Effects of Air Pollution from China on South Korea Over a Decade with Attention on $PM_{2.5}$ and PM_{10}

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All figures created by author in RStudio or ArcGIS Pro

Republic of Korea is regularly subjected to large amounts of air pollution from China, particulate matter (PM) ranging from 2.5 microns and under in length ($PM_{2.5}$) to 10 microns and under in length (PM_{10}). Particulate matter is a particularly dangerous form of air pollution, which can cause serious health effects when inhaled. These include ischemic heart disease, stroke, obstructive pulmonary disease and lung cancer when exposed over a long period of time. These harmful pollutants are transported from China by the winds across the Yellow Sea. PM_{10} is a pollutant which can irritate the eyes and nose, the particles are too big to make their way into the lungs. $PM_{2.5}$ on the other hand is considered more harmful since it can penetrate deep into the lungs. There are natural and man-made sources of $PM_{2.5}$ The growth of the Chinese economy in the past decade, paired with much looser environmental regulations than most developed countries, has led to a worsening of the situation. Korea's Nation Institute for Environmental Research (NIER) has been monitoring the situation for years using both stationary air quality monitoring stations, along with adapted airplanes designed to measure and study air quality over the Yellow Sea between China and Korea.

Particulate matter is a very complex source of pollution. PM can come from a variety of sources, including direct and secondary. Natural sources include volcanic ash, smoke from wildfires and sea salt, while man-made sources include emissions from internal combustion engines, coal-fired power plant emissions and manufacturing by-products. Secondary formation of $PM_{2.5}$ can occur through complex chemical reactions which occur between man-made emission and wave vapor in the air and are driven by sunlight.

Due to the highly political nature of the subject, it can be a difficult issue to address. As with any politicized matter, it remains important to evaluate only the data without letting bias or personal sentiments interfere. While diesel emissions from vehicles contribute to the problem on local urban scales, the issue is more widespread than just emissions from vehicles and coal-fired power plants. The World Health Organization maintains public databases of air quality measurements from countries all over the world. Data on both PM_{10} and $PM_{2.5}$ is available for South Korea (although the PM_{10} records are more consistent). $PM_{2.5}$ pollution data is the only pollutant data available for China. In addition to reviewing scientific literature pertaining to these types of air pollution in Korea, RStudio was used to filter the WHO air quality data and visually display the data as well as run comparative analysis. The data was then formatted and loaded into ArcGIS Pro for spatial visualization and geostatistical analysis.

The measurements for NO_2, PM_{10}, and $PM_{2.5}$, which were recorded in the latest WHO database, span from 2010 to 2020. The readings were all taken at fixed recording stations. While general air pollution analysis was conducted, the focus of this paper is on particular matter, particularly $PM_{2.5}$. Quantile-Quantile plots were initially created to assess if the temporal coverage data followed a normal trend in both South Korea and China as a whole. Temporal coverage refers to the time (given as a percentage) during which a given area is affected by recorded levels of pollution.

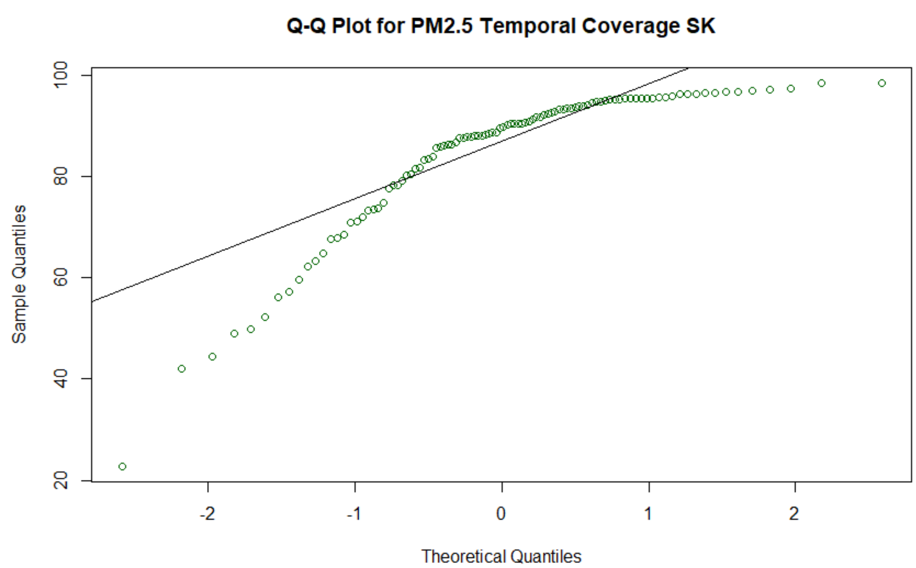

Fig. 1 – Q-Q Plot showing abnormally distributed data for PM2.5 temporal coverage (%) in South Korea

