AIR POLLUTION AND CRIMINALITY IN BALTIMORE CITY, MD: DOES POLLUTION AFFECT RATES OF VIOLENT CRIME?

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AIR POLLUTION AND CRIMINALITY IN BALTIMORE CITY, MD: DOES THE CONCENTRATION OF PARTICULATE MATTER AND AIR QUALITY INDEX VALUE AFFECT RATES OF VIOLENT CRIME?

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ABSTRACT

The effects of pollution on human health, cognition, and behavior have been widely studied by researchers from a myriad of backgrounds. Findings of this sort of research have underpinned many public health interventions in the United States aimed at improving people's quality of life. Air pollution, a pervasive and often invisible threat, has been a central target of such policies and programs. This thesis intends to build on that momentum by couching the effects of air pollution within another perennial policy concern that is too often overlooked as a matter of public health: crime control. Building off of similar studies in the field, this analysis focuses on the concentration of $PM_{2.5}$ and rates of violent crime in Baltimore City, MD over a period o five years between 2014 and 2018. In better understanding the relationship between air pollution and violent crime, policymakers can design policies that simultaneously protects the public health from two persistent, existential environmental threats.

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CHAPTER ONE

Introduction

Over time, the effects of air pollution have been studied from a variety of angles, ranging from childhood development to far-reaching public health concerns. These fields are well-researched and documented. Within academic literature, however, the cognitive and social relationship(s) between air pollution and criminality has received little attention.

Emerging research has shown that high levels of air pollution increase violent crime in our communities (Herrnstadt & Muehlegger, 2015). Explanations for this phenomenon suggest that cognitive and psychological effects of such pollution can increase irritability and aggression, while decreasing rational thought, ultimately leading to proclivity to violence (Heyes & Saberian, 2015).

As the global community barrels rapidly towards climate change and widespread environmental decay, understanding the full spectrum of air pollution's impact on societal functioning is all the more imperative. Ever-warming global temperatures catalyze a positive feedback loop that creates conditions for increases in air pollution, which in turn lead to more warming (Environmental Protection Agency, 2020); global trends, then, suggest that air pollution will continue to mount and become more pervasive.

This interval-based, fixed effects research model builds on previous studies that have examined the relationship between levels of air pollution and trends of violent crime in urban areas by applying similar research methods to an unstudied city: Baltimore, Maryland. My research follows a general framework set forth by a group of economic researches from institutions around the world who have worked independently and in tandem to pioneer this intersectional field: Evan Herrnstadt, Anthony Heyes, Erich Muehlegger, and Soodeh Saberian. In turn, my work seeks to further discussion and analysis of the less-visible, yet important, impacts of air pollution. True to the findings of Herrnstadt, Heyes, Muehlegger and Saberian, I hypothesize that days with higher air pollution will also show spikes in violent crime. Their studies have unveiled statistical insights such as observing nearly a 4 percent increase in daily assaults based on a rise in ambient ozone pollution (Herrnstadt, Heyes, Muehlegger and Saberian, 2018). As this field of research expands, and other cities are incorporated into the field of analysis, novel findings can help inform policymakers interested in environmental causes and/or criminal justice as they develop policies to keep our communities safe from harm of any source.

Background

The impacts of pollution at large have been widely studied by environmentalists, climatologists, public health officials, economists, and psychologists. Over the decades, this research has produced many breakthroughs: most notably, a better understanding of childhood development and life outcomes (through the study of lead poisoning, for example) and the identification of invisible public health effects (ranging from groundwater contamination to airborne particulate matter) (Mason, Harp and Han, 2014). My research is framed within the context of these particular developments as I explore the relationship between air pollution and violent criminal activity.

Air pollution, of course, has been understood as a public health concern for some time. A plethora of research has unveiled the myriad health risks of both short and long term exposure to criteria air pollutants, including ground-level ozone and particulate matter (specifically, $PM_{2.5}$ and

PM_{10}) (American Lung Association, 2020). Policies, programs, and technological advancements have arisen from the knowledge produced in such studies.

Though not often framed as such, violent crime, too, is a public health concern. Public health encompasses community well-being as it relates to "the health of the community as a whole, especially as the subject of government regulation and support"; it is "the art and science [of] dealing with the protection and improvement of community health by organized community effort" (Merriam-Webster, 2020). As a matter of "government regulation and support" that deals "with the protection" of a community, violent crime falls within this purview.

My research merges these understandings to produce a statement about violent crime as an additional -- and increasingly threatening -- public health concern related to air pollution.

Evan Herrnstadt and Erich Muehlegger have greatly influenced this paper through their own research. In a 2015 study submitted for publication by the National Bureau of Economic Research, Herrnstadt and Muehlegger show that "downwind" areas of Chicago experience a greater number of violent crime offenses on heavy pollution days than do "upwind" areas. In their later co-authored paper, "Air Pollution as a Cause of Violent Crime" (n.d.), they explain the physiological and psychological underpinnings of this interplay, citing "biological evidence linking [ground-level] ozone exposure… to mood and emotional states that might sensibly be regarded as precursors or risk factors for violent criminal behavior" (Herrnstadt et. al., n.d.). Indeed, short term exposure to air pollution seems to reduce humans' capacity for irritation; feelings of stress, agitation, and impulsivity.

To date, studies on the relationship between air pollution and violent crime have focused on urban areas. This is significant for a few reasons. Air pollution is generally more prevalent in cities, due to both the volume of polluting activity that takes place there, as well as structural barriers like high-rises that block wind and trap pollution at ground-level. More importantly, however, is that cities are densely populated, and are only projected to increase in population size in the coming decades (United Nations, 2018). Not only will this increase the volume of polluting activities that take place in cities, it will increase human proximity and interaction, exacerbating conditions that are linked to crime rates. As countries across the world undertake the transition to urbanization, it is all the more important to understand how city environments drive social interactions, particularly as they relate to public health and safety.

