Fine Particulate Matter and Low Weight Births in Mexico City, Mexico

Kennedy Cohn
University of Mississippi

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FINE PARTICULATE MATTER AND LOW WEIGHT BIRTHS IN MEXICO CITY, MEXICO

by
Kennedy Cohn

A thesis presented in partial fulfillment of the requirements for completion
Of the Bachelor of Arts degree in International Studies
Croft Institute for International Studies
Sally McDonnell Barksdale Honors College
The University of Mississippi

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Approved by

__________________________________________
Advisor: Dr. Kate Centellas

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Reader: Dr. Oliver Dinius

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Reader: Dr. Courtney Roper
ABSTRACT

Fine particulate matter (PM$_{2.5}$) exposure has been associated with several negative health consequences, and recent studies suggest a potential relationship between PM$_{2.5}$ exposure and adverse birth outcomes, including low birth weight (LBW). This thesis investigated a potential relationship between fine particulate matter concentration and low birth weight in Mexico City, Mexico between 2008-2016. Maternal pollution exposure was estimated at the city-wide level by averaging PM$_{2.5}$ measurements from various monitoring stations. Birth weight was collected from the SINAC database. Logistic regression models were run for different temporal scales (by trimester, and 10-month periods); however, there were no significant relationships found between PM$_{2.5}$ concentration and low birth weight. This study was limited in many ways. More research is needed to determine if specific PM$_{2.5}$ components are generated negative health consequences rather than mere concentration.
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ABBREVIATIONS

ABO  Adverse Birth Outcome
AMIA Mexican Vehicle Manufacturer’s Association
AQG  Air Quality Guidelines
CAA  Clean Air Act
CDMX Mexico City
CI   Confidence Interval
EPA  Environmental Protection Agency (U.S.)
GDP  Gross Domestic Product
HDI  Human Development Index
ICAPPO The International Collaboration on Air Pollution and Pregnancy Outcomes
IT   Interim Target
LAC  Latin America and Caribbean
LBW  Low Birth Weight
NOM  Normas Oficiales Mexicanas
OEEC Organization for European Economic Control
OR   Odds Ratio
PAH  Polycyclic Aromatic Hydrocarbon
PAHO Pan American Health Organization
PM   Particulate Matter
PM$_{2.5}$ Fine Particulate Matter (<2.5µm)
PM$_{10}$ Coarse Particulate Matter (<10µm)
PTB  Pre-Term Birth
<table>
<thead>
<tr>
<th>Acronimo</th>
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<tr>
<td>RAMA</td>
<td>La Red Automática de Monitoreo Atmosférico</td>
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<td>REDDA</td>
<td>La Red de Depósito Atmosférico</td>
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<td>REDMA</td>
<td>La Red Manual de Monitoreo Atmosférico</td>
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<tr>
<td>REDMET</td>
<td>La Red de Meteorología y Radiación Solar</td>
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<tr>
<td>ROS</td>
<td>Reactive Oxygen Species</td>
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<tr>
<td>SES</td>
<td>Socioeconomic Status</td>
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<tr>
<td>SGA</td>
<td>Small for Gestational Age</td>
</tr>
<tr>
<td>SIMAT</td>
<td>El Sistema de Monitoreo Atmosférico</td>
</tr>
<tr>
<td>SINAC</td>
<td>El Subsistema de Información sobre Nacimientos</td>
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<td>WHO</td>
<td>World Health Organization</td>
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Chapter 1 - Introduction

Ambient air pollution is a global health problem that affects millions of people by producing a multitude of adverse health consequences. In 2016, over 91% of the world’s population lived in cities that did not comply with the World Health Organization (WHO) air quality guidelines. (WHO, n.d.). That same year over 4.2 million premature deaths were attributed to ambient air pollution, which has been shown to cause cardiovascular disease, respiratory disease, and cancers. (WHO, n.d.). In addition to being a widespread phenomenon, recent literature has shown that air pollution has the ability to produce transgenerational effects. Pregnant women who are exposed to various types of air pollution potentially expose the fetus to these toxic environmental contaminants, which have the ability to induce poor perinatal outcomes, including low birth weight (<2,500g) and preterm birth. (World Health Organization, 2014, p. 1). Both of these outcomes are significant because they influence the infant’s health not only during the first year of life, but long-term as well. According to Harris et al., “Low birth weight (LBW) infants have mortality rates more than 20 times those of normal weight infants. They are at increased risk for neurological outcomes, particularly cerebral palsy. Low birth weight is associated with health issues in adolescence and beyond, including asthma, low I.Q., and hypertension.” (Harris et al., 2014, p. 2).

While there is a growing body of literature surrounding the issue of air pollution exposure and adverse birth outcomes, it is incomplete in several ways. As previous
studies have shown, air pollution composition can vary by location, and these individual components can be responsible for causing adverse outcomes. Thus, it is important to look at the observed effects in all parts of the world in order to develop targeted, local solutions to a global problem. Yet, there is a lack of research that exists for certain regions of the world, including Latin America. This thesis will focus on filling a gap in the existing literature by looking at the relationship between ambient fine particulate matter (PM$_{2.5}$) and the prevalence of low birth weight in Mexico City, Mexico.

1.1 Conceptualization of Air Pollution

Air pollution has not always been characterized as a “problem,” but in fact was once conceived in the opposite way- as a sign of “progress.” Beginning with the industrial revolution, factories, and tangentially their smokestacks, were seen as a sign of development that stemmed from modernization. The most industrialized cities of the time which were found in Western Europe, as well as the United States, did not begin to conceptualize air pollution as a health concern until decades later.

The middle of the 20th century proved to be a turning point with regards to air pollution because of two events that brought attention to the unseen danger. The Donora, Pennsylvania smog incident of 1948 and the “London Great Smog” of 1952 represent a turning point in the conceptualization of air pollution from progress to problem. The smog in Donora began as the result of temperature inversions which trapped the sulfur dioxide, nitrogen dioxide, and fluorine emissions of nearby steel plants close to the ground. This incident killed around 20 people and over 800 animals, while sickening up to 1/3 of the town’s population. The London Great Smog proved to have even more dire
consequences. Between the period of December 5th to 9th 1952, emissions from a coal processing plant produced a smog that blanketed the city of London and ultimately caused over 13,000 deaths. (Wexler & Anderson, 2014, p. 976). These episodes translated the unseen toxicity of air pollution into a very real human health threat, one with the potential to kill. This new understanding sparked a period of scientific inquiry and public concern which led to widespread efforts to understand and mitigate the effects of pollution.

After these urban pollution episodes, the World Health Organization (WHO) as well as the Organization for European Economic Control (OEEC) began pouring resources into studying this issue and providing information to European and the U.S. governments in order to control the problem. (Soto-Coloballes, 2020). In the U.S., these incidents led to the development of the Air Pollution Control Act of 1955 which was the first federal legislation concerning air pollution. While this act did not prevent the creation of air pollution, it allotted funding for research. In 1963, the Clean Air Act was passed “to improve, strengthen, and accelerate programs for the prevention and abatement of air pollution.” (Wexler & Anderson, 2014, p. 976). The Clean Air Act (CAA) encouraged the creation of emissions standards and was amended in 1967 to extend emissions standards to the national level and created Air Quality Control Regions to monitor ambient air quality. (Wexler & Anderson, 2014, p. 976). On an international level, in 1969 the WHO released air pollution monitoring protocols which led to the establishment of air pollution networks in several countries which are of central importance today. (Soto-Coloballes, 2020).
This brief history of the conceptualization of air pollution is limited in many ways but serves an important purpose of highlighting the central position of both the United States and Europe with regard to air pollution. The link between these regions as the first to “develop” and their early problems with pollution, situates air pollution as a problem of “modernized nations.” While today this paradigm may be changing as we begin to see a global understanding of the air pollution problem, I argue that because of the historical viewpoint of air pollution being connected to modernity, the scientific inquiries into this problem also followed the development trend with resources going to Western Europe and the U.S. first, and then permeating into less developed areas. Thus, it is not that developing regions such as Latin America altogether lack air pollution studies, but rather these regions seem to be studied after other regions when really, they should be at the forefront. Air pollution research should be of critical importance in developing regions because pollution tends to be very high in these regions, thus it is important monitor these levels and understand what potential impacts they have on the population. Pollution does not only threaten human health in developed countries but affects the majority of the world and research should reflect that.

A 2013 report by the WHO Regional Office for Europe highlights this lack of research when it mentions the “new” research that has developed between the time of the last report (2005) and the current publication (2013). The report mentions “A significant number of new prospective cohort studies from Asia, Canada, Europe and the United States have been reported since 2005” (WHO Regional Office for Europe, 2013, p. 7) and that “these Asian, Canadian, European and United States studies cover a variety of environmental settings, PM mixtures, baseline health conditions, personal characteristics
and health practices.” (WHO Regional Office for Europe, 2013, p. 8). Thus, this report highlights the fact that while air pollution studies are continuing to emerge and are being conducted in various parts of the world, there is a lack of research focused on Latin America.

