ABSTRACT

Title of Thesis: AIR QUALITY ASSESSMENT OF RESIDENTIAL EXPOSURE TO PARTICULATE MATTER AND VOLATILE ORGANIC COMPOUNDS NEAR A CONCRETE BLOCK PLANT AND TRAFFIC IN BLADENSBURG, MARYLAND

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Ambient air pollution from stationary sources, industrial traffic, and commuter traffic can negatively impact air quality and human health. Ernest Maier, a concrete block plant located in Bladensburg, Maryland wants to expand to include a concrete batching plant on the same property. This expansion could further degrade air quality and impact the health of vulnerable residents. Air quality monitoring were conducted in the community at five personal sites using the Airbeam and Atmotube, which are wearable, real-time sensors that can measure $PM_{2.5}$ and VOCs respectively. Sampling and traffic counts were conducted in thirty minutes' periods to capture morning on-peak, afternoon off-peak and evening on-peak periods. Pearson's correlation revealed that a weak correlation among the $PM_{2.5}$ and VOC concentrations observed between the different sites and some of the values were found to be statistically significant. ANOVA analysis showed that the $PM_{2.5}$ levels were significantly different at the different sites (p-value 0.001).

AIR QUALITY ASSESSMENT OF RESIDENTIAL EXPOSURE TO PARTICULATE MATTER AND VOLATILE ORGANIC COMPOUNDS NEAR A CONCRETE BLOCK PLANT AND TRAFFIC IN BLADENSBURG, MARYLAND

By

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Dedication

In loving memory of Bartholomew A.C Ezeugoh and Franca C. Ezeugoh

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Chapter 1

Introduction

What is Air Pollution?

Air pollution is the contamination of air via physical, biological or chemical alteration to the air in the atmosphere which is detrimental to human health. It is classified into two categories which are outdoor air pollution and indoor air pollution [1]. Outdoor air pollution occurs outside of indoor built environment and can include fine particles from fossil fuel combustion, noxious gases, ground level ozone and tobacco smoke [1]. Indoor air pollution refers to exposures that take place within houses and buildings to particulates, carbon oxides and other pollutants via indoor air and dust; which include gases, household products, building materials, outdoor indoor allergens, tobacco smoke, mold and pollen [1,2].

Outdoor air pollution is an important environmental health issue in the 21st century and is the cause of ~3.7 million deaths globally [3,4]. Exposure to outdoor air pollution can cause adverse effects to humans, other living organisms and the natural environment [4,5]. Also, it has been associated with global climate change, acid rain, ozone depletion and damage to crops [3]. Air pollutants are categorized as primary and secondary pollutants. Primary pollutants are obtained from natural and anthropogenic processes, such as ash from a volcanic eruption or dust from production of cement; while secondary pollutants are produced in the air via the interaction of primary pollutants [6]. Air pollutants include ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, volatile organic compounds (VOCs) and particulate matter (PM) [7].

Air Pollution and Industrial Sources

Air pollution can occur via emissions from stationary and mobile sources. A stationary source is a fixed location such as factories, refineries, boilers and power plants, which releases different types of air pollutants [8]. Stationary sources are divided into point and area sources. Point sources are linked to manufacturing and industrial processes, while; area sources refer to small and extensively distributed emission sources which may possess substantial cumulative emissions such as residential water heaters, wood burning fireplaces [9,10]. Pollutants may be released from smokestacks, storage tanks, equipment leaks, process vents, loading and unloading operations [11]. While, mobile sources refer to non-stationary sources which are divided into on-road vehicles (automobiles, buses, trucks, motorcycles) and non-road vehicles and engines (e.g., ships, trains, heavy equipment, locomotives and aircrafts) [12].

Industrialization plays an important role in economic growth and social development; however, it can result in environmental degradation, ecological threats and adverse human health effects. Unfortunately, studies have revealed that small and mid-sized industries do not utilize pollution control measures, which increase the release of air pollutants especially in populated areas [13]. Presence and proximity of industrial sources can increase the risk of air pollution apart from topography, meteorology, traffic emissions and population crowding in urban zones [14].

Air Pollution and Traffic Sources

In urban areas, research has shown an increase in traffic-related air pollution (TRAP) and its effects on ozone levels, as well as, human health [15]. Due to urbanization, there has been a rise in private and commercial vehicle use. This trend has been attributed to a rapid increase in traffic, vehicular and industrial emissions. As an important source of air pollutants, vehicular emissions have been associated with particulates, CO, SO_x, NO_x, heavy metals, PM, VOCs and polyaromatic hydrocarbons (PAHs) [16]. Also, traffic is a unique source of air pollution because pollutants are released close to human receptors and may not be quickly diluted in the atmosphere [17].

Exposure to traffic-related air pollution (TRAP) has been associated with deleterious health effects. Air pollution has a temporal relationship with heart failure hospitalization and heart failure mortality [18]. Wjst discovered that high rate of road traffic reduces forced expiratory flow and increases respiratory symptoms in children [19]. Another study demonstrated that an increase in exposure to traffic-related air pollution led to an increase in the prevalence of cough and bronchitis, and not with atopic conditions in children [20]. A case-control study found that living within 90 meters of a main road correlates with proximity-related wheezing in children [21]. Inner-city asthmatic children were found to have adverse respiratory health effects due to short-term increases in air pollutant concentrations [22] (i.e., increases due to traffic). There is an increased risk of developing airway disease and sensitization in preschool children due to early life TRAP exposure [23]. Exposure to traffic-related air pollution, especially diesel particulates have been linked with reduced lung function in children living near major motorways [24]. Truck traffic intensity and exhaust were associated with chronic respiratory symptoms which were more prominent in girls than boys [25].

Research has demonstrated a strong correlation between lung cancer and various markers of air pollution from traffic near local neighborhoods [26]. Evidence from case-control studies suggest that there is a relationship between traffic-related emissions and lung cancer [27]. Also, TRAP has been linked with decreased cognitive function in older men in the normative aging study (NAS) in Boston, MA [28]. TRAP exposure has been also associated with an increased mortality risk after hospitalization with acute heart failure [29]. Maternal exposure to TRAP can increase the risk of preeclampsia and preterm birth [30]. Research has demonstrated that the effects of air pollution on life expectancy are not evenly distributed, rather they are dependent on certain factors like education and antioxidant vitamin status. These exposures can negatively impact the life expectancy of economically disadvantaged groups [31,32]. Another study suggests that TRAP exposure is correlated with cardiorespiratory deaths and could impact life expectancy [33].

Purpose

The purpose of this study is to provide scientific information on particulate matter ($PM_{2.5}$) and volatile organic compound (VOC) levels near residential areas close to commuter traffic and industrial activity associated with a concrete block plant in Bladensburg, Maryland. Residents of Bladensburg are fighting against the siting of a concrete batching plant in the heart of their town. They believe it may increase air and noise pollution, stormwater runoff, traffic congestion and result in adverse health outcomes, thus affecting public health and safety of residents.

The site for the concrete batching plant is a property owned by Ernest Maier, Inc., which is a mid-Atlantic masonry company. Unfortunately, this location is next door to a historic African-American church (Kingdom Missionary Baptist Church) and is close to the Peace Cross, Battle of Bladensburg Memorial, Anacostia River and historic Bladensburg Waterfront Park, which are heritage and environmentally protected sites.

Currently, there is limited scientific information about the spatial and temporal variation of PM and VOCs near the proposed concrete batch plant in an area with heavy commuter and industrial traffic.

Specific Aims

1. To determine human exposure to PM and VOCs in Bladensburg, Maryland. *Hypothesis 1: Areas close to the concrete block plant will have higher exposure levels of PM and VOCs than areas farther away from the plant.*
2. To assess variation in human exposure to PM and VOCs at different locations during different times of the day in Bladensburg, Maryland. *Hypothesis 2: Individuals walking on highly trafficked roads will have higher exposure levels of PM and VOCs during on-peak periods than individuals walking on low trafficked roads during on-peak hours.*

Thesis Outline

This thesis is divided into five distinct chapters. Chapter 1 provides an overall introduction and the primary objectives of the thesis. Chapter 2 provides background and literature review on particulate matter and related adverse health outcomes, volatile organic compounds and its adverse health outcomes. Chapter 3 presents Paper 1 and provides results on particulate matter monitoring in support of the thesis's purpose. Chapter 4 provides Paper 2 and the results obtained for the monitoring of volatile organic compounds in line with the purpose of the thesis. Chapter 5 provides the synopsis, strengths, limitations and public health implication of the thesis.

Chapter 2

Literature Review

Particulate Matter

Particulate matter (PM) consists of a heterogeneous mixture of solid and liquid particles suspended in air that vary in size and chemical composition across space and time [34]. Primary particles are released from sources and secondary particles are produced in the atmosphere from gaseous emissions [35,36]. Primary and secondary PM can be dispersed and transported over long distances; and elimination from the atmosphere could take place through rainfall, gravitational sedimentation or coagulation with other particles [37]. The sources of PM are natural (e.g., volcanoes, fires, dust, storms, aerosolized sea salt) and anthropogenic or manmade (e.g., combustion in mechanical and industrial processes, vehicle emissions, tobacco smoke) [38]. Important sources of PM pollution are factories, power plants, incinerators, motor vehicles, construction activity, fires and windblown dust. They are distinguished by their aerodynamic diameter; those ≤ 10 µm are known as PM_{10}, while those ≤ 2.5 µm are referred to as $PM_{2.5}$ [7,38,39]. Other categories include ultrafine particles which are smaller than 0.1µm in aerodynamic diameter, fine particles which are smaller than 1 µm and coarse particles which are larger than 1 µm [34].

The size of these particles impacts the site of deposition as well as clearance in the respiratory tract. It is pertinent to note that PM_{10} contains ultrafine ($PM_{0.1}$; diameter less than or equal to 0.1µm) , fine ($PM_{2.5}$; diameter less than or equal to 2.5µm), coarse ($PM_{2.5-10}$; diameter between 10µm and 2.5µm), and nanoparticles ($PM_{0.05}$; diameter less than or equal to 0.05µm) particles or fractions [2,37,38,40]. Also, PM causes more harm than any other common air pollutants and has diverse constituents like nitrates, sulfates, elemental and organic carbon, organic compounds (e.g., PAHs), biological compounds (e.g., endotoxins) and metals (e.g., iron, copper) [5,34]. The USEPA regulates particulate matter under National Ambient Air Quality Standards (NAAQS); and $PM_{2.5}$ standards are 35 $\mu g/m^3$ for a 24 hour average and 12 $\mu g/m^3$ for an annual average [41].

Particulate matter can be generated via anthropogenic sources such as industrial dust during industrial production processes; which varies with location, season, and time of day [40,42]. Manufacturing, construction and cement industries release industrial dust during routine activities and processes, such as handling of materials and transportation of materials or products. Basically, there are three routes that lead to the formation of industrial PM – fuel combustion processes (e.g., furnaces, gas turbines), non-combustion processes (e.g., mechanical treatment of raw materials), and during handling, transport and storage of dusty raw materials (e.g., cement). For instance, in the cement industry, PM emissions occur via pre- and after-treatments such as milling processes. Industries involved in the utilization of cement provide an environment for diffuse PM emissions due to storage, transportation, and handling of bulk materials in open air.

An important source of PM emissions in urban areas is road transport which is classified based on the method of formation. Generally, there is an assumption that the principal method of PM formation is via combustion of fuels (gasoline and diesel) through internal combustion engines which result in emissions from tailpipes [40,43–45]. However, road transport emissions comprise of relationships between vehicles, road surface and the use of brakes which generates PM referred to as non-exhaust emissions. Non-exhaust emissions consisting of tire wear, brake wear, road surface wear (occurs via mechanical abrasion, grinding, crushing and corrosion processes) and resuspension of the dust on road surfaces [44,45]. Exhaust emissions contribute fine PM (<2.5 μm) while non-exhaust emissions contribute coarse PM ($PM_{2.5\text{-}10}$) into the atmosphere [43,44]. The use of laboratory and real-world simulations have revealed that PM emissions from diesel burning vehicles are higher than emissions from gasoline burning vehicles [40,46].

Maritime traffic is also a key source of PM emissions in coastal cities due to combustion processes which occur in ship engines; and are controlled by engine load factor, engine type and fuel type [40]. Also, PM can be released during loading and unloading operations of cargo from ships, which generate dust that sediment at the docks and may be resuspended via port-related traffic or wind. A study conducted on Los Angeles Metro revealed that commuters were exposed to high PM concentrations on the rail line [47].

Particulate Matter and Public Health

Certain factors such as composition of PM, the dose and time of exposure, size distribution, concentration, toxicity of PM as well as, exposure to chemical mixtures can affect human health in various ways [34,48]. The adoption of guidelines or standards for ambient PM pollution have centered around indicators of fine particles ($PM_{2.5}$), inhalable and thoracic particles (PM_{10}), and thoracic coarse particles ($PM_{10\text{-}2.5}$) [49]. Toxicological and physiological evidence suggests that fine particles can have the greatest adverse effects on humans due to their size and they can contain sulfates, nitrates, acids, metals and particles adsorbed on their surface. Also, they can be deposited deep in the lungs, remain deposited for longer time periods, easily gain access to the indoor environment, and transported over longer distances [42].

The National Morbidity Mortality and Air Pollution Study (NMMAPS) found a correlation between PM in the air and the risk of death from all causes and from cardiovascular and respiratory illnesses [49,50]. Another study identified PM as a risk factor for cause-specific cardiovascular disease mortality through processes such as pulmonary and systemic inflammation, accelerated atherosclerosis, and altered cardiac autonomic function [51]. PM exposure has also been linked to premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increase respiratory symptoms such as irritation of airways, coughing or difficulty in breathing [5,52].

Exposure to particulate matter can have negative health impacts on children. Exposure to PM leads to reduced lung function, lower airways irritation, upper airways irritation, increase in asthma hospitalization, higher asthma incidence, increased asthma exacerbations, respiratory allergy and bronchodilator usage [36,37,53]. The deposition of $PM_{10-2.5}$ in the upper airways is significant for asthmatic responses and irritation [54]. Residing close to PM sources (traffic and industry) has been identified as a risk factor for increased allergic symptoms, reduced lung function and increased sensitization to aeroallergens [37,55,56]. $PM_{2.5}$ exposure can also lead to an increased risk of developing asthma; while $PM_{2.5}$ and NO_2 exposures increased the risk of developing wheeze, which is a crucial symptom of cancer in adult women [57]. A study conducted in central Phoenix showed that PM_{10} concentrations were associated with asthma incidents, particularly among children between the ages of 5 and 17 [53]. Another study found a stronger correlation between $PM_{10-2.5}$ on asthma hospitalizations when compared PM_{10} and $PM_{2.5}$ for both sexes [54]. Another study showed an increase in exposures to $PM_{10-2.5}$ and carbon monoxide was associated with an increased risk of severe asthma attacks and medication use [58].

Exposure to particulate matter can also lead to heart disease. Previous studies have shown that exposure to high PM can lead to increased hospitalizations for individuals with heart disease

[59,60]. There may be a correlation between particle concentration and cardiovascular disease (CVD) exacerbation [61]. Short term adverse health effects of PM on the cardiovascular system are CVD exacerbation and mortality; and increased incidence of ischemic heart disease and myocardial infarctions [62–65]. Studies have shown that individuals with existing conditions such as chronic obstructive pulmonary disease (COPD), congestive heart disease, myocardial infarction or diabetes were at an increased risk of exacerbation on days with high PM concentrations [66–69]. Increases in PM levels were associated with increases in stroke attack and cerebrovascular mortality and morbidity [70–73]. Elevated short-term increases in PM exposure has been linked with acute increases in blood pressure in adults; while long-term exposure is a risk factor for stroke [74–76].

Evidence has also shown a relationship between exposure to elevated PM concentrations and smaller total cerebral brain volume with increased odds of covert brain infarcts [77]. In elderly women, studies has shown associations between long-term exposure to PM and the development of cognitive impairment [66,67]. Elevated levels of PM has been linked with central nervous system diseases such as Alzheimer's; which is an age-related neurodegenerative disease that could result in dementia among the elderly [80]. The Nurses' Health Study observed that long-term exposure to PM may result in an increased risk of cognitive decline in older women [81].

Maternal exposure to PM during pregnancy has been shown to lead to negative birth outcomes (i.e., low birth weight and preterm births) [82–84]. Low birth weight and small for gestational age were related to maternal exposure to specific PM emissions from road dust, oil combustion and motor vehicles (traffic-related sources) [85,86]. Adverse birth outcomes have been correlated with increases in neonatal morbidity and mortality, childhood developmental problems and increased risk of depression or psychiatric illnesses in adulthood [82,87]. Also, autism has been linked with exposure to traffic-related air pollution, nitrogen dioxide and PM during pregnancy and the child's first year of life [88,89].

Furthermore, exposure to PM from anthropogenic sources has been associated with an increase of premature mortality (respiratory, cardiopulmonary and lung cancer) [90]. PM concentrations from traffic-related sources and construction (inorganic) dust are major contributors to PM exposure which may result in adverse health outcomes [91]. A study has demonstrated that an increase in PM exposure may result in a decrease in life expectancy [92–95]. A study conducted on 545 U.S counties showed that reduction in PM to low levels led to prolonged life expectancy, especially among urban and highly populated counties [96]. A decline in long-term exposure to certain chemical components of PM (sulfate, ammonium and sodium ions) were correlated with improved public health and life expectancy [97]. There is an increased risk of mortality linked with $PM_{2.5}$ exposure and the risks were higher than mortality risks related to PM_{10} exposures [98].

Volatile Organic Compounds (VOCs)

VOCs are organic compounds which have a boiling point below 250^{o}C at ambient atmospheric pressure [99]. They include many chemicals such as benzene and its derivatives, simple aliphatic hydrocarbons (such as hexane), chlorinated hydrocarbons (such as chloroform), terpenes (such as limonene), alcohols, aldehydes and ketones with low carbon numbers such as isopropanol, hexanal and butanone [99,100]. They are released into the atmosphere from anthropogenic and biogenic sources, and could be formed in the atmosphere as products of the atmospheric transformations of other VOCs [100,101]. The important anthropogenic sources are stationary fuel related (i.e., combustion from power plants, service stations), transport related (i.e., combustive and evaporative emissions from vehicles) and industrial (i.e., storage and transport); while biogenic emissions may occur from vegetation, ocean or soils [101]. VOCs produce a primary component of smog known as ozone via reaction with nitrogen oxides and other airborne chemicals in the presence of sunlight [102].

The study of VOCs as air pollutants is important due to their role in ozone depletion, ozone formation, toxic and carcinogenic human health effects, and enhancement of the global greenhouse effect [103]. Outdoor VOC concentrations are influenced by season, nearness to emission sources (e.g., industry, traffic, gas stations) and meteorological conditions such as temperature [104]. Vehicle emissions contribute to ambient VOCs in urban areas [105,106]. They are also emitted from power plants, gas stations, auto body and paint shops, solvents used in chemical industry and diesel and gasoline-powered vehicles (i.e., vehicle exhaust, gasoline evaporation) [107,108]. Motor vehicle emissions are an influential source of VOC emissions, particularly in areas with few industrial sources, because they account for 35% of total VOC emissions [109]. Also, VOCs constitute 45% of on-road mobile source emissions in Southern California [110]. Vehicle emissions contribute to ambient VOCs in urban areas [105,106,106,111]. They are also emitted from power plants, gas stations, auto body and paint shops, solvents used in chemical industry and diesel and gasoline-powered vehicles (vehicle exhaust, gasoline evaporation) [107,108].

Chronic health effects associated with VOC exposure can be non-carcinogenic or carcinogenic. Non-carcinogenic effects include irritation, sensory effects, headache, eye irritation, skin irritation and airway irritation, damage to the liver, kidneys and central nervous system, asthma and respiratory effects [112–114]. While the carcinogenic effects of VOCs are lung, blood, liver, kidney and biliary tract cancers [112–114]. Also, exposure to VOCs may result in negative impacts on reproductive systems or birth defects [115]. Elevated VOC concentrations have been observed at high traffic intensity streets compared to low traffic intensity streets [107,116,117]. A study conducted in Kanawha County, West Virginia revealed that exposure to VOCs was associated with increased rates of chronic respiratory symptoms [118]. VOC exposure has been linked with cancers of the brain, nervous system, skin, melanoma, endocrine system and thyroid cancers in Indiana [119].

Susceptible and Vulnerable Populations

Susceptibility to air pollution involves inter-individual variability or heterogeneity in human responses to air pollutants, which result in certain populations being at an increased risk of adverse health outcomes associated with air pollution [120,121]. Susceptibility encompasses biological or intrinsic factors (e.g., life stage, sex, genetics); while vulnerability includes nonbiological or extrinsic factors (e.g., socioeconomic status, differential exposure). Factors which impact susceptibility are age, nutritional status and predisposing conditions [34]. However, they could be used interchangeably including terms such as “at-risk population” and “sensitive population” to include and explain these concepts generally. It is difficult to distinguish between susceptibility and vulnerability because both concepts are overlapping in nature which contributes to the complexity surrounding them [120,122].

For instance, one study defined susceptible population (relating to PM) as individual and population level characteristics which increases the risk of PM-related adverse health effects; such as genetics, birth outcomes (e.g., low birth weight, birth defects), race, gender, lifestyle, preexisting conditions, socioeconomic status, and properties that could modify exposure to PM

[120]. Children are more susceptible than adults when exposed to comparable levels of PM due to the greater time spent outdoors, higher activity levels, small volume per unit body weight and developing body organs or systems [41,120,122,123]. This could result in higher PM dose per lung surface area and lead to adverse effects on their developing lungs [41,120,122,123]. A significant correlation was observed between exposure to PM and their acidity and lung function and symptoms of bronchitis among children living in 24 US and Canadian communities [124].

Also, older adults or elderly individuals are a susceptible population due to the stepwise reduction in physiological processes over time [125]. Preexisting cardiovascular diseases and diabetes could increase their susceptibility to the adverse effects of PM exposure [41,68]. Epidemiological studies of asthmatic children demonstrated that short-term exposure to $PM_{2.5}$ was linked with an increase in medication use and respiratory symptoms; while short term PM_{10} exposure was connected with morning symptoms and respiratory symptoms [120,126–129]. Females are more susceptible than males to the adverse health effects due to PM exposure [35,122]. Various indicators of SES, such as income, social status measured by education, and work status measured by occupation can impact a population’s susceptibility to adverse health effects associated with PM exposure [120]. Also, low SES is linked with a higher frequency of preexisting conditions, limited access to medical care, and food deserts which can lead to increased susceptibility to adverse health effects of PM exposure [130]. Studies revealed that individuals with low SES experience higher PM-associated health risks [122].

Environmental Justice, Hazards, and Air Pollution

Environmental justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people, including racial, ethnic, or socioeconomic groups, should bear a disproportionate share of the negative environmental consequences, resulting from industrial, municipal, and commercial operations or the executive of federal, state, local, and tribal programs and policies [131,132].

Environmental Justice (EJ) as defined by Bunyan Bryant refers to "those cultural norms and values, rules, regulations, behavior, policies, and definitions that support sustainable development, so that people can interact with confidence that their environment is safe, nurturing and productive. EJ is served by when people can realize their highest potential, without experiencing the "isms." EJ is supported by decent paying and safe jobs; quality schools and recreation; decent housing and adequate health-care; demographic decision-making and personal empowerment; and communities free of violence, drugs and poverty. EJ communities are where both cultural and biological diversity are respected and highly revered distributive justice prevails" [133,134].

The definitions above presents the different views of the spectrum of environmental justice. EPA's definition is policy driven, bureaucratic, reactive and focuses on the equal enforcement of environmental laws. Also, it ignores historical environmental discrimination and geographic patterning and does not seek to address the historical burden of environmental hazards on communities of color and poor communities; thus omitting social justice and political empowerment which are important EJ goals [134]. Bryant's definition is proactive and has a more holistic centered approach for creating sustainability in communities with environmental justice issues.

The foundational tenet of environmental justice is embedded in Title VI of the Civil Rights Act of 1964 which bans discrimination based on race, color, or national origin under any program or activity receiving federal financial assistance [135]. The US Department of Justice and US EPA utilize similar bans when implementing regulations, especially, the location of an industrial site or facility in a discriminatory manner. The concept of environmental justice began over the past two decades as a model which combines class, race, gender, environment and social justice concerns [136]. This occurred via the dispute over the siting of industrial facilities in the US and has become a tool for poor people and communities of color which have borne disproportionate burdens of environmental hazards and locally unwanted land uses (LULUs) (e.g., landfills, power plants, prisons, factories, incinerators, chemical plants, sewage treatment plants, coal-fired plants, cement producing plants) while having restricted access to environmental amenities such as parks. A typical example was the case instituted by South Camden Citizens in Action against New Jersey Department of Environmental Protection, which sought an injunction and judgement on the grant of permits to construct and operate a cement producing plant by St. Lawrence Cement Company as a violation of Title VI [135].

People of color and low-income persons have endured more environmental and health risks than other groups in regards to where they live, work, play, and pray [132]. Environmental injustice can be defined as the disproportionate exposure of communities of color and the poor (or other vulnerable groups) to pollution, and its concomitant effects on health and environment, as well as the unequal environmental protection and environmental quality provided through laws, regulations, governmental programs, enforcement, and policies [137].

Urban communities of color are disproportionately overburdened by high levels of criteria air pollutants which are released from vehicle exhaust in highly trafficked neighborhoods and factories within these communities [134,138]. Studies have shown that there is a differential burden of environmental hazards on disadvantaged groups [139–141]. Several studies have demonstrated a positive correlation between residential proximity to hazards and race/ethnicity and SES [140–143]. In South Carolina, it was illustrated that there were burden disparities in the distribution of burden disparities of superfund facilities at the block and census-tract level based on race/ethnicity and socioeconomic status [144]. Also, there are disparities between census tracts that host leaking underground storage tanks (LUSTs) and those that do not host LUSTs based on race and socioeconomic status in Charleston, South Carolina [145]. This knowledge is based on the discovery that environmental stressors (such as air, water and land pollution) are disproportionately distributed among communities of color and low-income communities [146]. Also, a study has positively demonstrated that the percentage of individuals living in nonattainment air quality areas is significantly higher for Latinos and African-Americans compared to Whites [146].

In Maricopa County, Arizona, evidence suggests that there is environmental discrimination against Asians in the siting of hazardous facilities [147]. Findings have revealed that African-Americans were more likely to reside in close proximity to an industrial emission source and within two miles of multiple sources than Whites [148]. There is evidence which suggests that economically disadvantaged individuals are more vulnerable to emissions from industrial facilities compared to others [149]. There are racial and socioeconomic disparities in exposure to emissions from polluting industrial facilities in the US which can lead to adverse health outcomes among individuals of low socioeconomic status [150]. For example, individuals without high school diplomas were more likely to reside close to TRI facilities compared to individuals with higher educational attainment [150].

Evidence has shown that people of color and economically disadvantaged individuals have increased residential exposure to traffic and traffic-related air pollution [117,151–153]. Low-income groups and people of color are more likely to live in highly trafficked areas [152,154,155]. People of color from low-income groups had an increased cancer risk from traffic-related air pollution [156]. Pacific Islanders, African-Americans and Asians were observed to have higher pollution exposures and were twice as likely to live in the most polluted counties [157] than Whites. Elementary schools in economically disadvantaged communities were found to be exposed to very high traffic in California [158]. Economically disadvantaged individuals and communities of color were observed to be disproportionately exposed to traffic and air pollution which may result in an increased risk of adverse health outcomes [159–162]. Latinos, especially Cubans and Colombians have increased cancer risk from vehicular air pollution in Miami, Florida [156].