Literature Review

Literature from a variety of sources and disciplines has been used to provide the foundation for this analysis. This section summarizes the most relevant studies and reports that have guided my research.

I. Air Pollution

A. Types of Air Pollution & Their Sources

Air pollution is undoubtedly the most ubiquitous form of pollution on the planet. Almost all human activity creates some sort of air pollution -- even breathing. Highly mobile by nature, air pollution is able to travel great distances and has dispersed effects that can span across entire geographic regions.

There are many types of air pollution, but the Environmental Protection Agency ("EPA") marks six in particular as "criteria air pollutants" -- those that are especially harmful to public and environmental health (EPA, 2018). These six pollutants are regulated by the EPA using National Ambient Air Quality Standards ("NAAQS") set forth by the Clean Air Act ("CAA"). These standards fall into two categories: primary standards, which are focused on public health protection, particularly for "sensitive" subsets of the population, like children and those with pre-existing respiratory conditions; and secondary standards, which are intended to protect the public welfare.

While each of the six criteria air pollutants can cause irreparable harm to both humans and the environment if left unchecked, this research will focus on the effects of just one: particulate matter. This sort of pollutant has been part of the analyses conducted by Herrnstadt et. al. and is also considered one of the most ubiquitous of the air pollutants, rendering regulatory efforts to struggle to meet success.

Particulate matter ("PM"), or particulate pollution, is a conglomerate of microscopic solid and liquid particles suspended in the air. The pollutant is categorized by size: coarse, fine and ultrafine. Those that are most commonly studied are PM_{10} and especially $PM_{2.5}$, within the coarse and fine categories, respectively. PM is formed by a multitude of sources, such as motor vehicle combustion, construction, and agriculture; as ground is broken for buildings and roads, and farmers till, irrigate, and harvest their crops, untold amounts of dust and water bits are released into the air where they combine with other chemicals and become pollutants. In California, a significant and growing cause of PM pollution is smoke from wildfires. PM pollution is perhaps the most common form of air pollution, precisely because of its myriad sources (American Lung Association, 2019).

B. Public Health Impacts

The primary health impacts of air pollution affect the respiratory system, but it is becoming increasingly clear that many other health and/or well-being complications can arise from both short and long-term exposure to air toxins.

PM pollution is sinister. Premature death is the greatest risk of PM exposure, irrespective of duration; this means that exposure to high levels of PM pollution for even a single day can cause swift mortality, from immediate death to decease within two months of inhalation. Of course, the risk only becomes greater as exposure lengthens. Older populations are most susceptible to such extremes, but PM pollution certainly does not discriminate against victims. Increased mortality amongst infants has also been observed, along with the development of asthma in children, and delayed functional growth in the lungs as children transition into their teenage years. Other health risks include cardiovascular complications, such as exacerbating COPD in adults and/or risk of heart attack.

C. Air Pollution in Baltimore, MD

In the early 2000s and into the 2010s, Baltimore's air pollution was not only recorded as the highest of all counties in the state, but also surpassed national averages in fluctuation over a period of years (Environmental Integrity Project, 2017). As such, asthma prevalence and respiratory-related hospitalizations reached alarming levels (Ibid.). Baltimore's location makes the city vulnerable to extremely potent sources of air pollution: nearby coal-fired power plants and trash incinerators. Travelling emissions from these polluters compound upon the heavy vehicle traffic and continuous construction throughout the city.

Much has improved in the last decade through legislation at the state and local level, but residents of Baltimore remain at risk. According to the American Lung Association's ("ALA") most recent State of the Air Report, Baltimore received a failing grade for the number of days ozone exceeded permissible levels; with regard to particulate matter, however, Baltimore received a stronger "B"-level score.

II. Understanding Criminality

A. Defining "Violent Crime"

The Federal Bureau of Investigation ("FBI") defines violent crime as "those offenses that involve force or threat of force" (FBI, 2020). These offenses fall into four categories: murder (including nonnegligent manslaughter), robbery, rape, and aggravated assault. Save for robbery, which for the purposes of this study are considered more closely related to property than violence as a behavior, these are the sorts of offenses that are studied in this thesis.

B. Violent Crime in Baltimore, MD

Baltimore regularly tops the lists ranking homicide rates in cities across the country. The city often exceeds 300 murders per year. A prominent drug culture and poverty rates that fluctuate between 20 to 25 percent are prone to drive residents into desperate circumstances. In fact, it has been reported that Baltimore's violent crime rates (including the categories beyond homicide) have reached as high as 64 incidents per 1,000 residents (Miller, 2012). Soaring crime levels, naturally, led to an increase in the number of police patrolling Baltimore streets; it is worth mentioning here that greater police presence keeps crime rates high due to more frequent arrests, but that alone does not account for the consistently high crime rates. Rates of rape are also notably high, ranging from 19 to 32 incidents per 10,000 residents in the years between 2010 and 2019 (Ibid.). On average, though, while violent crime rates remain high, they have been decreasing over the past decade.

CHAPTER TWO

Conceptual Model: Connecting the Dots between $PM_{2.5}$ Pollution and Criminality

This empirical analysis contributes to the branch of research that studies the psychological and neurological health effects of air pollution on human behavior in terms of criminality. For reasons still debated, and perhaps related, air pollution causes an increase in violent crime. The neurological perspective holds that these upticks are a matter of biology; as humans inhale air pollutants, the toxins are filtered into the bloodstream and eventually make their way to the central nervous system, where they cause inflammation and impair cognitive functioning. The psychological perspective suggests that pollution causes discomfort, which lends itself to stirring up aggressive or antisocial behavior in humans (Herrnstadt & Muehlegger, 2015).

Research Question:

Does particulate matter pollution and the resulting air quality index measure affect criminality in Baltimore, Maryland?

