ST306 Mini Project

S/18/368

January 2024

1 Introduction

This project aims to analyze and discover the trends in air quality across the London city. It involves an integrated method that includes data collection, processing, statistical analysis and interpretation within the contexts of environmental science and public health. London, like many other big cities, is suffering air pollution issues that may have major implications for both the heath of its citizens and the environment.

The main steps of this project are,

1. **Data Collection:**
   In this project, we analyze and discover the trends in air quality across London city based on data collected at 36 air monitoring sites located in London from 01/01/2022 to 31/12/2022. These sites measure pollutants like Nitrogen oxide (NO_x), Nitrogen monoxides (NO), Nitrogen dioxide (NO_2), particulate matter ($PM_{10}, PM_{2.5}$), Ozone (O_3), Carbon monoxides (CO) and Sulfur dioxide (SO_2).

2. **Data Processing:**
   The collected data needs to be cleaned and processed. This may involve handling missing data , correcting anomalies and normalizing data from different sources.

3. **Statistical Analysis**
   Using R studio, trends and the patterns in the air quality data will be identified. This could include time series analysis to understand how air quality fluctuates daily or monthly and determine what are the main factors effect to air pollution in London.

2 Literature Review

Air pollutants can be mainly categorized into particulate matter (PM), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon oxides (CO_2), and ozone (O_3). The following summary touches on key findings and significant research areas within each category.

- **Particulate matter** (PM)
  PM is a common proxy indicator for air pollution. There is strong evidence for the negative health impacts associated with exposure to this pollutant. Research has frequently associated PM, particularly tiny particles (PM2.5), to cardiac and respiratory diseases, death at an early age, and maybe even to diabetes and cognitive decline (Pope III et al., 2002; Lelieveld et al., 2015).

- **Nitrogen oxides** (NO_x)
  NO_x is primarlly produced from vehicular and industrial processes. It contributes to smog, acid rain and eutrophication of water bodies (Seinfeld & Pandis, 2016).

- **Sulfur oxide** (SO_x)
  SO_x emissions, mainly from burning fossil fuels are primary contributors to acid rain, which damages ecosystems and structures.

  Literature discusses successful cases of SO_x reduction through policy measures, like the clean Air Act Amendments in the USA (Schreifels et al., 2012).

- **Carbon oxides** (CO_x)
  CO_x's health impact are well documented, including its ability to reduce oxygen delivery in the body, affecting cardiovascular health (Raub et al., 2000).

  As a greenhouse gas, CO_2's role in climate change is extensively studied, highlighting the urgent need for reducing emissions (IPCC Reports).

- **Ozone** (O_3)
  Ground level ozone is a harmful air pollutant, unlike stratospheric ozone, which protects life by filtering UV radiation. Also this ground level ozone affects in respiratory problems and vegetation damage (Bell et al., 2004).

3 Results and Discussion

3.1 Site Locations

First the locations of monitoring sites which are used to collect data were visualized on a map using R packages called "ggmap" and "mapdata" as given below.

