Investigation of NO_x (in ppb), O_3 (in ppb), and $PM_{2.5}$ (in µg/m3) trends in Ontario from 2003 to 2022

Mohamad Damaj - 10109, Moham An, Jo Zhu

2025-03-18

1. Description of Datasets

The datasets analyzed in this report are three, one for each of NO_x (in ppb), $PM_{2.5}$ (in µg/m3), and O_3 (in ppb), all containing the same variables. These datasets contain records of the pollutant levels from 2003 (considered the earliest of all three) to 2022. Each dataset contains detailed information of pollutant levels in the form of the following variables:

```
##  [1] "Year"              "Station Number"   "City"             "Location"
##  [5] "Type"              "Valid Hour"       "10th Percentile"  "30th Percentile"
##  [9] "50th Percentile"  "70th Percentile"  "90th Percentile"  "99 Percentile"
## [13] "Mean"              "1-Hour Maximum"   "24-Hour  Maximum"
```

1. Year: The calendar year when the pollutant data was recorded.
2. Station Number: A unique numerical identifier for the monitoring station.
3. City: The name of the city where the pollutant was measured.
4. Location: A more specific description of the monitoring location (street, area).
5. Type: The type of monitoring station or measurement protocol used.
6. Valid Hour: The number of valid hourly measurements recorded for that pollutant in the given year.
7. Percentiles: Percentile statistics showing the distribution of pollutant levels (in ppb, µg/m3, ppb) throughout the year.
8. Mean: The annual average concentration of the pollutant (in ppb, µg/m3, ppb).
9. 1-Hour Maximum: The highest recorded concentration within a one-hour period during the year.
10. 24-Hour Maximum: The highest average concentration recorded over a 24-hour period in that year.

2. Background of the Data

The data used in this analysis was collected across various cities in Ontario, throughout the period from 2003 to 2022. These measurements were compiled and made available by the Ontario Ministry of the Environment, Conservation and Parks.

The information is publically avaliable and is helpful in assiting researchers, policymakers, and public health officials to investigate air quality trends, evaluate the impact of environmental regulations, and inform policy decisions. It provides a long-term view of pollutant levels in various cities in Ontario, allowing for improving environmental and public health outcomes in Ontario.

3. Overall Research Question

The aim of this paper is to investigate the spatial and temporal trends of air pollutants (NO_x, O_3, and $PM_{2.5}$) across various Ontario cities from 2003 to 2022.

1. How have annual mean concentrations (in ppb, µg/m3, ppb) for each pollutant changed from 2003 to 2022, and which years show the most significant shifts?
2. Which cities consistently rank among the highest (or lowest) in terms of average pollutant levels, and do these rankings shift over time?
3. How do the four pollutants correlate with each other across different cities and years, and what might this indicate about broader air quality patterns?
4. How do the four pollutants project into future years based on current trends?

4. Tables

4.1 The Top 10 Cities With the Highest Pollutant Concentration

NO_x Table (in ppb)

City	Conc.
Toronto West	31.32
Toronto East	21.82
Toronto Downtown	20.41
Toronto North	19.67
Hamilton Downtown	19.36
Windsor Downtown	18.00
Burlington	17.74
Hamilton West	17.63
Windsor West	16.89
Brampton	15.95

O_3 Table (in ppb)

City	Conc.
Port Stanley	32.84
Tiverton	31.93
Grand Bend	31.28
Parry Sound	30.56
Chatham	29.88
Belleville	29.63
Kingston	29.61
Newmarket	29.13
Hamilton Mountain	28.61
Peterborough	28.55

$PM_{2.5}$ Table (in µg/m_3)

City	Conc.
Sarnia	9.57
Windsor West	9.03
Hamilton Downtown	8.91
Etobicoke West	8.44
Windsor Downtown	8.36
Hamilton West	8.06
Hamilton Mountain	7.91
Toronto West	7.86
Toronto North	7.59
Kitchener	7.52

Table 1: Top 10 Cities with Highest Concentration of Each Pollutant

The table above is three separate tables each one for a respective pollutant, they are sorted in descending Mean and only the top 10 are being shown based on the overall Mean of the City, over all years from 2003 to 2022; as such, the cities with the high concentration will be listed first. Therefore, we can draw a few key observations about pollutant concentrations across these Ontario cities:

- The highest mean NO_x readings (31.32 ppb) appear at Toronto West, followed closely by other Toronto stations (Toronto East, Toronto Downtown) and industrial/urban areas like Hamilton and Windsor.
- Port Stanley shows the highest O_3 levels (32.84 ppb), with other high concentrations at Tiverton, Grand Bend, and Parry Sound—generally smaller or semi-rural communities.
- Sarnia tops the $PM_{2.5}$ list (9.57 µg/m_3), followed by Windsor (West and Downtown) and Hamilton stations, reflecting the influence of industrial facilities and cross-border pollution.

4.2 The Top 10 Regions and Years with Highest Concentration of Each Pollutant

In order to view the pollutant concentration changes by region, we grouped the cities by region based on the map of Ontario from the Ministry of Natural Resources and Forestry, and calculated the mean of the cities in each region grouped by year.

NO_x Table (in ppb)

Year	Region	Conc.
2003	Central Ontario	31.45
2005	Central Ontario	28.17
2003	Western Ontario	26.98
2004	Central Ontario	26.94
2006	Central Ontario	23.80
2007	Central Ontario	21.68
2004	Western Ontario	21.55
2008	Central Ontario	20.07
2005	Western Ontario	20.00
2004	Northern Ontario	19.04

O_3 Table (in ppb)

Year	Region	Conc.
2010	Western Ontario	29.54
2022	Western Ontario	29.49
2007	Eastern Ontario	29.46
2010	Eastern Ontario	29.20
2021	Western Ontario	29.10
2018	Eastern Ontario	28.97
2012	Western Ontario	28.82
2016	Western Ontario	28.79
2013	Western Ontario	28.57
2008	Eastern Ontario	28.54

$PM_{2.5}$ Table (in µg/m$_3$)

Year	Region	Conc.
2005	Western Ontario	9.48
2014	Western Ontario	9.27
2003	Western Ontario	8.93
2015	Western Ontario	8.79
2013	Western Ontario	8.72
2005	Central Ontario	8.56
2004	Western Ontario	8.44
2014	Central Ontario	8.33
2007	Western Ontario	8.30
2003	Central Ontario	8.26

Table 2: Top 10 Regions and Years with Highest Concentration of Each Pollutant

This table follows a similar format to the Table 1, listing the highest concentrations first. The concentrations of NO_x (in ppb) and $PM_{2.5}$ (in µg/m$_3$) were highest in the early to mid-2000s, particularly in Western and Central Ontario, and have since declined. Meanwhile, O_3 (in ppb) levels are highest in Western Ontario dominating the top 10 with Northern Ontario not occupying a single spot. The O_3 concentrations show minor decrease, likely reflecting O_3 long lifespan in the atmosphere.

4.3 The Top 10 Years with Highest Concentration of Each Pollutant

NO_x Table (in ppb)

Year	Conc.
2003	25.08
2004	23.42
2005	22.43
2006	17.87
2007	15.80
2008	15.04
2009	13.91
2011	12.36
2010	12.35
2012	11.23

O_3 Table (in ppb)

Year	Conc.
2010	28.41
2021	27.97
2018	27.88
2012	27.85
2007	27.83
2022	27.83
2013	27.73
2016	27.67
2017	27.43
2008	27.41

$PM_{2.5}$ Table (in µg/m$_3$)

