SEASONAL VARIATIONS OF AIR QUALITY IN GABON: CASE STUDIES OF LIBREVILLE AND FRANCEVILLE

by

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THESIS ABSTRACT

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Air pollution is becoming an increasing problem in Sub-Saharan Africa. Every year, it claims the lives of more than 712,000 people, which is more than the number of lives claimed by unsafe water and malnutrition. However, there is a lack of data on the topic in this region. I therefore designed my study to contribute to the small but growing literature on air pollution in Sub-Saharan Africa. My study looks at the relationship between local seasonal variations and air pollution levels. I am focusing on fine particles (PM2.5) because of their impacts on public health. My study revealed that average air pollution levels in Gabon meet the World Health Organization standards (WHO). However, daily variations suggest PM2.5 levels that exceed the recommended levels, which can be harmful to human health. I therefore recommend addressing pollution sources as a way of reducing overall pollution levels in the country.

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DEDICATION

To my mother, Mbomo Monique Epouse Asseko, who has always supported me and has sacrificed so much just to see me succeed. To my father, Asseko Mve Daniel, and my brothers, Asseko Darnick Karven, Mve Asseko Ivan Jeffry, and Ondo Asseko Axel Vladlain, who have always been there for me. To my husband, Juste Sylvain Obouonombele, and my best friend, Sandy Steven Assoko Mve, who share my daily struggles. Finally, to all the people who have supported me through my journey in one way or another.

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CHAPTER I

INTRODUCTION

Air pollution is becoming an increasingly big problem in Sub-Saharan Africa. Each year, more than 712,000 people die of premature death because of it (UNEP 2016). Air pollution, also called the "invisible killer," is now claiming more lives than malnutrition and unsafe water in Africa (Vidal 2016). However, governments and international organizations are still paying very little attention to the issue and prefer to focus their energy and resources towards infectious diseases (WHO 2016). Thus, there is a lack of research on the topic across the whole continent.

With the third highest GDP in the region, Gabon is one of the richest countries in Sub Saharan Africa. Between 1990 and 2015, the country's Human Development Index (HDI) increased from 0.62 to 0.67. This is an increase of 12.4%. However, these numbers hide a lot of inequalities (UNDP 2015). Despite the high HDI value; many Gabonese people are yet to meet their basic needs, including housing, healthcare, and food. The average Gabonese can only afford to buy second-hand cars. With more people migrating to urban areas, such as Libreville and Franceville in search of better living conditions, the number of cars has increased in the capital city. At the same time, the increase in urban population has created the need to build infrastructure such as houses, schools, and hospitals to accommodate them. Therefore, the increase in the urban population is leading to air pollution, a component of ever increasing environmental degradation.

The goal of my research was therefore to contribute to the small but growing literature on air pollution in Africa. I mostly focused on Gabon because this is the first study that is looking at how seasons impact pollution levels in the country. At the same time, this is the longest study on air quality in the country since the first study only lasted for three weeks (Ngo et al 2016).

For my research, I looked at how local seasons impact air pollution levels. At the same time, I also looked at which of my two cities had the highest pollution level. This study is important because air pollution is barely addressed in Africa. Even though air pollution is a growing problem on the continent, only a few countries have programs in place that monitor air quality. African countries are more focused on dealing with infectious diseases, which are still much prevalent on the continent and kill millions of people every year, than focus on air pollution. Therefore, air pollution is understudied and needs to get some attention now that it is killing more people than malnutrition and unsafe water.

My findings reveal that air pollution is definitely a serious problem in Africa and Gabon is no exception. Air pollution levels also differ between the seasons with the dry season resulting in higher pollution levels than the rainy season.

1. Overview

Gabon is a small sovereign state located on the west coast of central Africa (CIA 2012). It is bordered by Cameroon to the north, the Republic of Congo on the east and south, Equatorial Guinea to the northwest, and the Gulf of Guinea to the west (CIA 2012). The country has generally an equatorial climate made of two rainy and two dry seasons, a big and a small one in each case (CIA 2012). With a population of roughly 1.7 million people, Gabon is one of the least populated countries in Sub-Saharan Africa by ranking 46th out of the 54th countries on the continent (uneca 2015). Gabon's economy is mostly dependent on the extraction of minerals, such as oil and manganese. In fact, over the past five years, the oil sector alone has accounted for 80% of exports, 60% of budget revenues, and 45% of the GDP (WorldBank 2017). Before the discovery of oilfields, Gabon's economy was based on logging. Today, oil, logging, and manganese mining constitute the three main sources of income and employment in the country (Legabon.org).

Mineral extraction in Gabon started long before the country got its independence from the French in 1960 (BBC News 2015). After the French left, more oil reserves were discovered both onshore and offshores and the rate of extraction continued to increase, which brought huge revenues to the government and corporations such as Shell (afdb.org). Today for example, oil revenues account for 46% of the government budget, 43% of gross domestic product (GDP), and 81% of exports (Puthod et al.2015). However, even though Gabon has the third highest GDP per capita in the Sub-Saharan region, there are also huge inequalities in terms of income distribution. In fact, the richest 20% of the population earns more than 90% of the income while about more than one third of the population lives in poverty (BBC News 2015).

In addition, the lack of job opportunities in rural areas has forced many people, especially youth, to move to urban areas in search of better living conditions. According to the Central Intelligence Agency (CIA), Gabon's urbanization rate is about 2.7% per year and the total urban population accounts for 87.2% of the total population (CIA 2014). The most populated area is Libreville, the capital city of the country with a population of about 707,000 people (legabon.org). This increase in the urban population is putting more pressure on the environment because infrastructure must be built to accommodate the growing population. At the same time, there has been an increase in automobile use because as people get wealthier, they tend to buy more cars because urban cities demand the car as a mode of transportation, unless other mass transit options are available. (Galbraith 2014). However, despite the improvement in people's lives, the average Gabonese can only afford old cars, which emit a lot of atmospheric pollution.

2. Statement of the Problem

There is a general lack of data regarding air pollution monitoring in Africa and even more so in Sub-Sharan Africa. Carlos Dora, a coordinator in the WHO Public Health, Environment and Social Determinants of Health department, stated that the figures on air pollution monitoring in Africa are marked by an "N/A" symbol when he put up his slides on air pollution estimates around the world. This symbol is a way of showing how little is known about air pollution in Africa from an on-the-ground perspective, even though the problem is rapidly increasing (Chutel 2017). According to the WHO representative, most of the data they have on the continent is based on satellite images, existing emission inventories, and air pollutant estimates (Chutel 2017).

There are 54 countries in the continent of Africa in total. However, only a very small number of these countries are monitoring air pollution. Based on the World Health Organization, only five countries were monitoring PM2.5 as of 2006. These countries include Ethiopia, Ghana, Madagascar, Tanzania, and Zimbabwe (Shwela 2006). Since then, monitoring has even stopped in some of these countries while it has started in others. As of 2013, nine Sub-Saharan countries were monitoring air pollution. These countries include Algeria, Ghana, Nigeria, Senegal, Botswana, Tanzania, South Africa, Madagascar, and Mauritius. Ethiopia and Zimbabwe were taken off the list (WHO 2016). In four of these countries, the monitoring was for less than one year and it was very challenging accessing some of these countries' reports. For example, some reports are not available online, therefore, it was impossible for me to access them. The other reports that were online had missing information such as the period of time of the study.

In the past few years, a few programs were created to increase air pollution monitoring in Sub-Saharan Africa. However, with time, some of these programs were phased out. One such program was the Regional Air Pollution in Developing countries sponsored by the Swedish International Development Cooperation Agency (OECD 2016). The program was stopped because of the lack of funding and the lack of interests from countries, which preferred to focus their resources and energy toward infectious diseases among other things because of their immediate impacts on the population. At the same time, looking at the magnitude of infectious diseases, compared to chronic diseases, in Africa, the WHO and other organizations and governments prefer to invest in curing those diseases and care less about chronic diseases (OECD 2016).

As the population continues to grow, it is likely that the continent of Africa will release more pollution than China today (Vidal 2016). However, African countries are not in the position of China, which now has the means of tackling environmental pollution. African countries still have to struggles with other "more important" issues such as unsafe water and sanitation, malnutrition, and HIV (Vital 2016). That same point was reinforced by a WHO official who stated that after industrialization and improvement in public health, developed countries now have the means of protecting the environment. However, African countries must struggle with industrialization and environmental protection at the same time. This makes it hard for them to attain the sustainable development goals because unfortunately, they are putting more energy and efforts into developing so that they, also, can improve the overall health of their population before thinking about environmental protection.

3. Purpose and Significance of the Study

The purpose of this study is to contribute to the small but growing literature on air quality monitoring in Sub-Saharan Africa. In fact, there is a general lack of data on air quality in Africa. Even when there are data, studies are either conducted over short periods of time (a couple of weeks to a couple of months) or do not incorporate the influence of local seasonal variations on pollution levels. Plus, the lack of air quality research and monitoring in the region prevents the drafting and implementation of strong policies aimed at protecting the environment as well as public health. Therefore, I hope that this study will not only increase the knowledge on air pollution in Africa and particularly in Gabon but that it will also help draft and implement policies that protect both human health and the environment.

4. Research Questions

I formulated my research questions based on the gaps I observed in my literature review. In fact, even though there are some studies about air quality monitoring in Africa, very few of these studies, if any, look at local factors that could impact air quality. Such factors include seasonal variation as well as country specific sources of pollution. Based on my literature review, I therefore formulated two research questions:

a. What is the relationship between air quality and local seasonal variations? In other words, how do local seasons impact air quality?

b. What pollution sources might have greater impact on air quality? This question will be answered through the results of my analysis comparing Libreville to Franceville

5. Hypotheses

a. My first hypothesis is that air quality is worse during the dry season compared to the rainy season because there are a lot of activities that only take place during the dry season. At the same time, precipitations can disperse particulates, therefore, reduce pollution levels.

b. My second hypothesis is that air quality in Libreville, which has more cars than Franceville, will be lower than in Franceville because based on the literature, automobiles are among the major sources of outdoor air pollution.