### 1.2 Latin America

Air pollution in Latin America poses a chronic threat to health. While the region’s ambient air pollution levels do not rise to those of other regions such as Africa or Southeast Asia, the Pan American Health Organization (PAHO) states, “Air pollution is the largest environmental risk for public health in the Americas.” (Pan American Health Organization, n.d.). Figure 1 highlights the modelled PM$_{2.5}$ levels for Latin America which clearly indicate that an overwhelming majority of the region does not comply with the WHO standards for PM$_{2.5}$ concentration, which are 10µg/m$^3$. Pan American Health Organization, n.d.).
In addition to the fact that Latin America does not comply with WHO PM$_{2.5}$ guidelines, which means that its inhabitants are more likely to be exposed to higher levels of pollution and thus more likely to be adversely affected, Latin America is also an important region to study with regard to this issue because of socioeconomic trends. Over 80% of Latin America’s population lives in urban centers. (BBVA, 2017). This is of significance because anthropogenic air pollution tends to be highest in urbanized areas. Wang 2018 also notes that urban growth is expected to continue growing fastest in developing countries resulting in even more people facing the threat of ambient air pollution. (Wang, 2018). A note of further importance highlights the fact that while urbanization can positively affect health outcomes in some cases, “the favorable effects of urbanization on health outcomes were significantly reduced by air pollution in low-income countries.” (WANG, 2018, p. 1648) Thus, the positive health outcomes associated with living in an urban area are reduced due to the health consequences of air pollution.

Furthermore, Latin America possesses 13% of the world’s population and has a fertility rate of 2.0 which is higher than that of the European Union (1.5) and United States (1.7). (BBVA, 2017) (Fertility Rate, Total (Births per Woman) | Data, n.d.). The large concentration of population in this region combined with a relatively high birthrate further emphasize the need to study pollution in order to prevent adverse health outcomes in a large number of people now, and in the future.

Finally, Latin America presents a compelling region to study because of its inequality. Latin America has been deemed the “most unequal region in the world.” (Regional Human Development Report for Latin America and the Caribbean 2010, n.d.).
Inequality is an important characteristic to look at because it highlights the interconnectedness of various socioeconomic factors which have the ability to create a perpetual cycle of injustice which is exacerbated by environmental pollution. The link between inequality and air pollution is noted in the opening section of the REVIHAPP report which states, “There is significant inequality in exposure to air pollution and related health risks: air pollution combines with other aspects of the social and physical environment to create a disproportionate disease burden in less affluent parts of society.” (WHO Regional Office for Europe, 2013, p. 1). In another article, Laurent writes about “impact inequalities” which is the idea that people are not uniformly impacted by pollution, but rather the impact one faces is dependent upon other socioeconomic factors. She furthers this point by writing, “The results obtained by Janet Currie, who unveils the social-ecological perpetuation of poverty: children from poor families, Currie’s studies show, are more likely to be born in poor health due to the polluted environment experienced by their mother during her pregnancy, resulting in poor educational attainment and eventually lower income and lower social status. Injustice is then perpetuated in cycle, from environmental inequalities to social inequalities.” (Laurent, n.d.).

Air pollution further aggravates inequality because of the significant costs associated with it. As previously mentioned, air pollution has been linked to causing several different adverse health conditions, with poor birth outcomes representing just one category. While it is well-known that air pollution causes significant health problems, air pollution monitoring and enforcement is Latin America is still limited. A study by Riojas-Rodríguez et al. focused on analyzing the air quality control situation across the
Latin America and Caribbean (LAC) region. The study found that only about 20% of the LAC urban population lived in cities with air monitoring networks. Furthermore, PM$_{2.5}$ was only monitored in 13 out of 33 countries, and of the 57 cities that had PM$_{2.5}$ measurements, only 4 cities met the WHO 10µg/m$^3$ guideline. Figure 2 below was created as a part of this study and shows the average annual PM$_{2.5}$ levels for various cities. (Riojas-Rodríguez et al., 2016).

Figure 2 - Annual mean PM$_{2.5}$ concentration at Latin American cities
Figure 2 above shows the PM$_{2.5}$ measurements in relation to the WHO guideline as well as compared with the interim target (IT) goals, which are designed to help countries progressively lower their pollution levels. Figure 2 highlights the overall need to lower pollution levels across the region, while also demonstrating the variation that exists in fine particulate matter levels between countries and within countries. The lack of regulation has significant costs associated with it in terms of human health. In addition to the costs of other diseases, having a low-birth-weight infant can be very expensive.

According to Harris et. al, “Almond (2005) estimates the excess [U.S.] hospital costs for a 2 – 2.5 kg birth at $600, $6,800 for a 1.5 – 2 kg birth, and over $20,000 for lower birth weights.”¹ (Harris et al., 2014, p. 2). The high costs associated with these births continue the cycle of inequality by threatening the right to health of lower income people who may not be able to afford the necessary treatment.

Latin America presents several compelling reasons to be studied with regards to air pollution. However, one of the largest barriers to research is a lack of adequate infrastructure. In order to measure daily exposure, countries rely on air pollution monitoring networks which are a series of stations that contain the equipment necessary to collect a pollution sample and analyze its components as well as their concentrations. Mexico City presents an ideal case for this study because while it falls in the “developing” region of Latin America, it possesses the necessary monitoring networks with regard to both air pollution and birth data to be able to carry out this study. Figure 3 below shows the relatively sparse availability of data for Latin America compared to other regions. However, for the data that is shown, the majority of these measurements

¹ U.S. hospital costs, measured in year 2000 SUS
are above the WHO recommended levels. Figure 3 also highlights the relatively high prevalence of monitoring stations within Mexico. Chapter 3 will provide further details about Mexico City as a case study.


1.3 Conclusion

The present study will focus on informing the reader of the global health problem that exists with regard to air pollution by investigating the relationship between PM$_{2.5}$ exposure and low birth weight. By studying this trend in Mexico City, Mexico- within the context of Latin America as a developing region- this thesis will also argue the importance of conducting air pollution research in the global South where trends such as
urbanization, high fertility rates, and inequality put a large number of people at risk.

These studies are needed in order to provide governments with the information necessary to implement policies that reduce pollutant concentrations and/or components for the purpose of preventing future health consequences.
Chapter 2 - Background

This chapter is designed to provide the reader with an overview of relevant information regarding air pollution and its links to human health consequences. Included in this chapter are a brief introduction to air pollution and a literature review of reported associations between PM$_{2.5}$ and reproductive health consequences.

2.1 Air Pollution Introduction

Air pollution refers to the gaseous and particulate substances that are present in the air and hazardous to human health (National Institute of Environmental Health Sciences, n.d.). These components can come from natural or man-made sources such as wildfires and car emissions, respectively. Within the broad definition of air pollution, there are several sub-categories used to distinguish various pollutants. The common criteria pollutants monitored by the Environmental Protection Agency (EPA) include ground-level Ozone, Carbon Dioxide, Sulfur Dioxide, Nitrogen Dioxide, Lead and Particulate Matter (US EPA, 2014). There are other hazardous pollutants such as polycyclic aromatic carbons; however, these are not monitored by the EPA. For this study, I will be focusing specifically on fine particulate matter known as PM$_{2.5}$ which falls under the criteria pollutant of particulate matter (PM). Out of 57 cities that measure PM$_{2.5}$ in Latin America, only four comply with the Air Quality Guidelines set by the World Health Organization (WHO-AQG) (Riojas-Rodríguez et al., 2016, p. 154). The
World Health Organization has established guidelines for acceptable levels of air pollution in order to minimize detrimental health consequences that can arise from being exposed to higher levels of pollution. These guidelines vary depending on the type of air pollution. The average level of pollution in Latin America exceeds the WHO fine particulate matter (PM$_{2.5}$) guideline of 10 $\mu$g/m$^3$.

2.1.1 Fine Particulate Matter (PM$_{2.5}$)

Particulate matter refers to the mixture of solid and liquid particles in the air including dust, smoke, and drops of liquid that can be made up of hundreds of different chemicals (US EPA, 2016). Particulate matter is generally divided into two categories: coarse particulate matter (PM$_{10}$) and fine particulate matter (PM$_{2.5}$). These categories are distinguished based on their size, where PM$_{10}$ refers to particles with an aerodynamic diameter of 10 micrometers (µm) or less and PM$_{2.5}$ refers to particles with an aerodynamic diameter of 2.5µm or less (US EPA, 2019). Both of these classifications represent extremely small particles. PM$_{2.5}$ particles are roughly 30 times smaller than a single human hair (US EPA, 2016). The small size of these particles makes them particularly dangerous because they are able to diffuse into the bloodstream via the lungs and consequently create health problems in various bodily systems (Lippmann & Chen, 2009).