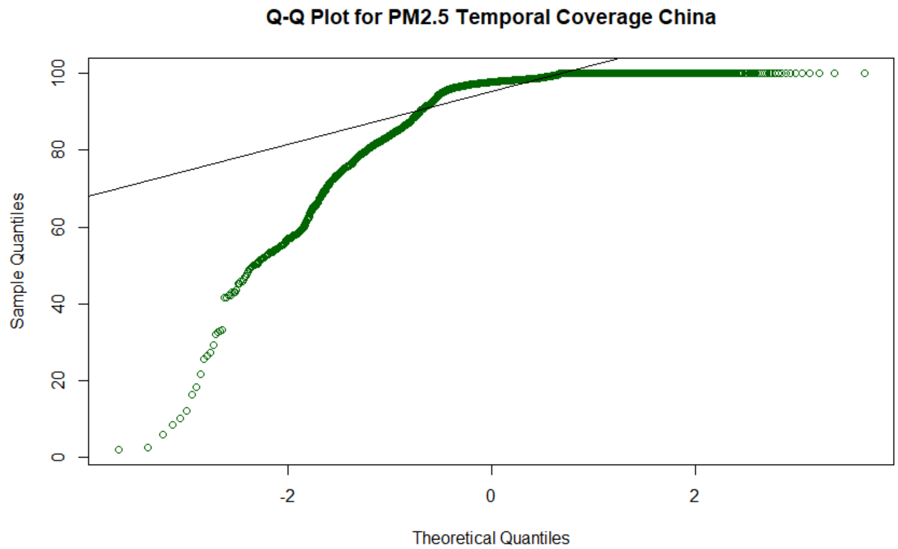

Fig.2 – Q-Q Plot showing abnormally distributed data for PM2.5 temporal coverage (%) in China

These initial Q-Q plots indicated that the temporal distribution of $PM_{2.5}$ was irregularly distributed. T-tests were also run against the $PM_{2.5}$ data from WHO, comparing China and South Korea overall. The means of South Korea and China were 23.27451 and 43.07299, respectively. Using those means, the p-value came to $2.2*10^{-16}$. This value was far less than 0.5, so it could be concluded that the relationship between the means of the datasets was not statistically significant. The statistical tests were only performed preliminarily to compare the means of the data. China has a much larger dataset than South Korea, due to the size difference of the two countries.

Shanghai is a point of interest in this discussion due to its proximity to South Korea (Seoul in particular). Both cities had some of the highest $PM_{2.5}$ readings compared to the other cities in their respective countries. The distance measured between Shanghai and Seoul in ArcGIS pro was 848.35 km (using the GCS_WGS_1984 projection). Only the Yellow Sea separates the eastern coast of China from the Western side of Korea. Levels of $PM_{2.5}$ in both Shanghai and Seoul were plotted for comparison:

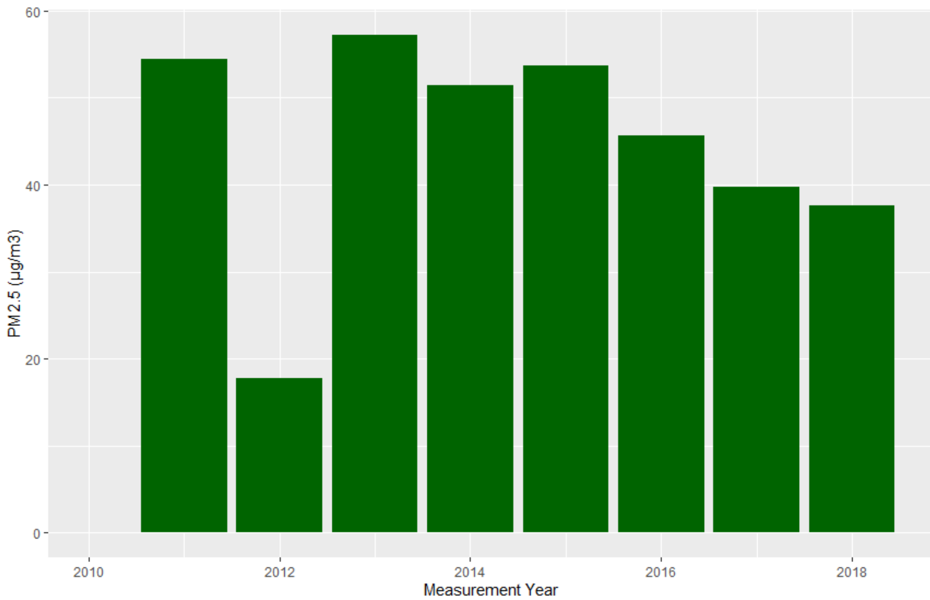

Fig. 3 – PM2.5 levels plotted against measurement year in Shanghai

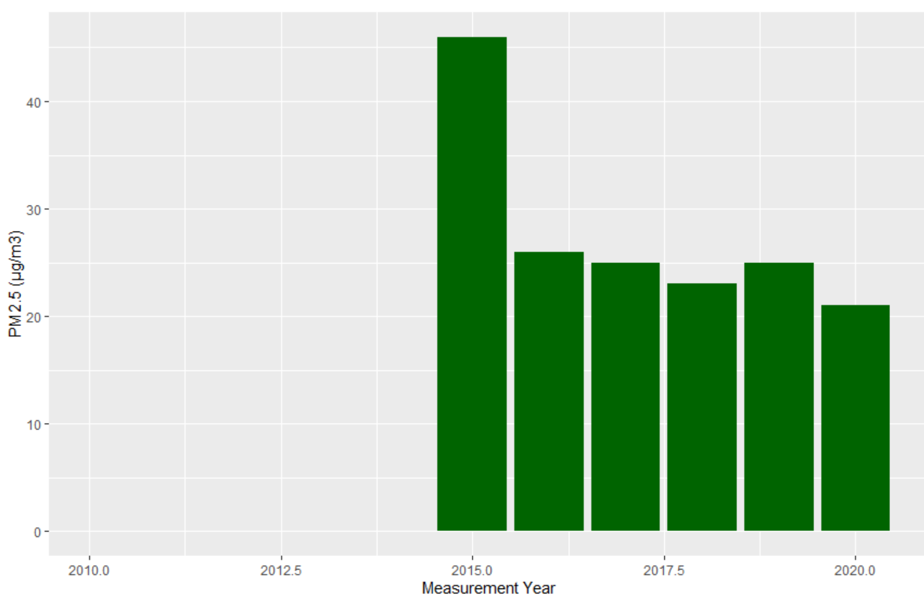

Fig. 4 – PM2.5 levels plotted against measurement year in Seoul

The $PM_{2.5}$ data for both South Korean and Chinese cities was loaded into ArcGIS Pro and subsequently geolocated. Once geolocated, the $PM_{2.5}$ data was able to be represented as a heat map (of density) on the map. $PM_{2.5}$ hotspots were also generated in both Chinese and South Korean Cities. In addition to pollution hotspots, kernel density calculations were run which calculates a magnitude per unit area for the input data.