CHAPTER II

LITERATURE REVIEW

Air pollution can be defined as the release of pollutants into the air. Air pollution includes many pollutants such as particulate matter (PM), nitrogen dioxide (NO2), and carbon monoxide (CO) (Pope et al. 20150). Among all these pollutants, PM has the greatest impacts on public health (Pope et al. 2006). Worldwide, there are more deaths per year as a result of air pollution than automobile accidents (sciencedaily 2016). The pollutants, which are made up of very small particles, can easily penetrate the lungs and cause severe health issues (WHO 2016). The main reported problems include lung malfunction, chronic and acute respiratory diseases such as asthma, adverse pregnancy outcomes such as premature birth, and in extreme cases, death (NIH 2016). As of today, more than 80% of the people living in urban areas worldwide are exposed to air pollution levels that exceed the WHO standards and people in low income countries are more affected than the rest of the world (WHO 2016). Even studies conducted in low income countries reveal difference in exposure between low income neighborhoods and high income neighborhoods. The first pilot study on air quality in Gabon revealed that people living in low income neighborhoods and close to roadways are exposed to higher pollution levels than people living in high income neighborhoods (Ngo et al 2016).

The World Health Organization (WHO) argues that ambient air pollution, especially fine particulate matter, which are airborne particles that have an aerodynamic diameter of 2.5µm or less ($PM_{2.5}$), is one of the greatest environmental issues today and causes over three million premature deaths every year around the world (WHO 2016). In 2012 alone, air pollution killed about 3.7 million people worldwide (Loury 2016). According to data published by the WHO, between 2008 and 2013, there has been an increase of 8% in particulate matter, especially in China, India, Southeast Asia, and many Middle Eastern countries (Loury 2016). The WHO estimates that more than 8 out of 10 people living in urban areas worldwide are exposed to pollutants far exceeding the WHO standards of 10ug/ m^3 for annual mean and 25ug/m^3 for 24-hour mean for $PM_{2.5}$ and 20ug/m^3 for annual mean and 50ug/m^3 for 24-hour mean for PM_{10} (Loury 2016). Most of the deaths occur in low and middle income countries and tend to affect mostly children under the age of five and the elderly. (Margilus et al. 2006). At the same time, studies have also shown that women are more vulnerable to air pollution compared to males. This would be related to the predisposition of the females to be more susceptible to develop respiratory diseases than males (Yoshizaki et al 2014). A report from the WHO from 2008 to 2013 showed that air pollution in WHO's Eastern Mediterranean and South-East Asia regions had levels between 5 and 10 times the WHO limits. Data on Africa are lacking but available information suggests that particulate matter levels are above the median. Therefore, developing countries share a higher death toll than their developed counterparts (WHO 2016). The latest air quality database of WHO states that 98% of cities in low income countries have levels of pollution that far exceed the WHO limit, while that number decreases to 56% in the developed countries (2016).

A study conducted in Ulaanbaatar over the course of two year from 2010 to 2012, Mongolia, measuring particulate matter ($PM_{2.5}$), revealed that 24-hour mean air pollution averaged about 70ug/m^3 in the city. This number is almost three times as high as the international standards set by the WHO (WHO 2015). This high pollution resulted in high rates of pneumonia in children, responsible for about 130 annual premature deaths, and cardiovascular disease in adults, accounting for approximately 1440 annual premature deaths (2014).

1. Air Pollution in Africa

There is little ground-based data regarding air pollution on the continent of Africa, even though it is one of the largest rapidly urbanizing global environments (Chutel 2017). Most of the data obtained by the WHO are gathered through satellites images, air pollution estimates models, and existing emission inventories (Chutel 2017). Death figures per capita from the WHO show that levels of ambient air pollution in Africa are below the world average; however, the lack of on-the-ground data is a major barrier to obtaining more accurate figures (Galbraith 2014). According to the WHO, there is very little air pollution monitoring on the continent because African countries are more focused on other problems (Galbraith 2014). Monitoring, implementing, and enforcing air quality standards require the use of fixed monitoring stations (Kumar et al. 2015, Snyder et al. 2013). However, those fixed monitoring stations cost thousands of dollars and therefore are inaccessible to many developing countries (Ngo et al 2016). At the same time, that equipment requires maintenance, which can also be costly for those countries. Because of the high cost of air quality instruments, countries would rather spend that money on infectious diseases such as HIV/AIDS, malaria, and Tuberculosis.

However, air pollution in Africa is reaching very worrisome levels that have greater impacts on the population compared to malnutrition and unsafe water. Air pollution in Africa is causing more premature deaths than childhood malnutrition, unsafe sanitation, and unsafe water (Vidal 2016). If not controlled, the problem could turn into a health and climate crisis. A study conducted by the WHO, looking at populationweighted concentration levels in the world found high levels of pollution in Egypt, Mauritania, and Libya with averages of 104.7ug/m³ 85.1ug/m³ and 79.2ug/m³ respectively (Fagan 2017). In comparison, India and China had levels of 74.3ug/m³ and 58.4ug/m³ respectively. However, levels varied by provinces (Fagan 2017). With a population of roughly 182 million people, Nigeria is the most populated country in Africa. About 94% of the population is exposed to levels of air pollution exceeding the WHO standards (Kuo 2015). Attempts to calculate the financial and human cost of air pollution suggests that in Africa, about 712,000 people are dying every year because of air pollution (Vidal 2016). When compared to 542,000 from unclean water and 275,000 from malnutrition, one can realize the devastating effects of air pollution on the continent. Annual deaths from ambient air pollution across the continent have increased by 30% from 1990 to 2013. The economic cost of premature deaths is estimated at roughly $215 billion a year (Vidal 2016).

Air pollution can be a result of urbanization, automobiles, industries, open cooking fire, open waste burning, unpaved roads, or weather conditions, among other factors (WHO 2016).

2. Urbanization and air pollution

It is estimated that by 2025, the urban population worldwide will double to more than five billion people. 90% of that increase will happen in developing countries. (Blacksmith Institute). Africa has the highest urbanization rate worldwide with an increase of five percent each year (Blacksmith Institute). Unfortunately, an increase in urbanization also means an increase in air pollution because more charcoal is used for cooking and the increase in cars also leads to more burning of petroleum. (Blacksmith

Institute). Studies have shown that an increased urbanization rate also leads to increased air pollution (Lin et al 2001).

A study conducted in Taiwan revealed that air pollution is greater in urban areas, followed by semi-urban areas, and then rural areas (Lin et al 2001). Another study conducted in Burkina Faso in 2007 revealed that air pollution is likely worse today than it was 10 years ago, because the population in the capital city of Ouagadougou has increased by more than 50%. The same study revealed that Gaborone, Botswana is the eight most polluted cities in the world due to its growing urbanization rate (Galbraith 2014). Finally, studies in Nairobi, Kenya have shown that levels of particulate matter in the air are 10 times higher than WHO standards (Svensoon, 2015).

3. Automobiles and air pollution

Old and unregulated automobiles are among the major sources of outdoor air pollution (IEA 2014). Cars are responsible for about 85% of the particulate matter, and almost all of the sulfur oxides and nitrogen oxides present in the atmosphere. A study conducted by the University of Toronto revealed that 25% of cars and trucks are responsible for 90% of the total pollution emitted from the world's vehicle fleet (Richard 2015). These are mostly old cars that have trouble properly burning already dirty fuels. Automobiles are therefore, the single most important man-made source of pollution (IEA 2014). Diesel, which is the fuel most used for transport, generates more than half the nitrogen oxide produced globally and leads to respiratory problems such as asthma and bronchitis (IEA 2014).

Air pollution in Africa is also increasing even though the continent has the lowest level of greenhouse gases emissions. This is mostly due to the use of fossil fuels in transport and the lack of regulations (SEI 2013). The GDP per capita in the continent is among the lowest worldwide (IEA 2014). Therefore, it is still very challenging for people to even afford cars in the first place. Most people who can afford cars can only purchase second-hand and poorly maintained cars that emit more pollution than newer and more energy efficient cars (Richard 2015). In addition to having a lot of old cars, many countries do not invest enough money into public transport to discourage the use of old cars, therefore, people have no other choice than relying on these old cars to get about their daily routines (IEA 2014). In addition, ride sharing options such as Uber, which is known to contribute to pollution, is also used in some countries such as Kenya. However, because those rides sharing options are not yet adopted by the majority of African countries, it is hard to quantify their effects on air pollution.

One way to try to reduce air pollution has been to completely phase out lead from gasoline. This was done in Egypt in the 2000s (IEA 2014). A more drastic way to reduce pollution would be to remove sulfur from gasoline for example. However, only a small number of African refineries have the capacity to produce low-sulfur fuels. In addition, low sulfur fuels are more expensive than regular fuels, which many African people cannot afford. Therefore, there is also a lack of incentive from refineries to produce those low sulfur fuels because they cannot make a lot of money out if it (IEA 2014). The Environmental Protection Agency has stringent regulations that push fuel manufacturers to move more toward cleaner energy. For example, companies who produce dirtier energy tend to pay more in carbon taxes than those producing cleaner energy. Therefore, companies are forced to produce cleaner energy in order to pay less in carbon taxes (EPA 2017).

In addition, even though some countries such as Nigeria, Egypt, and Gabon have regulations that prevent the importing of old cars to prevent the dumping into those countries of outdated and inefficient cars, these regulations are less likely to be effective (IA 2014). In 2015, the Gabonese government passed a law that prohibited the import of cars older than three years and with a mileage of less than 6000km (Gabonese presidency 2015). A few exceptions include cars that are used by religious groups, diplomats, and expatriate returning home (Gabonese presidency 2015). This regulation was meant to reduce pollution by decreasing the number of old cars that enter the country. However, those regulations have also resulted in unattended consequences.

One consequence of the policy is that people are now using their cars much longer than they used to, leading to greater air pollution. For example, instead of using a car for ten years and then resell it to buy a new, more efficient car, people are now keeping their cars for 15 to 20 years because they now have a difficult time purchasing newer cars from overseas. Therefore, the reduction in air pollution from cars remains a very challenging issue which many developing countries, more particularly African countries, are still struggling to address.