It is important to distinguish between coarse and fine particulate matter because each have unique characteristics. Coarse particulate matter tends to be made up of “primary” particles which are those released directly into the atmosphere from sources such as smokestacks, fires or construction sites. In contrast, fine particulate matter is
generally composed of “secondary” particles which are those that form as a result of complex reactions in the atmosphere (US EPA, 2019). Secondary particles represent the majority of particulate matter (US EPA, 2016). The reactions that form secondary particles rely on gaseous emissions such as sulfur dioxide and nitrogen dioxide which can be released from power plants, industrial plants, and other combustion sources. These precursor molecules then undergo complex reactions in the atmosphere where they generate secondary particulate matter (US EPA, 2019).

Another important distinction between coarse and fine particulate matter is their atmospheric behavior. Because PM$_{10}$ is generated by primary particles, it is released into the atmosphere near its source. The larger size of these particles results in them being airborne for only a short period of time. PM$_{2.5}$, however, can remain airborne for much longer periods allowing these pollutants to travel hundreds of miles away from the original source to locations where they may have an impact on human health (US EPA, 2019).

One of the contributing factors to the inherent danger of PM$_{2.5}$, is that fine particulate matter is not composed of one particular substance but rather hundreds of different chemicals. These chemicals, and their respective properties, are absorbed onto PM$_{2.5}$ which as previously discussed, can end up in the bloodstream. Once these chemicals are in the bloodstream, they are thought to create reactive oxygen species (ROS) through redox reactions. The capability to create these ROS is known as oxidative potential (Yadav & Phuleria, 2020). Identifying the oxidative potential of PM$_{2.5}$ and its various components is well-represented in the literature because of its importance for potentially understanding the human health effects. Because PM$_{2.5}$ is generated via
different sources, its composition varies with location. While scientists have not fully elucidated the oxidative potential of all PM$_{2.5}$ constituents, transition metals, polycyclic aromatic hydrocarbons (PAHs) and quinones are thought to negatively impact human health (Lavigne et al., 2018).

For the purpose of this study, I will be focusing on PM$_{2.5}$. The small size of PM$_{2.5}$ can produce significant health consequences because these particles are able to travel deep into the respiratory system where they can ultimately diffuse into the bloodstream. PM$_{2.5}$ is linked to several health consequences including respiratory diseases, cardiovascular diseases, cancer and reproductive health problems. In terms of respiratory diseases, PM$_{2.5}$ can affect lung development and is linked to emphysema, asthma, chronic obstructive pulmonary disease, and chronic bronchitis (National Institute of Environmental Health Sciences, n.d.). The cardiovascular effects associated with PM$_{2.5}$ include reduced blood vessel function and more rapid calcification of the arteries. Many cancers are also associated with air pollution, including breast cancer in women. In addition to the aforementioned health consequences, more recent investigations have begun to link air pollution exposure to adverse birth outcomes (ABOs). The next section of this paper will provide a literature review of past studies which have shown associations between PM$_{2.5}$ exposure and perinatal health outcomes.

### 2.2 Literature Review of Studies Linking PM$_{2.5}$ and Adverse Birth Outcomes

Research regarding the potential health implications of air pollution has become increasingly prevalent as studies show links between air pollution exposure and health consequences. One such subfield of literature focuses on the association between air
pollution exposure during the gestational period and adverse birth outcomes. Studies have accessed these interactions in a number of ways looking at different types of pollutants (PM$_{2.5}$, PM$_{10}$, as well as elemental pollutants) and correlating these exposures with adverse perinatal outcomes including preterm birth (PTB), small size for gestational age (SGA) and low birth weight (LBW). While this field of literature looks at a broad range of associations, the articles discussed below pertain to PM$_{2.5}$ exposure and low birth weight. Low birth weight is defined by the World Health Organization as births less than 2,500g (5.5lbs) and is of particular interest because of the potential health consequences associated with it (World Health Organization, 2014, p. 1). LBW is linked to infant morbidity and mortality as well as long term chronic health problems (Hao et al., 2016), (Kannan et al., 2006), (Ha et al., 2014, p. 2).

While several studies have been conducted regarding exposure to PM$_{2.5}$ and adverse birth outcomes, including low birth weight, results published across articles present inconsistent results. Several articles will be analyzed with special attention paid to differences in methods as well as potential limitations of the studies.

2.2.1 PM$_{2.5}$ Exposure and Low Birth Weight Studies: Methodological Variation

Attempting to study the relationship between PM$_{2.5}$ exposure and its effects on perinatal outcomes is challenging for multiple reasons. Like other health outcome studies, researchers are unable to utilize the traditional experiment method to determine causality because doing so would be unethical. Thus, researchers have relied on population studies in an attempt to observe an association between PM$_{2.5}$ exposure and potential impact on birth weight. In order to conduct these cohort studies, researchers have to operationalize
both the baby’s birth weight as well as the mother’s PM$_{2.5}$ exposure during a specified period. Past studies have relied on obtaining birth weight by accessing birth records for the population of interest and/or survey data collected at time of birth (Liu et al., 2019), (R. Li et al., 2019), (Wojtyla et al., 2020). While obtaining birth weight data is relatively straightforward, many factors are known to influence birth weight including mother’s age, birth parity, mother’s socioeconomic status, tobacco use, prenatal care, pre-existing health conditions in the mother, and the infant’s sex (Bell Michelle L. et al., 2007, p. 1). In some cases, researchers have access to data to control for these confounding factors; however, there is high variability among studies as to how these confounding factors are controlled for and furthermore which variables are controlled. An example of this variability can be seen by comparing a study by Hao et. al (2016) which estimates socioeconomic status by using the poverty percentage of each county while other studies such as Parker et al. (2011) use maternal education as an indicator for socioeconomic status (SES). This represents just one example of potential discrepancies which could contribute to inconsistency in results across the field.

Perhaps the variable of more concern, per the heterogeneous measurement across studies, is PM$_{2.5}$ exposure. There are several ways to measure/estimate the mother’s PM$_{2.5}$ exposure that differ based on availability of data such as the mother’s residential or work address, as well as infrastructure such as air pollution monitoring networks. In a review article by Sun et al. (2016) they identified the different exposure measurement methods as well as the source of this information. According to their findings across 32 studies, PM$_{2.5}$ exposure could be measured based on the individual level, semi-individual level or regional level, with data being collected from monitoring network data, emission and
land use data, remote sensing data, and personal monitor data. Individual level measurement was considered to be highly accurate because it relied on “complex dispersion models that included various databases including traffic, meteorology, roadway geometry, vehicle emission, air quality monitoring data, and land use.” (Sun et al., 2016, p. 40). Semi-individual exposure was based off of monitor data for the station closest to the subject’s residence, and regional exposure was calculated for all individuals within a region without accounting for individual differences in exposure (Sun et al., 2016).

In addition to differences in measuring or estimating PM$_{2.5}$ exposure, these studies also differ in the statistical methods used to determine association. Some studies measure associations by interquartile range increases (X. Li et al., 2017) while others use an increase of 10µg/m$^3$ or 5µg/m$^3$ (Pedersen et al., 2013). Studies also apply different statistical tests such as logistic regression with LBW being a categorical variable and PM$_{2.5}$ being measured continuously or linear regression models with birth weight also being measured continuously.

### 2.2.2 Variation in Exposure Period

Further variation exists in the period of exposure and whether a significant correlation was reported. Studies report findings based on exposures over the entire pregnancy, by trimesters or specific months; however, results tend to be inconsistent and thus require further research. Ha et al. (2014) in a Florida study concluded that exposure to PM$_{2.5}$ at any time during pregnancy increased the odds of LBW but found exposure during the second trimester to have the strongest association. Yet, in a study by Bell et al.
they found that exposure to PM$_{2.5}$ was only significantly associated with LBW during the third trimester.

2.2.3 Potential Mechanisms and Animal Studies

As previously mentioned, one of the largest limitations related to these studies is the inability to utilize the traditional experiment method. Thus, animal studies seek to enhance the existing literature by providing experimental evidence to back up epidemiological observations regarding PM$_{2.5}$ exposure and LBW. A study by Blum et al. (2017) used a mouse model to test the link between PM$_{2.5}$ exposure and whether adverse outcomes are linked to exposure during specific gestational periods. The study used four exposure periods to correspond with important gestational events. Period 1 represented fertilization and implantation, period 2 corresponded to placental development, vascularization, nutrient transport, and embryonic organogenesis, period 3 was the timeframe when placental maturation and rapid fetal growth occurred, and period 4 represented exposure across the entire gestational period (Blum et al., 2017, p. 7). The results found that exposure across the entire pregnancy reduced birth weight by 11.4% compared with the control group (filtered air). Furthermore, exposure during periods 1, 2, and 4 was significantly associated with a decrease in birth weight. While there are few animal studies that have been conducted, these experiments provide critical evidence that amplifies understanding of the results presented by observational cohort studies.