Hypothesis:

The null hypothesis of this study asserts that air pollution levels do affect criminality in Baltimore. If this hypothesis is confirmed there should be a statistically significant positive correlation between days of high air pollution and instances of crime.

Functional Model:

Conceptualizing violent crime as a function of air pollution and other natural factors that affect air pollution, the model follows this general structure:

$$violentcrime = f(air\ pollution + precipitation + average\ temperature)$$

Data and Methods

I. Data Collection

Crime is reported and collected at local, state, and federal levels. Data used in this analysis was sourced from Baltimore's participation in "The Python Project," a nationwide effort targeting key metropolitan areas, using Python to store and analyze the data. Baltimore's Python Project data spans decades; for the purposes of this research, however, the scope of analysis has been limited to 2014 - 2018 for the purposes of matching it with the most recent available air pollution data.

Air pollution data was collected from a monitor located near Baltimore's Inner Harbor. Though there is no way to accurately determine the radius of accuracy for the pollution observed, reasonable intuition underpins the assumption that differences in PM2.5 concentration recorded at this monitor are negligibly, if at all, different from concentrations in other parts of the city.

Average temperature and precipitation were collected from the nearest available monitor, located near the Baltimore-Washington International airport, about approximately ten miles beyond city limits. Again, educated extrapolation assumes that the levels of precipitation and average temperatures collected by this monitor are not significantly different from conditions within the city.

In conducting the regression analysis, a standard *fixed-effects model* reporting at yearly and seasonal intervals. For each independent variable, four separate models were run.

II. Defining Variables

Air pollution and instances of crime are measured in daily time intervals at the city level. $PM_{2.5}$ is measured and reported in micrograms per cubic meter (ug/m3 LC), with additional reference to the Air Quality Index (AQI), which serves as a scale indicating levels of air quality ranging from Good (0 to 50 on the Index) to Hazardous (301 and higher). Other factors that affect air pollution are also included in this analysis: average daily temperature, in Farenheit and daily precipitation, in inches.

Table 1: Data Description

Concept	**Operational Definition**	**Variable(s) & Measurement(s)**
Air Pollution	The level of $PM_{2.5}$ observed in a single day	*Daily means, maxes & minimums* of $PM_{2.5}$ observed per day in micrograms per cubic meter
Temperature	Average temperature for a 24-hour period	*Average temperature* in degrees Fahrenheit
Precipitation	Absolute measurement of rain in a 24-hour period	*Precipitation* in inches
Criminality	Instances of violent crime (murder, rape, aggravated assault, etc.) recorded in a given day	Daily aggregates of each specific violent crime (murder, rape, aggravated assault, common assault, and shootings), as well as the total number of all violent crimes committed in a given day

<u>Summary Statistics</u>

The following tables organize the data collected in substantive groupings and report basic, yet important characteristics of the data that help inform later analysis. Crime data is categorized by type of offense and sub-divided by year; for each year, daily statistics are summarized with key indicators including the average number of specific offenses per day (mean), the standard deviation, the maximum number of a given offense observed in a single day, and the minimum number observed in a single day.

Air pollution data is similarly categorized by indicator ($PM_{2.5}$ concentration [an absolute measurement], and AQI Index value [a relative, scaled measurement]), and is also sub-divided by year. For each year, the air pollution variables are summarized by mean daily value, standard deviation, maximum value observed on a single day, and minimum value observed in a single day. These air pollution indicators are then further sub-divided by season throughout each year. Because air pollution is so intricately affected by seasonal variables such as temperature and precipitation, this more detailed breakdown of the air pollution data provides clearer insight as to the fluctuations in means, maximum observations, and minimum observations at more frequent intervals during the given year.

Weather data is separated into its respective indicators – temperature and precipitation – and reported at seasonal intervals within each year. Summarizing characteristics are average measurement (whether in degrees Fahrenheit for temperature, or inches for precipitation), standard deviation, maximum single-day observation, and minimum single-day observation. Summarized as such, the following tables give a cursory illustration of crime and air pollution trends in Baltimore, MD.

I. Crime

Table 2: Aggravated Assaults per Day, by Year

Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	11.68	4.17	27	1	4,264
2015	13.05	6.67	90	3	4,763
2016	14.07	5.52	35	1	5,149
2017	16.01	4.97	31	3	5,843
2018	15.35	4.82	32	3	5,604
Aggravated Assaults per Day, 2014 - 2018					
2014 - 2018	14.03	5.05	90	1	**25,623**

Table 3: Common Assaults per Day, by Year					
Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	20.45	5.5	41	7	7,463
2015	19.16	5.2	38	5	6,992
2016	20.5	5.84	41	5	7,498
2017	23.98	6.21	45	5	8,751
2018	22.93	5.8	42	10	8,369
Common Assaults per Day, 2014 - 2018					
2014 - 2018	21.4	6	45	5	**39,073**

Table 4: Homicides per Day, by Year					
Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	0.58	0.81	4	0	211
2015	0.94	1.05	5	0	342
2016	0.87	0.99	5	0	318
2017	0.94	0.97	5	0	342
2018	0.85	0.99	5	0	309
Homicides per Day, 2014 - 2018					
2014 - 2018	0.83	0.99	5	0	**1,522**

Table 5: Rapes per Day, by Year					
Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	0.66	0.82	4	0	241
2015	0.78	0.95	5	0	283
2016	0.79	0.98	5	0	289
2017	0.99	1.05	6	0	362
2018	0.96	1.06	6	0	349
Rapes per Day, 2014 - 2018					
2014 - 2018	0.83	0.98	6	0	**1,524**

Table 6: Shootings per Day, by Year					
Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	1.01	1.41	6	0	369
2015	1.73	1.81	9	0	632
2016	1.82	1.71	11	0	666
2017	1.93	1.65	8	0	703
2018	1.85	1.81	11	0	677
Shootings per Day, 2014 - 2018					
2014 - 2018	1.67	1.68	11	0	**3,047**

