Impact of COVID-19 Lockdown on Outdoor Air Quality in Virginia

Final Technical Report

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Abstract

The goal of this project is to compare changes in air quality index (AQI) levels for two pollutants, before the COVID-19 Virginia lockdown, with levels recorded during the lockdown. The pollutants involved in the research are carbon monoxide (CO) and nitrogen dioxide (NO_2).

Data was downloaded from the United States Environmental Protection Agency web portal, and cleansed and imported into the JupyterLab virtual computing environment. Here, average monthly values were found for the years of 2017 through 2019, to establish a baseline of what normal AQI levels for each pollutant are expected to be. After setting the baseline from averages from years past, the average AQI levels for the year of 2020 were calculated as well. Values were calculated on a per-county basis, since separate counties were responsible for measuring and recording the daily AQI levels for each pollutant.

After calculating the baseline AQI averages and the 2020 AQI averages, the 2020 averages were then subtracted from the baseline averages to determine if any changes or patterns became apparent. Evidently, there were stark differences in both pollutants, across all counties, for 2020. CO and NO_2 levels both decreased for all counties during the prime lockdown months (April and May) of 2020 when compared to the previous baseline levels established.

Since the burning of fossil fuels to power cars, trucks, and other machinery is known to be one of the leading contributors to CO and NO_2 pollution, this supports the idea that humans are leaving their mark on earth, simply just by transportation to and from their responsibilities throughout daily life.

Introduction

Aside from the physical health of individuals across the globe, the COVID-19 pandemic has had a profound and immeasurable impact on the world. The disease spread rapidly across the globe, dramatically altering the daily lives of citizens across every nation. Effects of the pandemic and lockdown were seen immediately, as countries went into quarantine, citizens went into isolation, and the global economy came to a screeching halt. With millions of Americans filing for unemployment over the course of the past year, after many jobs were lost due to the lockdown, it became obvious that humans were having a drastically reduced impact on the world. Since individuals were sent home from work, and less manufacturing going on, some of the improvements noted in the environment were improved air and water quality, less noise pollution, along with reduced dumping and generation of waste. One of the first examples of the environmental changes the world witnessed, was when Italy restricted travel and went into lockdown. After locking down all ports and sending their citizens into quarantine, Italy immediately saw improved clarity and quality in their water, due to less boats and other human activity happening throughout their harbors (Clifford).

With environmental changes like this becoming apparent almost immediately, one cannot help but wonder what other lasting footprints does humanity leave on nature and the delicate yet sensitive balance of the world. That is why this project will look at evaluating the environmental impact of the coronavirus lockdown period in Virginia, on air quality measurements for certain pollutants across the state.

Air quality and pollutant data were retrieved from the United States Environmental Protection Agency web portal, where daily recorded levels of multiple pollutants are available for download. The pollutants being studied specifically in this project are carbon monoxide (CO) and nitrogen dioxide (NO_2). Air quality index (AQI) levels for each of the two pollutants, from the first six months of the years 2017 through 2019, will be averaged together. This monthly average, will establish the baseline of what one can expect the AQI levels to be for each month in 2020. Next, the baseline from the prior years will be compared with the average AQI levels for the first six months of 2020, to gauge how much the index levels differ from the baseline set from years past.

Most people think of carbon monoxide when they are taught not to leave their car running inside a closed garage, as this can lead to carbon monoxide poisoning and if exposed long enough, death. The most common sources for carbon monoxide being introduced into the environment are cars, trucks, and other machinery that burn fossil fuels for energy. High levels are more likely to be found indoors, because of the enclosed spaces, so one needs not to worry about contracting carbon monoxide poisoning outdoors, however, there are certain groups of people that are at a greater risk when exposed to carbon monoxide when compared to others. For instance, those with certain types of heart disease should have a higher concern for carbon monoxide levels in

the air than those that do not. These people already have a difficulty bringing oxygenated blood to their hearts, so adding carbon monoxide into the mix, and reducing the oxygen levels in the blood even more, can lead to lethal complications (EPA). People with heart disease who are exercising outdoors is a specific example of when someone should pay attention to CO levels in the air.

As for nitrogen dioxide, like carbon monoxide, it too primarily enters the air as a result of the burning of fuel. These emissions can come from cars, buses, and trucks, as well as industrial power plants, and off-road equipment. NO_2 is particularly harmful to humans because it can irritate the airways and respiratory system. According to the Environmental Protection Agency, "exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms. Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections". NO_2 also chemically reacts with water and oxygen found in the atmosphere to form acid rain. Acid rain can be especially destructive since it is harmful to sensitive ecosystems such as forests and lakes. Additionally, the nitrate particles that result from nitrogen dioxide make the air hazy, and dramatically reduce visibility (EPA).