Because of studies such that by researchers Blum et al. which contribute evidence to an association between PM$_{2.5}$ and LBW, other areas of the literature have responded by
proposing potential mechanisms to explain how PM$_{2.5}$ could contribute to low birth weight.

Z. Li et al. (2019) highlights several potential mechanisms that link PM$_{2.5}$ exposure to adverse health outcomes including oxidative stress, DNA Methylation and mitochondrial DNA (mtDNA) content alteration, and endocrine disruption. Z. Li et al. explain that oxidative stress, which creates an adverse intrauterine environment, is caused by reactive oxygen species (ROS). PM$_{2.5}$ is thought to contribute to ROS formation in numerous ways including the organic chemicals on PM$_{2.5}$, the redox recycling of environmentally persistent free radicals, and the Fenton reaction which relies on certain metals contained in PM$_{2.5}$ (Z. Li et al., 2019, p. 251). Z. Li et al. also presents evidence for the DNA methylation and mtDNA content alteration. DNA methylation plays an important role in epigenetics and responding to environmental stimuli. DNA methylation and mtDNA content alteration change in response to PM$_{2.5}$ exposure and affect fetal growth and development. Lastly, Z. Li et al. highlights endocrine disruption as another potential mechanism. Endocrine disruption occurs when the components of PM$_{2.5}$ interfere with hormone synthesis which can negatively affect fetal development (Z. Li et al., 2019, p. 252).

This literature overview has focused on calling attention to differences between studies which may contribute to the inconsistency in results. Reducing inter study variability is important in order to better understand the association between PM$_{2.5}$ exposure and LBW. Because air pollution has the potential to affect a tremendous number of pregnant women as well as their fetuses, developing a consistent and reliable body of research is an important step toward being able to develop air regulation policies.
2.3 Conclusion

While methodological variations potentially help to explain why some researchers report associations between PM$_{2.5}$ and low birth weight while others do not, these variations do not fully account for the differences. The International Collaboration on Air Pollution and Pregnancy Outcomes (ICAPPO) in a study published by Parker et al. (2011) found that even when applying the same statistical methods across studies, there was still a variation in relationships with some places having a significant association between PM$_{2.5}$ and birthweight/LBW and others not. This study highlights a finding present in others as well, which suggest that it is not merely the concentration of PM$_{2.5}$ which must be taken into account, but the idea that specific components of PM$_{2.5}$ which may be responsible. Ebisu & Bell (2012) further the idea that specific chemical components of PM$_{2.5}$ are responsible for the association between exposure and birth weight (aluminum, elemental carbon, nickel and titanium).

These findings are significant not only for their potential policy implications which could focus on the regulation of specific chemical components, but also because they highlight the need to study the relationship between PM$_{2.5}$ and birth weight in diverse locations because of differing PM$_{2.5}$ constituent profiles (Snider et al., 2016).

The significance of differing PM$_{2.5}$ profiles across location calls attention to a potential gap within this field of literature which is where these studies are taking place. As noted by Sun et al. (2016) in their review and meta-analysis is that there appears to be an overrepresentation of some regions, with the literature pertaining mostly to certain countries/regions (USA/Europe). For example, 23 of the 32 articles included in their
review pertained to the USA. While it is not surprising that middle and low-income
countries are particularly understudied with regards to PM$_{2.5}$ exposure and perinatal
outcomes, it is important to recognize this gap and study these populations given that the
majority of the world’s births occur in developing countries (Fleischer et al., 2014).
According to Walker (2016), the developing world will account for 97% of the world’s
population growth between 2015 and 2050. The present study will help to contribute to a
gap in the literature by looking at the Latin American megacity, Mexico City.
Chapter 3 - Mexico City

3.1 Introduction

This study will focus on Mexico City for several reasons. As previously mentioned, there is a lack of literature that focuses on the world’s developing regions. Some research has been conducted in parts of Asia, yet the regions of Latin America and Africa are often underrepresented. While one reason for a lack of research in these regions is due to limited monitoring infrastructure, Mexico City was chosen because it has a highly developed, regulated, and reliable air pollution monitoring network. Furthermore, there is widespread availability of data for birth outcomes and other associated control variables (i.e. maternal education, mother’s age, parity etc.). Mexico City is a booming metropolis that has suffered from some of the worst air quality which due to its population size, puts a large number of people at risk and thus it is very useful to understand if there is a link between PM$_{2.5}$ and LBW in this region. This section will focus on providing context as to why Mexico has such a developed system with regard to pollution and birth data.

In 1992, the United Nations declared Mexico City as having some of the poorest air in the world. During the previous year, Mexico City’s air quality was linked to 44 environmental emergencies which had widespread societal consequences from closing down several industries and schools, to prohibiting vehicles from driving for 61 days that year (Silva Rodríguez de San Miguel, 2019, p. 579). These conditions were characteristic
of Mexico’s air quality during the early 90’s and ultimately led the government to take charge on a plan to reduce air pollution, which including no driving campaigns such as *Hoy No Circula* among others which will be discussed in greater detail later. This initiative led to the development of an extensive air pollution monitoring network in order to be able to track progress and monitor emissions, as well as the implementation of several different policies such as requiring better fuels and stricter emissions standards (Silva Rodríguez de San Miguel, 2019, pp. 579–580). This chapter will begin by addressing some of the factors that contribute to Mexico City’s high level of pollution and will then discuss more recent conditions.

### 3.2 Prone to Pollution?

Mexico City’s historic reputation as the world’s most polluted city can be attributed to various factors (O’Connor, 2010). One of the primary reasons for the high level of pollution was the rapid growth and industrialization of the city. Between 1950 and now, the population grew from 3 million people to over 20 million people in the greater Mexico City area (International Development Research Center, 2011). With the population growth, came an influx of personal vehicles, which serves as the city’s main source of pollution (International Development Research Center, 2011). As of 2011, there were approximately 3.5 million vehicles that were circulating in the metropolitan area. It is estimated that these vehicles accumulate a daily distance that is equivalent to about 5,932 trips around the Earth. Figure 4 below was created by the Mexico City government and shows the contribution of emissions by different sources.² Figure 4 highlights

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²Translation of figure: Title-Particles less than 2.5µm, Categories (top to bottom)- transportation, residential businesses and services, industry, other.
transportation as being the biggest contributor to PM$_{2.5}$ emissions within CDMX. In addition to transportation, industry also contributes about 13% of the total PM$_{2.5}$ emissions. According to the government, the manufacturing of mineral based products such as concrete as well as the food industry are the biggest emissions contributors within this category, together contributing about 7% of the fine particulate emissions (Gobierno de CDMX, n.d.-c).

![Figure 4- Contribution of PM$_{2.5}$ by various sectors. Source: Gobierno de CDMX. (n.d.-c). Principales generadores de emisiones en la CDMX - Partículas. Aire CDMX. Retrieved March 3, 2021, from http://www.aire.cdmx.gob.mx/default.php?opc=%27ZKBhnnWkYg=%27](http://www.aire.cdmx.gob.mx/default.php?opc=%27ZKBhnnWkYg=%27)

Furthermore, Mexico City’s pollution can be attributed in part to a high level of industrialization that occurred during development. Silvia Rodríguez de San Miguel writes, “According to Mayer (1999), the acute nature of the pollution issue in Mexico is explained by significant over-industrialization in the country’s largest and most densely populated areas, in fact it is an industrial powerhouse in Latin America” (Silva Rodríguez de San Miguel, 2019, p. 578). Additionally, as global production and trade continued to increase and developed countries began to implement stricter environmental controls,
polluting industries were sometimes transferred to places where such environmental regulations had yet to be put into force, such as Mexico (Silva Rodríguez de San Miguel, 2019, p. 578). Thus, Mexico did not only suffer from an abundance of industry but may have been the receptor country for several polluting industries.

3.2.1 Geographical Features Contributing to Pollution

In addition to the historic urbanization and industrialization that gave rise to Mexico City’s high levels of pollution, there are important geographical features that also impact air pollution levels. Mexico City is situated in an inland basin at roughly 2,240 meters (approximately 7,350 feet) above sea-level (World Meteorological Organization, 2015). Due to the high elevation, there are lower levels of atmospheric oxygen which results in incomplete fuel combustion (International Development Research Center, 2011). The incomplete fuel combustion produces molecules that serve as precursors to secondary particulate matter which then contributes to increased levels of PM$_{2.5}$ (Collins & Scott, 1993, p. 128).

