URBA6001
The University of Hong Kong

LONDON AIR QUALITY REPORT

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Content

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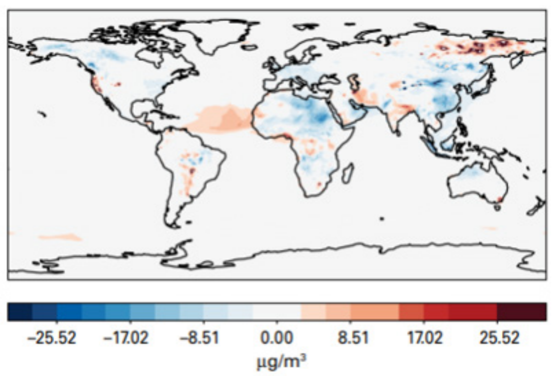
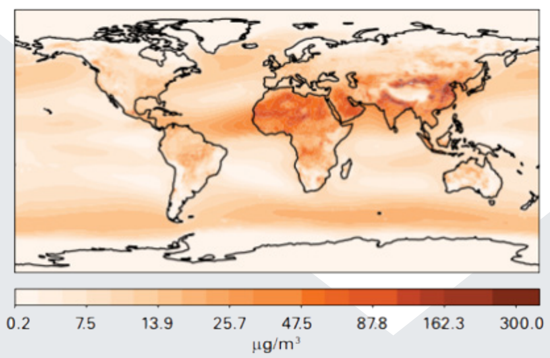
INTRODUCTION

1.1. Pandemic Prompted Clear Fall in Air Pollution

In December 2019, a new coronavirus (COVID-19) was detected in China, shortly after, it resulted in a global pandemic at an alarming speed.

In response to this situation, lockdowns were introduced restricting travel and industrial activity to control pandemic spread in many countries. As a result, the air quality experienced a significant improvement during COVID-19, which was confirmed by the World Meteorological Organization in WMO air quality and climate bulletin. Besides, many studies and media widely indicate that the pandemic prompted a clear fall in air pollution.

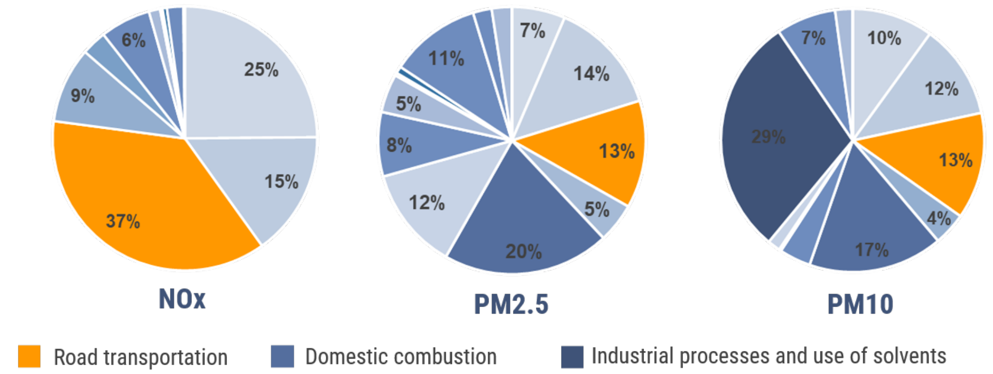




1.2. Air Quality Index And Sources

In fact, Air pollution has long been one of the most serious environmental problems. The World Health Organization (WHO) estimates that 90% of people breathe air containing high levels of pollutants and about 7 million air pollution-related deaths globally per year. Air Quality Index has been developed make information available about six most common air pollutants (also known as "criteria air pollutants"): Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Carbon Monoxide (CO), ozone (O^3) and Particulate Matter pollution (including PM10 and PM2.5). Different from other air pollutants, O^3 doesn't directly form from the air, but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of heat and sunlight. Therefore, the change of O^3 concentration is likely to be affected by the concentration of NO2 pollutants.

Then, we investigated the source of these pollutants based on the UK annual emissions source statistics from 1990 to 2019. The result suggested that road transportation is one of the main emissions sources in the UK. From Figure 2, we can see that road transportation made up the largest proportion (37%) in NOx emissions in the past 30 years. As for PM2.5 and PM10



1.3. The Reason behind Air Quality Change

In March 2020, the lockdown measure was implemented step by step in London with the goal of controlling the spread of the pandemic. In general, the restrictions introduced, including stay-at-home, closing factories, schools and other public spaces, reduced human mobility and transportations in this period. Then, the media widely reported falls in air pollution of 40%-60% in early April (Khoo, 2020; Telegraph Reporters., 2020). At the same time, the UK Department for Environment Food & Rural Affairs (Defra) indicated that the Daily Air Quality Index reached the highest level on its 10-point measurement scale. Based on current findings and studies, we assume this air quality improvement is related to the reduction in vehicle emissions during the lockdown.

Therefore, the goal of this study is to discuss to what extent the changes in air quality can be explained by human mobility during the pandemic. First, through a comparison of air pollutant concentrations in 2020 with those in 2005–2019 and 2021 respectively, we demonstrate the changes of four main air pollutants: NO2, O^3, PM2.5, PM10. Then, the human mobility changes are described in terms of traffic flows and mobility trends. Furthermore, we attempt to detect the relationships between air quality and mobility changes, not only with statistical analysis but also spatial analysis.

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LITERATURE REVIEW

2.1. Lockdown Policy

After the Covid-19 pandemic breakout in 2020, many cities and countries were executed to control virus spread. Previous functions exist in the city were forced to cease or change after the lockdown policy, for example, indoor shopping malls, office buildings, and schools were blocked, most people are required to stay in the community, at some risky communities, the residents even cannot leave their home (Collins and Duffy, 2020). The original urban facilities become deserted, individual houses become people`s main activity area. Along with the improvement of the pandemic, people were allowed to go out, the lockdown policy ended gradually (Musinguzi and Oppong Asamoah, 2020). During such time period, the individual behavior appeared significant change, mobility change and transportation flow change could be regarded as the obvious feature.

2.2. Air Quality Change Lead by Lockdown Policy

With the implementation of the lockdown policy, there are many researchers found the environmental changes appeared.

In India, there exist significant air quality improvement, which is believed to be the result of the reduction of human activities (Sharma et al., 2020). In China cities, there also observed the air quality changes, by comparing with the air quality, economic performance, and traffic data in previous years, it is found that the air quality changes are mostly led by economic activity and mobility reduction (Wang and Su, 2020), also corresponding with the effect of lockdown policy, the reduced economic activities decreased the traffic demand to a great extent, and effect on traffic emission changes. Affected by the decreased traffic emission, the nitric oxide (NOx) level is directly impacted and decreased in many cities (Venter et al., 2020). Apart from the nitric oxide change, the particulate matter changes are the joint result affected by transport emissions and factory emissions (Sicard et al., 2020), but can also be referenced as one of the evaluating indexes to the effect of mobility changes.

Also, some researchers found that although the air quality improvement is the result affected by traffic flow, or could be regarded as the result of pandemic control strategy, the improved air quality itself can also enhance the pandemic control. The pollutant particles, including NOx and PM, may become the carrier of the Covid-19 virus, and therefore the improved air quality could have a positive effect on the pandemic control process (Fattorini and Regoli, 2020). After all, the lockdown policy could be regarded as an effective air quality improvement policy in the short term, reducing the traffic demand and enhancing pandemic control.

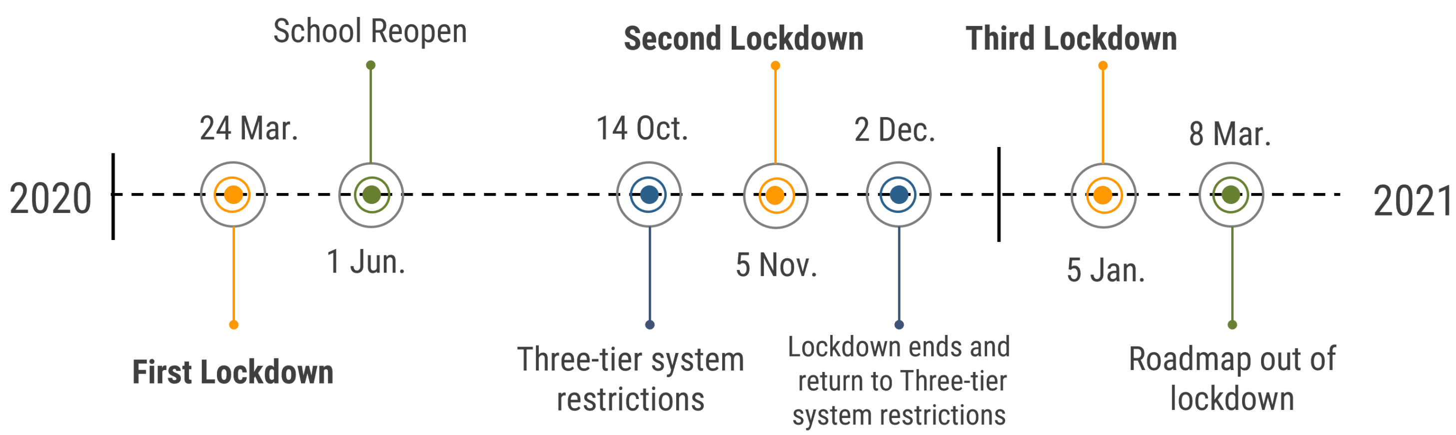
However, this air quality improvement mode cannot be applied sustainably, should face a long-term air quality improvement strategy (Zambrano-Monserrate, Alejandra Ruano, and Sanchez-Alcalde, 2020).