Another consequence is that people are now using other techniques to import their cars. For example, instead of purchasing their cars and importing them to Gabon, people now import them to either Cameroon or Equatorial Guinea. Once there, the cars are registered and then can easily enter Gabon based on agreements, which allow the free movement of people and cars between these countries, as long as the cars and people are lawfully on the territory. Once the cars enter Gabon, they are registered in Gabon and can freely start operating

4. Mass Transportation and air pollution

Mass transportation is one effective way of reducing air pollution. In fact, a bus or light-rail train can accommodate hundreds of people at once and therefore they reduce the number of cars on the road. For example, the new urban metro in Addis Ababa can accommodate about 60,000 passengers per hours. As of now, about 200,000 people are riding it every day (the Economist 2015). This greatly reduces the number of cars on the road and therefore reduces air pollution.

However, mass transportation is still very limited in sub-Saharan Africa. In fact, as of 2015, only two countries, South Africa and Ethiopia, had light rail trains (the Economist 2015). Buses are also very limited and do not serve the majority of the population in these countries. Consequently, minibuses, shared taxis, trucks, and personal cars fill up the gap (lonely planet 2017). This results in more cars on the road and greater air pollution.

Gabon is no exception to the issue. In fact, the whole country only has one public transportation company called Societe Gabonaise de Transport, simply called SO.GA.TRA (Sogatra 2013). The company mainly serves the capital city of Gabon and just recently started serving a few other cities, leaving the remaining of the country without public transportation. In addition, even though SOGATRA can transport hundreds of passengers every day, there are not enough buses to serve the cities they are operating in. Even the buses that are available are not reliable because, during rush hours, the buses are stuck in traffic for hours. Therefore, the majority of people still have to rely on other modes of transportations, including personal cars to go about their daily activities. This once gain results in more cars on the road and greater air pollution.

5. Open cooking fires and air pollution

Approximately 3 billion people worldwide still rely on solid fuels for cooking, heating, and energy generation. Most of these people live in low and middle-income countries (Pope et al. 2015). Of this number, 2.4 billion use biomasses, such as wood, while the remaining people mostly use coal (Bruce et al 2015).

Woodfuels which comprise firewood and charcoal are the most important energy sources in many developing countries (Brouwer et al.2006). This can be explained by the fact that in many developing countries, woodfuel is still the most available, affordable, and sometimes even cost-free cooking and heating fuel (Pokhrel et al.2015). Usually, woodfuels make up 50%-90% of all the energy consumed in a country (Miranda et al. 2010). This is for example the case of Uganda, Sierra Leone, and Mozambique.

Asia is the continent with both the highest levels of production and consumption of woodfuel. As a matter of fact, India and China consume more than one quarter of the global production of woodfuel (Brouwer et al.2015). While Asian consumption has decreased by 3.2% between 2008 and 2013, consumption in Sub-Saharan Africa has continued to increase, but has remained mostly stagnant in Latin America [FAO Stat 2013]. A study conducted in Uganda in 2000 revealed that 93% of the energy consumption comes from woodfuel such as firewood and charcoal (Tabuti et al 2003). 95% of the wood supply is used to generate energy. 15-20% of the wood supply is used to produce charcoal. Another study conducted in 2010 stated that by 2015, 75% of the population would still heavily rely on woodfuel to meet their energy needs (Ministry of energy and mineral development 2001). However, it is not clear what share of the wood is used for household cooking. (Tabuti et al 2003). Solid fuel combustion releases air pollution that can have high health impacts, especially related to respiratory and cardiovascular diseases. Some of the pollutant that are released include, but are not limited to, carbon monoxide (CO), particulate matters (PM2.5), nitrogen dioxide (NO2), and some carcinogenic compounds (Pope et al. 2015).

6. Cement production and air pollution

Cement is a necessary material for the building of infrastructures such as roads, bridges, hospitals, and schools; therefore, it is linked to the global economy (Rubenstein 2012; Rosenthal 20017). The production of cement is high energy (burning of fuels such as coal and gas to generate energy) and emissions intensive due to the high heat required to produce the material (Rubenstein 2012, CIF 2017). As many countries are developing, the demand for cement is constantly increasing. The production for cement is growing every year by about 2.5% and is supposed to rise to 3.7 billion tons by 2050 from 2.55 billion in 2006 (Rubenstein 2012). Cement plants are responsible for the emission of roughly 5% of carbon dioxide, the main cause of global warming (Rosenthal 2007). Particulates are mostly released when demolishing buildings and when the cement is drying out. These particulates are so small that they are almost invisible to the naked eye but can cause a lot of health damage.

Millions of dollars have been invested by cement producers in green programs as a way of reducing emissions. For example, about 610 pounds of carbon dioxide is emitted for every ton of cement produced compared to 763 pounds in 1990 (Rosenthal 2007). However, it is unlikely that emissions could be reduced much further because 60% of the pollution emitted in the industry comes from the chemical reaction that creates cement, therefore, only about 40% of the pollution can be avoided (Rosenthal 2007).

In addition, stringent environmental policies in developed parts of the world such as western Europe pushed many manufacturers to close their businesses. They have now moved to other parts of the world with less stringent regulations like Ukraine and other countries in Eastern Europe (Rosenthal 2007). At the same time, local production of cement is also increasing in Sub-Saharan Africa and Asia as countries there are developing.It is hard to tackle pollution related to the cement industry. In fact, while environmental regulations are meant to reduce production and therefore reduce pollution, it is almost impossible for these regulations to work in this industry. The growing demand for infrastructures pushes manufacturers to keep producing cement and therefore impact the environment. The only way for reducing pollution will be to use greener energy to produce cement. However, pollution cannot be reduced much further because 60% of the pollution comes from the chemical reaction associated with the production of the material.

7. Climate and air pollution

Many studies have shown the relationship between climate and air pollution. In fact, warm and dry climates are usually associated with high levels of pollution while cooler climates are associated with low levels of pollution. This is for example the case of countries such as Indonesia and China. However, we do acknowledge that there are other factors such as winter inversion that can impact pollution levels. In fact, studies conducted in Ohio, Philadelphia, Pennsylvania, and Illinois showed that air pollution levels tend to be higher during summers (Moolgavka and Luebeck, 1996). Other studies were conducted in nine Italian cities and all showed that air pollution was higher during summers (Stafoggia et al. 2008).

However, in some cases, air pollution can also be greater during the winter. High levels of pollution during the winter is mostly related to winter inversion, which traps pollutants in the atmosphere and prevent them from dispersing, and therefore causes an increase in local air pollution. a seasonal analysis of short-term effects of PM on hospital admissions in 202 US counties revealed higher rates of air pollution during the winter and resulted in higher rates of hospital admissions (Bell et al. 2008). Other studies in several Asian cities such as Shangai (Kan et al 2008), Wuhan (Qian et al 2010), and Hong-Kong (Wong et al. 2001) also argued that air pollution is worse during winters or cool months. Finally, a study conducted in 17 Chinese cities, measuring $PM_{2.5}$, saw air pollution peaks both in the winter and in the summer (Chen et al. 2013). Therefore, pollution levels depend on local climates. That is why many studies conducted in Asian cities, such as Hong-Kong, showed that air pollution is greatly influenced by temperatures and relative humidity (RH) (Qiu et al. 2013)

Climate in Gabon

Gabon has the moist and hot climate typical to countries located in tropical regions. Its climate is divided into two main seasons; the dry season and the rainy season. The dry season goes from June to September, with precipitation averaging 24mm/month while the rainy season goes from October to May, with precipitation averaging 269mm/month (Memiaghe 2015). November and March are the wettest months of the year with precipitation averaging 406mm and 303mm respectively while July is the driest month with precipitation averaging 11mm (Shell Gabon unpublished data, 1985 to 2015). The hottest month is March while the coldest month is July (holiday-weather.com). The humidity year-round averages 80% with humidity reaching 100% in March and dropping to 70% in July.

Even though both Libreville and Franceville are in the same zone (B zone located on the map), the length of their seasons slightly differs as well as the amount of precipitation. While the dry season goes from June to September in Libreville, it is slightly longer in Franceville and goes from mid-May to September (climatestotravel.com). Annual precipitation generally range from 1,500mm to 2,000mm in the country. However, that number is close to 3,000 in the northern part of the coast where Libreville is located (climatestotravel.com). There is very little variation in temperatures over the course of the year in the north and central part of the country with an average temperature of 30 °C while that number drops to 24/25 °C in the south-central part of the coast and to 27/28 °C inland, which includes Franceville (climatestravel.com).

The climate in Gabon makes it possible to have high levels of pollution in the dry season and low levels in the rainy season. The high amount of precipitation observed during the rainy season might favor the dispersion of particles while the lack of precipitation during the dry season, associated with other factors such as waste burning which only happens during the dry season, increases the likelihood of high pollution levels.

CHAPTER III

METHODOLOGY

1. Study Locations

The study occurred over a period of six months, from July to December. We chose this time frame to make sure that we capture the two seasons in the country, namely the dry and the rain season. However, each season is also divided into a small and a big season. Therefore, our study captured part of the big dry season, which goes from mid-May to mid-September, and the small rainy season, that goes from mid-September to mid-December. We also obtained some data from the small dry season, which usually goes from mid-December to mid-February.

Libreville

Located on the northwest coastal part of the country, Libreville is the capital city of Gabon. Its geographical coordinates are 0°23′24″N 9°27′0″E and it is in the Estuaire province. Even though the capital city is populated, most of the Estuaire province is still surrounded by untouched tropical rainforest. Libreville houses more than half of the country’s population and has, by far, the highest number of cars. It is a trading center where mainly timber is exported overseas. In addition, the city is home to one of the three public universities in the country, namely the Universite Omar Bongo Ondimba, which I partnered with for my research.

