Air Quality Analysis in the Lombardia region for the year 2023

Andrea Ongarini

February 21, 2024

Contents

1 Introduction

1.1 Problem description

The ARPA Lombardia air quality detection network is made up of fixed stations which, by means of automatic analysers, provide continuous data at regular time intervals. The pollutant species monitored continuously are Lead (Pb), Arsenic (As), Cadmium (Cd), Nickel (Ni), Black Carbon, Nitrogen oxides (NOX), Nitrogen dioxide (NO2), Nitric oxide (NO), Sulfur dioxide (SO2), Carbon oxide (CO), Ozone (O3), PM10, PM2.5, Benzene (C6H6), Ammonia (NH3). Depending on the environmental context in which monitoring is active, the type of pollutants that need to be detected is different. Therefore, not all stations are equipped with the same analytical instrumentation. The regional stations are distributed throughout the regional territory according to the population density and the type of territory respecting the criteria defined by Legislative Decree 155/2010.

1.2 Dataset and features

This analysis was done using 4 datasets:

- the first one[1], cointaining the detections of harmful substances in the air of the Lombardy region carried out during the year 2023. This dataset is made up of 5 attributes:
  - **IdSensore**: Unique identifier that distinguishes the sensor
  - **Data**: date and time
  - **Valore**: -9999 = invalid data. The absence of a record indicates that the data is not available
  - **Stato**: VA = valid data; NA = invalid data. The data in this archive, relating to the current year, still contain uncertain values which may undergo changes following validation processes based on statistical analyzes of the measured series. The data validation process includes a final evaluation phase which ends by March 30th of the year following the measurement year. Therefore, prior to that date, the data must be considered non-definitive.
  - **idOperatore**: 1 is the only value

  and contains 2.62 million instances (single detections).

- the second dataset[2], with the same format as the first one, which contains the detections of harmful substances in the air of the Lombardy region carried out between 2018 and 2023. I only took those relating to the current year (2023), subsequently combining them with the first dataset, in in order to obtain a bigger dataset.

- A third and fourth datasets[3], containing the list and position of monitoring stations and sensors. Consisting of 16 attributes:

  - **IdSensore**: Unique identifier that distinguishes the sensor
  - **NomeTipoSensore**: type of pollutant detected in the air (Biossido di Azoto, Biossido di Zolfo, Ozono, Monossido di Carbonio, Benzene, Ossidi di Azoto, PM10 (SM2005), Particelle sospese PM2.5, Ammoniaca, Nikel, Arsenico, Cadmio, Piombo, BlackCarbon, Monossido di Azoto)
  - **UnitaMisura**: measurement unit of the detected substance
  - **Idstazione**: unique identifier that distinguishes the monitoring station
  - **NomeStazione**: name of the monitoring station
  - **Quota**: elevation at which the monitoring station is located
  - **Provincia**: province in which the monitoring station is located
  - **Comune**: municipality in which the monitoring station is located
  - **Storico**
  - **DataStart**: monitoring station's inauguration date
  - **DataStop**: monitoring station's closing date
  - **Utm_Nord**: UTM North coordinate
  - **UTM_Est**: UTM East coordinate
  - **lat**: latitude
  - **lng**: longitude
  - **location**: union of latitude and longitude

  and containing 970 + 233 sensors divided into 174 detection stations located in the Lombardy region.

1.3 Goals

Perform an analysis on the data contained in the dataset.
Main objectives:

- Check compliance with the concentration limits established by law for the substances detected in the air
- Graph the pollutant's trend in the air during the months of 2023 for each province and make comparisons
- Draw up a ranking of the more or less polluted provinces by calculating the AQIs and comparing them

2 Data Preprocessing

2.1 Dataset import and analysis

Import the two dataset (same format) containing the data about the substance detection.

```
dati2023 <- read.csv("dati/Dati_sensori_aria_2023.csv")
dati2018 <- read.csv("dati/Dati_sensori_aria_dal_2018.csv")

head(dati2023)
```

	idSensore	Data	Valore	Stato	idOperatore
1	5504	01/01/2023 12:00:00 AM	42.1	VA	1
2	5504	01/01/2023 01:00:00 AM	41.1	VA	1
3	5504	01/01/2023 02:00:00 AM	39.7	VA	1
4	5504	01/01/2023 03:00:00 AM	38.6	VA	1
5	5504	01/01/2023 04:00:00 AM	36.9	VA	1
6	5504	01/01/2023 05:00:00 AM	33.5	VA	1

Figure 1: Raw Air Data Lookalike

Convert the data attribute and filtered the 2023's instances, then merged the two datasets into a single one:

```
# the two dataset have different format for the date

# convert time in a 24h format and POSIXlt object
dati2018$Data  <- strptime(dati2018$Data, format = "%m/%d/%Y␣
   %I:%M:%S␣%p")

# convert time in a 24h format and POSIXlt object
dati2023$Data  <- strptime(dati2023$Data, format = "%d/%m/%Y␣
   %I:%M:%S␣%p")

# filter 2023 datas
dati23 <- subset(dati2018, format(Data, "%Y") == "2023")
dati2023 <- subset(dati2023, format(Data, "%Y") == "2023")

# Dataset concatenation
airData <- rbind(dati2023, dati23)

# check on the year
```

```
unique(format(airData$Data, "%Y"))
```

Import the two dataset containing the data about detection's station.

```
# import station dataset
stationData1 <- read.csv("dati/Stazioni_qualit__dell_aria_
    2024.csv")
stationData2 <- read.csv("dati/Stazioni_qualit__dell_aria_NRT
    _2024.csv")
head(stationData1)
```

```
  idSensore         NomeTipoSensore UnitaMisura Idstazione                  NomeStazione Quota
1     10431         Ossidi di Azoto       µg/m³       1264             Sondrio v.Paribelli   290
2      9968         Ossidi di Azoto       µg/m³        679             Valmadrera v.Pozzi    247
3      5543       Biossido di Azoto       µg/m³        540 Garbagnate Milanese v. Villoresi   175
4     20197           PM10 (SM2005)       µg/m³        598   San Rocco al Porto v.Matteotti    50
5      5611       Biossido di Azoto       µg/m³        608                 Codogno v.Trento    59
6     10347 Particelle sospese PM2.5      µg/m³        670                Mantova S.Agnese    22
  Provincia              Comune Storico  DataStart   DataStop Utm_Nord UTM_Est      lat       lng
1        SO             Sondrio       N 11/11/2008            5113073  567873 46.16785  9.879210
2        LC          Valmadrera       N 16/02/2006            5076576  527307 45.84221  9.351658
3        MI Garbagnate Milanese       S 11/12/1992 30/07/2018  5046467  506105 45.57172  9.078242
4        LO  San Rocco al Porto       N 01/01/2002            4992297  555154 45.08199  9.700788
5        LO             Codogno       N 13/01/2000            5000892  554872 45.15937  9.698148
6        MN             Mantova       N 21/12/2007            5002356  641122 45.16057 10.795564
                               location
1 (46.167852440665115, 9.879209924469903)
2 (45.842207261022544, 9.351658166127958)
3    (45.5717162655023, 9.07824159056828)
4  (45.081986696978625, 9.70078817718398)
5   (45.15937280234111, 9.69814824935254)
6  (45.16056833010576, 10.79556411370788)
```

Figure 2: Raw Station Data Lookalike

Concatenate them in a single dataset

```
# convert from integer to character
stationData2$Quota <- as.character(stationData2$Quota)

# concatenation
stationData <- bind_rows(stationData1, stationData2)
```

2.2 Failed Detection

I checked for the presence of detections with errors within the first dataset.

```
nrow(airData[airData$Valore == -9999.0,])
```

That instruction returns "73174" → the number of detections in which the sensor had a malfunction, i simply remove them from the dataset:

```
# save the instance with errors to study them
errorSensor <- airData[airData$Valore == -9999.0,]

# removing from the dataset
airData <- airData[airData$Valore != -9999.0,]
```

2.3 Duplicate instances

I check for duplicate instances within both datasets.

```
library("dplyr") # contains function distinct()

nrow(distinct(airData)) == nrow(airData)
length(unique(stationData$IdSensore)) == nrow((stationData))
```

Both instruction return FALSE → there are duplicate instances in both datasets. I remove them using:

```
airData <- airData %>% distinct()
stationData <- stationData %>% distinct(IdSensore, .keep_all
   = TRUE)
```

2.4 Data manipulation

Create a new attribute to clarify which of the station are still open and which are already closed

```
stationData$Open <- ifelse((stationData$DataStop == "" |
                            is.na(stationData$DataStop)), "YES",
                               "NO")
```

and plotted all the station, using a geoJSON file[4]

```
library(sf)
library(osmdata)
library(ggmap)

# Read the GeoJSON Shapefile
lombardia_provinces <- st_read("lombardy_.geojson")

ggplot() +
geom_sf(data = lombardia_provinces, fill = "lightblue", color
    = "black") +
```

```
# Add points from stationData
geom_point(data = stationData, aes(x = lng, y = lat), color =
     "red", size = 2) +
theme_minimal()
```

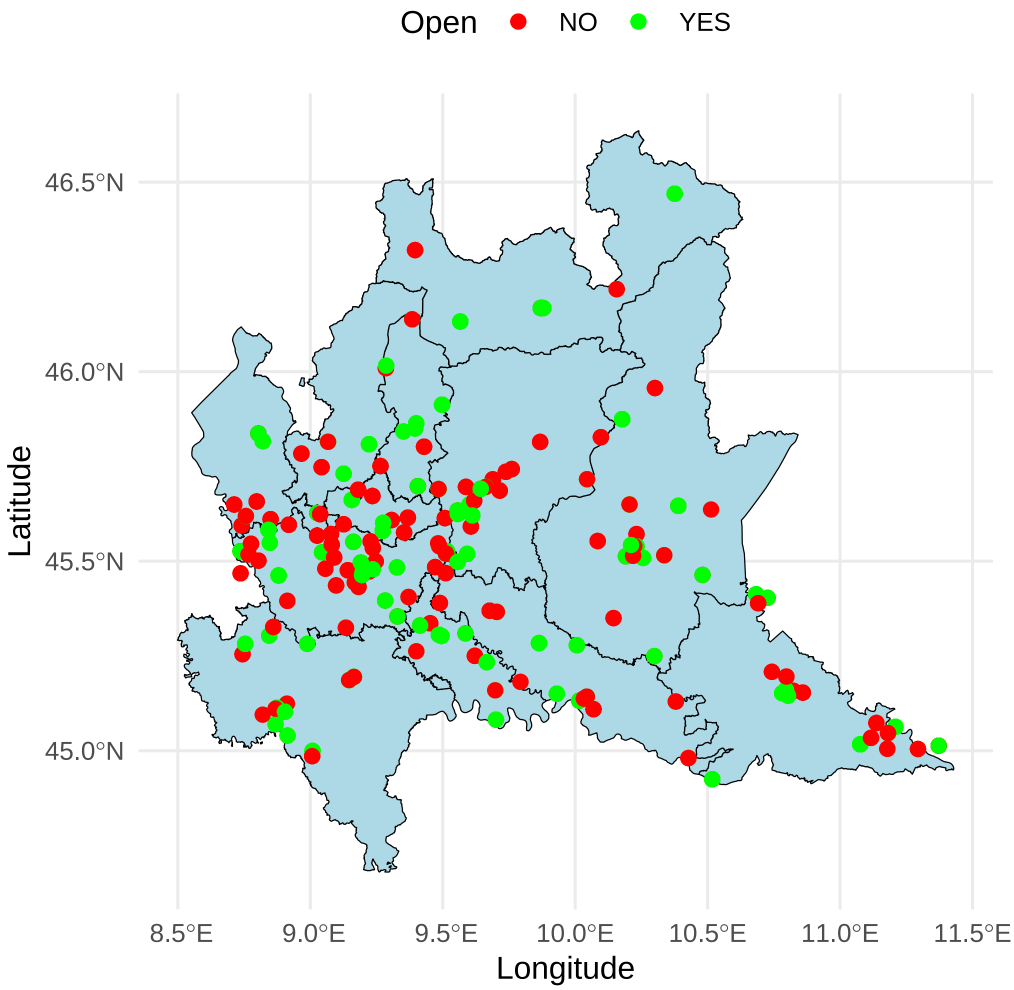

Figure 3: Detection Station

Air Quality Index[5]
The air quality index (IQA) is an indicator that allows us to provide an immediate and synthetic estimate of the air's state. For the definition of this indicator, currently, in Italy and Europe, it is possible to use different formulations that take into account the measured, estimated or predicted

	Very good	Good	Acceptable	Poor	Very poor
PM2.5	0-10	10-20	20-25	25-50	50-800
PM10	0-20	20-35	35-50	50-100	100-1200
NO2	0-40	40-100	100-200	200-400	400-1000
O3	0-80	80-120	120-180	180-240	240-600
SO2	0-100	100-200	200-350	350-500	500-1250

Table 1: Air quality status for AQI calculation

concentrations of a variable number of pollutants that have effects, especially of a respiratory, cardiac and cardiovascular nature, on health.
The following parameters are defined for each pollutant:

- for PM10 particulate matter, the daily average;
- for PM2.5 particulate matter, the daily average;
- for biossido di azoto the hourly maximum;
- for ozono, the hourly maximum;
- for biossido di zolfo, the hourly maximum.

The air quality state is attributed to each pollutant on the basis of the value assumed by the parameter according to the thresholds shown in the table (fig. 4). The overall IQA corresponds to the worst among those evaluated on the 5 pollutants.

2.5 Dataset's merge

I merge the two datasets using the attribute "IdSensore".

```
fullData <- merge(airData, stationData, by = "IdSensore")

#save the lost instances
lostInstances <- anti_join(airData, fullData, by = "IdSensore
   ")
```

6967 instances are lost in the merging operation, there are three Id Sensor that cannot be found, so all the instances for these are lost.
I tried to find more dataset containing the detection station but i only found the two that have been used in this report.
I used the function

```
str(fullData)
```

to see the variable's type of all the attributes of the dataset, in order to be able to modify them, according to my needs.

```
> str(fullData)
'data.frame':   2475160 obs. of  21 variables:
 $ IdSensore      : int  5504 5504 5504 5504 5504 5504 5504 5504 5504 5504 ...
 $ Data           : POSIXct, format: "2023-01-07 08:00:00" "2023-01-06 04:00:00" "2023-01-06 22:00:00" ...
 $ Valore         : num  35.6 29.4 42.4 38.5 37.6 43.9 31.6 49.7 41.1 39.3 ...
 $ Stato          : chr  "VA" "VA" "VA" "VA" ...
 $ IdOperatore    : int  1 1 1 1 1 1 1 1 1 1 ...
 $ NomeTipoSensore: chr  "Biossido di Azoto" "Biossido di Azoto" "Biossido di Azoto" "Biossido di Azoto" ...
 $ UnitaMisura    : chr  "µg/m³" "µg/m³" "µg/m³" "µg/m³" ...
 $ IdStazione     : int  501 501 501 501 501 501 501 501 501 501 ...
 $ NomeStazione   : chr  "Milano v.Marche" "Milano v.Marche" "Milano v.Marche" "Milano v.Marche" ...
 $ Quota          : chr  "129" "129" "129" "129" ...
 $ Provincia      : chr  "MI" "MI" "MI" "MI" ...
 $ Comune         : chr  "Milano" "Milano" "Milano" "Milano" ...
 $ Storico        : chr  "N" "N" "N" "N" ...
 $ DataStart      : chr  "18/09/1980" "18/09/1980" "18/09/1980" "18/09/1980" ...
 $ DataStop       : chr  "" "" "" "" ...
 $ UTM_Nord       : int  5038105 5038105 5038105 5038105 5038105 5038105 5038105 5038105 5038105 5038105 ...
 $ UTM_Est        : int  514918 514918 514918 514918 514918 514918 514918 514918 514918 514918 ...
 $ lat            : num  45.5 45.5 45.5 45.5 45.5 ...
 $ lng            : num  9.19 9.19 9.19 9.19 9.19 ...
 $ location       : chr  "(45.49631644365102, 9.190933555313624)" "(45.49631644365102, 9.190933555313624)" "
(45.49631644365102, 9.190933555313624)" "(45.49631644365102, 9.190933555313624)" ...
 $ Open           : chr  "YES" "YES" "YES" "YES" ...
```

Figure 4: Variable type for fullData's attribute

I created a new variable (i called it "Sigla") containing the chemical formula corresponding to the substance.

```
# create a table of correspondence between the values and the
    acronyms
tabella_corrispondenza <- data.frame(
  NomeTipoSensore = c("Ammoniaca", "Arsenico", "Benzene","
      Biossido di Azoto","Biossido di Zolfo","Black Carbon","
      Cadmio","Monossido di Azoto","Monossido di Carbonio", "
      Nikel", "Ossidi di Azoto", "Ozono", "Piombo", "
      Particelle sospese PM2.5", "PM10 (SM2005)"),
  Sigla = c("NH3", "As", "C6H6", "NO2", "SO2", "BC", "Cd", "
      NO", "CO", "Ni", "NOX", "O3", "Pb", "PM2.5", "PM10")
)

# join the correspondence table to the dataset to add the '
    acronym' column
fullData <- merge(fullData, tabella_corrispondenza, by = "
    NomeTipoSensore", all.x = TRUE)
```

3 Data Analysis

3.1 Plotting Datas

In order to understand what kind of substance have been measured in which Lombardia's zone and how many instances i have for each substance i plotted the following graphs.

```
library(ggplot2)

# generate a scatterplot showing which types of substances
# are measured in which zone
ggplot(fullData, aes(x = Provincia, y = NomeTipoSensore)) +
                      geom_point() +
                      labs(x = "Zone", y ="Measured Substance
                         ",
                      title = "Measured Substance in
                         different zones")

# find number of instances for each substance
instanceNumber <- as.data.frame(table(
   fullData$NomeTipoSensore))

par(mar = c(5, 8, 2, 2))  # Adjust the margins (bottom, left,
    top, right)

custom_values <- instanceNumber$Freq
custom_labels <- instanceNumber$Var1[which(
   instanceNumber$Freq
 %in% custom_values)]

barplot(instanceNumber$Freq, names.arg = custom_labels,
        horiz = TRUE, las = 1, col = "transparent",
        main = "Number of instances for each substance", cex.
           names = 0.7)
```

From the graph (Fig. 6) we can see how it is not possible to make comparisons between zones regarding some pollutants, such as Piombo, Arsenic, Cadmium, Nikel and Black carbon, as their measurements are present in only one province. For the remaining substances: in some cases they are present in all the provinces, in others only for a limited group.