A higher incidence of asthma among low-income individuals has been linked with higher traffic exposure and susceptibility factor such as health status and access to healthcare [162]. In California, it was revealed that nonwhite children were three or four times more likely to reside in highly-trafficked areas than White children; and children in low income communities had an increased risk to potential exposures from vehicle emissions [152]. Also, people of color and low income communities in Southern California may be disproportionately exposed to traffic-related air pollution [163]. A study on truck traffic and associated pollution in Hunts Point, New York, a primarily African and Latin-American community, low income individuals revealed that increased concentrations of elemental carbon were found at intersections and varied due to large truck traffic [164]. In low-income communities of Wilmington and western Long Beach, adjacent to the Ports of Los Angeles and Long Beach, California; the volumes of heavy-duty diesel trucks were as high as 400 to 600 trucks per hour for several hours around sensitive land use areas, such as, schools, parks and residences [163].

Evidence has demonstrated that traffic-related air pollution could lead to the development of asthma and other childhood respiratory diseases [165]. A study which assessed the association between residing near major roads, traffic flow and the risk of hospital admission for asthma in children younger than 5 years of age; revealed that children admitted with asthma diagnosis were more likely to live in high traffic flow which was less than 500 meters from a main road [166,167]. Traffic–related air pollution may lead to decreased lung function, particularly among girls that lived less than 300m to the motorways [168].

Latinos, Blacks and low-income individuals in Tampa, Florida were observed to reside in close proximity to TRI facilities, and Whites resided closer to air monitors [169]. Also, it was revealed that African-Americans in West Virginia, Louisiana and Maryland; resided in close proximity to TRI facilities compared to Whites [148]. In South Charleston, a study showed that there were burden disparities in the distribution of TRI facilities at the block and census-tract level by race/ethnicity and socioeconomic status [170]. A study conducted in the US observed that nonwhites were exposed to higher outdoor NO_2 concentrations compared to Whites, and low income populations were disproportionately exposed to higher outdoor NO_2 concentrations than high income populations [171].

Economically disadvantaged individuals and people of color often reside in areas which are air pollution hot spots, and could suffer increased health risks associated with ambient air pollution than the general populace [107]. This makes research in these areas of utmost importance because the data could assist regulatory agencies develop solutions and interventions to these communities and develop strategies mitigate exposure and health risks. EJ groups focus on outdoor air pollution by participating in civic activities and local-level organizing which may result in pushing for stronger air quality regulations and controlling hazardous plant emissions [172]. This has resulted in the development of partnerships between scientists and community leaders; which help to rank according to importance research needs of the community, obtain data, evaluate environmental exposures, pilot run interventions which will affect public policy, thereby, protecting the environment and health of all particularly people of color and economically disadvantaged communities [173]. These discoveries have led to various developments in the environmental justice field with a rising demand for participatory and comprehensive techniques to research and public health practice to tackle the social and environmental determinants of health and diseases which are observed in health disparities [146].

Community Engagement and Environmental Justice

Community engagement can be defined as the process of inclusive participation that supports mutual respect of values, strategies, and actions for authentic partnership; and working collaboratively with and through groups of people affiliated by geographic proximity, special interest, or similar situations to address issues of wellbeing of those people [174–178]. It occurs in different forms and is observed as a continuum of community involvement as shown in Figure 2.1. Community engagement in research is influential and a core element of any research for meaningful community involvement to address health problems facing communities [175]. Also, it requires power sharing, maintenance of equity, and flexibility in pursuing goals, methods, and time frames to fit the priorities, needs, and capacities within the cultural context of communities [175]. There are various models of community engagement, which include, community-based participatory research (CBPR), empowerment evaluation, participatory or community action research, and participatory rapid appraisal [175].

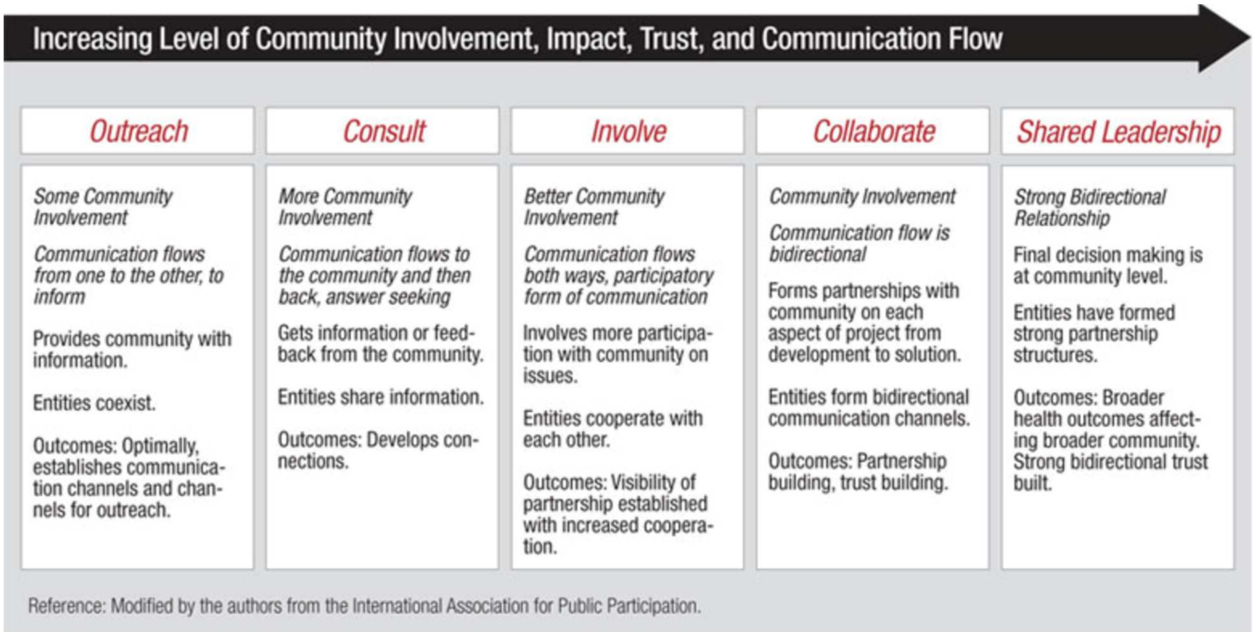


Figure 2.1 Community Engagement Continuum [174]

CBPR is a collaborative, partnership approach to research that equitably involves for example, community members, organizational representatives, and researchers in all aspects of the research process [179]. Also, it can be defined as a collaborative orientation to research which engages academic and community partners in knowledge generation and intervention strategies that benefit communities involved [180]. Partners provide their expertise and share responsibilities and ownership to increase understanding of a given event and incorporate the knowledge gained with action to improve the health and well-being of community members [179,181]. Also, CBPR embodies the experiences of community residents, thereby improving the validity and interpretation of research findings, thus providing a situation whereby residents can champion the implementation or application of their findings [180,182]. The CBPR process typically involves: (1) identification of a research question; (2) assessment of community strengths, assets, and concerns; (3) selection of priorities or targets; (4) development of research plan and data collection methodologies; (5) implementation of research plan and data collection and analysis; (6) interpretation of study findings; (7) dissemination of study findings; (8) and application of study findings to develop action plans to enhance individual and community well-being [183].

Studies in environmental justice currently utilizes participatory action research; which assists in filling the gaps in government data available at local level, and provide insight to disproportionate exposures that are neglected by politicians or overlooked by decision makers, thus, earning credibility for proposed policy changes and government action to eliminate environmental health disparities [184]. Various studies have utilized CBPR, such as, in the toxic free neighborhood campaign in Old Town National City, California [178]; PM concentrations on the sidewalks in Harlem, New York [185]; siting of a new port in North Charleston, South Carolina [186,187]; health survey in Richmond, California [188]; among others to address environmental justice issues in different communities.

Citizen Science and Community-Based Participatory Research

Citizen science is a process whereby citizens are involved in science as researchers which utilizes the concept of involving and encouraging the participation of the public in the observation, collection and record of data in research [189]. Also citizen science provides a unique opportunity for the public (community or volunteers)who may or may not have scientific training to work with scientists in organized scientific research [190,191]. Research could be community-driven or global investigations which will identify research questions, collect and analyze data, make new findings and develop interventions [190]. CBPR which is utilized in environmental health investigations, is an approach where scientists and local community work together in developing and implementing research concerns of community members [192].

Citizen science and CBPR frequently incorporate students or interns in the execution of the projects. Kinney et al utilized interns during their study on PM concentrations and diesel exhaust particles in Harlem, New York [185,193]. Also, in Bayview, San Francisco, high school students were affiliated with Literacy for Environmental Justice (LEJ) to determine the disparity in healthy food access [193]. Students played a role in Halifax County during the Concerned Citizens of Tillery (CCT) during its grassroot mobilization to introduce an intensive livestock ordinance [194]. In Mission Hill, Roxbury, Boston, students were trained on air pollution monitoring, project protocols and general issues in scientific inquiry to participate in the air quality characterization of the community [195].

The use of citizen science and CBPR in air quality monitoring has been facilitated by the availability of internet, smart devices, computers, statistical tools and computational techniques [196,197]. These have increased project visibility, functionality and accessibility; making individuals that previously could not be reached or served participate in citizen science [191]. The availability of low cost sensors has enabled citizens and communities to monitor air quality which can impact their daily lives [197]. Citizen science activities utilize the benefit of community-based participatory research and crowd-sourcing which involves individuals who willingly collect large amount of data that are assembled and analyzed [197]. The US EPA developed a citizen science toolbox which provided Ironbound, Newark, New Jersey, an environmental justice community, with the tools needed to support a community-based air monitoring program [198].

Citizen science has helped overburdened communities collect data useful in their efforts to advance an environmental justice agenda and address environmental health disparities. A study conducted in Northern California demonstrated racial and ethnic inequalities in asthma and hay fever which were independent of education [199]. A study performed with Community Action Against Asthma (CAAA) revealed that exposure to particulates were higher for indoor environments when compared against outdoor environments, and the cycle of exposures were similar to the areas of heavy industry and diesel truck traffic [146]. A study in Harlem revealed that diesel exhaust was a major source of air pollution and the community were part of the research which led to positive interventions [185]. In Hunts Point, citizen scientists participated in a study that showed how truck traffic was linked to PM and elemental carbon concentrations [164]. The Richmond, California health survey conducted by Communities for a Better Environment (CBE), citizen scientists, and university partners (Brown University, University of California) discovered that childhood asthma prevalence rates in Richmond was higher than Marin County [188,200]. Also, adult asthma prevalence rates were correlated with the length of time residents lived in Richmond.

Community-Based Participatory Research, Citizen Science and Air Pollution Studies

CBPR is a tool which addresses concerns via the direct involvement of the community in all stages of the research process; and could be applied to issues associated with air pollution at the community level [184,189,201]. Also, CBPR provides a framework that links science, practice and policy in the effort to minimize differences in air pollution exposures [189,193]. The innovation of low-cost sensors has provided a platform for community-based organizations to obtain air pollution data utilizing citizen science (CS); which is an approach where citizens are involved in science as researchers [189,202].

Utilizing CBPR and CS in air monitoring research provides a unique opportunity for eradicating environmental disparities due to community involvement and engagement in data collection, interpretation, dissemination and discussions that could result in policy changes [189]. There has been an increase in the involvement of citizen scientists in environmental health research due to the innovation of environmental monitoring technologies, the use of mobile devices to collect data and the growth of online data sharing [184]. Communities built partnerships to utilize CBPR and CS in air quality monitoring within their communities due to concerns of the health risk associated with air pollution [189]. Improved air pollution knowledge, reduced air pollution risk and reduced health burdens were important in motivating community participation [189]. The foundational framework is community engagement for participatory research in environmental health as demonstrated in Figure 2.2.

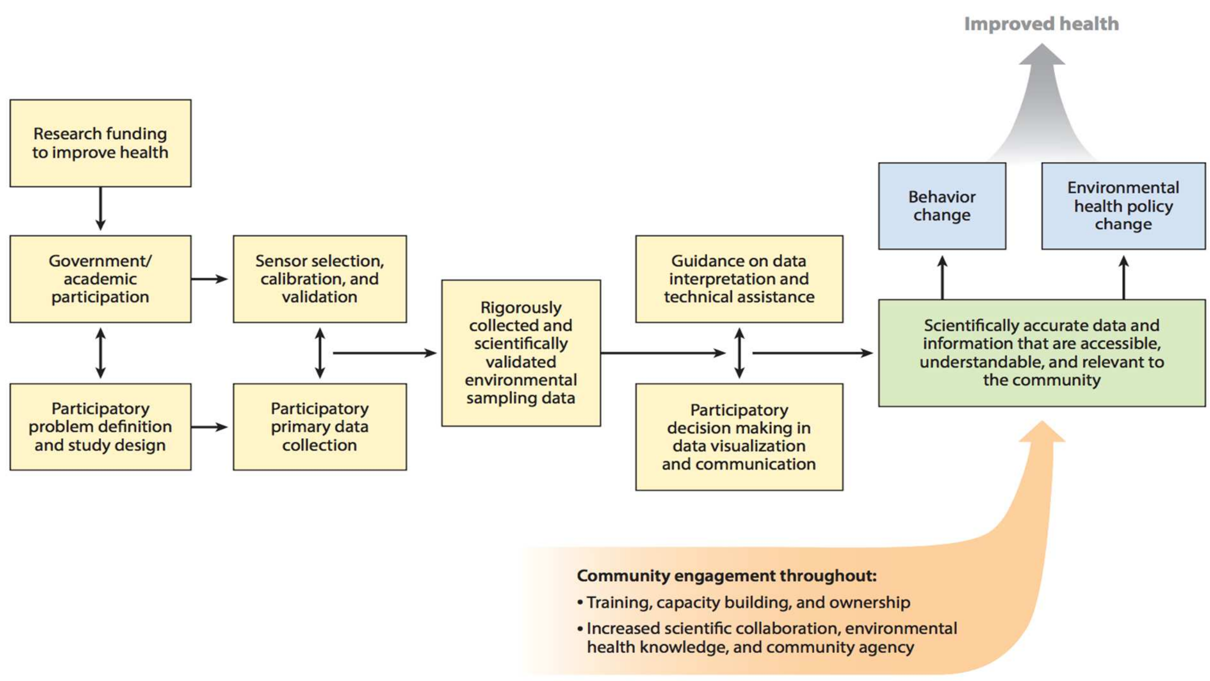


Figure 2.2 Conceptual model for participatory research for environmental health [184]

Air quality monitoring is an area of environmental protection which has received increased scrutiny, due to the low surveillance of toxic air pollutants, questionable self-reported emissions data by industry and limited state monitoring efforts [203]. The earliest example of participatory research in environmental justice context for air quality research was the "bucket brigades"; who are residents in industrial zones that were recruited and monitored near oil refineries, chemical factories and power plants [184,203]. In Harlem, New York, CBPR was utilized during the air quality monitoring of PM and diesel exhaust concentrations on Harlem sidewalks [185]. The monitoring of elemental carbon and $PM_{2.5}$ levels in Hunts Point, New York revealed exposure disparities due to truck traffic [164]. A study utilized CBPR during the baseline air quality assessment of PM before a port expansion in North Charleston, South Carolina [186]. Residents of Excelsior neighborhood in southeast San Francisco used CBPR approach during the investigations of traffic-related exposures and health hazards in the area [204].

There have been several outcomes associated with the use of CBPR and CS in research especially, the formation of strong and lasting partnerships among the community, academic researchers and other community organizations; which builds social capital and leadership skills [184,189]. Also, community residents gain knowledge about their local air quality and enhance their capacities; thus, becoming assets in their communities to address local problems [189]. Three reported benefits are increased research capacity, better knowledge and citizen benefits, such as, improved scientific literacy and environmental awareness, empowered communities, and engaged policy and decision making [184,205]. Finally, participatory research has led to effective positive policy change and implementation, thus, enhancing environmental monitoring efforts [178,184,206].

Background on Concrete Block Plants, Batching Plants, and Air Pollution

Cement is the binding material which is produced worldwide and utilized in construction. Dispersion of particulates, particulate bound metals and ions, VOCs into the atmosphere from concrete batching processes occur via atmospheric dynamics [207]. Pollutants released from cement plants can re-suspend and deposit in soils which may get into the food chain via crops and water [207]. Industries which manufacture and utilize cement release about 5% of global carbon emissions especially CO_2 and utilizes a high amount of energy [208]. The production of concrete involves the mixing of cement with fine aggregate (sand), coarse aggregate (e.g., gravel, crushed stone or iron blast furnace slag), water and in some cases small amounts of chemicals known as admixtures or pozzolan minerals (such as fly ash, silica fume) [209]. Chemical admixtures create and retain bubbles of air, reduce the amount of water required, plasticity, and controls the setting rate and time [209,210]. The production of the mixture depends on the end use or product, type of cement and proportions of aggregates, cement and water [211]. Dust (cement and pozzolan) generation as a visible pollutant, is released in considerable amounts by concrete production. Cement or concrete plant emissions can be classified as fugitive or point source emissions [212]. Fugitive emissions are open or nonpoint emissions which are not released via a vent or stack, for instance, dust from stockpiles, materials handling and PM from vehicular movements [207]. Point source emissions are released through a single point source via vent or stack into the atmosphere [207].

Potential sources of PM and VOC emissions from these plants could include raw material handling, storage, bulk loading and packaging of final product. Also, particulates released from cement industry fall within 0.05 to 5.0 microns in diameter, while, plants without dust control technology emit particles less than 10 and 2.5 microns [207,213]. Currently, there is limited information on the emission of $PM_{2.5}$ and VOCs from cement and concrete batching plants. Crystalline silica, lime, gypsum, nickel, cobalt and chromium compounds are found in cement which are detrimental to human health [207].

Research has shown linkages between exposure to cement dust and adverse effects on human health. Construction workers exposed to inorganic dust (e.g., asbestos, man-made material fibers, cement, concrete and quartz) had increased COPD mortality [214]. Also, construction and cement workers had a higher risk of COPD and nonspecific lung disease because of exposure to inorganic dust [215,216]. Blue-collar workers (e.g., contractors, plumbers, construction and cement workers) exposed to inorganic dust have increased risks of developing IgG4-related diseases (i.e., autoimmune pancreatitis) [217]. One study found an increased risk in hospitalizations for cardiovascular or respiratory illnesses due to exposure from cement plant emissions, with children being more susceptible [123]. Residing near a cement plant leads to an increased risk of mucous membrane of the eye and respiratory system from exposure to emissions (including particulate matter) [218,219].

Air Quality General Permit Process for a Concrete Batching Plant in Maryland

A concrete batch plant involves a procedure that merges different substances to form concrete. Concrete batch plants are classified as ready-mix plants and central mix plants; which contain a variety of equipment (such as mixers, cement batchers, conveyors, radical stackers, heaters). A general air quality permit for a concrete batch plant is required when plants are newly built or modified [220]. This permit process assists businesses to obtain environmentally sound permits in a timely manner; and increases the efficiency of Maryland Department of Environment (MDE) through the issuance of generic permits to group of industries or plants with similar operation, equipment installations and emission characteristics [221]. Eligibility for the permit requires that the plant does not manufacture concrete or cement products (e.g., cinder block, concrete pipes) and does not utilize dry concrete or Portland cement in a production process besides the making of wet concrete. Also, a facility must get a new general permit to construct a new plant. A general permit is a generic document for a specific kind of activity which has similar environmental impacts [222]. Maryland's general permit is accepted and recognized by the US EPA and limits issuance to true minor sources whose potential to emit (PTE) criteria air pollutants is less than 100 tons per year [223]. The Maryland air quality permit considers concrete batch plants as minor sources of hazardous air pollutants (HAPs) which would be below the emission limitations established for the general permit and located at true minor source review (MSR) sources [223]. Therefore, concrete batch plants are required to compare their potential to emit (PTE) to the NSR major source threshold for attainment areas of 250 tons per year [223]. Also, there is no requirement for the facilities to conduct air quality monitoring to demonstrate the comparison between PTE and NSR.

Ernest Maier requested about 3.95 acres from the 4.63 acre lot, Lot 4 of their property in Bladensburg for a concrete batching plant [224,225]. The proposed concrete batching plant will be in the center of the property and at the west of the existing concrete block plant; whereby both plants will jointly utilize raw material stockpiles. Also, both plants will share open aggregate storage bins and heavy equipment used in loading aggregates into feed hoppers and conveyors which service both plants. The applicant requested a variance of the minimum setback distance for a concrete batching plant of 100 feet from the boundary line of an adjacent property in an industrial zone [226]. This will enable the concrete batching plant to be constructed 12.8 feet of the property located to its south. Also, another variance was sought for the 25 feet roadway setback requirement to enable the facility to retain the existing bins at their current location which will be 20.3 feet from Kenilworth Avenue on the east of the property.

Many residents in the Port Towns of Bladensburg, Cottage City, Colmar Manor and Edmonston are in opposition to the special exception permit which was granted to Ernest Maier Inc. to construct a concrete batching plant on its property [227]. Residents are organizing and working with Port Towns Environmental Action (PTEA) to ensure that the expansion does not happen [185,187,188]. Residents and PTEA are concerned about the proximity of the plant to historic sites and the negative impacts of the concrete block plant on the African-American church next door to the plant. Also, they are concerned about storm water runoff, air and noise pollution, traffic congestion and public health and safety in their community [227]. The plant is in close proximity to the Anacostia River and Chesapeake Bay which will make the plant a potential runoff hazard [227]. Residents have created an EcoDistrict which will aid environmentally-focused tourism and economic development, and the proposed expansion may hinder this [228].

The Significance and Relevance of the Project to Environmental Health

This study will provide valuable scientific information on human exposure to PM and VOCs released from the concrete block plant, and nearby industrial and commuter traffic in Bladensburg. Also, this will expand a pilot study that was conducted during the summer of 2017. The air quality in Bladensburg is poor in comparison to other towns in Maryland. Bladensburg has an air quality index (AQI) of 49.1 and is ranked 142 out of 682 municipalities in Maryland

[229]. This study will provide information on the impact of the concrete block plant and current traffic levels on air quality in Bladensburg particularly for vulnerable groups who live, walk, learn, play, and pray near the facility.

Industries bring economic development to towns; however, they may release a variety of pollutants which can have adverse effects on human health and the environment. The concrete block plant (and future concrete batching plant) are environmental hazards which can increase PM and VOC exposures, thus leading to adverse health effects, such as asthma among local residents. The findings of the study will be used to prepare an executive summary for the residents of Bladensburg and help them with future decision-making related to the growth and development of their community. It also will be made available to state and local governments who could use the information from the study in regulatory decision-making process to develop preventive strategies and identify and implement appropriate and adequate regulations and standards. Furthermore, the results could be used to inform future epidemiological studies that evaluate PM and VOC exposures in neighborhoods near industrial settings.

CHAPTER 3

Paper 1

Particulate Matter Concentrations near a Concrete Block Plant and Traffic in Bladensburg, Maryland

Abstract

Background: Ernest Maier, a concrete block plant located in Bladensburg, Maryland wants to expand to include a concrete batching plant on the same property. This expansion could further degrade air quality and impact the health of vulnerable residents. The purpose of this study is to provide information on particulate matter ($PM_{2.5}$) levels near residential areas close to commuter traffic and industrial activity associated with the concrete plant.

Method: Air quality monitoring was conducted in the community at five sites using the Airbeam, a wearable, real-time sensor that can measure $PM_{2.5}$. Sampling were conducted in thirty minutes' periods to capture morning on-peak, afternoon off-peak and evening on-peak periods. Also, traffic counts were conducted at the five locations.

Results: Average values for cars ranged from 0.67 to 247.5, while mean truck values ranged from 0.17 to 26.33. Mean $PM_{2.5}$ concentrations ranged from 2.2 to 46.71 µg/m^3 across the five monitoring locations. Pearson's correlation revealed that there was weak correlation among the $PM_{2.5}$ concentrations observed between the different sites and some of the values were found to be statistically significant. ANOVA analysis showed that the $PM_{2.5}$ levels were significantly different at the different sites (p-value 0.0013).

Conclusion: Our results revealed spatial and temporal variations of $PM_{2.5}$ levels at the site closest to the concrete factory. There were higher PM levels at locations closer to roadways and during rush hour traffic.

Introduction

Residents of urban neighborhoods are faced with diverse stationary and mobile sources of air pollution. A stationary source is a fixed location such as a factory, while, mobile sources refer on-road vehicles (automobiles, buses, trucks, motorcycles) and non-road vehicles and engines (ships, trains, heavy equipment, locomotives and aircrafts) [8–10,12]. Many urban neighborhoods host industries that may play an important role in economic growth and social development; however, their activities may result in environmental degradation, ecological threats and adverse human health effects. Unfortunately, studies have revealed that small and mid-sized industries do not utilize pollution control measures, which increase the release of air pollutants especially in populated areas [13,230]. Also, there has been an increase in traffic-related air pollution (TRAP) and its effects on human health, due to urbanization, which has led to a rise in private and commercial vehicle use [15]. This has resulted in a rapid increase in traffic, vehicular and industrial emissions. Vehicles are important sources of air pollution including CO, SO_x, NO_x, heavy metals, particulate matter (PM), volatile organic compounds (VOCs), and polyaromatic hydrocarbons (PAHs) [16]. Traffic is a unique source of air pollution because pollutants are released close to human receptors and may not be quickly diluted in the atmosphere [17]. Exposure to traffic-related air pollution (TRAP) has been associated with deleterious health effects, such as, wheezing and reduced lung function in children, lung cancer, chronic respiratory symptoms, cardiorespiratory deaths, birth defects and a decrease in life expectancy [21,24,25,27,30,31]. The effects of air pollution on life expectancy are not evenly distributed in the US, rather they are dependent on certain extrinsic factors like socioeconomic status and educational attainment; and these exposures can negatively impact the life expectancy of economically disadvantaged groups [31,32].

Particulate matter is an important air pollutant associated with industrial emissions and traffic. It consists of a heterogeneous mixture of solid and liquid particles suspended in air that vary in size and chemical composition across space and time; which could be primary or secondary particles [34–36]. PM is distinguished by their aerodynamic diameter and cause more harm than any other common air pollutants and has diverse constituents like nitrates, sulfates, elemental and organic carbon, organic compounds (e.g., PAHs), biological compounds (e.g., endotoxins) and metals (e.g., iron, copper) [7,44,231–233]. Industrial PM can be formed via three major routes – fuel combustion processes (e.g., furnaces, gas turbines), non-combustion processes (e.g., mechanical treatment of raw materials), and during handling, transport and storage of dusty raw materials (e.g., cement) [42].

Road traffic is an important source of PM formation via combustion of fuels (gasoline and diesel) through internal combustion engines which result in emissions from tailpipes [40,43–45]. Also, road traffic emissions comprise of relationships between vehicles, road surface and the use of brakes which generates PM referred to as non-exhaust emissions [44,45]. Exhaust emissions contribute fine PM (<2.5 μm) while non-exhaust emissions contribute coarse PM ($PM_{2.5\text{-}10}$) into the atmosphere [43,44]. Studies have shown that PM emissions from diesel burning vehicles are higher than emissions from gasoline burning vehicles [40,46,234]. PM emissions from diesel engines are the major source of $PM_{2.5}$, $PM_{0.1}$ and $PM_{0.05}$, which can be deposited deep into the respiratory tract and even transfer to extrapulmonary organs, including the central nervous system leading to adverse health effects [234,235].