As the administrative capital of the country, Libreville is a vibrant city. Its population is mainly made of workers and students, which means that cars are used there a lot. The daily routine for a typical worker/student in Libreville consists in waking up around 5am-6 am and be on the road around 6:30 to go to work/school, which they all resume at 7:30 am. Then, students get off school around 1:15pm while workers get off work between 3:30-5pm. This means that typical rush hours in Libreville are between 6:30am and 8am and between 3:30pm and 5pm.

Cities in Gabon are built in such a way that everything is centered around downtown (see map 4 in Appendix C). For example, downtown is where most, if not all of the industries and agencies are located. Therefore, people have to live their neighborhoods and all converge toward the downtown. This creates a lot of traffic as there are not enough roads to accommodate that many people at the same time. Also, the heavy congestion causes people to rely on personal transportation because most buses, minibuses and shared cars are stuck in traffic and can remain there for long periods of time (sometimes for a whole hour). These situations cause a lot of pollution as many cars are on the road at the same time and are moving slowly, thus releasing more pollution.

We chose this location because it is the most affluent city in the country in terms of population size and traffic. Therefore, our results will show the air quality breathed by more than half of the Gabonese population. At the same time, in 2015, Pr. Nicole Ngo and I conducted our baseline air quality in the city. However, it was only for a very short period (three weeks). It will then be interesting to see how the result of a longitudinal study differs from those of our first study.

Originally, we were supposed to place the monitor on the rooftop of the Omar Bongo university library, like we did the year before for the baseline study. However, fear of instability and closure of the university during the presidential election that happened in August, pushed us to choose a different location. The new location chosen was then the offices of the Gabon-Oregon transnational center.

The Gabon-Oregon center is a seven-story building located in the administrative district of the city (see photo2 on appendices D). It is on a hill facing the Atlantic Ocean on one side and administrative buildings on its other sides. That location was chosen because of the security and the easy accessibility it provides. In fact, the administrative district, which includes the presidency, is protected 24/7 by the army and therefore provides a secure way for us to download our data and keep the monitor safe. Even the presidential election did not affect it much because the army always made sure that government staff worked in a safe environment.

Franceville

Franceville (see map 5 in Appendix C) is the third largest city in Gabon in terms of population size and is in the province of Haut-Ogooue. The city is an active trading center in a mining region (Hoogastren et al 2017). The exploitation of manganese to the northwest has constantly created population growth and commerce in the city (Hoogastren et al 2017). The city also has a lot of falls and rivers, such as the “Ogooue river” and the “chute of Poubara”. The city is also home to the Universite des Sciences et Techniques de Masuku, which is the other university with whom I partnered for this project.

Like Libreville, Franceville is also mainly composed of workers and students. However, the low population also translates into low number of cars. This means that while there are many people and many cars in Libreville, there are less people and therefore less cars in Franceville. That is why, there is almost no traffic in the city unless there is an accident. The low number of cars also means less air pollution in the city from cars. However, other sources of air pollution in the city include the making of cement, barbeques, and the extraction of manganese among other pollution sources.

We chose to conduct our study in Franceville because of the presence of the scientific university and because of its proximity to Moanda. In fact, the study wanted to compare air quality in an automobile heavy city (Libreville) versus a mining town to know which one of the two variables has greater impacts on air quality. However, because of the refusal of the Moanda's local government to have the study take place in their city, we decided to use a nearby city, which has almost the same characteristics. Since 2015, Franceville has started exploiting manganese like Moanda. Therefore, it would be interesting the see the impacts on air quality even though that might be too early to know. At the same time, the fact that Franceville is so close to Moanda means that some of the pollution emitted in Moanda travels to Franceville. So, I still have a chance of capturing the impacts of mining extraction on air quality.

We wanted to place the monitor in the center of the city, more precisely on the top of the city hall, however, the local government did not approve of our project. Therefore, the university offered to house the monitor since they do not need permission from the government to conduct studies. The university is located on the south side of the city and is near a major road called “la national” (see photo 3 on appendices D).

2. Study Design

To perform our study, we used a portable device called, dylos logger DC1700. The DC1700 is an improved version of the DC1100, and is a battery-operated air quality monitor (dylosproducts.com). The LCD screen shows two size ranges of particle concentrations. The first one size represents the small particles; less than 0.5 micron and the second size represents the large particles, less than 2.5 microns (dylosproducst.com). It records the air quality levels per minute, hour, and day.

To record continuous levels of air quality, the monitor must constantly be charged, using a wall adapter. In case of power outage, the monitor can still work for up to 6 hours, after which the device will be turned off. The device has an internal memory that can store up to one week's worth of data, which is about a sample of 10,000 recordings. Once that limit has been reached, the oldest data will start to be erased from the device.

The many options of the device include changing the time and date to more accurately reflect the time zone needed by the user. At the same time, the DC1700 is shielded against electro-magnetic interference. This simply means that even when placed near interferences such as high voltage power supplies, the device can still accurately record the air quality level.

The dylos logger is a low cost portable device that can be easily purchased for air quality studies. In fact, in comparison to other air quality monitoring devices, which are more efficient and cost thousands of dollars, the dylos logger only costs $450. It is used a lot for pilot studies and for measuring particulate matter (PM2.5). Therefore, it makes the replicability of studies easier. At the same time, it can be purchased by agencies and countries that are interested in air quality monitoring and therefore increase the general knowledge on the topic.

3. Data Collection

Our study occurred over a period of roughly five months, from July 12th to December 2nd 2016. We chose this period because we wanted to capture both the dry season and the rainy season. This project was made possible through a collaboration with students and faculty members from both the *universite Omad Bongo Ondimba* in Libreville and the *universite des sciences et Technique de MASUKU* in Franceville.

When I arrived in Libreville, I spent two days at the Gabon-Oregon office leading a training session, with students from the Omar Bongo University, on how to use the monitors. The first day mainly consisted in downloading the dylos logger software onto each computer to transfer the air quality data from the monitors to individual computers for the analysis. Then we ran a practice test to see how the transfer of data was to be done. At the end of the first day, we decided to leave the monitors on for a whole day to see what the data will look like. The next day when we came back, we downloaded the data and graphed them on Excel just to have an idea of what the graph would look like. At that point, we realized that some computers had trouble downloading the data because the version of their computers was not compatible with the dylos software. We then spent the rest of the day trying to find ways that would help those students get the data on their computers. At the end of the day, we decided to leave the monitors on for two days to see how air quality would change.

We came back two days later and repeated the same steps of downloading the data and graph them. After that, we went to the rooftop to identify the exact place where we would put the monitor. We wanted to make sure that the place was slightly covered on the top to prevent the rain from entering the device during the rainy season. We were fortunate to find a good spot that had a good protection but at the same time, did not prevent the air from flowing in and out of the monitor. We then fixed the monitor with tape but we made sure that we did not obstruct the fan of the device and impact the flow of the air. This was on June 30th. We kept the monitor off because we wanted to start the study in both cities on July 6th.

On July 2nd, I traveled to Franceville by train to also provide training and install the monitor there. I arrived on the 3rd in the morning and I went straight to the training session. In contrast to Libreville, where I mostly trained university students, I had to train university students, faculty, local government officials, and medical professionals on how to use the device. Upon my arrival, I was asked to give a presentation of my work in front of all those people and a local channel, which came especially for the occasion. I was also told that the monitors would be placed at the City Hall and that is why the third adjunct to the mayor was present. After the presentation, we opened for a question and answer session. It was only later in the day that we started the actual training. At the end of the first day, some people were still confused on how to use the monitors, therefore, we had to continue the training the next day.

The next day, we continued the training session and had our first practice run. It went well in general but we still encountered the same issue of some computers not being able to download the data from the monitors. Apparently, the dylos logger software was not compatible with Microsoft office older than 2007 while many people had office 2010. We spent the rest of the day trying to find a solution to that problem and we left the monitors overnight as a way of getting a whole day's worth of data. We came back the next day and downloaded the data and graphed them. We left again the monitor for two days and came back later to once again download the data. At that point, we had decided to postpone the beginning of the study because the training in Franceville was taking longer than expected. After the training session and all the obstacles that we encountered (which I explain in more details later in the thesis), we finally managed to place the monitor on the third floor of a student dormitory.

The student dormitory we placed the monitor on is a three-story building surrounded by other dormitories. The building faces the main road (la national) and since it is one of the tallest buildings on campus, there is not much obstruction from other buildings. North of the building, across the street from the building, there is a cement company and south, a few miles (~2-3) from the school, there is a construction company.

The lack of protection for the monitor against the rain pushed us to order a metallic cover to mimic the setting in Libreville. The metallic cover had two bars on the inside where we could fix the monitor with a tape. When ordering, we made sure that the dimensions would not completely cover the monitor and prevent the flow of air. Once the protection was ready, we fixed the monitor to it and fixed the metallic cover to the ground using some ropes and four bricks. We tested it to make sure that the air could normally flow in and out and that worked. On July 12th, we officially began the study in both cities and turned on the monitors to start recording the data.

I stayed in Franceville for one more week after the beginning of the study to make sure that there was no problem with the monitors since I would not be going back there. After five days, the teams in both cities downloaded the data onto their computers and shared it on a Dropbox folder that we created for the occasion so that we would all have access to them. Once I was sure there was no problem with the monitor, I left Franceville and came back to Libreville. I also checked that there was no issue with the monitor there and I came back. The monitors were recording data 24 hours a day but due to the limited capacity of the devices, every five to six days, two students in each city downloaded the data onto their computers and shared it on the Dropbox folder we created. We officially sopped the study on December 2nd, 2016.

4. Data Presentation

Table1 (see appendix B) presents my raw data after I cleaned them up and calculated my particulate matter (PM2.5) in both cities represented here by pmfcv (for PM2.5 in Franceville) and pmlbv (for PM2.5 in Libreville). In this table, one can see that the data were recorded in terms of large and small particles, represented respectively by smallfcv and largefcv for small and large particles in Franceville, and smalllbv and largelbv for small and large particles in Libreville. Small particles are those that are less than 0.5 micrometer in dimeter and large particles are those that are less than 2.5 micrometer in diameter. All data were recorded. The difference between small and large particles approximates PM2.5 (EPA 2014). The date and time columns indicate that the data were recorded continuously, every minute, during the study period.