The wind patterns in the city are also important. Winds generally enter the basin from the North or Northeast because the mountains are lower. This area of the city is heavily industrialized and has a large number of roads and railroads. Thus, the winds tend to blow into the city carrying the pollution from this area but are not strong enough to blow the pollution over the other mountains on the opposite side of the basin. Thus, the pollution remains suspended above the city (Collins & Scott, 1993). Another important relationship between air pollution and the city’s geography has to do with temperature inversions. During the winter months, Mexico City experiences thermal inversions that
result in particulate matter being trapped in higher concentrations at lower elevations.
During these polar inversions, the air is prevented from mixing vertically which leads to higher levels of pollution (Collins & Scott, 1993, p. 121). The Mexico City government refers to these winter months as “particle season” because of the increased levels of particles that are generated from holiday celebrations, the use of fireworks, and increased vehicle activity which are then trapped in the air because of polar inversions (Gobierno de CDMX, 2018).

3.3 Air Pollution Mitigation and Current Conditions

The high levels of pollution in Mexico City have led the government to take steps to create air pollution mitigation programs. As Molina (2019) highlights, “In Mexico, the right to clean air and a healthy environment is supported by different levels of Mexican legislations: (a) Constitution: Article 4 recognizes the right to a healthy environment, (b) the recent Constitution of Mexico City: Article 16 guarantees the right to a healthy environment and requires the development of public policies for the protection of the environment, including the atmosphere.” (Molina et al., 2019, p. 2). In addition to the rights endowed by the Mexican government on various levels, air pollution standards have also been addressed at the international level. In 2015, the U.N. created the “Agenda for Sustainable Development” in which three goals specifically deal with air pollution including, “3.9 (to substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination), 7.1 (to ensure universal access to affordable, reliable and modern energy) and 11.6 (to reduce the adverse per capita environmental impact of cities, including by paying special attention to
air quality and municipal and other waste management)” (Pan American Health Organization, n.d.). Thus, mitigating air pollution has garnered substantial attention on both the national and international level.

In Mexico, several steps have been taken to reduce pollution levels. The first air quality standards in Mexico were established in 1994 and have since been updated in 2014 as a part of the “Normas Oficiales Mexicanas” which establishes the PM$_{2.5}$ guideline at 12µg/m$^3$ (Molina et al., 2019) (Instituto Nacional de Ecología y Cambio Climático, 2020). Since air pollution monitoring began, air quality has improved significantly. Mexico was able to achieve a reduction in pollution levels through several different initiatives, most of which targeted transportation. These transportation-based initiatives ranged from reducing the number of vehicles on the road through “no driving days” to requiring stricter vehicle emissions standards and cleaner fuel.

One of the major reforms implemented was “Hoy No Circula” which was designed to prevent cars from driving one day a week. The program was first implemented to limit cars based off of the license plate number and while it was successful at first, the public reaction quickly became unfavorable which resulted some people acquiring second, often older and less efficient, cars in order to avoid the restriction. The program was later adapted to reflect the environmental impact of specific cars. Cars were assigned a “0” and were unrestricted if they were newer and had a catalytic converter, cars were classified as “1” and were not allowed to drive one day per week if they did not have a catalytic converter but had an electronic fuel injection system, and cars that were the least efficient were given a “2” and were prohibited from driving
one day a week and during air pollution episodes (Silva Rodríguez de San Miguel, 2019, p. 584), (Energy Policy Institute, University of Chicago, n.d.).

Mexico also reduced pollution by requiring stricter vehicle emissions standards and cleaner fuel. While the stricter vehicle emissions standards were originally opposed by the Mexican Vehicle Manufacturers Association (AMIA), the government responded by creating incentives for companies that manufactured vehicles according to the new standards such as being exempt from certain inspections. These incentives garnered a positive response from vehicle manufacturers (Silva Rodríguez de San Miguel, 2019, p. 584). Furthermore, fuel-generated pollution was mitigated by using unleaded fuel instead of leaded fuel and lowering the Sulphur levels in diesel (Silva Rodríguez de San Miguel, 2019, p. 580). In recent years, initiatives have continued to focus on transportation but have pursued new directions such as improving public transportation by introducing new fuel-efficient buses and also encouraging the use of bicycles as a means of transportation (Energy Policy Institute, University of Chicago, n.d.).

While these initiatives have no doubt been successful at lowering overall pollution, their success is limited to a certain extent. The progress that has been made has not been achieved uniformly for all pollutants and the overall air quality still does not consistently meet the standards set by the WHO or the Mexican government. Silvia Rodríguez de San Miguel notes that while Mexico has observed a significant decrease in primary pollutants, secondary pollutants (PM$_{2.5}$), have not been reduced to the same extent (Molina et al., 2019, p. 580). Thus, the potential health consequences attributed to

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3 Asociación de la Industria Automotriz (AMIA)
PM$_{2.5}$ still produce substantial concern and need to be studied. The next section will focus on the contemporary conditions in Mexico City and why it was selected as a case study.

### 3.4 Mexico City as a Case Study

While the introduction to this thesis discussed the significance of Latin America in the context of air pollution, this section will highlight why Mexico City was selected among other places. While Latin America as an overall region may not have as high of pollution levels as places such as Asia, Mexico City itself tends to have among the highest pollution levels in the region. In a recent study published in the Journal of Environmental Research, Vohra et al. (2021) investigated the global mortality associated from PM$_{2.5}$ generated by fossil fuel combustion. Figure 5 below was created as a part of this study.

![PM$_{2.5}$ from Fossil Fuel Combustion](image_url)

While at first glance it is easy to overlook the Americas in favor of focusing on the brightly colored Asia and Europe, upon closer consideration Mexico City stands out as having one of the highest PM$_{2.5}$ concentrations due to fossil fuel combustion. This is significant in the context of Vohra et al.’s study which concluded that the health effects attributed to PM$_{2.5}$ from fossil fuels are graver than estimated in previous studies. Despite reductions in overall pollution, Mexico City still has very high PM$_{2.5}$ levels which endanger the millions of people living there.

For the current study I will analyze the relationship between PM$_{2.5}$ concentration and low birth weight in Mexico City, Mexico during the period of 2008-2016. For the purpose of this study, the term ‘Mexico City’ refers to the federal district of Mexico City, commonly referred to as both ‘Distrito Federal’ and ‘Ciudad de México.’ Mexico City
presents an ideal case for this study because it is among one of the few cities in Latin America that has complete and reliable data for both air pollution and birth outcomes. According to a study by Riojas-Rodriguez et al., only 117 cities in 17 of the 33 Latin American and Caribbean countries have air pollution data, and of these very few have PM$_{2.5}$ measurements (Riojas-Rodríguez et al., 2016). A 2006 report by the World Bank also highlights a similar lack of air pollution monitoring capabilities among LAC countries. However, this report notes that there is not necessarily a distinct pattern that determines whether or not a country has air pollution monitoring networks. The report finds, “Distribution of resources to monitor air quality among selected countries is not clearly correlated with development indicators such as GDP, as one might otherwise expect. While advanced monitoring networks are indeed found in Brazil, Chile, and Mexico—countries with relatively high GDP per capita—this capability tends to be limited to a few cities, particularly in Brazil and Chile. In addition, in certain relatively wealthy countries where one would expect to find advanced monitoring capability—namely Argentina and Costa Rica—air quality monitoring networks are rudimentary or nonexistent.” (Della Maggiora & Andrés López-Silva, 2006, p. xiii). Thus, despite the report being fairly old, it highlights the important role of Mexico as one of the few LAC countries to possess air pollution monitoring capabilities, and more notably, the ability to monitor PM$_{2.5}$.

Mexico City also has a subnational Human Development Index (HDI) greater than 0.8 for the study period (2008-2016) (Sub-National HDI - Subnational HDI - Global Data Lab, n.d.). This signifies a “very high” level of development which is important in this study because birth outcomes depend on a multitude of other factors such as access
to health care, mother’s education level, socioeconomic status, etc. Because of the “very high” level of development, this study will not divulge into a nuanced analysis of potential inter-regional standard of living disparities, but rather will assume that the average standard of living is sufficient as to not distract from the purpose of the study. While in any city there are undoubtably differences in exposure between specific neighborhoods, these impacts may be more subtle and are not the focus of this study which is interested in examining population level effects.

Furthermore, because this study is concerned with the relationship between PM$_{2.5}$ and low birth weight, Mexico City is a suitable option because it has PM$_{2.5}$ levels that exceed the World Health Organization’s recommended level of $< 10$ µg/m$^3$ (World Health Organization, 2018b). According to the WHO’s ambient air pollution database, the average annual PM$_{2.5}$ concentration for Mexico City in 2018 was 22 µg/m$^3$, which is over twice the recommended concentration (World Health Organization, 2018a). Mexico City is the largest metropolis in North America, thus it is crucial to understand the impacts of air pollution in this area especially, because of the very large public health risk posed (Mexico City, Mexico Population (2020) - Population Stat, n.d.).
Chapter 4 - Research Design

4.1 Hypothesis

Based off of the work done in previous studies as addressed in Chapter 2, I hypothesize that there will be a statistically significant relationship between PM$_{2.5}$ levels and low birth weight. I expect to find that with increasing levels of PM$_{2.5}$ there is an increase in low weight births which will result in an odds ratio $>1$.