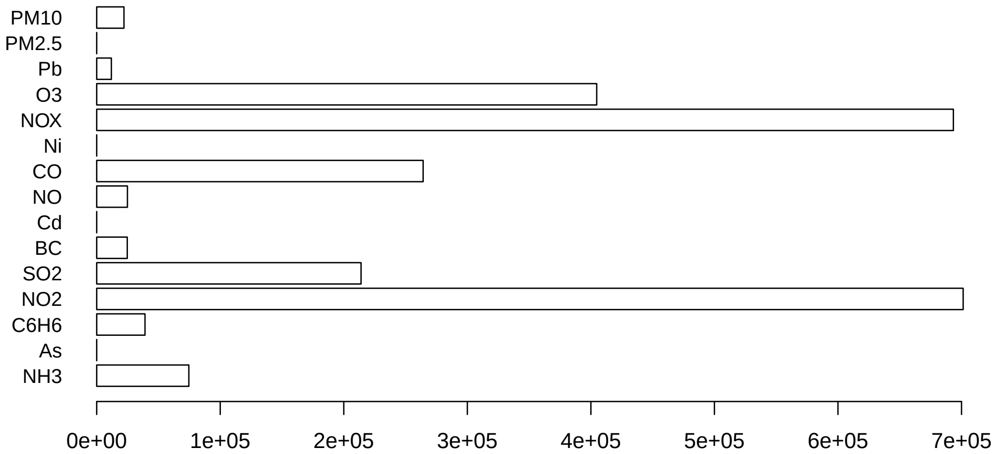

Figure 5: Instance number for substance

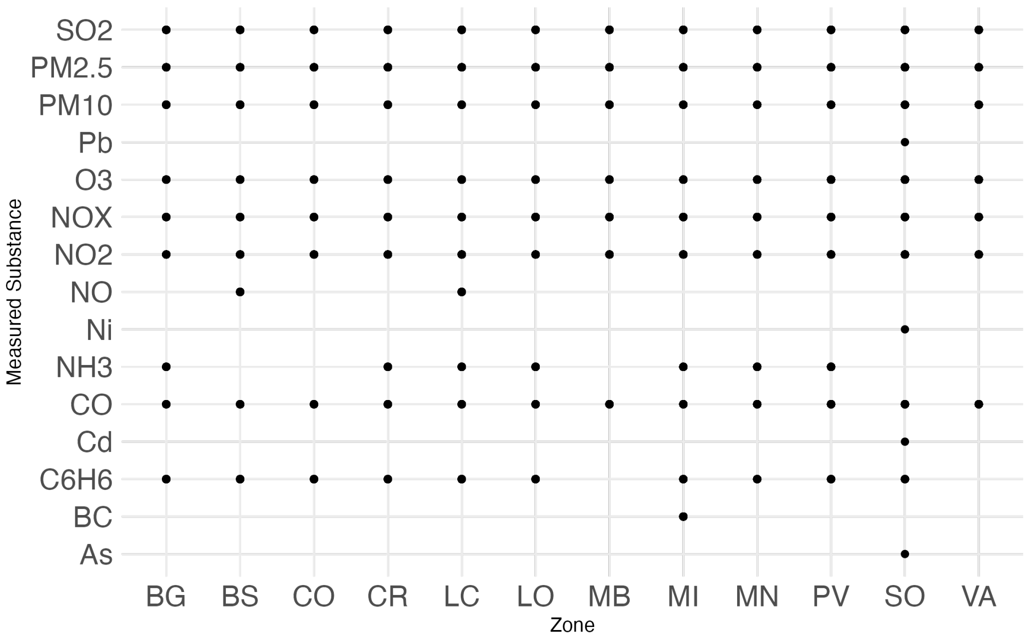

Figure 6: Measured substances for zone

In order to make a better analysis of the data, i studied them following two alternative paths:

- split the original dataset in a dataset for every different substance
- split the original dataset in a dataset for every different zone (Provincia)

In this way i was able to compare results between different zones and also to compare results between different substances in the same zone.

3.2 Analysis by substance

3.2.1 Lead (Pb) - Arsenic (As) - Cadmium (Cd) - Nikel (Ni)

For these 4 substances i only found one instance each in the dataset (Tab. 3), that's the annual average value.
According to the Arpa site[6] the limit value for these pollutants are:

Substance	Arsenic	Cadmium	Nickel	Lead
Limit Value[1]	6 ng/m^3	5 ng/m^3	20 ng/m^3	0.5 ng/m^3

Table 2: Limit values for Cadmium, Lead, Nickel, Arsenic

Attribute	**Arsenic**	**Cadmium**	**Nickel**	**Lead**
Id Sensore	12674	12675	12673	12695
Data	2023-08-12	2023-08-12	2023-08-12	2023-08-12
Valore	0.461	0.1	0.85	2.514
UnitaMisura	ng/m^3	ng/m^3	ng/m^3	ng/m^3
Idstazione	1264	1264	1264	1264
Provincia	SO	SO	SO	SO
Comune	Sondrio	Sondrio	Sondrio	Sondrio

Table 3: Instances for Cadmium, Lead, Nickel, Arsenic all measured by Sondrio v. Paribelli station

As we can see there is only one station that carried out this measurement, which is provided to us as an annual average.
We can notice that for 3 of the 4 substances the annual limit value was respected, the only one that exceded it was lead.

3.2.2 BlackCarbon

There are only 3 stations that measure this substance, all located in Milan (in a small area), so i plotted a graph (Fig. 7) containing the annual trend, where each different line represents a different station.
It's part of PM10 but there are no limits for its concentration in the air[7], so there's no much we can say about it, the only thing i was able to notice is that the value is lower in the warmer seasons (months from April to August) and higher in the colder seasons (months from September to March).

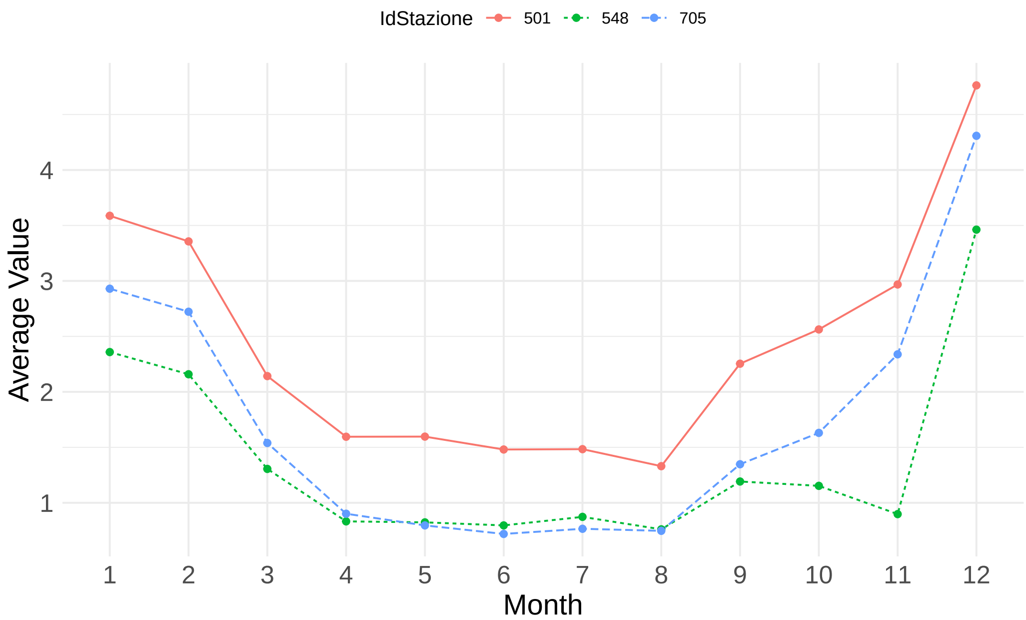

Figure 7: Black Carbon Trend in 2023

3.2.3 PM10

The datas are provided as an average over the previous 24 hours.
The **daily limit** value is 50 $\mu g/m^3$ as an hourly average, and must not to be exceeded more than 35 days/year[6].
I counted for each zone the number of the days that at least one station is above the limit and showed the results as a barplot.

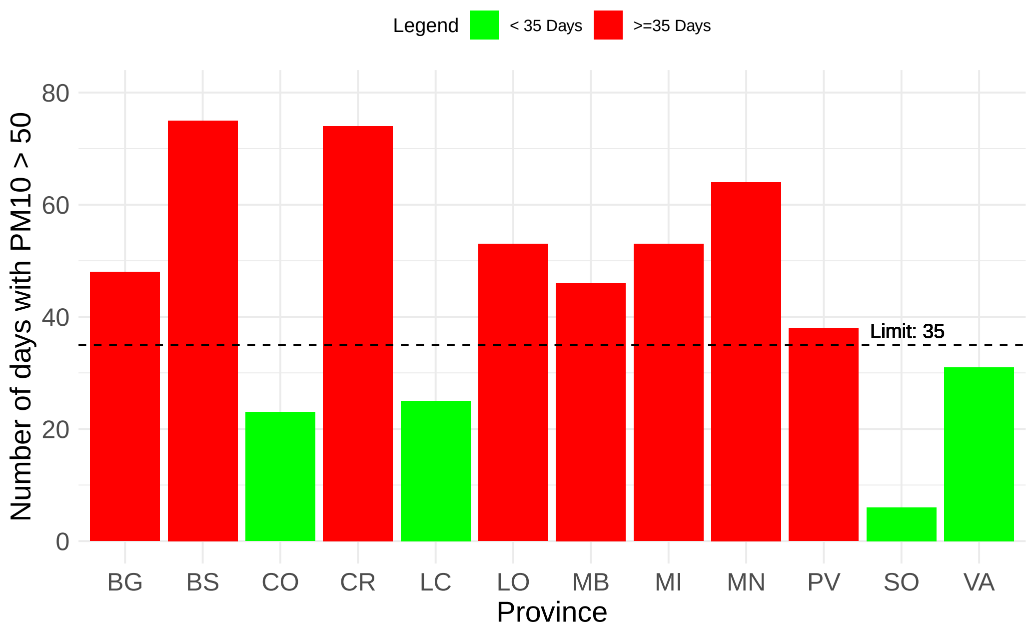

Figure 8: Compliance with the daily limit

From the graph (Fig. 8) we can see that only a few zones are in the right range: Como (CO), Sondrio (SO), Varese (VA) and Lecco (LC).
The worst zones are Brescia (BS) and Cremona (CR), followed by Mantova.
The best zone is Como (CO) province.

The **annual limit** value that must not be excedeed is 40 $\mu g/m^3$ on an yearly average[6]. I calculated the annual average for each station, then i summarized them by area by averaging the stations in each area, finally i checked which zones exceeded the value established by law.
I used another barplot to show the obtained results.

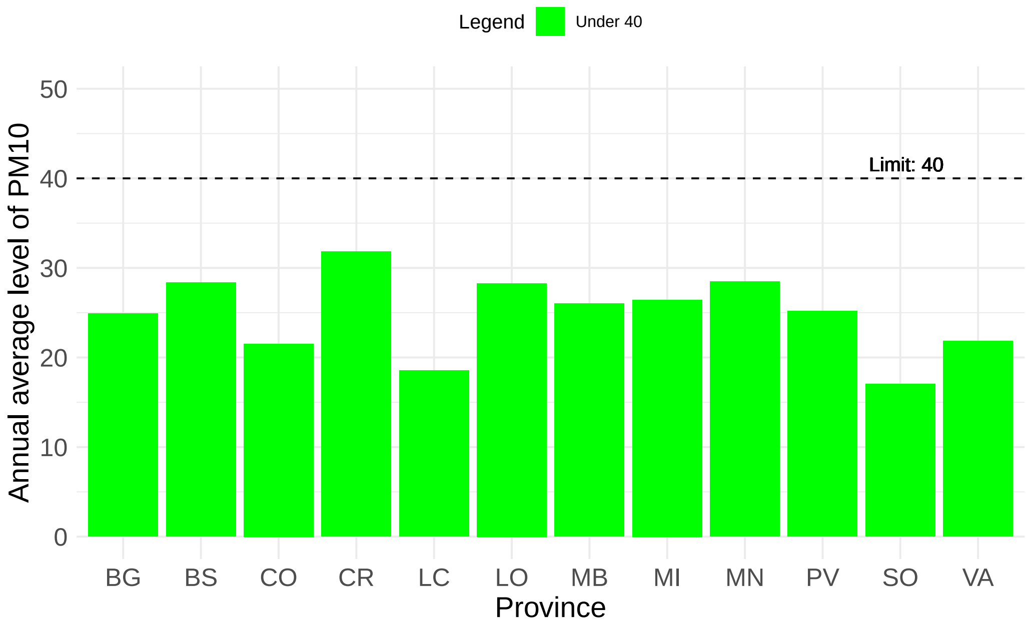

Figure 9: Compliance with the yearly limit

By observing the graph (Fig. 9) we can see that in each area the yearly average PM10 limit established by law has been respected.
The values reflect those contained in the previous graph: the three worst provinces slightly matches the previous ones and have the highest annual values and the four zones that respect the daily limit are also the four zones with the lowest annual values.

In order to have a better view on the PM10's level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 10) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

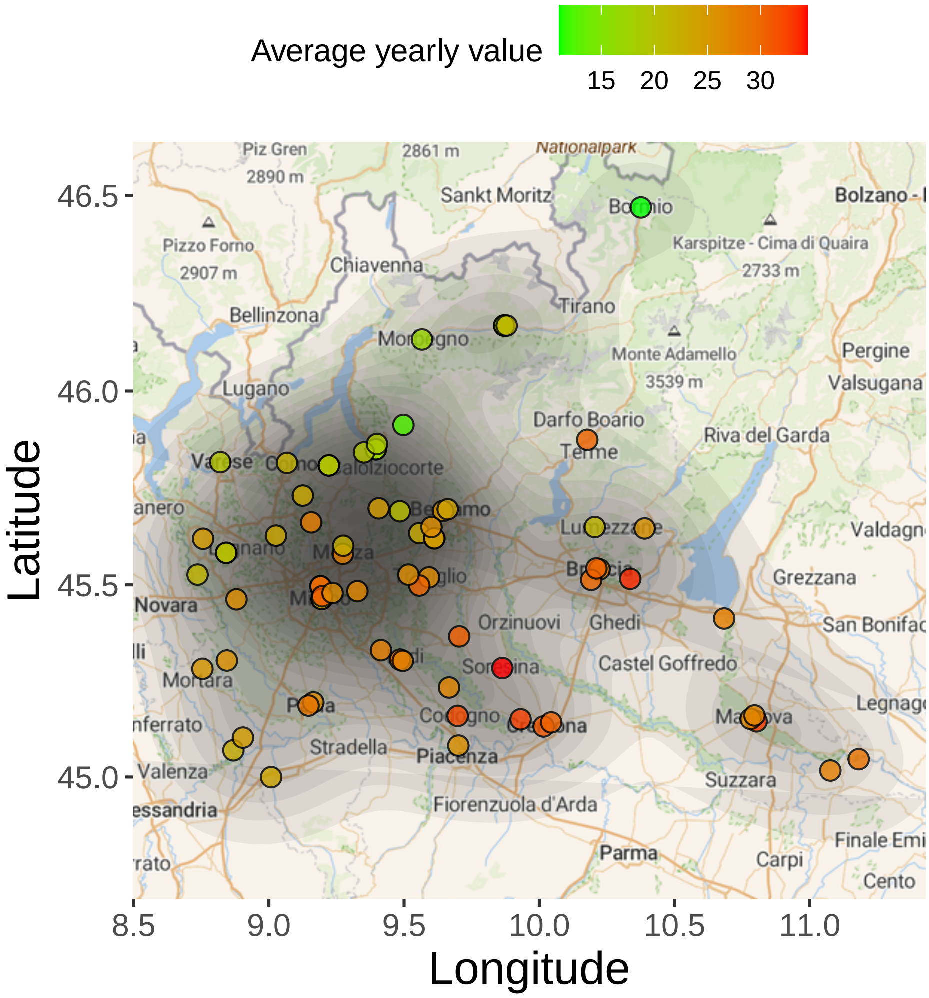

Figure 10: Annual Average PM10 by Station

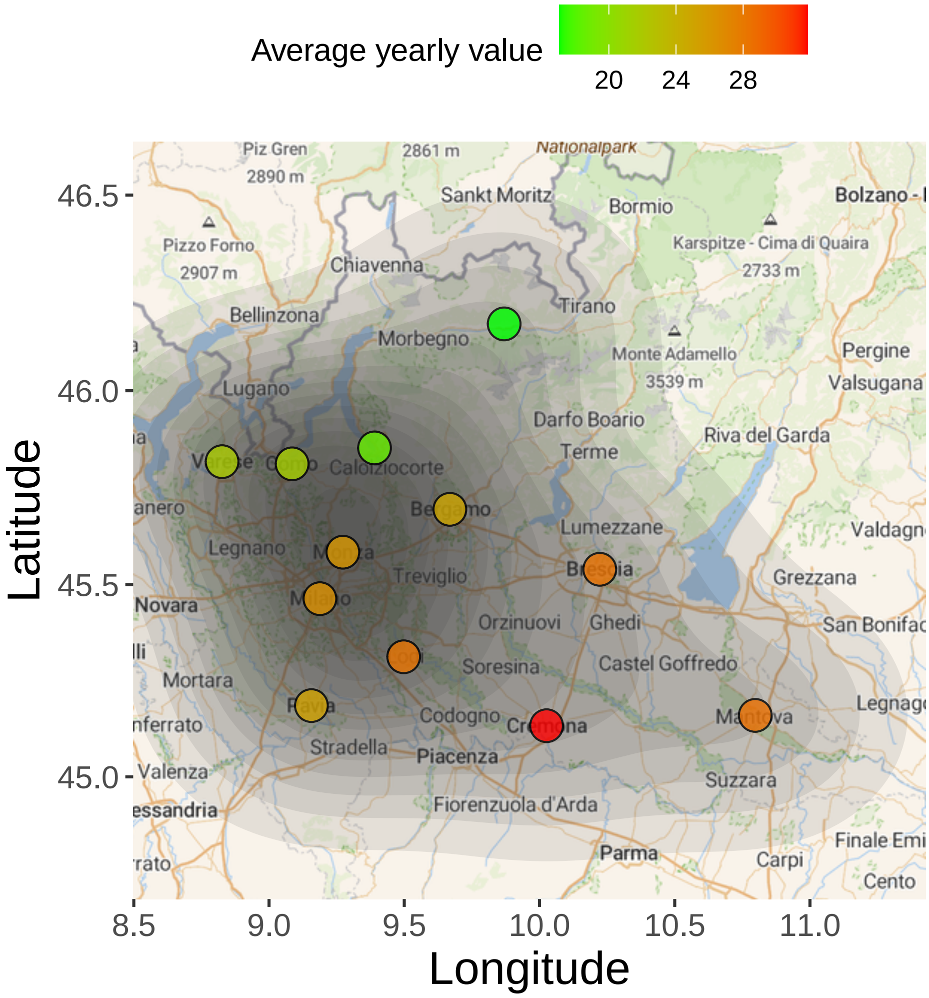

Figure 11: Annual Average PM10 by Zone

To obtain this second graph (Fig. 11) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.4 PM2.5

The datas are provided as an average over the previous 24 hours.
The **annual limit** value is 25 $\mu g/m^3$ as annual average[9]. I calculated the annual average for each station, then i summarized them by area by averaging the stations in each area, finally i checked which zones exceeded the value established by law, i used a barplot to show the obtained results.