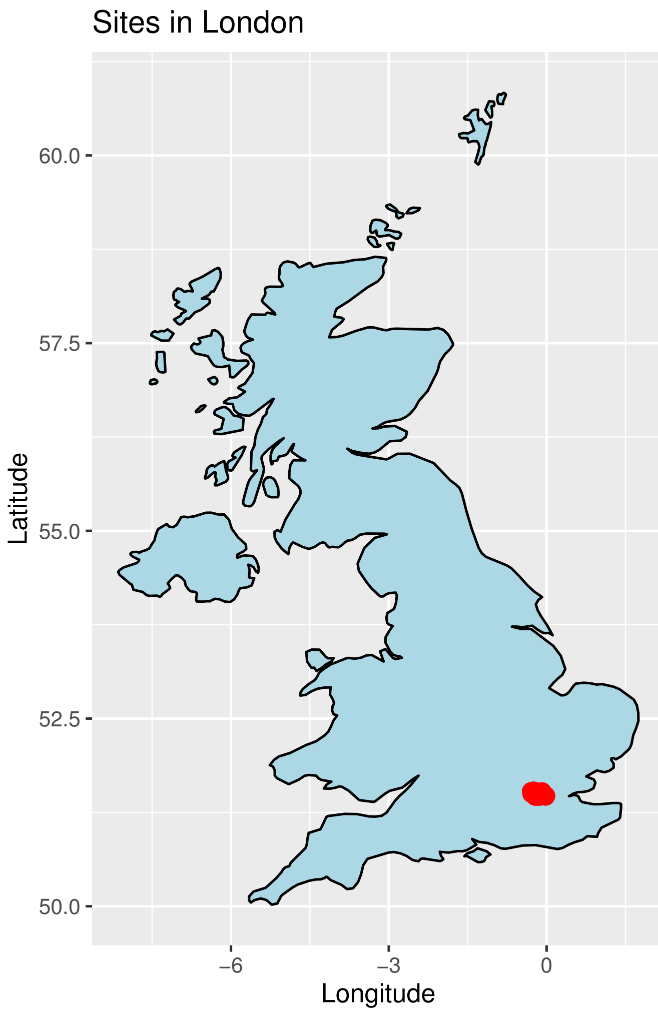

Figure 1: Site Locations in London

To get a clear idea about locations, following map also had plotted.

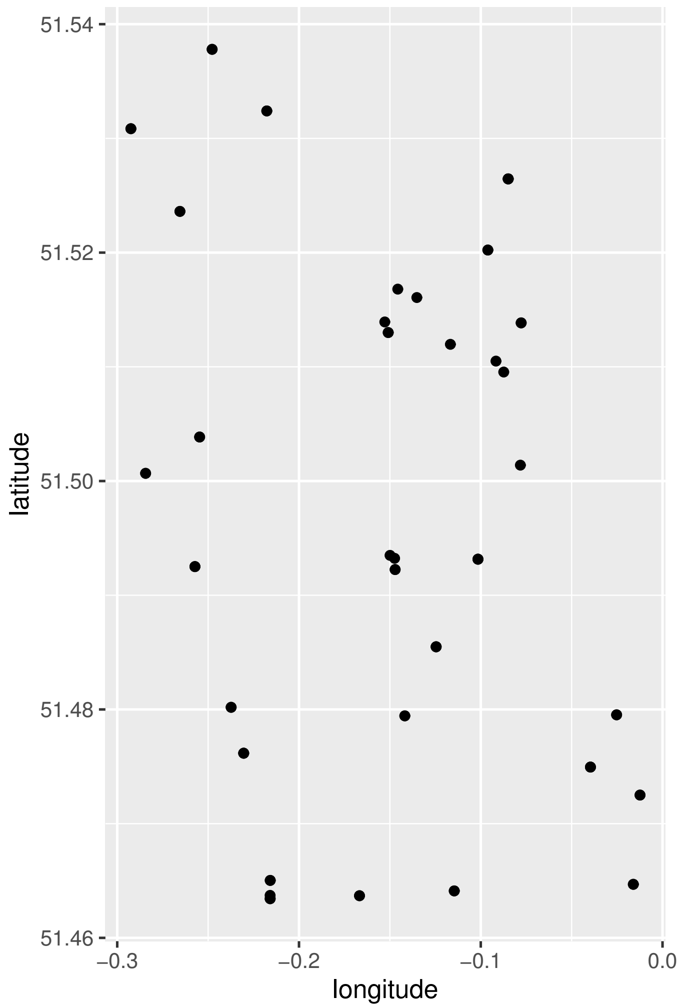

Figure 2: Site Locations in London

From the above two maps (Figure 1 & Figure 2), we can get an idea about the site locations that were used to collect data. There are 36 sites in London and they are located covering the entire city of London.

3.2 Maximum values of Pollutants

Using R studio, the site with the highest record of each air pollutant was found.

Accordingly,

- The site with the highest nitrogen oxide value is Lewisham - Loampit Vale and that value is 1111.1.
- The site with the highest nitrogen monoxide value is Lewisham - Loampit Vale and that value is 631.5.
- The site with the highest nitrogen dioxide value is Lambeth - Brixton Road and that value is 285.1.
- The site with the highest particulate matter value is Hounslow Gunnersbury and that value is 300.8.