The results of the research will be comparing Air Quality Index values for each pollutant, with past averages. There are five different AQI values daily, as five major pollutants are measured and have separate AQI values. This project focuses on the CO and NO_2 AQI values. The figure below provides more understanding on what to expect an acceptable AQI value to be.

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQI is in this range:	*...air quality conditions are:*	*...as symbolized by this color:*
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Figure 1: AirNow AQI Chart - https://www.airnow.gov/sites/default/files/2018-04/aqi_brochure_02_14_0.pdf

Objectives

With a vast portion of human life shut down during the lockdown and quarantine periods in Virginia, one would expect to see the pollutant levels fall throughout 2020- this research project seeks to confirm that.

This will be done by looking at each pollutant, CO and NO_2, separately. For the years 2017 to 2019, the daily AQI value on a specific day will be averaged with the other two daily AQI values from that same day in the other two years. This will be done per county as well, as each county has differing AQI levels on the same day. The average from years prior is what one would expect to see at that same time of the year, every year. That is why this daily AQI average that each county will have, now becomes the baseline that 2020 will be compared against.

There are multiple testing centers in each county, however not all centers test for both CO and NO_2. As a result of this, the averages are split up and grouped by county, instead of by testing site name and location. After establishing what question this analysis aims to answer, and how it will do so, the next phase of the process is to look at gathering the data, determining what data is necessary for the project, and preparing the data to be manipulated to provide that answer.

The Data

The data required for the analysis is publicly available, and was generated from the United States Environmental Protection Agency (EPA), and transferred into CSVs upon download from the website. It can be found here: https://www.epa.gov/outdoor-air-quality-data/download-daily-data.

The raw data downloaded from the EPA portal originally came with 20 attributes. Some of the attributes in the spreadsheets were redundant and excluded from the analysis. Examples of these redundant attributes were COUNTY CODE and COUNTY, along with STATE CODE and STATE. The code values were essentially unique ID numbers for the state and counties. COUNTY CODE was irrelevant because the county names were already present, and they were used instead of the numbers, to simplify the analysis process. Both STATE and STATE CODE were unnecessary since the sole focus of the research was strictly on the state of Virginia. Other examples of unnecessary attributes that were dropped from the analysis were the SITE_NAME attributes, for each of the EPA's testing centers. The county names that the testing centers belonged in, were all that were necessary, since the results of the AQI research were grouped by county, and not testing center.

Some important attributes to the analysis were DATE, DAILY_AQI_VALUE, and COUNTY. DAILY_AQI_VALUE was especially important as those values were what the entire project was centered around. Originally, the research intended to measure the daily maximum concentration of both of the pollutants as well, and compare the data with years past, in addition to the air quality index values, however it became evident that it was not feasible to include this. The daily

max concentration levels were excluded from analysis, because these recordings had units attached to them. CO was measured in parts per million, and NO_2 was measured in parts per billion, and conversions and added zeros from decimals would complicate the analysis and presentation of the data. Additionally, CO was measured in "Daily Max 8-Hour Concentration," and NO_2 was measured in "Daily Max 1-Hour Concentration." After generating the results, and beginning the analysis, it would be difficult to compare the two pollutants together using this daily maximum attribute, as they were measured over varying periods of time. The decision was made to focus strictly on the daily AQI levels for each pollutant, instead of the daily max attributes, as AQI is a unitless number and each pollutant involved in this analysis has a separate daily number.

A screenshot of a brief portion of the extensive carbon monoxide spreadsheets that were downloaded from EPA website is below. More attributes are present in the raw data outside of what is included in the image.

Date	Source	Site ID	POC	Daily Max 1-hour NO2	UNITS	DAILY_AQI_VALUE	Site Name	DAILY_OBS_COUNT
1/1/20	AQS	510130020	1	34	ppb	32	Aurora Hills	23
1/2/20	AQS	510130020	1	36	ppb	34	Aurora Hills	24
1/3/20	AQS	510130020	1	22.7	ppb	21	Aurora Hills	22
1/4/20	AQS	510130020	1	20.8	ppb	19	Aurora Hills	23
1/5/20	AQS	510130020	1	30.7	ppb	28	Aurora Hills	24
1/6/20	AQS	510130020	1	35.4	ppb	33	Aurora Hills	24
1/7/20	AQS	510130020	1	37.8	ppb	35	Aurora Hills	22
1/8/20	AQS	510130020	1	26.7	ppb	25	Aurora Hills	22
1/9/20	AQS	510130020	1	19.5	ppb	18	Aurora Hills	24
1/10/20	AQS	510130020	1	20.3	ppb	19	Aurora Hills	23
1/11/20	AQS	510130020	1	23.4	ppb	22	Aurora Hills	24
1/12/20	AQS	510130020	1	11.2	ppb	10	Aurora Hills	24
1/13/20	AQS	510130020	1	25.5	ppb	24	Aurora Hills	23
1/14/20	AQS	510130020	1	21.6	ppb	20	Aurora Hills	20