3
MATERIALS AND METHODS

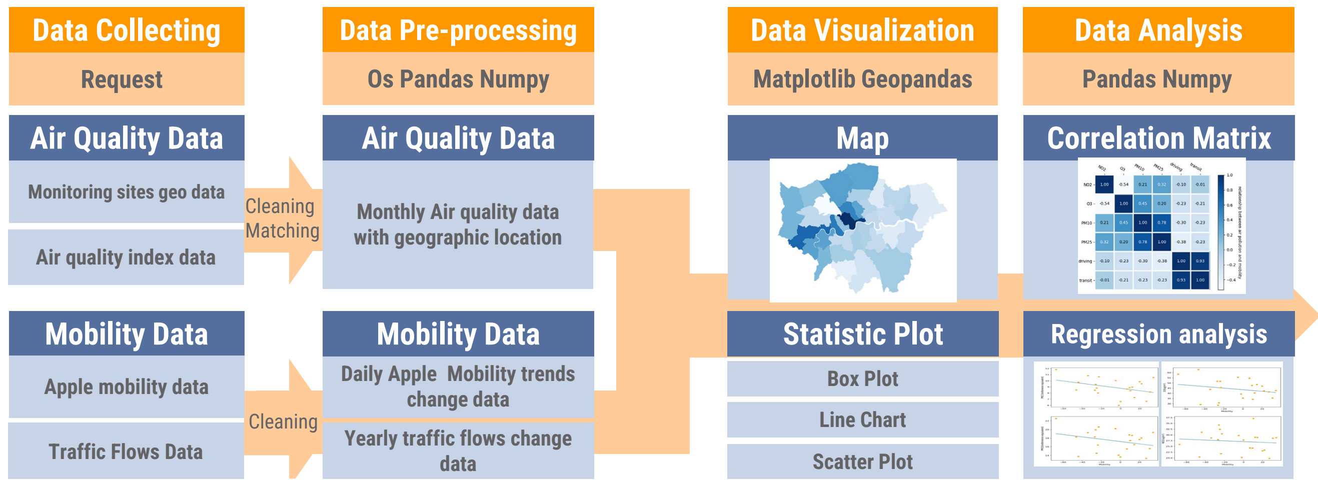
3.1. Study Area

The study area is chosen in Greater London, UK, in the borough level. London is announced a lockdown policy in early 2020, and the signal from the government revealed the intention to control the pandemic. As the capital of the UK, London owns many air quality monitoring stations, and with highly urbanized city area, suitable for data collecting and accuracy.

3.2. Timeline



3.3. Technical Flow

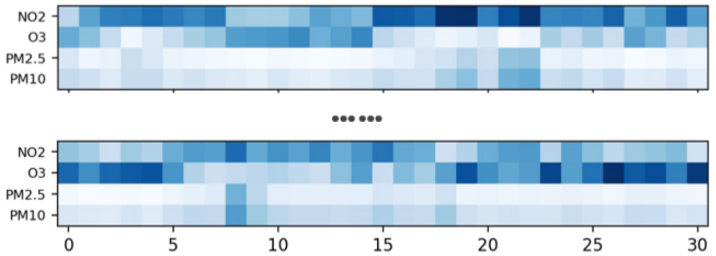


- Firstly, the request package is utilized to obtain the location of monitoring sites. With downloading the air quality index data, mobility data, the raw dataset is established for this research.
- Secondly, data pre-processing used os package to process the files that downloaded and use pandas and numpy to clean and match both air quality and mobility data.
- Thirdly, to visualize the collected data, matplotlib and geopandas packages are utilized to display statistical plot and maps, to have a more clearly view on the changes. Finally, pandas and numpy are utilized to analysis the changes.

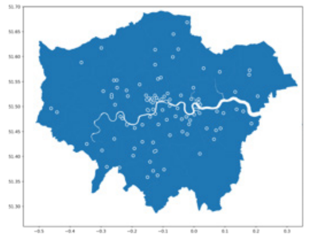
3.4. Data Collection

3.4.1. Air Quality Dataset

Based on the published London air quality database, different air quality indexes, including Ozone, Nitrogen Dioxide, PM 10, and PM 2.5, are provided. The downloaded scattered data is displayed as a dairy unit, in each monitoring station, from November 2015 to November 2021. To construct a geographical connection between the location and air quality, the monitoring stations with their longitude and latitude are downloaded with EPSG:4326 coordination system

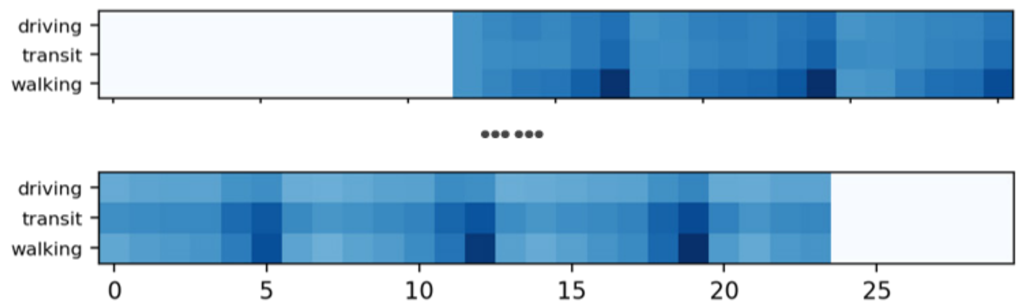


Air quality dataset (2015.1-2020.10)

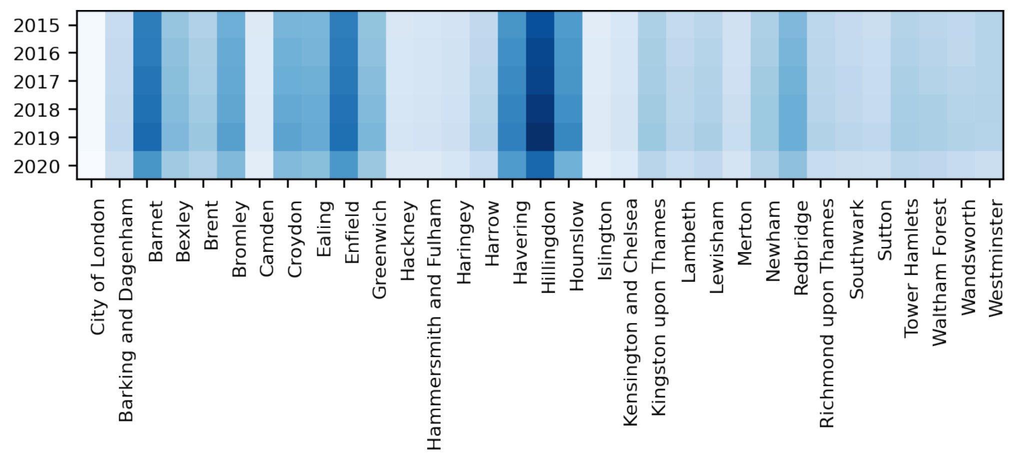

Monitoring sites geo dataset

3.4.2. Mobility Dataset

To have a corresponding geographical scale with air quality data (London borough Level), the traffic flow collected by Department of Transport, London, is utilized. This dataset consists of annual traffic flow data at the borough level. Meanwhile, to have a detailed mobility analysis, the Apple Mobility Data is collected by days, based on the individual digital devices, to get the mobility situation to help the Covid-19 related research.



Traffic flow dataset by boroughs (2015-2020)



Apple mobility dataset by boroughs (2015-2020)

3.5. Data Preprocessing

Statistical Data

Raw Data

Air quality data: Daily Scattered Data by Stations
Apple mobility data: Daily mobility Data in term of driving and transit and walking
Traffic Flows Data: Yearly Traffic Flows Data by Boroughs

Data Cleaning

- **Step1:** Day Format to Month/Year Format
- **Step2:** Delete Null and Outliers Data
- **Step3:** Select suitable dataset for input
- **Step4:** Calculate data

Input Data

- **Air Quality Data**(data in April in 2015-19; 2020; 2021)
- **Daily Apple Mobility trends change data**
- **Yearly traffic flows change data** (2015-19; 2020)

Geographical Data

Raw Data

Geographic Shp Data

- **STEP1:**Transfer Coordinate System
- **STEP2:**Combination with **Monitoring sites geo data**
- **STEP3:**Combination with **Yearly traffic flows change data**

Input Data

Air Quality & Traffic Flows geodata

- The data cleaning, processing, analyzing, and visualization would be operated in python by utilizing different packages to realize the final result, including Pandas, NumPy, Matplotlib, geopandas, and plotly to carry the operation.
- The data processing is carried by two branches, the statistical and geographical data. For further analysis demand, the raw air quality data is cleaned to fit the Monthly and Yearly data instead of daily data and reach out the invalid or noisy data to get the result. The statistical data preparation is done with the combination of air quality and mobility data.
- The geographical data are collected from different coordination systems. The utilized data are in the same coordination system.