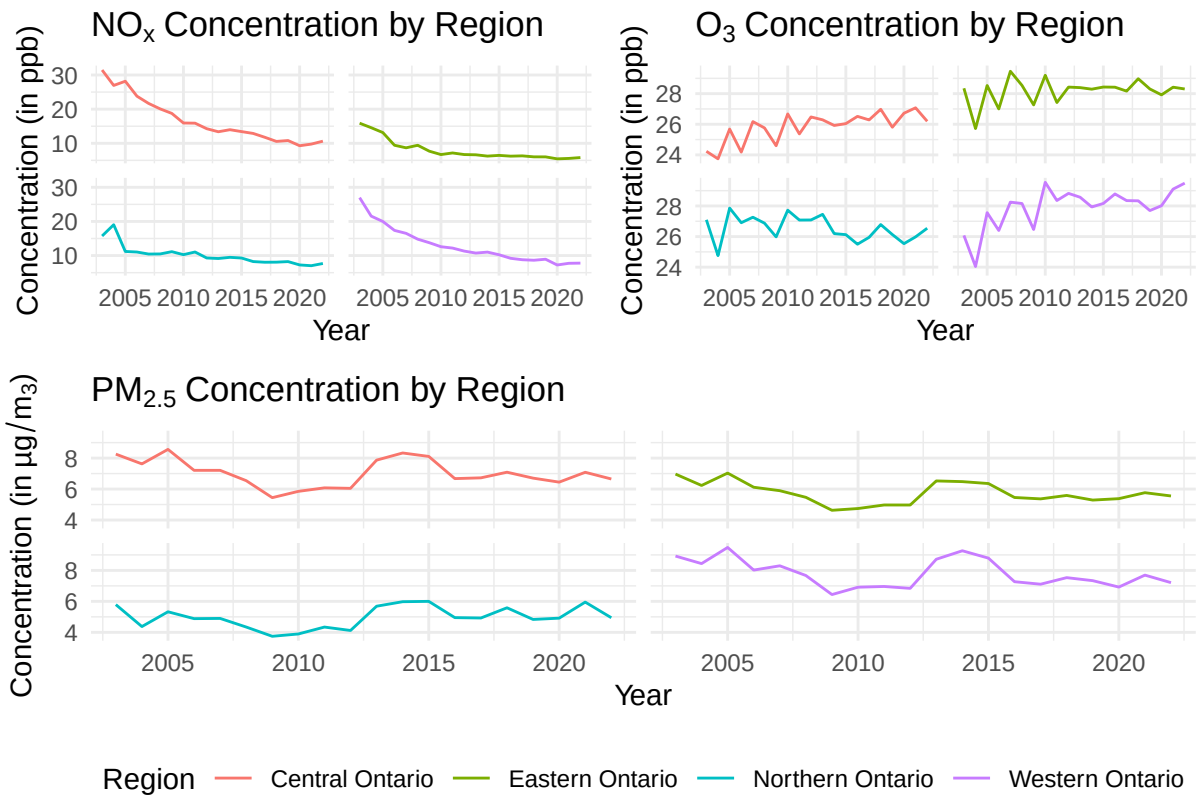
Year	Conc.
2005	8.36
2003	8.04
2014	7.96
2015	7.73
2013	7.61
2004	7.30
2006	7.04
2007	7.03
2021	6.92
2018	6.78

Table 3: Top 10 Years with the Highest Concentration

The table reveals that NO_x levels peaked in 2003 – the first year of the dataset – and has steadily decreased since. Additionally, $PM_{2.5}$ concentrations were highest in the mid-2000s before decreasing, and O_3 levels, which peaked around 2010–2012, have remained relatively high before a minor decrease in later years.