Table 7: Crimes Against Persons per Day, by Year					
Year	Mean	Standard Deviation	Max	Min	Total for Period
2014	34.38	8.16	66	13	12,548
2015	35.65	10	102	11	13,012
2016	38.03	9.51	74	7	13,920
2017	43.84	9.35	74	12	16,001
2018	41.94	8.94	70	18	15,308
Crimes Against Persons per Day, 2014 - 2018					
2014 - 2018	38.77	9.88	102	7	**70,789**

II. Air Pollution

Table 8: $PM_{2.5}$ Concentrations per Day (in ug/m3), by Year				
Year	Mean	Standard Deviation	Max	Min
2014	10.28	4.77	32.9	2.1
2015	10.47	5.73	35.2	0
2016	8.31	4.34	35.7	0
2017	8.09	4.11	39.2	1.6
2018	9.19	4.42	25.2	1.2
$PM_{2.5}$ Concentrations per Day (in ug/m3), 2014 - 2018				
2014 - 2018	9.27	4.81	39.2	0

Table 9: AQI Values per Day (on a scale of 0 - 301+), by Year				
Year	Mean	Standard Deviation	Max	Min
2014	40.4	15	92	11.5
2015	40.42	17.65	8	98.5
2016	33.55	14.93	101.5	0
2017	32.83	14.42	110	6.5
2018	36.74	15.34	79	5
AQI Values per Day (on a scale of 0 - 301+), by Year				
2014 - 2018	36.8	15.83	110	0

Table 10: Pollution Indicators by Year, by Season						
Year	**Season**	**Metric**	**Average**	**Standard**	**Max**	**Min**
2014	**Winter**	**$PM_{2.5}$**	13.4	6.1	31.7	2.1
		AQI Values	49.4	16.9	95	11.5
	Spring	**$PM_{2.5}$**	9	3.3	32.9	4
		AQI Values	36.8	11.9	65	16.5
	Summer	**$PM_{2.5}$**	9	3.2	16.7	2.8
		AQI Values	36.8	12	61	12
	Fall	**$PM_{2.5}$**	9.8	4.6	21.8	3
		AQI Values	38.5	15.1	71	9
2015	**Winter**	**$PM_{2.5}$**	12.1	5.9	35.2	2.5
		AQI Values	45.5	17.6	92	10.5
	Spring	**$PM_{2.5}$**	9.1	4.5	29.9	0
		AQI Values	36.6	15.6	88.5	0
	Summer	**$PM_{2.5}$**	10.5	4.3	22.9	2.9
		AQI Values	41.5	14.1	73.5	12
	Fall	**$PM_{2.5}$**	10.2	7.5	34.5	2.4
		AQI Values	38	21.8	100	10
2016	**Winter**	**$PM_{2.5}$**	10.1	5.3	27.6	1.8
		AQI Values	39.5	17.1	83.5	7.5
	Spring	**$PM_{2.5}$**	7.5	3	20.9	3.1
		AQI Values	31.1	11.5	69.5	13
	Summer	**$PM_{2.5}$**	7.7	2.7	14	2.5
		AQI Values	31.7	11.5	55	0
	Fall	**$PM_{2.5}$**	8	5.2	36.2	0.5
		AQI Values	31.8	17.4	103	3.5
2017	**Winter**	**$PM_{2.5}$**	8.3	3.9	20.4	1.5
		AQI Values	33.5	14.4	68.5	6
	Spring	**$PM_{2.5}$**	7.3	3.4	16.2	1.6
		AQI Values	29.9	13.4	59.5	6.5
	Summer	**$PM_{2.5}$**	8	3.1	17.6	2.9
		AQI Values	32.8	12	62.5	11.5
	Fall	**$PM_{2.5}$**	9	5.7	40	2.3
		AQI Values	35.6	17.5	112	9.5
2018	**Winter**	**$PM_{2.5}$**	9	4.7	25.2	2.1
		AQI Values	35.9	16.1	79	9
	Spring	**$PM_{2.5}$**	8.5	3.7	19	2.1
		AQI Values	34.5	13.7	66	9
	Summer	**$PM_{2.5}$**	10.9	4.5	25.8	3.9
		AQI Values	42.6	14.4	80	16
	Fall	**$PM_{2.5}$**	8.4	4.4	22.5	0.8
		AQI Values	34	15.9	73	3

III.Weather

Table 11: Average Temperature (in degrees Fahrenheit) by Season, by Year					
Year	**Season**	**Average**	**Standard Deviation**	**Max Single-Day Average**	**Min Single-Day Average**
2014	Winter	33.2	10.4	54	10
	Spring	62.9	11.3	86	31
	Summer	72.4	5.4	84	59
	Fall	48	11	71	26
2015	Winter	33.4	11.7	67	9
	Spring	64.6	11.6	83	32
	Summer	74.6	4.8	86	63
	Fall	51.7	8	68	33
2016	Winter	39.2	11.5	69	15
	Spring	62.4	11	85	37
	Summer	77.3	5.6	89	61
	Fall	50	11.4	74	19
2017	Winter	40.3	11	65	18
	Spring	65.2	10	84	46
	Summer	73.7	6	86	60
	Fall	50.1	12.1	77	26
2018	Winter	37.4	10.8	12	66
	Spring	63.8	12.1	83	37
	Summer	76	5.6	87	61
	Fall	48.5	12.6	76	27