After establishing what attributes were going to be involved, and discarding the unnecessary ones, the next decision was made to consolidate the testing centers into counties, and display the results based on county instead. Not all testing centers measured each of the same pollutants; some measured just one of CO and NO_2, and not both. That would have impacted the results as some data for displaying the AQI averages would be incomplete. The results are based on county, as the county is still a small enough region to be able to accurately depict the climate and air in a given area, and it is then able to include recording levels for both pollutants across the last four years.

There were twelve unique testing centers included in the datasets: twelve for NO_2, and eight for CO. After combining the testing centers into their respective counties, there are a total of eleven distinct counties that will be displayed in the results. The counties for NO_2 are: Arlington, Charles, Fairfax, Hampton, Henrico, Loudon, Norfolk, Richmond, Roanoke, and Rockingham. CO includes Arlington, Fairfax, Hampton, Henrico, Norfolk, Roanoke, and Richmond. Each of

the counties are spread throughout the state evenly enough that they are able to represent five unique parts of the state, with varying environments and industrial sectors present in each.

When moving to the data pre-processing phase, the first step was to assimilate a master spreadsheet that included all of the data, across all of the years involved, where all of the code would query. This was done with each pollutant. One spreadsheet was downloaded for each year, and then all of the data across the five separate spreadsheets was combined into a single spreadsheet. Each of the five spreadsheets with raw data for each year, had roughly 3,900 records, and the largest master spreadsheet had over 23,000 total records. After the formation of the master spreadsheet, the YEAR attribute was also manually added to all the records, as a way to easier identify the year for the analysis, instead of pulling it from the DATE attribute. After the two raw data files had been prepared for analysis they were then imported into JupyterLab to begin the remaining data pre-processing steps. The analysis was coded to scrub and cleanse the data prior to actually performing any other technical analysis steps. The spreadsheets were imported, and immediately stripped of all null values, all white spaces, and all duplicates. The data provided by the EPA was already high-integrity data, so there were no issues with duplicates for the records that were present.

This project originally intended to include the years 2015 through 2020, however upon inspection of the data during the pre-processing steps, it was discovered that for carbon monoxide, Fairfax County was missing values for 480 out of the 730 possible days in 2015 and 2016. Norfolk was also missing a substantial amount of values for those two years as well.

One can see in the screenshots provided, with 2015 to 2016 above and 2017 to 2019 below, the count of all the missing values for Fairfax and Norfolk. This complicated the analysis, so ultimately, it was decided to drop both 2015 and 2016 from the analysis.

```
for i in CO.COUNTY.unique():
  missed=pd.date_range('2015-01-01','2016-12-31' ).difference(CO[CO.COUNTY
==i].Date)
  print('Dates missing in ' + i + ' are:',len(missed))
```

```
Dates missing in Arlington are: 28
Dates missing in Henrico are: 44
Dates missing in Roanoke are: 16
Dates missing in Hampton City are: 39
Dates missing in Norfolk City are: 87
Dates missing in Richmond City are: 23
Dates missing in Fairfax are: 480
```

```
for i in CO.COUNTY.unique():
  missed=pd.date_range('2017-01-01','2019-12-31' ).difference(CO[CO.COUNTY
==i].Date)
  print('Dates missing in ' + i + ' are:',len(missed))
```

