AMERICAN UNIVERSITY OF BEIRUT

ASSOCIATION OF EXPOSURE TO FINE AIRBORNE PARTICULATE MATTER AND CARDIOVASCULAR DISEASES IN BEIRUT, LEBANON

by
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Last but not least, special thanks to my family, my father, who was willing to walk across every corner of Beirut just to support me in my research, my mother, who always reminds me that whether I hit or miss, I should always aim high, my brother and my two sisters, Omar, Amal and Dina, though not close, but were always there for their little brother.

AN ABSTRACT OF THE THESIS OF

Alaa Said Imad for Master of Engineering
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Title: Association of Exposure to Fine Airborne Particulate Matter and Cardiovascular Diseases in Beirut, Lebanon

Ambient air pollution represents worldwide an environmental risk factor to cardiovascular diseases (CVDs). Previous studies have reported an association between exposure to ambient air pollution and CVDs in Lebanon. However, no studies in Lebanon used a modeled spatial distribution of air pollutants to investigate this association. This study aimed to determine the relationship between the level of exposure to airborne particulate matter and obstructive coronary artery diseases (CAD) in the city of Beirut using a modeled spatial distribution of $PM_{2.5}$.

Information on demographic characteristics, smoking habits and place of residence were collected for a group of subjects living in Beirut from March 2014 to December 2017 under the Vascular Medicine Program (VMP) in the American University of Beirut Medical Center (AUBMC). All participants signed an IRB approved informed consent and their coronaries were visualized by cardiac catherization at AUBMC. In parallel, a modeled spatial distribution of $PM_{2.5}$ for a representative meteorological situation in Beirut was obtained from the mesoscale and micro-scale dispersion model system GRAMM-GRAL (versions v17.1 and v18.1). The modeled distribution of $PM_{2.5}$ was used to determine the level of $PM_{2.5}$ exposure at the participant's place of residence.

Results from univariate linear regression revealed that obstructive CAD was significantly associated with the levels of $PM_{2.5}$ among smokers (OR 1.052, 95% CI (1.016–1.089), $P < 0.01$) per 1 $\mu g.m^{-3}$ rise in $PM_{2.5}$ concentration. After adjusting for age and smoking habits, results from multivariate linear regression revealed also a significant association among males (OR 1.030, 95% CI (1.003–1.059), $P < 0.05$). This knowledge will be certainly useful for assessing the impact of $PM_{2.5}$ on CVDs and urging public health interventions to reduce air pollution in Beirut.

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ABBREVIATIONS

AUBMC	American University of Beirut Medical Center
AAP	Ambient Air Pollution
BMI	Body Mass Index
CVD	Cardiovascular Disease
CAD	Coronary Artery Disease
EDL	Electricite du Liban
GRAMM	Graz Mesoscale Model
GRAL	Graz Lagrangian Model
IHD	Ischaemic Heart Disease
LMIC	Low- and Middle-Income Country
PM	Particulate Matter
VMP	Vascular Medicine Program
WHO	World Health Organization

DEDICATION

In my eyes, Beirut is great.

In my eyes, I see the greatness of Beirut every time I look at the blue Mediterranean Sea and the white summit of Mount Lebanon standing side by side, every time I imagine the orange and rubber trees that once stood between the colorful old houses and the scent of jasmine from the windows.

Today, the memory of my beloved city is being destroyed, the trees and the sight of the sea and mountain are being ravaged by a jungle of concrete and steel and the smell of jasmine is being replaced with the smell of pollution.

I spent my entire 24 years in Beirut. I grew up here, I learned from the people living in this city that, despite the darkness, change is yet to come, and therefore this work is to the city I love, to my city, Beirut.

CHAPTER I

INTRODUCTION AND BACKGROUND

A. Introduction

After the end of the Lebanese civil war and the start of reconstruction activities in 1993, the government initiated new projects to rehabilitate the power sector in order to meet the increasing demand for electricity. Today, the power sector in Lebanon constitutes one of the largest drains on the state's treasury, responsible for 40 percent of the country's fiscal deficit, according to the World Bank. The country's power generation capacity is nearly 2050 megawatts (MW), excluding the capacity of two temporary power barges, while the demand is estimated at 3500 MW [1]. This gap between power generation capacity and demand leads the state-owned electricity utility, Electricite du Liban (EDL), to institute scheduled power outage periods ranging from 3 to 16 hours per day depending on the area and season. People handle this gap by using private neighborhood or individual power generators, which have higher electricity tariff than the average tariff set by EDL. Most of these generators run on diesel fuel and only few generators run on natural gas. The higher cost of diesel generators is not only confined to electricity pricing, but also extends to the environmental cost. Due to the lack of environmental regulations on private power providers, emissions from diesel generators may lead to higher levels of ambient air pollution (AAP), particularly in dense urban areas like Beirut. High human exposure to AAP, such as fine airborne particulate matter, is increasingly associated with many diseases, such as cardiovascular diseases (CVDs). In this respect, is the exposure to fine airborne particulate matter emitted from diesel generators significantly associated with cardiovascular diseases in Beirut, Lebanon?

This thesis aims to help answer this question, in two phases. The first phase is to model the spatial distribution of fine airborne particulate matter, also known as $PM_{2.5}$, emitted from an estimated number of diesel generators for a representative meteorological situation in the city of Beirut using the mesoscale and micro-scale dispersion model system GRAMM-GRAL.