4.2 Methodology

4.2.1 Air Pollution: PM$_{2.5}$

In order to conduct my study, I have operationalized my variables in the following ways. For “air pollution” I am looking at the ambient (outdoor) concentration of PM$_{2.5}$. In order to obtain these measurements, I am relying on data collected by “el Sistema de Monitoreo Atmosférico” (SIMAT) which I accessed on the “Aire CDMX” website (Gobierno de CDMX, n.d.-a). The purpose of SIMAT is to measure the principal air pollutants in order to generate information about compliance with Mexico’s air standards (Normas Oficiales Mexicanas (NOM)), to quantify the population’s air pollution.

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4 Translation, “The Atmospheric Monitoring System”
5 Per NOM-025-SSA1-2014, the Mexican government permits annual PM$_{2.5}$ levels of 12 µg/m$^3$ which differs from the WHO’s recommendation of annual PM$_{2.5}$ exposure of 10 µg/m$^3$
exposure levels including possible health risks, and to generate data that can be used to
direct air pollution management strategies (Instituto Nacional de Ecología y Cambio
Climático, 2020) (Gobierno de CDMX, n.d.-b). The SIMAT contains 40 measurement
stations within Mexico City and the surrounding metropolitan area.

The SIMAT contains four sub-systems: La Red Automática de Monitoreo
Atmosférico (RAMA), La Red Manual de Monitoreo Atmosférico (REDMA), La Red de
Meteorología y Radiación Solar (REDMET), and La Red de Depósito Atmosférico
(REDDA). This study relies on data from the RAMA subsystem which has 34 stations
that measure sulfur dioxide, carbon monoxide, nitrogen dioxide, ozone, PM$_{10}$, and PM$_{2.5}$.
The RAMA measures PM$_{2.5}$ using methods recommended by the U.S. Environmental
Protection Agency (US EPA or EPA). These methods include gravimetry or attenuation
of beta radiation (Gobierno de CDMX, n.d.-b). The data collected by SIMAT is reliable,
as the measuring stations undergo regular auditing by an independent agency to ensure
that the machines are functioning properly, and that the recorded values are valid. The
audit reports as well as the collected data are published on the Aire CDMX website.

From the Aire CDMX website, I downloaded hourly measurements for the years
2007-2016. While this study is concerned with 2008-2016, in order to determine
gestational exposure to PM$_{2.5}$ for births in January-September 2008, data from 2007 is
needed. After obtaining the data and importing to Microsoft Excel, I filtered out
measurements that were recorded by stations outside of Mexico City. Based on the
“Estaciones de monitoreo”\textsuperscript{6} table on the Aire CDMX website, the stations outside of
Mexico City, which were therefore excluded were Acolman (ACO), Atizapán (ATI),

\textsuperscript{6} Translation, “monitoring stations”
Chalco (CHO), Cuautitlán (CUT), FES Acatlán (FAC), FES Aragón (FAR), Investigaciones Nucleares (INN), La Presa (LPR), Los Laureles (LLA), Montecillo (MON), Nezahualcóyotl (NEZ), San Agustín (SAG), Tlalnepantla (TLA), Tultilán (TLI), Villa de las Flores (VIF), and Xalostoc (XAL). These stations were excluded because they are in the State of Mexico, which is outside the geographical area of interest for this study. Table 1 below shows the stations used for each of the years as well as the number of valid and invalid measurements. The invalid measurements were represented by “-99” and were filtered out using Excel. Please see the footnotes for a complete list of the full station names.\(^7\)

**TABLE 1- STATIONS FROM WHICH MEASUREMENTS WERE COLLECTED, INCLUDING NUMBER OF VALID MEASUREMENTS AND INVALID MEASUREMENTS.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Stations</th>
<th># of Invalid Measurements</th>
<th># of Valid Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>MER, COY, UIZ, SJA, CAM</td>
<td>3803</td>
<td>39997</td>
</tr>
<tr>
<td>2008</td>
<td>MER, COY, UIZ, SJA, CAM</td>
<td>5239</td>
<td>38681</td>
</tr>
<tr>
<td>2009</td>
<td>MER, COY, UIZ, SJA, CAM</td>
<td>9530</td>
<td>34270</td>
</tr>
<tr>
<td>2010</td>
<td>MER, COY, UIZ, SJA, CAM</td>
<td>6018</td>
<td>37812</td>
</tr>
<tr>
<td>2011</td>
<td>MER, COY, UIZ, SJA, CAM, PED</td>
<td>8166</td>
<td>44394</td>
</tr>
</tbody>
</table>

\(^7\) Merced (MER), Coyoacán (COY), Camarones (CAM), UAM Itztapalapa (UIZ), San Juan de Aragon (SJA), Pedreal (PED), Hospital General de México (HGM), UAM Xochimilco (UAX), Centro de Ciencias de la Atmósfera (CCA), Santa Fe (SFE), Ajusco (AJU), Ajusco Medio (AJM), Benito Juarez (BJU), Gustavo A. Madero (GAM), Miguel Hidalgo (MGH), Milpa Alta (MPA), Cuajimalpa (CUA)
<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Observations</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>MER, COY, UIZ, SJA, CAM, PED, HGM, SFE, UAX</td>
<td>10905</td>
<td>68151</td>
</tr>
<tr>
<td>2013</td>
<td>MER, COY, UIZ, SJA, CAM, HGM, PED, SFE, UAX</td>
<td>7317</td>
<td>71523</td>
</tr>
<tr>
<td>2014</td>
<td>MER, COY, UIZ, SJA, CAM, CCA, HGM, PED, SFE, UAX</td>
<td>15898</td>
<td>71702</td>
</tr>
<tr>
<td>2015</td>
<td>MER, COY, UIZ, SJA, PED, CAM, AJM, AJU, BJU, CCA, GAM, HGM, MGH, SFE, UAX</td>
<td>37212</td>
<td>94188</td>
</tr>
<tr>
<td>2016</td>
<td>MER, COY, UIZ, SJA, PED, CAM, AJM, AJU, BJU, CCA, GAM, HGM, MGH, MPA, SFE, UAX</td>
<td>47236</td>
<td>93308</td>
</tr>
</tbody>
</table>

*Table 1 Continued*

### 4.2.2 Birth Weight

The second variable I will be looking at in this study is birth weight, with a specific focus on whether the birth is considered to be low birth weight (<2,500g). In order to operationalize this variable, I am relying on birth data collected through “el Subsistema de Información sobre Nacimientos” (SINAC). SINAC is a subsystem that falls under Mexico’s Secretary of Health. The purpose of SINAC is to collect data relating to the mother as well as the newborn child at the time of birth. The data collected...
includes sociodemographic factors, obstetric and prenatal data from the mother, as well as the newborn’s condition at time of birth.

After downloading information for 2008-2016, I filtered the data to only include variables of interest which included baby’s birthdate, location of birth, gestational weeks at birth, and birth weight. After filtering the data, I then excluded any births that did not take place within the federal entity of “Distrito Federal.” Next, I selected only births that occurred between 37-41 weeks. Births that occur during weeks 37-41 are considered “term births.” I choose to exclude pre and post-term babies because of the effect that their weights would have. Previously conducted similar studies also excluded preterm babies (Morello-Frosch et al., 2010, p. 3).

4.2.3 Sample Population

Due to the large number of cases that fit the criteria, a sample of 1000 births per year was collected to represent the population and to facilitate data manipulation. The sample was randomly chosen from the included births using the “RAND()” function in Excel. A random number was assigned to each of the cases which were then sorted from smallest to largest with the first 1000 births representing the population. This was repeated for each of the 9 years to yield a sample size of 9,000 term births in Mexico City for the period 2008-2016.

After the sample population was extracted, the variables were coded so they could be included in the statistical model. In addition to the dependent variable of birth weight (in grams), and the independent variable of air pollution exposure (which was broken into trimesters as well as 10-month averages), several control variables were also accounted
for. These variables included mother’s age, mother’s education level, birth parity, whether prenatal care was received and when the first visit was, and the baby’s sex. Studies have shown each of these variables to potentially affect birth weight (Bell et al., 2010).

For mother’s age, the variable was transformed to represent whether the mother presented an age risk. If the mother was younger than 20 years old or older than 35 years old, she was considered to be an age risk. Birth parity refers to the order of the birth and was coded in a similar manner. Nulliparity (the mother’s first birth) has been correlated with low birth weight (Shah & Knowledge Synthesis Group on Determinants of LBW/PT births, 2010). Thus, the birth was coded as “Parity Risk” if it was the mother’s first birth. Table 2 below presents an overview of the coding used.