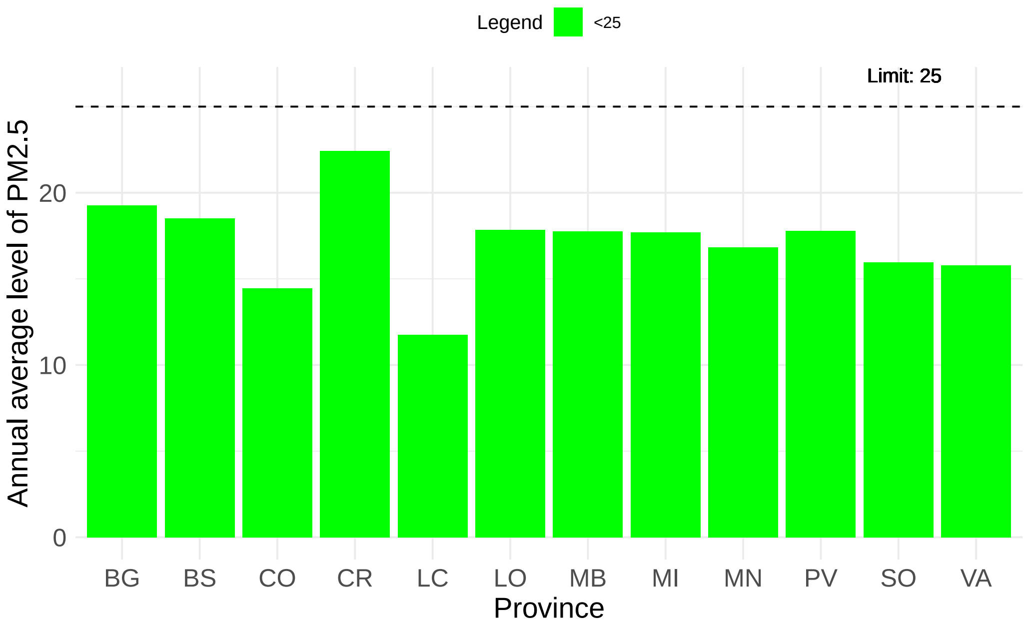

Figure 12: Compliance with the yearly limit per zone

From the graph (Fig. 12) we can see that in each area the yearly average PM2.5 limit established by law has been respected.
The area with the highest average value of PM2.5 is the Cremona (CR) province, the area with the lowest average value is the Lecco (LC) province.

In order to have a better view on the PM2.5's level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 13) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

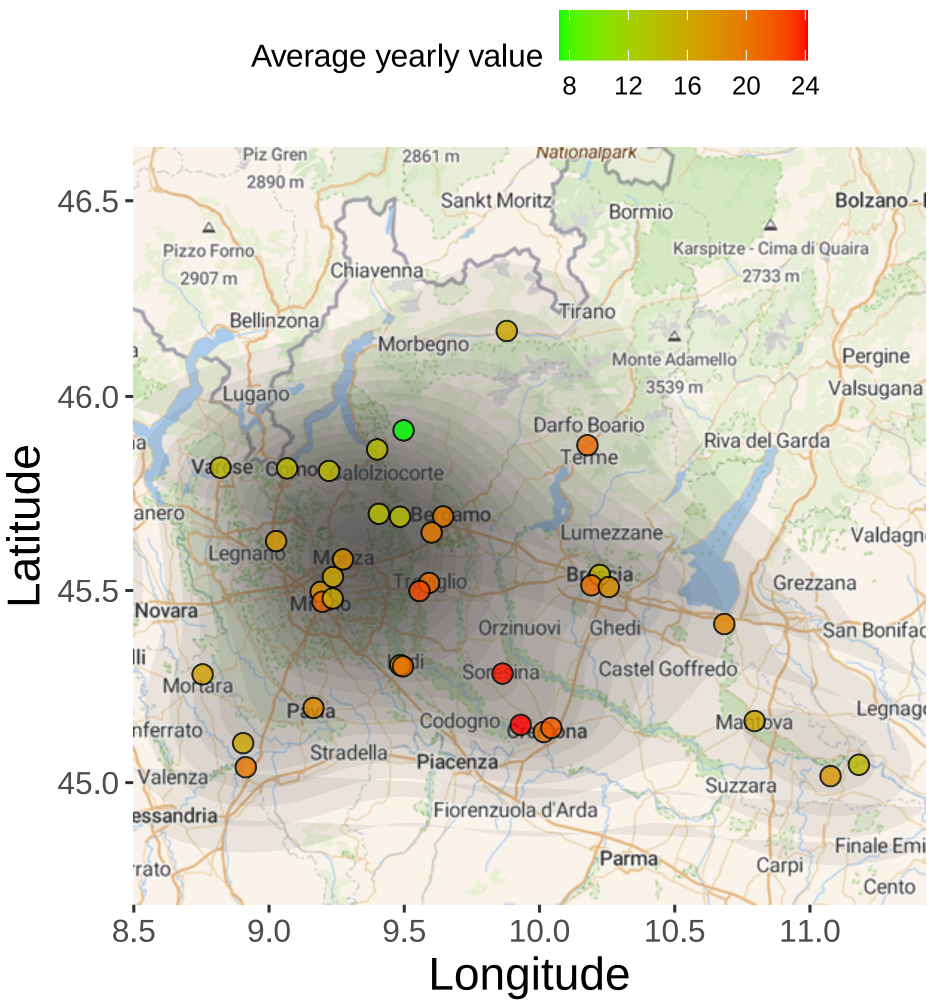

Figure 13: Annual Average PM2.5 by Station

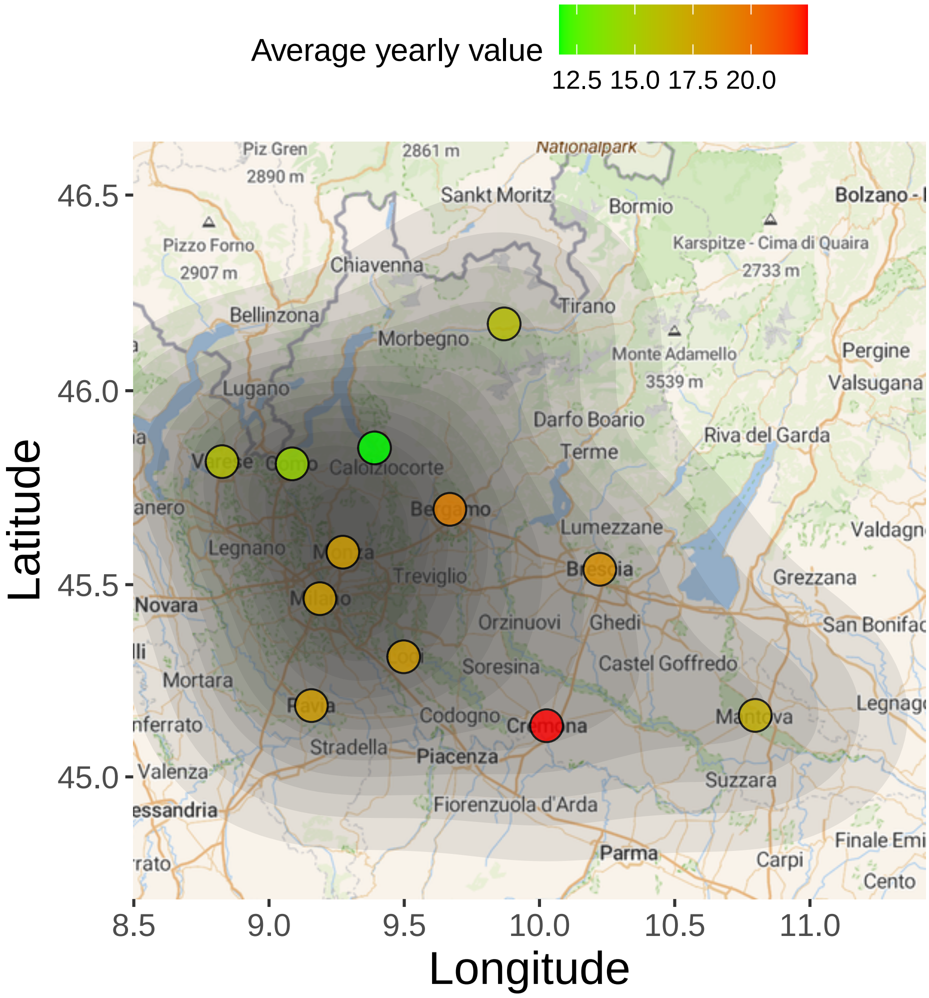

Figure 14: Annual Average PM2.5 by Zone

To obtain this second graph (Fig. 14) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.5 Nitrogen dioxide (NO2)

The **daily limit** value is 200 $\mu g/m^3$ as an hourly average, and must not to be exceeded more than 18 times/year[6].
I counted for each zone the number of times that at least one station is above the limit and show the results as a barplot.

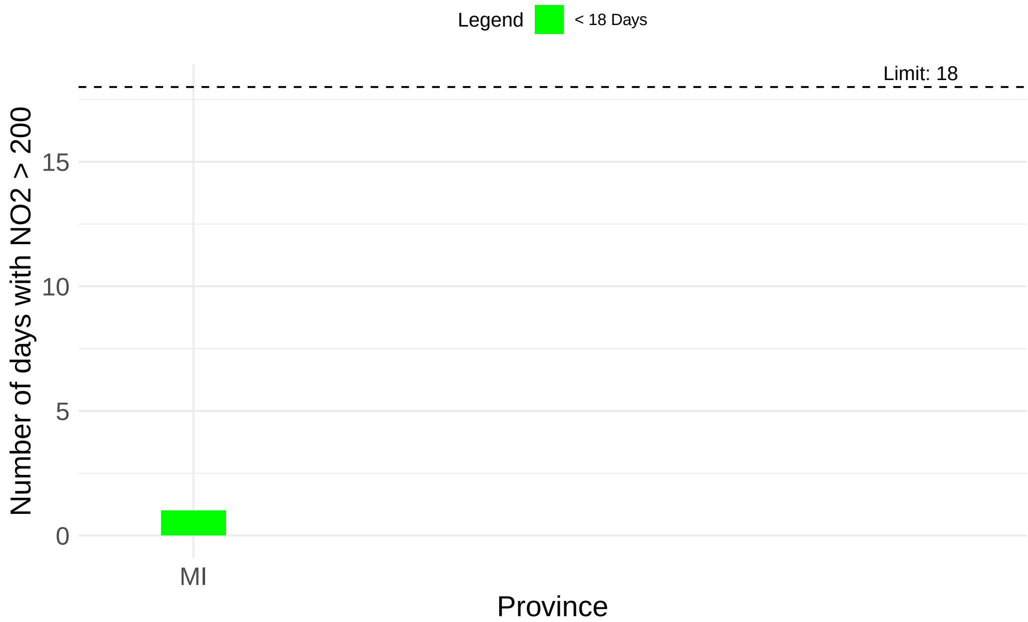

Figure 15: Compliance with the daily limit

From the graph (Fig. 15) we can see that in each area the daily nitrogen dioxide average limit established by law have been respected by every zone. Only one station in the province of Milan exceeded the limit of 20 $\mu g/m^3$ for 2 days, the stations in the other provinces did not exceed it even for one day.

The **annual limit** value that must not be excedeed is 40 $\mu g/m^3$ as annual average[6]. I calculated it for each station, then i summarized it by area by averaging the stations in each area and finally i checked which areas exceeded the value established by law.
I used another barplot to show the results obtained.

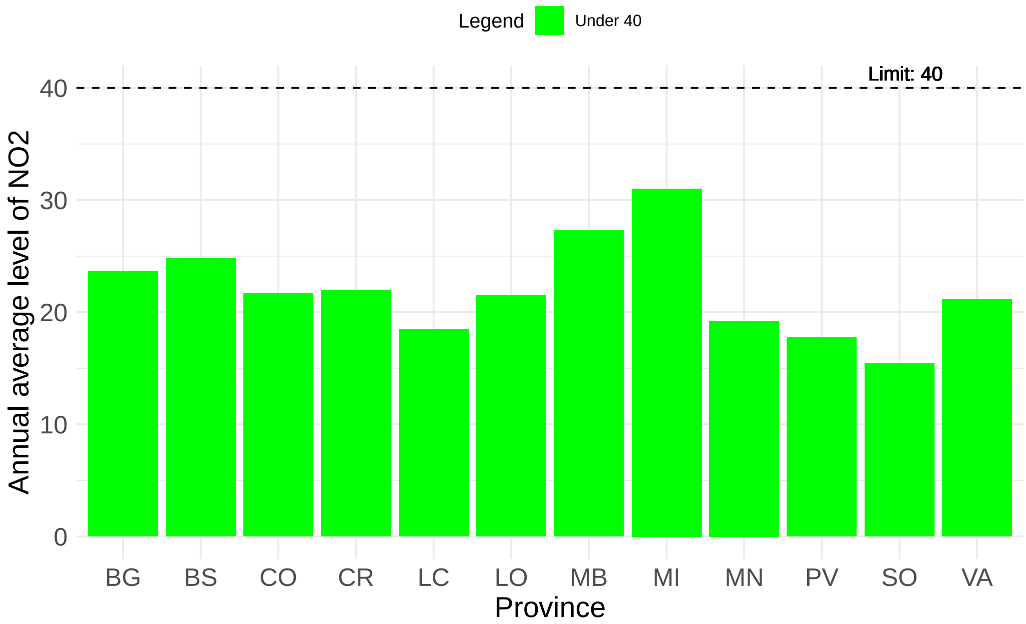

Figure 16: Compliance with the yearly limit

From the graph (Fig. 16) we can see that also the yearly average limits established by law have been respected by every zone.
The areas with the highest yearly average values are the Milano (MI) and Monza Brianza (MB) provinces, the areas with the lowest is Sondrio (SO) province.

In order to have a better view on the Nitrogen dioxide's level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 17) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

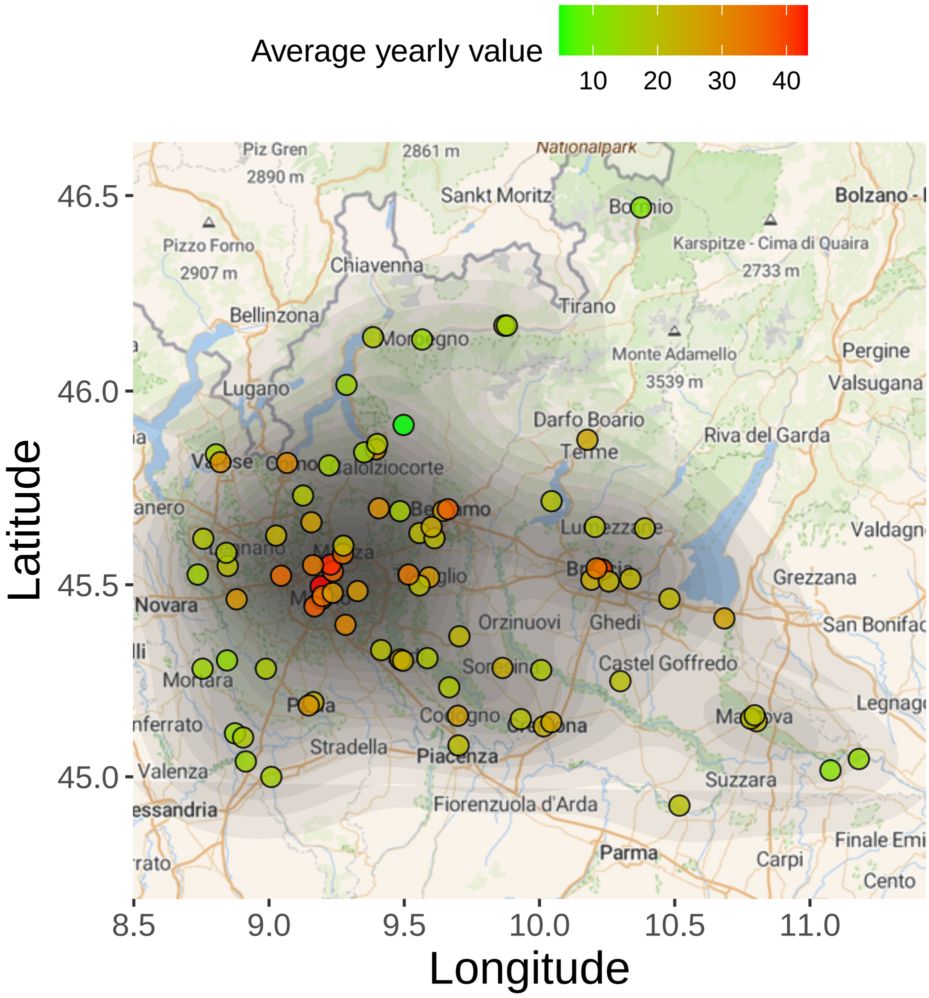

Figure 17: Annual Average NO2 by Station

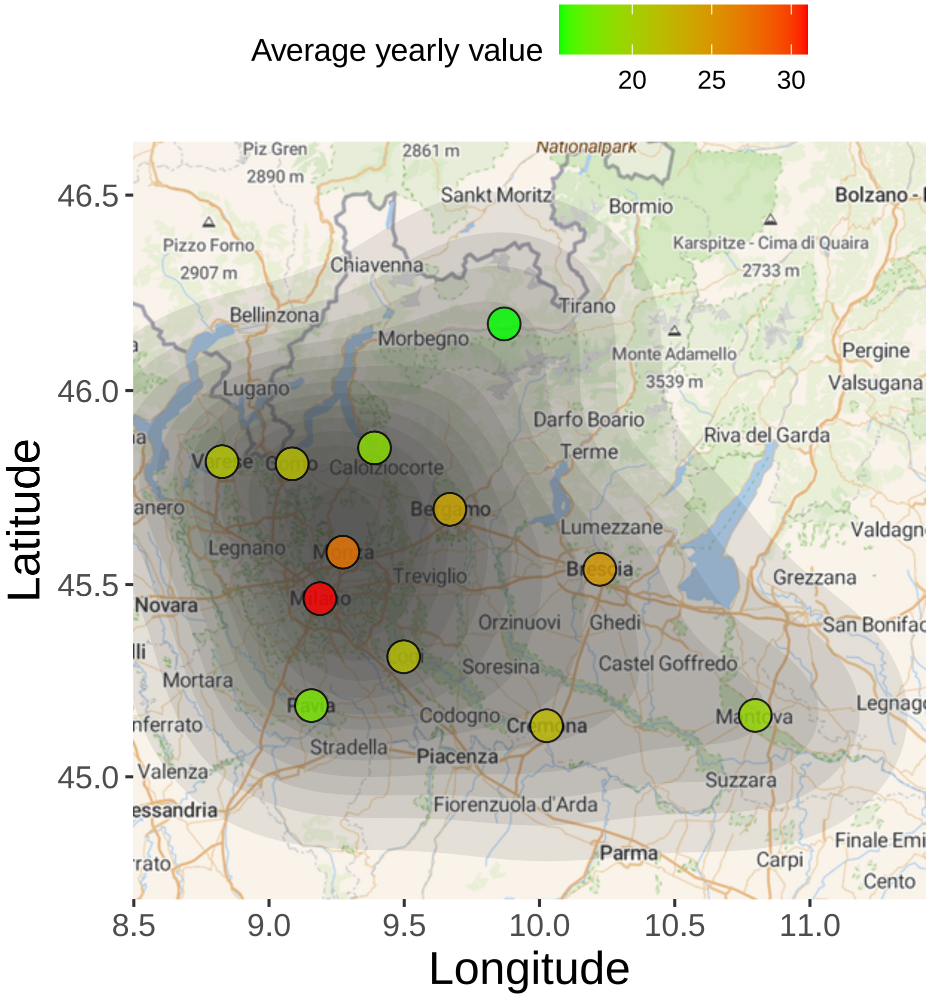

Figure 18: Annual Average NO2 by Zone

To obtain this second graph (Fig. 18) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.6 Sulfur dioxide (SO2)