In collaboration with the Vascular Medicine Program (VMP) in the American University of Beirut Medical Center (AUBMC), the second part consists of collecting information on demographic characteristics, smoking habits and place of residence for a group of subjects living in Beirut. In addition, all participants will get their coronaries visualized by cardiac catherization to check for any major obstruction in their coronaries. The level of $PM_{2.5}$ exposure at the participant's place of residence will be then extracted from the modeled distribution of $PM_{2.5}$. Finally, the odds ratio and the p-value will be calculated using univariate linear regression to determine the association between obstructive coronary artery disease (CAD) and the level of exposure to $PM_{2.5}$ and to check whether susceptible groups are more greatly affected. In addition, multivariate linear regression will be conducted to adjust for age and smoking habits.

B. Literature Review

One hundred years ago, less than 10% of deaths was caused by CVDs. As the risk of dying from communicable diseases decreased and the population aged, the trend in mortality from CVDs increased [2]. In this connection, an estimated number of 17.5 million deaths in 2012 was caused solely by CVDs worldwide [3]. Of these deaths, over three quarters occur in low- and middle-income countries (LMICs). In 2015, more than any other group of CVDs, ischaemic heart disease (IHD), also known as coronary artery disease (CAD), was responsible for around 50% of deaths caused by CVDs, followed by stroke with 35% and hypertensive heart disease with 5% [4].

Besides, the annual PM levels were estimated to have increased globally by 8% during the period from 2008 to 2013. In LMICs in the Eastern Mediterranean, including Lebanon, around 60% of city population experienced increasing $PM_{2.5}$ or PM_{10} annual means over this period and only around 20% experienced decreasing levels [5]. In Lebanon, it was estimated that, the annual median concentration of $PM_{2.5}$ was equal in 2012 in urban areas to 31 $\mu g.m^{-3}$ with an upper bound reaching 45 $\mu g.m^{-3}$. These values exceed the recommended level set by the World Health Organization (WHO) Air Quality Guidelines (20 $\mu g.m^{-3}$ and 10 $\mu g.m^{-3}$ annual average for PM_{10} and $PM_{2.5}$ respectively).

In this perspective, AAP is increasingly recognized as a risk factor for many diseases, such as CVDs [5]. According to WHO, air pollution represents the biggest environmental risk to health. In 2012, around 3 million deaths were attributable solely to AAP, from which about 87% occurred in LMICs, which represent 82% of the world population. It was estimated that 36% of total deaths worldwide attributable to AAP in 2012 were caused by IHD. In Lebanon, it was estimated that in 2012, 1434 deaths (30 per 100 000 capita) were related solely to AAP (with uncertainty interval between 1183 and 1679), from which 921 deaths were caused by IHD [5].

A study was conducted to determine the relationship between short-term variations in ambient concentrations of particulate matter (PM_{10} and $PM_{2.5}$) and emergency hospital admissions in the city of Beirut [6]. It was found that total respiratory admissions were significantly associated with the levels of PM_{10} (RR 1.012 [95 % CI 1.004-1.02]) per 10 $\mu g.m^{-3}$ rise in daily mean pollutant concentration for PM_{10} and 1.016 [95 % CI 1.000-1.032] for $PM_{2.5}$ on the same day. With regard to susceptible groups, total respiratory admissions were significantly and nearly significantly associated with $PM_{2.5}$ and PM_{10} within the same day in children and adults, respectively.

Another study conducted in 2015 investigated the association between exposure to traffic and diesel emission and CVDs among adults in Lebanon [7]. The information on exposure to outdoor air pollution were used as proxy instead of the quantitative air pollutant measurements due to the lack of air monitoring stations in Lebanon. The results showed that subjects living within 100 m near a highway or near a local diesel generator had a significantly higher risk of CVDs. Moreover, an increased risk of CVDs was noted with long duration of living near a busy highway or a local diesel generator.

In the United States, a study analyzed the effects of short- and long-term $PM_{2.5}$ exposure on C-reactive protein, white blood cells, fibrinogen and homocysteine were analyzed using multiple linear regression, adjusting for cardiovascular risk factors, temperature and ozone [8]. The exposure to $PM_{2.5}$ was found by linking the participant's address with meteorological and modeled air pollution data. In the overall population, no significant positive associations were noted for either short- or long-term $PM_{2.5}$ exposures for any of the biomarkers after controlling for confounders. However, stronger associations were found among obese, diabetics, hypertensive and smokers.

CHAPTER II

RESEARCH METHODOLOGY

A. Study area and meteorological conditions

Beirut is the capital of Lebanon and has an area of 20.8 km^2. The city is located on the eastern coast of the Mediterranean Sea at a latitude line of 33:49N and a longitude line of 35:29E. Despite not having a recent census, latest official reports put the number of residents in Beirut governorate in 2007 at around 361000 residents, which makes 9.6% of the total population in Lebanon [9]. Among the eight governorates of Lebanon, Beirut has the highest population density, which reaches up to 19195 population/km^2.

Information on elevation were extracted at 25 m horizontal resolution [10]. The digital representation of Beirut topography was then obtained as shown in Figure 1. The topographic map shows a complex topography in Beirut characterized by two hills, each at approximately 100 m above sea level, separated by a pass. Both hills overlook the Mediterranean Sea: one facing the west side and the other facing the north side of the city. The east side of the city is characterized by a falling slope created by Beirut River that separates the district of Matn in the Mount Lebanon Governorate from the city of Beirut. Finally, in the south side at the borders with the district of Baabda in the Mount Lebanon Governorate, slopes are less common than in the north side of the city. This complex topography played an important role in modeling the wind field and therefore the dispersion of air pollutant.