Table 12: Precipitation (excluding snow, in inches) by Season, by Year					
Year	**Season**	**Average**	**Standard**	**Single-Day**	**Single-Day Min**
2014	Winter	0.1	0.2	1.43	0
	Spring	0.2	0.6	3.99	0
	Summer	0.1	0.6	5.42	0
	Fall	0.1	0.3	1.15	0
2015	Winter	0.1	0.3	2	0
	Spring	0.2	0.4	2.8	0
	Summer	0.1	0.3	2	0
	Fall	0.1	0.3	1.7	0
2016	Winter	0.1	0.2	2.5	0
	Spring	0.1	0.2	1.3	0
	Summer	0.2	0.5	2.5	0
	Fall	0.1	0.2	0.9	0
2017	Winter	0.1	0.2	1.2	0
	Spring	0.1	0.3	1.74	0
	Summer	0.1	0.4	3.5	0
	Fall	0.1	0.2	1.1	0
2018	Winter	0.1	0.2	1.2	0
	Spring	0.2	0.5	3.2	0
	Summer	0.3	0.6	3	0
	Fall	0.2	0.4	2	0

CHAPTER THREE

Regression Results

Two different sets of regressions were run for this analysis: a standard linear model, and a log model. This was done with the intent of spanning prospects of interpretation, but the results of the regression analysis are not wholly conclusive. While it does appear that there is a statistically significant, positive correlation between $PM_{2.5}$ concentration and rates of violent crimes against persons, this effect is not observable across each individual type of violent crime (aggravated assault, common assault, homicide, rape, shooting). In fact, the only particular violent crime for which $PM_{2.5}$ concentrations were observed to have a statistically significant impact was aggravated assault (See Appendix A for full results).

Instead, seasonal changes and weather-related factors seemed to carry greater influence over rates of violent crime. Excluding rape, each category of violent crime displayed statistically significant fluctuations – both in the positive and negative direction – contingent upon changes in season, rising temperatures, or increased precipitation. Each of these variables is of course related to air pollution in some manner: on individual days and across seasons, heat in the atmosphere interacts with chemicals that comprise air pollutants in a positive feedback loop; wind speed and direction consistent with changing weather patterns may carry away or deliver masses of pollutants from one locale to the next; precipitation drives pollution levels down, while humidity exacerbates them. In light of these relationships, one could argue that PM2.5 concentration is part and parcel of these variables' impact on rates of violent crime. My research does not attempt to parse out these finer details, but the subject is addressed in other scholars' works that helped lay the framework for this thesis.

Discussion

That air pollution increases aggression leading towards aggravated assault is a conclusion corroborated by other studies in this field. The findings of the linear regression analysis convey that an increase of 20 ug/m3 in $PM_{2.5}$ pollution would result in approximately one more aggravated assault per day, on average. Referring back to the summary statistics regarding observed maximums and minimums in daily $PM_{2.5}$ concentration, it is evident that such increases, while they may not occur within the span of 24 hours, do occur throughout the year. While this evidence is not enough to support an indisputable causal link between air pollution and violent criminality, it further supports the hypothesis that rates of violent crime can change over the course of time with respect to fluctuating air pollution levels. Still, there are many considerations to account for when examining the specific relationship between air pollution and aggravated assault that the results of this research unveils.

As the summary statistics for the data illustrated, aggravated assault is second-largest contributor to overall incidents of violent crime against persons in the five-year period of this study. These incidents constitute a micro-sample within the larger dataset. An understanding that a larger sample size yields more reliable results is the cornerstone of statistical analysis; as it pertains to this research, one could argue that because aggravated assaults comprised 36 percent of all violent crimes in Baltimore recorded between 2014 and 2018, a clearer and more significant correlation between levels of air pollution and rates of this particular type of violent crime could be drawn.

Conversely, $PM_{2.5}$ appeared to bear no statistically significant impact on homicides, rapes, or shootings. Notably, the sum of each of these sorts of violent crimes over the five-year period amounts to less than a quarter of the total number of aggravated assaults recorded over the same timeframe. Therefore, it is plausible that the comparably little data available on homicides, rapes and shootings does not produce a statistically significant result not because one does not exist, but because the sample size is insufficient for thorough analysis.

Of course, that calls into question the outcomes of the regression as they pertain to common assault. Common assault is the most frequently recorded violent crime analyzed in this thesis, yet the p-value attached to both iterations of the $PM_{2.5}$ independent variable and both iterations of the AQI independent variable in the regression analysis are far beyond the boundaries of statistical significance. Why would $PM_{2.5}$ concentration have an impact on only one type of assault? That is query for future research.

Limitations

Data collection and subsequent analysis were limited in certain respects that may serve to explain, in part, the lack of clarity in the results of the regression analysis.

Data accessibility proved to be a significant constraining factor in this study. For my research, three distinct categories of geographically-based quantitative data were collected. The data varied across unit measurement, frequency of recording, and geographic designation. As such, it was extremely challenging to translate and consolidate the data into one coherent dataset.

Crime data was collected across the entire span of Baltimore City. Each observation was connected to a street address, and geographically organized by neighborhood. The data was reported daily, with the number of observations recorded per day varying.

The availability of pertinent data related to air pollution and weather trends for Baltimore City was scarce. For the entire city – comprised of 92 square miles – there was only one air pollution monitor registered through the EPA, located close to the heart of the city at the Inner

Harbor (See Appendix B for map). Further, the monitor only collected data about one relevant air pollutant: particulate matter. The data was collected on a daily basis and measured in absolute and index averages for that period of time.

Weather data was collected from beyond city limits, near the Baltimore-Washington International Airport (See Appendix B for map). This was the closest available monitor for the Baltimore City area. Data was collected at hourly intervals.

Due to the varied methods of collection that produced the data used for this study, the limited availability of collection points for the independent variables, air pollution and weather, and the disparities in geographic compatibility between the datasets, the results of this regression are not a conclusive as they otherwise would have been. While differences in major indicators such as air pollution concentration or temperature were likely minimal, if existent, there nonetheless may have been interactions between the independent variables and the variable of interest that went undetected due to underspecified data. A greater number of collection points that were dispersed throughout the Baltimore City area would have led to much more robust data collection that, in all likelihood, would have produced stronger regression results.