**TABLE 2- VARIABLE CODING**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categorical Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother’s Age</td>
<td>&lt;20 or &gt;35 – age risk</td>
</tr>
<tr>
<td></td>
<td>20-35 – no age risk</td>
</tr>
<tr>
<td>Mother’s Education Level</td>
<td>None, less than high school, high school, some post-</td>
</tr>
<tr>
<td></td>
<td>graduate, post-graduate complete, some professional,</td>
</tr>
<tr>
<td></td>
<td>professional complete</td>
</tr>
<tr>
<td>Birth Parity (Birth Order)</td>
<td>Nulliparity (1st born) – risk</td>
</tr>
<tr>
<td></td>
<td>Previous births- no parity risk</td>
</tr>
<tr>
<td>Prenatal Care First Received</td>
<td>None, first trimester, second trimester, third trimester</td>
</tr>
<tr>
<td>Baby’s Sex</td>
<td>Male, Female</td>
</tr>
</tbody>
</table>
4.2.4 Statistical Analysis

The statistical analysis methodology applied to this data set was modelled after the procedure used by the International Collaboration on Air Pollution and Pregnancy Outcomes. Logistic regression was used with low birth weight (LBW) as the binary dependent variable and PM$_{2.5}$ concentration ($\mu$g/m$^3$) as the covariate. Two models were created. The first model as described above only included LBW and PM$_{2.5}$ concentration. A second model was generated to include other covariates such as maternal education, birth parity, mother’s age, prenatal care, and baby’s sex. All data was analyzed using SPSS 27.

4.3 Limitations

Because this study aims to look at a human health outcome, it is inherently limited in the sense that low birth weight, and health in general, are dependent on many factors. This makes it difficult to narrow the focus and attempt to look at the relationship between just two variables. In addition to other confounding factors, there are further limitations as well. First, this data only represents births that take place within the hospital system and not those that occur in other locations such as the home. Moreover, one of the greatest limitations is that this study approximates a mother’s exposure to air pollution by looking at the average air pollution for the federal entity of Mexico City. This is a limited way of considering a mother’s air pollution exposure because it does not account for the fact that some areas of the city represent much higher levels of pollution while other areas are lower. Thus, it is likely that exposures were overestimated for some
cases and underestimated for others. Finally, this study looks at birth that occurred in Mexico City which does not account for the fact that the mother could have travelled to Mexico City to have the baby or could have been there temporarily without living there—both situations that would not be accounted for by using the overall average air pollution of Mexico City.

Given the scope of this study and the availability of time and resources, the methodology described above was designed to be as accurate and valid as possible within the limiting circumstances. Nevertheless, there are weaknesses apparent within the study design.
Chapter 5 - Results and Discussion

5.1 Overview

This chapter will present the findings of the study in addition to providing descriptive statistics about the birth data and air pollution data that were used in the analysis. The chapter will begin with a discussion of the birth data including maternal and infant characteristics. The chapter will then follow with a discussion of air pollution averages for the selected period. Finally, the chapter will present the results from the statistical analysis which will be followed with an interpretation and discussion of the results.

5.2 Birth Data

This study included a total of 9,000 births that fit the inclusion criteria of being term births (37-41 weeks) that occurred within the federal entity of Mexico City. After excluding births that did not fit the criteria, a random sample of 1,000 births was selected for each of the nine years beginning with 2008 and ending with 2016. Among all the study births, the mean birth weight was 3,112g with a standard deviation of ±373.8g. 3.8% of the births were classified as low birth weight (n=340). The average weight of the LBW group was 2,330g ± 183.8g (normal birth weight average was 3,143 ± 344.9g).
Figure 6 below shows the distribution of the births which tends to follow a normal distribution pattern.

Additional maternal characteristics were analyzed that have been previously included in other similar studies because they are thought to be correlated with LBW. Among these included variables were mother’s age, birth parity, infant sex, maternal education (as proxy for socioeconomic status) and prenatal care. There were no significant differences between the prevalence of LBW among women in these risk categories. Women who were designated as being at risk for LBW because of age (<20 or >35 years) only represented a slightly higher percentage of the low-birth-weight population than those who were not an age risk (3.9%, 3.7% respectively). Table 3 below presents a full description of the included cases.
TABLE 2- CHARACTERISTICS OF STUDY BIRTHS (N=9000)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low Birth Weight (&lt;2500g, n=340 (3.80%))</th>
<th>Normal Birth Weight (n=8660 (96.2%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight (g)</td>
<td>2330 ± 183.8g</td>
<td>3143 ± 344.9g</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>172 (50.59%)</td>
<td>4437 (51.24%)</td>
</tr>
<tr>
<td>Female</td>
<td>168 (49.41%)</td>
<td>4223 (48.76%)</td>
</tr>
<tr>
<td>Birth Parity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity Risk (=1st Birth)</td>
<td>130 (38.34%)</td>
<td>3275 (37.28%)</td>
</tr>
<tr>
<td>Maternal Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age Risk (&lt;20, &gt;35)</td>
<td>95 (27.94%)</td>
<td>2351 (27.15%)</td>
</tr>
<tr>
<td>Maternal Education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>7 (2.06%)</td>
<td>80 (0.92%)</td>
</tr>
<tr>
<td>Less than high school</td>
<td>170 (50.00%)</td>
<td>4758 (54.94%)</td>
</tr>
<tr>
<td>High school complete</td>
<td>76 (22.35%)</td>
<td>2114 (24.41%)</td>
</tr>
<tr>
<td>Some post graduate</td>
<td>0 (0%)</td>
<td>4 (0.05%)</td>
</tr>
<tr>
<td>Post graduate complete</td>
<td>8 (2.35%)</td>
<td>131 (1.51%)</td>
</tr>
<tr>
<td>Some professional</td>
<td>1 (0.29%)</td>
<td>45 (0.52%)</td>
</tr>
<tr>
<td>Professional complete</td>
<td>78 (22.94%)</td>
<td>1528 (17.64%)</td>
</tr>
</tbody>
</table>
5.3 Air Pollution Data

During the study period, 2008-2016, air pollution data was collected and analyzed from stations in Mexico City’s air pollution monitoring network, SIMAT (Sistema de Monitoreo Atmosférico). Because the 2008-2016 timeline refers to the births that took place during those years, air pollution from 2007 was also included to correspond with the gestational period during that time. During the years for which data was analyzed, it was consistently above the WHO recommended level of 10µg/m$^3$. The calculated yearly average for included stations was highest in 2007 with a PM$_{2.5}$ concentration of 26.63µg/m$^3$ (± 5.17) and lowest in 2016 with an average of 21.83µg/m$^3$ (± 3.36). Thus, the average overall concentrations during the study timeframe were approximately twice that of the recommended level.

For the purpose of this study, yearly concentrations were not utilized but rather averages were calculated for each of the trimesters. Figure 7 below graphs the average PM$_{2.5}$ concentration by trimester for each of the corresponding birth months. There is significant variation among the average PM$_{2.5}$ concentrations by trimester due to seasonal variation in air pollution. There is a tendency toward higher pollution levels during the winter months given an increased use of apparatuses that create pollution (i.e., heating equipment, personal vehicles, etc.). This phenomenon, referred to as “particle season” (temporada de partículas) as mentioned in Chapter 3, is reflected in the graph below which tends to peak during the trimesters that correspond to the winter months (December, January, February). The cyclical spiking pattern reflects the annual pollution trends with fine particulate matter spiking during the winter both due to increased
emissions as well as atmospheric conditions that trap the pollution. (Gobierno de CDMX, 2018). The same pattern appears three times (yellow, blue, green) to reflect the timing of ‘particle season’ with respect to whether it corresponded with the first, second, or third trimester.

This study also looked at the relationship between 10-month PM$_{2.5}$ concentration and LBW in addition to the concentration by trimester. The calculated 10-month PM$_{2.5}$ concentration averages are displayed in figure 8 below. Note that the concentration values on the vertical axis of the graph below begin at 10µg/m$^3$, which is the WHO recommended limit. Thus, the averages for all 10-month periods were significantly above the recommended levels.
5.4 **Statistical Analysis**

The goal of this study was to identify whether there was a correlation between PM$_{2.5}$ concentration and low birth weight in Mexico City during the period 2008-2016. In order to determine whether there was a relationship, a logistic regression model was applied following the methodology described in Chapter 4. The logistic regression model used the binary outcome of LBW/not-LBW and regressed it with PM$_{2.5}$ concentrations from across different temporal scales (i.e. trimesters, and 10-month gestational period). The study applied two different models to obtain an unadjusted Odds Ratio as well as an Adjusted Odds Ratio. The first model used LBW as the dependent variable and PM$_{2.5}$ as the covariate. The adjusted model was run with LBW as the dependent variable and PM$_{2.5}$
exposure, age risk, parity risk, maternal education, infant sex, and prenatal care as the covariates.