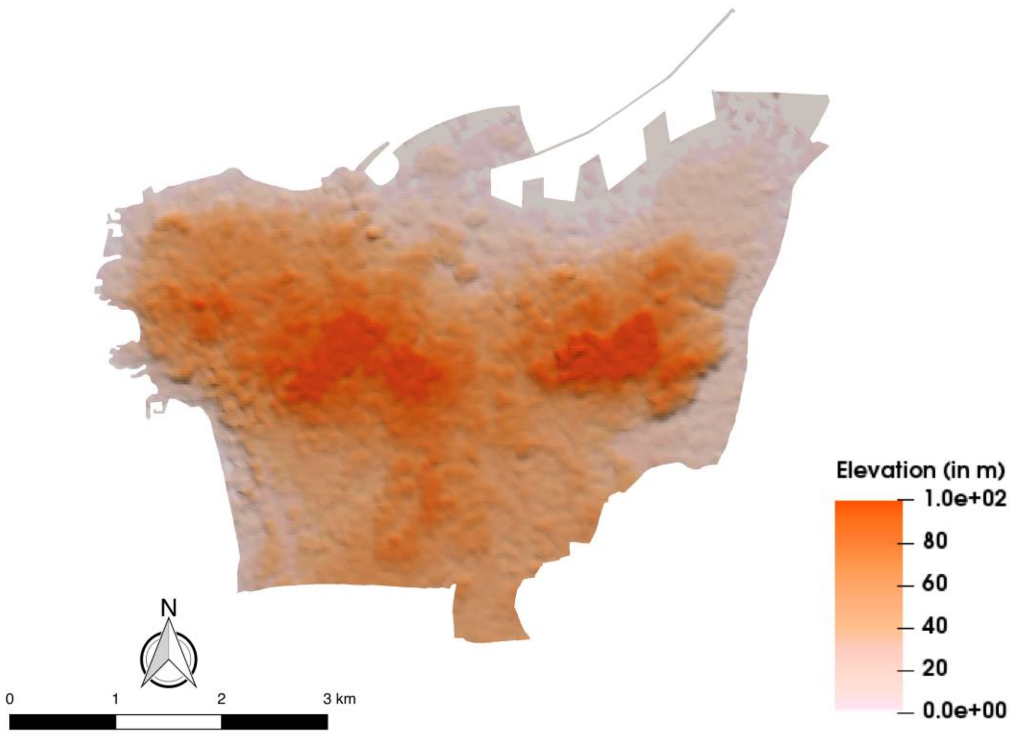

Figure 1: Topographic map of Beirut

Observations of the wind speed and wind direction over the years in Beirut were necessary to determine a representative meteorological condition for the city. Based on hourly measurements of the wind speed on a site in Beirut at an elevation of 40 m above sea level for a period extending from 2005 to 2007, the frequency distribution of the wind speed in Beirut was generated [11]. It was found that the wind speed of 3 m/s had the highest frequency in Beirut, which reached up to 22.07%. It was also found that the average wind speed over the 3 years period was 3.409 m/s.

With respect to the dominant wind direction, a wind statistic based on real observations was extracted from the weather station at Beirut Airport at 27 m elevation taken between June 2005 and September 2018 daily from 7am to 7pm [12]. These values were used to determine the frequency distribution of the wind direction in Beirut. Based on annual average, it was found that the wind directions of 225° (SW) and 247.5° (WSW) had both the highest frequency in Beirut, which reached up to 19.2% for each of the two wind directions. Consequently, a meteorological situation of 3 m/s wind speed and 247° wind direction was considered a representative meteorological condition for Beirut.

B. Emission sources

Beirut is a city with very few green spaces which occupy 0.64 km^2 or 3 % of its surface. The road network is dense (325 km of length in total) and the road transport emissions are considered one of the main sources of air pollution. The city has no significant industries and the industrial activity in the surrounding cities is not well developed. However, as for assessing the impact of pollutants emitted from diesel generators, only one study investigated the association between exposure to outdoor pollutants from diesel generators and CVDs in Lebanon [13].

In order to model the spatial distribution of $PM_{2.5}$ emitted from diesel generators, the count of diesel generators in Beirut, the emission factor of $PM_{2.5}$ and information on the height and diameter of the stack were required. An estimate number of diesel generators was obtained from a survey conducted in the Hamra region by a team of students at the American University of Beirut (AUB) [14]. As reported, the total number of surveyed buildings in Hamra was 588 out of which 310 had one or more diesel generators, which makes approximately half of the surveyed buildings. Knowing that the overall number of buildings in the city of Beirut was 18457, an extrapolation of the results found in Hamra over the entire city of Beirut provided an estimate number of 9721 buildings with one or more diesel generators in Beirut. For simplification, it was assumed that the 9721 buildings were equipped with only one generator. As shown in Figure 2, the 9721 diesel generators were distributed such that every two consecutive buildings were equiped with one diesel generator.