The composition of PM, the dose and time of exposure, size distribution, concentration, toxicity of PM as well as, exposure to chemical mixtures can affect human health in various ways [34,48]. Toxicological and physiological evidence suggests that fine particles can have the greatest adverse effects on humans due to their size and they can contain sulfates, nitrates, acids, metals and particles adsorbed on their surface [42,49]. Also, they can be deposited deep in the lungs, remain deposited for longer time periods, easily gain access to the indoor environment, and transported over longer distances [42]. The National Morbidity Mortality and Air Pollution Study (NMMAPS) found a correlation between PM in the air and the risk of death from all causes and from cardiovascular and respiratory illnesses [49,50]. Studies have shown that individuals with existing conditions such as chronic obstructive pulmonary disease (COPD), congestive heart disease, myocardial infarction or diabetes were at an increased risk of exacerbation on days with high PM concentrations [66–69]. Maternal exposure to PM during pregnancy has been shown to lead to negative birth outcomes (i.e., low birth weight and preterm births) [82–84]. Autism has been linked with exposure to traffic-related air pollution, nitrogen dioxide and PM during pregnancy and the child's first year of life [88,89]. A study conducted in central Phoenix showed that PM_{10} concentrations were associated with asthma incidents, particularly among children between the ages of 5 and 17 [53]. Another study conducted on 545 U.S counties showed that reduction in PM to low levels led to prolonged life expectancy, especially among urban and highly populated counties [96].

People of color and low-income persons are disproportionately burdened with more environmental and health risks than other groups in regards to where they live, work, play, and pray [132]. Studies have shown that there is a differential burden of environmental hazards on disadvantaged groups [139–141]. Also, there is a positive correlation between residential proximity to hazards and race/ethnicity and SES, which is based on the discovery that environmental stressors (i.e., air, water and land pollution) differentially impact communities of color and low-income communities [140–143,236]. Also, the percentage of individuals living in nonattainment air quality areas is significantly higher for Latinos and African-Americans compared to Whites [146]. Evidence has shown that people of color and economically disadvantaged individuals have increased residential exposure to traffic and traffic-related air pollution [117,151–153]. Economically disadvantaged individuals and communities of color were observed to be disproportionately exposed to traffic-related air pollution which may result in an increased risk of adverse health outcomes, such as asthma, cardiovascular diseases and respiratory illnesses [159–162].

Recent environmental justice and air pollution studies utilize citizen science, which is a process whereby citizens are involved in science as researchers which utilizes the concept of involving and encouraging the participation of the public in the observation, collection and recording of data [186,189,237]. Citizen science has helped overburdened communities collect data useful in their efforts to advance environmental justice and address environmental health disparities. A study conducted in Northern California demonstrated racial and ethnic inequalities in asthma and hay fever which were independent of education [199]. A study performed with Community Action Against Asthma revealed that exposure to particulates were higher for indoor environments when compared against outdoor environments, and the cycle of exposures were similar to the areas of heavy industry and diesel truck traffic [146]. Additional research performed in Harlem revealed that diesel exhaust was a major source of air pollution and the use of the CBPR framework led to positive interventions [185]. In Hunts Point, citizen scientists participated in a study that showed how truck traffic was linked to PM and elemental carbon concentrations [164]. The Richmond, California health survey conducted by Communities for a Better Environment (CBE), citizen scientists, and university partners (Brown University, University of California) discovered that childhood asthma prevalence rates in Richmond was higher than Marin County [188,200]. In Charleston, South Carolina, researchers working with the Low Country Alliance for Model Communities (LAMC) found that there were no statistically significant difference in mean concentrations of $PM_{2.5}$ and PM_{10} across neighborhood sites, whereas, mean PM_{10} neighborhood concentrations were significantly lower than mean PM_{10} reference concentrations for Union Heights, Accabee and Rosemont [186].

Residents of Bladensburg, who are predominantly African-American and/or Latino, are faced with environmental hazards because Bladensburg is an industrial corridor; with a school bus depot, a trash company, Ernest Maier concrete block plant, other industrial facilities and a high volume of industrial traffic. Many residents in the Port Towns of Bladensburg, Cottage City, Colmar Manor and Edmonston are in opposition to the special exception permit which was granted to Ernest Maier Inc. to construct a concrete batching plant on its property [227]. Residents are organizing and working with Port Towns Environmental Action (PTEA) to ensure that the expansion does not happen [225,227,228]. They are concerned about the proximity of the plant to historic sites, storm water runoff, air and noise pollution, traffic congestion, the mixture of air pollutants emitted by the concrete block plant and traffic or mobile sources (cars, trucks and buses) and public health and safety in their community [227]. An EcoDistrict has been created in the community which will aid environmentally-focused tourism and economic development, and the proposed expansion by Ernest Maier may hinder this [228].

The study is aimed at providing data on temporal and spatial variation in human exposure to PM due to commuter traffic, industrial traffic and industrial activities near the concrete block plant. Monitoring was conducted near roadways to determine the impact of traffic on PM levels. The study investigated diurnal patterns based on time of the day and rush hour traffic by conducting air quality assessment and traffic counts during morning on-peak (rush hour), afternoon off-peak and evening on-peak (rush hour) periods.

METHODS

Community Background and Site Selection

Bladensburg has a total area of 1.01 square miles with 1.00 square miles as land and 0.01 square miles as water. It shares borders with Edmonston on the north, Hyattsville on the northwest, Cottage City and Colmar Manor on the southwest, and Cheverly on the southeast Air pollution from the location of the concrete block plant is of utmost importance because the plant is open for six days a week excluding Sunday. There is a bus depot, a trash company, a concrete block plant and high volume of industrial and commuter traffic in Bladensburg.

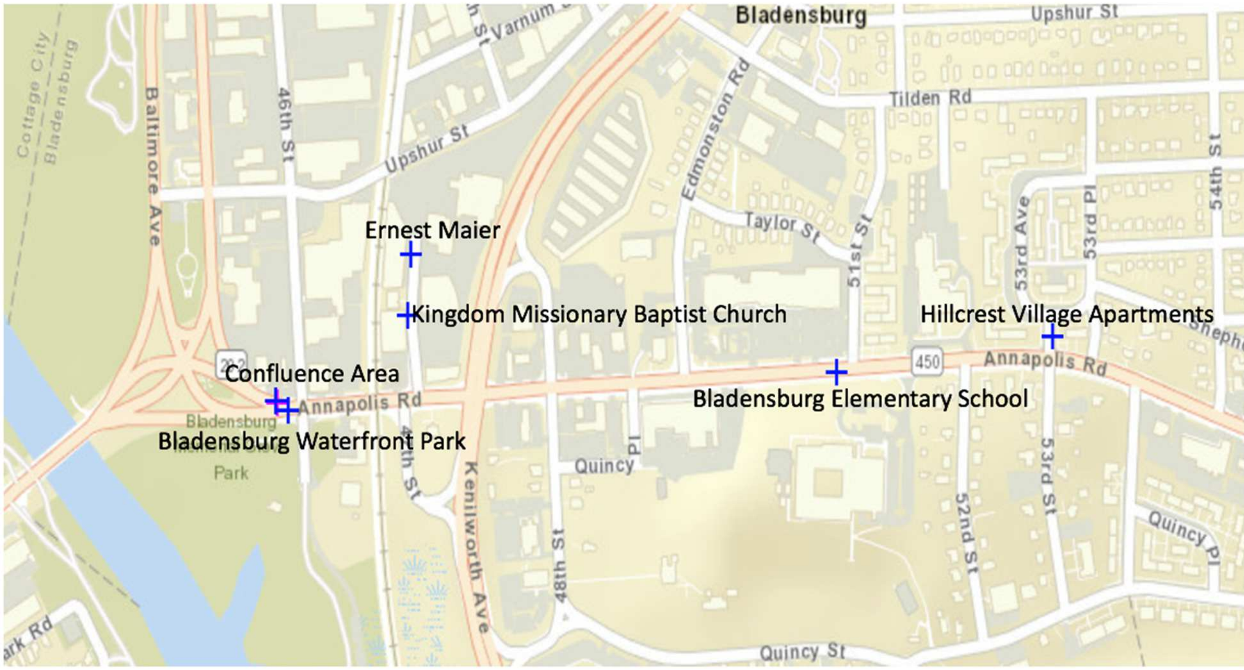


Figure 3.1. Map showing the five personal monitoring locations at Bladensburg and the concrete block plant (EJScreen)

We selected five locations for the study of $PM_{2.5}$ levels which were Kingdom Missionary Baptist Church (site 1), Bladensburg Waterfront Park (site 2), Bladensburg Elementary school (site 3), Hillcrest Village Apartments (site 4) and Confluence area (King Pawn Auto Shop – site 5). These locations were chosen due to concerns about high traffic and the concrete block plant, as well as, proximity to receptor sites [185].

The concrete block plant is on a property, which belongs to Ernest Maier, Inc. and is close to some historic sites in Bladensburg – Peace Cross, Battle of Bladensburg Memorial, Anacostia River and Bladensburg Waterfront Park [227]. The plant is located at 4700 Annapolis Rd, Bladensburg, MD 20710. The selection of the monitoring locations was driven by concerns about high traffic and location of the concrete block plant for $PM_{2.5}$ monitoring. Personal monitoring locations were chosen based on close proximity to the plant and are within 1609 meters from the plant; which are important human receptor sites among children, adults and the elderly (offices, residential, school and recreational complexes) [185]. Near roadway air quality monitoring was utilized because it will provide a measure of the exposure of individuals who live and work along these traffic routes [17].

Particle Concentration Measurements

Air quality monitoring and traffic counts were conducted jointly by interns from the University of Maryland and residents from the community. Each location was staffed by two persons who wore AirBeam sensors and conducted traffic counts. Also, the researcher was present during all sampling periods; however, most of the work was carried out by interns. The interns were trained in the operation, use and placement of the AirBeam sensors. They were responsible for the sampling operations at each site which was overseen by the researchers.

Air sensors used were low-cost, easy-to-use, portable air pollution sensors which provide high-time resolution data in near real time [197]. The AirBeam sensor is a wearable air monitor that maps, graphs, and crowdsources $PM_{2.5}$ exposures in real-time via the AirCasting Android app. It measures $PM_{2.5}$ in $\mu g/m^3$ by utilizing a light scattering method which is registered by a detector and converted into measurements that estimate the number of particle in the air [238]. The measurements are sent through Bluetooth to the app on the android device which creates maps and graphs in real time on the device. At the end of the session, it is sent to the AirCasting website where the data is crowdsourced to generate heat maps indicating where $PM_{2.5}$ concentrations are highest and lowest. AirBeams were worn around the neck in the breathing zone at the personal monitoring locations.

At the five monitoring locations, monitoring for PM was carried out from Sunday to Saturday during traffic peak and off-peak periods in a thirty-minute time frame. Traffic peak times were 7:00am to 9:00am and 4:00pm to 6:00pm, while off peak time was between 11:00am to 1:00pm. Monitoring was conducted from 8:30am to 9:45am, 11:00am to 12:15pm and 4:00pm to 5:15pm. Air quality monitoring was conducted from March to May 2018 because it was spring, so that residents and interns were not exposed to the adverse effects of the cold weather while monitoring. Monitoring on Saturdays will aid in ensuring consistency in data collection and coincides with when the facility operates (i.e., Monday through Saturday) and captures time periods when there is less commuter traffic compared to Monday-Friday when there is more commuter traffic. On Sundays, the plant was closed and monitoring will account for no activity at the plant and reduced commuter and industrial traffic.

Traffic Count

Traffic counts were performed at each monitoring site while the team is assessing personal exposure to $PM_{2.5}$. This involved counting the number of motor vehicles, including cars, buses, vans, trucks that drive past during the sampling period. Heavy duty trucks included trucks larger than pick-up trucks including buses, while vans and sport utility vehicles were counted as cars. Traffic counts were done manually and data was entered into the data sheets. Counts were conducted in 5 minutes intervals during each thirty minute sampling period or window [185]. The counts were summed to provide daily counts, averaged/day, averaged per each site, and average across each week, and averaged across the entire sampling period.

Statistical Analysis

Descriptive statistics (e.g., mean, median, standard deviation, minimum and maximum) were tabulated and plotted for the six locations at different times of the day to assess the spatial and temporal variation in $PM_{2.5}$ concentrations. Analysis of Variance (ANOVA) was used to determine the spatial and temporal variations in $PM_{2.5}$ levels at the monitoring sites based on location and on-peak or off-peak period. Site (monitoring location), time (monitoring period) and day were used as independent variables; while the mean PM concentrations were the dependent variables in ANOVA. The mean PM concentrations was calculated based on the thirty minutes monitoring period. This would explain the variability between the PM data obtained at different locations during the on-peak and off-peak periods. Pearson correlation was used to evaluate the associations and significance between PM concentrations at different locations and times. This helped to determine the level of association between the PM concentrations recorded at different locations during on-peak and off-peak periods. The data collected will be analyzed using SAS Enterprise Version for Windows 9.3 at a significance level of 0.05 and lower ($P \leq 0.05$).

RESULTS

The 2010 Census as shown in Table 3.1, revealed that there are 9,148 people in Bladensburg of which 53.06% of them are female, while 46.94% are male [239]. African-Americans constitute 65.58% and Latinos are 26.92% of the population. 73.08% of the population are 18 years and over, while 26.83% are under 18 years of age. Also, Table 1 displays the educational attainment of Bladensburg; 28.48% of residents aged 18 to 24 years have less than high school education. 31.83% of residents aged 24 years and over have less than a high school degree. The median household income in Bladensburg is $34,966 as shown in Table 3.1.

The percentage of families in Bladensburg within the poverty level is 11.7%, while the percentage of people within the poverty level is 12.1% (Table 3.1).

Table 3.1. Sociodemographic Composition of Bladensburg [239]

Population	**Number**	**%**
Total Population	9,148	100
Population by Sex		
Male	4,294	46.94
Female	4,854	53.06
Population by Age		
Under 18	2,454	26.83
18 & over	6,694	73.17
Population by Ethnicity		
Hispanic or Latino	2,463	26.92
Non-Hispanic or Latino	6,685	73.08
Population by Race		
White	1,149	12.56
African-American	5,999	65.58
Asian	187	2.04
American Indian and Alaska Native	50	0.55
Native Hawaiian and Pacific Islander	2	0.02
Other	1,515	16.56
Identified by two or more	246	2.69
Educational Attainment		
Population 18 to 24 years	748	
Less than high school graduate	213	28.48
Population 25 years and over	4,781	
Less than high school graduate	1,522	31.83
Income in 1999		
Median household income (dollars)	34,966	
Poverty levels in 2010		

All families		11.7
with related children under 5 years		23.5
All people		12.1
related children under 5 years		21.6

USEPA's EJSCREEN places Bladensburg in the 3rd percentile in the state, 24th percentile in the EPA region and 39th percentile in the US for ozone, which can be formed by VOCs in the presence of sunlight (Table 3.2). Also, Bladensburg is ranked in the 88th percentile in the state, 90-95th percentile in EPA region and 80-90th percentile in the US for air toxics cancer risk. Traffic proximity and volume in Bladensburg is placed at 89th percentile in the state, 94th percentile in EPA region and 91st percentile in the US. The demographic indicators as shown in Table 3.2 revealed that the minority population in Bladensburg constitute 95% and low-income population account for 53%. Of residents in Bladensburg. Also, 9% of the residents are under the age of 5 years, while 8% of the population are 64 years and above. 31% of the population have less than a high school education, and 27% of the population are linguistically isolated.

Table 3.2. EPA's Environmental and Demographic Indicators for Bladensburg (EJSCREEN)

Selected Variables	Value	State Average	Percentile in State	EPA Region Average	Percentile in EPA Region	USA Average	Percentile in USA
Environmental Indicators							
Particulate Matter ($PM_{2.5}$ in ug/m^3)	9.28	9.26	31	9.26	46	9.14	48
Ozone (ppb)	37.1	38.4	3	37.9	24	38.4	39
NATA* Diesel PM (ug/m^3)	1.73	1.1	91	0.92	90-95th	0.938	80-90th
NATA* Air Toxics Cancer Risk (risk per MM)	55	45	88	42	80-90th	40	90-95th

NATA* Respiratory Hazard Index	2.8	2	88	1.8	90-95th	1.8	80-90th
Traffic Proximity and Volume (daily traffic count/distance to road)	1500	580	89	360	94	590	91
Lead Paint Indicator (% pre-1960s housing)	0.56	0.3	78	0.37	73	0.29	79
Superfund Proximity (site count/km distance)	0.11	0.13	66	0.15	64	0.13	71
RMP Proximity (facility count/km distance)	1.8	0.65	89	0.61	91	0.73	89
Hazardous Waste proximity (facility count/km distance)	0.22	0.14	85	0.11	89	0.093	92
Wastewater Discharge Indicator (toxicity-weighted concentration/m distance)	0.0061	0.18	85	100	75	30	78
Demographic Indicators							
Demographic Index	74%	35%	95	30%	95	36%	91
Minority Population	95%	47%	88	31%	95	38%	93
Low Income Population	53%	23%	92	29%	87	34%	79
Linguistically Isolated Population	27%	3%	98	2%	98	5%	96
Population with Less Than High School Education	31%	11%	95	11%	95	13%	89
Population under Age 5	9%	6%	78	6%	81	6%	77
Population over Age 64	8%	13%	26	15%	19	14%	23

Thirty-minute traffic counts for cars and trucks at the four locations for the different time shifts are summarized in Table 3.3. The average cars and truck vehicle counts varied at the different locations on different days and at different times. The confluence area had the highest average of car counts at different days and monitoring periods. Also, Kingdom Missionary Baptist Church and Hillcrest Apartments consistently had low average cars and truck counts; while the average cars and truck counts at the Waterfront Park varied and may be attributed to activities at the park.

Table 3.3. Mean and Standard Deviation of 30-minutes Traffic Counts at Five Sites in Bladensburg

		Morning		Afternoon		Evening	
		Cars	Trucks	Cars	Trucks	Cars	Trucks
Day	Sites	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Wednesday 0606	Church	7.92 (1.93)	1.25 (0.75)	6 (2.34)	3.33 (2.02)	2.75 (2.22)	0.17 (0.58)
	Waterfront Park	122.2 (131.82)	10.7 (11.52)	162.2 (26.71)	9.8 (2.59)	169.33 (46.42)	17.33 (19.88)
	Elementary School	50.17 (97.99)	17.5 (5.01)	72 (15.03)	16.5 (3.02)	135 (15.74)	26.17 (3.43)
	Hillcrest Apartments	3.33 (2.5)	1 (1.55)	0.67 (1.21)	0.17 (0.41)	5.83 (2.79)	1 (1.1)
	Confluence	210.71 (55.67)	11.58 (3.32)	185.14 (25.81)	12.86 (3.18)	185.83 (25.38)	9.83 (4.88)
Thursday 0607	Church	6.58 (1.56)	1.92 (0.9)	9.33 (3.11)	2.25 (1.14)	4.1 (1.19)	1.5 (0.58)
	Waterfront Park	2.17 (1.47)	1.4 (0.55)	2.31 (0.57)	1 (-)	2.2 (1.1)	*
	Elementary School	57.67 (9.05)	*	66.67 (10.21)	22 (8.07)	136.5 (7.12)	25.83 (4.02)
	Hillcrest Apartments	1.5 (1)	*	1 (-)	*	3.6 (1.67)	1 (0)
	Confluence	185.43 (25.75)	16.29 (2.69)	184.5 (18.84)	14.17 (2.99)	192 (27.03)	6 (1.73)
Saturday 0609	Church	11.25 (3.620	1.17 (0.83)	6.33 (3.45)	0.17 (0.39)	2 (1.41)	*
	Waterfront Park	39.75 (27.67)	9.63 (3.81)	137.83 (36.64)	4 (1.26)	3 (1.67)	*
	Elementary School	53.17 (10.15)	16 (2.82)	87.5 (21.32)	13.17 (2.93)	94.17 (11.3)	14.83 (3.13)
	Hillcrest Apartments	1.4 (0.89)	1 (1.55)	1.4 (0.55)	*	2.75 (1.5)	2 (-)
	Confluence	73 (16.49)	9.17 (3.92)	177.17 (34.67)	4 (3.22)	81 (17.46)	3 (-)
Wednesday 0613	Church	9.75 (3.7)	0.67 (0.89)	6.83 (3.51)	1.08 (1.62)	1.92 (1.73)	0.08 (0.29)
	Waterfront Park	1.83 (1.83)	*	2.67 (1.63)	*	2.17 (0.98)	*
	Elementary School	56.17 (3.82)	17.67 (3.5)	51.67 (5.64)	19.5 (5.54)	119.67 (10.58)	24.17 (6.74)
	Hillcrest Apartments	1.17 (0.98)	*	1.67 (1.37)	1 (-)	4.83 (2.64)	2 (1.73)
	Confluence	159.83 (56.29)	13.83 (3.06)	183.83 (10.57)	12 (1.1)	247.5 (26.2)	5.33 (1.37)
Thursday 0614	Church	9.33 (3.08)	1.64 (0.81)	9.58 (2.02)	1.83 (0.83)	3.25 (2.22)	*
	Waterfront Park	2.17 (1.17)	1 (0.71)	4.17 (1.33)	1 (0)	2.4 (1.14)	*
	Elementary School	52 (14.18)	14.33 (2.25)	60.83 (10.87)	12 (2.83)	124.5 (17.51)	26.33 (6.31)
	Hillcrest Apartments	3.2 (1.3)	1.6 (0.55)	2.5 (1.22)	1 (-)	5.5 (4.14)	1.33 (0.58)
	Confluence	90.17 (11.32)	13.83 (3.13)	80.83 (13.93)	15 (2.9)	203.33 (22.04)	6.83 (3.31)
Saturday 0616	Church	13.75 (4.27)	1.6 (0.89)	9.83 (4.17)	1.29 (0.49)	1 (0)	1 (-)
	Waterfront Park	5.17 (2.93)	*	4.5 (2.95)	*	7 (3.58)	*
	Elementary School	52.33 (7.61)	10.33 (4.32)	76.33 (19.54)	15.4 (5.41)	119.33 (17.57)	1.25 (0.5)
	Hillcrest Apartments	3.8 (0.84)	1 (-)	3.2 (2.28)	1.67 (1.15)	4.6 (3.58)	2 (1.41)
	Confluence	165.83 (47.05)	7 (4.76)	228.17 (21.71)	6.33 (2.88)	209.33 (36.81)	3 (0.82)

*No truck data observed

Forest plots were used to summarize the descriptive statistics obtained from $PM_{2.5}$ ($\mu g/m^3$) monitoring at the different locations, monitoring shifts and days. The use of forest plots or meta-analytic pooling aids researchers to display their findings in a graphically appealing way but in a statistically correct way [240]. The forest plot of all the shifts for Thursday (0614) and Saturday (0616) as displayed in Figure 3.2 (Appendix A), revealed that there was no difference in the minimum values of $PM_{2.5}$ concentrations; however, the means and maximum values differ across the locations and monitoring times. Thursday (0614) and Saturday (0616) monitoring shifts at the Waterfront Park is shown in Figure 3.3 (Appendix A), which has revealed that the minimum, mean and maximum values of $PM_{2.5}$ concentrations differ on both days among the locations and monitoring periods. Figure 3.4 (Appendix A) represents the forest plot for monitoring periods on Thursday (0614) and Saturday (0616) at Bladensburg Elementary School; that displays a significant difference in maximum values of PM concentrations.

PM concentrations on Thursday (0614) and Saturday (0616) at Hillcrest Apartments as displayed in Figure 3.5 (Appendix A), revealed that the minimum and mean values are not significantly different; while the maximum values are different. Figure 3.6 (Appendix A) shows the $PM_{2.5}$ concentrations at the confluence area on Thursday (0614) and Saturday (0616), which reveals that the minimum, mean and maximum values are significantly different. A forest plot of minimum, mean and maximum PM concentrations obtained during Thursday (0614) morning shifts at the five locations is shown in Figure 3.7 (Appendix A), and revealed that minimum and mean values are not different; however, the maximum values differ at the different locations. Figure 3.8 (Appendix A) displays a forest plot of minimum, mean and maximum values observed on Saturday (0616) morning shifts at the five locations which are significantly different at the different locations. The minimum, mean and maximum values of $PM_{2.5}$ concentrations as shown in Figure 3.9 (Appendix A) represent weekday morning shifts at the church, which revealed that the minimum and mean values are not significantly different, whereas, the maximum values differ at Kingdom Missionary Baptist Church.

Our findings revealed that Kingdom Missionary Baptist Church had the lowest vehicle traffic, and we looked at the trend of PM concentrations at the Church on Saturday (0616) in the morning, afternoon and evening monitoring periods. Figures 3.10, 3.11 and 3.12 (Appendix A) display the trend and showed that the morning shift had the highest number of peak $PM_{2.5}$ concentrations when compared to afternoon and evening shifts. The $PM_{2.5}$ concentrations observed at the Kingdom Missionary (Figure 3.13, Appendix A) on Saturday afternoon (0609) was compared to the readings at the Confluence area (Figure 3.14, Appendix A) using a trend graph. It was observed that the $PM_{2.5}$ levels exceeded the annual average standard of 12 $\mu g/m^3$ during most of the monitoring period but were lower than the 24-hour average standard of 35 $\mu g/m^3$ during some of the monitoring period. While at the Confluence area, both standards were not exceeded. Also, Figures 3.15 and 3.16 (Appendix A) are trend graphs of $PM_{2.5}$ concentrations observed at the Kingdom Missionary Baptist Church and the Waterfront Park on Wednesday morning (0613). The trend graphs reveal that both NAAQS standards for $PM_{2.5}$ were exceeded at the Church but not at the Waterfront Park.

Pearson's correlation was calculated to determine if there was correlation in $PM_{2.5}$ concentrations observed between the various sites at different monitoring periods on Thursday (0614) as shown in Table 3.4. The results revealed that there was weak correlation between the different sites and some of the values were found to be statistically significant, because the p-values were less than 0.05. Also, Pearson's correlation was calculated to ascertain the correlation between different sites at the different monitoring periods on Saturday (0616) in Table 3.5. Our findings revealed that a weak correlation exist among the $PM_{2.5}$ concentrations obtained between various sites at the different monitoring periods, although most of the values were statistically significant and had p-values less than 0.05. Pearson's correlation was conducted to examine the correlation between various sites at the different monitoring periods on Thursday (0614) and Saturday (0616) as displayed in Table 3.6. There is a weak correlation of $PM_{2.5}$ concentrations obtained at the various sites within the different monitoring periods, with most of the values being statistically significant.