The results are reported as odds ratios (ORs) which is a commonly used statistic among similar studies as well as within epidemiology more broadly. The odds ratio compares the probability of one event to the probability of another event by creating a ratio. This is done by looking at the odds that an outcome is present within an “exposed group” versus the odds that the same outcome is present among the “unexposed group”. For this study, the outcome of interest was low birth weight. While other studies have more “concrete” binary, exposure groups, this study used air pollution exposure as a continuous variable and thus the model produces an odds ratio for a 1 unit increase in air pollution exposure. In this study, the odds ratio was calculated by comparing the probability of LBW among mothers with higher exposure to the probability of LBW among mothers in the lower exposure group. An odds ratio that is =1 signifies that there is no increased risk associated with being in the “exposed group” (mothers with higher level of pollution) compared to the “unexposed group.” An OR <1 signifies that there is a lower probability, and an OR >1 indicates a higher probability. The ORs produced in this study are accompanied by lower and upper estimates for the 95% confidence interval (CI). A confidence interval that includes 1 (i.e. 95% CI, 0.97, 1.13), means that the results are insignificant. The table below shows the calculated ORs for model 1.
The results from model 1 were all statistically insignificant at the p<.05 level; however, the lower bound confidence interval was very close to 1, especially for the exposure period of Trimester 3 (95% CI lower, 0.994), and the 10-month exposure period (95% CI lower, 0.994). While the results are statistically insignificant at the population (sample) level, the Exp(B) is greater than 1 for each exposure period which suggests a possible tendency for a greater risk of low birth weight associated with increased exposure to PM$_{2.5}$.

The logistic regression model was run a second time, but this time included the covariates of maternal age (age risk), birth parity (parity risk), trimester when first prenatal care was received, and mother’s education level, and the infant’s sex. Despite factoring in these other variables, the model experienced virtually no changes in significance.

<table>
<thead>
<tr>
<th>TABLE 3- ODDS RATIO BY VARIOUS EXPOSURE PERIODS (MODEL 1, UNADJUSTED)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure Period</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Trimester 1</td>
</tr>
<tr>
<td>Trimester 2</td>
</tr>
<tr>
<td>Trimester 3</td>
</tr>
<tr>
<td>10-Month Period</td>
</tr>
</tbody>
</table>
TABLE 4- ODDS RATIO BY VARIOUS EXPOSURE PERIODS (MODEL 2, ADJUSTED)

<table>
<thead>
<tr>
<th>Exposure Period</th>
<th>Exp(B)</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>Trimester 1</td>
<td>1.006</td>
<td>.983</td>
</tr>
<tr>
<td>Trimester 2</td>
<td>1.003</td>
<td>.979</td>
</tr>
<tr>
<td>Trimester 3</td>
<td>1.017</td>
<td>.994</td>
</tr>
<tr>
<td>10-Month Period</td>
<td>1.034</td>
<td>.994</td>
</tr>
</tbody>
</table>

5.5 Discussion

The results obtained in this study did not align with my hypothesis which was that there would be an observable statistically significant relationship between low birth weight and PM<sub>2.5</sub> levels in Mexico City. The results proved inconclusive as they were not statistically significant. However, while the results from this did not provide evidence supporting a relationship between low birth weight and PM<sub>2.5</sub>, they do not provide evidence against this claim either. This study was structured to look at overall population level trends and relied on generalized estimations of pollution exposure. Thus, while there may not have been a statistically significant relationship at the population level, this does not mean that individual mothers are not still affected by the harmful consequences of fine particulate matter. The rigor of reaching p<.05 significance should be acknowledged as a potential limitation of the field in general. While achieving statistical significance is an important aspect in research, because of the complex nature of a multitude of factors it is important to not mistake a lack of statistical significance as
evidence of a lack of a relationship. These results suggest the need for further studies that have the ability to more accurately measure PM$_{2.5}$ exposure during the gestational period.

This study faced other limitations as well which may have influenced the ambiguity of the results. As mentioned briefly in Chapter 3, this study faced several limitations because it sought to investigate a human health outcome. The thesis was complicated by the fact that all cases were exposed to some level of air pollution and thus there was no “control” group. Herein lies another potential problem with the research design which is the intraregional variation in pollutant concentration. This study sought to look at the relationship between PM$_{2.5}$ concentration and the prevalence of LBW in the federal entity of Mexico City, which was estimated by taking the average of measurements from several different air pollution monitoring stations. Therefore, the concentrations used in this study do not represent raw measurements but have been manipulated in order to get an estimate of the PM$_{2.5}$ concentrations within the city.

This methodology can potentially misrepresent the actual exposure of the mother during pregnancy because the pollution concentrations differ by stations. For example, in 2014 the average PM$_{2.5}$ concentration was 22.16µg/m$^3$. However, the yearly average for the Santa Fe station (SFE) during the same year was 18.66µg/m$^3$, while the average for the Merced station (MER) was 26.18µg/m$^3$. While other PM$_{2.5}$ low birth weight studies have attempted to better control for this spatial variation by using various types of spatial modelling as well as different pollution measuring methods, this study noted the potentially confounding effect of intraregional concentration variation but did not have the means to control for it. This potentially impacted the significance of the data because it resulted in more generalized estimations of exposure compared to other monitoring
methods. Additionally, this study focused solely on ambient air pollution which does not account for the impacts of exposure to indoor PM$_{2.5}$.

Another potential limitation of this study was that it only looked at term low weight births. While this was present in other similar studies, it is possible that this exclusion criteria masked some of the effects of PM$_{2.5}$. Other literature has suggested that PM$_{2.5}$ can cause preterm births thus it is possible that the women in Mexico City who are negatively impacted by PM$_{2.5}$ exposure are suffering from preterm births which would thus exclude those cases from analysis.

A final factor that is worth noting with respect to the results of this study and that may be worth investigating further, is whether there is a certain PM$_{2.5}$ exposure threshold. The average levels of fine particulate matter concentration, even across different spatial (individual stations) and temporal (months, trimesters, gestational period, year) scales, exceeds the WHO recommended level of 10$\mu$g/m$^3$. Thus, perhaps being exposed to this elevated level of PM$_{2.5}$ masks the effects of variation above the threshold point. Because this study was limited in the sense that it was only able to compare participants who had been exposed to some level of pollution, and in all cases the estimated exposure level was >10$\mu$g/m$^3$, the lack of a “control” group may have inhibited the ability to draw statistically significant results.

Although this study may not have yielded statistically significant results, it makes a valuable contribution in highlighting what data exists with regard to both air pollution and birth data in Mexico City, and how future researchers may find these data sources helpful in their projects. This study highlights several potential research projects that would make valuable contributions to the literature, such as analyzing the PM$_{2.5}$
composition in Mexico City and whether there is a relationship with LBW, as well as investigating PM$_{2.5}$ exposure at the individual or semi-individual level which may be able to more accurately assess the relationship. On a regional level, this study makes a valuable contribution in highlighting the lack of literature that exists in Latin America with regards to PM$_{2.5}$ and its impacts on adverse birth outcomes specifically. It also highlights a potential lack of air pollution monitoring infrastructure as a challenge to scholarship development in this field.
Chapter 6 - Conclusion

The goal of this thesis was to explore the possibility of a population level relationship between fine particulate matter and low birth weight in Mexico City. Over the past two decades, research into fine particulate matter and specifically its effects on human health have become an important focus. PM$_{2.5}$ stands out among other pollutants as being particularly threatening to human health because of its small size. These microscopic particles are able to travel deep into the lungs where they diffuse into the bloodstream and react with cells in all parts of the body. More recently, these human health studies have transcended into the realm of reproductive health impacts. One such outcome, low birth weight, has received particular attention because it is tied to increased infant morbidity and mortality as well as long-term health consequences.

While there is a growing body of literature with regards to PM$_{2.5}$ and its impact on birth weight, the literature tends to focus on the global North or heavily polluted Asian cities, with little focus on Latin America. This thesis argues that there are several reasons that support studying this phenomenon in Latin America. Latin America as a region suffers from above recommended PM$_{2.5}$ levels especially in urban areas. This is significant because much of the region’s population lives in these urban centers, thus potentially exposing them further to dangerous pollution levels. Additionally, inequality has the potential to compound the health of effects of fine particulate matter. This is especially relevant in Latin America which is often characterized as being unequal.
One of the potential reasons that there is not much research relating to birth
related impacts of PM$_{2.5}$ in Latin America is due to limited air quality monitoring
networks across the region. Mexico is one of the exceptions to this trend, as they have a
reliable, widespread air pollution monitoring network. This is in part due to a history of
very polluted air quality which led the government to take initiatives to mitigate pollution
and monitor progress by developing a monitoring network. Both Mexico’s history of
polluted air, as well as the availability of data were important factors in selecting it as the
case for this study.

Despite this thesis not producing statistically significant results, air pollution
remains a critical and persistent global health challenge. As the world population
continues to grow, especially within developing countries, there will be more reliance on
vehicles and energy production- both of which contribute to PM$_{2.5}$ emissions. Thus,
research should not only be conducted in the global North, but rather across the globe in
order to help inform policy decisions and prevent negative health outcomes.
Chapter 7 - References


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