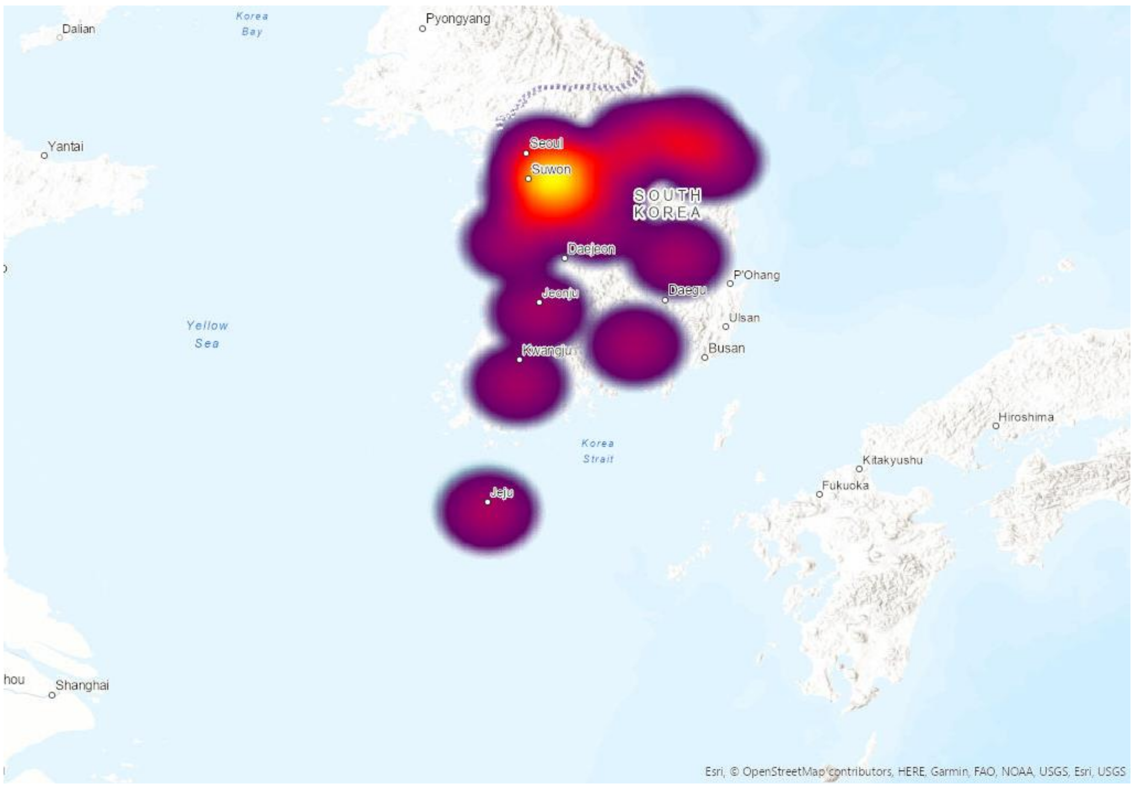

Fig.5 – Heat map showing the density of PM2.5 over South Korean Cities (radius of 35 km)

In the map, lighter colors indicate worse pollution levels on a graded scale. Seoul has the highest levels of $PM_{2.5}$, which decreases as the distance from the population centers increases. While the capital city of S. Korea has the highest levels of pollution, most major populated area follows the same trend as Seoul to a lesser degree. The kernel density calculation was used to determine the weight of the statistical impact of $PM_{2.5}$ in the given metropolitan area over the time that measurements were taken.

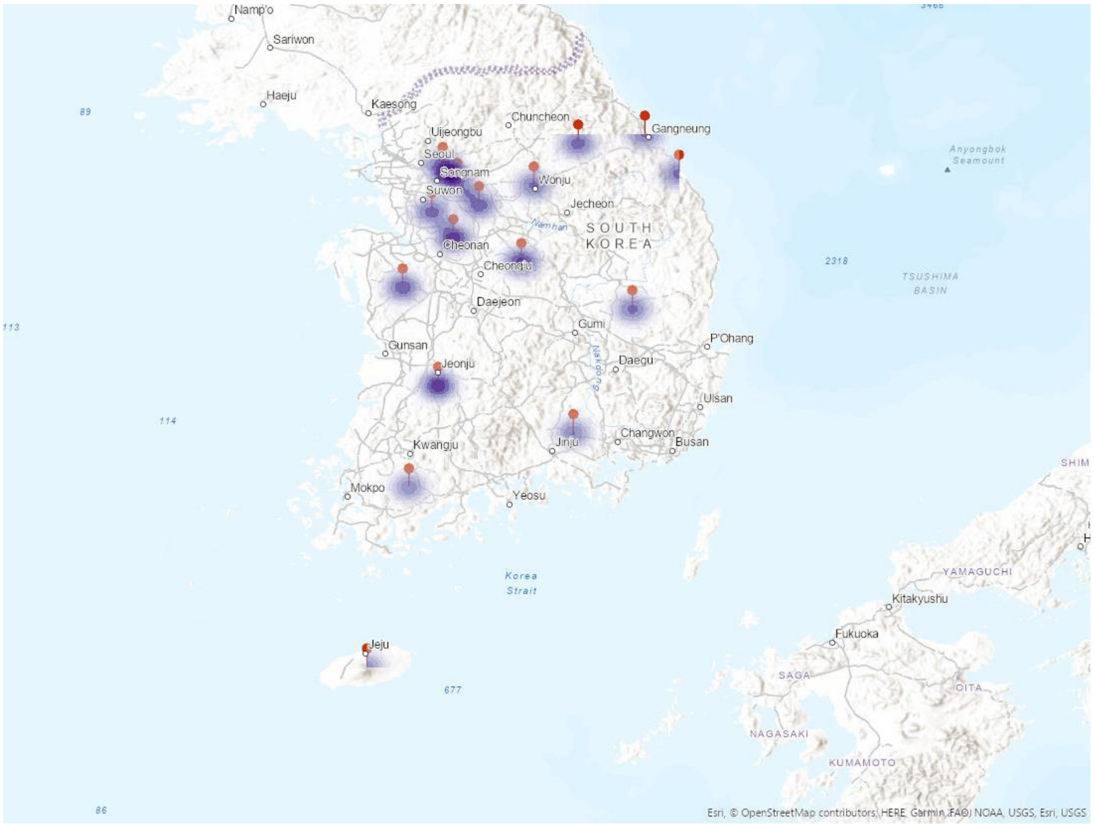

Fig 6 – Kernel densities for $PM_{2.5}$ pollution in South Korean Cities (Darker colors indicate higher statistical density)