5. Missing Data

We are missing about five weeks of data in both cities. In Libreville, we are missing data for the following dates: July 2 to July 12, September 26th to October 2nd, and November 5th to November 12th. In Franceville, we are missing data from September 24th to October 1st; November 14th to November 23rd. Missing data was due to a few reasons, which I describe below.

First, power outage caused the loss of some data. During the study period, there were two power outages, one in Libreville and one in Franceville. The power outage in Libreville lasted for about three days while the one in Franceville lasted for about one week. The power outage in Libreville happened during a long weekend in which the electricity units were exhausted and the card needed to be recharged. However, the GOC agents forgot to monitor that. This was bad because the monitors can only function on their own for up to 6 hours. Luckily, once the GOC realized the situation, they quickly recharged the electricity card and the monitor started working again. In Franceville, it was a totally different story. The electricity was cut off because of tensions that arose after the presidential elections. In fact, the MASUKU University has always been known for protesting and opposing the political party in power because there is a lack of investment in education. Therefore, every time there is a presidential election, the government will cut off the electricity and have the students vacate their dormitories to prevent them from assembling and protesting. This can last from a couple of days to a couple of weeks depending on the level of tension.

Another reason for the loss of data was the malfunctioning of the equipment. The equipment that I used were the same ones that we used the previous year for the baseline study. Therefore, they had not been used for a whole year. The lack of maintenance prevented two of the monitors from properly working the first couple of days. It is only a couple of days after the beginning of the study that we realized that two of the monitors could not charge properly. This was a big problem because the monitors had to constantly be charged in order to record the data. Without chargers, the monitors can only record data for up to 6 hours and then they will be turned off. We quickly managed to get the monitors to work, but by that time, we had already lost a couple of days of data.

The remaining missing data happened because of the participants' difficulties with using the instruments. Some of these difficulties included properly downloading the data onto their computers (because participants had old computers that did not match with the monitor's software and therefore made it challenging for them to get the data out of the monitor and transfer them to me).

CHAPTER IV

DATA ANALYSIS AND RESULTS

1. Data Analysis

I downloaded the recorded data on my computer to clean them up and arrange them. The data contained three variables: date/time, small particles (less than 0.5 micron) and large particles (less than 2.5 microns). To determine particulate matter (PM2.5), I subtracted the large particles from the small particles and I divided my results by 1000. According to the Dylos Logger manufacturer, the device has a switch button that selects "cubic foot" whereas it should be "cubic foot /100". Therefore, all the results that are recorded in cubic foot should be divided by 100 to get the real particle count. At the same time, to convert from particle count to PM2.5, we must divide by an additional 100. So, at the end, I divided my results by 1000 to find the true values of PM2.5.

Once I had my results, I performed a descriptive statistical analysis to see the mean and standard deviation of my particles in both cities (Table 2). I was also interested in seeing how air quality varied over the course of the study, which was from July 12th to December 2nd. I therefore decided to break down my data to observe how air quality levels are changing per months and to see what time of the day has greater pollution levels. Consequently, I first made a two-way line graph to compare levels of PM2.5 in Libreville versus Franceville each month. Then, I made a second graph that shows daily air quality levels over the study period. In addition, I made a graph that only captures the dry season, going from July to September. Then, I made a graph of the month of August to observe how air quality levels changed over the course of one specific month. Plus, I made a graph of the average daily PM2.5 levels per hours. I also decided to make a graph of humidity and precipitations in both cities because of their impacts on air quality levels. My final graph presents the changes in air quality levels between the dry season and the rainy season in each city.

2. Results

The summary statistics (see table 2 on Appendix B) revealed that the mean PM2.5 levels in Franceville is 25ug/m^3 compared to 15ug/ m^3 in Libreville while the standard deviation in Libreville is approximately 22/m^{3}ug versus 31 m^3/ in Franceville. The number of observations is 134869.

Graph 1 (see appendix A) compares levels of PM2.5 during the dry season versus the rainy season in both cities. In Franceville, levels of PM2.5 reach about 36ug/m3 during the dry season then go down to about 10ug/m3 in the rainy season. Similarly, in Libreville, PM2.5 levels reach about 19ug/m3 during the dry season and the go down to about 10ug/m3 during the rainy season.

Graph 2 (see appendix A) revealed that overall, air quality levels are low during the dry season (July-September), and high in the rainy season (October-December). However, there are a few variations between the two cities. In fact, during the dry season, PM2.5 are above 100ug/m^3 on different occasions in both cities, then go down to about 20ug/m^3 as we are getting closer to the rainy season. The highest level of PM2.5 in Franceville is about 115ug/m^3 while it is about 105ug/m^3 in Libreville. During the rainy season, levels in both cities are around or below 20ug/m^3.

Graph 3 (see appendix A) represents the month of August to see what days, especially, have the highest levels of air pollution. Based on the graph, air quality is lower mostly the first few days of the month, with averages of over 100ug/m^3 in Franceville and over 20ug/m^3 in Libreville. Then the air quality improves a little bit until mid-August with averages of 10ug/m^3 in Franceville and 19ug/m^3 in Libreville. the air quality drops again with averages of over 100ug/m^3 in Franceville and about 90ug/m^3 in Libreville. Then the air quality improves again by the end of the month with averages of about 20ug/m^3 in both cities.

Graph 4 (see appendix A) presents the average levels of PM2.5 over the course of the study per hour. The idea was to observe what times of the day resulted in more air pollution than others. Based on the graph, we can say that air quality tends to be low in Franceville between 2 am and 7 am and between 5pm and 10pm with averages of about 37ug/m^3 and 34ug/m^3 respectively. Then air quality improves between 8am and 5pm and after 10pm with averages as low as 12ug/m^3. In Libreville, air quality is low between 6am and7:30am and between 3:30pm and 9pm with averages of about 17ug/m^3 and 19ug/m^3 respectively. Then the air quality improves between 8am and 3pm and after 9pm with averages of 11ug/m^3.

Graph 5 (see appendix A) depicts the precipitations over the course of 2016. The idea was to see how precipitations vary during the different seasons of the year, even though we are mostly interested in the precipitations during the study period. Based on the graph, precipitations are behaving the same way in both cities over the course of the year. However, there are some variations regarding the amount of precipitations and the relative time at which precipitations start. In Libreville, precipitations are high between

February and April and between October and November with averages of 350mm and about 490mnn respectively. Then the precipitations decrease from April to June with averages of about 50mm. Then from June to August, there are almost no precipitations with averages close to 0mm. Finally, the precipitations start to slowly increase in September and October with averages of about 420mm before reaching its peak in October and November. In Franceville, precipitations are high between January and February, March and May, and between October and December with averages of about 180mm, 140mm, and 160mm respectively. The precipitations start decreasing between May and September with averages close to 0mm.

Finally, graph 6 (see appendix A) presents the humidity in both cities over the course of 2016. Overall, the humidity level in both cities is constantly over 70% regardless of the time of the year. However, depending on the season, the humidity varies slightly. Based on the graph, humidity is high in Franceville from February to May and from September to November with averages of 82% and 87% respectively. The humidity is low from May to August with averages of sometimes 72% in July. In Libreville, the humidity is high between February and May and between September and November with averages of 83% and 85% respectively. The humidity is lower between June and August with averages of 80%. Then it starts increasing again in September.

CHAPTER V

DISCUSSION

We conducted a summary statistics for 24-hr average rooftop PM2.5 (table 2) to get an idea of the average concentration of particles matters in both cities. Overall, our results suggest that average air quality in both cities is generally good with averages of 15ug/m^3 in Libreville and 25ug/m^3 in Franceville. This could mean that air quality in Libreville is good because it is well below the WHO standards of 25ug/m^3 while Franceville is right at the level set by the WHO.

However, a closer look at the data at the daily level, shows a slightly different picture. In fact, we found in graph 2 that from July to about mid-September, PM2.5 levels are far exceeding the levels set by the WHO in Franceville with averages reaching more than 100ug/m^3. In Libreville, the same observation is made with PM2.5 levels also exceeding the WHO standards with averages of Sometimes 90ug/m^3.

The high concentrations of particles from July to September can be explained by the season. As mentioned above, the period from July to September is known in Gabon as the dry season. Therefore, there are many activities that take place during that time that do not take place the rest of the year. This period is for example praised by local people for burning. Farmers, especially in provinces, use that time to burn their farmlands to get them ready for the planting season. Garbage collection company also use that time to burn landfills. The unpaved roads get dustier as we move further into the summer. In addition, the dry season also results in an increase in open barbecues around the cities, which also contribute to the air pollution problem. A study conducted by the NASA argued that the summer results in higher levels of dust that fills the air and becomes one of the main sources of pollution, especially in the developing world (2010). However, Pm2.5 tends to be lower during the rainy season. That is because rain clean the environment and therefore leads to better air quality.

Graph 3 shows how August is the month with the highest levels of pollution. Pollution in Franceville peaks from the 11^{th} to the 20^{th} while pollution in Libreville peaks from the 16^{th} to the 20^{th}. This might be explained by the traveling of people from the capital city to provinces to spend the Independence Day with family. At the same time, many people living abroad also return home to spend the holidays with family members. Government officials tend to travel to their provinces a few days before the holiday and organize big feasts. That might explain the air pollution peaks earlier in Franceville compared to Libreville. Then they return to the capital city the day before Independence Day to take part in the many activities happening there along with the president. Then right after the holiday, people return to the city to go back to their activities.

Graph 4 shows hourly air pollution levels in both cities. We found that air pollution is high in Franceville between 4am and 7am and after 5pm, with averages of 38ug/m3 and 35ug/m3 respectively. These pollution levels coincide with the time at which mining workers depart for work (4-5am) and when students and other workers go about their daily activities. At the same time, there is a cement manufacturing facility just across the street from where the monitor was placed. The company usually starts their operations around 4-5 am so that cement can be delivered around 7-8am when constructions sites open. Based on the literature review we know that the production of cement results in a lot of air pollution, so the presence of that manufacturing company might have an impact on the local air quality. At the same time, there is also a construction company a few miles from the university. They constantly transport materials such as sand, cement, and gravel to their construction sites. Therefore, their operations might also result in a lot of air pollution as their trucks are open top. The evening peak might be caused by the return of most people from work. Street vendors also start operating their barbecues around 5pm by using charcoal and letting it sit for about 30mn just to get the fire going. They start the actual barbecues around 5:30-6pm.