The **hourly limit** value is 350 $\mu g/m^3$ as hourly average, and must not to be exceeded more than 24 times/year[6].
I counted for each zone the number of times that at least one station is above the limit.

```
# Calcolo del numero di volte over il limite per provincia
SO2OverLimit <- SO2 %>%
  filter(Valore > 350)%>%
  group_by(Provincia, Data) %>%
  group_by(Provincia) %>%
  summarize(TimesAbove350 = n())

nrow(SO2OverLimit)
```

This return the value 0, so no province has ever exceeded the hourly sulfur dioxide limit in the year 2023. As a check i also did

```
nrow(SO2[SO2$Valore> 350,])
```

but ended up obtaining 0 rows.
The **daily limit** is 125 $\mu g/m^3$ daily average, and must not to be exceeded more than 3 days/year[6].
I calculated the average daily value for each area and counted the number of times that value exceeded the limit imposed by law.

```
# Calcolo della media giornaliera per provincia
SO2DailyAverage <- SO2

# Convert the "Data" column to Date type
SO2DailyAverage$Data <- as.Date(SO2DailyAverage$Data)

# Group by "Provincia" and "Data", then calculate the daily
    average for each group
daily_avgs <- SO2DailyAverage %>%
  group_by(Provincia, Data) %>%
  summarise(DailyAvg = mean(Valore))

# Count the number of distinct days where the average value
    is greater than 125 for each "Provincia"
SO2distinct_days_count_per_province <- daily_avgs %>%
  filter(DailyAvg > 125) %>%
  group_by(Provincia) %>%
  summarise(DaysAbove125 = n_distinct(Data))

# Display the resulting data frame
nrow(SO2distinct_days_count_per_province)
```

This return the value 0, so no province has ever exceeded the daily sulfur dioxide limit in the year 2023. As a check i also did

```
SO2[SO2$Valore> 125,]
```

and ended up getting only 4 instances, so i assume my results about daily average for province were correct.
Even though there is **no annual limit**, i still have created two density maps that show the annual average, both by station and by province, in order to have a better view on the sulfur dioxide's level.

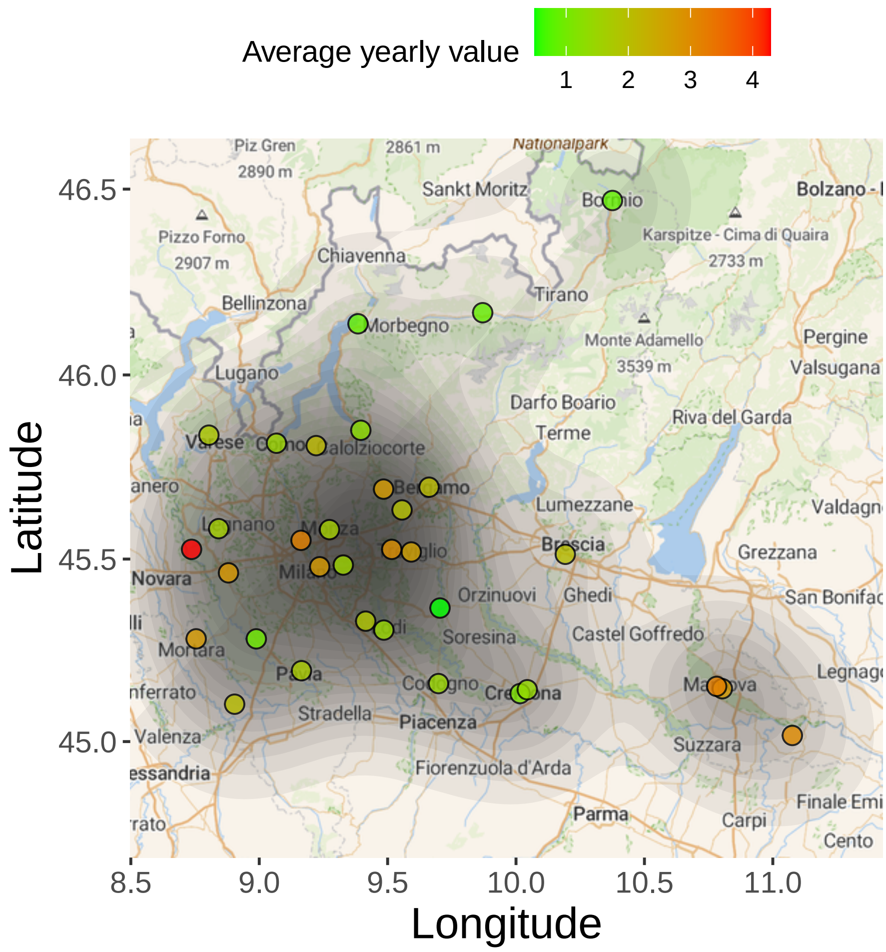

Figure 19: Annual Average SO2 by Station

The density plot (Fig. 19) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more

station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

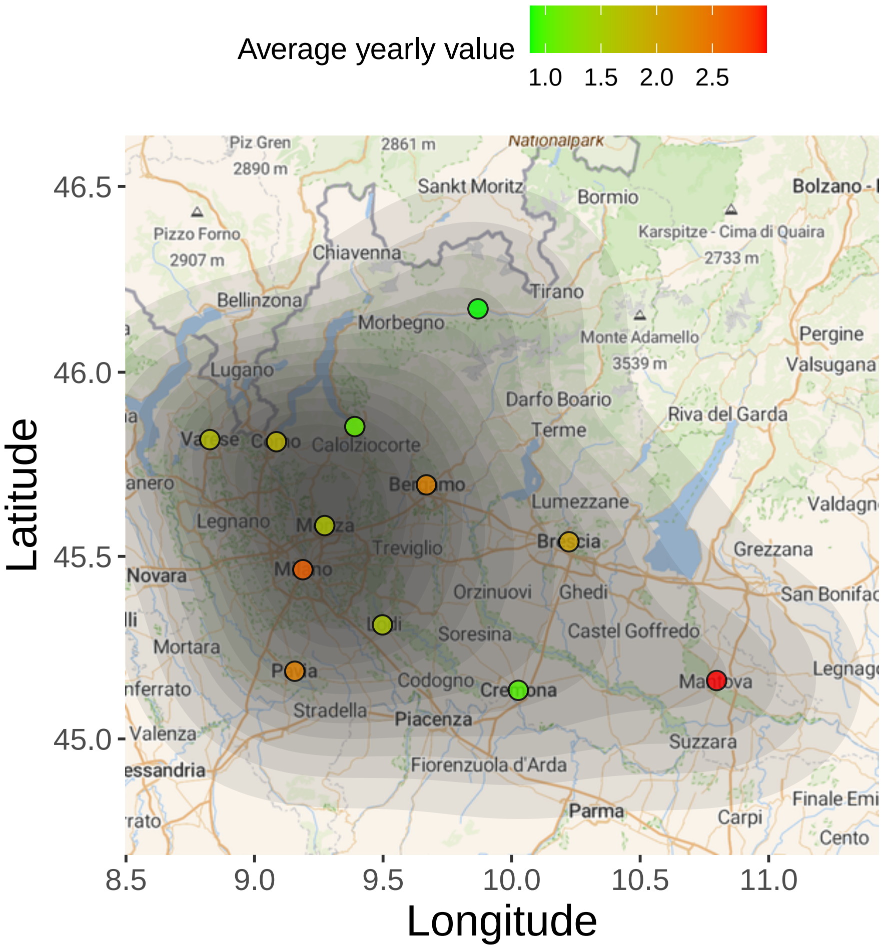

Figure 20: Annual Average SO2 by Zone

To obtain this second graph (Fig. 20) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.7 Ozone (O3)

The **limit value** is 120 $\mu g/m^3$ as 8h moving average, and must not to be exceeded more than 25 times/year[6].
I counted for each zone the number of times that at least one station is above the limit and show the results as a barplot (Fig. 21).

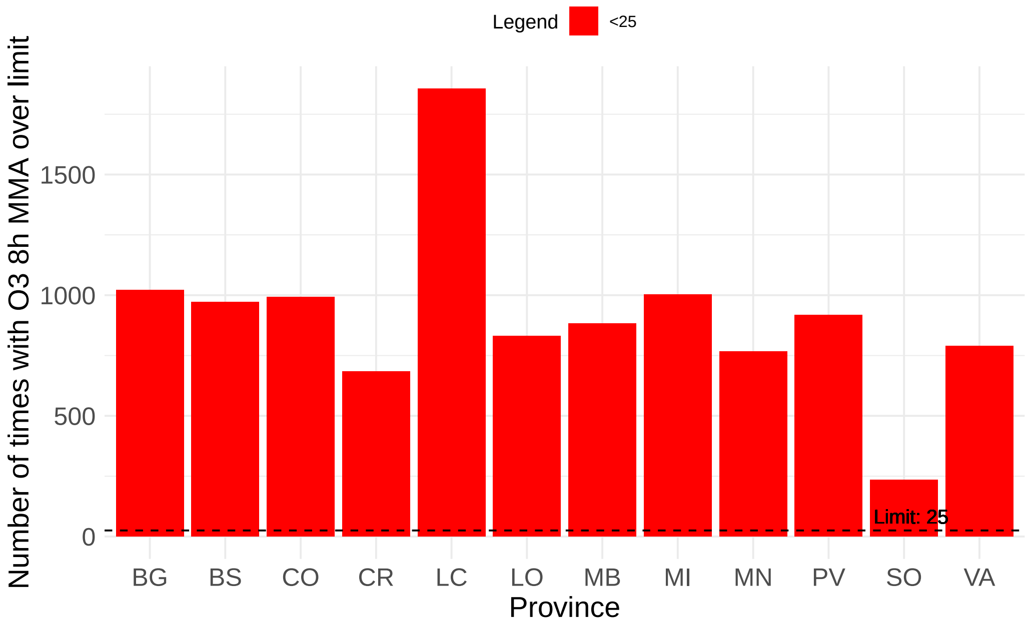

Figure 21: Number of times O3 is over limit

From the graph (Fig. 21) it is possible to notice that in every zone the ozone level is much higher than the limit allowed by law.
The worst zone is Lecco (LC) province, the best one is Sondrio (SO).

In order to have a better view on the ozone level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 22) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

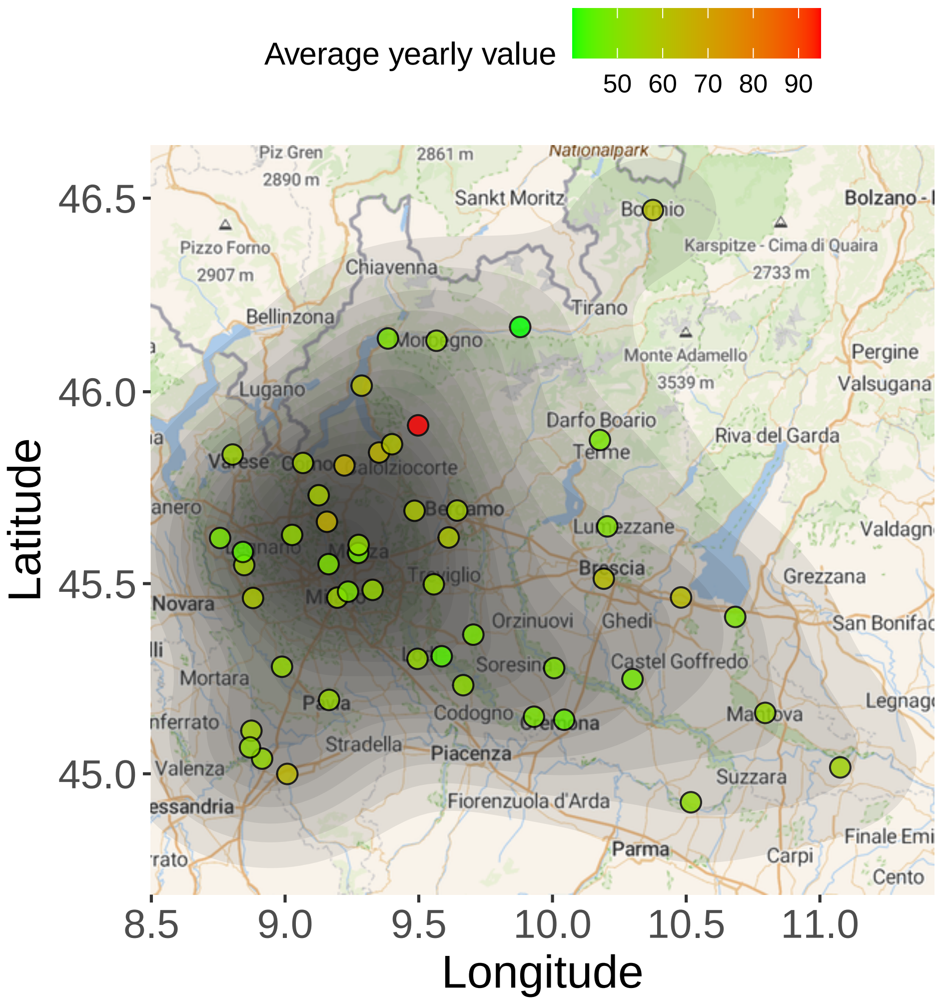

Figure 22: Annual Average O3 by Station

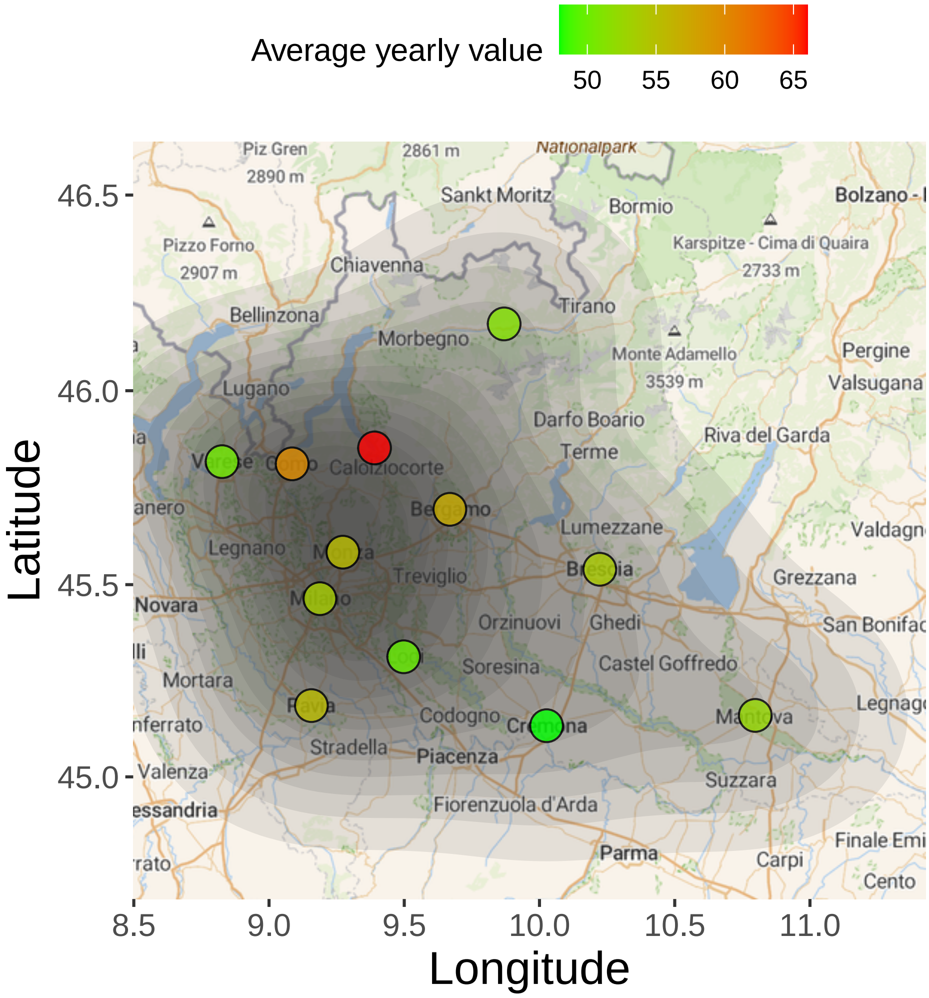

Figure 23: Annual Average O3 by Zone

To obtain this second graph (Fig. 23) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.8 Carbon oxide (CO)

For the carbon oxide is given the 8h moving average on the previous 8 hours. The **daily limit** value is 10000 $\mu g/m^3$ as 8h moving average[9].
I calculated the average daily value for each area and counted the number of times that value exceeded the limit imposed by law.

```
# Calcolo del numero di volte over il limite per provincia
COOverLimit <- CO %>%
  filter(Valore > 10) %>%
  distinct(Provincia, Data) %>%
  group_by(Provincia) %>%
  summarize(TimesAbove10 = n())

nrow(COOverLimit)
```

This return the value 0, so no province has ever exceeded the carbon oxide limit in the year 2023. As a check i also did

```
nrow(CO[CO$Valore> 10,])
```

but ended up obtaining 0 rows.