Table 3.4. Correlation Between Sites at Different Times of the day on Thursday (0614)

		Thursday Morning	Thursday Afternoon	Thursday Evening
Site	**Site**	**R**	**R**	**r**
Church	**Waterfront Park**	0.20329**	0.09992*	-0.18346**
Church	**Elementary School**	0.0708*	0.25356**	0.02205
Church	**Hillcrest Apartments**	-0.14584**	0.04366	-0.24135**
Church	**Confluence Area**	0.10354*	-0.00357	-0.06307*
Waterfront Park	**Elementary School**	-0.34847**	-0.08758*	0.03075
Waterfront Park	**Hillcrest Apartments**	0.12419**	-0.14866**	0.18504**
Waterfront Park	**Confluence Area**	0.12587**	-0.06093*	-0.01247
Elementary School	**Waterfront Park**	-0.34847**	-0.08758*	0.03075
Elementary School	**Hillcrest Apartments**	-0.19543**	0.14794**	-0.26591**
Elementary School	**Confluence Area**	-0.11702**	0.05029	-0.16258**
Hillcrest Apartments	**Waterfront Park**	0.12419**	-0.14866**	0.18504**
Hillcrest Apartments	**Elementary School**	-0.19543**	0.14794**	-0.26591**
Hillcrest Apartments	**Confluence Area**	0.20239**	-0.08367	0.08276
Confluence Area	**Waterfront Park**	0.12587**	-0.06093*	-0.01247
Confluence Area	**Elementary School**	-0.11702**	0.05029	-0.16258**
Confluence Area	**Hillcrest Apartments**	0.20239**	-0.08367	0.08276

**** - p-value <0.0001 * - p-value <0.05**

Table 3.5. Correlation Between Sites at Different Times of the day on Saturday (0616)

Site	Site	Saturday Morning R	Saturday Afternoon R	Saturday Evening r
Church	**Waterfront Park**	0.0466	-0.06619*	-0.03632
Church	**Elementary School**	0.16102**	-0.09496*	0.44019**
Church	**Hillcrest Apartments**	-0.06705*	0.08941*	0.30877**
Church	**Confluence Area**	-0.11263*	0.08147*	-0.06771*
Waterfront Park	**Elementary School**	-0.12063**	-0.04136	-0.20502**
Waterfront Park	**Hillcrest Apartments**	0.01075	-0.17965**	-0.11258*
Waterfront Park	**Confluence Area**	0.15508**	0.16529**	0.238**
Elementary School	**Waterfront Park**	-0.12063**	-0.04136	-0.20502**
Elementary School	**Hillcrest Apartments**	0.23331**	0.04199	0.17829**
Elementary School	**Confluence Area**	-0.01256	-0.06602*	0.01661
Hillcrest Apartments	**Waterfront Park**	0.01075	-0.17965**	-0.11258*
Hillcrest Apartments	**Elementary School**	0.23331**	0.04199	0.17829**
Hillcrest Apartments	**Confluence Area**	-0.00583	-0.10108*	-0.25771**
Confluence Area	**Waterfront Park**	0.15508**	0.16529**	0.238**
Confluence Area	**Elementary School**	-0.01256	-0.06602*	0.01661
Confluence Area	**Hillcrest Apartments**	-0.00583	-0.10108*	-0.25771**

**** - p-value <0.0001 * - p-value <0.05**

Table 3.6. Correlation Between Sites at Different Times of the day on Thursday (0614) and Saturday (0616)

	Thurs and Sat Morning	Thurs and Sat afternoon	Thurs and Sat evening
	r	r	R
Church	-0.1347**	0.2411**	0.06487*
Waterfront Park	0.13391**	-0.02773	-0.06177*
Elementary School	0.1816**	0.23349**	0.37148**
Hillcrest Apartments	-0.02586	-0.02244	0.061*
Confluence area	-0.16551**	0.18703**	-0.01438

**** - p-value <0.0001 * - p-value <0.05**

We used generalized linear models to ascertain whether day of the week: Wednesday (a day with heavier traffic) versus Saturday (less traffic) was a significant predictor of mean $PM_{2.5}$ concentrations. The results revealed that monitoring day is not a significant predictor of $PM_{2.5}$ concentrations with an F test statistic =0.02 (p-value =0.89). Least square means were very similar 12.2 $\mu g/m^3$ for Wednesday compared to 11.3 $\mu g/m^3$ for Saturday. Time of day for measurement (morning, afternoon, evening) also was not a significant predictor of $PM_{2.5}$ concentrations with an F value = 0.14 (p-value=0.87). Least square means were comparable with lowest mean $PM_{2.5}$ concentrations in the morning (8.2 $\mu g/m^3$) and highest in the afternoon (13.2 $\mu g/m^3$) and 11.9 $\mu g/m^3$ in the evening. However, generalized linear models revealed site is a significant predictor of $PM_{2.5}$ measurements with an F value =6.97 (p-value=0.007). Comparison of least square means showed $PM_{2.5}$ concentration for site 1 – Kingdom Missionary Baptist Church (39.3 $\mu g/m^3$) is significantly higher than other sites (ranging from 3.3 to 5.1 $\mu g/m^3$).

DISCUSSION

Monitoring occurred at a small number of sites and days, the findings reveal that $PM_{2.5}$ concentrations are determined by proximity to traffic and the concrete block plant. Our study showed spatial and temporal variations at the different sites, especially at the Kingdom Missionary Baptist Church. This variation may imply that health risks such as asthma, respiratory illness, cardiovascular illness which are associated with $PM_{2.5}$ exposure may also vary across the community based on traffic and industrial sources of PM [185]. Also, our findings conform to the suggestions that $PM_{2.5}$ concentrations are influenced by industrial sources at the concrete block plant and vehicular traffic. These results emphasize the concerns raised by the residents about the effects of air pollutants from traffic and the concrete block plant in Bladensburg.

The average $PM_{2.5}$ concentrations ranged from 2.2 to 46.71 $\mu g/m^3$ across the five monitoring locations. In Allen Park, Detroit, Michigan the $PM_{2.5}$ levels averaged 16.8 $\mu g/m^3$ in a study which used time-series and simulation models to estimate vehicle contributions to pollutant levels near roadways [241]. In Barcelona, the mean daily $PM_{2.5}$ levels was 17 $\mu g/m^3$, while in Mexico, the mean ranged from 53-84 $\mu g/m^3$ [242,243].The mean concentrations were within the levels reported in urban areas, except at the Kingdom Missionary Baptist Church (7.02 – 46.71 $\mu g/m^3$) ,where the values were above reported levels [185]. These levels exceeded the annual National Ambient Air Quality Standard of 12 $\mu g/m^3$. Our study findings demonstrated that there were higher PM levels in areas close to the concrete block plant compared to areas farther away from the plant. A study in Detroit revealed that traffic and industrial plants are major sources of PM [244]. Plant emissions was identified as the major source of PM exposure in and around

Braddock [245]. PM concentrations may increase around areas close to the plant and from goods movement activities related to truck traffic [186].

Also, we observed differences in mean values of $PM_{2.5}$ concentrations between high traffic and low traffic areas during on-peak and off-peak times. Mean $PM_{2.5}$ concentrations observed at the Confluence area (0607) was 10.47 $\mu g/m^3$ during the morning on-peak period and 6.68 $\mu g/m^3$ during the afternoon off peak period. At Bladensburg Elementary School, the mean $PM_{2.5}$ concentrations were 11.39 $\mu g/m^3$ during the morning on-peak and 7.5 $\mu g/m^3$ during the afternoon off-peak periods. Also, there were higher mean $PM_{2.5}$ values during on-peak periods compared to off-peak periods due to commuter traffic, industrial traffic and industrial activities around the concrete block plant. Mean $PM_{2.5}$ concentrations observed at Bladensburg Elementary School (0616) were 8.45 $\mu g/m^3$, 3.64 $\mu g/m^3$ and 3.87 $\mu g/m^3$ respectively during the morning on-peak, afternoon off-peak and evening on-peak periods. The Confluence area had observed mean $PM_{2.5}$ levels of 5.72 $\mu g/m^3$, 3.17 $\mu g/m^3$ and 3.88 $\mu g/m^3$ respectively for morning on-peak, afternoon off-peak and evening on-peak periods. PM concentrations began to increase in the morning when traffic starts due to direct dust resuspension by road traffic [242]. Another study in New York city observed a diurnal cycle with significant peaks between 7.00 and 9.00am (morning rush hours) and 5.00 and 11.00pm [246]. A Detroit study demonstrated that PM levels decrease slightly before sunrise and increases at a steady rate between mid and late morning, decrease until early afternoon, then PM level rises until midnight [244]. A study conducted in Braddock, Pennsylvania observed large temporal variation with higher PM concentrations in the morning compared to afternoon [245].

There are some limitations of the study, which include the focus on PM exposure only and did not include an assessment of potential adverse health effects among the residents in

Bladensburg. The short duration of our study restricts our ability to make claims about long-term relationship PM measurements, traffic and industrial activities associated with the cement block plant. Our spring-only data may distort associations, if the patterns are significantly different based on season. Our study did not compare the data collected with any federal reference method, which is considered the best characterization of concentration of any given pollutant and are supported by a comprehensive quality assurance program. We did not adjust for accuracy of the AirBeam sensors by calibrating and adjusting the slope and offset against a co-located reference/equivalent station. During air quality monitoring, the AirBeam sensors were observed to be sensitive to harsh sunlight or extreme temperature, which may have affected our data. The traffic counts conducted at the Kingdom Missionary Baptist Church did not capture the truck traffic which was suspected to occur within the early hours of the morning.

Also, the study did not address the cumulative PM exposures from the various industrial facilities in the community. Our study did not incorporate a health impact assessment of PM exposure from traffic and near the concrete block plant. The topography and weather conditions (e.g., wind speed and direction) in Bladensburg were not considered in the study. We trained the residents on the use of the air sensor but due to the timing of the monitoring shifts and residents availability, residents were not a part of the data collection. We were not able to install PurpleAir sensors which would have measured PM_{10}, $PM_{2.5}$ and PM_1 due to accessibility to the monitoring locations and logistic challenges.

Exposure assessment and epidemiologic research are conducted utilizing case crossover, case-control and time-series epidemiologic studies, and Bayesian analysis, to examine associations between air pollution and respiratory and/or cardiovascular morbidity. Case-crossover and time-series studies take advantage of temporal contrasts in exposure, particularly for regional pollutants ($PM_{2.5}$) that exhibit greater spatial homogeneity. Cohort studies have shown associations between long-term exposure to air pollution and various health endpoints by utilizing air pollution data from regulatory monitoring networks that are operated by government [247]. Our study showed spatial variations in $PM_{2.5}$ exposures within Bladensburg; however, it did not include or indicate if the variations in PM exposures was associated with variations in the rates of PM-related health outcomes such as respiratory illness, cardiovascular illness and premature mortality.

Future research should develop a unique study design at the Kingdom Missionary Baptist Church which is the closest site to the concrete block plant; to capture the truck traffic around the plant. This was because we observed high mean $PM_{2.5}$ concentrations and low truck traffic observed at the location. Also, monitoring should be conducted year-round at more locations to reflect seasonal variations in $PM_{2.5}$ concentrations. Geographic Information System (GIS) modeling and spatiotemporal mapping should be incorporated into the study design to take into consideration topography and weather patterns on different monitoring days. The present study focused on community-level exposures which does not represent individual exposure to $PM_{2.5}$; therefore, future study should consider individual exposures within their various microenvironments. Our future study would investigate the variations of PM_{10} and PM_1 concentrations within the community.

CONCLUSION

This study revealed the spatial and temporal variations in the $PM_{2.5}$ concentrations in Bladensburg and may provide baseline information on residential exposure to $PM_{2.5}$ due to commuter traffic, industrial traffic and industrial activities associated with the concrete block plant. Also, this work could serve as a model to researchers who would like to incorporate CBPR and citizen science in their approach to address environmental issues. The findings of this work may assist to improve the knowledge and understanding of residential $PM_{2.5}$ exposures among economically disadvantaged individuals; however, we would recommend longer monitoring periods and more locations.

Chapter 4

Paper 2

Investigation of Volatile Organic Compound (VOC) Levels near a Concrete Block Plant and Traffic in Bladensburg, Maryland

Abstract

Background: Ambient air pollution from stationary sources, industrial traffic, and commuter traffic can negatively impact air quality and human health including emissions of particulate matter and volatile organic compounds (VOCs). Ernest Maier, a concrete block plant located in Bladensburg, Maryland wants to expand to include a concrete batching plant on the same property. This expansion could further degrade air quality and impact the health of vulnerable residents. The purpose of this study is to provide information on volatile organic compounds (VOCs) levels near residential areas in close proximity to commuter traffic and industrial activity associated with the concrete plant.

Method: Air quality monitoring was conducted in the community at five personal sites using the Atmotube, a wearable real-time sensor that can measure total VOCs via Air Quality Score Android app. Also, traffic counts were conducted at the five personal monitoring locations.

Results: The mean VOC concentrations observed ranged from 0.11ppm to 0.68ppm and the highest values were obtained at the Kingdom Missionary Baptist Church. Our findings revealed that there could be an association of the VOC levels obtained at different sites at different times of the day. Also, we observed some spatial and temporal variations in VOC levels due to traffic and industrial activity at the plant as key emission sources.

Conclusion: Our results revealed spatial and temporal variations of VOC concentrations at the site closest to the concrete factory. We observed higher VOC levels at locations closer to roadways and during rush hour traffic.

Introduction

Individuals living in urban neighborhoods are plagued with a diverse range of outdoor environmental risks including poor air quality [185]. Air pollution is a great concern for residents of Bladensburg, Maryland due to local industrial and mobile sources of pollution. Volatile organic compounds (VOCs) are a concern and include many chemicals such as benzene and its derivatives, simple aliphatic hydrocarbons (such as hexane), chlorinated hydrocarbons (such as chloroform), terpenes (such as limonene), alcohols, aldehydes and ketones with low carbon numbers such as isopropanol, hexanal and butanone [99,100]. They are released into the atmosphere from anthropogenic and biogenic sources, and could be formed in the atmosphere as products of the atmospheric transformations of other VOCs [100]. VOCs produce a primary component of smog known as ozone via reaction with nitrogen oxides and other airborne chemicals in the presence of sunlight [102,103,106,248].

VOCs are emitted from mobile and stationary sources in large amounts due to combustion, solvent and fuel evaporation and tank leakage. Emissions of VOCs as gases occur from various daily emission sources such as driving cars, painting buildings or cooking [111]. Vehicles are a major source of VOC emissions and account for 35% due to relatively heavy traffic and adverse dispersion conditions in urban areas, which could lead to an accumulation of high levels that can adversely affect air quality and human health in street canyons, especially in urban areas [105,106,109,111,249]. Also, VOCs constitute 45% of on-road mobile source emissions in Southern California play a key role in urban and rural atmospheres because they constitute 70% of hazardous air pollutants [110,250]. Emissions occur from power plants, gas stations, auto body and paint shops, solvents used in chemical industry and diesel and gasoline-powered vehicles (vehicle exhaust, gasoline evaporation) [107,108]. The study of VOCs as air pollutants is important due to their role in ozone depletion, ozone formation, toxic and carcinogenic human health effects, and enhancement of the global greenhouse effect [103]. Outdoor VOC concentrations are influenced by season, nearness to emission sources (industry, traffic, gas stations) and meteorological conditions such as temperature [104].

Chronic health effects associated with VOC exposure can be non-carcinogenic or carcinogenic. Non-carcinogenic effects include irritation, sensory effects, headache, eye irritation, skin irritation and airway irritation, damage to the liver, kidneys and central nervous system, asthma and respiratory effects [111–114]. While the carcinogenic effects of VOCs are lung, blood, liver, kidney and biliary tract cancers [112–114]. Also, exposure to VOCs may result in negative impacts on reproductive systems or birth defects [115]. Elevated VOC concentrations have been observed at high traffic intensity streets compared to low traffic intensity streets [107,116,117]. A study conducted in Kanawha County, West Virginia revealed that exposure to VOCs was associated with increased rates of chronic respiratory symptoms [118]. VOC exposure has been linked with cancers of the brain, nervous system, skin, melanoma, endocrine system and thyroid cancers in Indiana [119].

Evidence has demonstrated that TRAP could lead to the development of asthma and other childhood respiratory diseases [165]. In California, nonwhite children were three or four times more likely to reside in highly-trafficked areas than White children; and children in low income communities had an increased risk to potential exposures from vehicle emissions [152]. A study revealed that children younger than 5 years of age who were admitted with asthma diagnosis were more likely to live in high traffic flow which was less than 500m from a main road [166,167]. TRAP may lead to decreased lung function, particularly among girls that lived less than 300 m to the motorways [168]. Latinos, Blacks and low-income individuals in Tampa, Florida were observed to reside in close proximity to Toxic Release Inventory (TRI) facilities, and Whites resided closer to air monitors [169]. Also, it was revealed that African-Americans in West Virginia, Louisiana and Maryland resided in closer proximity to TRI facilities compared to Whites [148]. A study conducted in the US observed that nonwhites were exposed to higher outdoor NO_2 concentrations compared to Whites, and low income populations were disproportionately exposed to higher outdoor NO_2 concentrations than high income populations [171].

Economically disadvantaged individuals often reside in air pollution hot spots, and could suffer increased health risks associated with ambient air pollution than the general populace [107]. EJ groups focus on outdoor air pollution by participating in civic activities and local-level organizing which may result in pushing for stronger air quality regulations and controlling hazardous plant emissions [172]. This has resulted in the development of partnerships between scientists and community leaders with a rising demand for participatory and comprehensive techniques to research to tackle the social and environmental determinants of health and diseases which are observed in health disparities [146,173]. Current studies leverage on citizen science (CS) and community-based participatory research (CBPR) as important and integral tools. CS is a process whereby citizens are involved in science as researchers in the observation, collection and record of data in organized research; which could be community-driven or global investigations [189–191]. CBPR is an approach where scientists and local community work together in developing and implementing research concerns of community members [192]. Students or interns are usually incorporated in the execution of these projects. Kinney et al utilized interns during their study on PM concentrations and diesel exhaust particles in Harlem, New York [185,193]. In San Francisco, students were affiliated with Literacy for Environmental Justice (LEJ) to determine the disparity in healthy food access [193]. Students were involved in Halifax County for the Concerned Citizens of Tillery (CCT) during its grass root mobilization to introduce an intensive livestock ordinance [194]. In Mission Hill, Boston, students were trained on air pollution monitoring, project protocols and general issues in scientific inquiry to participate in the air quality characterization of the community [195].

CS and CBPR in air monitoring has helped overburdened communities collect data to advance an EJ agenda and address environmental health disparities. The US Environmental Protection Agency (USEPA) developed a citizen science toolbox which provided Ironbound, New Jersey, with the tools needed to support a community-based air monitoring program [198]. A study conducted in Wyoming, Arkansas, Pennsylvania, Colorado and Ohio, within communities near oil and gas production revealed that there were high levels of volatile organic compounds near oil and gas production sites [251]. In California, a study on exposures of Vietnamese women working in nail salons showed that there were high observed levels of toluene, methyl methacrylate and total volatile organic compounds [252]. A study performed in Boston, Massachusetts, which conducted air quality survey of nail salons, demonstrated that there were higher total VOCs in salons with less ventilation and higher levels were observed when tasks were being performed [253].

Residents of Bladensburg, who are predominantly African-American and/or Hispanic, are faced with environmental hazards because Bladensburg is an industrial corridor; with a school bus depot, a trash company, Ernest Maier concrete block plant, other industrial facilities and a high volume of industrial and commuter traffic. Many residents in the Port Towns of Bladensburg, Cottage City, Colmar Manor and Edmonston are in opposition to the special exception permit which was granted to Ernest Maier Inc. to construct a concrete batching plant on its property [227]. Residents have partnered with PTEA to address the health concerns and exposures associated with industrial and commuter traffic near a concrete block plant. The study is aimed at providing data on temporal and spatial variations in human exposure to VOCs due to commuter traffic, industrial traffic and industrial activities near the concrete block plant. Also, the study will assess the variation in human exposure at different receptor sites and locations during different times of the day in Bladensburg, Maryland.

METHODS

Community Background and Site Selection

Bladensburg has a total area of 1.01 square miles with 1.00 square miles as land and 0.01 square miles as water. It shares borders with Edmonston on the north, Hyattsville on the northwest, Cottage City and Colmar Manor on the southwest, and Cheverly on the southeast. Air pollution from the location of the concrete block plant is of utmost importance because the plant is open for six days a week excluding Sunday. There is a bus depot, a trash company, a concrete block plant and high volume of industrial and commuter traffic in Bladensburg.

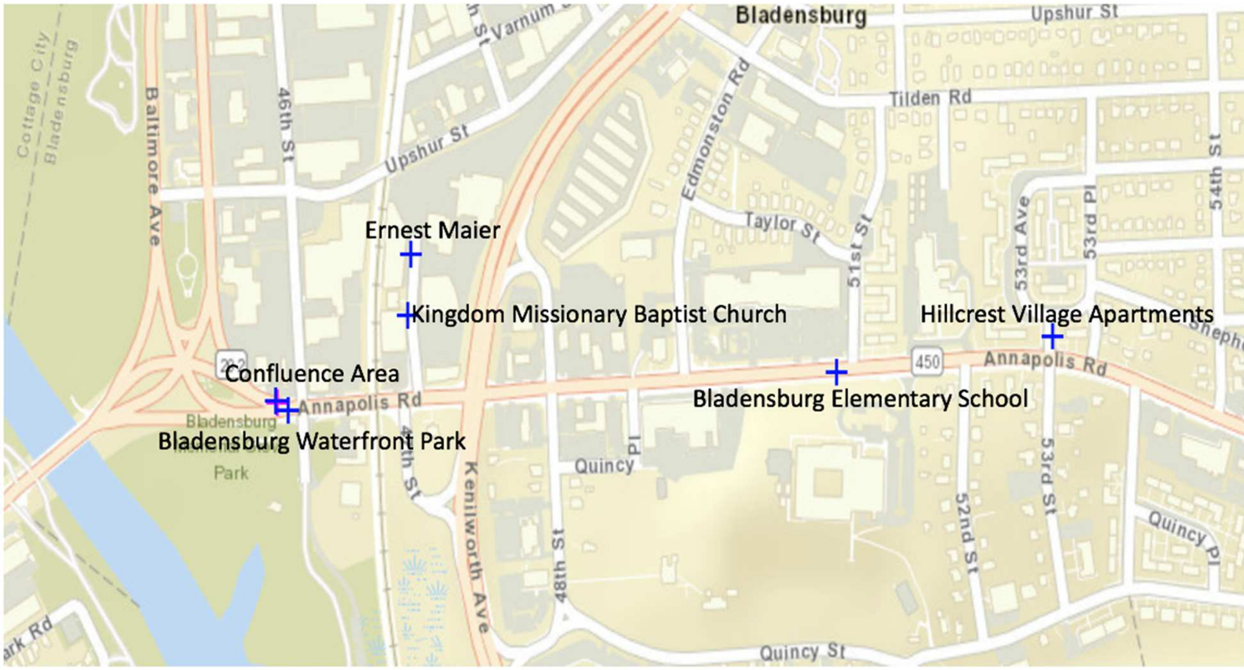


Figure 4.1. Map showing the five personal monitoring locations at Bladensburg and the concrete block plant (EJScreen)

We selected five locations for the study of VOCs which were Kingdom Missionary Baptist Church (site 1), Bladensburg Waterfront Park (site 2), Bladensburg Elementary school (site 3), Hillcrest Village Apartments (site 4) and Confluence area (King Pawn Auto Shop – site 5). These locations were chosen due to concerns about high traffic and the concrete block plant, as well as, proximity to receptor sites [185]

The concrete block plant is on a property, which belongs to Ernest Maier, Inc. and is close to some historic sites in Bladensburg – Peace Cross, Battle of Bladensburg Memorial, Anacostia River and Bladensburg Waterfront Park [227]. The plant is located at 4700 Annapolis Rd, Bladensburg, MD 20710. The selection of the monitoring locations was driven by concerns about high traffic and location of the concrete block plant for monitoring of VOC emissions. Personal monitoring locations were chosen based on close proximity to the plant and are within

1609 meters from the plant; which are important human receptor sites among children, adults and the elderly (offices, residential, school and recreational complexes) [185]. Near roadway air quality monitoring was utilized because it will provide a measure of the exposure of individuals who live and work along these traffic routes [17].

Environmental Assessment

Air quality monitoring and traffic counts were conducted by interns from the University of Maryland. Each location was staffed by two persons who wore Atmotube sensors and conducted traffic counts. Also, the researcher was present during all sampling periods; however, most of the work was carried out by the interns. The interns were trained in the operation, use and placement of the Atmotube sensors. The trained interns were responsible for the sampling operations at each site which was overseen by the researchers.

Air sensors used were low-cost, easy-to-use, portable air pollution sensors which provide high-time resolution data in near real time [197]. The Atmotube is a wearable, portable device which measures the presence of total VOCs in the real-time via Air Quality Score Android app. Measured data are sent via Bluetooth low energy (LE) protocol to your mobile phone. The device has an LED color which represents the Air Quality Score and alerts you whenever the air is unsafe. Also, measurements are uploaded to a secure cloud and is aggregated on the air quality map. Atmotube sensors were worn around the neck in the breathing zone at the personal monitoring locations.

At the personal monitoring location, VOC monitoring occurred from Sunday to Saturday during traffic peak and off-peak periods in a thirty-minute time frame. Traffic peak times were 7:00am to 9:00am and 4:00pm to 6:00pm, while off peak time was between 11:00am to 1:00pm.

Monitoring was conducted from 8:30am to 9:15am, 11:00am to 12:15pm and 4:00pm to 5:15pm. Air quality monitoring was conducted from March to May 2018 because it was Spring, so that residents and interns were not exposed to the adverse effects of the cold weather while monitoring. Monitoring on Saturdays will aid in ensuring consistency in data collection and coincides with when the facility operates (i.e., Monday through Saturday) and captures time periods when there is less commuter traffic compared to Monday-Friday when there is more commuter traffic.

Traffic Counts

Traffic counts were performed at each monitoring site while the team assessed personal exposure to VOCs. This involved counting the number of motor vehicles, including cars, buses, vans, trucks that drive past during the sampling period. Heavy duty trucks included trucks larger than pick-up trucks including buses, while vans and sport utility vehicles were counted as cars. Traffic counts were done manually and data was entered into the data sheets. Counts were conducted in 5 minutes intervals during each thirty minute sampling period or window [185]. The counts were summed to provide daily counts, averaged/day, averaged per each site, and average across each week, and averaged across the entire sampling period.

Statistical Analysis

Descriptive statistics (e.g., mean, median, standard deviation, minimum and maximum) were tabulated and plotted for the six locations at different times of the day to assess the spatial and temporal variation in VOCs. Pearson correlation was used to evaluate the associations and significance between VOCs at different locations and time; and between VOC concentrations and traffic counts. This helped to determine the level of association between the VOCs recorded at different locations during on-peak and off-peak periods. The data collected was analyzed using SAS Enterprise Version for Windows 9.3 at a significance level of 0.05 and lower ($P \leq 0.05$).

RESULTS

The 2010 Census as shown in Table 4.1, revealed that there are 9,148 people in Bladensburg of which 53.06% of them are female, while 46.94% are male [239]. African-Americans constitute 65.58% and Hispanics are 26.92% of the population. 73.08% of the population are 18 years and over, while 26.83% are under 18 years of age. Also, Table 4.1 displays the educational attainment of Bladensburg; 28.48% of residents aged 18 to 24 years have less than high school education. 31.83% of residents aged 24 years and over have less than a high school degree. The median household income in Bladensburg is $34,966 as shown in Table 4.1. The percentage of families in Bladensburg within the poverty level is 11.7%, while the percentage of people within the poverty level is 12.1% (Table 4.1).

Table 4.1. Sociodemographic Composition of Bladensburg [239]

Population	**Number**	**%**
Total Population	9,148	100
Population by Sex		
Male	4,294	46.94
Female	4,854	53.06
Population by Age		
Under 18	2,454	26.83
18 & over	6,694	73.17
Population by Ethnicity		
Hispanic or Latino	2,463	26.92
Non-Hispanic or Latino	6,685	73.08
Population by Race		

White	1,149	12.56
African-American	5,999	65.58
Asian	187	2.04
American Indian and Alaska Native	50	0.55
Native Hawaiian and Pacific Islander	2	0.02
Other	1,515	16.56
Identified by two or more	246	2.69
Educational Attainment		
Population 18 to 24 years	748	
Less than high school graduate	213	28.48
Population 25 years and over	4,781	
Less than high school graduate	1,522	31.83
Income in 1999		
Median household income (dollars)	34,966	
Poverty levels in 2010		
All families		11.7
with related children under 5 years		23.5
All people		12.1
related children under 5 years		21.6

Thirty minutes' traffic counts for cars and trucks at the four locations for the different time shifts are summarized in Table 4.3. The average cars and truck vehicle counts varied at the different locations on different days and at different times. The confluence area had the highest average of car counts at different days and monitoring periods. Also, Kingdom Missionary Baptist Church and Hillcrest Apartments consistently had low average cars and truck counts; while the average cars and truck counts at the Waterfront Park varied and may be attributed to activities at the park.

