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AIR POLLUTION ASSESSMENT VIA STATISTICAL REASONING AND ITS IMPLICATIONS: A CASE STUDY OF BAEKRYEONG ISLAND IN REPUBLIC OF KOREA

SEOK HO CHANG[A,1] AND SOONHUI LEE

[a]*College of Business, Hankuk University of Foreign Studies, Republic of Korea*

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ABSTRACT

The frequency and intensity of air pollution are two of most critical issues the world faces in dealing with global environmental problems. They are both important areas that need to be improved. Our previous research examines the assessment of fine dust pollution in Baekryeong island by statistical reasoning through one specific example of inland city (Yanggu) in Republic of Korea; however, given that Baekryeong Island is a remote island, there has been little focus on in-depth examination of its effect on the high density of fine dust in Baekryeong Island. The purpose of this article is twofold: (i) to examine the effect of a remote island on the high density of fine dust on Baekryeong Island using statistical reasoning and to provide a more specific statistical basis for the claim that one of the non-negligible factors influencing the high density of fine dust on Baekryeong Island is the geographic proximity to China; and (ii) to present brief discussion of fundamental cause of fine dust and global air pollution issues, which are not discussed in Chang and Lee (2018).

KEY WORDS : Fine dust pollution, Ozone layer and climate change, Global environmental problems, Statistical reasoning, Air pollution assessment, Particulate matter (PM)

INTRODUCTION

The international journal Nature in 2017 reported that the ultrafine dust emitted from China could harm the health of people around the world. It suggested that 7 million people died worldwide each year due to fine dust in the spring (Zhang *et al.* 2017). According to that paper (Zhang *et al*., 2017), atmospheric particulate matter (PM) with diameter of less than 2.5 μm can move across the country and other countries, such as China, leading to premature death. China has the greatest number of early deaths due to fine dust (1.9 million deaths), followed by India (580,000 deaths), Southeast Asia (450,000 death), the Middle East and North Africa (280,000 deaths), Eastern Europe (220,000 deaths), and Western Europe (200,000 deaths) (Zhang *et al.*, 2017). Other East Asian countries including Republic of Korea, Mongolia, North Korea and Japan have about 89,000 deaths due to fine dust. Analysis shows that 90% of premature deaths from cardiovascular diseases are due to ultrafine dusts designated as carcinogens (Zhang *et al.,* 2017).

According to IQAir AirVisual 2018 World Air Quality Report, Republic of Korea is now the second most polluted country among Organization for Economic Cooperation and Development (OECD) nations. According to a report (Financial Times, 2017) by Financial Times in the UK in 2017, Republic of Korea has joined the ranks of the world's most polluted countries, with air pollution in the first months of 2017 soaring to record levels. Long associated with Asian capitals such as Beijing or Delhi, hazardous smog has for weeks blanketed Seoul — a city now appearing among the world's three most polluted in daily rankings (Financial Times, 2017).

In June 2016, the OECD warned serious air pollution problems in Republic of Korea surrounded by fine dust and called for aggressive responses (OECD report, 2016). The OECD published a report on the economic consequences of outdoor air pollution, and calculated the social costs associated with increased particulate and surface ozone (OECD report, 2016). Among neighboring countries of China, Republic of Korea and Japan accounted for half (39,900) of total deaths (89,000) due to fine dust. The analysis shows that 90% of premature deaths from cardiovascular diseases are due to ultrafine dusts designated as carcinogens (OECD report, 2016).

According to a recent report on the smog in the Seoul area, China's Xinhua news agency mentions that the cause of the smog that sometimes appears in Seoul is caused by the basin terrain, population density, large diesel cars, enormous quantities of dust and vehicles. It does not rule out the effects of smog from neighboring country (Xinhua report).