3.2.9 Benzene (C6H6)

For the benzene is given the 24h moving average on the previous 24 hours.
Looking at the "Measured substances for zone graph" (fig. 6), we can see that for 2 zones (MB, VA) there are no detections for benzene, therefore they will not be shown in the subsequent graphs.
The **annual limit** is 5 $\mu g/m^3$ as annual average[6], i calculated the annual average for each station, then i summarized them by area by averaging the stations in each area, finally i checked which zones exceeded the value established by law, i used a barplot to show the obtained results.

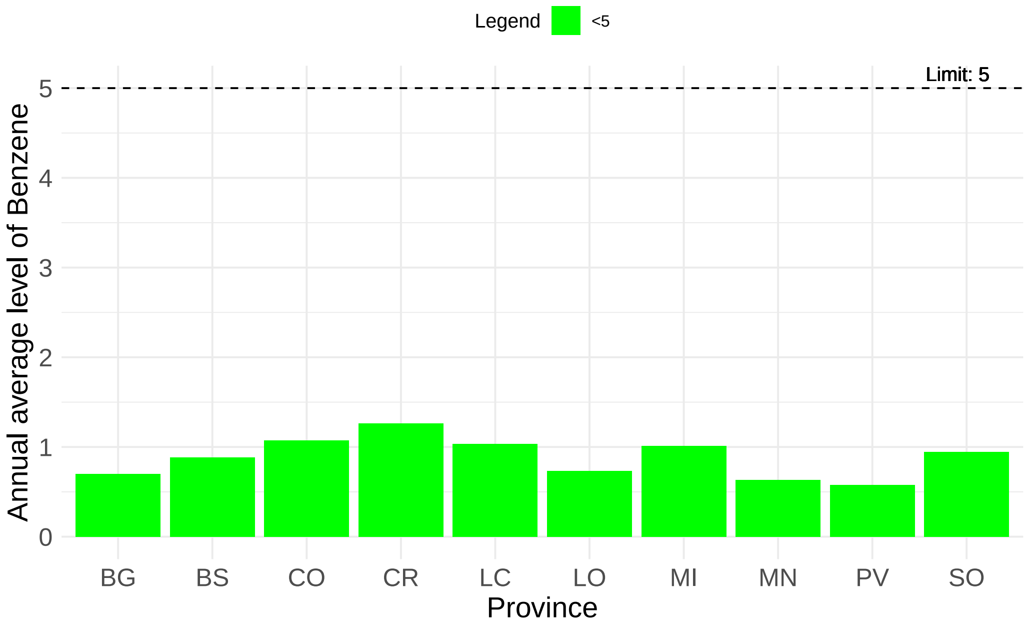

Figure 24: Compliance with the yearly limit per zone

From the graph (Fig. 24) we can see that in each zone the yearly average benzene limit established by law has been respected.
The area with the highest average value is the Cremona (CR) province, the one with the lowest value is Pavia (PV).

In order to have a better view on the benzene's level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 25) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

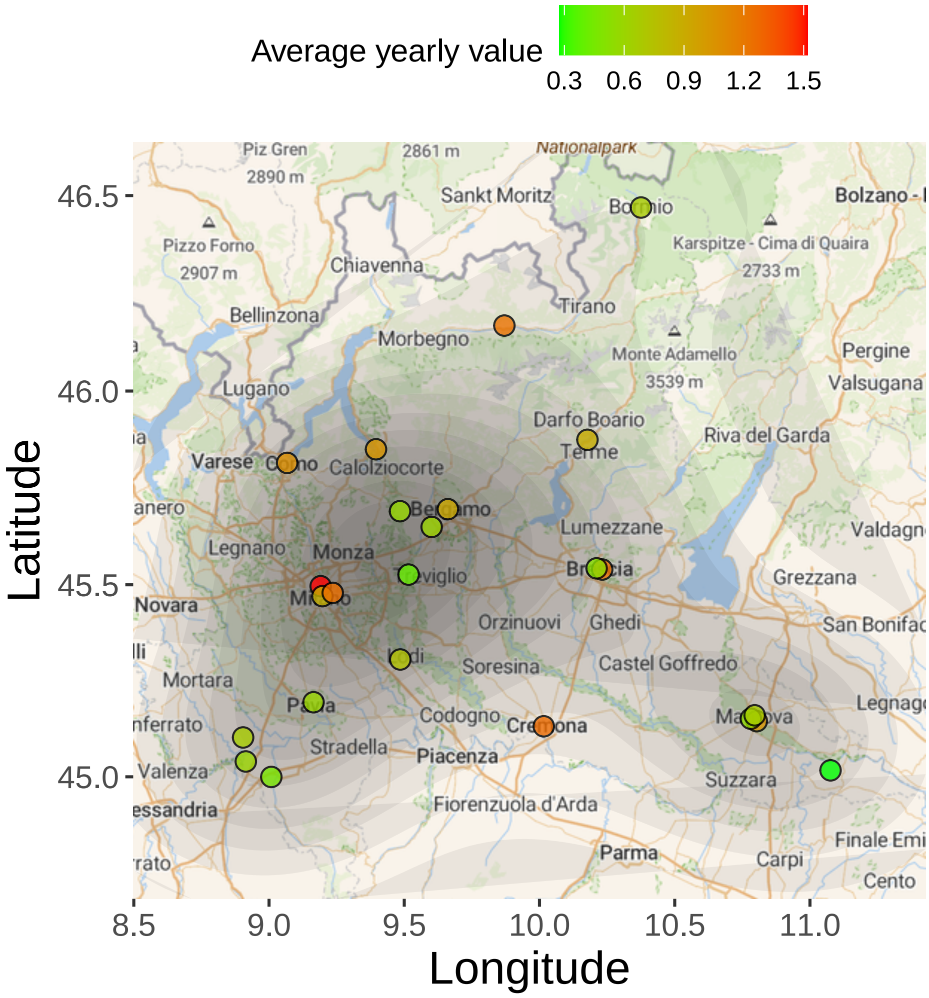

Figure 25: Annual Average C6H6 by Station

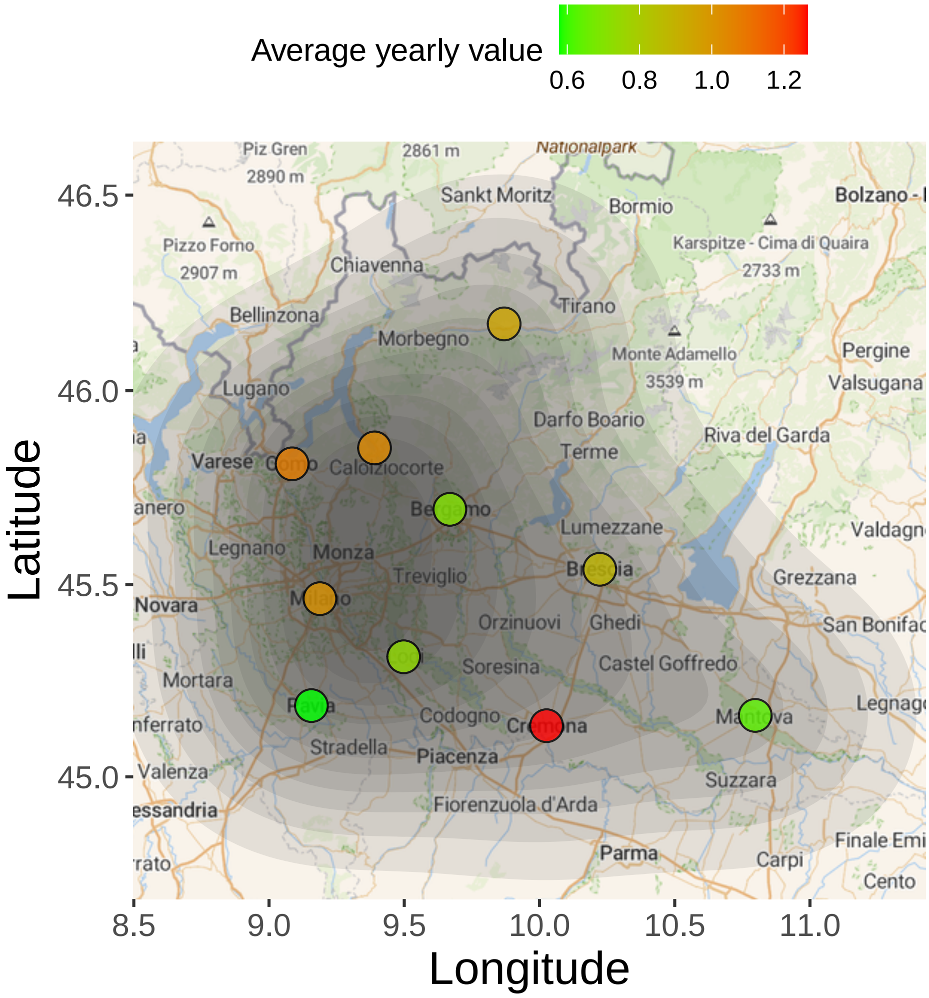

Figure 26: Annual Average C6H6 by Zone

To obtain this second graph (Fig. 26) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.10 Ammonia (NH3)

Looking at the “Measured substances for zone graph” (fig. 6), , we can see that for 5 zones (BS, CO, MB, SO, VA) there are no detections for this substance, therefore they will not be shown in the subsequent graphs.
For ammonia ther is **no limit** estabilished by law, but it’s still present in the air (concentration in urban area: 20 $\mu g/m^3$), i will use this value as if it were the limit[10].

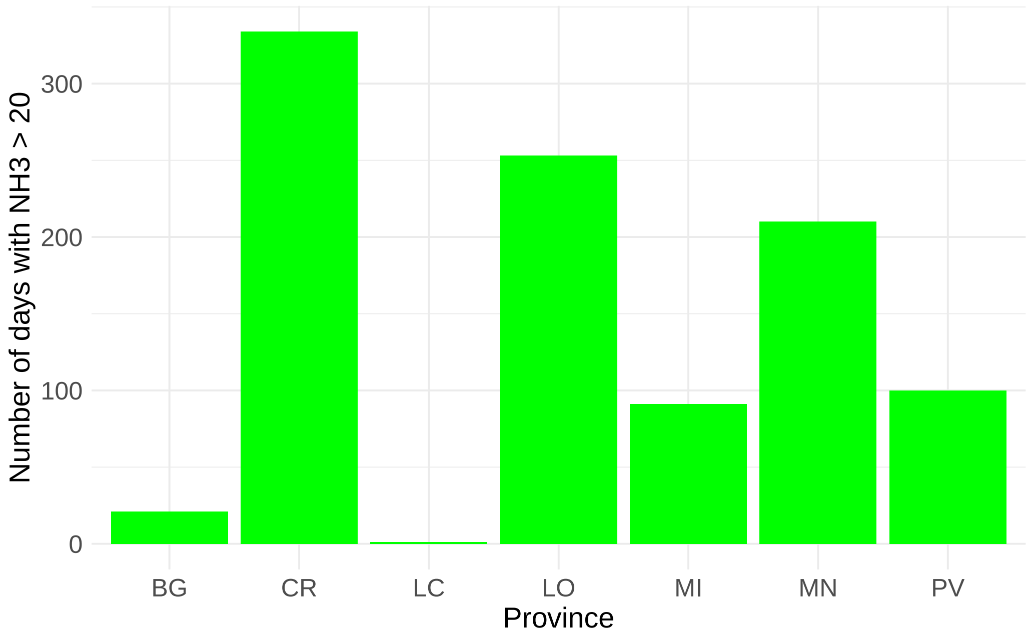

Figure 27: Compliance with the daily limit per zone

In order to have a better view on the ammonia's level, i also plotted two density maps to see which zones are more polluted.
The point's scale color is correct, but the density plot (Fig. 28) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.
The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

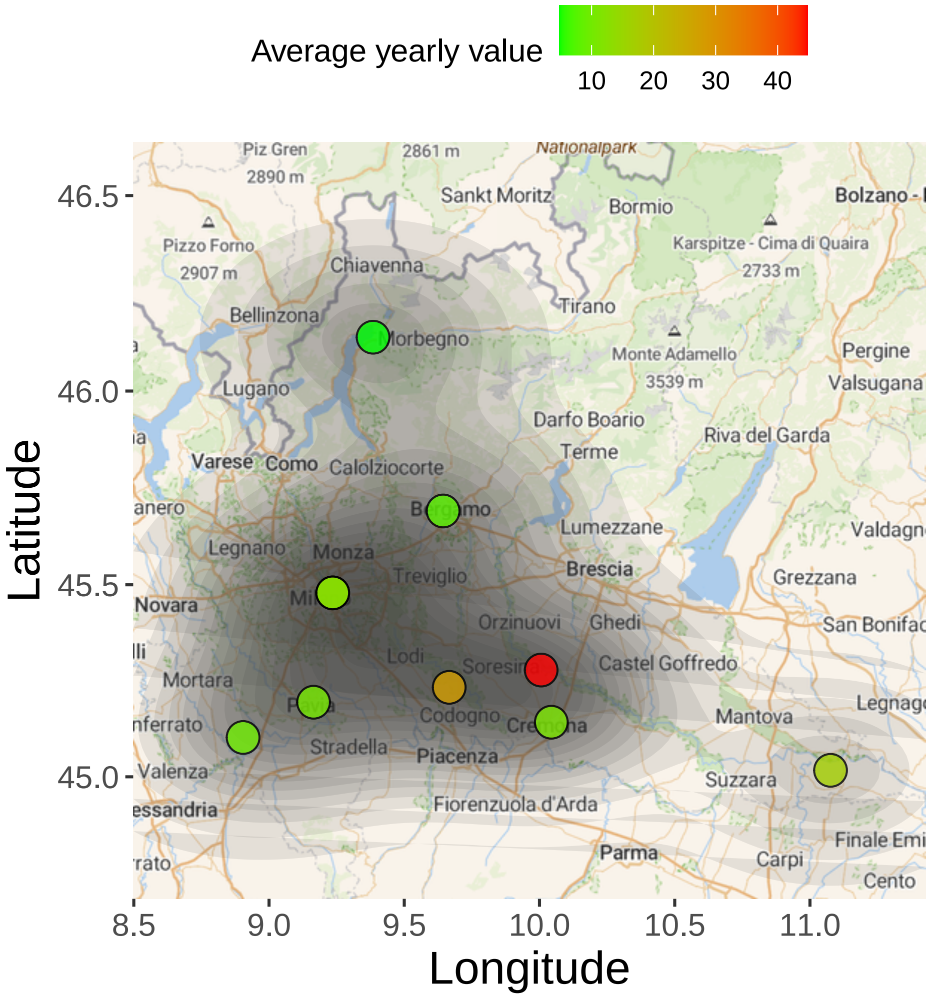

Figure 28: Annual Average NH3 by Station

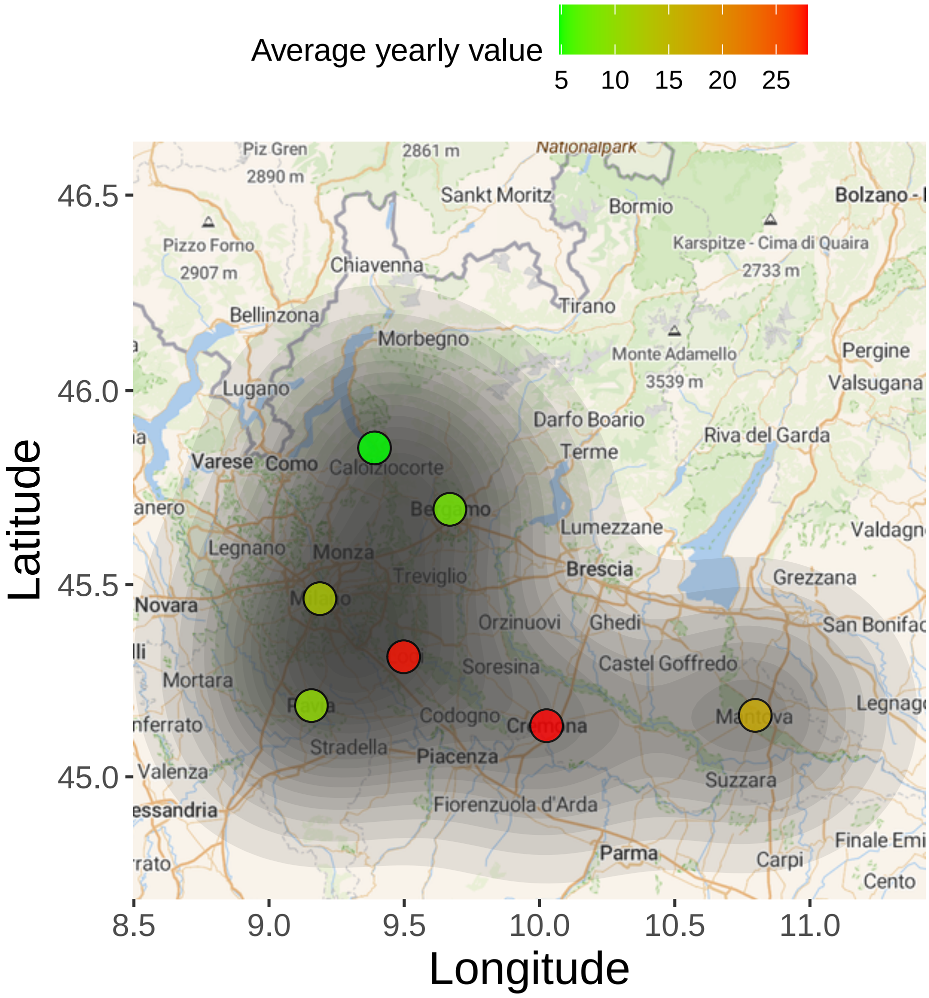

Figure 29: Annual Average NH3 by Zone

To obtain this second graph (Fig. 29) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.11 Nitrogen oxides (NOX)

For nitrogen oxides i didn't find a limit established by law, so i simply plotted two density maps showing the average yearly value for every station and the average yearly value for every zone, in order to see which zones have the higher concentration.