Table 4.2 Mean and Standard Deviation of 30-minutes Traffic Counts at Five Sites in Bladensburg

		Morning		Afternoon		Evening	
		Cars	Trucks	Cars	Trucks	Cars	Trucks
Day	Sites	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Wednesday 0606	Church	7.92 (1.93)	1.25 (0.75)	6 (2.34)	3.33 (2.02)	2.75 (2.22)	0.17 (0.58)
	Waterfront Park	122.2 (131.82)	10.7 (11.52)	162.2 (26.71)	9.8 (2.59)	169.33 (46.42)	17.33 (19.88)
	Elementary School	50.17 (97.99)	17.5 (5.01)	72 (15.03)	16.5 (3.02)	135 (15.74)	26.17 (3.43)
	Hillcrest Apartments	3.33 (2.5)	1 (1.55)	0.67 (1.21)	0.17 (0.41)	5.83 (2.79)	1 (1.1)
	Confluence	210.71 (55.67)	11.58 (3.32)	185.14 (25.81)	12.86 (3.18)	185.83 (25.38)	9.83 (4.88)
Thursday 0607	Church	6.58 (1.56)	1.92 (0.9)	9.33 (3.11)	2.25 (1.14)	4.1 (1.19)	1.5 (0.58)
	Waterfront Park	2.17 (1.47)	1.4 (0.55)	2.31 (0.57)	1 (-)	2.2 (1.1)	*
	Elementary School	57.67 (9.05)	*	66.67 (10.21)	22 (8.07)	136.5 (7.12)	25.83 (4.02)
	Hillcrest Apartments	1.5 (1)	*	1 (-)	*	3.6 (1.67)	1 (0)
	Confluence	185.43 (25.75)	16.29 (2.69)	184.5 (18.84)	14.17 (2.99)	192 (27.03)	6 (1.73)
Saturday 0609	Church	11.25 (3.620	1.17 (0.83)	6.33 (3.45)	0.17 (0.39)	2 (1.41)	*
	Waterfront Park	39.75 (27.67)	9.63 (3.81)	137.83 (36.64)	4 (1.26)	3 (1.67)	*
	Elementary School	53.17 (10.15)	16 (2.82)	87.5 (21.32)	13.17 (2.93)	94.17 (11.3)	14.83 (3.13)
	Hillcrest Apartments	1.4 (0.89)	1 (1.55)	1.4 (0.55)	*	2.75 (1.5)	2 (-)
	Confluence	73 (16.49)	9.17 (3.92)	177.17 (34.67)	4 (3.22)	81 (17.46)	3 (-)
Wednesday 0613	Church	9.75 (3.7)	0.67 (0.89)	6.83 (3.51)	1.08 (1.62)	1.92 (1.73)	0.08 (0.29)
	Waterfront Park	1.83 (1.83)	*	2.67 (1.63)	*	2.17 (0.98)	*
	Elementary School	56.17 (3.82)	17.67 (3.5)	51.67 (5.64)	19.5 (5.54)	119.67 (10.58)	24.17 (6.74)
	Hillcrest Apartments	1.17 (0.98)	*	1.67 (1.37)	1 (-)	4.83 (2.64)	2 (1.73)
	Confluence	159.83 (56.29)	13.83 (3.06)	183.83 (10.57)	12 (1.1)	247.5 (26.2)	5.33 (1.37)
Thursday 0614	Church	9.33 (3.08)	1.64 (0.81)	9.58 (2.02)	1.83 (0.83)	3.25 (2.22)	*
	Waterfront Park	2.17 (1.17)	1 (0.71)	4.17 (1.33)	1 (0)	2.4 (1.14)	*
	Elementary School	52 (14.18)	14.33 (2.25)	60.83 (10.87)	12 (2.83)	124.5 (17.51)	26.33 (6.31)
	Hillcrest Apartments	3.2 (1.3)	1.6 (0.55)	2.5 (1.22)	1 (-)	5.5 (4.14)	1.33 (0.58)
	Confluence	90.17 (11.32)	13.83 (3.13)	80.83 (13.93)	15 (2.9)	203.33 (22.04)	6.83 (3.31)
Saturday 0616	Church	13.75 (4.27)	1.6 (0.89)	9.83 (4.17)	1.29 (0.49)	1 (0)	1 (-)
	Waterfront Park	5.17 (2.93)	*	4.5 (2.95)	*	7 (3.58)	*
	Elementary School	52.33 (7.61)	10.33 (4.32)	76.33 (19.54)	15.4 (5.41)	119.33 (17.57)	1.25 (0.5)
	Hillcrest Apartments	3.8 (0.84)	1 (-)	3.2 (2.28)	1.67 (1.15)	4.6 (3.58)	2 (1.41)
	Confluence	165.83 (47.05)	7 (4.76)	228.17 (21.71)	6.33 (2.88)	209.33 (36.81)	3 (0.82)

*No truck data observed

Forest plots were used to summarize the descriptive statistics obtained from VOC monitoring at the different locations, monitoring shifts and days. The use of forest plots or meta-analytic pooling aids researchers to display their findings in a graphically appealing way but in a statistically correct way [240]. A forest plot is a powerful tool that illustrates heterogeneity which are the differences in results; while displaying the pooled result which is the overall combined result from the various measurements [254]. The monitoring shifts conducted on the first Wednesday at the Kingdom Missionary Baptist Church and the Waterfront Park were graphically represented in a forest plot as shown in Figure 4.2. We observed that the minimum, mean and maximum values were different for both locations during all the shifts. Figure 4.3 represents a forest plot of the minimum, mean and maximum values obtained from monitoring at the Kingdom Missionary Baptist Church and Hillcrest Apartments. It was observed that all the values of VOC concentrations were different across the sites and monitoring periods. The descriptive statistics of VOC levels obtained at the Kingdom Missionary Baptist Church and Bladensburg Elementary School were graphically illustrated as shown in Figure 4.4. The findings revealed that the minimum, mean and maximum values are different across the sites irrespective of the monitoring shift. A forest plot of the minimum, mean and maximum values gotten from monitoring VOC concentrations on Wednesday at the Kingdom Missionary Baptist Church and confluence area is displayed in Figure 4.5. The plot revealed that the values were different at both locations, however, the values for each location were similar.

A comparison of the minimum, mean and maximum values obtained for VOC concentrations at the Kingdom Missionary Baptist Church and the confluence area on the second Wednesday were presented in a forest plot as shown in Figure 4.6. The forest plot revealed that all the values differed across the sites during different monitoring shifts. The forest plot in Figure 4.7 demonstrated that the minimum, mean and maximum values were different at the Kingdom Missionary Baptist Church and the Waterfront Park across the monitoring periods. The minimum, mean and maximum values obtained at the Kingdom Missionary Baptist Church and Bladensburg Elementary School illustrated that the values differ at both sites across the monitoring shifts. The forest plot in Figure 4.9 demonstrated that the minimum, mean and maximum values obtained at the Kingdom Missionary Baptist Church and Hillcrest Apartments were different during the monitoring shifts at both locations.

We compared the minimum, mean and maximum values for VOC concentrations at the Kingdom Missionary Baptist Church on both Wednesdays (Figure 4.10, Appendix A). The plot showed that the values were different on both days at the Church. A comparison of the minimum, mean and maximum VOC values obtained on both Wednesdays at the Waterfront Park (Figure 4.11, Appendix A) showed that the values differed on both days at the park. The forest plot of minimum, mean and maximum VOC values at Bladensburg Elementary School recorded on both Wednesdays (Figure 4.12, Appendix A) demonstrated that the values differ on both days at the school which was irrespective of monitoring period. Figure 4.13 (Appendix A) represents the forest plot of minimum, mean and maximum values of VOC levels on both Wednesdays at Hillcrest Apartments which showed that the values were different on both days at Hillcrest Apartment which differed at the monitoring shifts. The forest plot of minimum, mean and maximum values of VOC concentrations obtained for both Wednesdays at the confluence area (Figure 4.14) showed that the values were different on both days, but the values for the first Wednesday were similar.

Trend graphs were created for observed VOC levels at different locations during different dates and monitoring periods. Figures 4.15 and 4.16 (Appendix A) display the trend of VOC concentrations observed on Saturday afternoon (0609) at the Waterfront Park and Confluence area. It was observed that at the Confluence area the readings were below 0.13ppm, while at the Waterfront Park, the concentrations were below 0.25ppm. The trend graph of VOC levels observed on Wednesday evening (0613) at the Bladensburg Elementary School and the Kingdom Missionary Baptist Church are shown in Figures 4.15 and 4.16 (Appendix A). It demonstrates that the VOC levels at the Church were within 0.25 – 0.45ppm, while at the school the VOC levels were within 0.2 – 0.35ppm.

We conducted Pearson's correlation to ascertain the associations between the VOC concentrations obtained at various monitoring locations on Wednesday (0606). Table 4.4 displays the results obtained in which most of the results had a weak correlation and were not statistically significant. The findings revealed that as the VOC concentrations increased at the Kingdom Missionary Baptist Church, VOC levels decreased at Hillcrest Apartments during the evening shift and 89.17% of the variability in concentrations were explained by the relationship. Also, as VOC concentrations increased at Bladensburg Elementary School, there was observed increase at the Hillcrest Apartments; which the 67.85% and 61.17% of the variability in the data obtained during the morning and afternoon shifts were explained by the relationship. It was observed that as the VOC levels increased at Bladensburg Elementary School during the morning shift, the readings at the confluence area increased; and 50.44% of the variability in VOC levels were explained by the relationship.

Table 4.3. Correlation Between Sites at Different Times of the day on Wednesday (0606)

		Wed 0606 Morning	Wed 0606 Afternoon	Wed 0606 Evening
Site	**Site**	**r**	**R**	**r**
Church	**Waterfront Park**	0.69545	-0.19958	
Church	**Elementary School**	0.94911*	0.58211	0.45551
Church	**Hillcrest Apartments**	-0.17859	-0.101	-0.89172*
Church	**Confluence Area**	0.54481	-0.12603	
Waterfront Park	**Elementary School**	0.17951	-0.05199	-0.08816
Waterfront Park	**Hillcrest Apartments**	0.01286	0.09	0.04854
Waterfront Park	**Confluence Area**	0.01423	-0.0353	0.31382
Elementary School	**Waterfront Park**	0.17951	-0.05199	-0.08816
Elementary School	**Hillcrest Apartments**	0.67853**	0.61172*	0.03106
Elementary School	**Confluence Area**	0.50444*	-0.13142	0.26628
Hillcrest Apartments	**Waterfront Park**	0.01286	0.09	0.04854
Hillcrest Apartments	**Elementary School**	0.67853**	0.61172*	0.03106
Hillcrest Apartments	**Confluence Area**	0.20643	0.06702	0.39088*
Confluence Area	**Waterfront Park**	0.01423	-0.0353	0.31382
Confluence Area	**Elementary School**	0.50444*	-0.13142	0.26628
Confluence Area	**Hillcrest Apartments**	0.20643	0.06702	0.39088*

**** - p-value <0.0001 * - p-value <0.05**

Pearson's correlation was conducted to determine the associations between the VOC concentrations recorded at different locations on Wednesday (0613) during the various monitoring time periods (Table 4.5). The results revealed that as the VOC levels increased at the Kingdom Missionary Baptist Church, there was an observed decrease at the Waterfront park during the afternoon shift and 62.27% of the variability in data could be explained. Also, there were observed increases in the VOC levels at the Kingdom Missionary Baptist Church and Hillcrest Apartments of which 88.22% and 65.91% of the variability in the data obtained during the morning and afternoon shifts can be explained. The VOC concentrations at the Kingdom Missionary Baptist Church and the confluence area were increased during the afternoon shift and 60.52% of the variability in VOC levels could be explained. The findings demonstrated that as the VOC levels at the Waterfront Park increased, there was a decrease in the levels obtained at the confluence area, 51.54% of the variability in the data obtained during the afternoon shift could be explained. An increase in the VOC concentrations observed at Bladensburg Elementary School was associated with an increase in VOC levels at the confluence area of which 64.26% of the variability in the data could be explained.

Table 4.4. Correlation Between Sites at Different Times of the day on Wednesday (0613)

Site	Site	Wed 0613 Morning r	Wed 0613 Afternoon R	Wed 0613 Evening r
Church	**Waterfront Park**	0.23653	-0.62267*	-0.11342
Church	**Elementary School**	0.45077	-0.0539	-0.03113
Church	**Hillcrest Apartments**	0.88215*	0.65907*	0.23734
Church	**Confluence Area**	0.15495	0.60517*	0.00238
Waterfront Park	**Elementary School**	-0.1148	0.28424	0.03057
Waterfront Park	**Hillcrest Apartments**	-0.30291	-0.38314*	0.10667
Waterfront Park	**Confluence Area**	0.08932	-0.51538*	0.05315
Elementary School	**Waterfront Park**	-0.1148	0.28424	0.03057
Elementary School	**Hillcrest Apartments**	0.19293	-0.35597	0.39684
Elementary School	**Confluence Area**	-0.39671	-0.21992	0.64256*
Hillcrest Apartments	**Waterfront Park**	-0.30291	-0.38314*	0.10667
Hillcrest Apartments	**Elementary School**	0.19293	-0.35597	0.39684

Hillcrest Apartments	**Confluence Area**	-0.31129	0.20813	0.3433
Confluence Area	**Waterfront Park**	0.08932	-0.51538*	0.05315
Confluence Area	**Elementary School**	-0.39671	-0.21992	0.64256*
Confluence Area	**Hillcrest Apartments**	-0.31129	0.20813	0.3433

**** - p-value <0.0001 * - p-value <0.05**

DISCUSSION

Monitoring occurred at a small number of sites and days, the findings reveal that VOC concentrations are higher in locations close to traffic and the concrete block plant. The mean VOC concentrations observed ranged from 0.11ppm to 0.68ppm and the highest values were obtained at the Kingdom Missionary Baptist Church. A study conducted to determine traffic related differences in VOC concentrations, showed that VOC levels were 100% higher at homes located within high traffic intensity roadways [255]. This was consistent with our findings which revealed high mean values at the confluence area and Bladensburg Elementary School which were high traffic roadways. Our study revealed that there could be an association of the VOC levels obtained at different sites at different times of the day, such as between the elementary school and Hillcrest Apartments, the church and the elementary school; and the elementary school and the confluence area, which are high traffic intensity areas. Therefore, we observed some spatial and temporal variations in VOC levels due to traffic and industrial activity at the plant as key emission sources. Mobile sources are important contributors to outdoor VOC concentrations [103]. VOC levels are usually high around areas with industrial facilities and heavy traffic; which decreases with increasing distance from emission sources [256]. These results emphasize the concerns raised by the residents about the effects of air pollutants from traffic and the concrete block plant in Bladensburg.

Many residents in the Port Towns of Bladensburg, Cottage City, Colmar Manor and Edmonston are in opposition to the special exception permit which was granted to Ernest Maier Inc. to construct a concrete batching plant on its property [227]. Residents are organizing and working with Port Towns Environmental Action (PTEA) to ensure that the expansion does not happen [225,227,228]. They are concerned about the proximity of the plant to historic sites, storm water runoff, air and noise pollution, traffic congestion, the mixture of air pollutants emitted by the concrete block plant and traffic or mobile sources (cars, trucks and buses) and public health and safety in their community [227]. An EcoDistrict has been created in the community which will aid environmentally-focused tourism and economic development, and the proposed expansion By Ernest Maier may hinder these activities [228].

Evidence has shown that people of color and economically disadvantaged individuals have increased residential exposure to traffic and traffic-related air pollution (TRAP); and are more likely to live in highly trafficked areas which may result in an increased risk of adverse health outcomes, such as cancer [110,117,151–153,156,159–162]. Asian Pacific Islanders, African Americans and Asians were observed to have higher pollution exposures and were twice as likely to live in the most polluted counties than Whites [157]. Elementary schools within economically disadvantaged communities were found to be exposed to very high traffic in California [158]. Hispanics, especially Cubans and Colombians have increased cancer risk from vehicular air pollution in Miami, Florida [156]. Higher incidence of asthma among low-income individuals has been linked with higher traffic exposure and susceptibility factor such as health status and access to healthcare [162]. People of color in Southern California may be disproportionately exposed to TRAP [163]. A study conducted in Hunts Point, New York revealed that increased concentrations of elemental carbon were found at intersections and varied due to large truck traffic [164]. In Wilmington and western Long Beach, adjacent to the Ports of Los Angeles and Long Beach, California; the volumes of heavy-duty diesel trucks were as high as 400 to 600 trucks per hour for several hours around sensitive land use areas, such as, schools, parks and residences [163].

There are some limitations of the study, which include the focus on VOC exposure only and did not include personal exposure or an assessment of potential adverse health effects among the residents in Bladensburg. Also, the study did not address the cumulative VOC exposures from the various industrial facilities and indoor exposures within the community. Our study did not incorporate a health impact assessment of VOC exposure from traffic and near the concrete block plant. The topography and weather conditions (such as wind speed and direction) in Bladensburg were not considered in the study because we did not utilize geographic information systems (GIS) modeling and spatiotemporal mapping.

The Atmotube sensors have not been tested with any other sensors associated with VOC measurements; therefore, we may not have information about its accuracy and the impact of extreme weather conditions on the sensors. During air monitoring, we observed that the sensor often disconnected from the mobile device, which may impact the data collected. Also, the data was not easily accessible after each session because they had to be downloaded from the mobile device that was used. The short sampling period (March to May) was not adequate to collect data to display seasonal variations in VOC concentrations. The study was conducted in the spring season and there could be the possibility that the exact magnitude of differences found between high and low traffic intensity roadways may be different if the VOC concentrations during other seasons were measured. Also, there is limited literature on outdoor VOC levels, whereas literature is focused on indoor VOC concentrations [82,112,257–259].

Future research should develop a unique study design at the Kingdom Missionary Baptist Church which is the closest site to the concrete block plant; to capture the truck traffic around the plant. This is due to the high VOC concentrations and low truck traffic observed at the location. It will be beneficial to utilize fixed monitors and electronic traffic counters because we believe that a majority of the truck traffic at the concrete block plant occurred during the early part of the day. Also, monitoring should be conducted year-round at more locations to reflect seasonal variations in VOC concentrations. GIS modeling should be incorporated into the study design to take into consideration topography and weather patterns on different monitoring days. The present study focused on community level exposures which does not represent individual exposure to VOC; therefore, future study should consider individual-level exposure. Our future study will provide a baseline exposure assessment and epidemiological study to examine changes in individual health outcomes associated with VOC exposure such as asthma among residents of Bladensburg, Maryland.

CONCLUSION

Spatial and temporal variation in VOC concentrations were observed at some of the monitoring sites, such as the Kingdom Missionary Baptist Church, Confluence area and Bladensburg Elementary School; which were attributed to high traffic intensity and industrial activities at the concrete block plant. We observed an irregular trend and variations in the observed VOC measurements in areas close to high traffic roads such as the Waterfront Park and Hillcrest Apartments, which may underestimate residential exposure and the potential health risks linked with VOC exposure for residents. Also, we would recommend that measurements and monitoring should be conducted throughout the year. And it may be beneficial to increase the number of monitoring locations around the plant; which may provide information on which locations are directly impacted by industrial activities at the concrete block plant. The use of meteorological data in our future work will explain the effects of wind pattern, temperature, humidity and rainfall on the dispersion and distribution of VOC concentrations within the community. It would be important to identify and differentiate the different truck traffic when conducting traffic counts in future studies because this information may provide information on the exposure levels associated with the different types of truck traffic.

CHAPTER 5

Synopsis, Strengths, Limitations, and Public Health Implications

This chapter presents an overview of our findings, strengths and limitations of our study. The previous chapters assessed the literature and provided a framework for the development of our study and laid credence to the specific aims of our study. We conclude with public health implications that provide a basis for future research studies on air quality assessment of residential exposure to particulate matter and volatile organic compounds.

5.1 Specific Aim #1: To determine human exposure to PM and VOCs in Bladensburg, Maryland. *Hypothesis 1: Areas close to the concrete block plant will have higher exposure levels of PM and VOCs than areas farther away from the plant.*

The findings from our study revealed that the Kingdom Missionary Baptist Church, which was the closest monitoring location to the concrete block plant, had the highest mean values for $PM_{2.5}$ and VOC concentrations. This may be attributed to industrial traffic and industrial activities at the concrete block plant. Also, we observed high mean $PM_{2.5}$ and VOC concentrations at the confluence area and Bladensburg Elementary School, which may be associated with high commuter and industrial traffic. The Waterfront Park and Hillcrest Apartments which were further away from the concrete block plant, had smaller mean PM and VOC values compared to other locations. Our results indicate that there was weak correlation in the observed $PM_{2.5}$ concentrations between the different sites on different monitoring days. The results obtained from Pearson's correlation revealed that there was an observed association of the $PM_{2.5}$ measurements at the Kingdom Missionary Baptist Church during all the monitoring shifts. Also, the correlation analysis conducted demonstrated that there was an observed association in the VOC measurements obtained at the Kingdom Missionary Baptist Church, Bladensburg Elementary School and confluence area. Furthermore, the results of the one-way ANOVA analysis revealed that the monitoring site had an impact on the observed $PM_{2.5}$ measurements, that is, $PM_{2.5}$ measurements were changing in various ways based on the monitoring locations.

5.2 Specific Aim #2: To assess variation in human exposure to PM and VOCs at different locations during different times of the day in Bladensburg, Maryland.

Hypothesis 2: Individuals walking on highly trafficked roads will have higher exposure levels of PM and VOCs during on-peak periods than individuals walking on low trafficked roads during on-peak hours.

Our results revealed that Bladensburg Elementary School and the confluence area were highly trafficked roads. The highest mean traffic count of 136.5 cars was observed at Bladensburg Elementary School, while the confluence area had 247.5 cars within a thirty-minute monitoring period. The highest average $PM_{2.5}$ concentration observed at Bladensburg Elementary School was 18.18 $\mu g/m^3$, while 17.69 $\mu g/m^3$ was recorded at the confluence area. The results from our correlation analysis revealed that there was an inverse relationship of both sites. As the $PM_{2.5}$ levels at the confluence area increases, we would observe a decrease in $PM_{2.5}$ concentrations at Bladensburg Elementary School, and vice versa. The findings from one-way ANOVA to determine the impact of site, time or monitoring period and day on $PM_{2.5}$ measurements demonstrated that there are changes in $PM_{2.5}$ measurements at the various sites, and the changes could occur in various ways.

Also, the highest average value for total VOC concentration recorded at Bladensburg Elementary School was 0.37ppm, and 0.68ppm at the confluence area. Pearson's correlation analysis showed that there was an inverse relationship or association of both sites. The highest mean traffic count truck value was 26.7 trucks at Bladensburg Elementary School and 16.24 trucks at the confluence area.

5.3 Strengths

The AirBeam sensors have been tested to demonstrate a linear relationship with Thermo Scientific pDR 1500 (reference monitor) for concentrations less than 100µg/m^3 [260]. Therefore, the AirBeam was an effective sensor in the measurements of $PM_{2.5}$ concentrations at the various locations. Several studies have looked at $PM_{2.5}$ exposure within communities of color with high traffic or industrial activities, however, our study provided baseline data in Bladensburg for $PM_{2.5}$ and VOC concentrations from commuter traffic, industrial traffic and industrial activities near a concrete block plant [164,185–187]. This information will be useful in assisting decision makers and residents on how to improve the quality of life of residents.

An important strength is the partnership with the residents, Port Towns Environmental Action (PTEA) and UMD-College Park. This partnership utilizes CBPR which promotes collaborative research between academic partners and the community, while fostering trust, community empowerment and building local capacity [189,193,201,261]. Residents were trained on the use of the air sensors which improved their knowledge on air pollution and air quality. We also chose different monitoring locations which were within a 2 km radius of the concrete block plant to monitor the residential exposure to $PM_{2.5}$ and VOC levels. Also, the locations reflected different environmental settings of traffic, residential and recreational uses within the community. These locations were categorized as high and low trafficked roads; and traffic counts were conducted at these locations to assist. By comparing these locations, it provided a better understanding of $PM_{2.5}$ and VOC concentrations from traffic and industrial activities; and the variations in $PM_{2.5}$ and VOC levels. Also, we conducted air quality monitoring during traffic on-peak and off-peak periods to capture $PM_{2.5}$ and VOC concentrations caused by the volume of traffic at the monitoring locations.

5.4 Limitations

There were some limitations inherent in our study. An important limitation could be that the AirBeam sensors exhibits a non-linear relationship for concentrations higher than 100µg/m^3 during the testing of the sensors [260]. Particle coincidence may have occurred when using the AirBeam sensors, which could result in undercounting when multiple particles are coincident in the sensing zone [260]. Also, the AirBeam sensors were observed to be very sensitive to harsh sunlight during the monitoring period which was carried out during the spring. We did not adjust for accuracy of the AirBeam sensors by calibrating and adjusting the slope and offset against a co-located reference/equivalent station. The Atmotube has not undergone testing and comparison with a reference sensor. The Atmotube website did not collate and store data on the cloud, but stored them on the smart devices used. This made data collection difficult because the data had to be collected from each device at the end of each monitoring session.

The short duration of our study restricts our ability to make claims about long-term relationship among VOC and $PM_{2.5}$ measurements, traffic and industrial activities associated with the cement block plant. Our spring-only data may distort associations, if the patterns are significantly different based on season. Our study did not compare the data collected with any federal reference method, which is considered the best characterization of concentration of any given pollutant and are supported by a comprehensive quality assurance program. Residents may be mobile throughout the day and may be exposed to various air pollutants in different indoor and outdoor environments; therefore, our study does not estimate personal exposure to air pollutants. Also, the study did not address the cumulative $PM_{2.5}$ and VOC exposures from the various industrial facilities in the community. Our study did not incorporate a health impact assessment of $PM_{2.5}$ and VOC exposure from traffic and industrial activities associated with the concrete block plant. Although, our study showed spatial variations in $PM_{2.5}$ exposures within Bladensburg; however, it did not include or indicate if the variations in $PM_{2.5}$ exposures was associated with variations in the rates of PM-related health outcomes such as respiratory illness, cardiovascular illness and premature mortality.

Although we partnered with the residents to design the study and trained them on the use of the sensors, they were not involved in the data collection phase of the study due to availability and logistic challenges. Our study did not consider the effect of meteorological data on $PM_{2.5}$ and VOC measurements at the monitoring locations and did not use GIS mapping in conducting the study. Also, we did not conduct biomarker analysis or study individual VOCs. Our study examined only two pollutants. It would be helpful to investigate other traffic-related air pollutants such as NO, CO, and black carbon. Also, we were not able to conduct fixed air quality monitoring by installing the Purple Air sensors which would have measured PM_{10}, $PM_{2.5}$, and PM_1 due to accessibility to the monitoring locations and logistic challenges. Although, we had five monitoring locations, it would have been beneficial to have more locations which would have covered 360^o around the concrete block plant and provided information about the locations highly impacted by traffic and industrial activities of the concrete block plant.