Policy Implications

The landmark Green New Deal (H. Res. 109), introduced in 2019, signified a palpable shift in the policy agenda as it called upon Congress to engage with climate change and environmental protection as a top national priority. The language is unambiguous: "it is the *duty* of the Federal Government to create a Green New Deal." Within this Resolution, legislators recognize that all types of pollution contribute to "systemic injustices" that affect "frontline and vulnerable communities" in terms of health, prosperity, security and wellbeing. Further, they lay the groundwork for policy development at the local level to attend to the unique challenges presented by pollution in individual communities; the proposed Green New Deal urges "mitigating and managing the long-term adverse health, economic, and other effects of pollution and climate change, including by providing funding for community-defined projects and strategies" on the part of the federal government.

The results of this study, bolstered by comparable findings from similar studies, implores lawmakers to reevaluate their regulatory approach to curbing air pollution and broaden strategies of crime prevention; existing endeavors such as the Green New Deal (though not yet cemented into formal legislation) encourage such innovative thinking and initiative at the local level, particularly in vulnerable communities.

Baltimore City has taken steps towards pollution control in its own right in recent years. Days after the Green New Deal was introduced to the House, in February 2019, Baltimore City Council unanimously approved the Baltimore Clean Air Act. This statute was designed to target the city's two greatest sources of air pollution – garbage incinerators – and force them to meet stringent pollution standards or face shutdown. Though signed into law by Mayor Pugh in March 2019, federal courts struck down the legislation the following year, in March 2020, citing "conflict" between the city's law and state law. Still tied up in the courts, the fate of Baltimore's Clean Air Act is uncertain, but nonetheless highlights the capacity of local governments to identify their own greatest risk factors – in this case, air pollution caused by incinerators – and take individualized action to mitigate them.

Crime prevention, too, is a perennial concern of Baltimore City's policymakers. Mayor Pugh released her Violence Reduction Update in 2017, where she laid out the strategy which would guide the city's approach to mitigating violent crime. She set out four overarching goals, of which the second is most relevant here: “Our strategies to improve Baltimore’s public safety [are focused on] … keeping Baltimore healthy by expanding resources and opportunities for people in need.” From the outset, this language affirms the link between health (i.e. exposure to air pollution) and violence. Further, the strategies are meant to “engage various community agencies, community groups and external partners, to reduce the violence that threatens the growth of Baltimore.” Broad-thinking, holistically-oriented policy design such as this encourages innovative collaboration between an array of stakeholders; it is through such pathways that two seemingly distinct public problems – air pollution and criminality – converge, become mutually validating, and can be dually targeted through creative legislation.

The policy behind Mayor Pugh’s Violence Reduction Update provides opportunity for statutes such as Baltimore’s Clean Air Act to become a central pillar of crime prevention. In such a model, crime prevention is recognized as an additional public health benefit to pollution mitigation, while reducing air pollution becomes a concurrent goal in reducing violence locally. This thesis shows preliminary evidence that supports this rationale. Studies such as my own invite policymakers to be pioneering in their approach to solving these public issues.

Conclusion

The data collected and used for this study were limited in several respects, causing the results of the regression analysis to be less compelling than in other iterations of similar research; nonetheless, the evidence presented here supports the growing multidisciplinary consensus that there is a correlation between greater levels of air pollution and higher incidences of violent criminality, while also illuminating ample opportunities for further study of this phenomenon.

Baltimore City, with its historically significant concentrations of air pollutants, chronic battle with urban violence, and emerging landscape for contemporaneous policy development addressing these issues, served as a prime locale for this study. The city is poised to become a "policy lab" for actions aimed at reducing air pollution and curbing violent crime rates in one fell swoop; continued research that explores the interplay between air pollution and criminality in Baltimore City is an integral component of actualizing this ideal.

APPENDICES

Appendix A: Regression Results*

Table 13a: Crime on Persons										
Independent Variable	Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.095	3.789	0.287	2.199	0.183	-3.41	0.809	3.217	8.947	7.337
P-Value	0.027	0	0.759	0	0	0	0.19	0	0	0

Table 13b: Crime on Persons										
Independent Variable	*(Log)* Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.7	3.73	0.23	2.19	0.183	-3.41	0.843	3.2	8.92	7.33
P-Value	0.089	0	0.804	0	0	0	0.173	0	0	0

Table 13c: Crime on Persons										
Independent Variable	Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.026	3.763	0.239	2.2	0.247	-3.766	0.825	3.183	8.94	7.33
P-Value	0.044	0	0.798	0	0	0	0.182	0	0	0

Table 13d: Crime on Persons										
Independent Variable	*(Log)* Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.66	3.7	0.21	2.17	0.18	-3.42	0.85	3.18	8.9	7.31
P-Value	0.14	0	0.823	0	0	0	0.17	0	0	0

* University formatting policies required that Tables 13 – 18 be abridged in the following manner. "Avg" stands for "Average." "Conc." Is abbreviated "Concentration." "Spr" is abbreviated "Spring," and "Sum" is for "Summer." "Precip" is abbreviated "Precipitation." The years (2015 – 2018) have been abbreviated to their most condensed form.