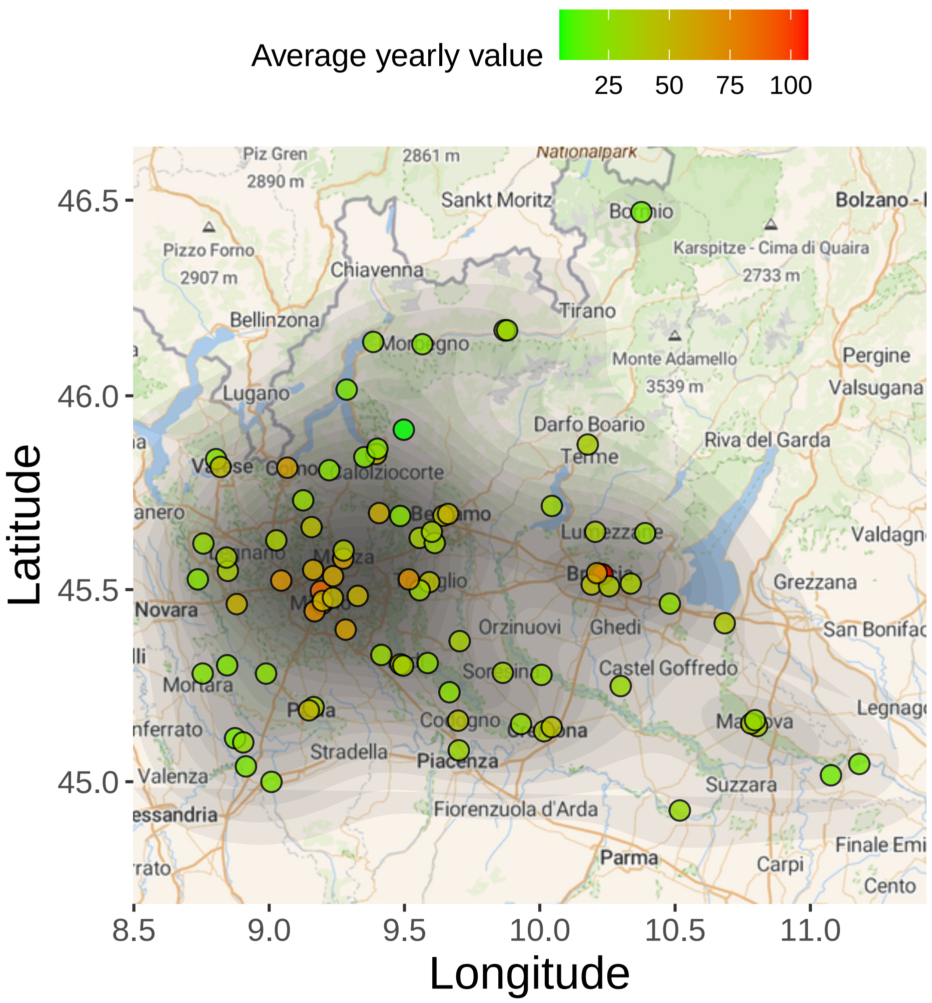

Figure 30: Annual Average NOX by station

The point's scale color is correct, but the density plot (Fig. 30) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.

The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

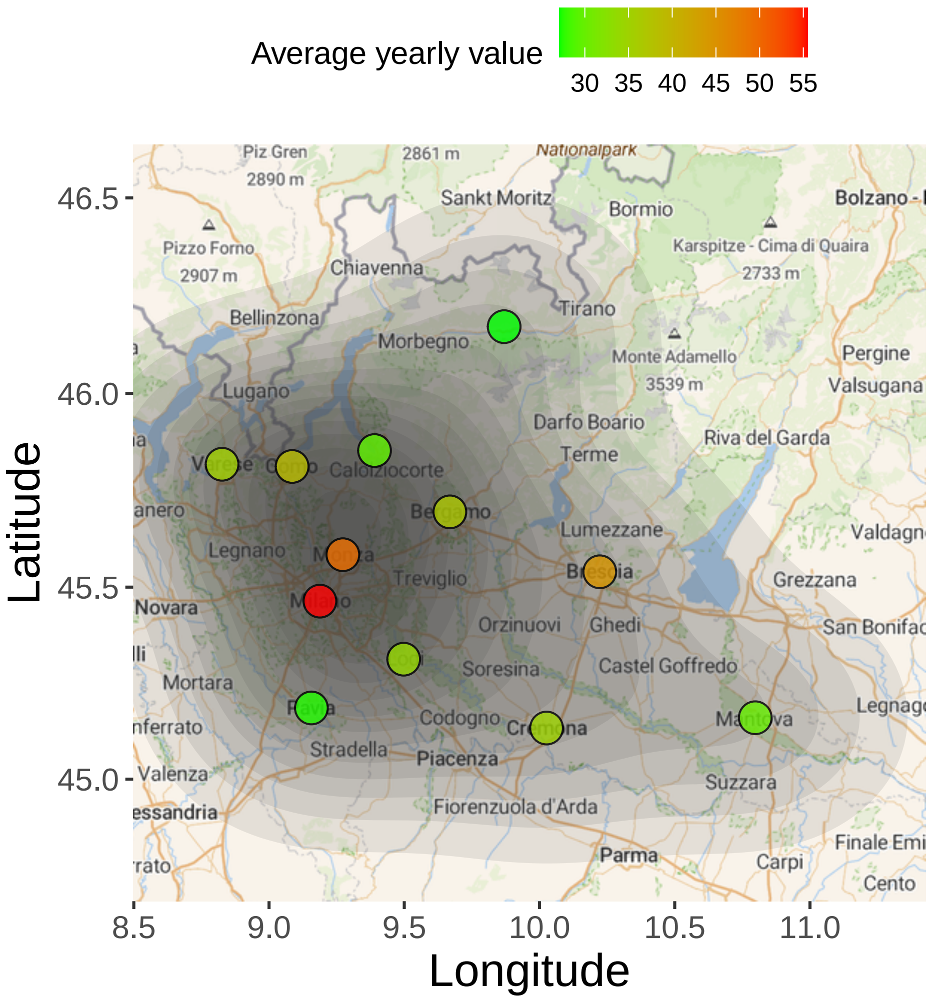

Figure 31: Annual Average NOX by Zone

To obtain this second graph (Fig. 31) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.2.12 Nitric oxide (NO)

For nitric oxides i didn't find a limit established by law, so i simply plotted two density maps showing the average yearly value for every station and the average yearly value for every zone, in order to see which zones have the higher concentration.

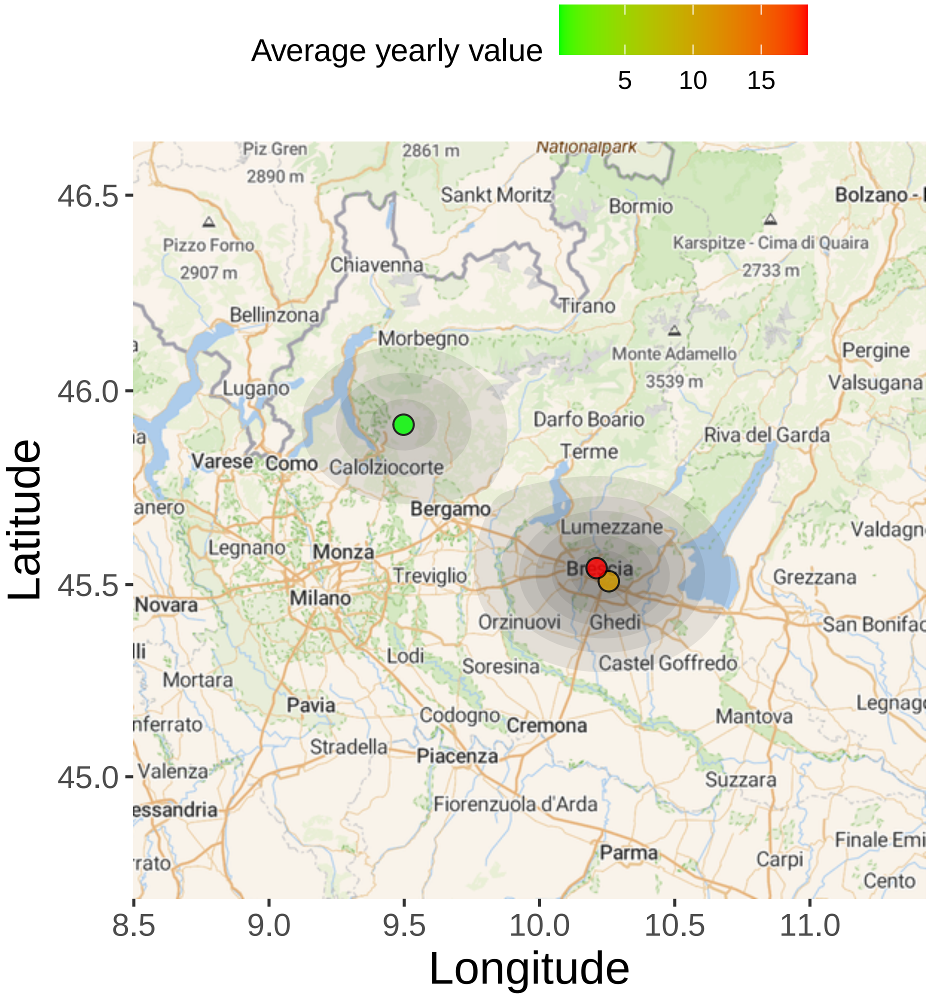

Figure 32: Annual Average NO by station

The point's scale color is correct, but the density plot (Fig. 32) is a little biased by the number of the monitoring station located in the area: there are darker zones where there are more station.

The graphs are still correct because we have darker zones where the values are higher, in both cases.
The color scale is only used to understand the concentration level of the substance in the air, it does not provide information on whether or not the limit imposed by law is respected.

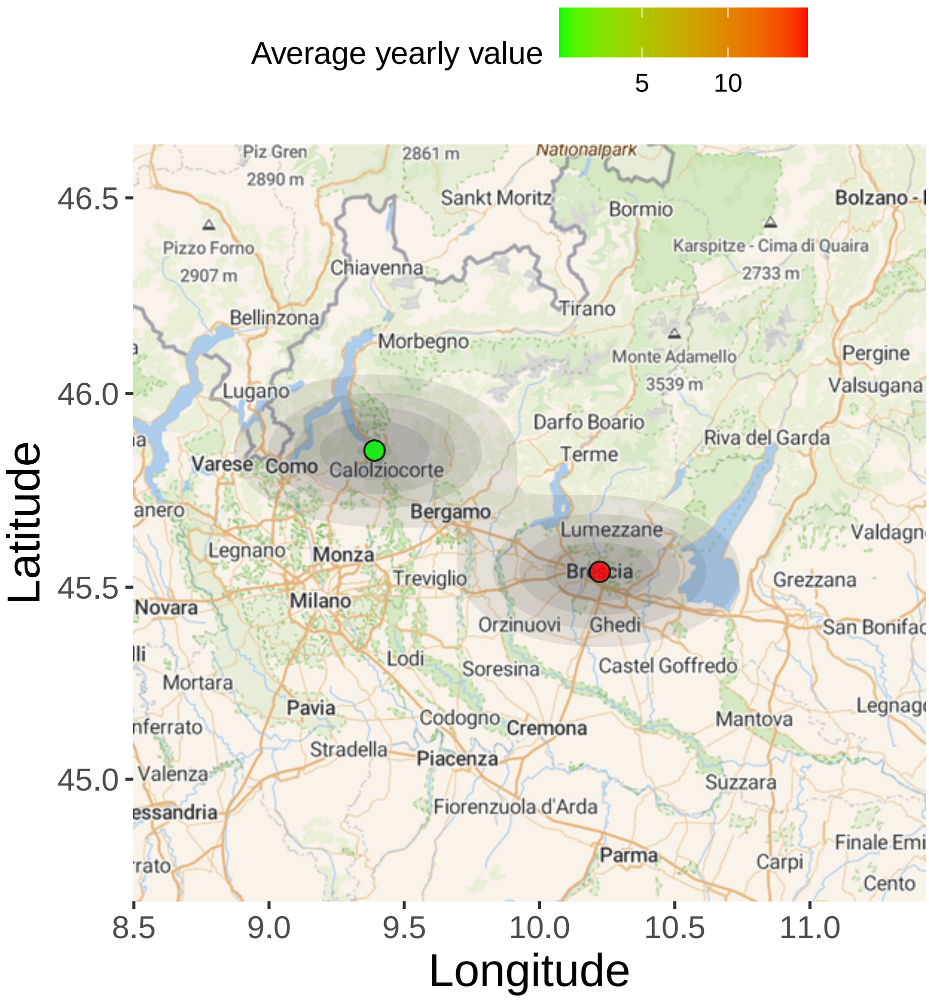

Figure 33: Annual Average NO by Zone

To obtain this second graph (Fig. 33) i only calculated the average between stations located in the same zone. The first graph shows the annual average for each station, in this one the values has been summarized for each area. The colors and values reflect those visible in the previous graph.

3.3 Analysis by Zone

I divided the data by area, for each area i created a graph that shows the trends of each substance during the months of 2023 and also a correlation matrix showing the correlation between each substance.

3.3.1 Brescia (BS)

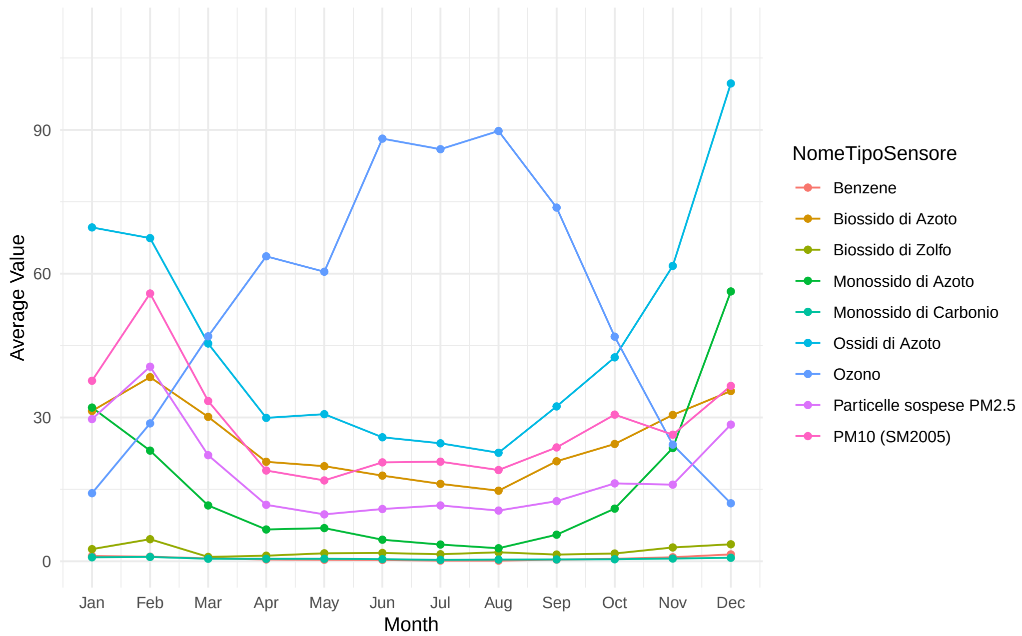

Figure 34: Brescia Trend in 2023

	C6H6	NO2	SO2	NO	CO	NOX	O3	PM10	PM2.5
C6H6	1	0.92	0.73	0.96	0.86	0.99	-0.95	0.74	0.82
NO2	0.92	1	0.74	0.8	0.88	0.90	-0.92	0.89	0.91
SO2	0.73	0.74	1	0.70	0.79	0.75	-0.64	0.77	0.79
NO	0.96	0.80	0.70	1	0.74	0.98	-0.86	0.60	0.70
CO	0.86	0.88	0.79	0.74	1	0.81	-0.84	0.83	0.90
NOX	0.99	0.90	0.75	0.98	0.81	1	-0.92	0.72	0.80
O3	-0.95	-0.92	-0.64	-0.86	-0.84	-0.92	1	-0.71	-0.77
PM10	0.74	0.89	0.77	0.60	0.83	0.72	-0.71	1	0.98
PM2.5	0.82	0.91	0.79	0.70	0.90	0.80	-0.77	0.98	1

Table 4: Correlation Matrix BS

3.3.2 Bergamo (BG)

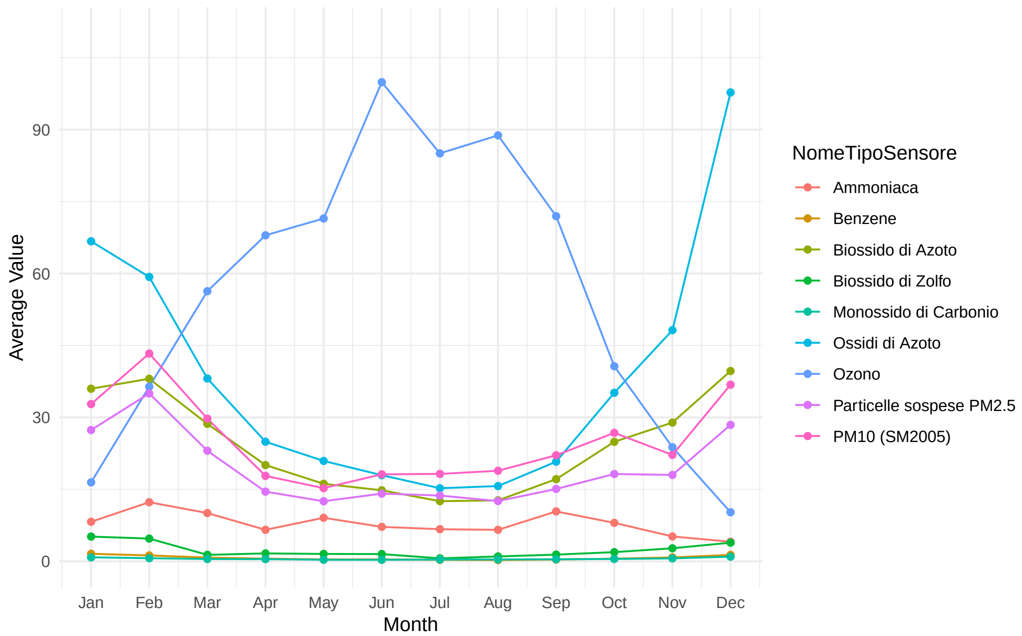

Figure 35: Bergamo Trend in 2023

	NH3	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NH3	1	0.03	0.07	0.12	-0.24	-0.19	0.12	0.31	0.30
C6H6	0.03	1	0.95	0.95	0.92	0.92	-0.87	0.85	0.90
NO2	0.07	0.95	1	0.89	0.90	0.94	-0.92	0.91	0.93
SO2	0.12	0.95	0.89	1	0.85	0.84	-0.81	0.82	0.87
CO	-0.24	0.92	0.90	0.85	1	0.97	-0.91	0.78	0.79
NOX	-0.19	0.92	0.94	0.84	0.97	1	-0.90	0.82	0.84
O3	0.12	-0.87	-0.92	-0.81	-0.91	-0.90	1	-0.73	-0.75
PM10	0.31	0.85	0.91	0.82	0.78	0.82	-0.73	1	0.98
PM2.5	0.30	0.90	0.93	0.87	0.79	0.84	-0.75	0.98	1