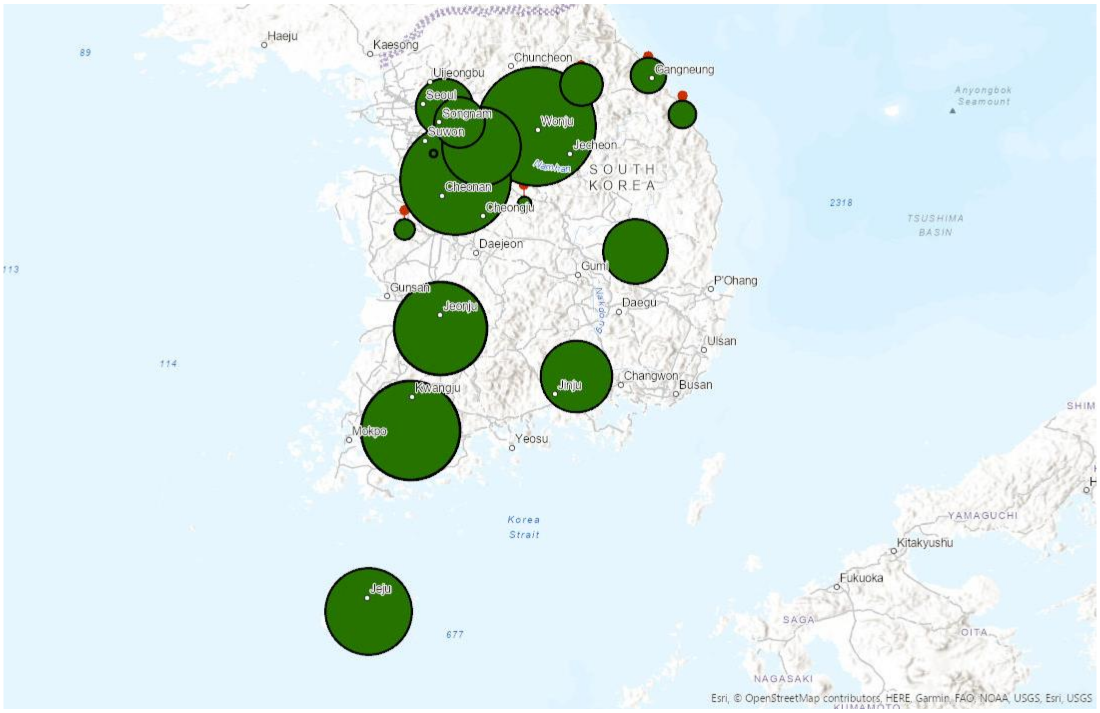

Fig. 7 – PM2.5 hotspots in South Korean Cities

The hot spots, kernel density and heat map showing $PM_{2.5}$ pollution all tell similar stories. $PM_{2.5}$ remains the worst in city centers over time and improves as the proximity to the city decreases. Some speculate that the pollution is coming almost entirely from local sources of pollution, such as diesel- and gas-powered vehicles. In order to evaluate this claim, mapping and geostatistics were also calculated for China, with a particular interest on Shanghai as a point of interest.