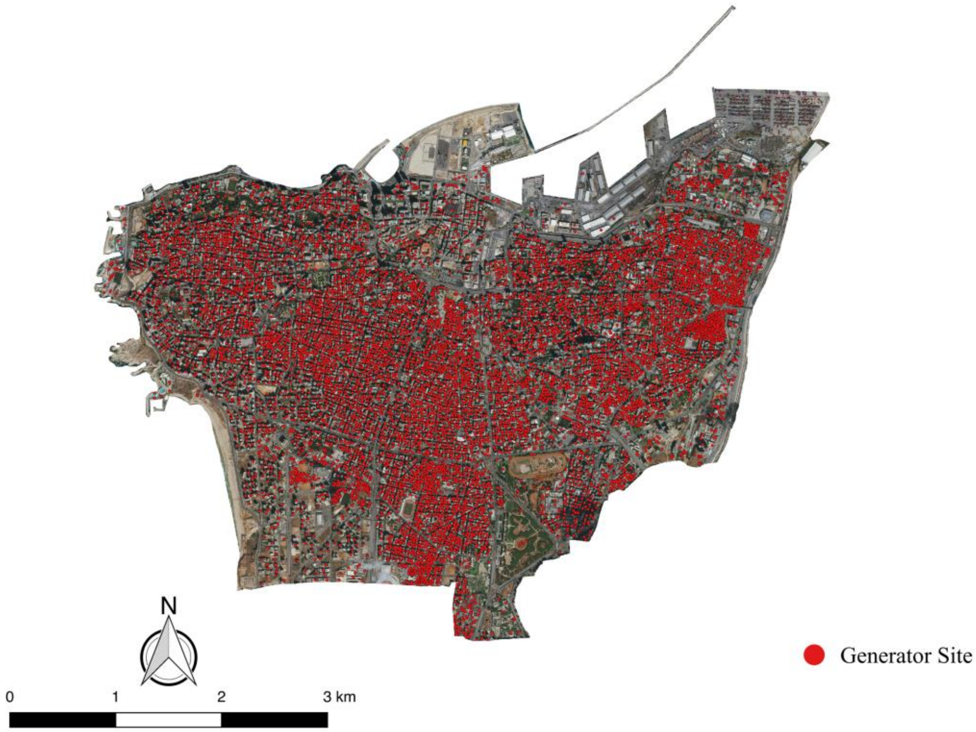

Figure 2: Estimated generator site in Beirut

Assuming that diesel generators in Beirut all ran at the same time, an estimate emission factor of $PM_{2.5}$ from all diesel generators was found equal to 0.32 MT/h (MT being Metric Tons) [14]. As a result, the emission factor of $PM_{2.5}$ per one diesel generator was set to 0.033 kg/h. Furthermore, stack height was assumed equal to the building height with an average of 21 m and the stack diameter was assumed constant for all generators and equal to 0.3 m.

A project carried out by a team of students at AUB developed the national vehicle inventory for Lebanon and assessed the emissions associated with land transport [15]. The emission of PM from land transport was found low relative to other pollutants such as CO_2 and CO (4750000, 44000 and 390 Tons per Year for CO_2, CO and PM respectively). Further investigation on this subject estimated that the upper and lower bound of the emission factor of $PM_{2.5}$ in Beirut was equal to 0.0067 and 0.0032 kg/h per 1 km street length. By taking the average emission factor of $PM_{2.5}$ from land transport and assuming that the emission rate of $PM_{2.5}$ from one diesel generator was equal to 0.033 kg/h, the emission of $PM_{2.5}$ from a street of 1 km length was considered equivalent to 15 % of the emission from one diesel generator. The emission of $PM_{2.5}$ from land transport were thus not taken into consideration in this study.

C. Modeling wind field using GRAMM-GRAL

A modeled spatial distribution of $PM_{2.5}$ for a representative meteorological situation in Beirut was obtained from the mesoscale and micro-scale dispersion model system GRAMM-GRAL. Both the GRAMM model (Graz Mesoscale Model) and the GRAL model (Graz Lagrangian Model) have been developed at the Graz University of Technology, Institute for Internal Combustion Engines and Thermodynamics since the 1990’s [16] [17]. The models were specifically designed to enable long-term city-wide building-resolving simulations with affordable computation costs. The wind field obtained from GRAMM model takes into account the influence of topography, land use and soil properties on a mesoscale area. Whereas the wind field from GRAL model accounts for the influence of buildings and highly resolved terrain details.

The GRAMM model is based on a set of Reynolds-averaged conservation equations that include conservation equation of momentum, mass, temperature and specific humidity. The mass conservation in the model is enforced by correcting the flow field by a pressure field after each iteration. Further information about the basic equations and approximations of GRAMM, the numerical schemes and validation studies can be found in the GRAMM documentation [16].

The GRAL model uses the basic principle of Lagrangian models to track a multitude of fictitious particles moving on trajectories within a 3-d windfield [17]. If buildings are included in the GRAL domain, their effect on dispersion will be taken into account using a micro-scale flow-field model. In the case of complex terrain without obstacles, GRAL is coupled with the prognostic, mesoscale wind field model GRAMM.

In this study, the GRAMM model was used to get the flow field over a complex terrain in a domain with surface area of 452 km^2, approximately ten times larger than the GRAL domain. The GRAMM grid had a horizontal resolution of 50 m and 15 vertical layers with a vertical thickness of 10 m for the first layer and a vertical stretching factor of 1.40. Homogenous values for land-use were assumed along the domain. The roughness length was set to 0.3 m, surface albedo to 0.1, heat conductivity to 1 $W.mK^{-1}$, thermal conductivity to 0.000001 $m^2.s^{-1}$, surface emissivity to 0.92 and soil moisture content to 0.1. The relaxation factor was set to 0.05 as recommended for a horizontal grid size of 25–50m.

No buildings or other obstacles were included in this study. Since we were concerned only with the overall distribution of $PM_{2.5}$ in Beirut, the influence of buildings and highly resolved terrain details was assumed negligible compared with the influence of topography. The GRAL domain covered all the surface of Beirut and had a surface area of 50 km^2. The horizontal grid size of the concentration grid was set to 5 m and the vertical dimension of concentration layers was set to 1 m. Dispersion time and particles released per second were set to 3600 s and 125, respectively.