Table 5: Correlation Matrix BG

3.3.3 Como (CO)

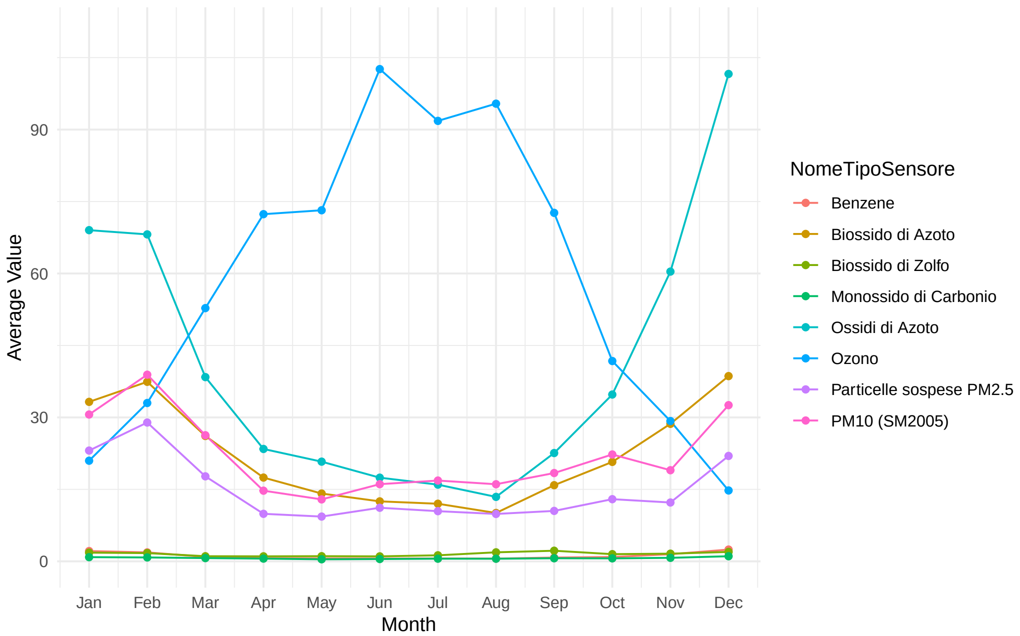

Figure 36: Como Trend in 2023

	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
C6H6	1	0.95	0.52	0.96	0.98	-0.89	0.85	0.84
NO2	0.95	1	0.36	0.91	0.96	-0.93	0.90	0.89
SO2	0.52	0.36	1	0.59	0.44	-0.40	0.42	0.34
CO	0.96	0.91	0.59	1	0.96	-0.86	0.84	0.79
NOX	0.98	0.96	0.44	0.96	1	-0.91	0.82	0.80
O3	-0.89	-0.93	-0.40	-0.86	-0.91	1	-0.76	-0.73
PM10	0.85	0.90	0.42	0.84	0.82	-0.76	1	0.98
PM2.5	0.84	0.89	0.34	0.79	0.80	-0.73	0.98	1

Table 6: Correlation Matrix CO

3.3.4 Cremona (CR)

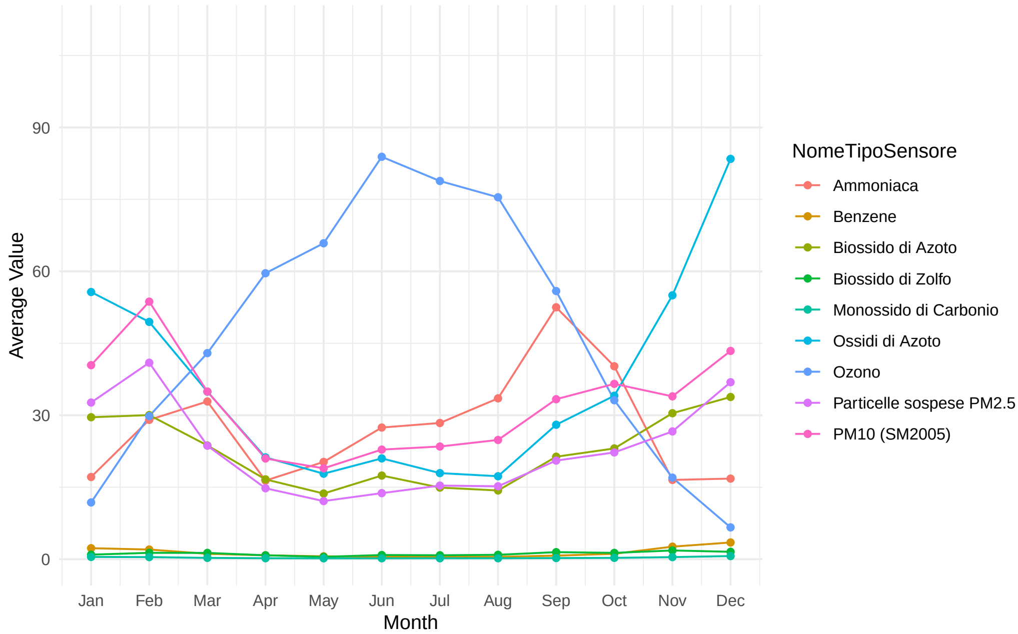

Figure 37: Cremona Trend in 2023

	NH3	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NH3	1	-0.48	-0.24	0.18	-0.41	-0.38	0.31	0.06	-0.18
C6H6	-0.48	1	0.94	0.65	0.99	0.99	-0.92	0.72	0.85
NO2	-0.24	0.94	1	0.77	0.94	0.95	-0.94	0.88	0.93
SO2	0.18	0.65	0.77	1	0.62	0.67	-0.67	0.66	0.62
CO	-0.41	0.99	0.94	0.62	1	0.99	-0.90	0.79	0.90
NOX	-0.38	0.99	0.95	0.67	0.99	1	-0.92	0.77	0.88
O3	0.31	-0.92	-0.94	-0.67	-0.90	-0.92	1	-0.79	-0.85
PM10	0.06	0.72	0.88	0.66	0.79	0.77	-0.79	1	0.97
PM2.5	-0.18	0.85	0.93	0.62	0.90	0.88	-0.85	0.97	1

Table 7: Correlation Matrix CR

3.3.5 Lecco (LC)

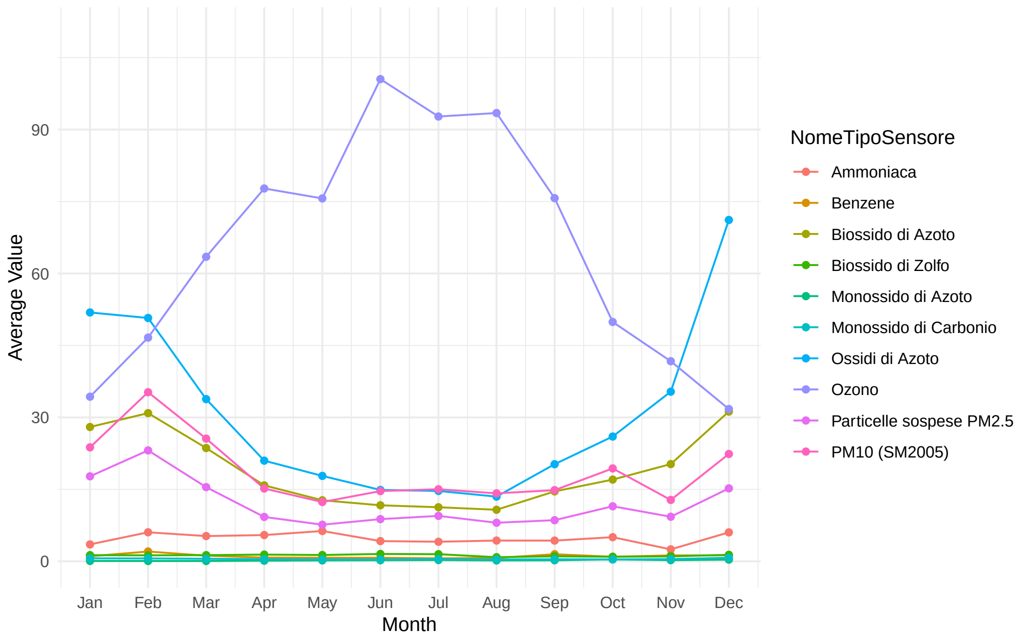

Figure 38: Lecco Trend in 2023

	NH3	C6H6	NO2	SO2	NO	CO	NOX	O3	PM10	PM2.5
NH3	1	0.18	0.22	0.25	-0.05	0.23	0.20	-0.03	0.38	0.28
C6H6	0.18	1	0.71	-0.20	-0.27	0.54	0.60	-0.58	0.74	0.73
NO2	0.22	0.72	1	0.07	-0.24	0.92	0.96	-0.87	0.82	0.89
SO2	0.25	-0.20	0.07	1	-0.18	0.26	0.09	0.20	0.09	0.12
NO	-0.05	-0.27	-0.24	-0.18	1	-0.15	-0.04	-0.04	-0.41	-0.42
CO	0.23	0.54	0.92	0.26	-0.15	1	0.95	-0.74	0.69	0.78
NOX	0.20	0.60	0.96	0.09	-0.04	0.95	1	-0.88	0.68	0.77
O3	-0.03	-0.58	-0.87	0.20	-0.04	-0.74	-0.88	1	-0.55	-0.65
PM10	0.38	0.74	0.82	0.09	-0.41	0.69	0.68	-0.55	1	0.98
PM2.5	0.28	0.73	0.89	0.12	-0.42	0.78	0.77	-0.65	0.98	1

Table 8: Correlation Matrix LC

3.3.6 Lodi (LO)

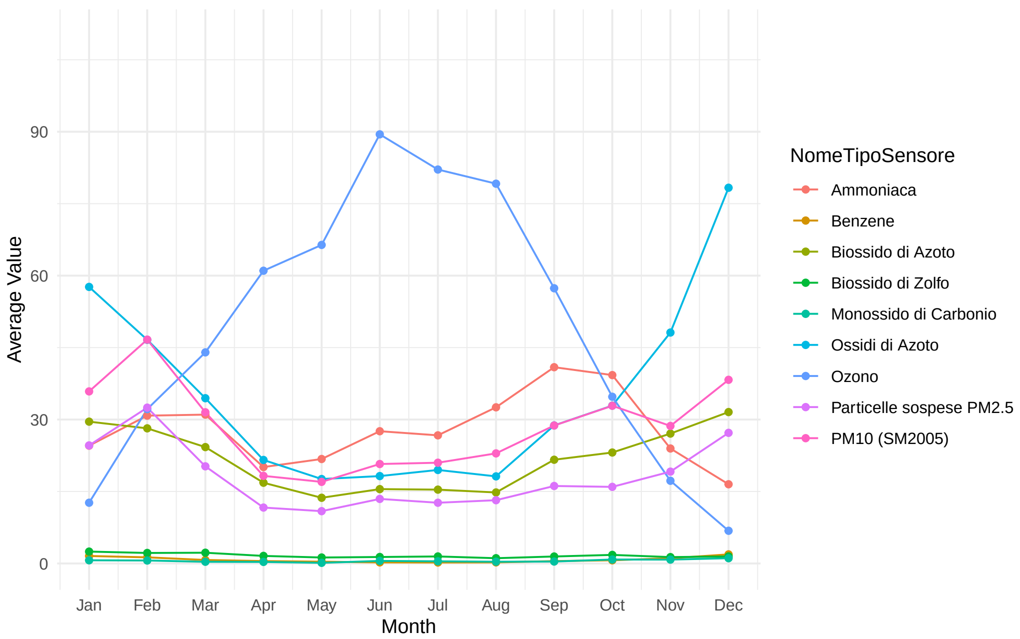

Figure 39: Lodi Trend in 2023

	NH3	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NH3	1	-0.38	-0.10	0.11	-0.15	-0.35	0.22	0.16	-0.09
C6H6	-0.38	1	0.94	0.51	0.75	0.98	-0.93	0.79	0.86
NO2	-0.10	0.94	1	0.60	0.77	0.94	-0.94	0.89	0.89
SO2	0.11	0.51	0.60	1	0.16	0.42	-0.52	0.66	0.64
CO	-0.15	0.75	0.77	0.16	1	0.82	-0.73	0.64	0.61
NOX	-0.35	0.98	0.94	0.42	0.82	1	-0.92	0.77	0.83
O3	0.22	-0.93	-0.94	-0.52	-0.73	-0.92	1	-0.76	-0.76
PM10	0.16	0.79	0.89	0.66	0.64	0.77	-0.76	1	0.96
PM2.5	-0.09	0.86	0.89	0.64	0.61	0.83	-0.76	0.96	1

Table 9: Correlation Matrix LO

3.3.7 Monza-Brianza (MB)

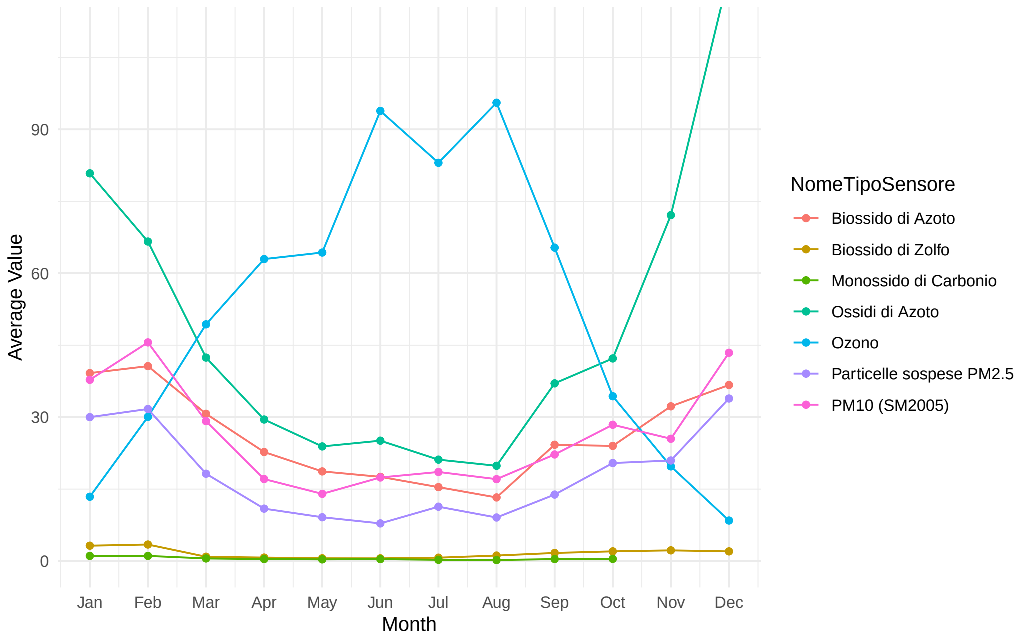

Figure 40: Monza-Brianza Trend in 2023

	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NO2	1	0.83	-	0.84	-0.9	0.91	0.93
SO2	0.83	1	-	0.68	-0.76	0.84	0.86
CO	-	-	1	-	-	-	-
NOX	0.84	0.68	-	1	-0.88	0.85	0.91
O3	-0.9	-0.76	-	-0.88	1	-0.81	-0.9
PM10	0.91	0.84	-	0.85	-0.81	1	0.98
PM2.5	0.93	0.86	-	0.91	-0.9	0.98	1

Table 10: Correlation Matrix MB

3.3.8 Milano (MI)

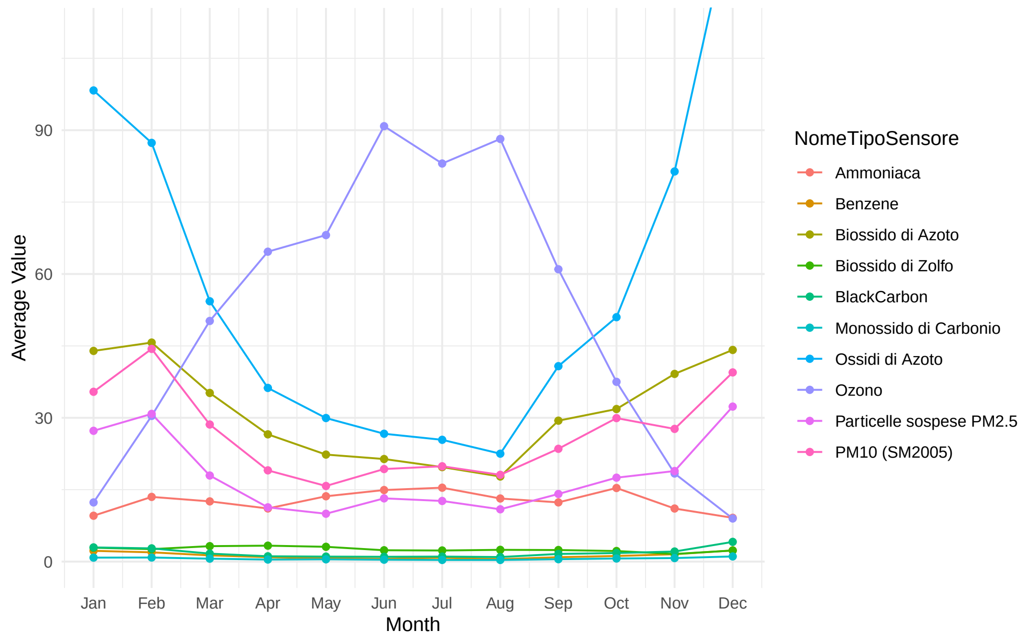

Figure 41: Milano Trend in 2023

	NH3	C6H6	NO2	SO2	BC	CO	NOX	O3	PM10	PM2.5
NH3	1	-0.68	-0.62	-0.12	-0.67	-0.63	-0.72	0.67	-0.41	-0.53
C6H6	-0.68	1	0.96	-0.09	0.96	0.96	0.97	-0.93	0.91	0.96
NO2	-0.62	0.96	1	-0.1	0.9	0.94	0.92	-0.94	0.93	0.92
SO2	-0.12	-0.09	-0.1	1	-0.19	-0.18	-0.2	0.2	-0.15	-0.15
BC	-0.67	0.96	0.9	-0.19	1	0.97	0.99	-0.89	0.89	0.96
CO	-0.63	0.96	0.94	-0.18	0.97	1	0.98	-0.94	0.91	0.94
NOX	-0.72	0.97	0.92	-0.2	0.99	0.98	1	-0.92	0.87	0.94
O3	0.67	-0.93	-0.94	0.2	-0.89	-0.94	-0.92	1	-0.83	-0.84
PM10	-0.41	0.91	0.93	-0.15	0.89	0.91	0.87	-0.83	1	0.97
PM2.5	-0.53	0.96	0.92	-0.15	0.96	0.94	0.94	-0.84	0.97	1