According to the above statements, the Lewisham - Loampit Vale has the highest NO_x value and the highest NO value. Nitrogen oxides are a group of gases that include nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The fact that both NO and NO_x levels are highest at the same site suggests a significant source of nitrogen oxide pollution in Lewisham - Loampit Vale.

Also the area of Lambeth - Brixton Road, has the highest concentration of nitrogen dioxide (NO_2) among the 36 sites. This high level of NO_2, a harmful air pollutant primarily produced from vehicle emissions and combustion processes, suggests significant air quality concerns in this area. It could indicate heavy traffic or other local sources of pollution, and poses potential health risks to the local population. This situation might require targeted environmental and public health interventions to reduce pollution and mitigate its impacts.

The area of Hounslow Gunnersbury has the highest concentration of particulate matter (PM_{10}) among the all 36 sites. A value of 300.8 is considerably high and suggests severe air pollution, potentially from sources like traffic, industrial activities, or construction. This high level of particulate matter poses significant health risks, particularly respiratory and cardiovascular issues, to the local population and may necessitate urgent air quality management and health protection measures.

3.3 Variation of Pollutants

Here the mean value of each pollutant was visualized in a bar chat using R package called "ggplot2".

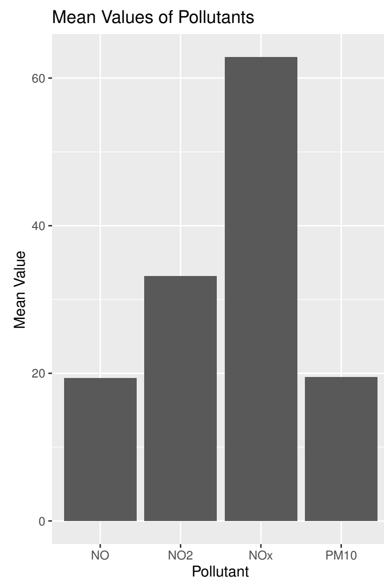

Figure 3: Mean Value Variation of each Pollutant

NO_x, NO_2, NO, and PM_{10} are key pollutants affecting air quality in London. From above bar chart (Figure 3) we can see that NO_x has the highest mean value and it is indicating its prevalence across the sites studied.

Also NO_2 has the second highest mean value, suggesting it's also a significant pollutant but typically at lower concentrations compared to NO_x.

NO and PM_{10} have the third highest and almost equal mean values, indicating they contribute similarly to air pollution. NO, a direct emission from combustion processes, and PM_{10}, comprising various particles from diverse sources, demonstrate comparable levels across the studied sites.

3.4 Density of Pollutants

Here the density of each pollutant was plotted using R package called "ggplot2". Following graphs are visualized the density of each pollutant.

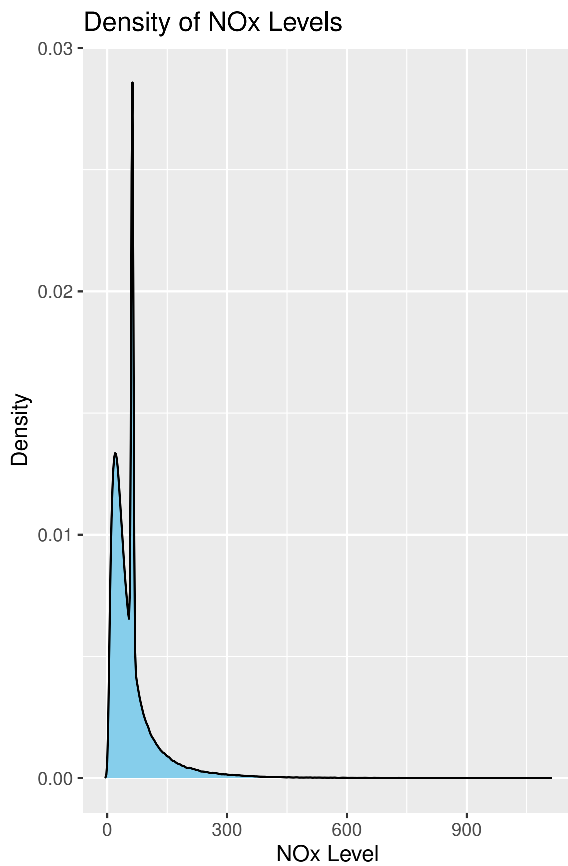

Figure 4: Density of NO_X

According to above density graph (Figure 4) of NO_x, we can see that there are two peaks approximately at 10 - 45 and 50 - 60 NO_x level. The lower peak in the 10-45 range likely represents areas with moderate NO_x pollution levels. These areas might be characterized by a mix of residential, commercial, and light industrial activities.