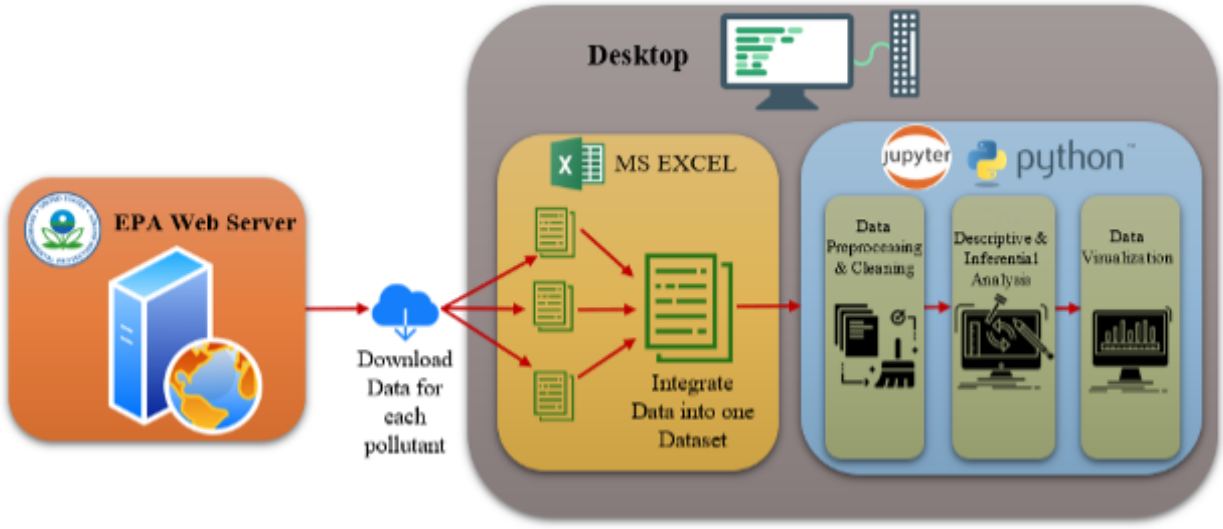
```
Dates missing in Arlington are: 29
Dates missing in Henrico are: 63
Dates missing in Roanoke are: 24
Dates missing in Hampton City are: 48
Dates missing in Norfolk City are: 63
Dates missing in Richmond City are: 32
Dates missing in Fairfax are: 48
```

Another important lesson learned from the data

preprocessing steps, was that a vast majority of some currently missing records were from the last six months of each year. Counties were missing some data for the months of July through December, so the decision was made to exclude those six months, and focus the analysis on the months of January through June, since those were the prime COVID lockdown months anyway.

The System

Regarding the architecture of the system, multiple spreadsheets of the data required will be downloaded from the EPA web servers, into a readable CSV that will then be edited in Microsoft Excel to include all the years required for analysis.



After the successful preparation of the two master spreadsheets for each of the pollutants, the spreadsheets will be imported to JupyterLab where the analysis will begin. The data preprocessing was first completed, to ensure the highest integrity data is used, and to also establish an improved understanding of what else is included in the data that was downloaded. The data preprocessing was completed, as discussed previously, and it was decided that the years 2017 through 2020 were the best fit, along with using just the months of January through June. Since all preprocessing steps are complete, now begins the phase of the analysis itself.

COUNTY Date	Arlington	Fairfax	Henrico	Roanoke	Hampton City	Norfolk City	Richmond City
January	4.336957	5.702381	3.963855	3.053763	3.261364	4.845238	5.279570
February	4.726027	6.000000	4.100000	3.000000	2.915663	4.072289	5.583333
March	4.063291	5.064516	3.193182	2.539326	2.439560	3.978495	3.838710
April	3.438202	4.941176	2.844444	2.544444	2.100000	2.837500	3.461538
May	3.774194	5.265060	2.428571	2.736264	1.811111	3.130435	3.336957
June	3.555556	5.213483	2.556818	3.034884	1.712329	3.022727	3.111111

Initial data processing steps consisted of gathering the average daily AQI values from

the years 2017 to 2019 for each pollutant to set the baseline of what normal levels are expected to be. The raw averages for carbon monoxide are above, and nitrogen dioxide below.

COUNTY	Arlington	Charles	Fairfax	Loudoun	Prince William	Roanoke	Rockingham	Hampton City	Norfolk City	Richmond City
Date										
January	23.329670	11.782609	26.813187	19.078652	11.666667	14.516129	19.903226	11.311828	21.082353	24.629213
February	24.428571	11.678571	30.204819	19.250000	11.809524	14.523810	21.250000	11.119048	21.526316	27.424658
March	22.451613	11.651685	27.565217	16.666667	9.543210	11.774194	20.806452	8.870968	18.494624	26.612903
April	18.188889	10.775281	28.181818	10.910112	7.011236	10.755556	18.614458	6.477778	14.033333	24.733333
May	13.612903	10.597826	24.989247	8.387097	5.623656	8.516129	15.847059	5.483146	11.510870	19.838710
June	12.111111	10.137931	21.366667	6.388889	4.688889	7.875000	15.600000	5.400000	11.853933	18.288889

Since the baseline averages have been established, now the analysis can move to 2020, to set the actual AQI levels and look to compare them with years prior.