Figure 3 shows the modeled steady-state flow field over Beirut for a single meteorological situation (3 $m.s^{-1}$ wind speed, 247° wind direction and an atmospheric stability class of 7) at 3 m height from the ground. The wind speed varied from 0 to 5 $m.s^{-1}$ and originated mainly from the South-West. A deviation in the wind direction was observed in the east side of the city along Beirut River. The highest wind speed was in the north-west side where the elevation in topography was higher relative to the other regions of Beirut. The lowest wind speed was observed in the Port region in the north-east side.

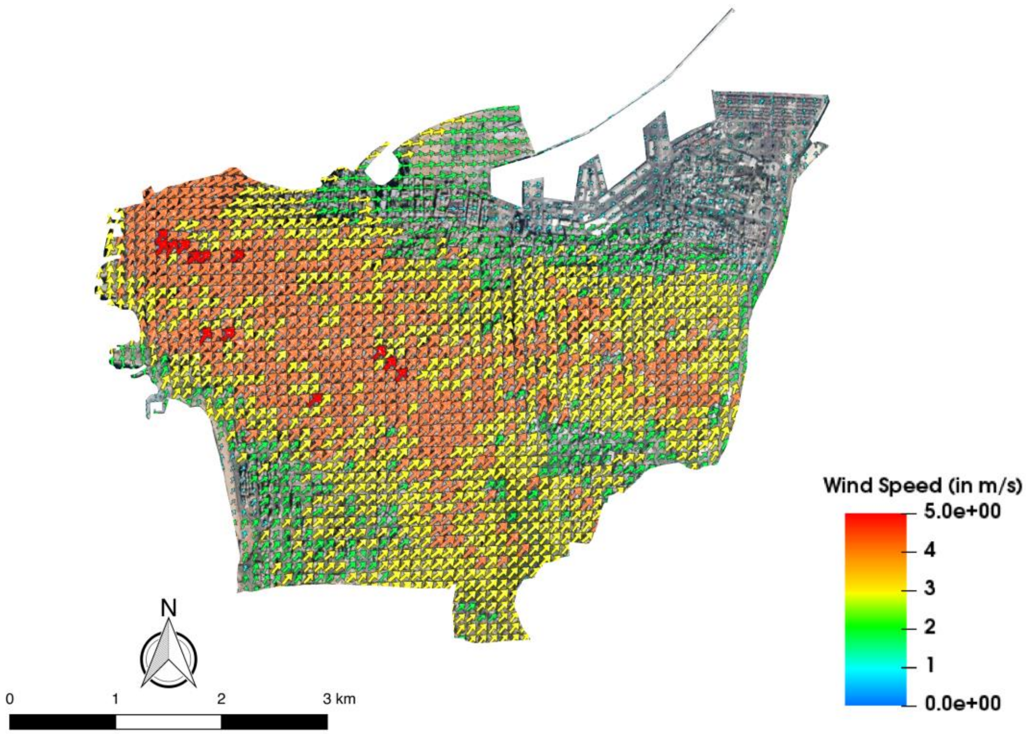

Figure 3: Steady-state flow field over the complex area of Beirut

D. Case Study

We evaluated in this study the correlation between the level of exposure to $PM_{2.5}$ and obstructive CAD for a group of subjects living in the city of Beirut who signed an IRB approved informed consent and were admitted for cardiac catheterization at AUBMC.

1. Health Data

The Vascular Medicine Program (VMP) at AUBMC is a multidisciplinary unit that utilizes numerous clinical and research resources across campus, directed to promote vascular health and reduce the burden of CVDs in Lebanon and the region [18]. The VMP has been collecting clinical data from March 10, 2014 to December 14, 2017 for 526 subjects. Their coronaries were visualized by cardiac catherization and were then divided into two categories: those who were diagnosed with obstructive CAD and those who were not. Subjects who were diagnosed with obstructive CAD had at least 50 % obstruction in any of the coronaries.

2. Covariates

We obtained data on demographic variables, including age and sex, and smoking status. The smoking status was treated as dichotomous variable: either smoker or non-smoker. Participants who fell into the first category included smokers of cigarettes, cigars or narguileh with number of packs varying from half to four packs per day for cigarette smokers. Those who fell into the second category included participants who never smoked in life or had smoked in life but currently not smoking. Other potential risk factors for CVDs, such as body mass index (BMI), total cholesterol, HDL cholesterol, diabetes, history of any CVDs, hypertension or secondhand smoke exposure were not available.

3. Collecting Addresses

After excluding participants with missing or unclear data on place of residence, there were 340 participants in our analysis. Because the location of buildings was not computerized in Beirut and to better locate the participants, the GPS coordinates of the buildings were collected for participants who provided the name of their building. In total, the exact locations of 235 participants were collected. For the remaining 105 participants and after excluding those who lived on a street longer than 750 m, the GPS coordinates of the street were extracted from Google Map for each of the participants. The location of each participant was then projected on the topographic map of Beirut as shown in Figure 4. The figure shows that most of the participants were located on the north and west side of the city. This might be explained by the location of AUBMC in the north-west side of Beirut.