In recent years, Republic of Korea's air pollution has become one of major social issues (Korea Times, 2018, Korea Herald, 2019): Thick ultrafine particulate pollution blanketed most of Republic of Korea on March 5, 2019, prompting authorities to enforce emergency measures to combat fine dust for a sixth consecutive day in Seoul, Incheon and Gyeonggi and the North and South Chungcheong provinces (Korea Herald, 2019). On March 26-27 and April 6, 2018, Seoul reported that it had the highest level of fine dust in the world. PM2.5 warning has been issued four times already during the first half of 2018 (Korea Times, 2018). Ultrafine dust warning is issued when the average concentration per hour is over 90 $\mu g/m^3$ for 2 hours (Korea Times, 2018). According to the Ministry of Environment of the Republic of Korea, smog formation from China is getting worse and the period of occurrence is shortened. Although domestic pollutant emissions are reduced, high concentration fine dust is not decreasing (Report in NIER, 2015-2018). According to the report of the Gyeonggi Provincial Health and Environment Research Institute in Republic of Korea on April 10, 2018, there have been 42 cases of PM10 and PM2.5 warnings, with warnings for 16 days in four regions in the province. The average concentration and duration of announcement at the time of warning were worse this year (2018) than last year (2017) (Report in NIER, 2018).

The National Institute of Environmental Research (NIER) in Republic of Korea divides the causes of fine dust into domestic emissions and external influences. According to the research report in NIER, the ratio of impacts at home and abroad differs from researcher to researcher, but it is usually 40 ~ 70% (NIER report, 2016-2017). Domestic emissions are caused by economic activities such as energy consumption in daily life, automobile operation and industrial activities. In the case of the metropolitan area, automobiles and large-scale business sites nationwide are the largest sources. Domestic influences are big. However, the impact from abroad sometimes can be up to 70%. Thus, the influence of China cannot be ignored. NIER also announced the contribution rate analysis for fine dust. The amount of fine dust coming from outside the country varies by season and case. In 2016, the NIER and the NASA conducted three-dimensional observations on three aircraft, 18 NASA ground survey sites, and 6 satellites, including NASA's research aircraft, through a joint study of the Korean peninsula in spring (NIER report, 2016-2017, Earth Science Project Office Report, 2016). As a result, it was found that the foreign influence was 48% and the domestic emission was 52%. Among foreign influences, the influence of China was 34%, with the influence of the Shandong Peninsula region adjacent to our country accounting for 22% (NIER report, 2016-2017). Although China reported a significant improvement in air quality over the past few years due to its harsh smog warfare policy, many scientists, journals and press releases have pointed to the fine dust effects of China. However, China has not acknowledged that.

At the same time, it is reported that the number of domestic ozone (O_3) warning messages in Republic of Korea has been continuously increasing (Korea Times, 2018). Human health threat posed by invisible ozone can no longer be overlooked (Korea Times, 2018, Xinhua news, 2018). According to the Ministry of Environment's air quality database 'Air Korea' in Republic of Korea provided on February 27, 2018, the number of ozone warning messages issued nationwide was only 64 in 2012. It was increased to 276 in 2017, more than 4.3 times in five years. In addition, summer heatwave has become one of major social issues in Republic of Korea: In mid-July 2018, the average temperatures in Seoul and Daegu in Republic of Korea are 30.7 and 35.1 degrees, respectively. It was the highest in 24 years since 1994. According to Center for Disease Control and Prevention in Republic of Korea, there were 2,549 patients with hyperthermia (30 deaths) during the period from May 20, 2017 to May 2, 2018. During the 2017 summer season, total number of patients with hyperthermia was 975.