COUNTY	Arlington	Fairfax	Henrico	Roanoke	Hampton City	Norfolk City	Richmond City
Date							
January	4.580645	5.000000	3.833333	2.354839	1.931034	5.000000	4.450000
February	4.620690	5.689655	3.833333	2.758621	4.629630	4.551724	6.791667
March	3.451613	4.225806	2.413793	1.677419	4.700000	3.419355	6.096774
April	2.800000	3.366667	2.482759	1.566667	1.100000	1.733333	3.633333
May	2.612903	3.935484	2.129032	1.870968	2.612903	2.967742	2.838710
June	2.666667	4.766667	2.033333	2.233333	2.333333	3.566667	2.866667

To the left are the mean values for carbon monoxide AQI levels recorded in 2020. Below are the mean values for nitrogen dioxide. Upon first glance, it is evident that a majority of the 2020 averages are less than the baseline averages that were set for 2017 through 2019.

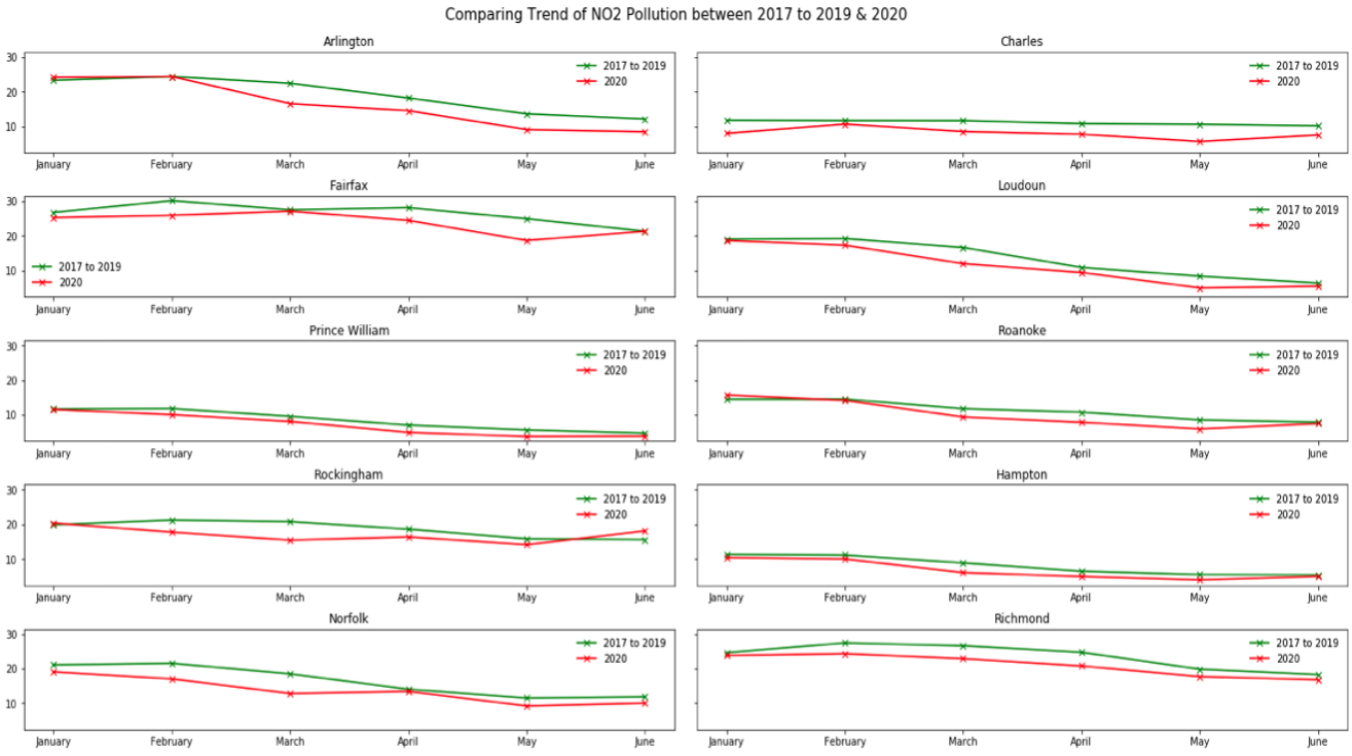
COUNTY	Arlington	Charles	Fairfax	Loudoun	Prince William	Roanoke	Rockingham	Hampton City	Norfolk City	Richmond City
Date										
January	24.193548	8.000000	25.322581	18.677419	11.548387	15.709677	20.387097	10.379310	19.064516	23.806452
February	24.413793	10.629630	25.965517	17.344828	10.034483	14.172414	17.758621	10.000000	17.035714	24.333333
March	16.551724	8.516129	27.172414	12.000000	8.064516	9.354839	15.451613	6.064516	12.806452	22.870968
April	14.533333	7.733333	24.500000	9.444444	4.900000	7.833333	16.384615	4.931034	13.413793	20.766667
May	9.064516	5.633333	18.709677	5.000000	3.709677	5.903226	14.129032	3.967742	9.225806	17.700000
June	8.448276	7.500000	21.366667	5.466667	3.800000	7.466667	18.115385	4.966667	10.033333	16.793103