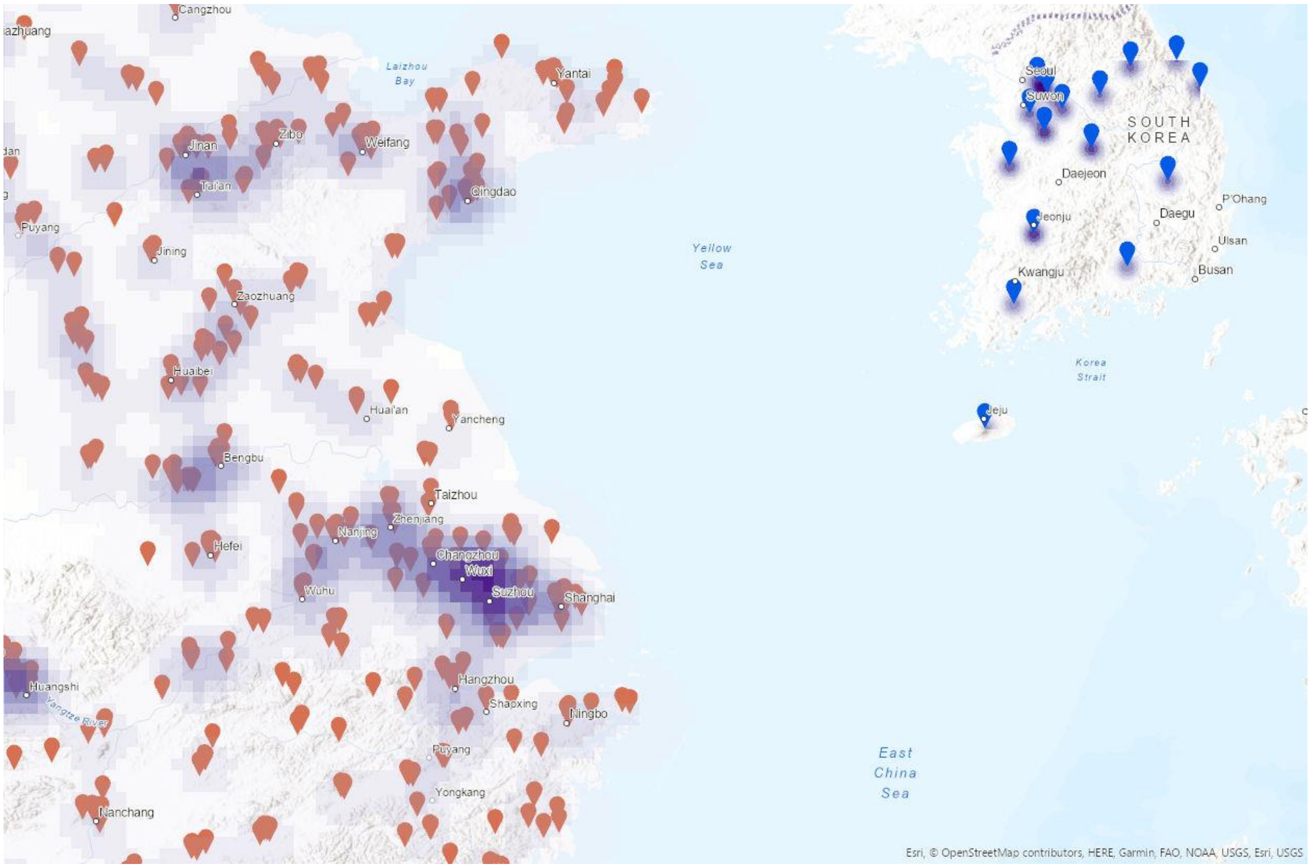

Fig. 8 – Kernel density calculated for Chinese cities with $PM_{2.5}$ pollution data

As seen from the map, Shanghai and the surrounding areas have some of the most densely polluted areas on the eastern side of China. Visual analysis can only go so far in correlating the pollution problem between these two countries. Studies have been conducted on the so-called “Yellow wind” from China, which is said to blow the pollutants across the Yellow Sea from China to Korea. Recalling figure 2, South Korea has been experiencing high levels of air pollution (particularly $PM_{2.5}$) in recent years. Unfortunately, the $PM_{2.5}$ data only accurately goes back as far as 2015, however NO_2 and PM_{10} have also been worsening in recent years. Geostatisitcal analysis and mapping were only performed with respect to $PM_{2.5}$; however, the subsequently mentioned records were plotted out for visualization. These images, while not the main topic of this paper, will be included below.