The higher peak in the 50-60 range suggests areas with higher NO_x pollution levels, potentially due to heavy traffic congestion, industrial activities, or a combination of both. These areas could be located near major roadways, industrial zones, or areas with dense vehicular traffic.

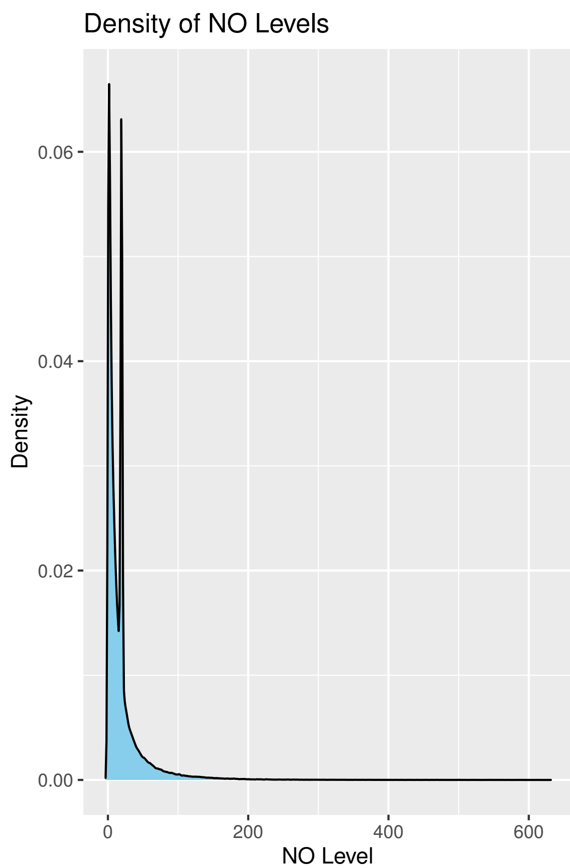

Figure 5: Density of NO

This density graph (Figure 5) showing two peaks in the variation of NO levels across 36 sites in London indicates that there are two distinct ranges or clusters of NO levels present in the data. First peak at approximately 0-15 suggests that a significant portion of the sites has relatively low NO levels, possibly indicating areas with better air quality or fewer sources of NO emissions. These areas might include residential zones, parks, or areas with less vehicular traffic.

The second peak (approximately at 15- 20) indicates another cluster of sites with higher NO levels, possibly representing areas with more traffic congestion, industrial activities, or other sources of NO emissions. These areas may include busy roads, industrial zones, or areas with high population density and transportation infrastructure.

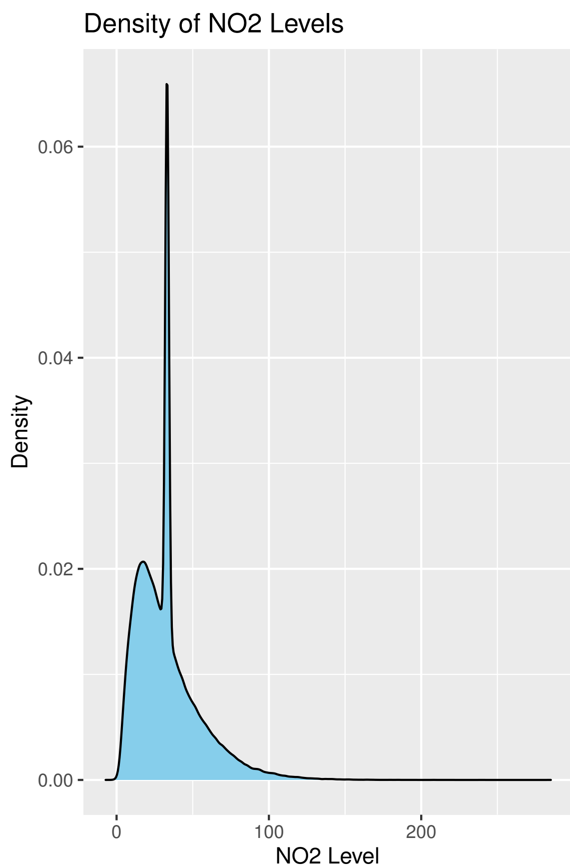

Figure 6: Density of NO_2

This density graph (Figure 6) with two peaks in the variation of NO_2 levels over 36 sites in London suggests that there are two distinct ranges of NO_2 concentrations that are more prevalent across the sites.