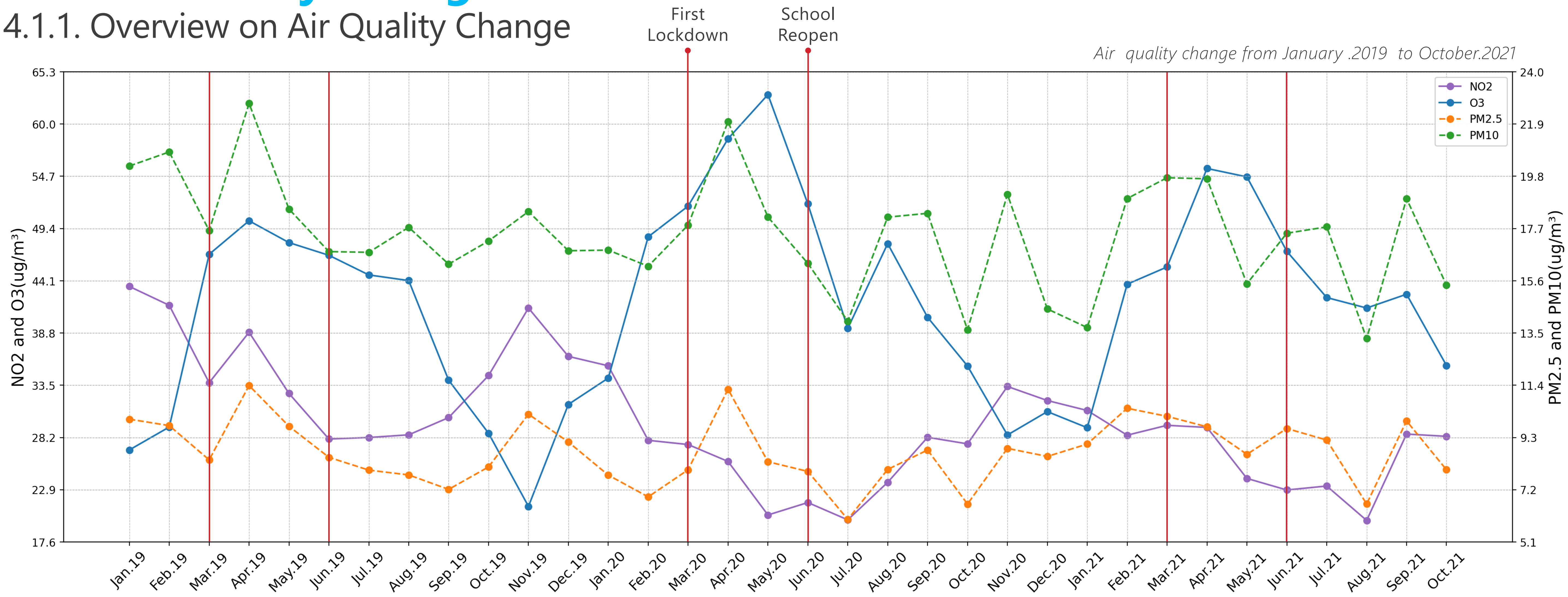
MATERIALS
AND METHODS

4

RESULT AND DISCUSSION

4.1. Air Quality Change

4.1.1. Overview on Air Quality Change



Air quality change from January .2019 to October.2021

In this study, the project team selected four types of air indicators: NO2, ozone, PM10, PM2.5

Nitrogen dioxide is an intermediate product in the industrial synthesis of nitric acid. Nitrogen dioxide is a major air pollutant as it is strongly irritating and corrosive to lung tissue when inhaled.

Ozone is mainly found in the ozone layer in the lower stratosphere, 20 km from the earth's surface, absorbing harmful short-wave ultraviolet rays and preventing them from reaching the ground.

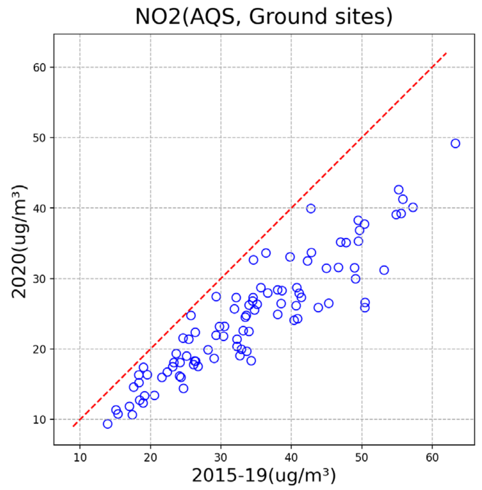
Airborne particulate matter (PM) is a mixture of several chemical species rather than a single pollutant. PM10 particles have a diameter of 10 microns or less and can be inhaled into the lungs, causing health problems. And Particles with a diameter of 2.5 diameters or less are classified as delicate particulate matter (PM2.5).

In conclusion, PM2.5 makes up a fraction of PM10.

- **The figure above demonstrated the trend of four types of air indicators from January 2019 to October 2021. During the lockdown period, NO2 has decreased, while O3, PM2.5, and PM10 first raised to a peak and fell.**
- **To further discuss the lockdown policy impact, the project team grouped the values by monitoring stations and calculated the mean value of three months, from March to June, in terms of the pre-pandemic period, 2020 and 2021.**

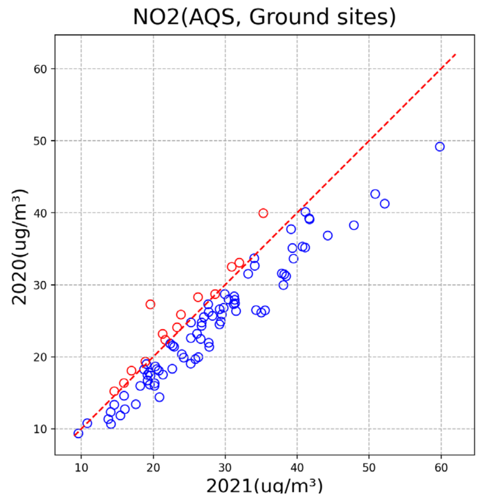
4.1. Air Quality Change

4.1.2. Subdivision Air Quality Comparison



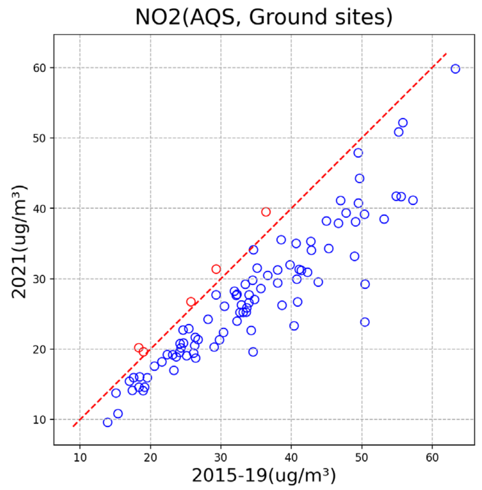
NO2
Compare 2015-2019 with 2020

- All air monitoring station in London shows a significant downward trend during the lockdown period.



NO2
Compare 2021 with 2020

- In 2021, many stations rebounded, with a few stations remaining at the level of 2020.



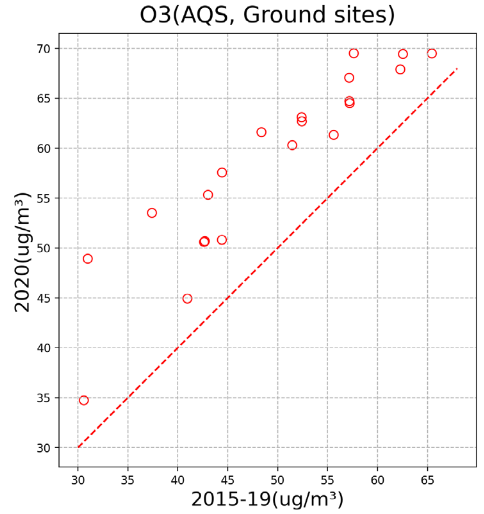
NO2
Compare 2015-2019 with 2021

- The NO2 level significantly decreased after the COVID-19 outbreak, with only five air monitoring stations in 2021 higher than the pre-pandemic period.

Each circle represents a different air monitoring station, and the x-axis and y-axis represent the mean value of different periods. When the air quantity level in x year is higher than y year, the circle's color turns blue. Otherwise, the circle's color will be red.

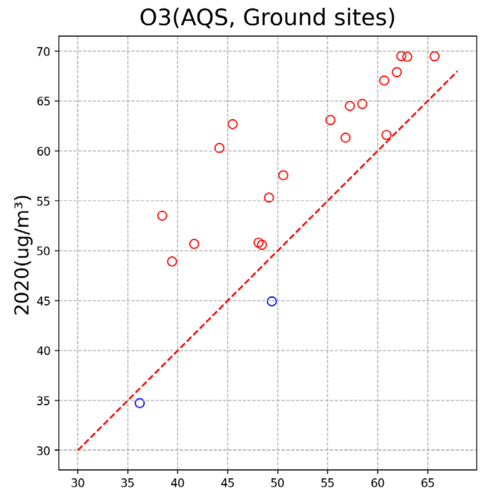
O^3
Compare 2015-2019 with 2020

- In 2020, the ozone levels at all air monitoring stations climbed considerably.