In Libreville, the picture is slightly different. While pollution is Franceville, in the morning might be caused by cement production and construction companies, pollution in Libreville might be caused by cars. The morning peaks in Libreville are between 6am and7:30 and coincide with the time at which people go about their daily activities such as work and school. This means that there are a lot of cars on the road and traffic, which can exacerbate the air pollution problem. Pollution in the evening also coincides with the time at which people come back from work. At the same time, street vendors also start operating their barbecues. In addition, because the capital city is more vibrant than Franceville for example, people go out a lot in the evening and engage in activities such as smoking, which also impact air quality.

Graph 5 shows the precipitation during the whole of 2016. This figure is consistent with the argument that air pollution is higher during the dry because of the lack of rain. In fact, studies have shown that precipitation can either increase pollution or reduce it by dispersing the pollutants. In fact, rainfall has a scavenging effect by washing out particulate matter and therefore improving overall air quality (Queensland government

2017). Similarly, a study conducted by the University of Michigan revealed that the weather plays a big role in the dispersion of pollutants (Watson 1988). The same study argues that high wind speed as well as precipitations dilute pollutants and therefore lead to high air quality in some areas (Samson 1988). In this case, we argue that rain might be dispersing the pollutants and that is why we have low levels of pollution from September to December with averages of about 20ug/m^3 in both cities. Across all our analysis, we found that pollution levels in Libreville are constantly lower than in Franceville. This might be explained by the position of the monitors. In fact, the position of the monitor in Libreville was affected a lot by wind and precipitation due to its location near the coast. Therefore, these two factors might have contributed to the overall reduction in air pollution in the city. In fact, studies have shown that when the air is calm and not dispersing, then pollution levels are higher because pollutants do not move and just build up (Queensland government 2017). In contrast, Franceville is located inland, is not as windy and does not have as much rainfall as the coast. Therefore, there is little room for pollutants dispersion, leading to high pollution levels in the city. Through this paragraph, we argue that air pollution is not necessarily worse in Franceville compared to Libreville. Geographical factors might have played a role on how much pollution is found in each city.

In addition, relative humidity also plays an important role in the amount of pollution observed in each city. In fact, graph 6 shows that humidity is low from June to August in both cities and high the rest of the year. This is consistent with the argument that humidity is low in cool seasons and high during the hot season. This is because during the rainy season, the air gets easily saturated and therefore results in high humidity. High humidity associated with high temperatures usually lead to high pollution levels (Queensland government). Similarly, during the dry season the air can absorb more water and therefore results in low humidity (Hu et al. 2006). Based solely on relative humidity and temperatures, we could argue that normally in Gabon, air quality should be higher during the rainy season because that is the time where temperatures are higher and the humidity is also high. However, rainfall and wind speeds and directions play a bigger role in the pollution levels by dispersing particles, especially fine particle such as PM2.5 (Hu et al 2006). A longitudinal study conducted in Hong-Kong from 1998 to 2007 revealed that higher levels of air pollution were observed during cool and low humidity days (Qiu et al. 2013).

Graph 1 shows the changes in pollution levels in both cities between the dry season and the rainy season. We found that air pollution in Franceville during the dry season is almost double the levels in Libreville during the same period. However, levels during the rainy season are almost the same in both cities. The difference in pollution during the dry season can also be explained by the geography of each area. Libreville is surrounded by tropical rainforest, which can absorb high amount of pollution and therefore reduce pollution levels at the city levels. In contrast, Franceville is surrounded by savannas, that are not as good reservoir for pollutants sequestration as forests. Similarly, the burning of farmlands by framers in rural areas to prepare for the planting season might also explain the difference in the pollution levels. A final explanation could be the position of Libreville. In fact, Libreville is located on the coast and can become windy at times with more and heavier precipitation. At the same time, the monitor in Libreville was placed on a building above sea levels. This means that the wind could have transported the pollutants offshore.

1. Comparison to other studies

Our study was also compared to other studies on air quality around the world to see how the air quality in Gabon compares to that of other countries. A study conducted in Accra, Ghana showed air pollution levels between 30 and 70ug//m^3 at residential sites. These levels are above the ones observed in our two cities (Dionisio et al.2010). Another study showed air quality levels reaching more than 500ug/m^3, these levels are also far exceeding levels observed in our data where the highest level was about 154ug/m^3 (Gould and Mosher 2017). Our levels are also far below the levels observed in countries such as Saudi Arabia, Qatar, Egypt, and Bangladesh with averages of 108ug/m^{3,} 103ug/m^{3,} 95ug/m^{3,} and 84ug/m^3 respectively (Gould and Mosher 2017). However, the levels observed in our data exceed some of the levels observed in cities such as Cape Town and Durban with levels of 16ug/m^3 and 14ug/m^3 respectively (aqicn 2015). In addition, none of the studies that I looked at make the connection between local seasonal variations and air quality.

2. Limitations of the study

Like many other studies, my study also presents some limitations that will be discussed in further details in the following lines.

One of the limitations of the study is the location of the monitor in Libreville. The monitor was placed in *Montagne saint*, which is located on a hill and facing the ocean. At the same time, the monitor was placed on the 7th floor of the building, which is high compared to most the buildings in the city. Montagne saint is a few feet above the city, which means that a lot of the pollution that was emitted at the city level by cars and other pollution sources might not have reached the monitor. At the same time, the fact that the monitor was facing the coast probably also played a role in how much pollution was recorded.

Another limitation is the direction of the wind. Unfortunately, I could not get information on the wind direction. That would have allowed me to know whether the wind is bringing in more pollution close to the monitor or is clearing the pollution away toward the ocean. However, the wind speed which was constantly between 7mph and 17mph suggests that the wind did not affect the amount of pollution recorded by the monitor.

Finally, the Dylos DC1700 does not monitor the composition of the particles. In fact, the monitor only records particles count and not the type of particles. This is a constraint because even with high number of particles, we will not be able to know the sources of pollutions. Therefore, we will only be able to speculate on the potential pollution sources.

3. Challenges on the field

Doing research in Gabon was a unique experience and through that, I got to meet a lot of people and make good connections. However, throughout my journey, me and my partners also encountered a lot of barriers. We mostly encountered barriers with local governments as well as health officials.

Barriers from local governments

When I arrived to Gabon, my first stop was in Libreville where I provided training to local researchers on how to use the monitors and show them the types of data that we will be collecting and their importance. I did not need to give presentations to local officials about the goal of the study because me and my instructor, Pr. Nicole Ngo, had already done that the year before when we first launched the baseline monitoring of air quality in the city. I therefore traveled to the second city, which was Franceville.

In Franceville, my partners from the local university arranged for me to give a presentation and run training sessions with local officials, such as the adjunct to the mayor and doctors, on the goal of the study and on how to use the monitors because such a study had never been done there. The goal was also to get local officials involved in the study because we needed their permission to conduct the study in the city and we also wanted them to use that opportunity to educate local people on the importance of our work. It was also a way of building local capacities and ensuring that follow up studies are done in the future. After the training sessions, government officials told us that they will get back to us regarding the location and day at which we could start the study. We waited for almost one week, without any response from them. When we finally managed to get a hold of the adjunct to the mayor, he simply told us that the mayor and his other colleagues did not understand the importance of the study and that therefore, we could not go on with the study. He also added that if it was "something more political, maybe we would have gotten the permission". This was a big disappointment to us but we had to respect their decision and not take the risk of going against them. Luckily for us, the local university is autonomous and we were able to install the monitors on their property without having to ask permission from the local government. That is exactly what we did and how we could collect our data. However, a bigger barrier awaited us in Moanda.

Moanda is a mining company, that has been extracting manganese since the 1960s**.** This is also the place where we had the highest pushback from the local government. In fact, as it is the custom, me and my partners went and met local officials to explain the goal of our research and how that could benefit the local people. The second adjunct to the mayor that we met seemed enthusiastic about the project and promised to give us his support and talk it over with the mayor. He asked us to come back in two days to provide training to his staff, from the technical department, on how to use the monitors. We came back exactly two days after our meeting and found two staff members that knew nothing about what we were doing there and just explained that they were sent to get trained. We had to reexplain the purpose of the study and how to use the monitors. As in Franceville, the staff members asked us to come back in three days after they would have spoken with the mayor so that they can give us the time and location for the study. We came back as promised and found out that once more, we could not conduct the study in the city. The local officials told us that there was no need for us to conduct the study because apparently, the local mining company had already hired French experts to conduct an environmental impact assessment of their activities. The experts concluded that the company's activities had no impacts on either the environment or on public health. Unfortunately, we were not able to access that document as it was confidential. When we insisted on conducting the study and promised that we would keep it purely academic, they just said that they "did not want troublemakers who will alert the population and create panic". On that note, we left the city because unfortunately there is no university there to install our monitors.

Barriers from health officials

In addition to the barriers we encountered with local governments, we also encountered some barriers with health officials. In fact, another aspect of my research involved collecting health data to see how I could potentially find a correlation between seasonal changes in air quality and their impacts on health. I wanted to focus on respiratory diseases such as asthma, bronchitis, and pneumonia among other diseases. The collection of health data was supposed to happen simultaneously with the collection of air quality data.

Collecting health data in Libreville was a big challenge because we first had to determine which hospitals to go to for the data, since there are so many of them. Then, we had to find doctors and other staff members, who will be willing to help. Because this process was very time consuming, we decided to wait until after the presidential election, which we knew will bring some tensions for at least a few weeks, before proceeding with the data collection. After the election, we know had to identify the hospitals to go to. However, every hospital we went to were very reluctant to give us the data, even though we were just asking for statistical data instead of identifiable data. The health officials we met always asked us to come back. This happened for months even after I came back. Even when my partners brought recommendation letters from university researchers, these health professionals still refused to release the data. Now my partners are trying to see if they can obtain permission from the ministry of health because that would be the only way of getting these data. Unfortunately for us, we had a similar experience in Franceville.