First peak indicates a moderate level of NO_2 concentration. It could suggest areas with medium traffic density, industrial activity, or other sources of nitrogen dioxide emissions. These levels are significant enough to indicate pollution but might not be exceptionally high.

Second peak suggests a higher level of NO_2 concentration. Areas experiencing this level of concentration might be closer to major roads, industrial zones, or other significant emission sources. NO_2 levels in this range could potentially exceed air quality standards and pose health risks, particularly to sensitive groups like children, the elderly, and individuals with respiratory conditions.

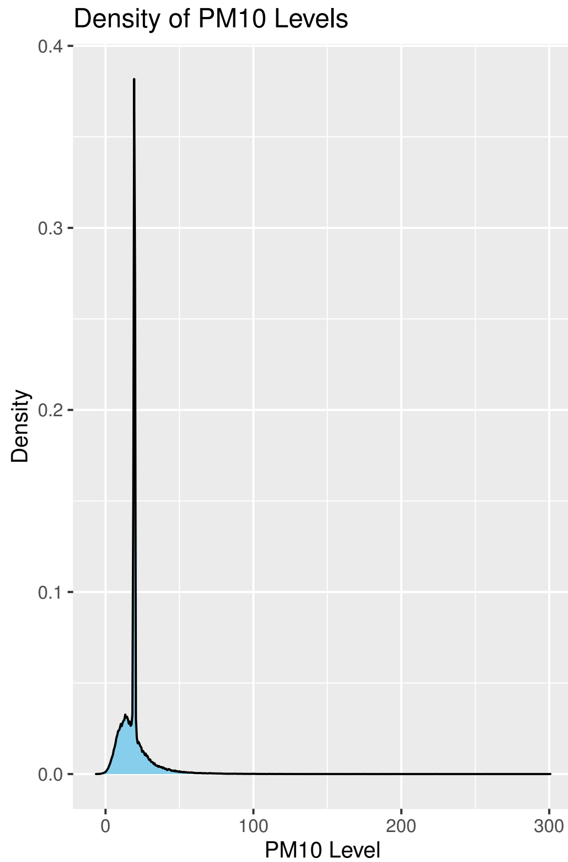

Figure 7: Density of PM_{10}

This density graph (Figure 7) has a peak around 20 and it suggests that the majority of sites in London have PM_{10} concentrations within a moderate range. However, without knowing the specific guidelines or standards for PM_{10} levels in London, it's challenging to determine whether this concentration is considered high, moderate, or low in terms of air quality standards.

Also this graph indicates spatial variability in PM_{10} levels across the 36 sites in London. Some areas might have higher concentrations, while others have lower concentrations, resulting in a distribution with a peak at 20.

3.5 Variation over Year

The mean value of each pollutant was grouped by month for each site and then variation of each pollutant over the year was plotted using "ggplot".