5. Graphs

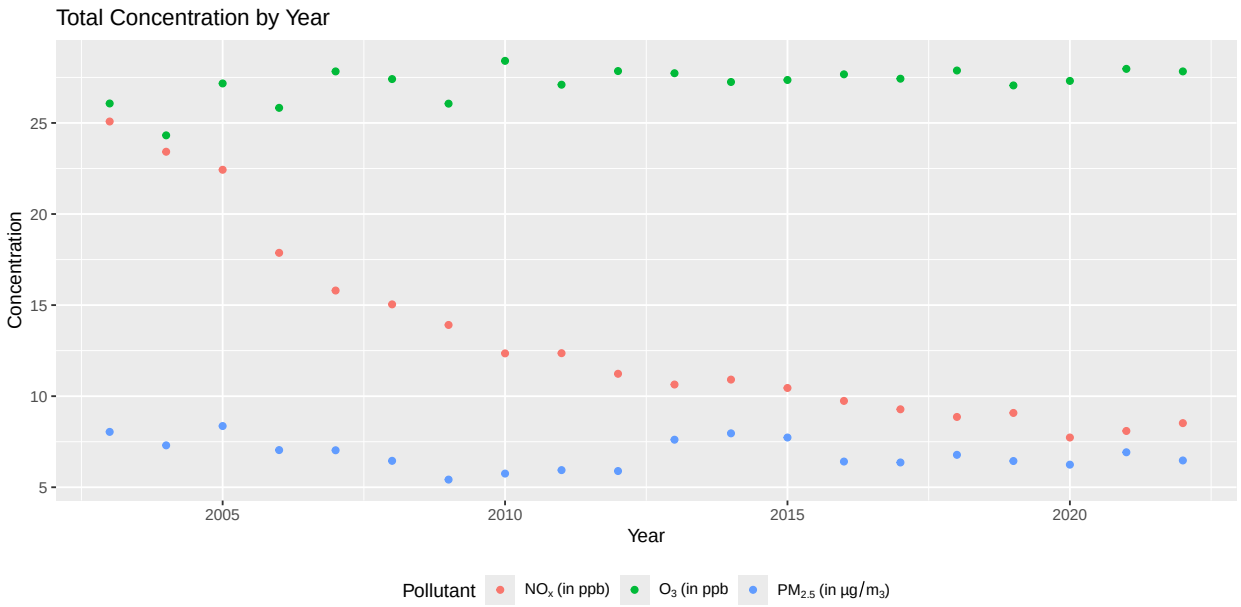
5.1 Line Charts of Yearly Concentration by Region



The Line Charts of Yearly Concentration by Region display the concentration of each pollutant faceted by region over 2003 till 2022. The x-axes represent the year and the y-axes represent the concentration of the pollutant at that year in its respective unit.

The graphs reveal a notable improvement in air quality over the years, with clear declines in both NO_x and $PM_{2.5}$ levels across all regions, suggesting that emission controls and cleaner technologies have had a significant impact. NO_x concentrations show a consistent downward trend from higher levels in the early years, converging towards lower values by 2020, while $PM_{2.5}$ levels exhibit a marked decrease, with the initial difference between regions decreasing over time. In contrast, O_3 concentrations appear relatively stable – with some fluctuations – which reflects the complex nature of ozone formation that depends on multiple factors such as sunlight, temperature, and precursor emissions.

5.2 Scatter Plot of Overall Pollutant Concentration by Year



This Scatterplot of Overall Pollutant Concentration by Region displays the overall concentration, calculated by taking the mean of each year for all cities in the dataset, of each pollutant over 2003 till 2022. The x-axes represent the year and the y-axes represent the concentration of the pollutant at that year in its respective unit.

The plot reveals a downward trends of NO_x until 2020, with concentrations appearing to drop from around 25 ppb to near 8 ppb in 2020. This substantial decrease suggests that measures aimed at reducing emissions through regulations and increased standards have been effectively implemented over the years. On the other hand, $PM_{2.5}$ and O_3 do not show a steady downward trend; instead, their concentrations fluctuate over the period analyzed. These fluctuations show the challenges in the efforts of controlling pollutants that are not directly emitted but are produced by chemical interactions in the atmosphere.

5.3 Heatmap

6. Hypothesis Testing

6.1 Paired T-test

compare the value of two years (2003, 2022), x_2003, x_2022 H_0: u_1 - u_2 = 0 H_a: u_1 - u_2 != 0

```
##
##  One Sample t-test
##
## data:  values$diff
## t = 8.2745, df = 19, p-value = 1.012e-07
## alternative hypothesis: true mean is not equal to 0
## 95 percent confidence interval:
##  11.31407 18.97593
## sample estimates:
## mean of x
##    15.145
```

```
##
##  One Sample t-test
##
## data:  values$diff
## t = -3.1488, df = 32, p-value = 0.00354
## alternative hypothesis: true mean is not equal to 0
## 95 percent confidence interval:
##  -2.7273569 -0.5847644
## sample estimates:
## mean of x
## -1.656061
```

```
##
##  One Sample t-test
##
## data:  values$diff
## t = 7.4834, df = 27, p-value = 4.748e-08
## alternative hypothesis: true mean is not equal to 0
## 95 percent confidence interval:
##  1.050617 1.844383
## sample estimates:
## mean of x
##    1.4475
```