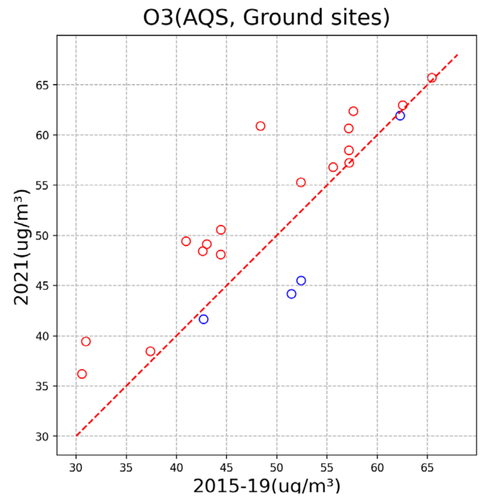
O^3
Compare 2021 with 2020

- Even in 2021, the post-pandemic period, the ozone level has kept upward. And only two air monitoring stations decreased in this year.



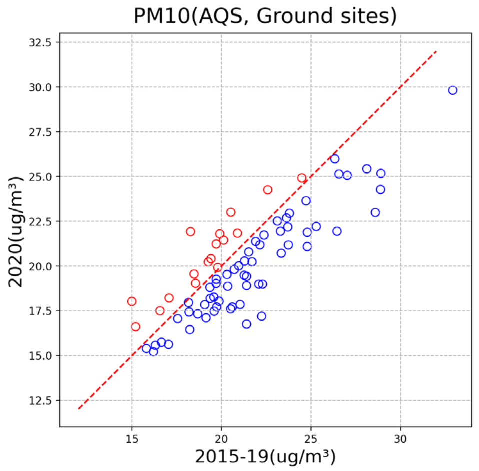
O^3
Compare 2015-2019 with 2021

- After the COVID-19 outbreak, the upward trend is noticeable without a doubt. Only four air monitoring stations did not show an upward trend.



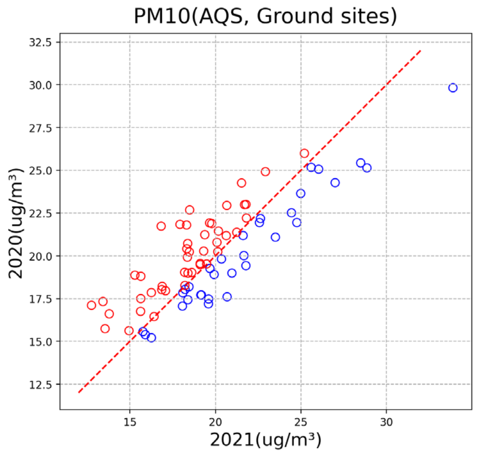
4.1. Air Quality Change

4.1.2. Subdivision Air Quality Comparison



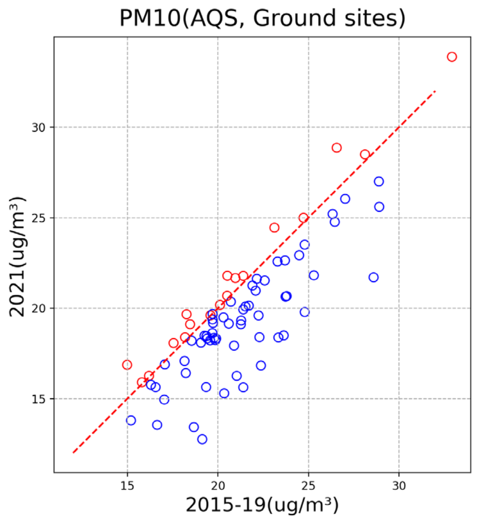
PM10
Compare 2015-2019 with 2020

- More than half of air monitoring stations show a downward trend during the lockdown period in 2020.



PM10
Compare 2021 with 2020

- In 2021, many air monitoring stations' PM10 level has rebounded.



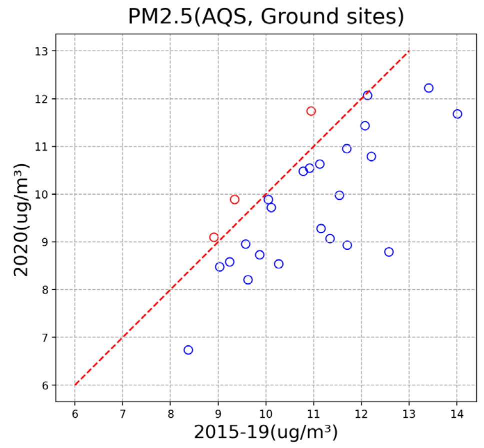
PM10
Compare 2015-2019 with 2021

- To further explore the trend of PM10 level, compare the pre and post-pandemic period. More than half of air monitoring stations decrease after the COVID-19 outbreak.

Each circle represents a different air monitoring station, and the x-axis and y-axis represent the mean value of different periods. When the air quantity level in x year is higher than y year, the circle's color turns blue. Otherwise, the circle's color will be red.

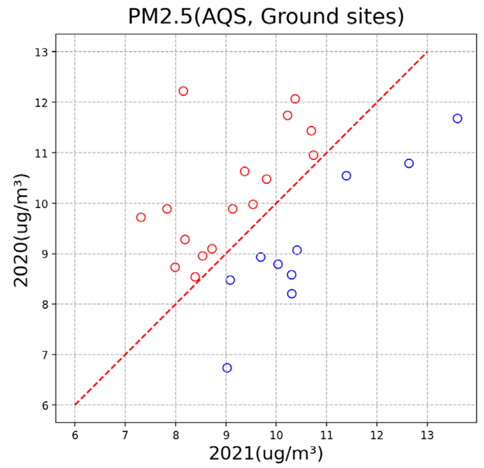
PM2.5
Compare 2015-2019 with 2020

- PM2.5 level demonstrated a more significant decreasing trend than PM10 level, in the contrast of 2020 and pre-pandemic period. Only three air monitoring stations did not decrease in 2020.



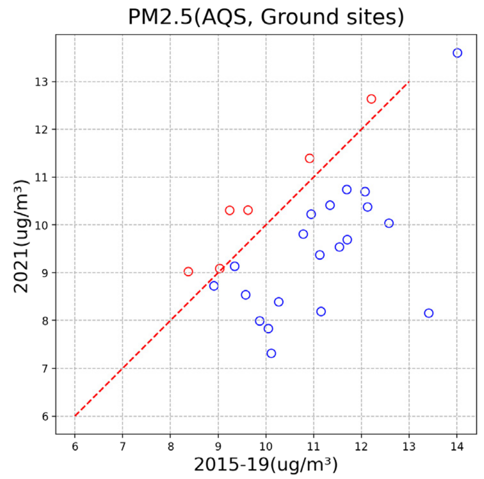
PM2.5
Compare 2021 with 2020

- In 2021, about half air monitoring stations collected the rebounding characteristic.



PM2.5
Compare 2015-2019 with 2021

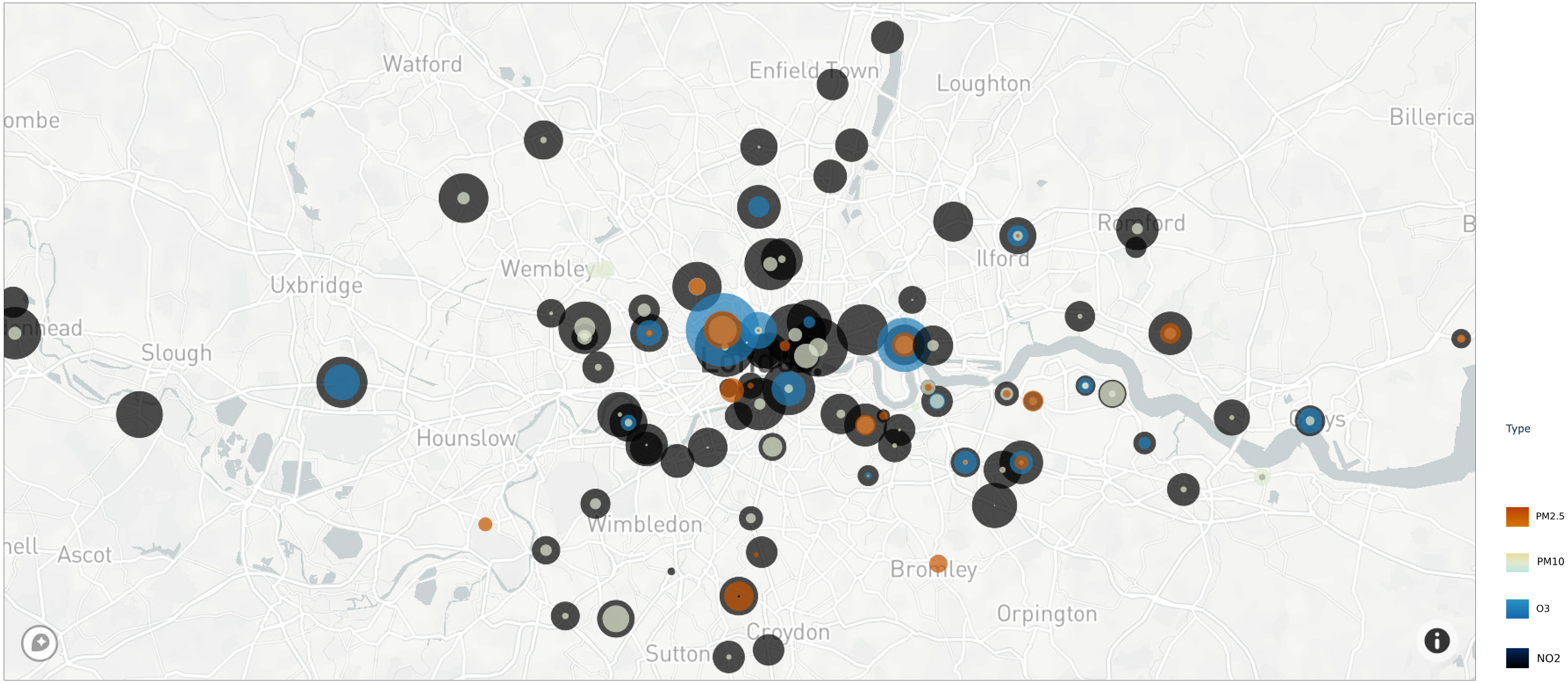
- Overall, the PM2.5 level has decreased compared to the pre-pandemic period, with an upward trend in five air monitoring stations.