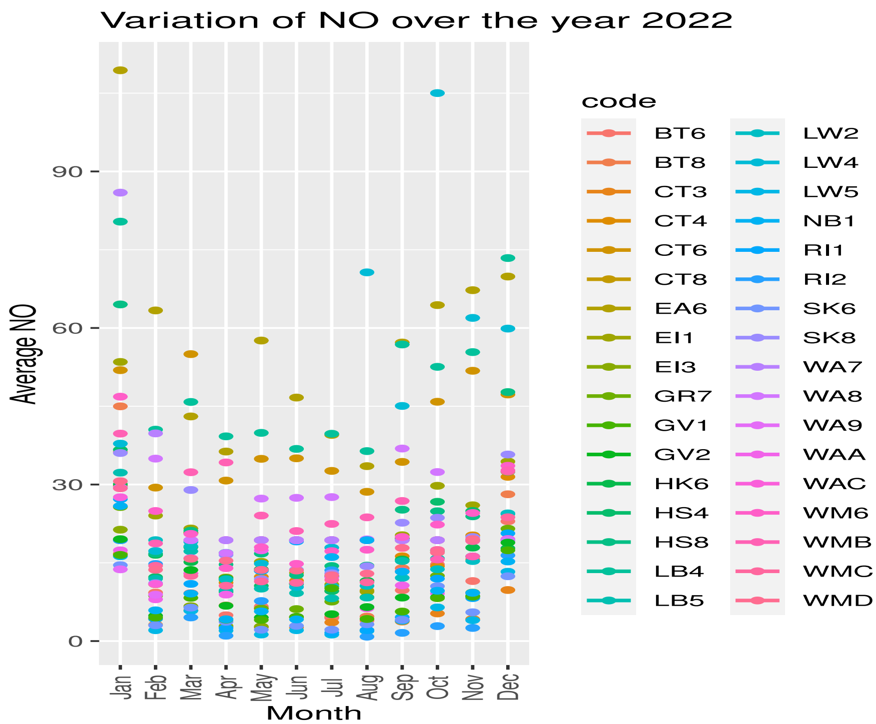

Figure 8: Variation of NO

According to above graph (Figure 8), we can see that some sites have a comparatively higher NO value at the beginning of the year (January to March) and a comparatively lower NO value in the middle of the year. Then again when it comes to end of year, some sites indicate a comparatively higher average NO value.

This pattern could be attributed to seasonal variations in weather conditions and atmospheric dynamics. During the winter months (January to March), colder temperatures and increased energy consumption (e.g., heating) may lead to higher emissions of pollutants like NO from sources such as vehicles, industrial processes, and residential heating systems. In contrast, during the middle of the year (spring and summer), factors such as increased atmospheric dispersion, enhanced photochemical reactions, and reduced heating demand could contribute to lower NO concentrations. The rise in NO levels again at the end of the year (late autumn to winter) could be due to factors similar to those observed in the beginning of the year.

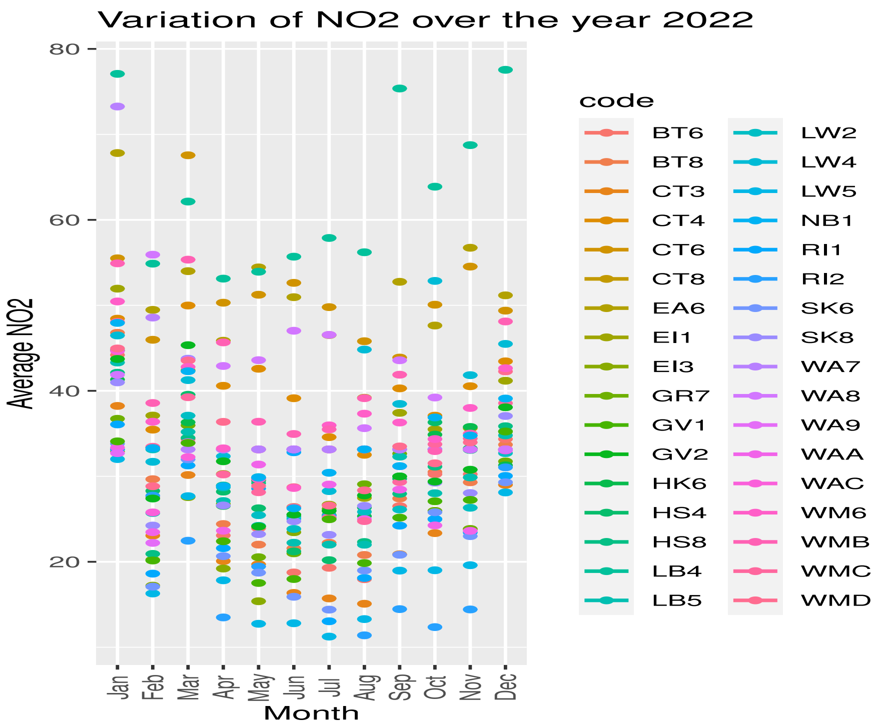

Figure 9: Variation of NO_2

By studying the graph of variation of NO_2, (Figure 9), we can see the same pattern as the variation of NO. But the average values of NO_2 are little higher than the values of NO.