Table 14a: Aggravated Assault										
Independent Variable	**Avg Daily $PM_{2.5}$ Conc.**	**Spr**	**Sum**	**Fall**	**Avg Temp**	**Avg Precip**	**‘15**	**‘16**	**‘17**	**‘18**
Coefficient	0.049	2.25	1.24	0.94	0.065	-1.44	1.18	2.29	4.14	3.6
P-Value	0.047	0	0.029	0.008	0	0	0.003	0	0	0

Table 14b: Aggravated Assault										
Independent Variable	***(Log)* Avg Daily $PM_{2.5}$ Conc.**	**Spr**	**Sum**	**Fall**	**Avg Temp**	**Avg Precip**	**‘15**	**‘16**	**‘17**	**‘18**
Coefficient	0.36	2.22	1.21	0.93	0.065	-1.44	1.2	2.28	4.13	3.6
P-Value	0.157	0	0.033	0.008	0	0	0.003	0	0	0

Table 14c: Aggravated Assault										
Independent Variable	**Avg Daily AQI Value**	**Spr**	**Sum**	**Fall**	**Avg Temp**	**Avg Precip**	**‘15**	**‘16**	**‘17**	**18**
Coefficient	0.014	2.24	1.21	0.94	0.065	-1.48	1.19	2.27	4.14	3.6
P-Value	0.067	0	0.033	0.008	0	0	0.003	0	0	0

Table 14d: Aggravated Assault										
Independent Variable	***(Log)* Avg Daily AQI Value**	**Spr**	**Sum**	**Fall**	**Avg Temp**	**Avg Preci**	**‘15**	**‘16**	**‘17**	**‘18**
Coefficient	0.35	2.21	1.2	0.92	0.065	-1.44	1.2	2.27	4.11	3.6
P-Value	0.212	0	0.034	0.009	0	0	0.002	0	0	0

Table 15a: Common Assault										
Independent Variable	Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.037	1.05	-1.45	0.81	0.095	-1.66	-1.49	-0.23	3.26	2.33
P-Value	0.189	0.035	0.016	0.042	0	0	0	0.578	0	0

Table 15b: Common Assault										
Independent Variable	*(Log)* Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.26	1.02	-1.47	0.802	0.09	-1.67	-1.48	-0.24	3.25	2.32
P-Value	0.319	0.039	0.014	0.045	0	0	0	0.562	0	0

Table 15c: Common Assault										
Independent Variable	Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.009	1.03	-1.46	0.8	0.094	-1.66	-1.48	-0.24	3.25	2.32
P-Value	0.317	0.038	0.014	0.045	0	0	0	0.559	0	0

Table 15d: Common Assault										
Independent Variable	*(Log)* Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.22	1.003	-1.49	0.79	0.095	-1.67	-1.48	-0.25	3.23	2.32
P-Value	0.435	0.043	0.013	0.048	0	0	0	0.539	0	0

Table 16a: Homicide										
Independent Variable	Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	‘15	‘16	‘17	‘18
Coefficient	0.003	0.12	0.22	0.17	0.004	-0.122	0.34	0.27	0.35	0.27
P-Value	0.59	0.142	0.034	0.012	0.053	0.029	0	0	0	0

Table 16b: Homicide										
Independent Variable	*(Log)* Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	‘15	‘16	‘17	‘18
Coefficient	0.005	0.11	0.21	0.17	0.004	-0.125	0.34	0.27	0.34	0.27
P-Value	0.922	0.162	0.038	0.015	0.051	0.027	0	0	0	0

Table 16c: Homicide										
Independent Variable	Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	‘15	‘16	‘17	‘18
Coefficient	0.0008	0.12	0.22	0.17	0.004	-0.13	0.34	0.27	0.35	0.27
P-Value	0.606	0.145	0.037	0.012	0.052	0.024	0	0	0	0

Table 16d: Homicide										
Independent Variable	*(Log)* Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	‘15	‘16	‘17	‘18
Coefficient	0.0005	0.11	0.213	0.17	0.0042	-0.13	0.34	0.27	0.34	0.27
P-Value	0.993	0.166	0.039	0.015	0.05	0.026	0	0	0	0

Table 17a: Rape										
Independent Variable	Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.0003	0.063	-0.095	-0.047	0.005	-0.02	0.11	0.12	0.32	0.3
P-Value	0.949	0.494	0.394	0.523	0.045	0.716	0.109	0.086	0	0

Table 17b: Rape										
Independent Variable	*(Log)* Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	18
Coefficient	0.015	0.07	-0.09	-0.04	0.005	-0.017	0.107	0.123	0.323	0.31
P-Value	0.736	0.469	0.407	0.549	0.047	0.749	0.107	0.078	0	0

Table 17c: Rape										
Independent Variable	Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.0005	0.065	-0.095	-0.045	0.005	-0.02	0.107	0.12	0.32	0.31
P-Value	0.755	0.477	0.392	0.54	0.045	0.68	0.109	0.085	0	0

Table 17d: Rape										
Independent Variable	*(Log)* Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.022	0.07	-0.09	-0.043	0.004	-0.016	0.107	0.12	0.33	0.31
P-Value	0.664	0.461	0.411	0.559	0.049	0.762	0.106	0.075	0	0