Baekryeong Island is an island of Republic of Korea. It is the largest island of the five islands in the west of the 5th degree (Wikipedia). It is 149km from Pyongyang in North Korea, and 225km from Weihai in China. It has the shortest distance from the mainland of Shandong Peninsula (Wikipedia). The Marine Corps of the Republic of Korea (ROK) is stationed at the forefront of North Korea as a military base (Wikipedia). It has been reported that the fine dust concentration in Baekryeong Island is close to that in Seoul (NIER report 2015-2017). Accordingly, there are articles and news claiming that China's overseas dust particles have significant effect on the high density of fine dust in Baekryeong Island considering that the pollution level of Baekryeong Island, which has lower levels of population and vehicles densities compared to those of Seoul, is close to that of Seoul (Chung, 2014, Korea Times and Wikipedia). On the other hand, some speculate that that high density of fine dust in Baekryeong Island are due to factors such as pollutants emitted from the forefront military bases and the influence of North Korea which is geographically close to the North (Wikipedia).

Previous research (Chang and Lee, 2018) has assessed the fine dust pollution in Baekryeong island by statistical reasoning through one specific example of inland city (Yanggu) in Republic of Korea. However, given that Baekryeong Island is a remote island, there has been little focus on in-depth examination of the effect of a remote island on the high density of fine dust in Baekryeong Island.

The purpose of this article is twofold: (i) to examine the effect of a remote island on the high density of fine dust on Baekryeong Island using statistical reasoning and to provide a more specific statistical basis for the claim that one of the non-negligible factors influencing the high density of fine dust on Baekryeong Island is the geographic proximity to China; and (ii) to present brief discussion of fundamental cause of fine dust and global air pollution issues not discussed in Chang and Lee (2018).

In this article, we present a series of statistical reasonings that leads to a rational conclusion from hypothesis setting and data. It is advantageous in that it is much more time- and cost- effective to validate the result, especially when there is time and budget limitation as opposed to methodology used in joint research of NIER and NASA.

The statistical analysis presented in this article provides a statistical basis for the claim that geographically proximity to China is one of the nonneglected factors influencing high density of fine dust in Baekryeong Island. This finding supports result of joint research of NIER and NASA that the neighboring country is one of the major external factors for the occurrence of the air pollution in Republic of Korea.

The rest of this article is organized as follows: In Section 2, this article briefly presents the definition and severity of fine dust, ozone, and global warming, issues associated with global environmental problems. In Section 3, this article provides a more specific statistical basis for the claim that one of the nonnegligible factors influencing the high density of fine dust in Baekryeong Island is the geographically proximity to China. Section 4, this article presents the implications of results, including some comments on the fundamental cause of fine dust, global air pollution issues (such as ozone, desertification, and global warming, sustainable energy), and subsequent international cooperation of global air pollution.

DEFINITIONS AND SEVERITY OF FINE DUST, OZONE AND GLOBAL WARMING

This section briefly presents the definition and severity of fine dust, ozone, and global warming, all of which are issues associated with global environmental problems.

Particulate Matter (PM) (Wikipedia)

Dust is divided into total dust, minute dust (PM 10) with diameter less than 10 μm, and ultrafine dust with diameter less than 2.5 μm (PM 2.5) depending on particle size. When people are exposed to fine dust for a long time, their immunity is rapidly lowered, making them susceptible to various diseases, including cardiovascular diseases, skin diseases, eye diseases, and respiratory diseases such as colds, asthma and bronchitis. Ultrafine dust having a diameter of less than 2.5 μm can particularly penetrate into the bronchi and deep into lungs of the human body (Wikipedia). Its heavy metal content is high enough to be called as fine heavy metal rather than fine dust (Wikipedia).

In Republic of Korea, the atmosphere is often smog with a lot of fine dust and other air pollutants coming from China. Particularly troublesome is that dust has a seasonal limitation. Fine dust can occur when the wind blows in the direction of Korea. Given that China is the country with the largest amount of fine dust, there are factors that cause damage to its neighboring countries such as Republic of Korea and Japan. In addition, there are factors that cause damage to its neighboring countries such as the Republic of India, Pakistan, Bangladesh, Iran, Afghanistan, northern Vietnam, and the Arabian Peninsula and Sahara Desert (Wikipedia). Karagulian *et al.,* (2015) provided a literature review on particulate matter (PM). Sternberg and Mona Edwards (2017) have reviewed desert dust and health. Literature on PM can be found from literature listed of Wikipedia and NASA articles.