NO is a precursor to NO_2 in the atmosphere through a series of chemical reactions. Therefore, higher concentrations of NO at certain times may lead to increased production of NO_2 through atmospheric oxidation processes. This could explain why the average values of NO_2 are higher than NO, despite exhibiting a similar seasonal pattern.

Also NO and NO_2 have different primary emission sources, although they can also be produced from similar sources. NO is primarily emitted from combustion processes, such as vehicle engines and industrial activities, while NO_2 can be formed directly from these sources or through atmospheric oxidation of NO. If there are additional emission sources contributing to NO_2 levels (e.g., power plants, industrial processes) that are not as prevalent for NO, this could contribute to the higher average values of NO_2.

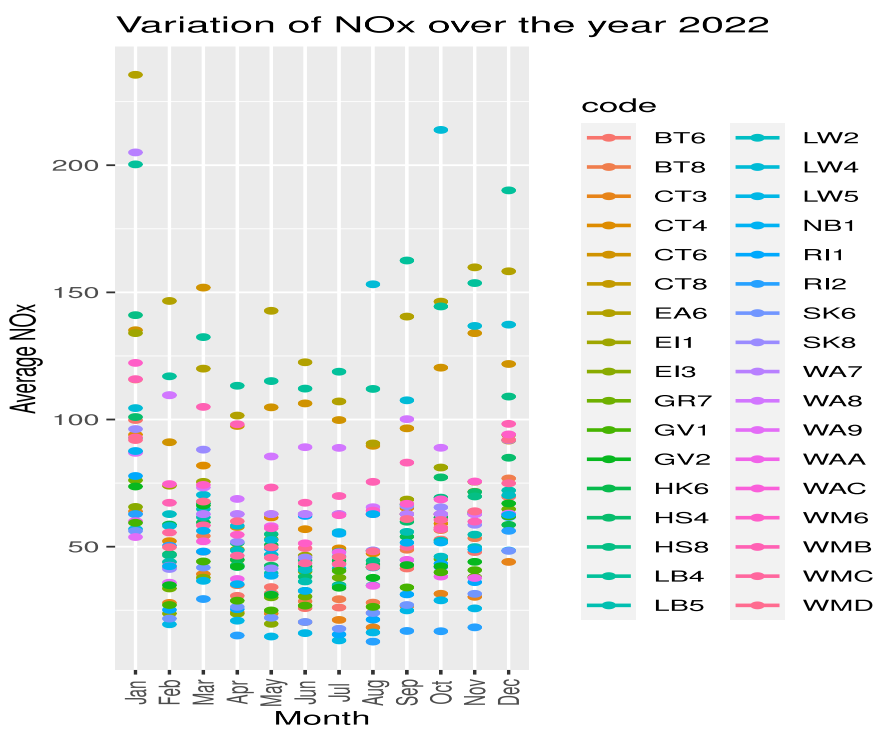

Figure 10: Variation of NO_x

By studying the graph of variation of NO_x, (Figure 10), we can see the same pattern as the variation of NO & NO_2. But the average values of NO_x are little higher than the values of NO and little lower than NO_2.

NO_x is a mixture of nitrogen oxides, including NO and NO_2, as well as other nitrogen-containing compounds such as nitrous oxide (N_2O). The varying contributions of NO and NO_2 to the overall NO_x concentration could result in intermediate average values compared to NO and NO_2 individually.

Different emission sources contribute to the formation of NO, NO_2, and other nitrogen oxides in the atmosphere. Variations in the relative contributions of these sources over time, such as changes in traffic patterns, industrial activities, and atmospheric conditions, can affect the overall composition and concentration of NO_x.