4.1. Air Quality Change

4.1.3. Geographically Overview on Air Quality Change

Air Quality Change in Geographically (2015-19 and 2020)

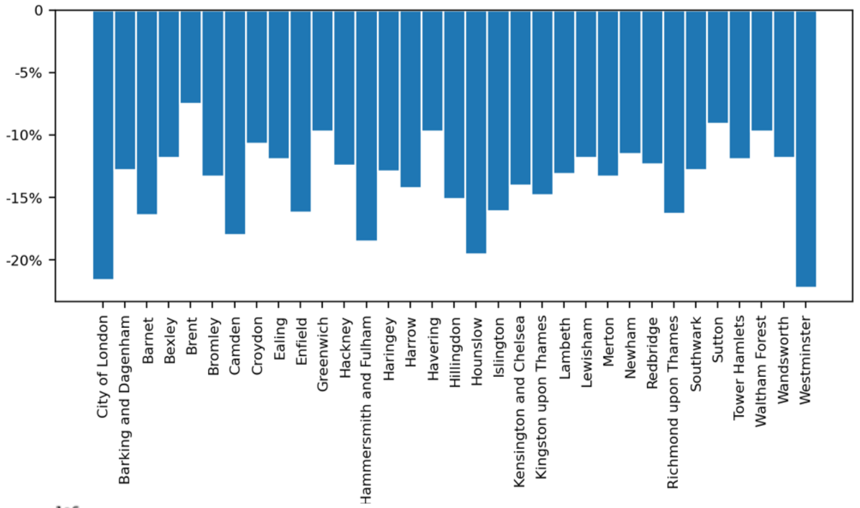


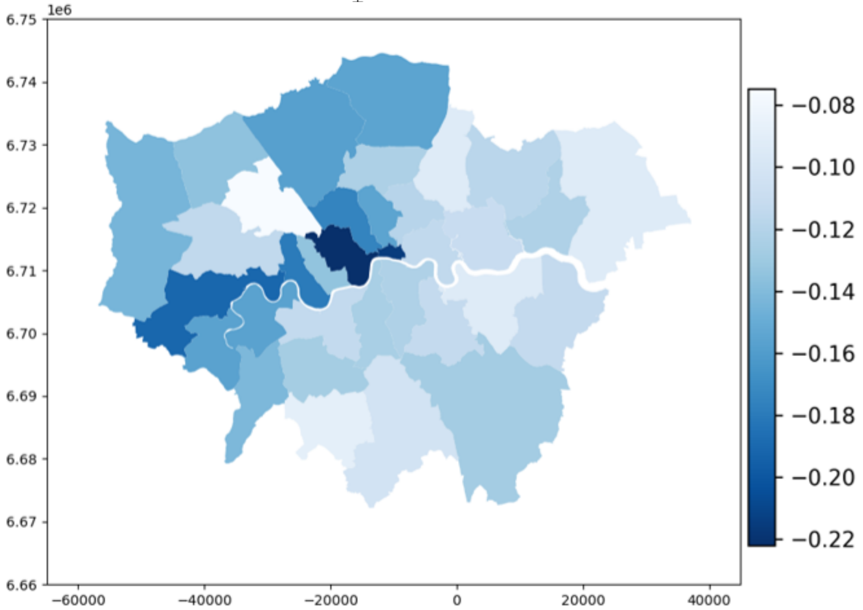
From the geographical scale, in the whole area of London, appeared a centralized trendency on the air quality change, which means the downtown area has a more significant change when compared with the periphery area. Among all the air quality index, the NO2 has the most significant change. The NO2 level appeared to be a general reduction during the lockdown period, and mostly concentrated in downtown London, along with the decrease of NO2 level, the O^3 level increased. PM2.5 and PM10 levels could be observed to have a decrease but not to the same extent to NO2 and O^3.

4.2. Human Mobility Change

In order to detect COVID-19 related transportation changes, we collect traffic flow data and driving & public transit data to describe the mobility trends before and during the quarantine.

Traffic flow change in boroughs between 2015-19 and 2020



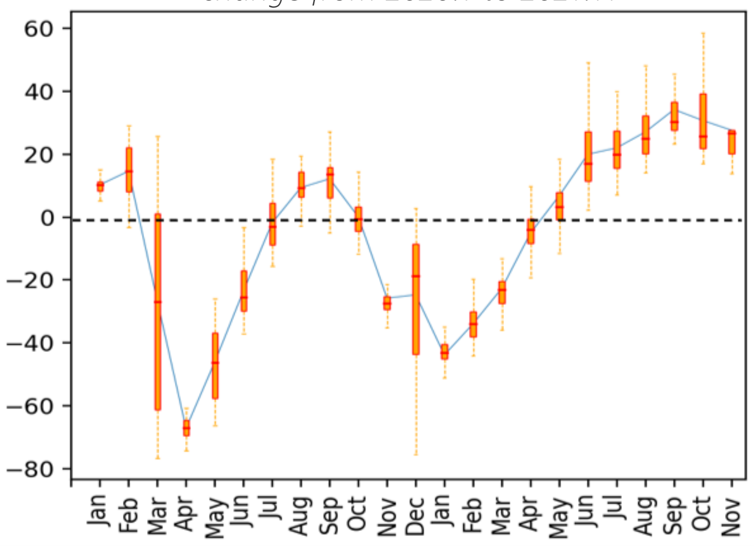


4.2.1. Traffic flow

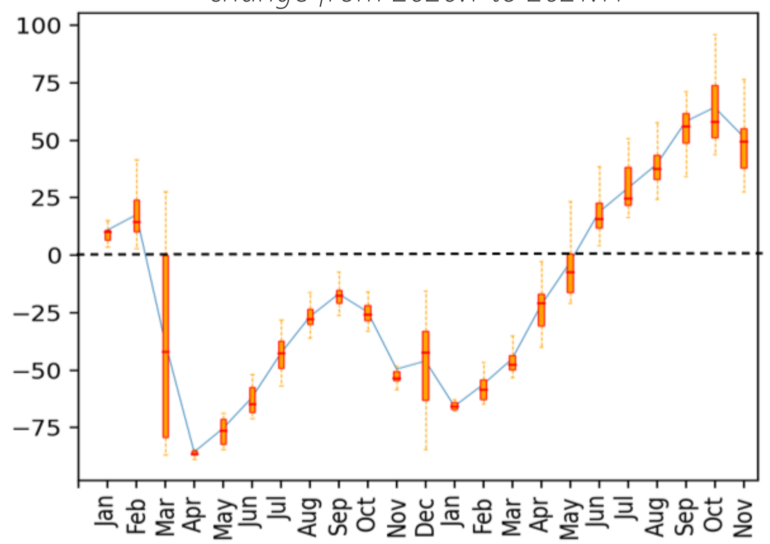
We can figure out that, compared to the last five years, all boroughs in London experienced a drop trend in traffic flows in 2020 and the rate of change ranges from 10% to 25%. The City of London and Westminster, which have high levels of road congestion, contribute the largest rate in traffic flow change, 21.6% and 22.2% respectively. Besides, due to the reduction of passengers in Hounslow Airport with the travel restriction, a significant reduction (19.5%) can also be observed in Hounslow. And the minimal reduction in traffic flows is shown in Brent, which is only 7.5%. This distinction between boroughs also can be seen.

4.2.2. Mobility Trends

Driving mobility trends change from 2020.1 to 2021.11



Transit mobility trends change from 2020.1 to 2021.11



In order to support research and policymaking to fight the Coronavirus pandemic, many internet companies have provided Mobility Reports derived from GPS position of smartphones and other mobile devices with GPS. Google mobility and Apple mobility data are widely used to estimate how human mobility has changed during the pandemic in relevant research. In this article, we use Apple mobility dataset, aggregated navigation data from Apple Maps, to detect the changes in driving and transit with reference to the baseline day before the pandemic outbreak: January 13th, 2020.

Affected by the lockdown policy implemented on 24 march 2020, the mobility in all modes plummeted and dropped to the bottom in April. After a slight recovery, driving mobilities rebound to the previous level in July. However, the second lockdown in November caused another lowest point, even though this decline was not as great as that in April. The similar behaviors in public transport trends can be seen. But different from driving, transit mobilities had remained declining trends until May 2021. This result shows that the pandemic has seriously reduced mobilities, and the transit mobility trend is more sensitive to lockdown and travel restriction policies.