Ozone (O_3) (Wikipedia)

Ozone is a colorless gas derived from the Greek 'ozein' which means 'smell'. It is a gas with strong oxidizing power and high energy. High concentration of ozone is harmful to the human body. When it occurs, ozone alarm is issued in Republic of Korea. There are three kinds of ozone alarm: 1) Caution, when ozone concentration 0.12 ppm or more; 2) Alarm, when ozone concentration 0.3 ppm or more; and 3) Critical alarm, when ozone concentration 0.5 ppm or more

High concentration ozone is mainly observed in the summer due to high temperature and high radiation dose. Recently, ozone warning is continuing from spring to autumn. This indicates that, while the average temperature on the surface of the earth continues to rise due to global warming, emissions of pollutants are also increasing. Ozone is an air pollutant. It is a greenhouse gas that can accelerate global warming which generates more ozone at the surface, leading to a vicious cycle. Ozone also has strong oxidizing power. It is involved in the production of ultrafine dust (PM2.5) (Wikipedia).

When ozone concentration is high, respiratory and lung function of a person will deteriorate. High ozone concentration can exacerbate symptoms such as eye and neck sting, airway constriction, dyspnea, headache, cough, nausea, bronchitis, heart disease, emphysema and asthma (Wikipedia). Elderly people and children with weak respiratory or pulmonary functions should be especially careful. They should not go out or exercise if there is ozone notice or warning. It is best to stay indoors as much as possible because indoor ozone is reduced by 30 ~ 50% compared to outdoor. It is important to reduce the use of cars when ozone concentration is high. The elderly should refrain from going out and children should stop outdoor physical activities at school when ozone concentration is high. In addition, high ozone concentration can be fatal to people with respiratory or cardiac conditions. Healthy people should keep in mind that ozone penetrates deep into the lungs and causes harm to the human body if they are exposed to ozone warnings. For literature review on ozone and its severity, see literature listed in Wikipedia.

Global warming (Climate Change) (Wikipedia, NASA top stories)

Global warming is also referred to as climate change. It is the observed century-scale rise in the average temperature of the earth's climate system and its related effects (Wikipedia, NASA top stories). Damage caused by global warming can be noticeably seen in animal habitat migration due to the continuous rise in temperature since the early 20th century. Habitat of animals such as squirrels and mice are moving further north. In addition to animal habitat, the disappearance of Arctic lakes is also an evidence that global warming is serious. Over the past few decades, 125 large northern giant lakes have disappeared. Tuvalu is the first country to suffer from global warming. Part of the country has been flooded due to rising sea level caused by global warming. The Tuvalu government has officially abandoned the country. The summit of the Himalayas has an enormous amount of water resources called the Earth's water tanks. People in Nepal, India, China and other neighboring countries of the Himalayas are living on this water using the melted water. However, this water is disappearing at a rapid pace due to global warming. Mecca (a desert valley in western Saudi Arabia) and the Maldives (a tropical nation in the Indian Ocean) are also examples of global warming damage. In fact, countries with coast have direct and indirect damages caused by global warming. The Maldives, like Tuvalu, has retreating coastline and reducing the size of its land. As a result, tourism, the largest industry in the Maldives, is being reduced.