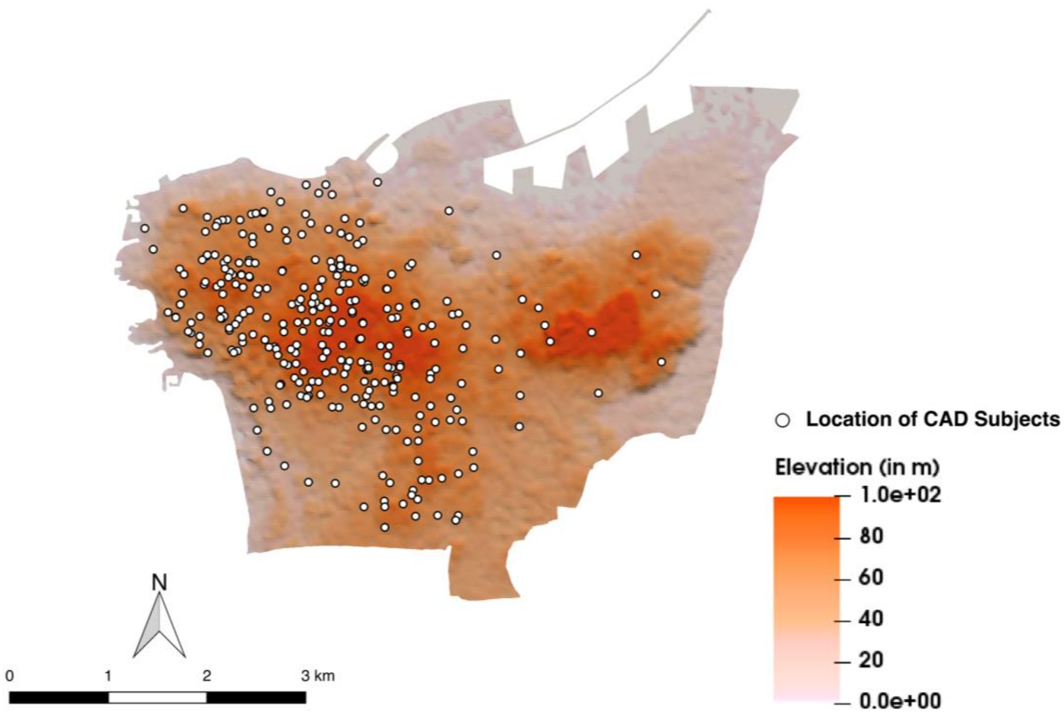

Figure 4: Location of 340 subjects projected on the topographic map

E. Statistical analysis

For the 340 subjects, the mean and the standard deviation of the modeled exposure to $PM_{2.5}$ emitted from diesel generators was equal to 18.37 ± 19.58 $\mu g.m^{-3}$. In order to reduce the standard deviation, any value of $PM_{2.5}$ exposure larger or equal than 2 times the standard deviation was excluded from the analysis. After removing the outliers, we were left with 323 subjects with mean $PM_{2.5}$ exposure equal to 15.25 ± 13.73 $\mu g.m^{-3}$.

Table 1 shows the number of subjects by age group for all participants and also for females and males, separately. For both sexes combined, the age groups between 61 and 70 years and 81 and 91 years had the highest and lowest portion, respectively. However, the age group between 71 and 80 years had the highest portion among females with 41 % from the total number of females. On the other hand, the age group between 39 and 50 years had the highest portion among males with 34 % from the total number of males. Therefore, in our sample, females tended to be older than males.

Table 1: Characteristics of the VMP subjects by Age

Age Group	Female	Male	Total	Portion of age group %
Age 39–60	23	76	99	30.65
Age 61–70	30	74	104	32.20
Age 71–80	41	53	94	29.10
Age 81–91	6	20	26	8.05
Total	100	223	323	100.00

Table 2 shows the number of subjects by smoking habit for all participants and for females and males, separately. For females and males combined, almost two-thirds of the participants were non-smoker. It was also found that, in this sample, males tended to smoke more than females with the portion of smokers being 38 % among males and 30 % among females.

Table 2: Characteristics of VMP subjects by smoking habit

Smoking habit group	Female	Male	Total	Portion of smoking habit group %
Non-smoker	70	138	208	64.40
Smoker	30	85	115	35.60
Total	100	223	323	100.00

Finally, Table 3 shows the number of subjects by CAD groups for all participants and for females and males, separately. Those who fell into the "yes" category had at least 50 % obstruction in any of the coronaries. Almost two thirds of the participants fell into the "yes" category. However, a difference in the portion of CAD groups was observed when taking the two sexes separately. It was found that 43 % of females and 77.58 % of males fell into the "yes" category.

Table 3: Characteristics of VMP subjects by CAD groups

CAD group	Female	Male	Total	Portion of CAD group %
No	57	50	107	33.13
Yes	43	173	216	66.87
Total	100	223	323	100.00

Statistical analysis was performed using SPSS IBM version 20.0. A univariate analysis using linear regression was performed with obstructive CAD being the dependent variable and modeled $PM_{2.5}$ exposure from diesel generators being the independent variable. A P value < 0.05 was considered statistically significant. The univariate regression model was stratified according to age (< 60 and ≥ 60 years), smoking status and sex (female and male) to test for presumed relationship of age, smoking status and sex with both CAD and exposure to $PM_{2.5}$. A multivariate linear regression was then carried out on all participants and on females and males, separately. Odds ratios and adjusted odds ratios and their 95 % confidence intervals were reported from the univariate and multivariate regression, respectively.

CHAPTER III

RESULTS AND ANALYSIS

A. Spatial distribution of PM2.5 in Beirut

The modeled steady state spatial distribution of $PM_{2.5}$ emitted from 9721 generators distributed in Beirut was obtained from GRAL model and shown in Figure 5 at 3 m above the ground. In this simulation, it was assumed that all generators were running at the same time and had a $PM_{2.5}$ emission factor of 0.033 kg/hr.