5.5 Public Health Implications

One public health implication of this study is that decision makers and stakeholders at the federal, state and county levels should engage and interact with residents or communities, especially economically disadvantaged communities of color before granting permits for industrial activities, siting and zoning of industries; and other land use decisions within communities. Our study revealed that Bladensburg is overburdened by $PM_{2.5}$ and VOC exposures associated with traffic and industrial activities linked with the concrete block plant. Ernest Maier has been in operation since 1926 and as such the facility is grandfathered with no site assessment or air quality assessment around the facility. Also, during the monitoring periods at the Kingdom Missionary Baptist Church, we observed that the workers did not use any personal protective equipment. Therefore, residents, business owners and industrial facilities should be educated, encouraged and work together to form community-based organizations. These organizations could conduct air quality assessment and work together with state and federal environmental agencies to improve and promote quality of life among residents and staff. This would lead to a reduction in illnesses associated with air pollution, such as asthma, respiratory and cardiovascular illnesses; thus, result in less sick leave and reduction in hospital visits and bills of staff and residents. Also, the results of this study can be used to allocate and prioritize resources to alleviate and remediate the effects of traffic and industrial activities in the community.

Also, we anticipate that federal, state and county officials could use the information from the study in regulatory decision-making process to develop preventive strategies and identify and implement appropriate and adequate regulations and standards. This study may strengthen partnerships among community institutions open to learning about air quality data, such as schools. It is anticipated that air quality monitoring would be included in middle and high school curriculum. It would encourage the use of data by community residents to improve their decision making to reduce the adverse effects of exposure to air pollutants. This would strengthen the community's competency in shaping local policies for transportation, development and construction projects affecting air pollution. Furthermore, the results could be used to inform future epidemiological studies that evaluate $PM_{2.5}$ and VOC exposures in neighborhoods near industrial settings.

Future studies will increase the scope of air quality monitoring around the concrete block plant by increasing the number of monitoring locations around the facility. Also, utilizing fixed and personal monitoring and a collocated federal reference monitor would provide insight into community and personal exposures. We will integrate meteorological data in our future work to identify the locations impacted by industrial activities at the plant. This will provide information on the wind patterns at different times of the day and during different seasons; and the impact of temperature, rainfall and humidity on the dispersion of these air pollutants. Future work will utilize GIS to produce distinct environmental layers which can be linked spatially and temporally and would assist with mapping spatio-temporal exposure distribution. Personal monitoring of residents and biomarkers may provide individual exposure information which could assist in identifying specific sources of interest (e.g. commuter traffic, industrial traffic and industrial activities).

APPENDIX A
FOREST PLOTS AND TREND GRAPHS

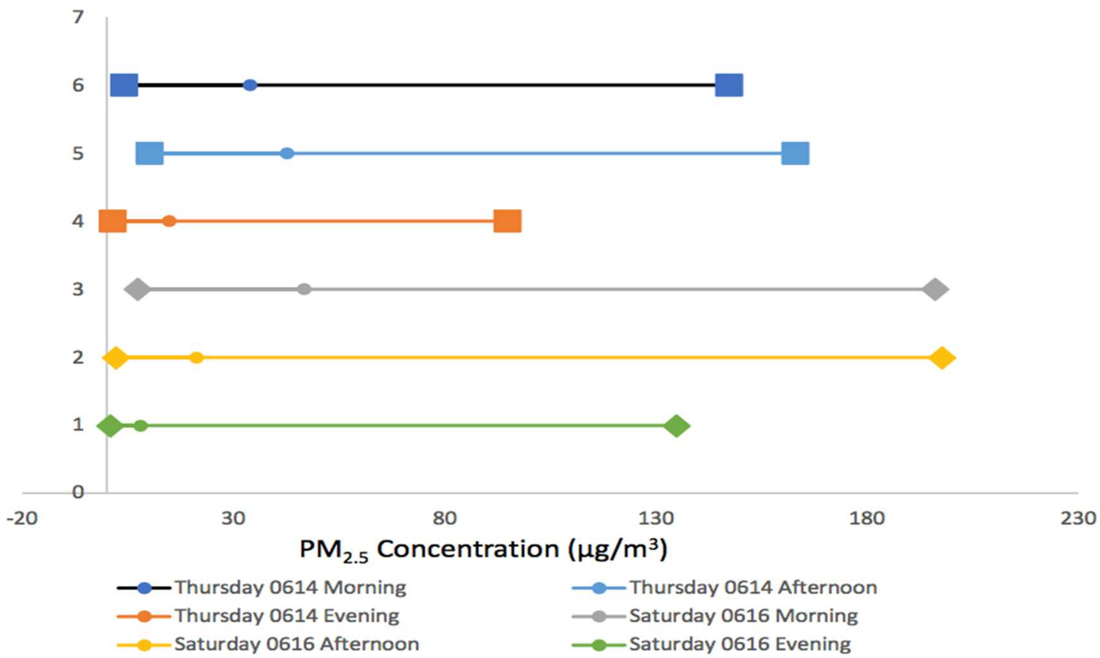


Figure 3.2. Forest Plot for Thursday and Saturday Shifts at the Church

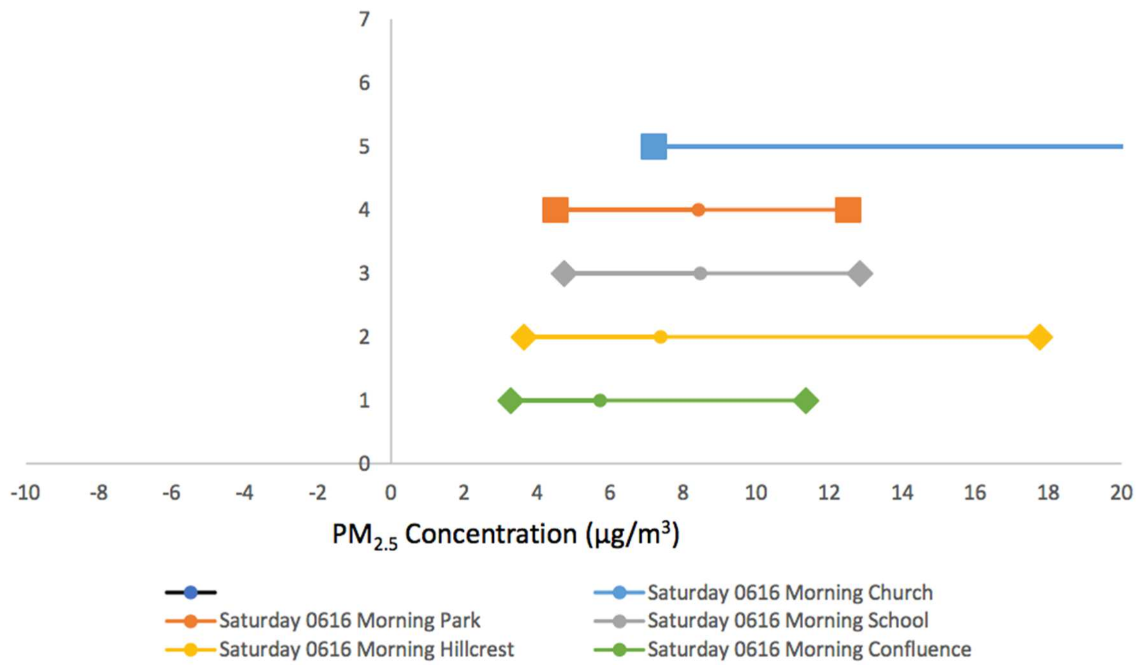


Figure 3.3. Forest Plot for Thursday and Saturday Shifts at the Waterfront Park

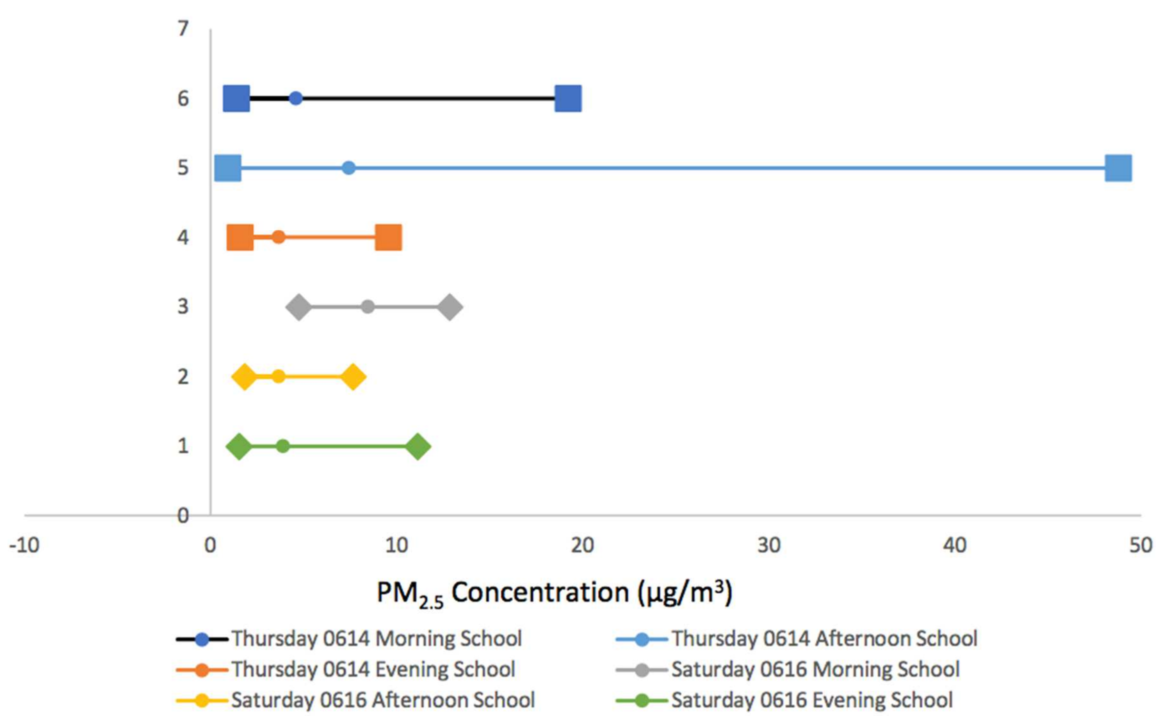


Figure 3.4. Forest Plot for Thursday and Saturday Shifts at the Elementary School

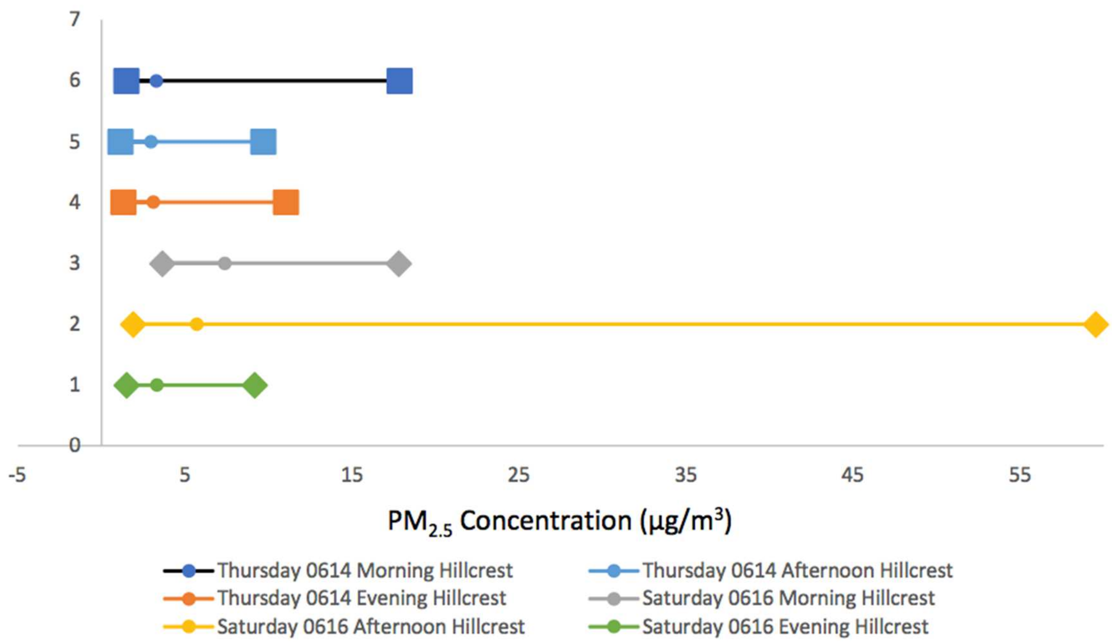


Figure 3.5. Forest Plot for Thursday and Saturday Shifts at Hillcrest Apartments

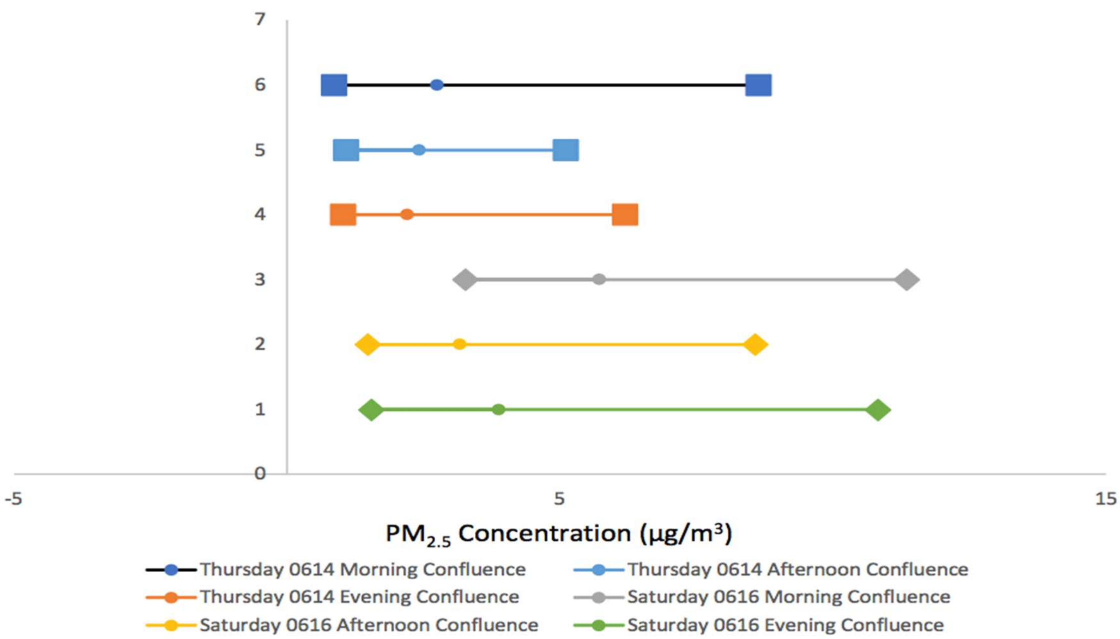


Figure 3.6. Forest Plot for Thursday and Saturday Shifts at the Confluence Area

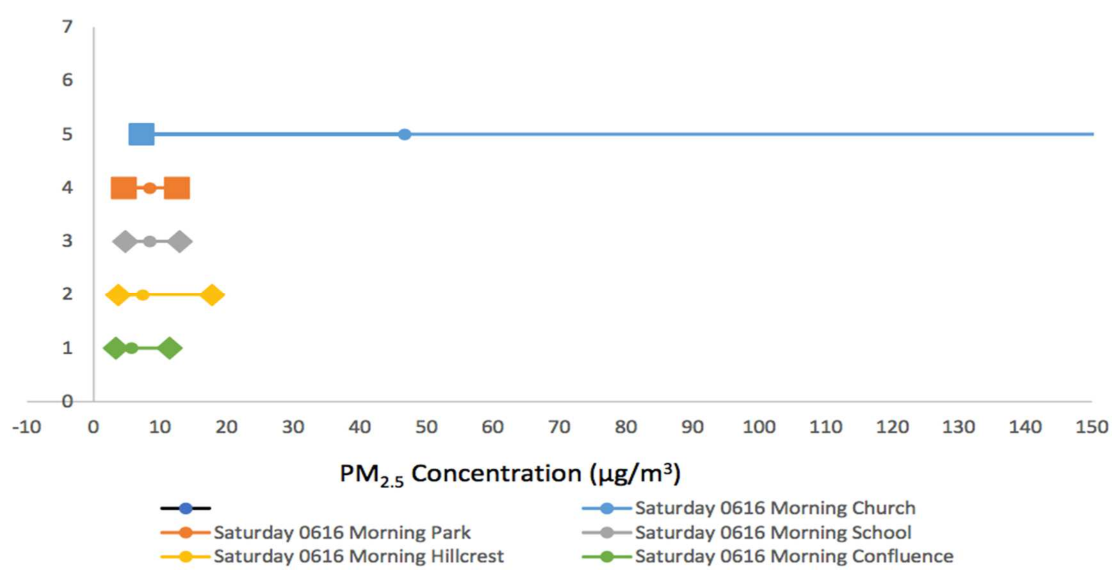


Figure 3.7. Forest Plot for Thursday Morning Shifts at the Five Sites

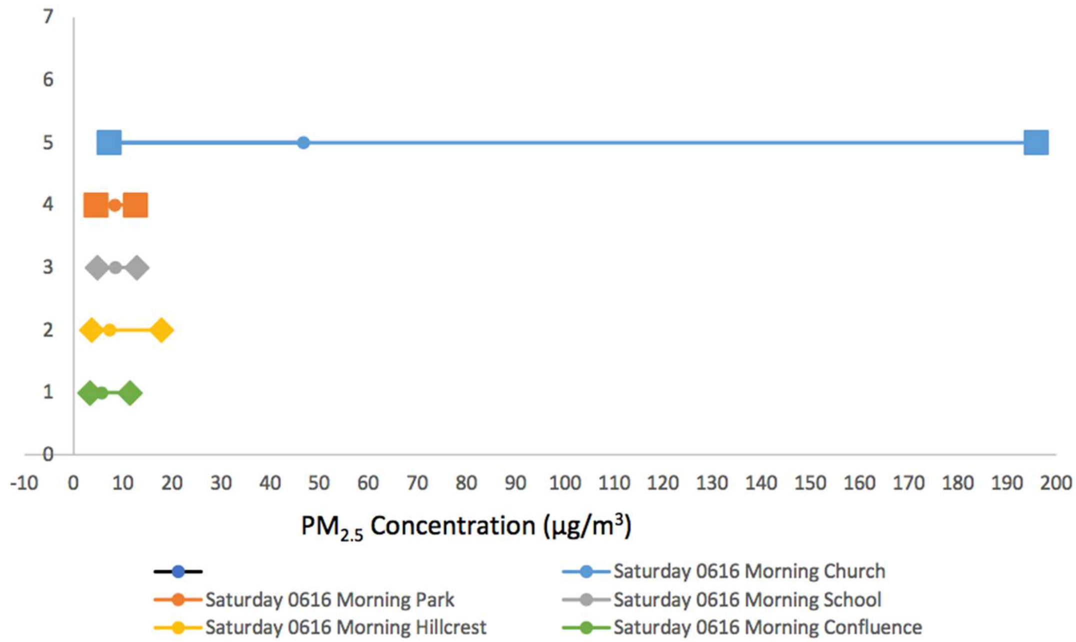


Figure 3.8. Forest Plot for Saturday Morning Shifts at the Five Sites

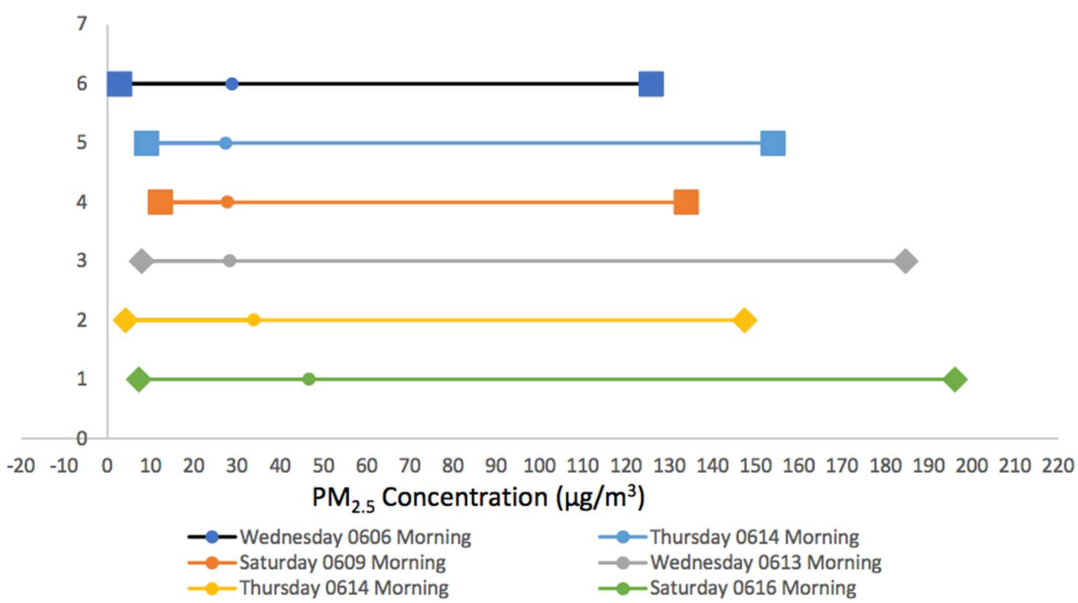


Figure 3.9. Forest Plot for Weekday Morning Shifts at the Church

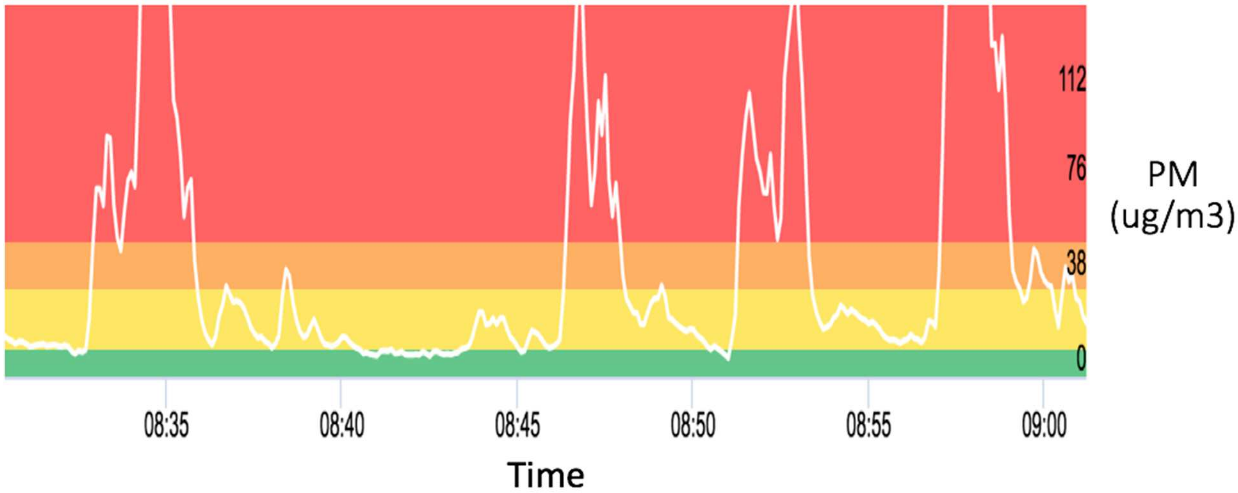


Figure 3.10. Trend at the Church During the Morning Shift on Saturday 0616 (aircasting.org)

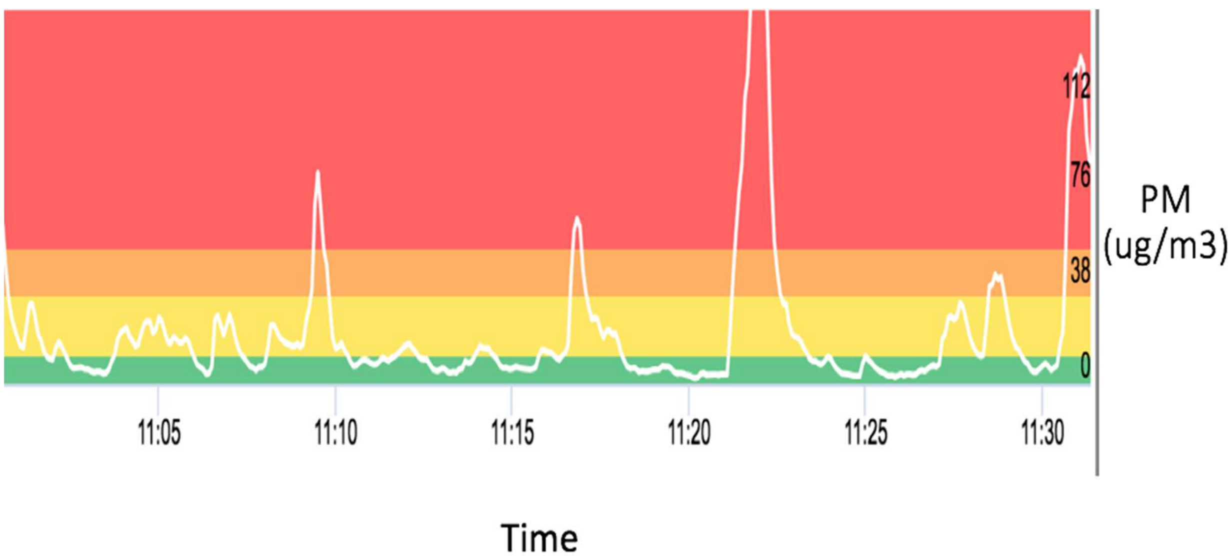


Figure 3.11. Trend at the Church During the Afternoon Shift on Saturday 0616 (aircasting.org)

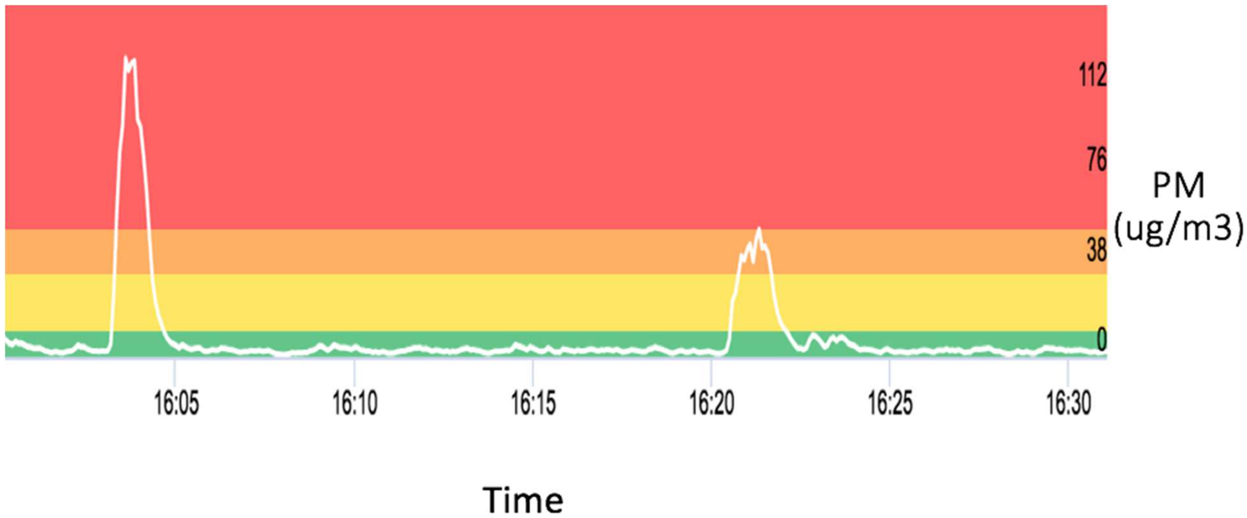


Figure 3.12. Trend at the Church During the Evening Shift on Saturday 0616 (aircasting.org)