In 2015, the Ministry of Environment and the Korea Meteorological Agency published a report on the scientific basis and impact of climate change in Republic of Korea. The Korea Climate Change Assessment Report 2014 is a compilation of 2,500 research results from 2010 to 2014. According to the Korea Climate Change Assessment Report 2014, the annual average temperature and sea level rise patterns are observed in Republic of Korea. An increase in anthropogenic greenhouse gases has been found to be a major cause. Average annual temperature of Korea has increased from 0.25 ^{o}C/ 10 years from 1954 to 1999, 0.41 ^{o}C/10 years from 1981 to 2010 and 0.5 ^{o}C/10 years from 2001 to 2010. Average annual temperature of the Korean peninsula has risen sharply since the 1980s. Researchers has evaluated that the warming of the Korean peninsula has a significant impact on the warming of the greenhouse gases that cause warming in Asia and East Asia. It has been predicted that health damage caused by heat will increase in the future due to rising temperature. According to the Korea Climate Change Assessment Report 2014, deaths from heatwaves in Seoul will increase by more than twice (from 0.7 per 100,000 during 2001-2010 to 1.5 per 100,000 population during 2036 to 2040). For literature review on global warming, see literature listed in Wikipedia and NASA articles.

Statistical Reasoning and Analysis

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

Known statistics

According to atmospheric environment of Republic of Korea, it is reported that average density of fine dust in Baekryeong Island is close to that in Seoul (NIER report 2015-2016).

Fig. 1. Location of Baekryeong Island (Baekryeong-do) (Wikipedia)

Besides, vehicles density in Baekryeong Island is much lower than that in Seoul (Table 2). Accordingly, there are articles and news claiming that China's overseas dust particles have significant effect on high density of fine dust in Baekryeong Island considering that air pollution level of Baekryeong Island, (which has lower levels of population and vehicles densities compared to those of Seoul), is close to that of Seoul (Chung, 2014, Korea Times, Wikipedia). On the other hand, some speculate that that high density of fine dust in Baekryeong Island are due to factors such as pollutants emitted from the forefront military bases and the influence of North Korea, which is geographically close to the North (Wikipedia).

Table 1. Average densities of fine dust in Seoul and Baekryeongdo (Jan 2015-June 2016)

	Seoul	Baekryeong Island
PM10	47.72 μg/m^3	47.88 μg/m^3
PM2.5	23.77 μg/m^3	23.71 μg/m^3

Table 2. Population and area of Seoul and Baekryeongdo (December 2017, Wikipedia)

	Seoul	Baekryeong Island
Population	9891,448 persons	5,721 persons
Area	605.2 km^2	51 km^2

Statistical reasoning and assumptions

This article approaches the issue of high density of fine dust in Baekryeongdo, the value of which is close to that of Seoul, based on a series of statistical reasonings:

Although, the fine dust emitted from China (or the geographically proximity to China) is suspected to be one of the main factors that affect the high density of fine dust in Baekryeongdo, we tentatively do not include the geographically proximity to China in the list of main factors that affect the high density of fine dust index in Baekryeongdo. Thus, we have the following assumption 1.

Assumption 1: Factors affecting the high density of fine dust in Baekryeongdo are assumed to be (i) the influence of geographically adjacent North Korea, (ii) the substances emitted from the foremost military units, which are the main factors suggested in the counter-argument. We assume that the geographically proximity to China does not affect the high value of fine dust index in Baekryeongdo significantly.

Since it is difficult to directly obtain data or quantify the factors that indicate the influence of geographically adjacent North Korea and the substances emitted from the forefront military bases of Baekryeongdo, we take an alternative approach:

We select Ulreung Island, a specific region in Republic of Korea that satisfy assumption 1 closely. The environment of Ulreoung Island is very similar to that of Baekryeongdo. It is geographically distant from China, thus satisfying assumption 1 approximately.

Ulreoung Island (Ulreoung-do) (Wikipedia)

Ullreung Island (sometimes called Ulreoung-do) is one of the islands in Republic of Korea. It is 120kim (75 mi) east of Korean Peninsula. It is one of the forefront areas that border South Korea with North Korea. In addition, it is geographically distant from China, thus satisfying assumption 1 approximately. In Ulreoung-do, there is Naval 118th Early Alert Squadron in the forefront. It is a guarding and book defending unit of the Navy 1st Fleet. It is responsible for defense of Ulreung-do. It performs maritime surveillance mission of the whole East Sea. Ulleungdo has a lower population density and fewer vehicles compared to Seoul (Wikipedia). Therefore, main factors affecting the fine dust index in this region are expected to be the factors such as the elements of the forefront military bases or North Korea due to the characteristics of the forefront. Ulreoung-do is a typical example of a remote island. Its environment of which is very similar to that of Baekryeongdo.