As I was providing training on how to use the monitors, I also explained to the doctors and nurses present the importance of collecting health data. At first they all seemed interesting and told us that they would be available to help since they were also interested in knowing what is happening with the air quality and how that is impacting the population. Little did we know that their motivation had a price. A week after a got to Franceville, I was asked to give a presentation to the director of the regional hospital to get his support and speed up the data collection process. The regional hospital treats more than 70% of the population and was therefore a good data source for us. The director seemed interested and urged the doctors in residency to collaborate with us and provide us with the necessary data. Those doctors asked us to come back two weeks later to start the data collection. However, because of my limited time there, I had to put my local partners in charge of collecting the data. Two weeks later, I checked in with my partners to see if they had started the collection. They told me that the doctors asked them to wait a little more so that they would have all the data ready for us. I waited for another two weeks and re-checked again, only to hear that the doctors wanted monetary compensations before releasing the data. I was very chocked because I did not understand why they would ask for money for something that will benefit them in the long run since I was planning on sending them my results once I would be done with the analysis. Then, I accepted to pay them only if it was official. I wanted to make sure that the money went to the hospital and not to private individuals. They refused my proposition and until now, we still have not gotten the data.

Through connections, we met one of the doctors of the regional hospital of Moanda. He was very enthusiastic about out study and decided to support us in any way he could. He accepted to give us the data for our study only if we got approved to do the research by the local government. He added that without the approval, he would not be able to help us because he, too, does not want to go against the authorities. Regardless of his condition, he agreed to help us revise our survey because he felt like a lot of details we missing. For example, he helped us break down the age group even more because he argued that each of these populations are affected by different respiratory problems. One important point he mentioned was that, there was something wrong with the air because in the past few years, he has observed an increase in respiratory problems in the population, especially among newborn and the elderly. While the newborn would mostly experience chronic bronchitis, the elderly would develop pneumonia. Unfortunately, because we were not given permission by the local government to conduct our research, we were also not able to get health data. Until now, we have no health data at all and we are only working with air quality data.

CHAPTER VI

POLICY IMPLICATIONS AND CONCLUSIONS

1. Policies

After this project, there are a few recommendations that I would like to make to improve air quality in general and more particularly urban air quality because that is where much of the population is living.

The first recommendation I would like to make is to invest in public transportation. In fact, the increase in air pollution is partly due to an increase in personal automobile use. In Africa, particularly, people use second hand cars that are very polluting to the environment. Therefore, investing in public transportation will not only reduce the number of cars on the road but also reduce the amount of pollution emitted, which will then improve public health.

Governments must also build infrastructures. Roads, to be more precise, roads are needed for public transportation to be efficient. Special roads for buses, for example, can be built to make public transportation more attractive as it is the case here in Eugene with the Emx. The efficiency of public transportation will push people to use them more instead of using their old cars and get stuck in traffic.

Use alternative energy in the production of cement. Such energies include solar, wind, and hydropower. Sub-Saharan Africa in general and Gabon, in particular, are very moist and hot places. Therefore, they have great potentials for developing green technologies. Since in Gabon, it is very sunny and windy, especially on the coast, governments can invest in solar and winds panels to refrain from using petroleum and coal and reduce environmental pollution. The excess energy can then be sold to nearby countries if possible. In fact, even though the natural process of producing cement already releases about 60% of the pollution in that industry, the remaining 40% of pollution could be reduced by using energy efficient technology. This will mean using fuel efficient cars for the transport of the cement and use energy efficient machines to produce the cement.

Educate people on the impacts of air pollution on public health. Many people use the techniques denounced above because of the lack of knowledge regarding the potential health impacts. Therefore, it is the responsibility of the government, organizations, and health professionals to educate the population on this issue.

2. Future Work

- In the future, it would be interesting to conduct a yearlong study to have an annual mean air pollution levels. This will also allow to have a better idea of the time at which air pollution is the worst to better identify intervention techniques.
- Another interesting research will monitor air quality in rural areas since they rely so heavily on wood fuel for their energy needs. They also have unpaved roads, which emits pollution from dust. This research could serve as a comparison in air quality in urban versus rural areas.
- A third research would look at particulate matter composition to better identify sources of pollution and use the appropriate measures to reduce the pollution.

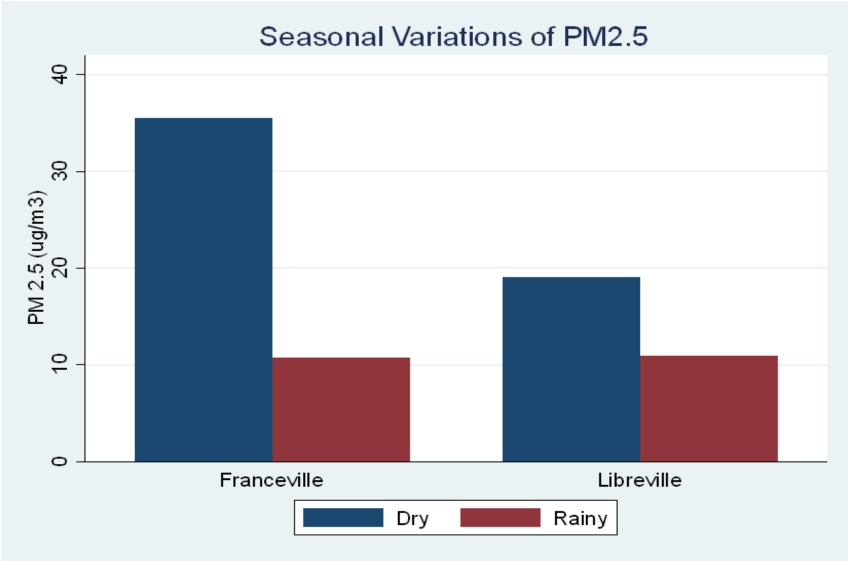
- A final research could also look at health data and see how air pollution is impacting the local population.

Conclusion

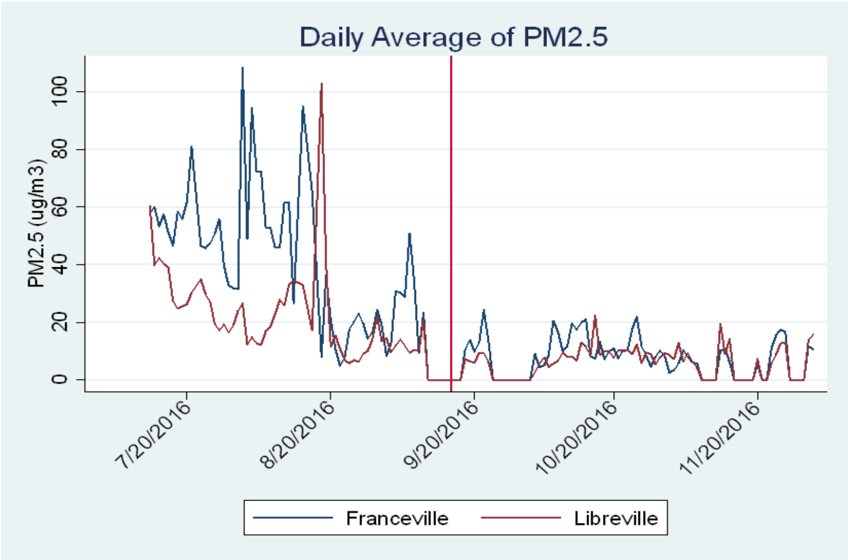
The result of my research suggests that air quality averages in Libreville and Franceville are right at the levels set by the WHO with Franceville having slightly higher levels than Libreville. However, a close look at daily variations suggests PM2.5 levels that exceed the recommended levels and can therefore be harmful to human health. The results of my analysis also confirm my hypothesis that pollution levels are higher during the dry season compared to the rainy season. This might be the result of the precipitations, which dissipate particulates and therefore reduces overall pollution levels. However, the results contradict my second hypothesis that air quality would be worse in Libreville compared to Franceville based on the number of cars. In fact, air quality is worse in Franceville compared to Libreville. This can be caused by the geographic location of the two sites. The fact that Libreville is located near the coast leads to lower pollution levels because of the wind that can easily transport the particulates offshore in contrast to Franceville, which is inland. In addition, the higher and heavier amount of rain in Libreville compared to Franceville also plays a role in reducing air pollution. Regardless of the small differences in pollution levels in both cities, measures must be taken to protect public health. At the same time, preventive measures must also be taken to ensure that air quality does not deteriorate further.