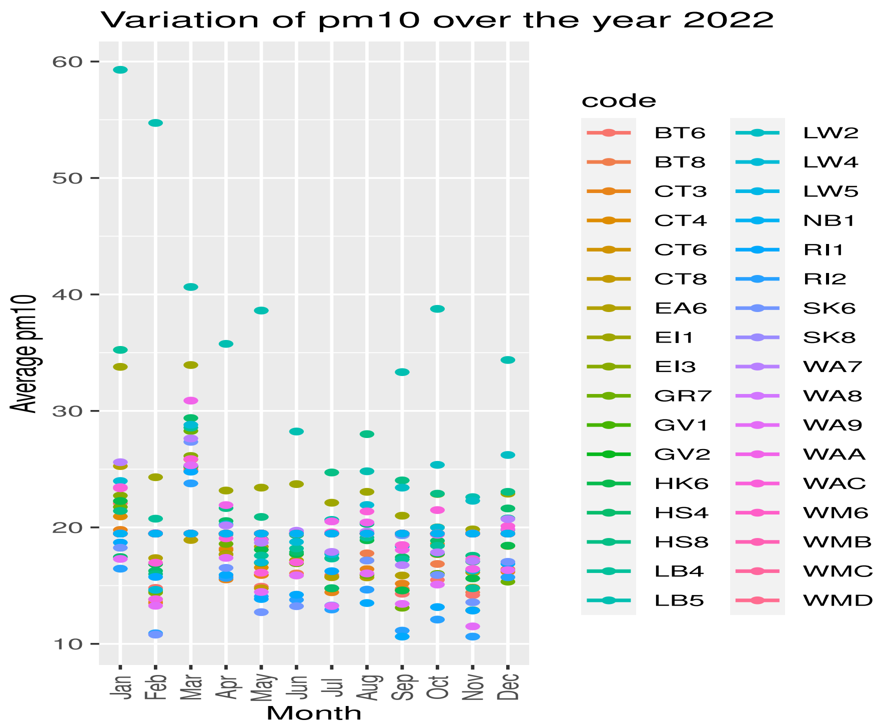

Figure 11: Variation of PM_{10}

According to variation of PM_{10} over year (Figure 11), we can see that a comparatively higher values in the beginning of the year and comparatively lower values in the end of the year.

Seasonal variations in PM_{10} levels are common and can be influenced by factors such as weather patterns, temperature, humidity, and atmospheric stability. In many regions, including urban areas like London, higher PM_{10} concentrations are often observed during the colder months (e.g., winter) due to increased emissions from sources such as residential heating, industrial activities, and vehicular traffic. During the warmer months (e.g., spring and summer), factors like enhanced atmospheric dispersion, reduced heating demand, and increased rainfall may contribute to lower PM_{10} levels.

Different sources contribute to PM_{10} emissions, including vehicle exhaust, industrial processes, construction activities, agricultural practices, and natural sources such as dust and pollen. Variations in the intensity and timing of these emission sources throughout the year can influence the observed patterns of PM_{10} concentrations.

4 Conclusion

- The findings on subsection 3.2 highlight the necessity for targeted environmental and public health interventions in areas like Lewisham - Loampit Vale and Lambeth - Brixton Road to reduce pollution levels and mitigate potential health impacts.

- Urgent air quality management measures are required in areas with severe pollution levels, such as Hounslow Gunnersbury, to protect the health of the local population and address potential respiratory and cardiovascular issues.

- The comparable contributions of NO and PM_{10} highlight the diverse sources of air pollution in London, including vehicular emissions, industrial activities, and combustion processes.

- Addressing air quality issues in London requires a comprehensive approach that considers reducing emissions from various sources contributing to NO_x, NO_2, NO, and PM_{10} pollution.

- Areas with moderate pollutant levels may benefit from measures to reduce emissions from local sources, such as promoting cleaner transportation options and implementing emission control measures in light industrial areas.

- In high pollution areas, strategies to address heavy traffic congestion, improve industrial emissions controls, and implement stricter regulations near major roadways may be necessary to reduce pollutant levels and mitigate health risks for residents.

- Understanding the factors influencing the variations in NO_x levels, such as changes in emission sources and atmospheric conditions, is essential for effective air quality management and pollution control efforts.

- The observed seasonal variation in PM_{10} levels underscores the importance of understanding the complex interplay of various factors, including weather conditions and emission sources, in determining air quality throughout the year.

- This understanding is crucial for developing effective air quality management strategies that can address the specific challenges associated with seasonal variations in PM_{10} concentrations.