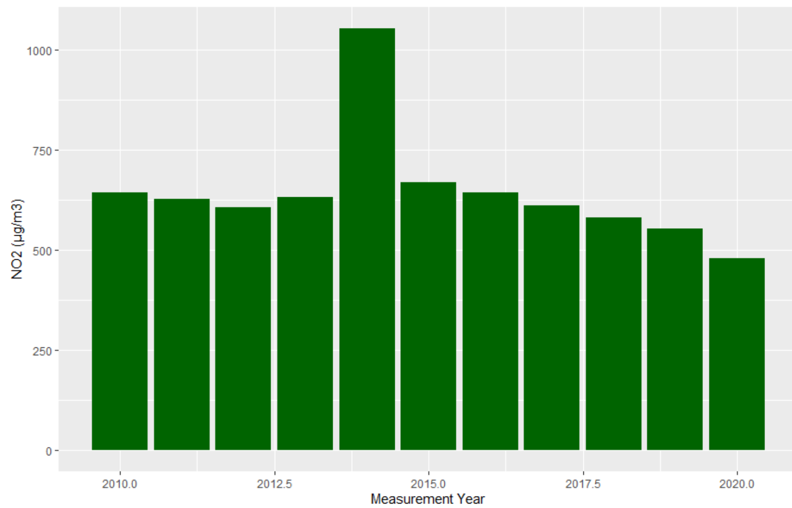

Fig. 9 – NO_2 measurements plotted against measurement year for South Korea

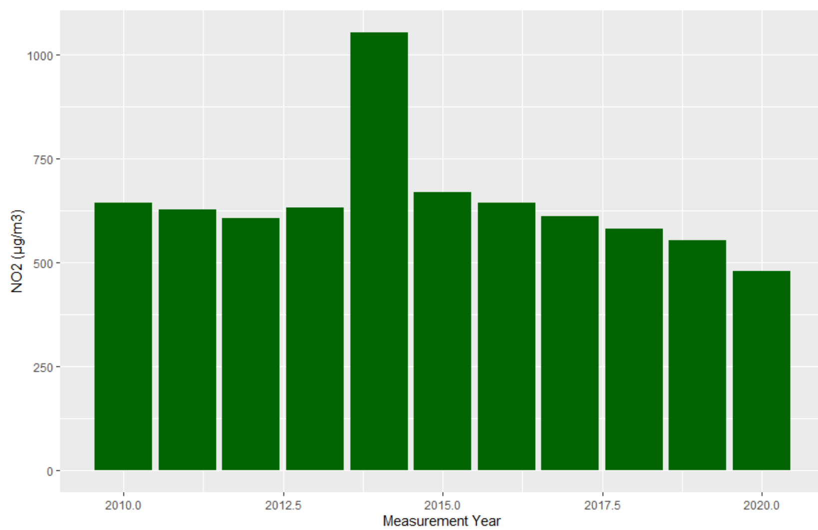

Fig. 10 – PM_{10} measurements plotted against time for South Korea

In a paper by Kim, Moon Joon (2019), the effects of "transboundary" air pollution from China to Korea is examined. According to NASA, Seoul has some of the worst air pollution when compared with other major cities in the world. A South Korean Island of Baekryeong-do (which is located close to the mainland of China) had its PM_{10} concentrations increase by 44.5 percent when the wind was blowing from the west or northwest (Kim, 2019). Several other studies listed in the paper by Kim (Li et al. (2014) and Park and Han (2014)) estimated that 26 to 30 percent of South Korean air pollution was transported there by wind, from China. A large reason for China's worsening air quality is their dependence on coal-fired power. Kim states that because the prevailing winds in that region move from west to east, much of this Chinese pollution is transported to Korea (Kim, 2019).

This paper used a series of methods, including calculating the ambient concentrations of PM_{10} within the aforementioned cities and used this data to calculate summary statistics for the concentrations during the different seasons of the year. The average wind direction and speed were then calculated using the U.S. environmental protection agency Meteorological Monitoring Guidance for Modeling Applications. Vector means for the winds direction and speed were then calculated. Several wind direction models were then used in unison with the pollution data to determine which wind directions yield the highest levels of pollution.

The calculations conducted in this paper determined that westerly wind increased the PM_{10} concentration by 9.5 $\mu g/m^3$ across Korea (Kim, 2019). It was also determined that the impact of air pollution from Shanghai was greater than Beijing. This conclusion corresponds with the hypothesis created from the calculated kernel densities on the maps above. Shanghai had the largest influence on overall air pollution in South Korea as a whole. Additionally, it was determined that the levels of PM_{10} were the worst in the summer months and the second highest in the winter months. Kim concluded that this was due to higher levels of pollutants being generated from both agricultural straw-burning and heating (Kim, 2019). The monitored locations used by Kim were as follows: Seoul, Busan, Incheon, Daegu, Daejeon, Gwangju, Ulsan (for major metropolitan areas). These locations overlapped with 7 of the 15 cities which were geolocated and used for statistical analysis in this essay.