The research was executed using Python in the JupyterLab virtual computing environment. In addition to the final results that will be graphically displayed later, more analysis was completed involving the differences in averages between April and May, the main COVID lockdown

months, and will be presented in the form of a choropleth map using PaintMaps - an online map generating tool(PaintMaps).

Results and Analysis

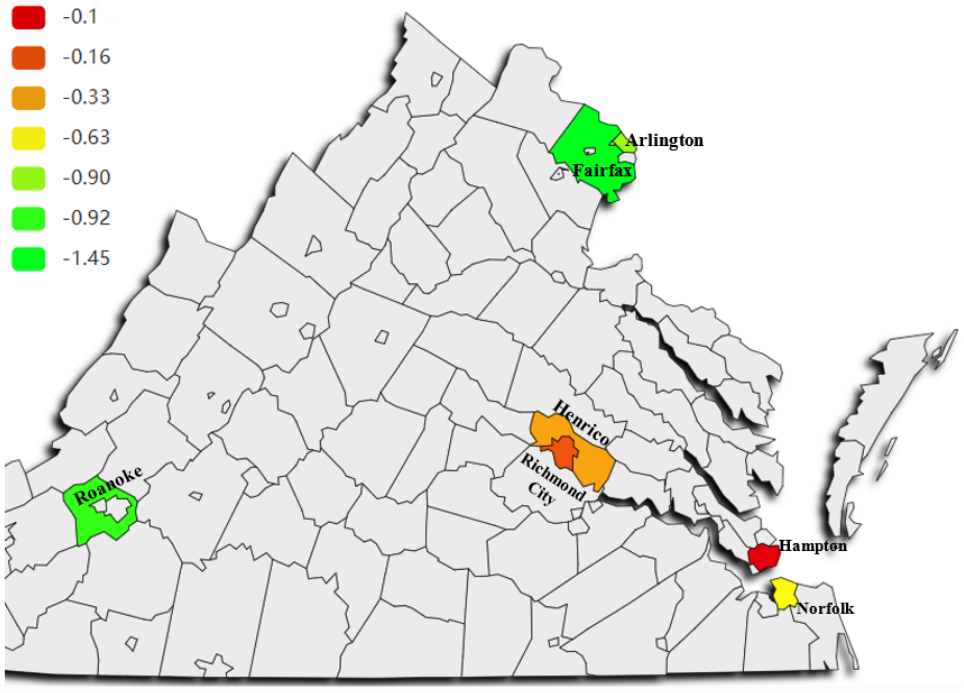
Pasted above are the graphical results for the carbon monoxide analysis. The green line displays the previous year expected baseline levels, and the red line details the actual AQI values from lockdown in 2020. Below is the line chart exhibiting the results for the nitrogen dioxide AQI levels.



The results in the line charts above indicate that a majority of the counties had a steep and obvious drop-off during the lockdown. The key months that should be focused on are April and May, since the primary lockdown period for Virginia started toward the end of March and lasted for a little over two months. For carbon monoxide, twelve out of the fourteen months (seven counties multiplied by two months) saw lower pollutant levels during the lockdown than the previous year's baseline. Only Richmond in April and Hampton in May had higher CO levels than the previous years.

Regarding the nitrogen dioxide AQI levels, during April and May, all twenty possible months had a lower average AQI level recorded than the average of the previous three years. Additionally, only one county out of the ten had a higher nitrogen dioxide AQI average in June than prior years.