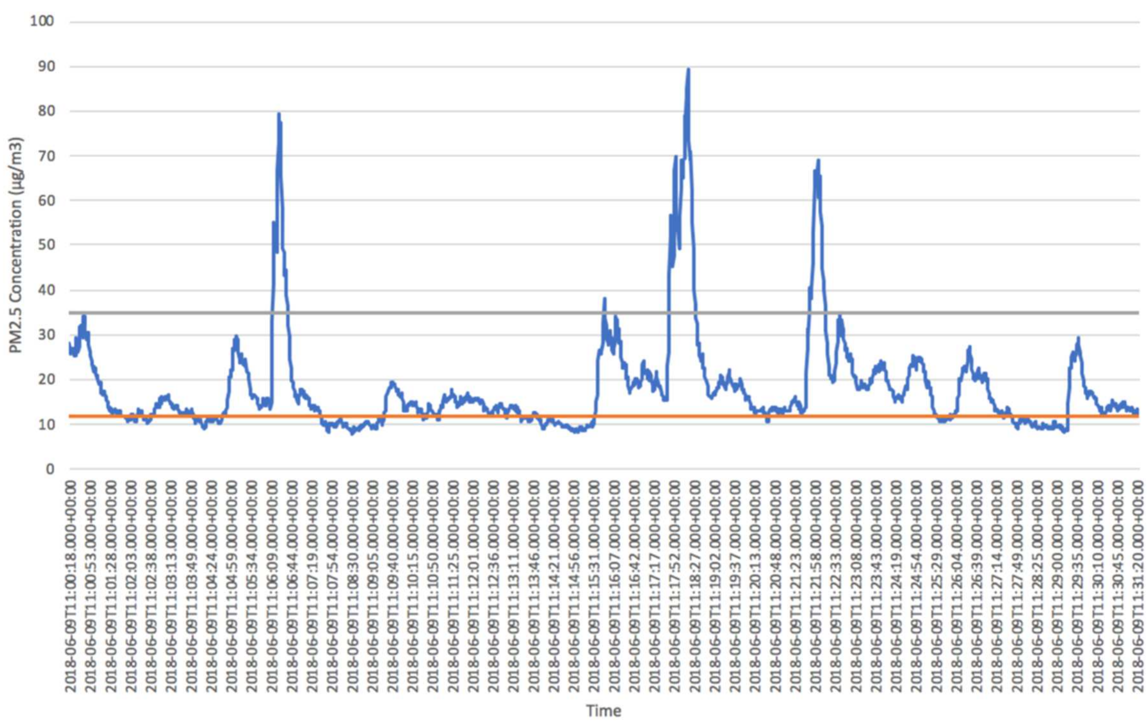


Figure 3.13 Trend Graph for Saturday Afternoon (0609) at the Kingdom Missionary Baptist Church ($PM_{2.5}$ Concentration)

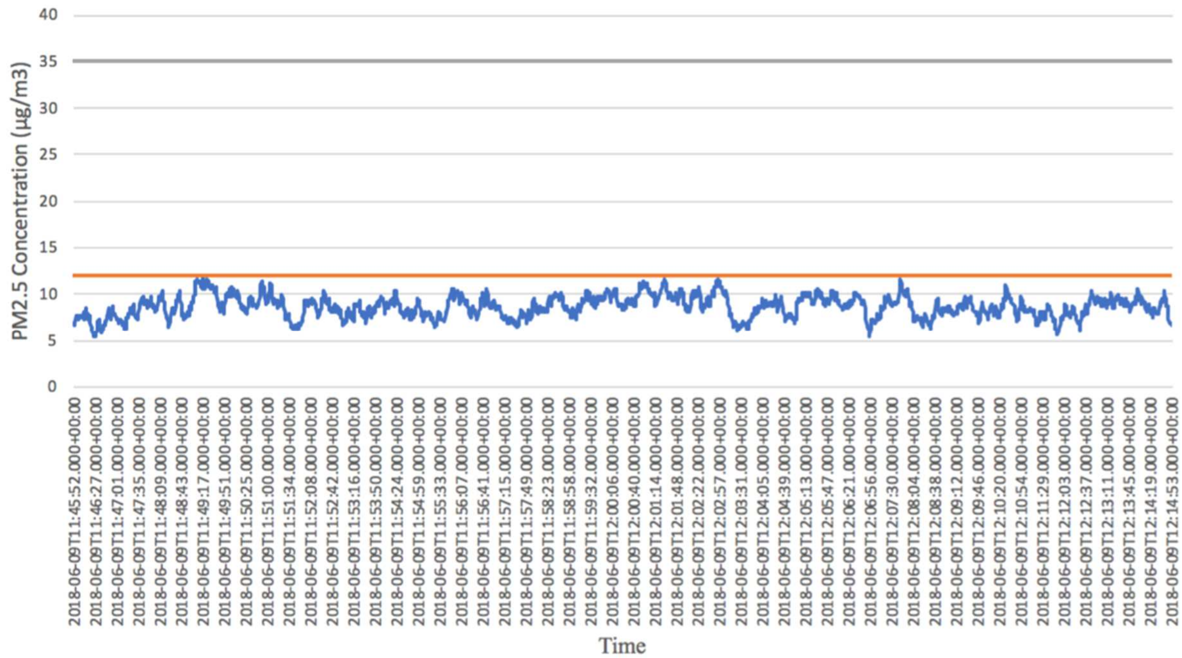


Figure 3.14. Trend Graph for Saturday Afternoon (0609) at the Confluence Area ($PM_{2.5}$ Concentration)

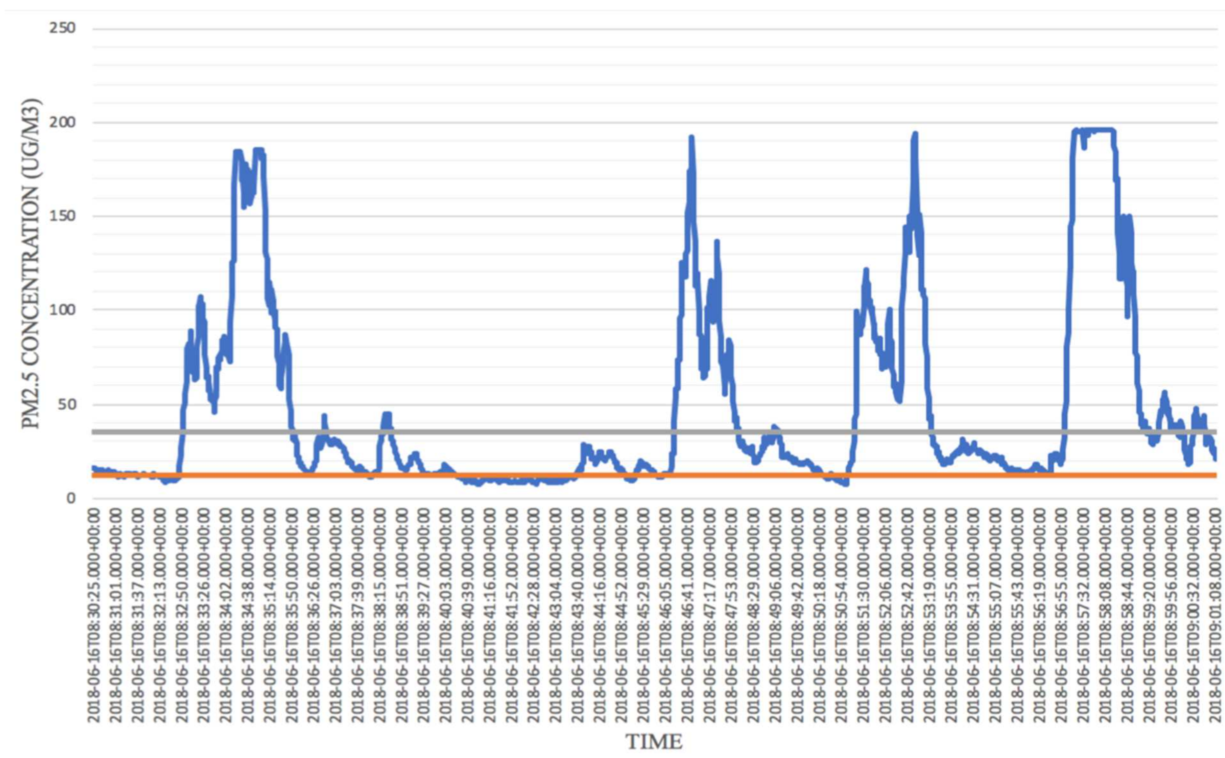


Figure 3.15. Trend Graph for Wednesday Morning (0613) at the Kingdom Missionary Baptist Church ($PM_{2.5}$ Concentration)

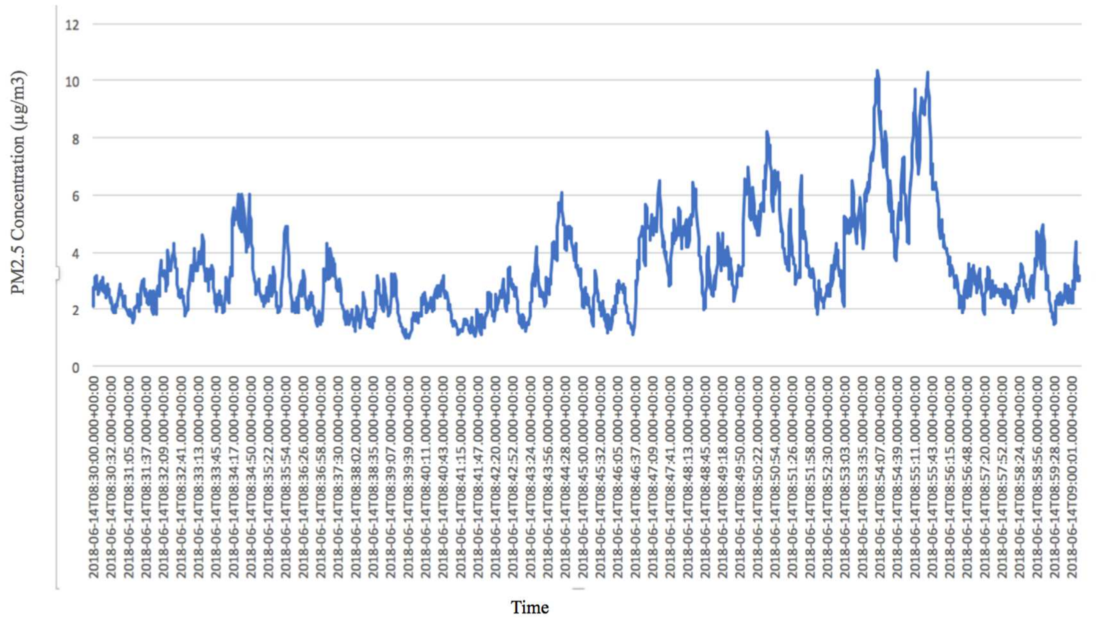


Figure 3.16. Trend Graph for Wednesday Morning (0616) at Waterfront Park ($PM_{2.5}$ Concentration)

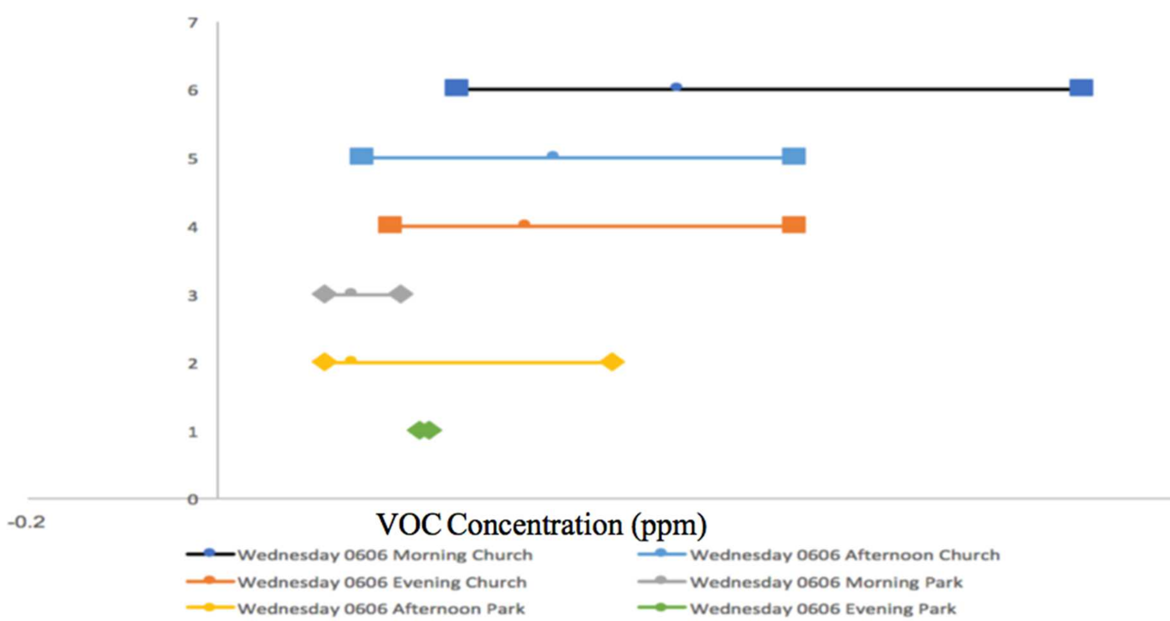


Figure 4.2. Forest Plot for Wednesday Shifts at the Church and Park

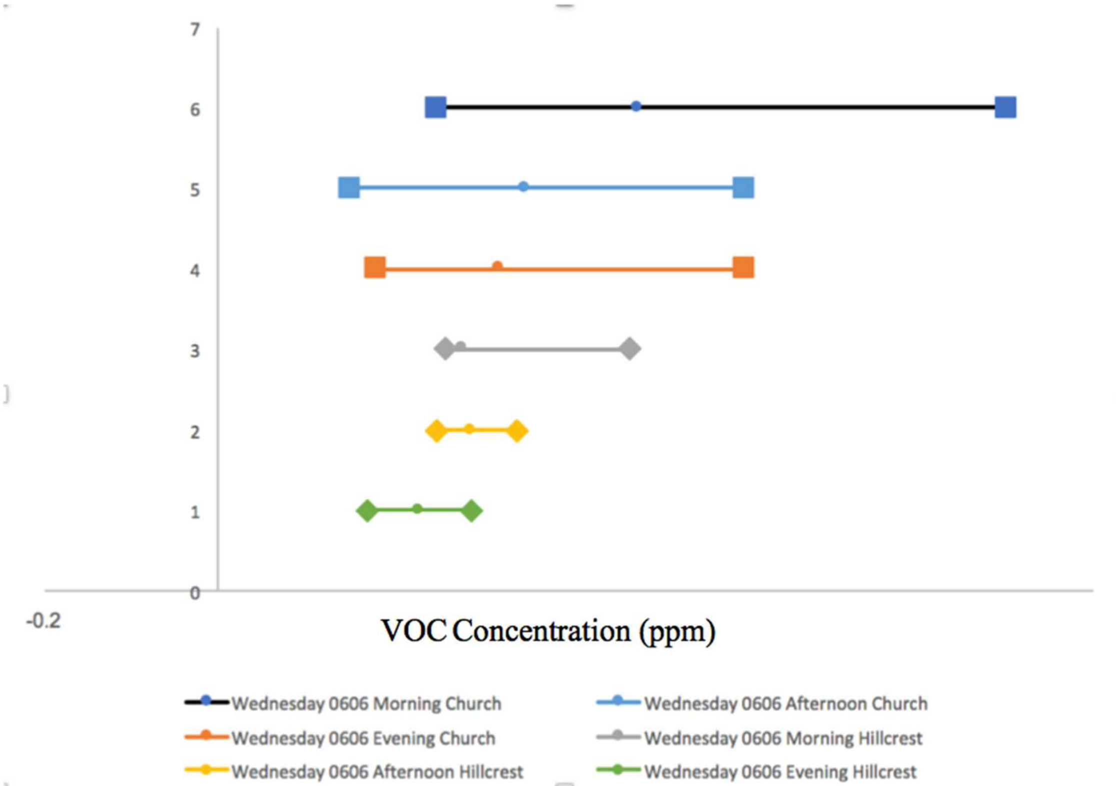


Figure 4.3. Forest Plot for Wednesday Shifts at the Church and Hillcrest Apartments

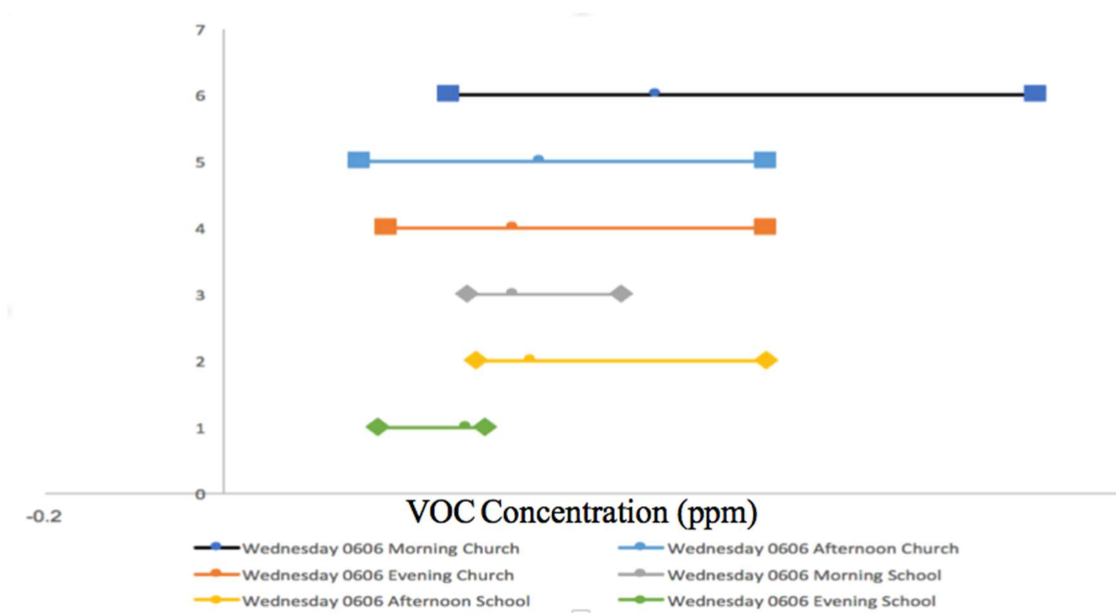


Figure 4.4. Forest Plot for Wednesday Shifts at the Church and Elementary School

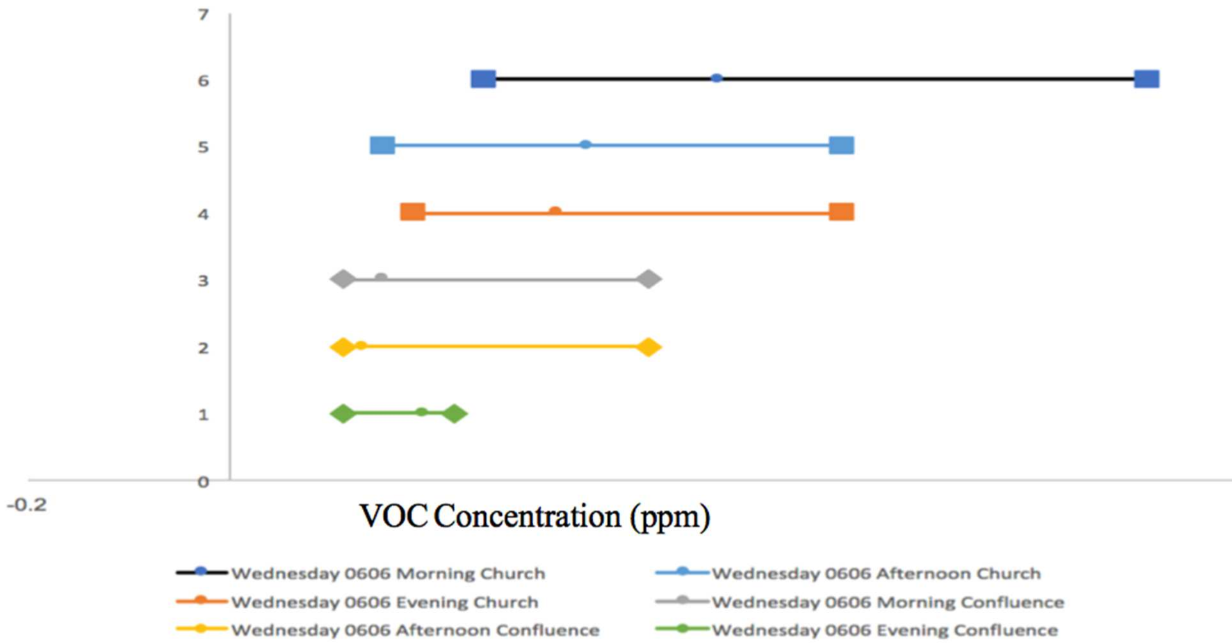


Figure 4.5. Forest Plot for Wednesday Shifts at the Church and Confluence Area

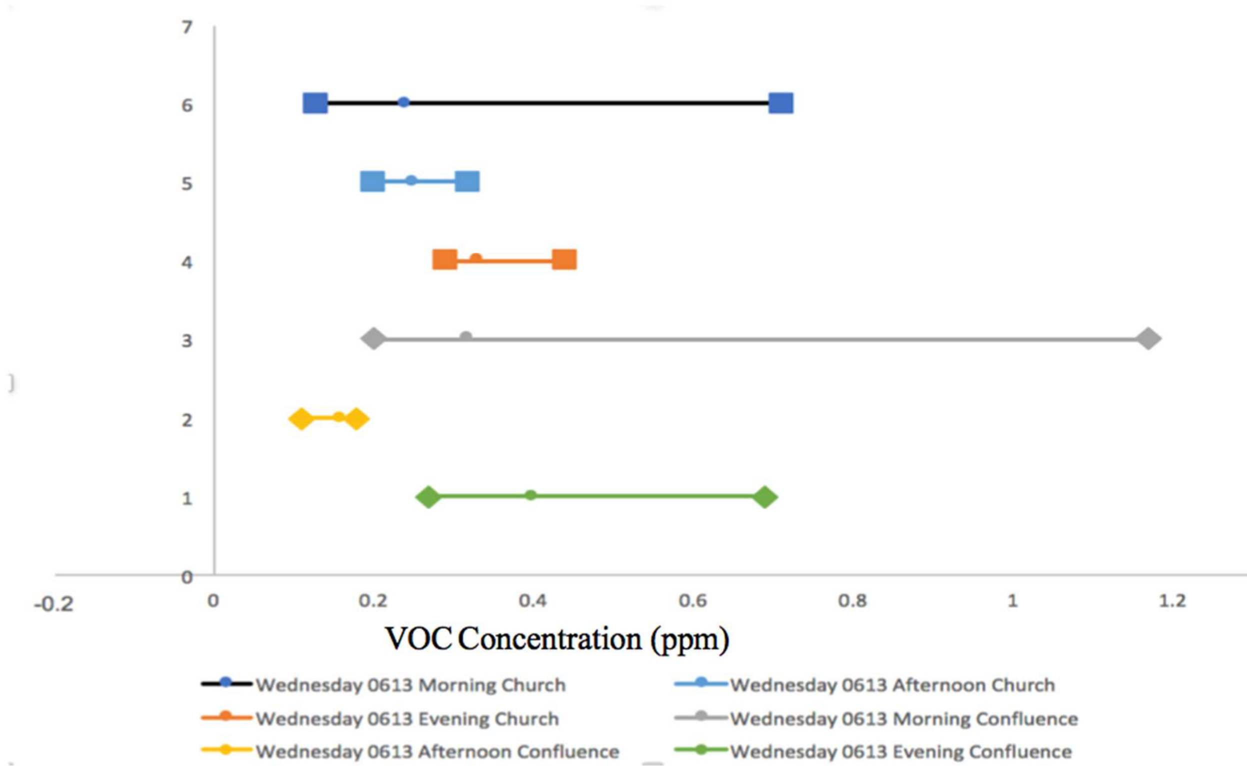


Figure 4.6. Forest Plot for Wednesday Shifts at the Church and Confluence Area

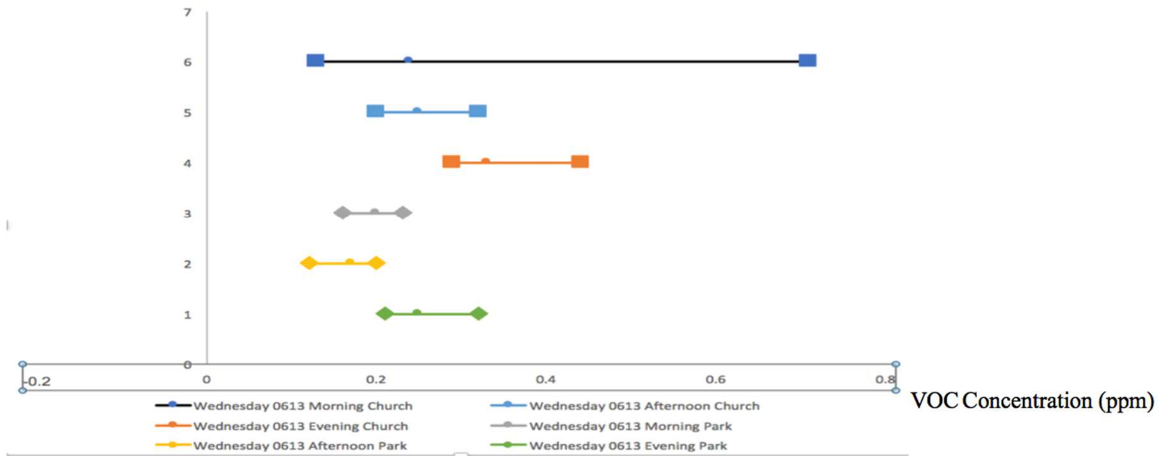


Figure 4.7. Forest Plot for Wednesday Shifts at the Church and Waterfront Park

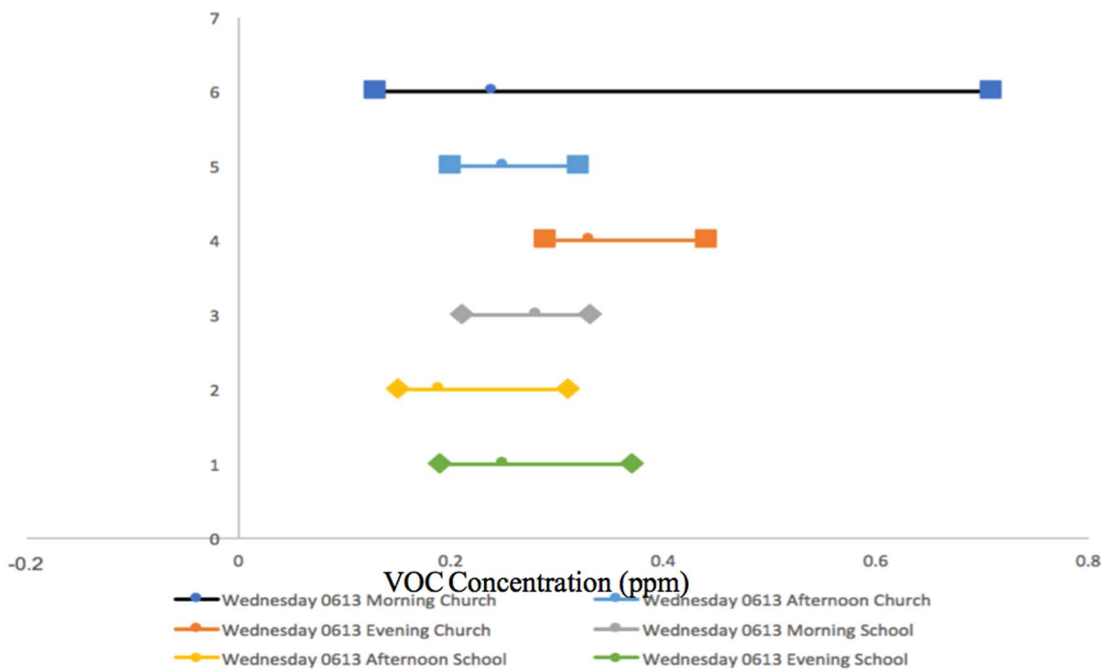


Figure 4.8. Forest Plot for Wednesday Shifts at the Church and Elementary School

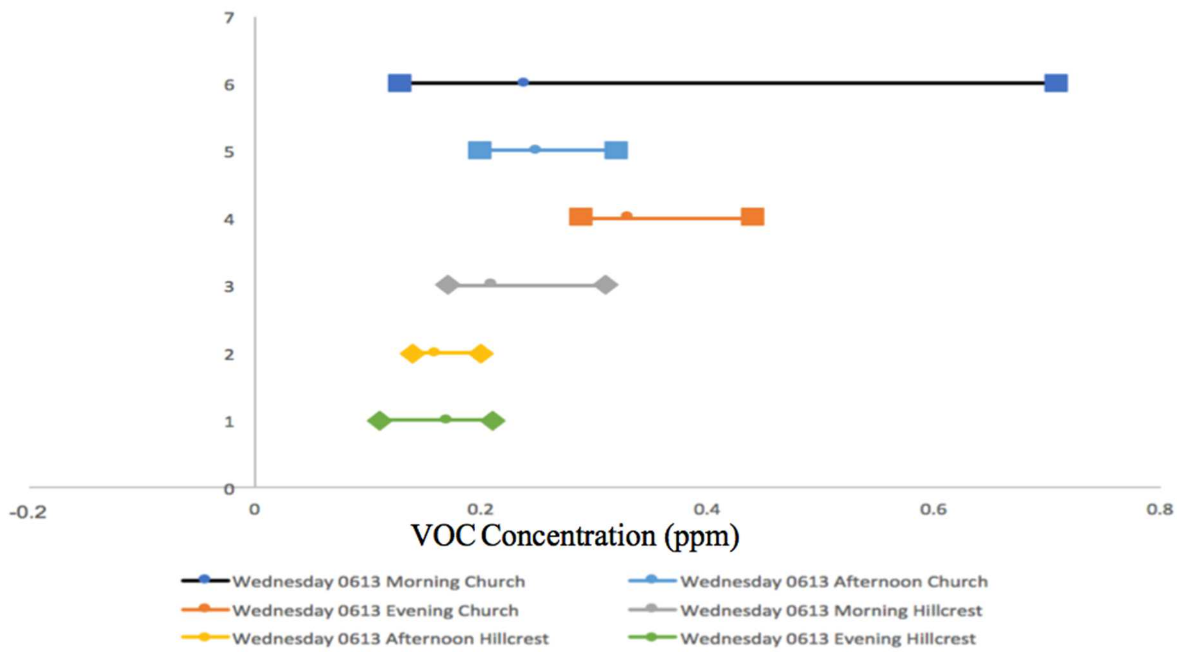


Figure 4.9. Forest Plot for Wednesday Shifts at the Church and Hillcrest Apartments