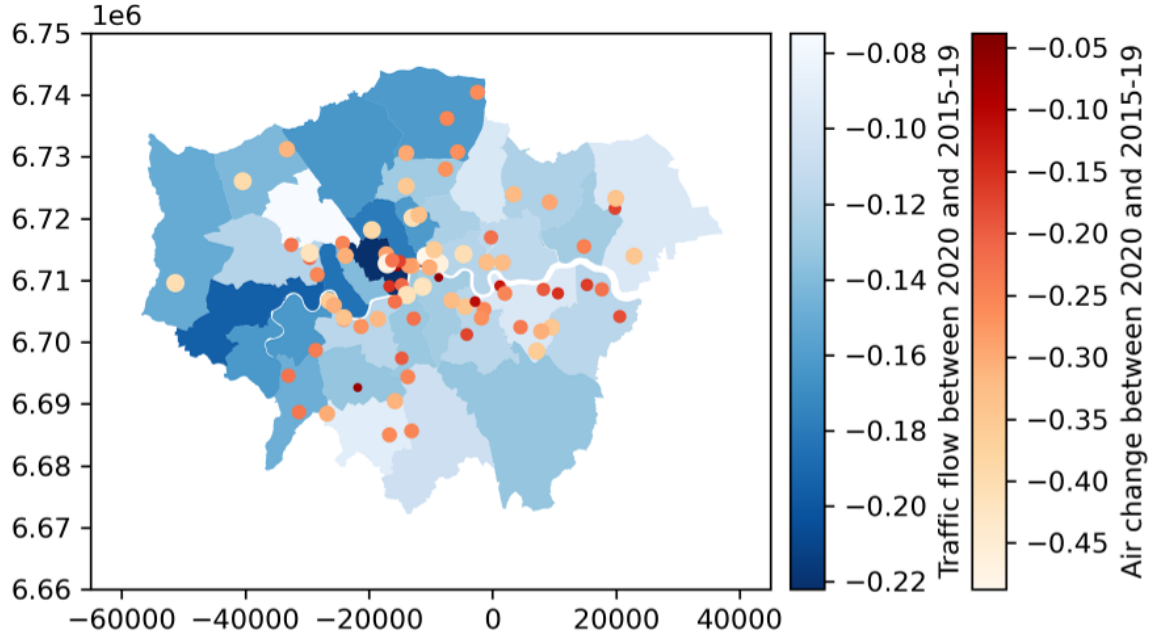
> Overall, the human movement in terms of driving and public transit were significantly reduced following the pandemic control measures implemented in London, and this change is more obvious in the city central of London.

4.3. Relationship

4.3.1. Descriptive Analysis

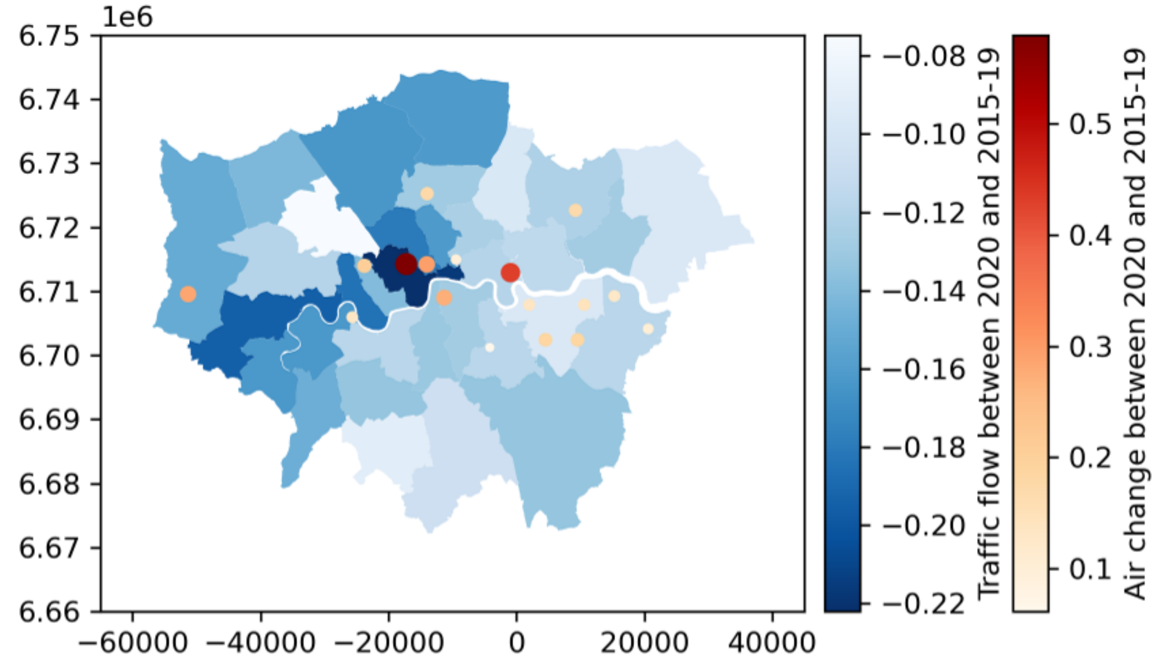
Along with the decrease of traffic flows, NO2 showed a decreasing trend and O^3 increased.

The change of NO2 concentration and traffic flow in 2020



- There was a decline in the NO2 concentration in all boroughs in London in 2020 compared with its average figure from 2015 to 2019. The traffic flow saw the same pattern. However, there was a huge difference between western London and eastern London. The NO2 concentration and the traffic flow were higher in Eastern London than those in Western London. Generally, the boroughs with more decrease in traffic flow had a large decrease in NO2 concentration.

The change of O^3 concentration and traffic flow in 2020



- The O^3 concentration increased in most boroughs in London, whereas the traffic flow all declined. The decrease in traffic flow on the west was greater than that on the east. However, the O3 concentration was different. Generally, the cities with more decrease in traffic flow had a large increase in O^3 concentration.

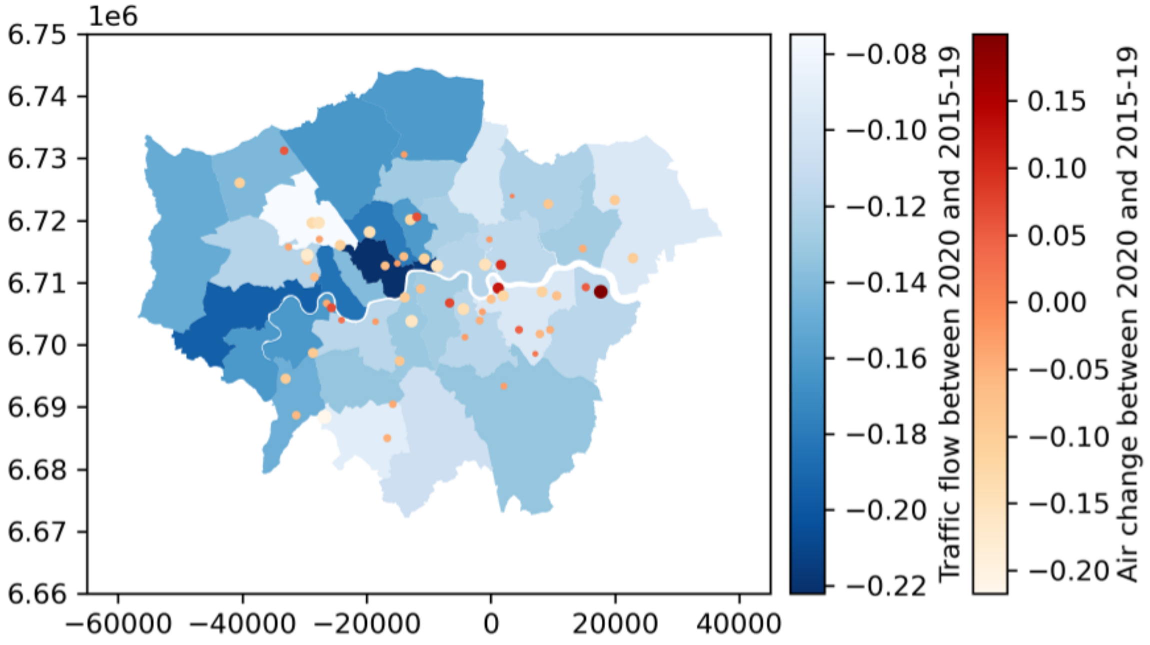
Red points represent the change of the NOx (O^3) concentration in 2020 compared to the average NOx (O^3) concentration from 2015 to 2019.
Blue areas represent the change of the traffic flow in 2020 compared to the average traffic flow from 2015 to 2019.