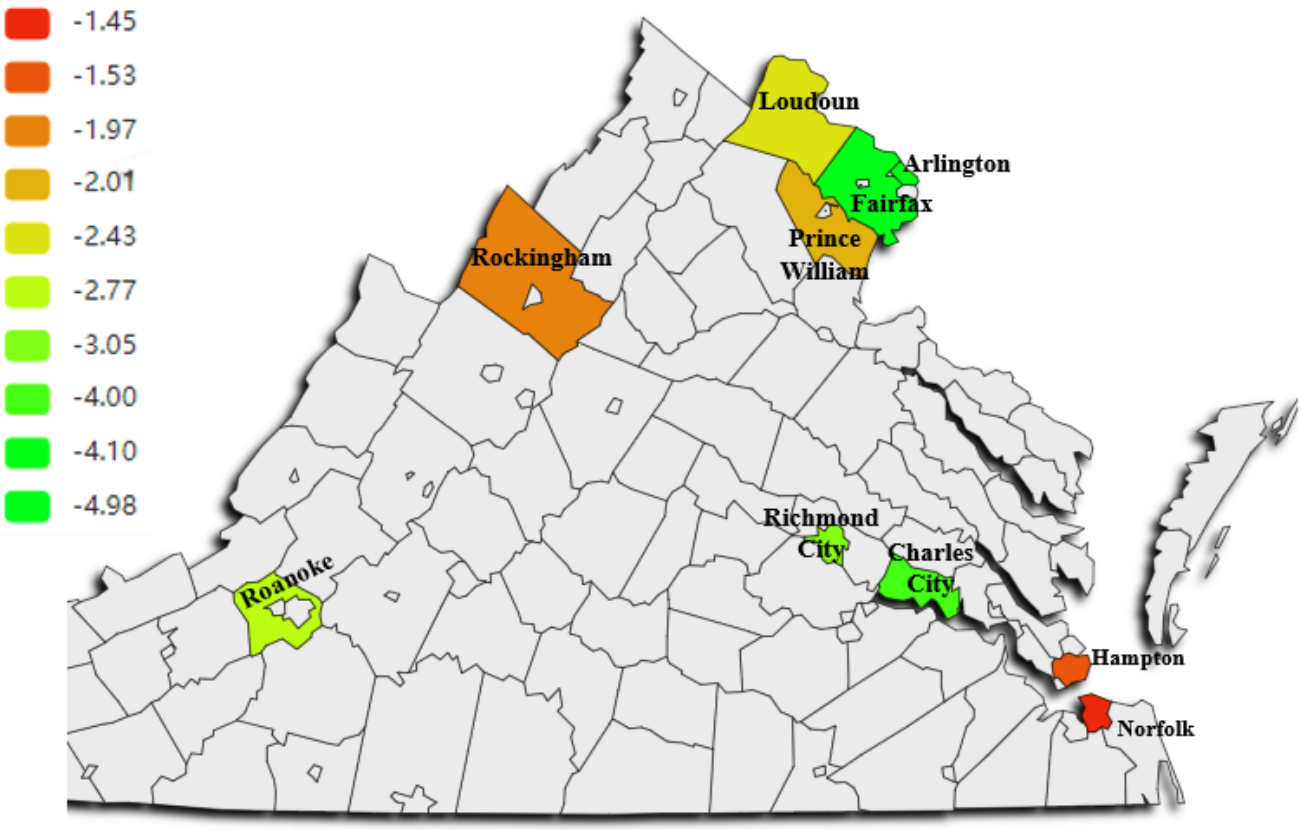
The next analysis steps performed were to take the 2017 to 2019 baseline average AQI values for April and May, calculate the mean between the two months, and then compare them to the averaged AQI values of April and May for 2020. Each county's April and May 2020 average was then subtracted from the county's baseline April and May average. The difference in averages was then displayed via a choropleth map using PaintMaps. This was done for both CO and NO_2. The results for CO are to the right, and the NO_2 choropleth map is below.



For CO, Hampton and Henrico county had the two lowest differences in averages, with Fairfax having the largest, and Roanoke the second largest. A 1.45 drop in AQI is huge, considering that most of the CO AQI baseline averages hovered around 4 for the months of April and May.

Regarding NO_2, the drop is obvious, however proportionately it is less extreme than CO. All counties' averages still dropped, yet not as severe as the AQI levels for CO. Average baseline

nitrogen dioxide levels across the state primarily fluctuated between 10 and 20, and the 2020 levels mainly stuck between 8 and 15.



Obviously, the drop in pollutant levels can be attributed to less activity throughout the state. During the lockdown, individuals were either sent to work from home, furloughed, or laid off completely. With the burning of fossil fuels from cars, buses, trucks, and industrial equipment being the leading cause of carbon monoxide and nitrogen dioxide emission, the swift and drastic change in work life for Virginians can effectively be deemed the cause of the steep dropoff among the primary lockdown months.