Table 11: Correlation Matrix MI

3.3.9 Mantova (MN)

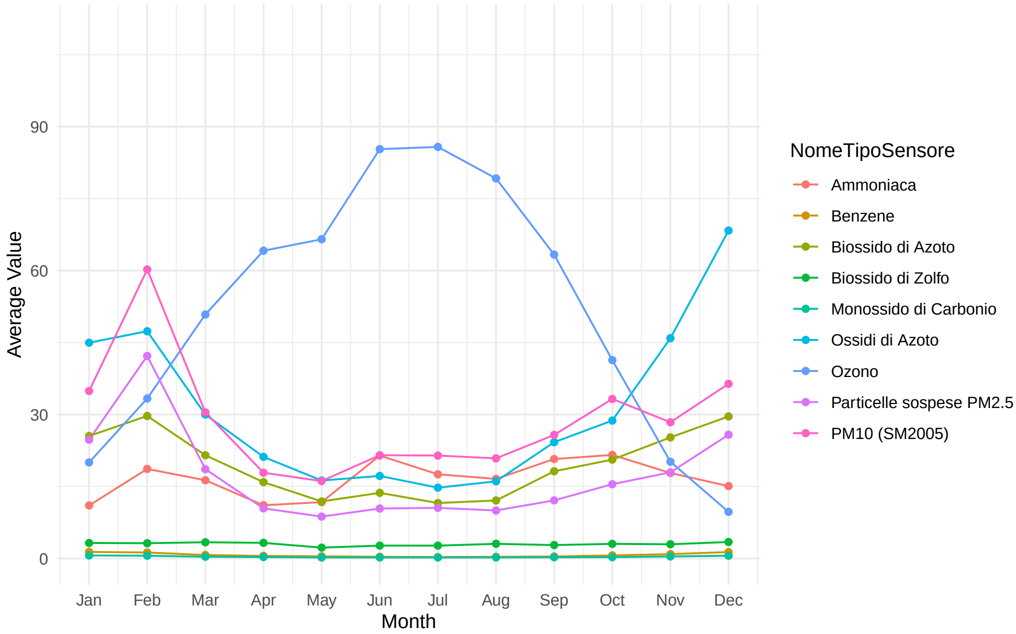

Figure 42: Mantova Trend in 2023

	NH3	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NH3	1	-0.28	0	-0.14	-0.3	-0.11	0.19	0.22	0.02
C6H6	-0.28	1	0.93	0.63	0.99	0.93	-0.92	0.76	0.85
NO2	0	0.93	1	0.68	0.92	0.94	-0.93	0.83	0.87
SO2	-0.14	0.63	0.68	1	0.66	0.63	-0.59	0.51	0.54
CO	-0.3	0.99	0.92	0.66	1	0.9	-0.88	0.76	0.86
NOX	-0.11	0.93	0.94	0.63	0.9	1	-0.94	0.69	0.77
O3	0.19	-0.92	-0.93	-0.59	-0.88	-0.94	1	-0.63	-0.7
PM10	0.22	0.76	0.83	0.51	0.76	0.69	-0.63	1	0.97
PM2.5	0.02	0.85	0.87	0.54	0.86	0.77	-0.7	0.97	1

Table 12: Correlation Matrix MN

3.3.10 Pavia (PV)

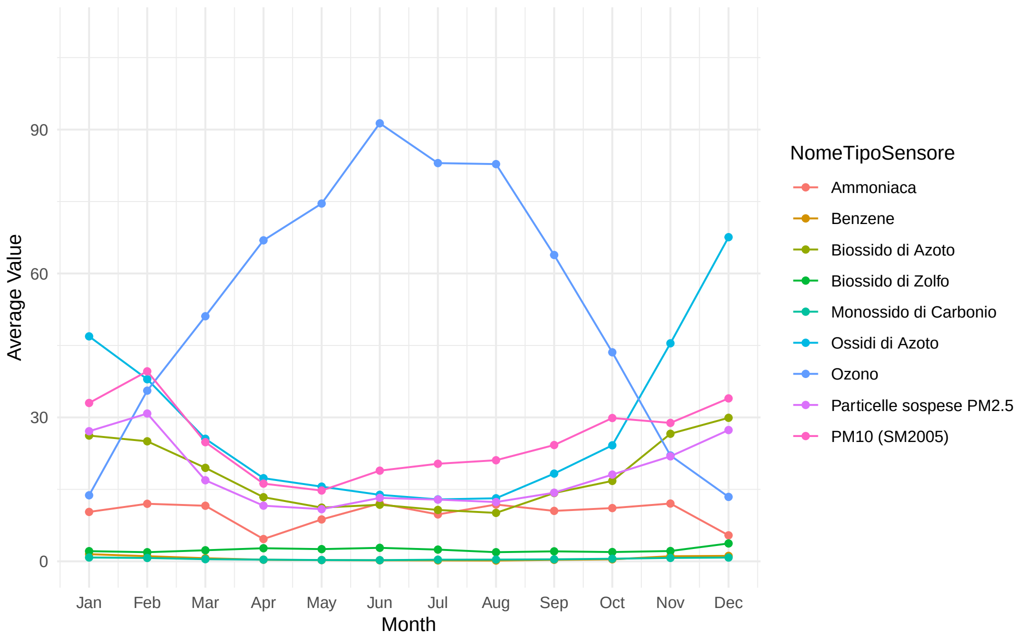

Figure 43: Pavia Trend in 2023

	NH3	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NH3	1	-0.02	-0.07	-0.72	-0.02	-0.23	0.11	0.21	0.07
C6H6	-0.02	1	0.95	0.07	0.94	0.9	-0.93	0.81	0.92
NO2	-0.07	0.95	1	0.19	0.96	0.96	-0.96	0.85	0.92
SO2	-0.72	0.07	0.19	1	0.03	0.38	-0.09	-0.13	0.03
CO	-0.02	0.94	0.96	0.03	1	0.92	-0.97	0.9	0.94
NOX	-0.23	0.9	0.96	0.38	0.92	1	-0.93	0.77	0.86
O3	0.11	-0.93	-0.96	-0.09	-0.97	-0.93	1	-0.82	-0.87
PM10	0.21	0.81	0.85	-0.13	0.9	0.77	-0.82	1	0.96
PM2.5	0.07	0.92	0.92	0.03	0.94	0.86	-0.87	0.96	1

Table 13: Correlation Matrix PV

3.3.11 Sondrio (SO)

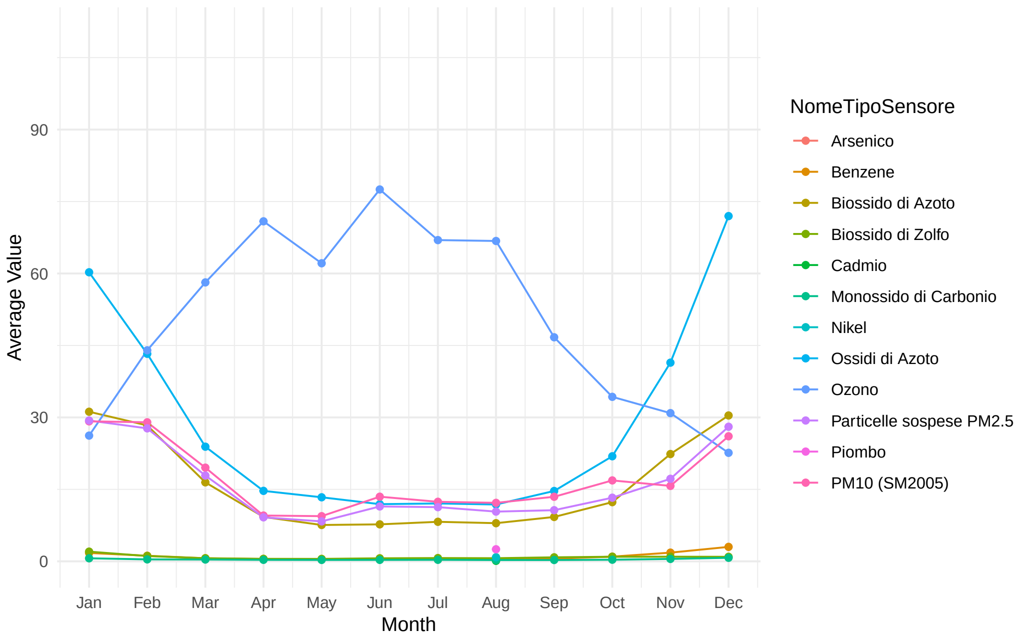

Figure 44: Sondrio Trend in 2023

	C6H6	NO2	SO2	CO	NOX	O3	PM10	PM2.5
C6H6	1	0.86	0.54	0.96	0.95	-0.86	0.7	0.79
NO2	0.86	1	0.75	0.89	0.96	-0.81	0.93	0.98
SO2	0.54	0.75	1	0.65	0.7	-0.71	0.77	0.76
CO	0.96	0.89	0.65	1	0.97	-0.79	0.76	0.85
NOX	0.95	0.96	0.7	0.97	1	-0.84	0.86	0.93
O3	-0.86	-0.81	-0.71	-0.79	-0.84	1	-0.71	-0.73
PM10	0.7	0.93	0.77	0.76	0.86	-0.71	1	0.98
PM2.5	0.79	0.98	0.76	0.85	0.93	-0.73	0.98	1

Table 14: Correlation Matrix SO

3.3.12 Varese (VA)

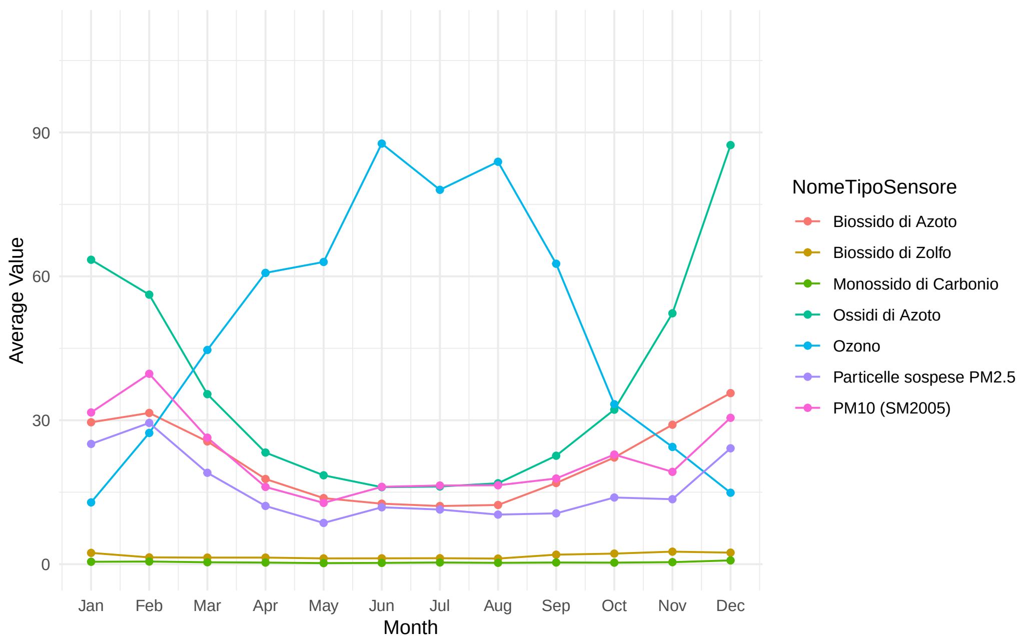

Figure 45: Varese Trend in 2023

	NO2	SO2	CO	NOX	O3	PM10	PM2.5
NO2	1	0.69	0.87	0.95	-0.95	0.84	0.85
SO2	0.69	1	0.56	0.71	-0.79	0.35	0.34
CO	0.87	0.56	1	0.94	-0.75	0.77	0.82
NOX	0.95	0.71	0.94	1	-0.9	0.78	0.83
O3	-0.95	-0.79	-0.75	-0.9	1	-0.76	-0.76
PM10	0.84	0.35	0.77	0.78	-0.76	1	0.98
PM2.5	0.85	0.34	0.82	0.83	-0.76	0.98	1

Table 15: Correlation Matrix VA

3.4 Air Quality Index

I calculated the monthly averages for each province and calculated the air quality index based on those, finally i added the monthly quality indices of each province to be able to compare the various scores on an annual basis.

Provincia	01	02	03	04	05	06	07	08	09	10	11	12	TOT
BG	4	4	3	2	2	2	2	2	2	2	2	4	35
BS	4	4	3	2	1	2	2	2	2	2	2	4	32
CO	3	4	2	1	1	2	2	2	2	2	2	3	28
CR	4	4	3	2	2	2	2	2	3	3	4	4	37
LC	2	3	2	1	1	2	2	2	1	2	1	2	21
LO	3	4	3	2	2	2	2	2	2	2	2	4	32
MB	4	4	2	2	1	2	2	2	2	3	3	4	33
MI	4	4	2	2	1	2	2	2	2	2	2	4	33
MN	3	4	2	2	1	2	2	1	2	2	2	4	29
PV	4	4	2	2	2	2	2	2	2	2	3	4	35
SO	4	4	2	1	1	2	2	2	2	2	2	4	30
VA	4	4	2	2	1	2	2	2	2	2	2	3	30
TOT	43	49	28	20	16	24	24	24	23	27	27	44	-

Table 16: AQI by month and zone (lower is better)

Air quality status legend:

1. Very good
2. Good
3. Acceptable

4. Poor
5. Very poor

Looking at the table containing the air quality indices for the different provinces it is possible to make several observations:

- May was the best 2023's month
- February was the worst 2023's month
- in the months with high temperatures (from April to September) the index has lower values -> the air quality is higher
- in the months with low temperatures (from October to March) the index has higher values -> the air quality is lower
- the zone with the lowest AQI total is Lecco (LC)
- the zone with the highest AQI total is Cremona (CR)

4 Conclusions

After carrying out an initial analysis by dividing the dataset into substances and comparing the different areas, i drew the following conclusions:

- the most polluted areas are those in the centre/south of the region, especially in the case of PM10, PM2.5, and nitrogen dioxide (NO2)
- for most substances the limits are respected, the most problematic ones are ozone (O3) and PM10. Also lead in the Sondrio province.

From a second analysis carried out by dividing the dataset into zones, i was able to observe the substances' trends in each individual province and subsequently calculate correlation matrices to understand how the presence of one pollutant can influence others.
By observing the trends obtained for each area, we can say that the substances followed the same trends:

- ozone (O3) tends to increase in the warmer months and decrease in the colder months
- all the other substances have an almost opposite trend

It is possible to confirm this also by observing the tables containing the correlation indices (Tab. 16): ozone has all negative correlation indices compared to other substances, which implies that as ozone increases, other substances tend to decrease.
The limits established by Italian law were respected, with a few exceptions (PM10 and Ozone). However, by consulting other sources of information it's possible to see that the area in northern Italy (the Po Valley) appears to be the most polluted in Italy and also in Europe.
This is mainly due to high vehicular traffic and industry, which emit a large amount of pollutants into the air. The climatic and meteorological conditions of the region also make the situation particularly critical.
In fact, these conditions contribute to increase the concentrations of PM10 and PM2.5 in the air, and make the dispersion of pollutants difficult and slow.
Eliminate these emissions is impossible, in the future it is desirable to try to reduce them by tending the concentrations towards zero, in order to preserve the health of the people living in the area.

References

[1] ARPA Lombardia, *ARPA Air Quality Dataset*, https://www.dati.lombardia.it/Ambiente/Dati-sensori-aria/nicp-bhqi/about_data

[2] ARPA Lombardia, *ARPA Air Quality Dataset*, https://www.dati.lombardia.it/Ambiente/Dati-sensori-aria-dal-2018/g2hp-ar79/about_data

[3] ARPA Lombardia, *ARPA Monitoring Station Dataset*, https://www.dati.lombardia.it/Ambiente/Stazioni-qualit-dell-aria/ib47-atvt/about_data, https://www.dati.lombardia.it/Ambiente/Stazioni-qualit-dell-aria-NRT/9xaz-9vbz/about_data

[4] Lombardy GEOJSON, *Lombardy GEOJSON*, https://cartographyvectors.com/map/420-lombardy

[5] Air Quality Index, *Air Quality Index*, https://www.arpalombardia.it/temi-ambientali/aria/modellistica/lindice-di-qualita-dellaria/

[6] ARPA site, *ARPA site*, https://www.arpalombardia.it/temi-ambientali/aria/inquinanti/inquinanti-in-sintesi/

[7] Black Carbon, *Black Carbon*, https://www.arpalombardia.it/temi-ambientali/aria/inquinanti/carbonio-elementare-organico-e-black-carbon/

[8] PM10 AND PM2.5, *PM10 AND PM2.5*, https://www.arpalombardia.it/temi-ambientali/aria/inquinanti/pm10-e-pm25/

[9] Substance limits, *Substance limits*, https://www.arpalombardia.it/temi-ambientali/aria/inquinanti/

[10] Substance limits, *NH3 limits*, https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/cittadini/salute-e-prevenzione/Sicurezza-negli-ambienti-di-vita-e-di-lavoro/inquinamento-atmosferico/inquinamento-atmosferico