4.3. Relationship

4.3.1. Descriptive Analysis

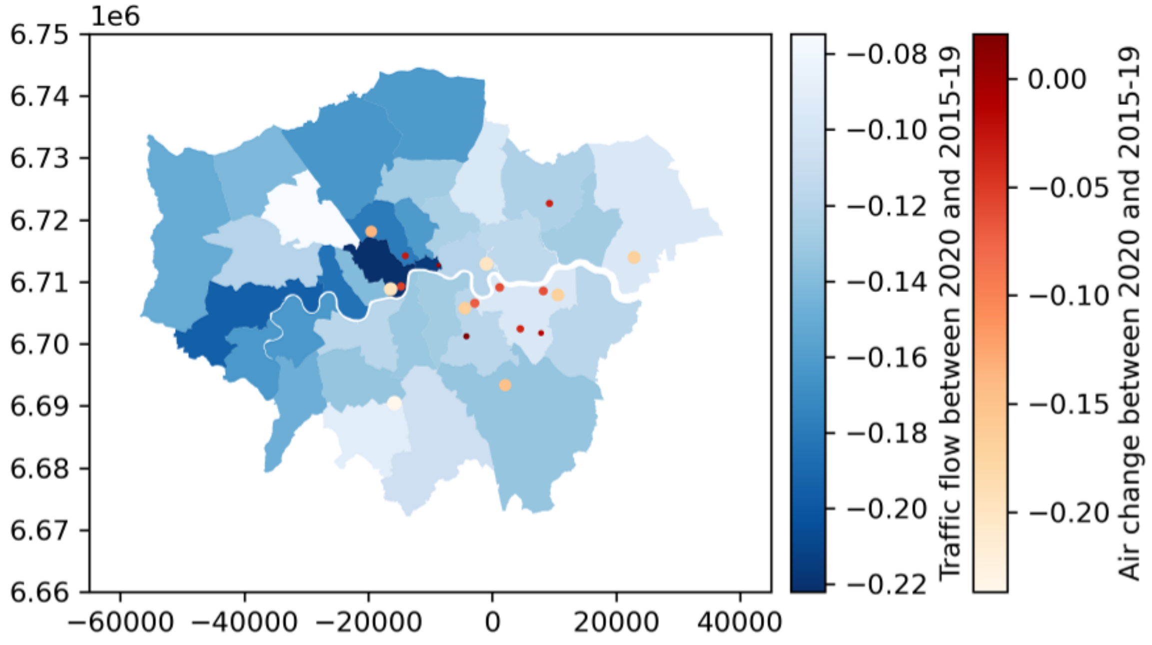
PM10 concentration shows spatial heterogeneity, the lower changed traffic flow may lead to limited PM10 change.

The change of PM10 concentration and traffic flow in 2020



- The PM10 concentration increased in a large number of boroughs in London. Basically, the PM10 concentration in eastern London was higher than that in western London. The boroughs with more decrease in traffic flow had a large decrease in PM10 concentration.

The change of PM2.5 concentration and traffic flow in 2020

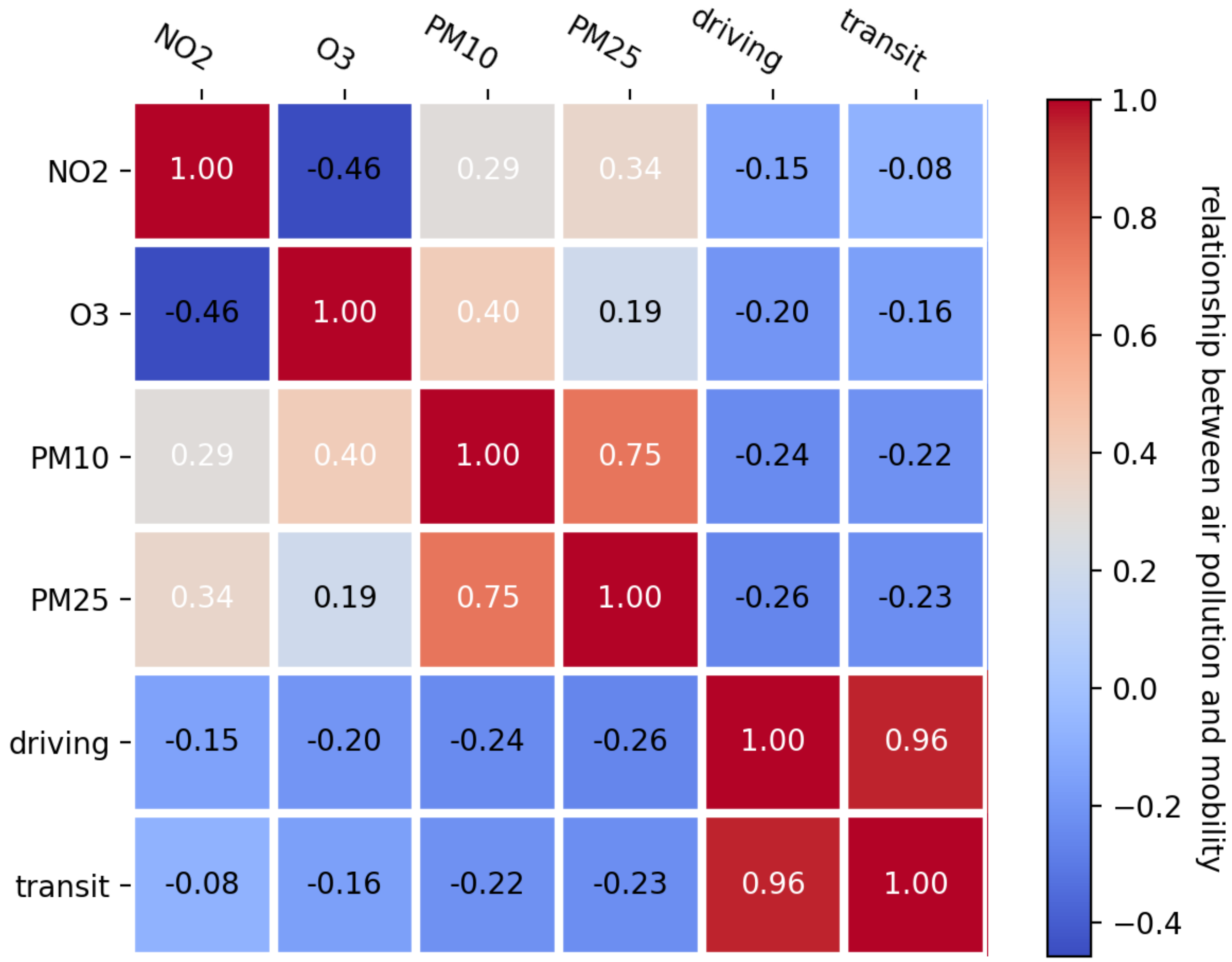


- The PM2.5 concentration increased mainly in several central boroughs in London. But generally, it dropped in most boroughs. There was no clear correlation between the traffic flow and the PM2.5 concentration.

Red points represent the change of the PM10 (PM2.5) concentration in 2020 compared to the average PM10 (PM2.5) concentration from 2015 to 2019.
Blue areas represent the change of the traffic flow in 2020 compared to the average traffic flow from 2015 to 2019.

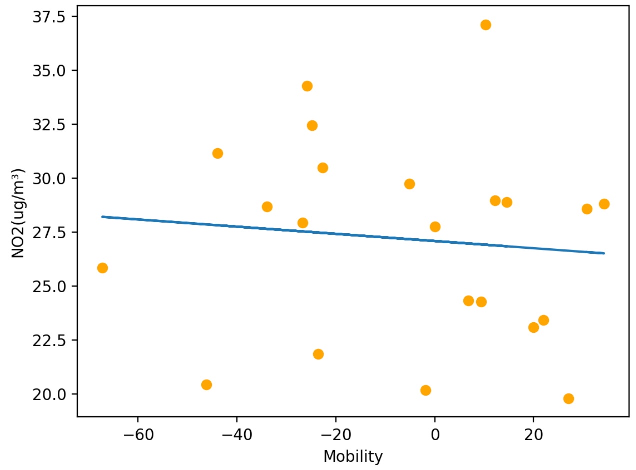
4.3. Relationship

4.3.2. Correlation Analysis

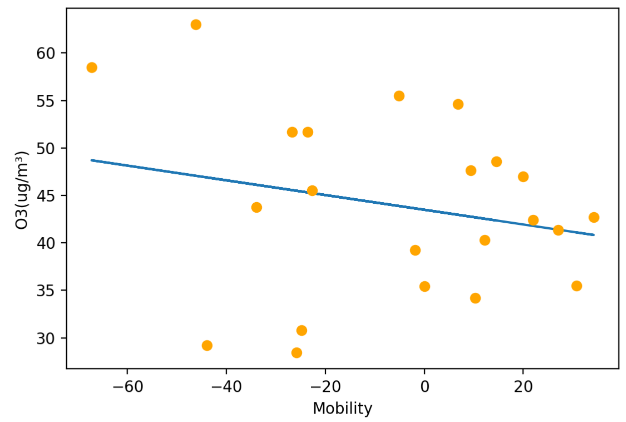


Relationship between air pollution and traffic mobility based on the correlation matrix

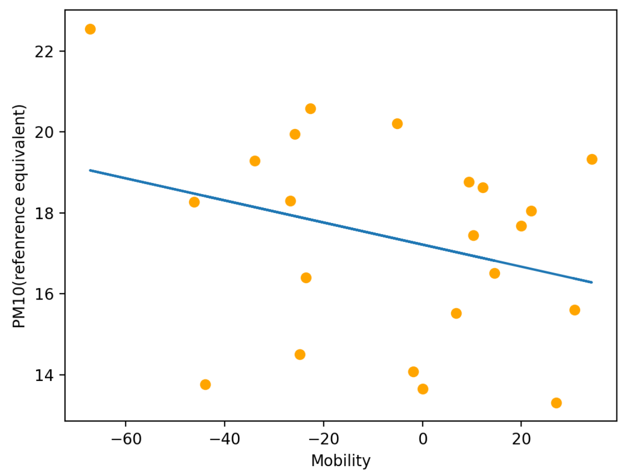
- By calculating the Spearman correlation coefficient among the mean value of each pollutant in every month, average driving volume and transit volume, we get the correlation matrix.
- From the figure above, the all contaminants have a negative but weak relationship with traffic flow.