On May 29th, 2020, Governor Ralph Northam allowed all of Virginia to enter Phase One, which was essentially the first step in opening the state back up. Public activity started to pick up just slightly, with a small amount of jobs becoming available again. Retail stores and places of worship opened back up again with 50% capacity (Graff). Consequently, one can also notice the slight uptick in AQI pollutant levels across every county for the month of June. Individuals were looking to leave their homes and enjoy the reduced CO and NO_2 levels in the air on their way to stores and other restaurants. This reinforces the notion that the decreased activity was the leading cause for the decline in CO and NO_2 presence in the air across the state of Virginia.

Finally, this research proves to be extremely valuable as it not only confirms the belief that humans are leaving a mark on planet Earth, but it also represents just how deep of a footprint is left wherever they go.

Conclusion

Many studies have already been done on the impact on the atmosphere that humans have, however due to the pandemic, this study has taken advantage of essentially a once-in-a-lifetime "before and after" type of experiment thanks to the lack of human activity from the lockdown.

The downward trend during the start of the pandemic, and leading into the lockdown months for Virginia, details the negative impact machinery and humans have on the environment. The graphs displaying the drop in average daily AQI levels for each pollutant is the most telling, as they paint quite a clear picture on what to expect when industrial operations and transportation is flourishing, and what it could be when there is reduced activity amongst some of the leading contributors to air pollution.

As a society, it is absolutely critical to learn from this lockdown period, and study it as extensively as possible, to gain a better grasp on the impact the human race has on each other, as well the planet. Much is still yet to be discovered about lasting effects of coronavirus and the data generated during the lockdown itself, however it is important to thoroughly analyze this dark time period in order to better educate and protect the future generations that will inherit the earth. Whether it be in regards to air pollution, an improved work-life balance due to working from home, or endangered coral reefs blossoming again, it is imperative that data scientists, graduate students, or even curious minds take the time to evaluate the impact of our minor disappearance from the world.

References

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Appendix

Below is an example of the code and values generated for the choropleth map for carbon monoxide constructed via PaintMaps using Python. The first line details the code and output for calculating the average baseline AQI values for April and May, and the second line shows the average AQI values for lockdown. The third line displays the values after they are subtracted, and the fourth line shows the average of the subtracted values for each county. These average subtracted AQI values in the fourth line are the exact values that were included in the choropleth map.

Mean value for years between 2019 and 2017

```
Baseline=CO[(CO.Date.dt.year <= 2019) & ((CO.Date.dt.month==4) | (CO.Date.dt.month==5)) ][['DAILY_AQI_VALUE']].groupby
([CO.Date.dt.month_name(),CO.COUNTY],sort=False).mean().unstack()
Baseline
```

	DAILY_AQI_VALUE						
COUNTY	Arlington	Fairfax	Henrico	Roanoke	Hampton City	Norfolk City	Richmond City
Date							
April	3.438202	4.941176	2.844444	2.544444	2.100000	2.837500	3.461538
May	3.774194	5.265060	2.428571	2.736264	1.811111	3.130435	3.336957

Mean value for 2020

```
Lockdown=CO[(CO.Date.dt.year == 2020) & ((CO.Date.dt.month==4) | (CO.Date.dt.month==5)) ][['DAILY_AQI_VALUE']].groupby
([CO.Date.dt.month_name(),CO.COUNTY],sort=False).mean().unstack()
Lockdown
```

	DAILY_AQI_VALUE						
COUNTY	Arlington	Fairfax	Henrico	Roanoke	Hampton City	Norfolk City	Richmond City
Date							
April	2.800000	3.366667	2.482759	1.566667	1.100000	1.733333	3.633333
May	2.612903	3.935484	2.129032	1.870968	2.612903	2.967742	2.838710

Mean Difference

```
Impact=Lockdown-Baseline
Impact
```

	DAILY_AQI_VALUE						
COUNTY	Arlington	Fairfax	Henrico	Roanoke	Hampton City	Norfolk City	Richmond City
Date							
April	-0.638202	-1.574510	-0.361686	-0.977778	-1.000000	-1.104167	0.171795
May	-1.161290	-1.329576	-0.299539	-0.865296	0.801792	-0.162693	-0.498247

```
Impact.mean().round(2).sort_values()
```

```
                COUNTY
DAILY_AQI_VALUE Fairfax        -1.45
                Roanoke        -0.92
                Arlington      -0.90
                Norfolk City   -0.63
                Henrico        -0.33
                Richmond City  -0.16
                Hampton City   -0.10
```