Three major areas were observed: The first area was located along the sea in the western part of Beirut where it was exposed to South-West wind. Such conditions were favorable to pollutant dispersion and therefore the lowest $PM_{2.5}$ values were measured in this area. The second area was located in the heart of the city along the dale and in the eastern part of the city where the wind has the lowest speed as shown in Figure 3. These conditions in topography and wind speed were responsible for the high $PM_{2.5}$ values observed in this area. The remaining part of the city constituted the third area where $PM_{2.5}$ values were in the middle. It is worth noting that only the first area had $PM_{2.5}$ values complying with the recommended level of 10 $\mu g.m^{-3}$ for $PM_{2.5}$ annual average set by the WHO Air Quality Guidelines.

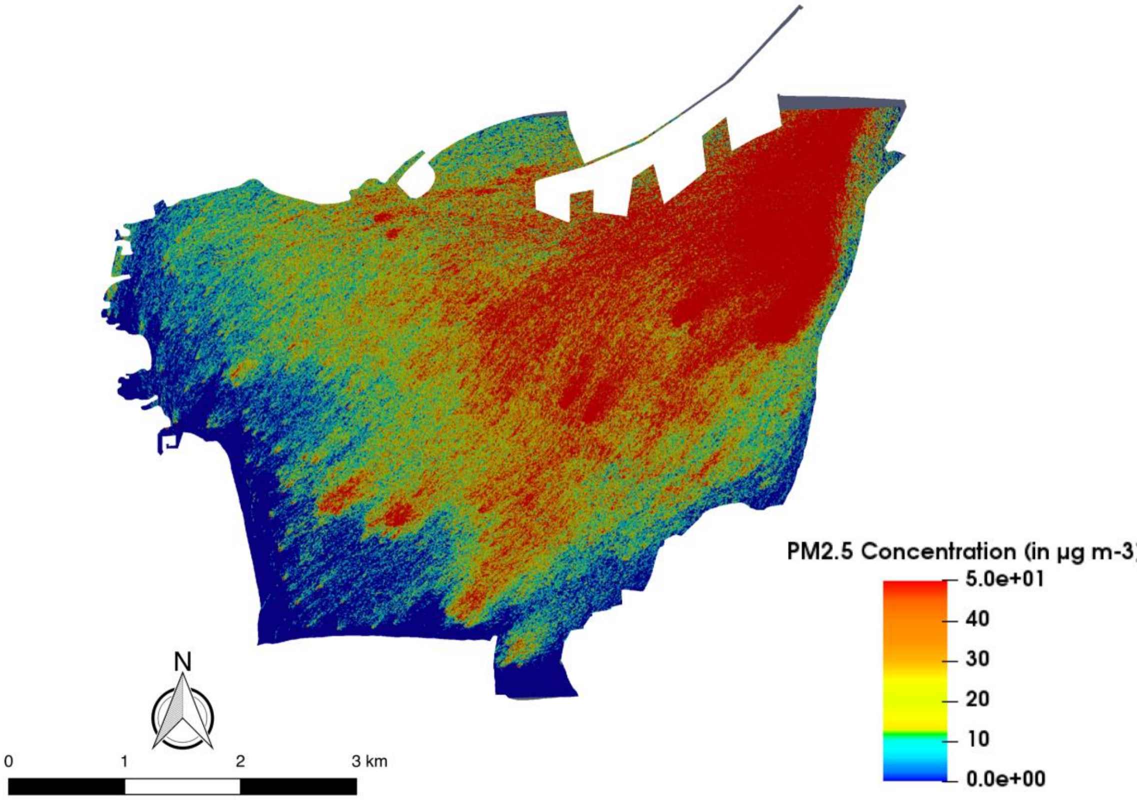

Figure 5: Spatial distribution of $PM_{2.5}$ emitted from diesel generators for a representative meteorological condition

B. Exposure-response relationship

The estimated levels of exposure to $PM_{2.5}$ in µg.m^{-3} at the place of residence of the 323 participants in this study were extracted from the map shown is Figure 5. Table 4 shows the descriptive statistics of $PM_{2.5}$ exposure. $PM_{2.5}$ estimated values varied between a minimum value of 0 and a maximum value of 55 µg.m^{-3}. It's worth noting that the mean of $PM_{2.5}$ exposure was 5.25 units higher than WHO $PM_{2.5}$ limit value. Moreover, the median of $PM_{2.5}$ exposure was equal to 12.77 µg.m^{-3} which shows that more than half of the participants were exposed to $PM_{2.5}$ levels above WHO $PM_{2.5}$ limit value.

Table 4: Descriptive statistics of modeled $PM_{2.5}$ exposure (in µg.m^{-3})

Statistic	$PM_{2.5}$ Exposure (in µg.m^{-3})
Count	323
Minimum	0.00
Maximum	54.72
1st quartile	3.68
Median	12.77
3rd quartile	22.56
Mean	15.25
Standard deviation	13.73

Considering all participants, no significant association between obstructive CAD and $PM_{2.5}$ exposure was found. However, different results were found when considering susceptible groups. The results of the univariate linear regression for $PM_{2.5}$ exposure and obstructive CAD stratified by smoking status are presented in Table 5. However, it was found that obstructive CAD was significantly associated with the levels of exposure to $PM_{2.5}$ among smokers (OR 1.052, 95% CI (1.016–1.089), $P < 0.01$) per 1 µg.m^{-3} rise in $PM_{2.5}$ concentration. No significant correlation was found among non-smokers.