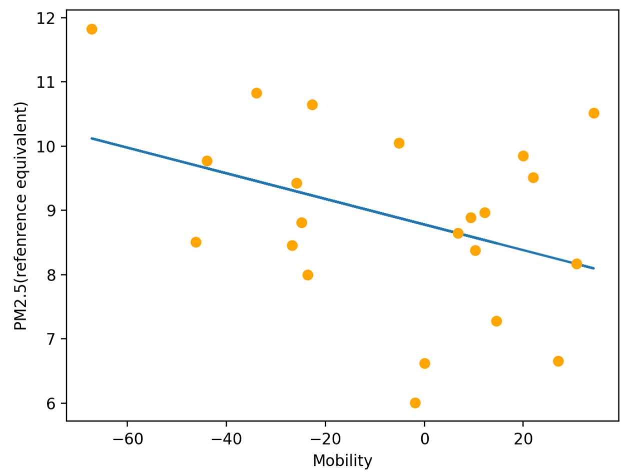
Relationship between NO2 and Mobility



Relationship between O³ and Mobility



Relationship between PM10 and Mobility



Relationship between PM2.5 and Mobility

- By linear regression analysis, the plots also show a negative but weak relationship between four air pollutants and the traffic flow. The linear regression results only provide a global relationship and scatter plots also indicate the relationships are unreliable so more detailed analysis needs to be done.

> **Four air contaminants all showed a negative but weak relationship with traffic flow.**

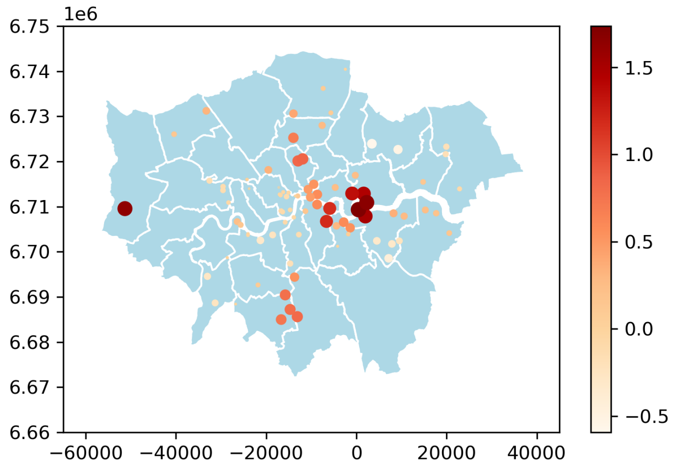
4.3. Relationship

4.3.3. Geographical Weighted Regression Analysis

Geographical Weighted Regression Analysis was used to analyze the relationship between air pollution and traffic flow.

Here, four air pollutants are dependent variables and traffic volume is the independent variable. The results are shown as below.

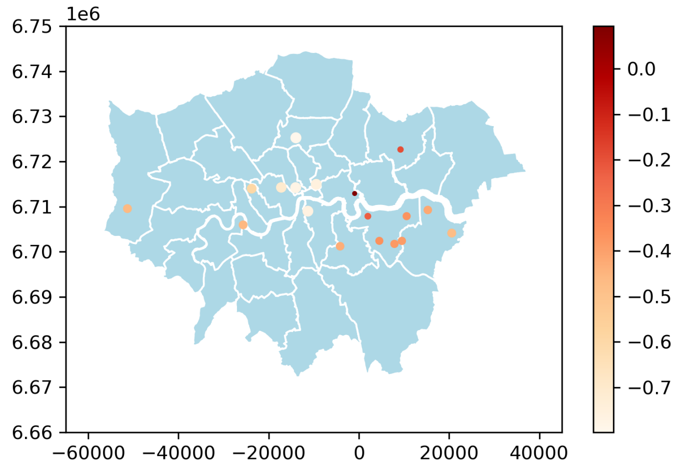
The coefficient of traffic flow in relationship with NO2



The performance of the GWR model of NO2		
Residual sum of squares	AICc	R^2
69.807	248.076	0.179

- The change of traffic volume has a positive impact on the change of NO2, especially in eastern London including Newham, Greenwich, Lewisham and Southwark. However, in west London the relationship is very weak.

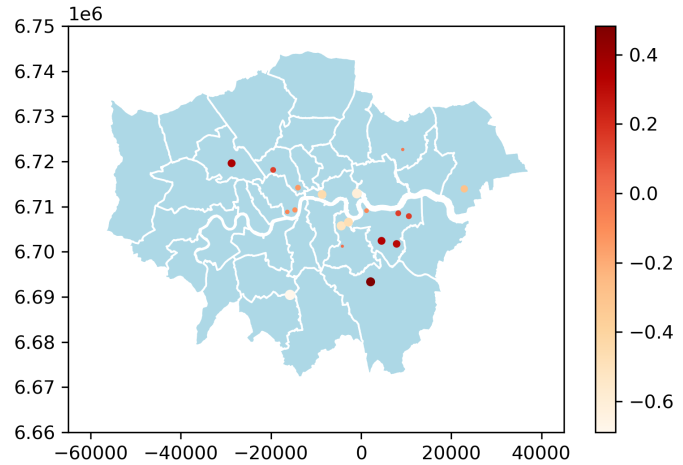
The coefficient of traffic flow in relationship with O^3



The performance of the GWR model of O^3		
Residual sum of squares	AICc	R^2
11.363	53.411	0.369

- The change of traffic volume has a negative impact on the change of O3, especially in the center including City of London, City of Westminster. Howerver, in east London, the relationship is very weak.

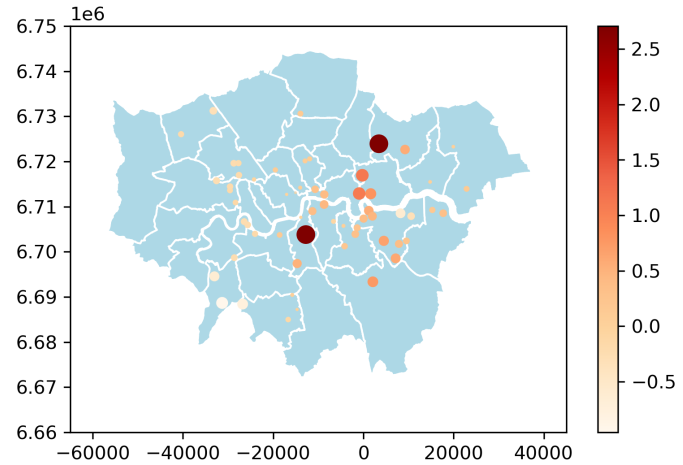
The coefficient of traffic flow in relationship with PM10



The performance of the GWR model of NO2		
Residual sum of squares	AICc	R^2
48.92	192.891	0.188

- The change of traffic volume has a positive impact on the change of PM10, especially in east and south London including Newham, Greenwich, Lambeth and Redbridge. However, in west London the relationship is very weak. In the southwest area, there are some negative relationships.

The coefficient of traffic flow in relationship with PM2.5



The performance of the GWR model of NO2		
Residual sum of squares	AICc	R^2
12.834	62.790	0.325

- The change of traffic volume has a positive impact on the change of PM2.5 in the suburb area and has negative impact in the center.

> **In eastern London, the relationship between the change of NO2, PM10, PM2.5 concentrations and the change of traffic volume is positive.**

5 DISCUSSION AND CONCLUSION

5.1. Discussion

- Along with the lockdown policy in London, the air quality has shown an improvement in 2020, and have not returned to the pre-pandemic standard at the current stage.
- The traffic flow, including driving and public transit decreased, caused by the lockdown policy, appeared a gradual increase in post-pandemic era.
- Resulted by transportation pollution, the improved air quality during pandemic exist correlation with the decreased traffic flow. Which may reflect the effect of lockdown policy in environmental field, but further research may focus on the social and economic changes after the pandemic, to deliver comprehensive research on post-pandemic air quality and mobility.

5.2. Conclusion

- According to the UK's annual emission source statistics, most emissions come from road traffic, so we attempt to discuss to what extent the changes in air quality can be explained by human mobility . Then we use descriptive analysis and correlation analysis and Geographically Weighted Regression Analysis to validate it.
- For air pollutants, NO2, PM10, PM2.5 concentration decreased in most monitoring sites while O^3 concentration increased in all sites in the lock-down period in 2020. Although NO2, PM10, PM2.5 concentration rebounded a little in 2021 and O^3 concentration dropped in 2021, they did not return back to its average value from 2015 to 2019.
- For traffic flow, all boroughs in London have a significant decrease in traffic volume, especially in the city center. The decrease in western London is larger than it in eastern London.
- For the relationship between air pollution and traffic flow, in eastern London, the change of traffic volume has a positive impact on the change of NO2, PM2.5, PM10 concentrations. In the city center, the change of traffic volume has a negative impact on the change of O^3 concentration.

5.3. Limitation

- This study only used the air quality data collected from ground monitoring stations only, without considering the data collected from satellite stations.
- The sulphur dioxide and carbon monoxide data isn't provided in London air quality website so we cannot calculate the air quality index(AQI)
- The number of air monitoring sites is few, so sample size for GWR could be small. Therefore, the regression results could be unreliable.
- Apple mobility data is generated based on the Route request changes since January 13, 2020, couldn't represent real mobility volume.
- This project only discusses the relationship between air quality changes and human mobility changes during pandemic. However, air pollution can be influenced by other factors including domestic combustion and industry. In the further research, more factors need to be taken into consideration.

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