Fig. 2. Location of Ullreung-do (Wikipedia)

Table 3. Population and area of Baekryeongdo and Ulreoung-do (December 2017)

	Baekryeong Island	Ulreoung Island
Population	5,721 Persons	9,975 Persons
Area	51 km^2	72.52 km^2

We now make the following assumption 2:

Assumption 2: Factors affecting the values of fine dust concentration in Ulreung-do is assumed to be: (i) the influence of geographically adjacent North Korea, (ii) the substances emitted from the foremost military units as main factors suggested in the counter-argument.

Under the assumptions 1 and 2, the following hypothesis are set for the fine dust index in Ulreoung-do:

H_0 (Null hypothesis): Average density of fine dust in Ulreung-do = average density of fine dust in Seoul.

H_1(Alternative hypothesis): Factors of the nearest military bases in Ulreung-do and neighboring North Korea do not have significant effect on the increase of the fine dust concentration of Ulreung-do to the level comparable to or exceeding Seoul 's fine dust index. That is, the value of fine dust concentration in Ulreung-do will be smaller than that in Seoul. (Average density of fine dust in Ulreung-do < average density of fine dust in Seoul)

Under the assumption that the null hypothesis is true, the average densities of fine dust in Seoul and Ulreung-do are compared between 2010 and 2017. Due to the limitation of space, we only present some of recent results (2016-2017) of average densities of fine dust in Seoul and Ulreoung-do (see appendix for details):

Remark 1> The following table 4 data was extracted from the Ministry of Environment, Air pollution status in Republic of Korea (NIER report, 2010-2017)

Remark 2> Statistical analysis was performed by extracting only the comparable year of each data

Since each data pair and the number of data is 88, a pairwise test was used to compare the differences between the two populations (Chang, 2018). The following is the result of the pairwise comparison test (significant level of test = 0.01) using Excel (2016):

As can be seen from the following table 5, the null hypothesis that the two population groups (Seoul and Ulreoung-do) have the same mean is true is rejected because the p-value is 0.0000000351856, which is less than the significance level 0.01. In other words, the assertion of the alternative hypothesis that the concentration of fine dust of Ulreoung-do is less that of Seoul is statistically significant, and the reliability of this conclusion is 0.99.

Table 4. Fine dust (PM10) Monthly air pollution (unit: μg/m³)

	Seoul	Ulreung-do
2016 Jan	50	28
2016 Feb	45	34
2016 Mar	64	46
2016 Apr	71	65
2016 May	56	57
2016 Jun	45	25
2016 Jul	33	26
2016 Aug	34	34
2016 Sep	37	32
2016 Oct	38	40
2016 Nov	52	47
2016 Dec	48	37
2017 Jan	53	46
2017 Feb	46	43
2017 Mar	60	54
2017 Apr	56	53
2017 May	63	53
2017 Jun	41	33
2017 Jul	33	30
2017 Aug	21	23
2017 Sep	32	33

Table 5. Results of t test, a pairwise comparison test
t-test results
Pairwise comparison test

	Seoul	Ulreung-do
Average	45.43181818	39.03409091
Sample variance	176.776907	115.159744
Number of observations	88	88
Pearson's correlation coefficient	0.659518153	
Difference between two means	0	
d.f.	87	
t statistics	5.892521365	
P(T<=t) one-sided p-value	3.51856E-08	
t statistics one-sided	2.369976779	
P(T<=t) two-sided p-value	7.03712E-08t	
statistics two-sided	2.633527229	

Remark 3> Similar statistical analysis was conducted for various inland regions (such as Ko-sung, Jeong-Sun, and Hoeng-Sung) in Republic of Korea with the forefront military bases, the environment of which are very similar to that of Baekryeongdo. All regions mentioned are geographically distant from China but geographically close to North Korea. They are also close to the forefront military bases, thus satisfying assumption 1 approximately. All of them have the same conclusions as those presented in this article. Due to the limit of space, we only present the results for Uleung-do.