Table 5: Odds ratios with their 95% confidence intervals from the univariate linear regression stratified by smoking status

Smoking Status					
Non-smokers			Smokers		
OR	95% CI	*p* value	OR	95% CI	*p* value
0.995	0.975–1.017	0.666	1.052	1.016–1.089	0.004

Table 6 shows the results of the univariate linear regression for $PM_{2.5}$ exposure and obstructive CAD stratified by age. The association between obstructive CAD was nearly significant with the levels of exposure to $PM_{2.5}$ among participants between 39 and 60 years (OR 1.034, 95% CI (0.999–1.017), P = 0.055). No significant correlation was found for participants older than 60 years.

Table 6: Odds ratios with their 95% confidence intervals from the univariate linear regression stratified by Age

Age					
	Age 39–60			Age 61–91	
OR	95% CI	*p* value	OR	95% CI	*p* value
1.034	0.999–1.017	0.055	1.009	0.988–1.030	0.405

Finally, the results of the univariate linear regression for $PM_{2.5}$ exposure and obstructive CAD stratified by sex are presented in Table 7. The obstructive CAD was nearly significantly associated with the levels of exposure to $PM_{2.5}$ among males (OR 1.025, 95% CI (0.999–1.051), P = 0.060). No significant correlation was found among females.

Table 7: Odds ratios with their 95% confidence intervals from the univariate linear regression stratified by sex

Sex					
Female			Male		
OR	95% CI	*p* value	OR	95% CI	*p* value
0.997	0.968–1.026	0.818	1.025	0.999–1.051	0.060

Table 8: Adjusted odds ratios with their 95% confidence intervals from the univariate linear regression stratified by sex

Sex					
Female			Male		
OR	95% CI	*p* value	OR	95% CI	*p* value
0.996	0.967–1.026	0.812	1.030	1.003–1.059	0.029

Smoking status, age and sex were all included in the multivariate linear regression.

Table 8 shows the results stratified by sex. When adjusted for smoking status and age, obstructive CAD and $PM_{2.5}$ exposure became significantly associated among males (OR 1.030, 95% CI (1.003–1.059), $P < 0.05$) per 1 $\mu g.m^{-3}$ rise in $PM_{2.5}$ concentration. However, the association remained not significant among females. Such results for both sexes can be explained by the fact that females tended to be older and smoke less than males in our sample, as seen previously.

CHAPTER IV

CONCLUSION AND FUTURE WORK

This is, to my knowledge, the first study conducted to evaluate the association between exposure to $PM_{2.5}$ and obstructive coronary artery diseases in Beirut using a modeled spatial distribution of $PM_{2.5}$. In a previous study for Lebanon, assessment of air pollution was based on self-reported information from participants [13]. In a second study for Beirut, the air pollutant data, particularly PM_{10} and $PM_{2.5}$, was collected from a network of stations distributed in Beirut [6].

Results from univariate linear regression revealed no significant positive association between obstructive CAD and $PM_{2.5}$ exposure in the overall sample. Similar results were observed in a previous study in the United States, where no significant positive associations were noted in the overall population for either short- or long-term exposure to $PM_{2.5}$ exposures for the biomarkers of cardiovascular disease risk [8]. However, after stratifying the sample by smoking status, results from univariate linear regression revealed a significant association between obstructive CAD and $PM_{2.5}$ exposure among smokers (OR 1.052, 95% CI (1.016–1.089), $P < 0.01$) per 1 $\mu g.m^{-3}$ rise in $PM_{2.5}$ concentration. A study conducted in Lebanon also revealed that the risk of CVD of subjects exposed to outdoor air pollution is higher for current smokers compared to nonsmokers [13]. Similarly, in the United States, significant associations between exposure to $PM_{2.5}$ and biomarkers of cardiovascular disease risk were noted only in susceptible groups, namely obese, diabetics, hypertensive and smokers [8]. A multivariate linear regression was then conducted to adjust for age and smoking habits. The results revealed a significant association among males (OR 1.030, 95% CI (1.003–1.059), $P < 0.05$) per 1 $\mu g.m^{-3}$ rise in $PM_{2.5}$ concentration.

The project can be continued in the future and improved. Further work can be done to have a more accurate model of the spatial distribution of $PM_{2.5}$ in Beirut. When computing the wind field from the GRAL model, the influence of buildings was assumed negligible compared with the influence of topography. However, buildings can be taken into account in future GRAL simulations either using a simple diagnostic or an advanced prognostic microscale wind field model. In addition, the background concentration of $PM_{2.5}$, whether from Beirut southern or eastern suburbs or from the sea, was not taken into account. Knowing that the wind direction in Beirut is predominantly originating from southwest (SW) and west-southwest (WSW), $PM_{2.5}$ emitted from diesel generators in Beirut southern suburb could be transported inside the city of Beirut depending on the wind field pattern in this region. Therefore, further work must be done on computing the wind velocity field in Beirut southern suburb and estimating the number of generators in this region based on the population and the socioeconomic factor.

The only covariables that were included in this study were age, sex and smoking status. Other potential risk factors for CVDs, such as BMI, cholesterol, diabetes, hypertension, history of any CVDs or secondhand smoke exposure were not available. In future analysis, these missing risk factors should be included in the multivariate linear regression in order to control any potential confounding effect on the association between obstructive CAD and $PM_{2.5}$ exposure.

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