APPENDIX A

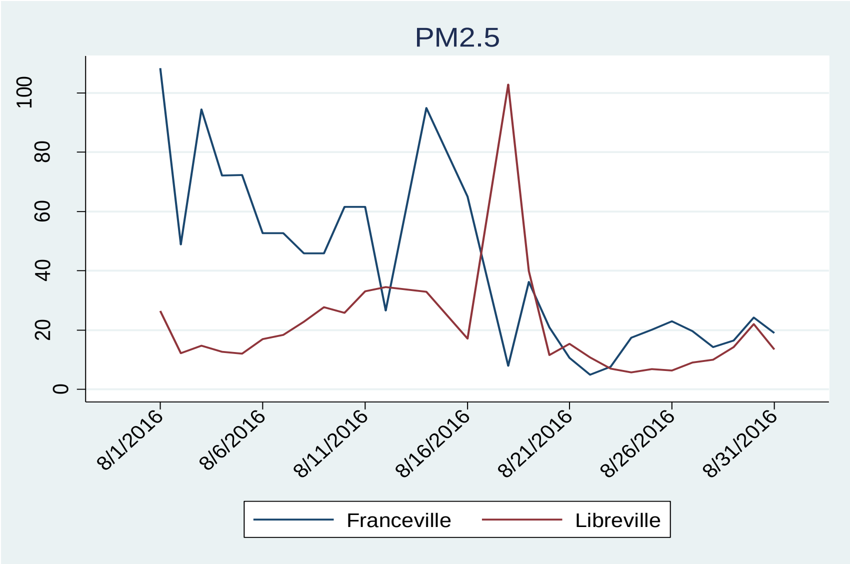
GRAPHICS



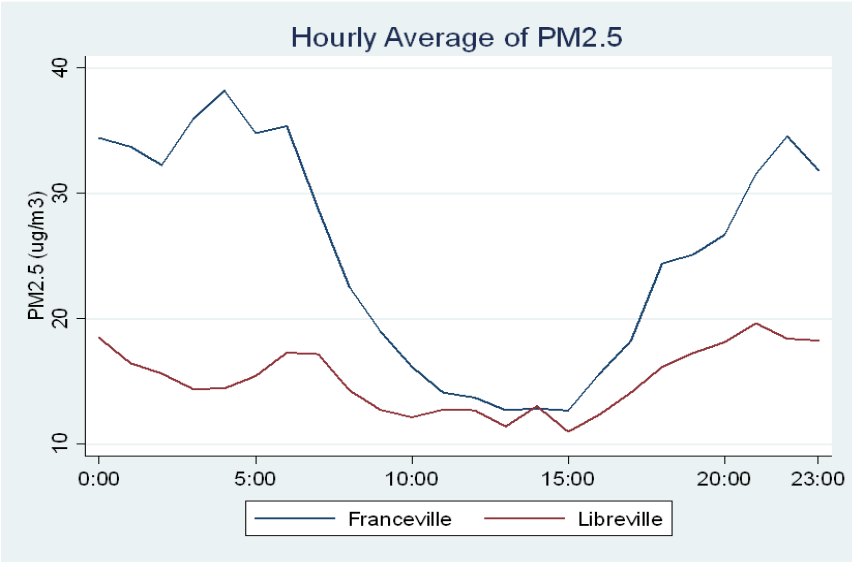
Graph1: Seasonal variations of PM2.5 from July12th to December 2nd 2016



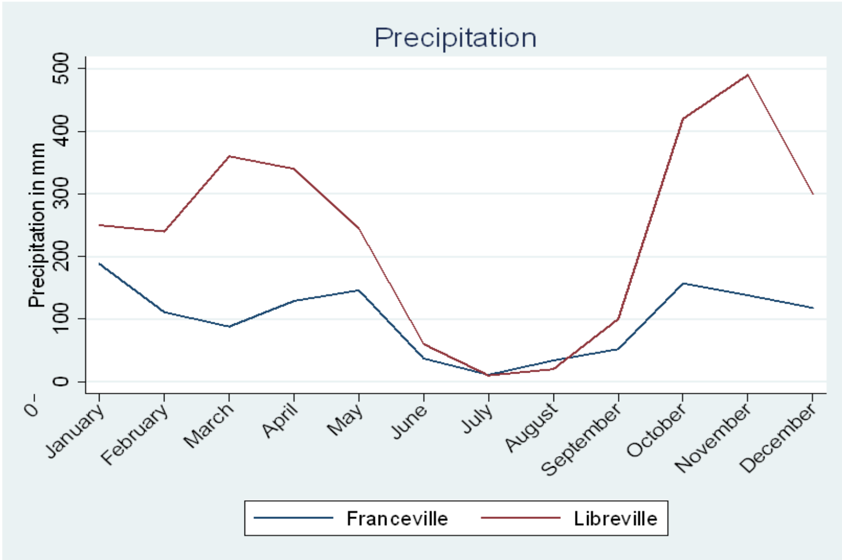
Graph2: Variations in PM2.5 during the study period per day. The red vertical line represents September 15th, which is the end of the dry season and the beginning of the rainy season



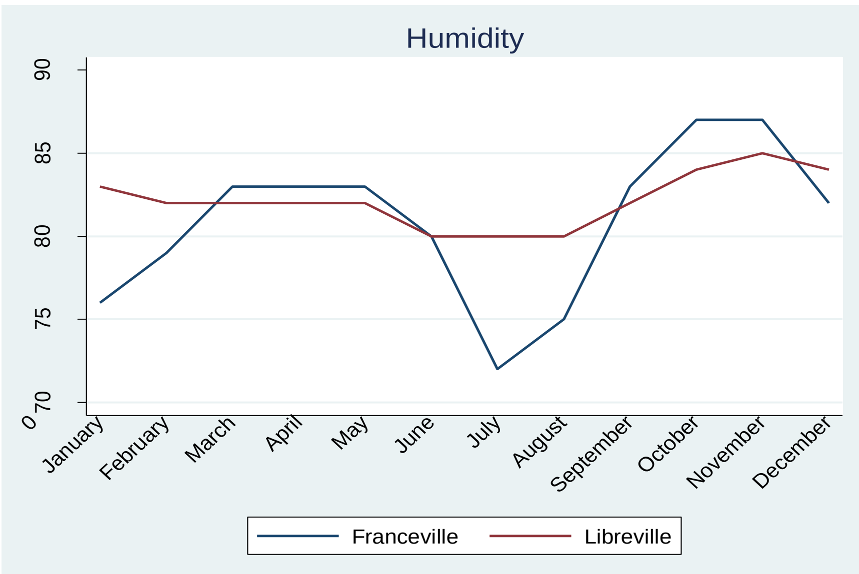
Graph 3: A close look at the month of August



Graph 4: Average hourly PM2.5 during the study period, from July12 to December 2nd, 2016.



Graph 5: Precipitation patterns in 2016



Graph 6: Humidity levels in 2016

APPENDIX B

TABLES

	date	time	smallfcv	largefcv	smalllbv	largelbv	pmfcv	pmlbv
2	7/12/2016	15:39	449800	5400	287800	7600	44.44	28.02
3	7/12/2016	15:40	460300	5500	300000	7900	45.48	29.21
4	7/12/2016	15:41	464900	11200	294400	8200	45.37	28.62
5	7/12/2016	15:42	459900	11300	291400	8800	44.86	28.26
6	7/12/2016	15:43	447400	6300	286900	7800	44.11	27.91
7	7/12/2016	15:44	443100	5000	294600	7500	43.81	28.71
8	7/12/2016	15:45	433100	4700	288300	8400	42.84	27.99
9	7/12/2016	15:46	445100	4600	295800	7900	44.05	28.79
10	7/12/2016	15:47	440900	6200	267800	8000	43.47	25.98
11	7/12/2016	15:48	441800	5200	272200	8600	43.66	26.36
12	7/12/2016	15:49	437200	5300	265100	7800	43.19	25.73
13	7/12/2016	15:50	448200	5200	274500	8800	44.3	26.57
14	7/12/2016	15:51	468100	23200	283700	8200	44.49	27.55
15	7/12/2016	15:52	441800	9100	293700	9100	43.27	28.46
16	7/12/2016	15:53	434400	7800	296800	9500	42.66	28.73
17	7/12/2016	15:54	432500	7400	283700	8100	42.51	27.56
18	7/12/2016	15:55	433600	5200	282500	8700	42.84	27.38
19	7/12/2016	15:56	431200	7100	289200	7800	42.41	28.14
20	7/12/2016	15:57	427600	5400	290900	8500	42.22	28.24
21	7/12/2016	15:58	422500	5000	284500	7800	41.75	27.67
22	7/12/2016	15:59	427700	4900	279400	7900	42.28	27.15
23	7/12/2016	16:00	416600	4900	285400	9700	41.17	27.57
24	7/12/2016	16:01	416500	4900	288100	9200	41.16	27.89

Table 1: Screenshot of raw data

Variable	Observations	Mean	Std. Dev.
Franceville	134869	25.2359	30.79059
Libreville	134869	15.16948	21.91879

Table 2: Summary statistics for 24-hour average rooftop PM2.5 in Libreville and Franceville. Data expressed in ug/m3

APPENDIX C

MAPS

Map1: Overview of Gabon

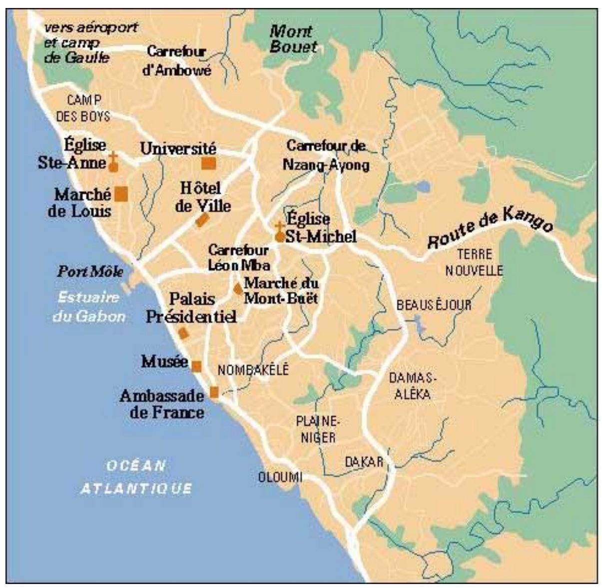
Source: The University of Texas at Austin

Map2: Gabon’s zones

Source: Leonard and Richard, cited by Robert NASI (1999).

Map3: The two study sites

Source : https://commons.wikimedia.org/wiki/File:Railways_in_Gabon.svg



Map 4: The city of Libreville

Source: http://www.mappery.com/Libreville-City-Map-2

Map 5: The city of Franceville

Source: http://www.weather-forecast.com/locations/Franceville

APPENDIX D

PHOTOS

Photo1: Open barbecue

Source : Visiter l'Afrique at: http://en.visiterlafrique.com/destinations/west-africa/mali/the-second-edition-of-the-barbecue-festival-in-bamako/

Photo 2: Gabon-Oregon Center in Libreville

Source: Brenda Ngana

Photo 3: Dormitories of the Masuku University

Source : Université des Sciences et Techniques de Masuku

Photo 4: Presentation of the Dylos Logger DC1700

Source: Nicole Ngo

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