Main factor affecting the high density in Baekryong Island, and implications

This article now goes back to our original question on the factors that have major impacts on the high density of fine dust of Baekryeongdo Island. The most important factors that influence the high density of fine dust of Baekryeongdo are suspected to be the factors influenced by the forefront military influence brought about by counterinsurgency and the geographically adjacent factors of North Korea.

Although it is not exactly geographically consistent with Baekryeong Island, some locations, such as Ulreoung Island, Ko-sung, Jeong-Sun, Hoeng-Sung, and Yang-gu have environments similar to Baekryeongdo (being geographically close to North Korea with the forefront military bases). Through these examples, we can see that factors such as (i) the influence of geographically adjacent North Korea, and (ii) the substances emitted from the foremost military units do not have a significant effect on the increase of the average density of fine dust of Ulreoung-do, Ko-sung, Jeong-Sun, Hoeng-Sung, and Yang-gu to levels comparable to or exceeding Seoul 's fine-dust index.

Now we apply above conclusion to the issue of high density of fine dust in Baekryeongdo. If our assumption 1 is true, there is not enough reason to expect the average density of fine dust in Baekryeongdo to be as high as that of Seoul. However, in reality, the average density of fine dust in Baekryeongdo is as high as that in Seoul. This means that our assumption 1 is not true. We also note that Ulreoung-do, Ko-sung, Jeong-Sun, Hoeng-Sung, and Yang-gu are farther away from China than Baekryeong Island (see Figure 4). Therefore, among the factors affecting the high density of fine dust in Baekryeongdo, the geographically proximity to China is one of nonnegligible factors that significantly affects high density of fine dust in Baekryeongdo.

CONCLUSION AND IMPLICATIONS

The statistical analysis presented in this article provides a statistical basis for the claim that geographically proximity to China is one of the nonneglected factors influencing high density of fine dust in Baekryeong Island. This finding supports the result of joint research of NIER and NASA that the neighboring country is one of the major external factors for the occurrence of the air pollution in Republic of Korea. Note that joint research of NIER and NASA conduct three-dimensional observations on three aircraft, 18 NASA ground survey sites, and 6 satellites, including NASA's research aircraft, through a joint study, which is time-consuming and costly.

The research methodology presented in this article is rather involved in the sense that it is a series of statistical reasonings that needed to have a rational conclusion from hypothesis setting and data. Although joint research of NIER and NASA can produce very detailed and accurate results in evaluating the air pollution in Republic of Korea, our research methodology presented in this article has some advantages: (i) It is much more time- and cost- effective in evaluating the main factors that affect the air quality of a certain specific region when there is time and budget limitation. (ii) It can also be used to validate the results of time-consuming and costly methodologies.

Based on the methodology presented in this article, further research is required to study the factors for the occurrence of the air pollution in Asia including Republic of Korea, China, and Japan.

Fine dust, desertification, ozone layer and global warming, and destruction of ecosystem are associated with global environmental problems. Solving one problem does not mean that other problems are solved. Unlike developed countries where industrialization and urbanization have progressed gradually since the Industrial Revolution, developing countries have undergone rapid economic growth, and industrialization and rapid population growth are continuing to put more emphasis on economic development. Such fine dust issues will naturally occur when we focus on industries that developed countries are trying to avoid with little awareness of the seriousness of fine dust pollution.

The world is a respiratory community. Air cannot be stopped at the border. In the end, the world must face its head to form a joint research team to identify the cause of the pollution and improve the air quality. It is necessary to identify and plan the management accordingly. While joint research and cooperation have made progress, much work remains to be done.