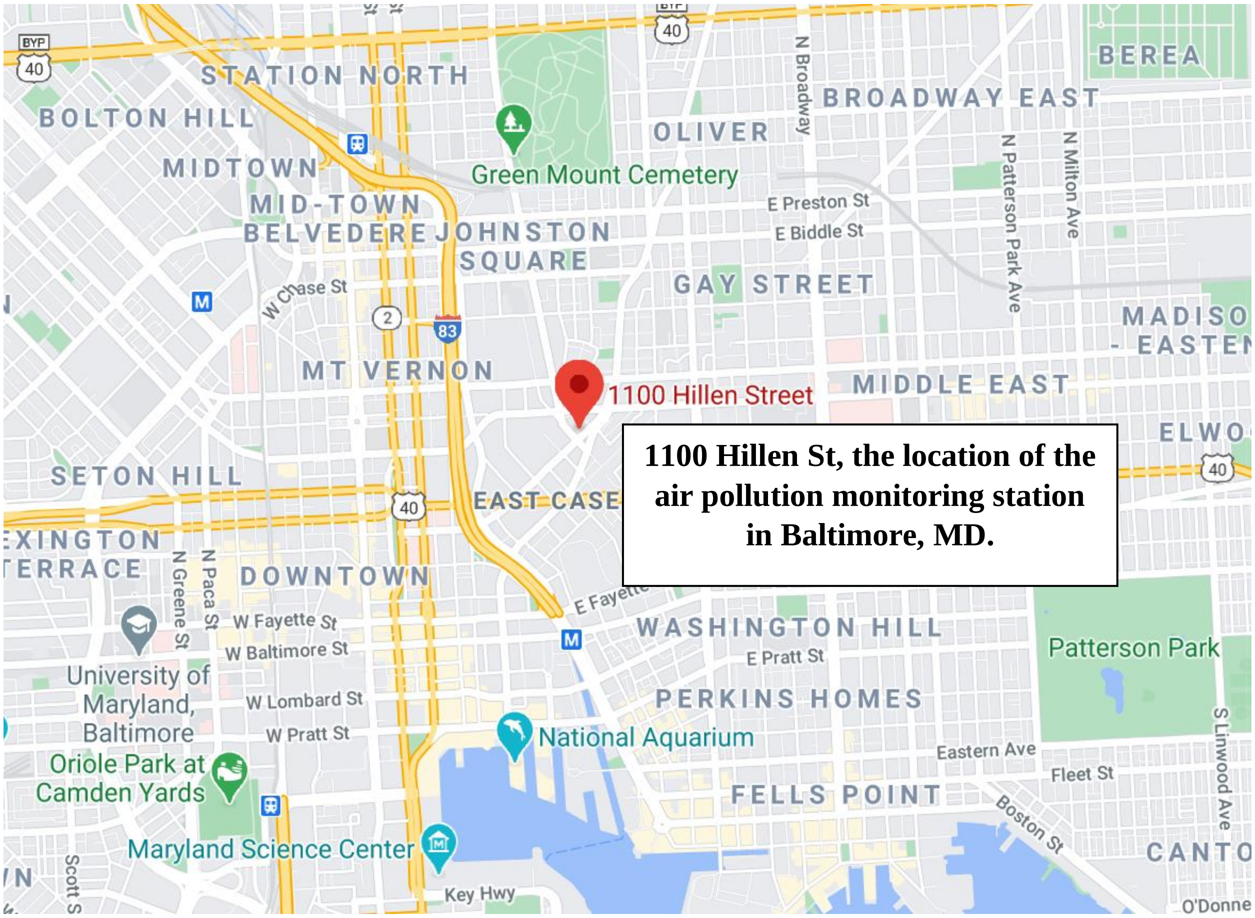
Table 18a: Shooting										
Independent Variable	Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.006	0.31	0.37	0.33	0.015	-0.17	0.68	0.76	0.87	0.84
P-Value	0.475	0.028	0.04	0.005	0	0.096	0	0	0	0

Table 18b: Shooting										
Independent Variable	*(Log)* Avg Daily $PM_{2.5}$ Conc.	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.057	0.31	0.37	0.33	0.015	-0.16	0.68	0.77	0.87	0.84
P-Value	0.48	0.028	0.04	0.005	0	0.104	0	0	0	0

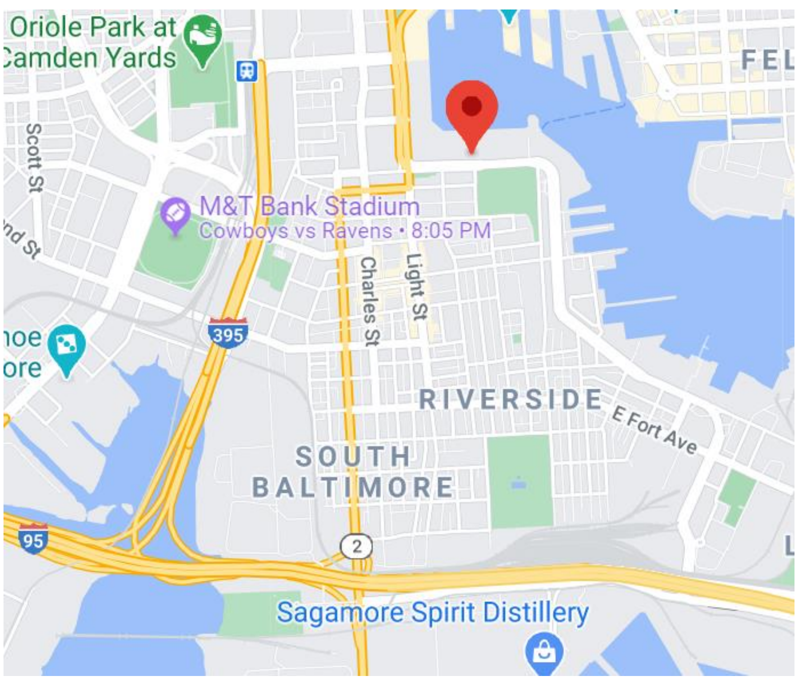
Table 18c: Shooting										
Independent Variable	Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.002	0.31	0.37	0.33	0.015	-0.17	0.68	0.76	0.86	0.84
P-Value	0.374	0.027	0.041	0.005	0	0.083	0	0	0	0

Table 18d: Shooting										
Independent Variable	*(Log)* Avg Daily AQI Value	Spr	Sum	Fall	Avg Temp	Avg Precip	'15	'16	'17	'18
Coefficient	0.065	0.31	0.37	0.33	0.014	-0.16	0.68	0.77	0.87	0.84
P-Value	0.461	0.028	0.04	0.005	0	0.106	0	0	0	0

Appendix B: Maps



1100 Hillen St, the location of the air pollution monitoring station in Baltimore, MD.



39°16'52.0"N 76°36'36.0"W / 39.281100, -76.610000 – the coordinates of the weather monitoring station.

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