A paper by Choi et al. (2019) titled "Impacts of local vs. trans-boundary emissions from different sectors on PM2.5 exposure in South Korea during the KORUS-AQ campaign" set out to determine the impact of both local South Korean $PM_{2.5}$ emission and $PM_{2.5}$ emissions from other countries in the region, particularly China. KORUS-AQ is a cooperative air quality field study in South Korea (Choi et al., 2019). Both South Korea and the United States launched this effort in order to obtain a better understanding of what factors were driving the poor air quality factors in South Korea. Ground monitoring stations, aircraft, and ships were all used to collect air quality data in this effort. This study classified four different meteorological conditions: dynamic weather period, stagnant period, extreme pollution period, and blocking period. During the extreme pollution period, there was a "strong, direct transport" of $PM_{2.5}$ pollution from China. $PM_{2.5}$ levels exceeded 50 $\mu g/m^{-3}$ for 24- hours (Choi et al., 2019).

Choi's paper used complex modeling to simulate the variations in $PM_{2.5}$ and abroad, as well as the elements which can lead to chemical formation of $PM_{2.5}$ in atmospheric reactions. The different meteorological periods had varying results with respect to both Chinese and local contribution to emissions. During the blocking period (named for a blocking pattern over east Asian during that time period), Chinese pollution only contributed to 25 percent of particulate matter pollution, while local emissions contributed to 57 percent (Choi et al., 2019). Conversely, Chinese pollution contributed to 68 percent of all particulate matter during the period of extreme pollution. The study determined that the source of $PM_{2.5}$ can vary widely, depending on the meteorological patterns in the region.

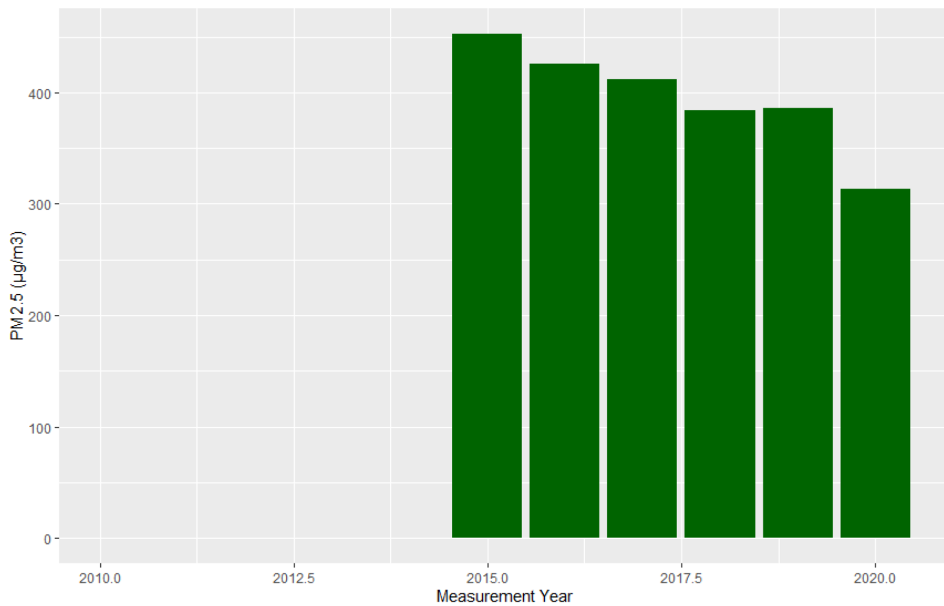

Fig. 11 – $PM_{2.5}$ measurement for Korea from 2015; Choi et all was written in 2019, which shows a slightly higher level than 2018, and a much higher level than 2020. Despite this, 2015 contains the highest measurements in the time series.

In conclusion, both the geostatistical analysis which was completed using data provided by the World Health organization, along with the studies specifically cited in this paper, it can be concluded that the Chinese pollution, particularly $PM_{2.5}$ and PM_{10} has a large impact on the air quality in South Korea. Depending on the seasonality and the wind patterns, Chinese pollution has the capacity to remain rather low, or increase dramatically. Kernel densities indicated that Shanghai was the most likely location for pollution to come from. The study by Kim confirmed this through models and statistical calculations based on pollution data taken from both China and South Korea. He also determined that seasonality, in addition to wind patterns, has a large effect on the air quality in South Korean cities due to seasonal activities in China. Choi et al. (2019) concluded that while both local and regional pollution had an impact on the air quality in South Korea, Chinese air pollution always had an impact to some degree. The magnitude of the pollution depends on the meteorological periods. Effort for improvement need to be two sided for them to be truly effective. To truly solve such a complex and multifaceted issues, the Chinese and South

Korean governments would have to work together in an effort to improve their air quality, and therefore, the quality of life for citizen in both countries.

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