Some specific ways we could do to help to reduce global air pollution include the effort to prevent desertification (NASA stories, Wikipedia), develop land in environmental friendly ways (Greenpeace forest solution, Wikipedia), reduce the use of disposables (Greenpeace forest solution, Wikipedia), make endeavor to have forests and trees (Greenpeace forest solution, Wikipedia), consider the use of sustainable energy (Sussman et al., McKenzie-Moir and Smith W, Sustainable Asian Conference Papers 2018), reduce greenhouse gases (NASA articles), reduce the amount of carbon dioxide emitted in daily life (NASA articles), and practice environment-friendly attitude (Greenpeace forest solution, Coronato 2008, Wikipedia).

APPENDIX A: AVERAGE DENSITIES OF FINE DUST IN SEOUL AND ULREOUNG-DO (2010-2017)

We present average densities of fine dust in Seoul and Ulreoung-do from 2010 to 2017.

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Table A1. Fine dust (PM10) Monthly air pollution (unit: μg/m³)

	Seoul	Ulreoung-do
2010 Jan	59	NA
2010 Feb	50	37
2010 Mar	61	43
2010 Apr	49	50
2010 May	56	49
2010 Jun	51	50
2010 Jul	33	45
2010 Aug	32	48
2010 Sep	25	39
2010 Oct	41	50
2010 Nov	71	55
2010 Dec	61	48
2011 Jan	44	33
2011 Feb	75	50
2011 Mar	65	58
2011 Apr	56	NA
2011 May	79	NA
2011 Jun	44	NA
2011 Jul	28	25
2011 Aug	27	18
2011 Sep	29	23
2011 Oct	42	33
2011 Nov	37	33

Table A1. *Continued*

	Seoul	Ulreoung-do
2011 Dec	46	29
2012 Jan	60	35
2012 Feb	50	38
2012 Mar	47	42
2012 Apr	51	50
2012 May	52	44
2012 Jun	40	32
2012 Jul	28	36
2012 Aug	22	34
2012 Sep	27	30
2012 Oct	33	39
2012 Nov	42	39
2012 Dec	41	31
2013 Jan	64	45
2013 Feb	45	44
2013 Mar	55	57
2013 Apr	52	46
2013 May	56	64
2013 Jun	40	42
2013 Jul	34	49
2013 Aug	35	51
2013 Sep	28	30
2013 Oct	29	30
2013 Nov	43	36
2013 Dec	55	32
2014 Jan	57	35
2014 Feb	57	37
2014 Mar	60	48
2014 Apr	58	52
2014 May	63	57
2014 Jun	38	32
2014 Jul	38	30
2014 Aug	29	22
2014 Sep	29	21
2014 Oct	33	27
2014 Nov	45	28
2014 Dec	43	28
2015 Jan	49	29
2015 Feb	84	46
2015 Mar	71	50
2015 Apr	45	44
2015 May	45	43
2015 Jun	35	29
2015 Jul	30	26
2015 Aug	34	39
2015 Sep	28	NA
2015 Oct	44	32
2015 Nov	33	24
2015 Dec	48	25
2016 Jan	50	28
2016 Feb	45	34
2016 Mar	64	46
2016 Apr	71	65
2016 May	56	57

Table A1. *Continued*

	Seoul	Ulreoung-do
2016 Jun	45	25
2016 Jul	33	26
2016 Aug	34	34
2016 Sep	37	32
2016 Oct	38	40
2016 Nov	52	47
2016 Dec	48	37
2017 Jan	53	46
2017 Feb	46	43
2017 Mar	60	54
2017 Apr	56	53
2017 May	63	53
2017 Jun	41	33
2017 Jul	33	30
2017 Aug	21	23
2017 Sep	32	33

APPENDIX B: LOCATION OF BAEKRYEONG-DO AND ULREOUNG-DO Wikipedia

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