, Global Nitrogen Dioxide Monitoring Homepage, Atmoshperic Chemistry and Dynamics Laboratory, April 3, 2022, Available online: https://so2.gsfc.nasa.gov/no2/no2_index.html

National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazard, Nitrogen Dioxide, Occupational Health Guideline for Carbon Monoxide, Centers for Disease Control and Prevention (CDC), US, Oct 30, 2019, Available online: https://www.cdc.gov/niosh/npg/npgd0454.html

Organisation for Economic Cooperation and Develpment (OECD) report, June 26, 2021, Air and GHG emissions (indicator), Available online: https://data.oecd.org/air/air-and-ghg-emissions.htm

Seoul Air Quality Assessment Report (in Korean), 2019, Available online: https://news.seoul.go.kr/env/archives/510612

Seoul Air Pollution: Real-time Air Quality Index (AQI), Available online: https://aqicn.org/city/seoul

Seoul Metropolitan Air Quality Information, Available online: https://cleanair.seoul.go.kr/statistics/dayAverage

UK Air Pollution Information System. (n.d.) (2019). Nitrogen oxides.

WHO global air quality guideline, Particulate matter, ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide, World Health Organization (WHO), 2022