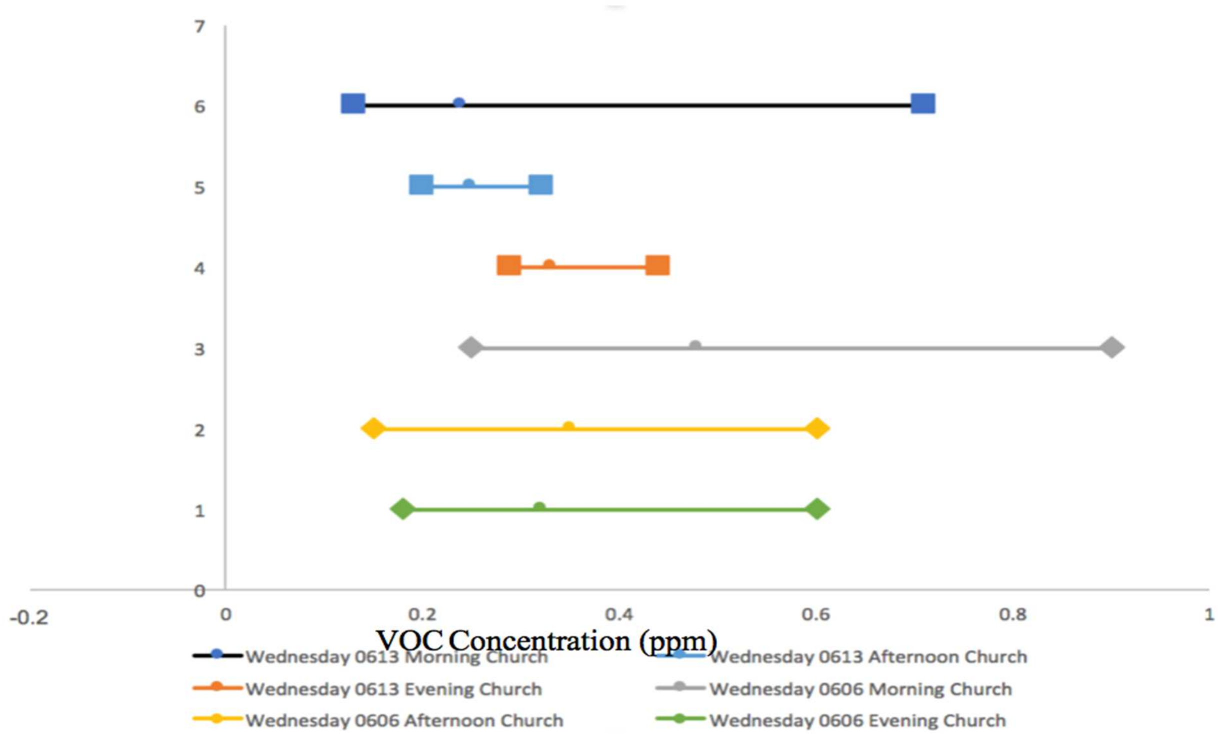


Figure 4.10. Forest Plot for Wednesday Shifts at the Church

Figure 4.11. Forest Plot for Wednesday Shifts at the Park

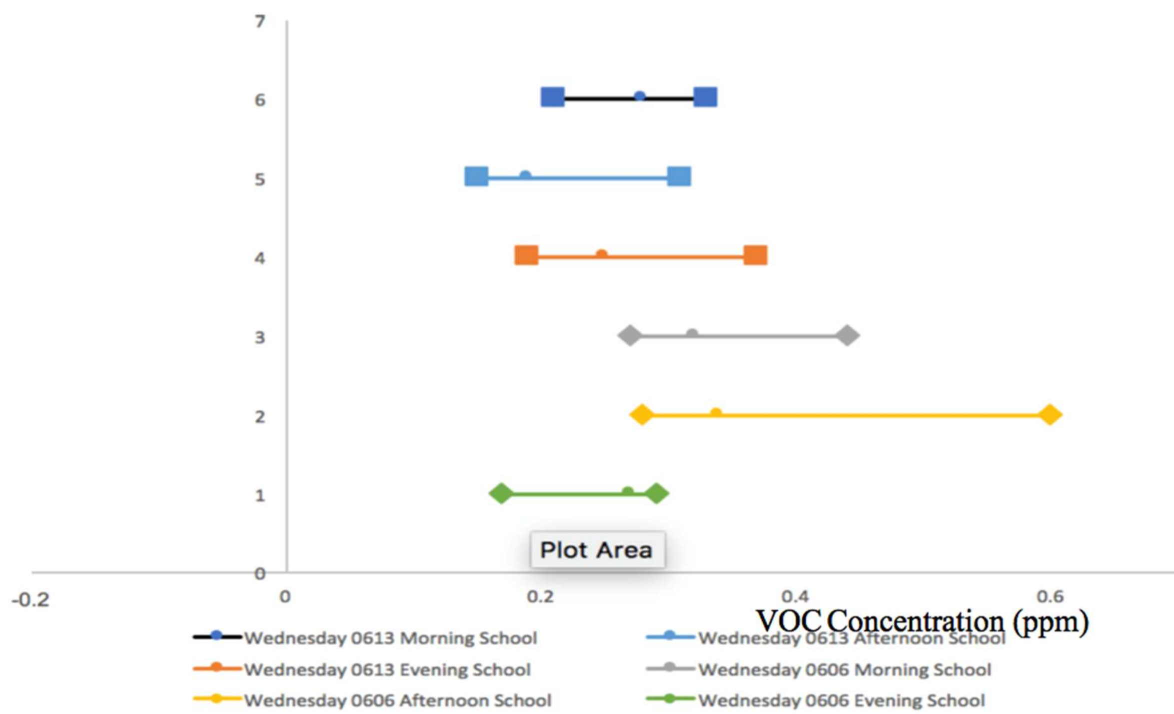


Figure 4.12. Forest Plot for Wednesday Shifts at the Elementary School

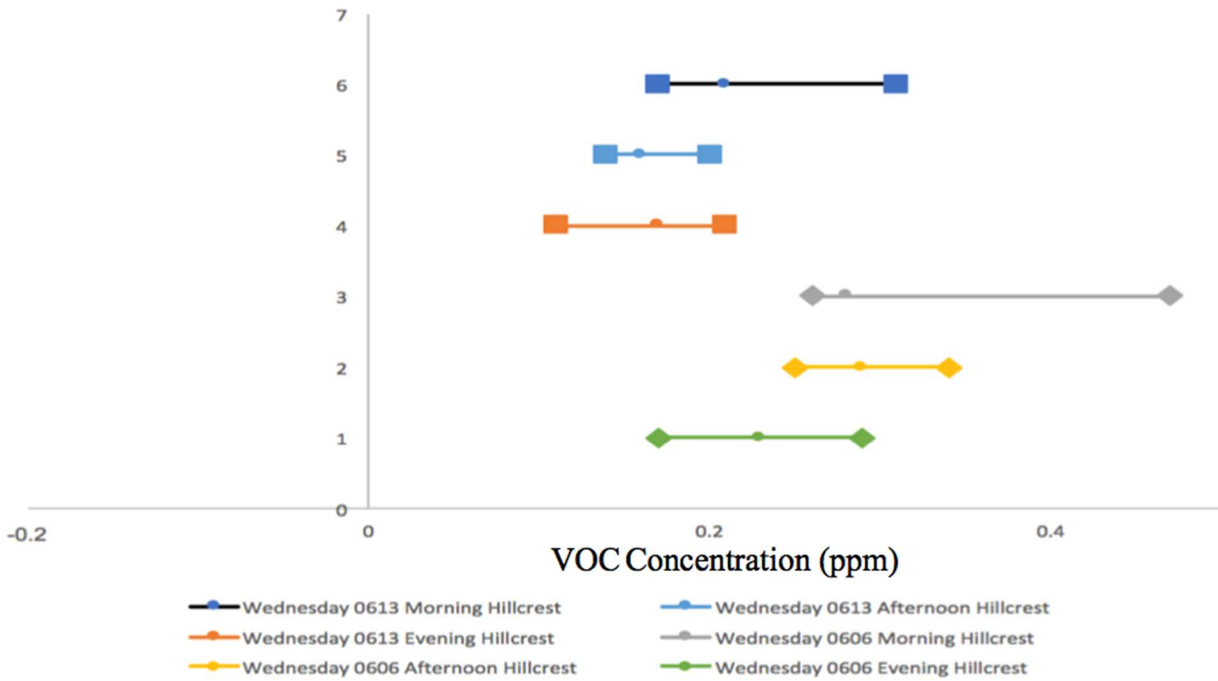


Figure 4.13. Forest Plot for Wednesday Shifts at the Hillcrest Apartments

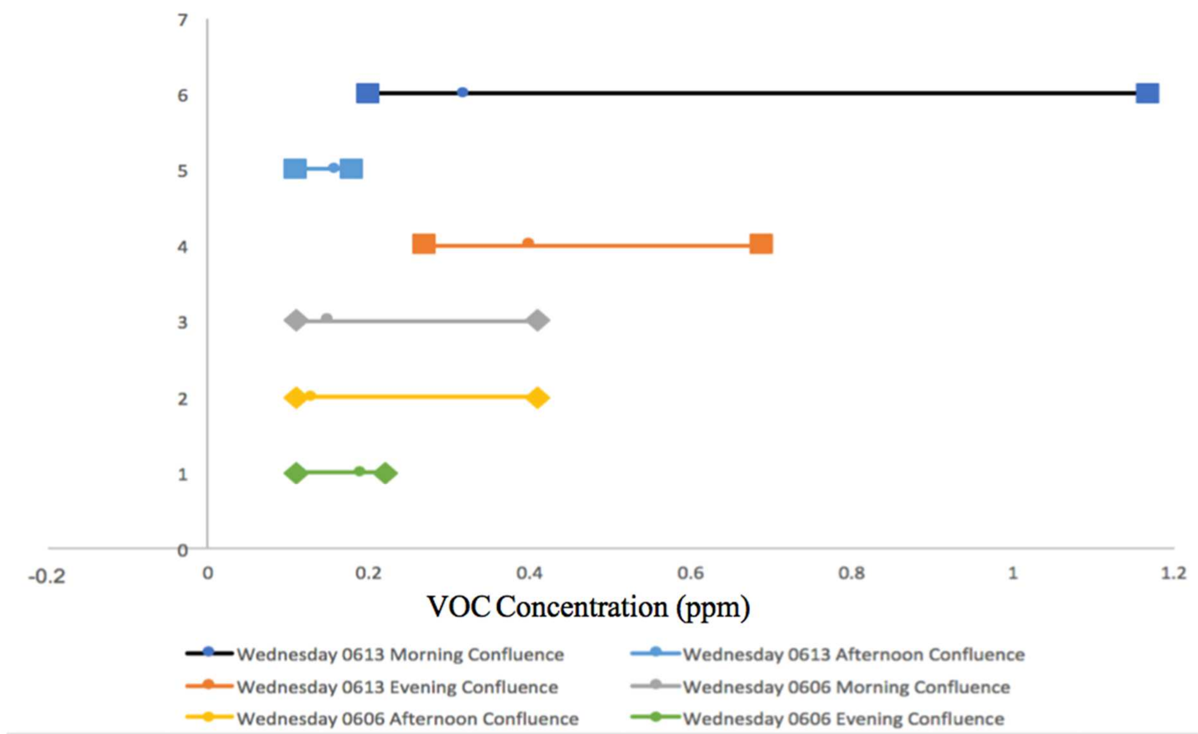


Figure 4.14. Forest Plot for Wednesday Shifts at the Confluence Area

Figure 4.15. Trend Graph for Saturday Afternoon (0609) at Waterfront Park (VOC)

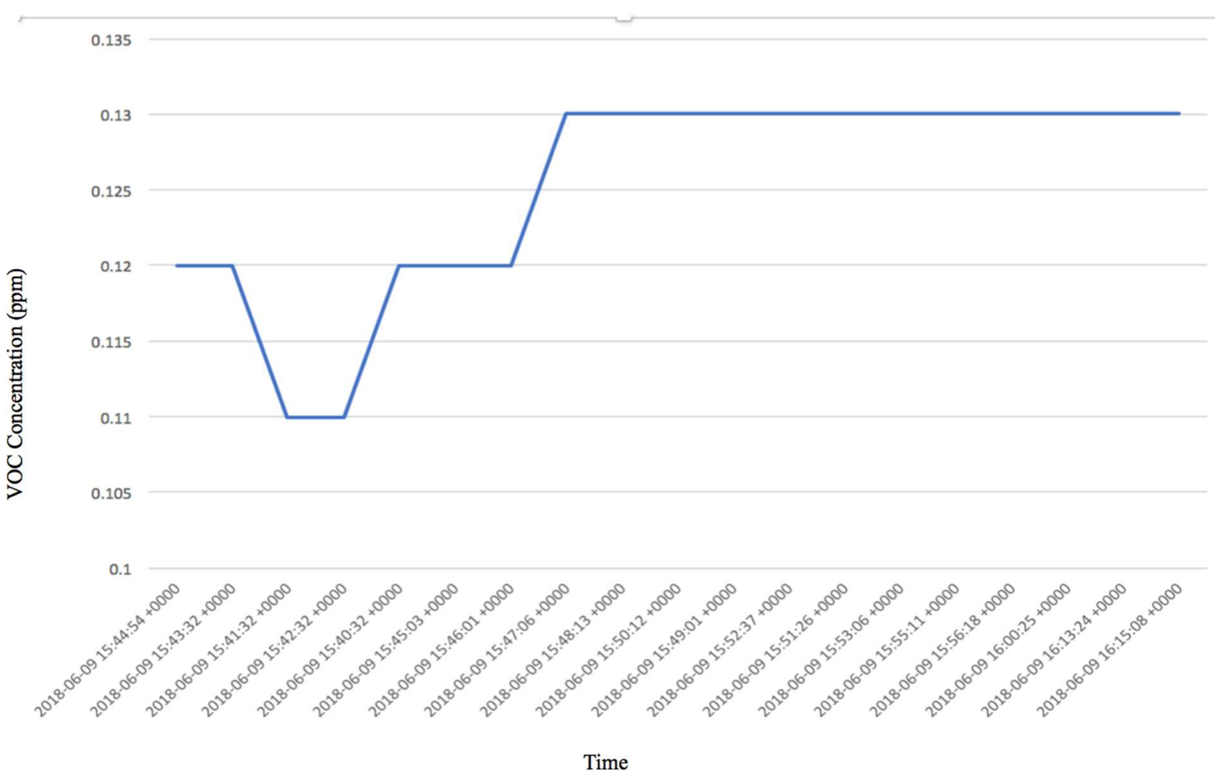


Figure 4.16. Trend Graph for Saturday Afternoon (0609) at Confluence Area (VOC)

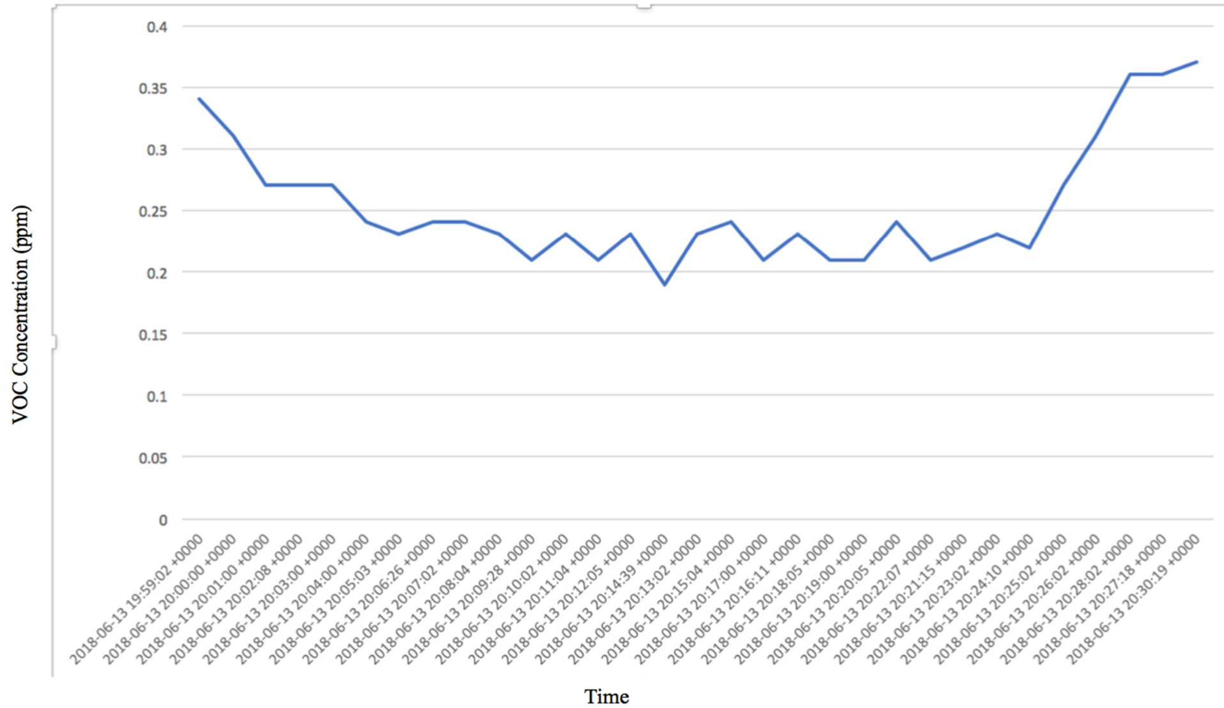


Figure 4.17. Trend Graph for Wednesday Evening (0613) at Bladensburg Elementary School (VOC)

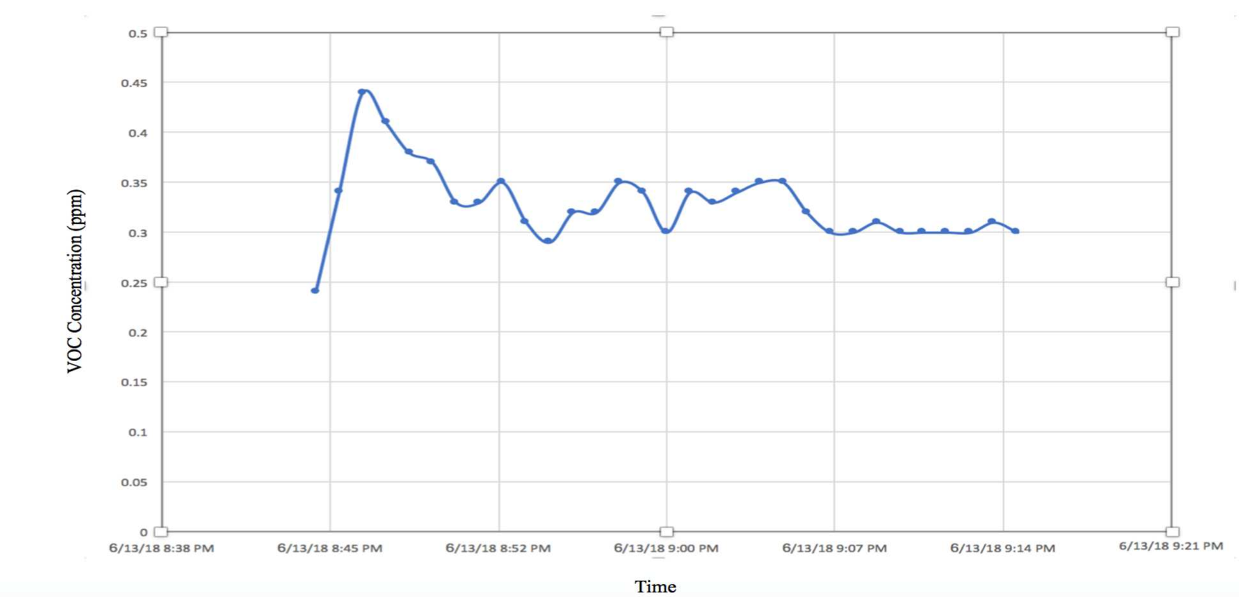


Figure 4.18. Trend Graph for Wednesday Evening (0613) at Kingdom Missionary Baptist Church (VOC)

APPENDIX B

A MONITORING PROTOCOL

FOR

AIR QUALITY ASSESSMENT OF RESIDENTIAL EXPOSURE TO PARTICULATE MATTER AND VOLATILE ORGANIC COMPOUNDS NEAR A CONCRETE BLOCK PLANT AND TRAFFIC IN BLADENSBURG, MARYLAND

By

Rosemary I. Ezeugoh

January, 2018

1. Introduction

1.1 History of Bladensburg

Bladensburg is a town founded 1742 as a regional commercial center in Prince George's County, Maryland, United States. Previously known as Garrison's Landing, it was renamed Bladensburg in recognition of Thomas Bladen (governor of Maryland, 1742-1747). Bladensburg was created by an act of the Maryland General Assembly. The creation of a government tobacco inspection system led to Bladensburg as a tobacco inspection and grading port. It is an important crossroads of routes north to Baltimore and Philadelphia, south and east to Annapolis and Upper Marlboro, and west to the District of Columbia.

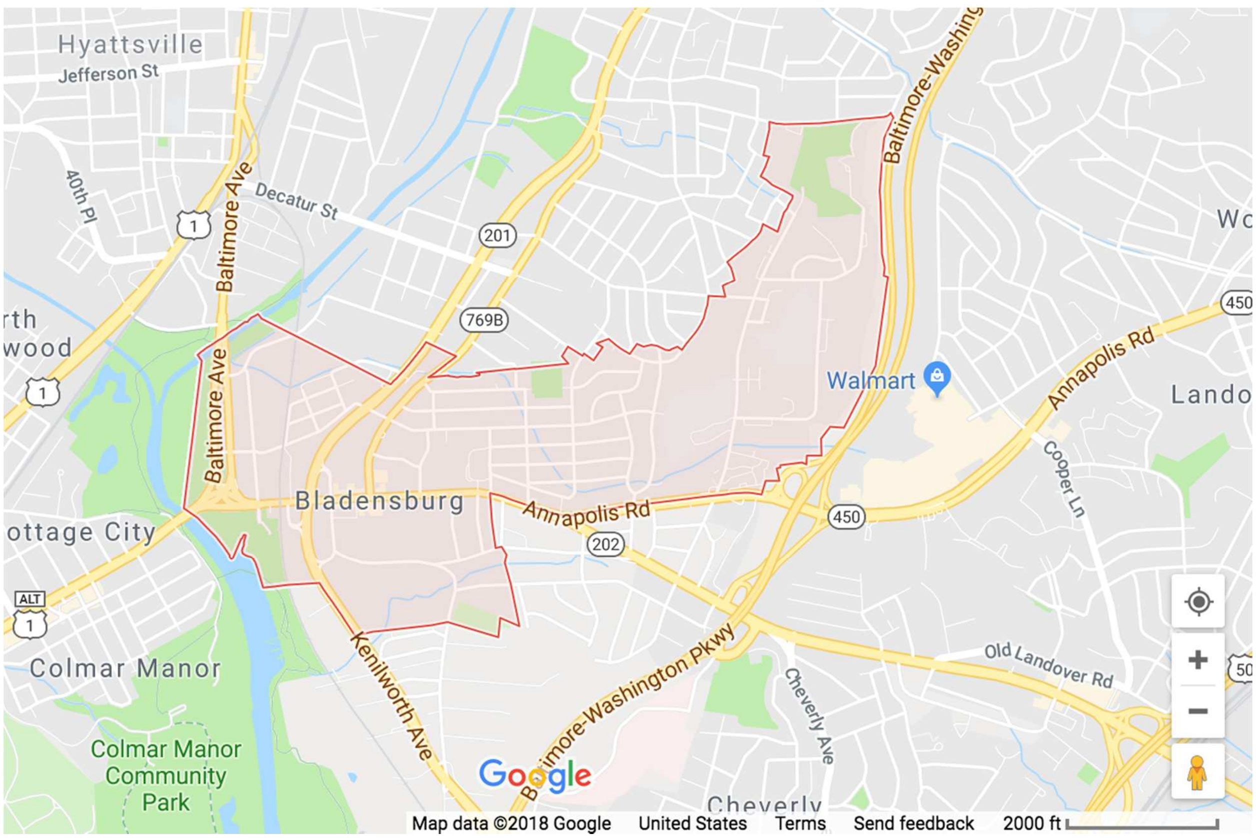


Figure 1. Map of Bladensburg, Maryland (Google maps)

Bladensburg is a town with several historic sites, which are Spa Springs, Bladensburg Dueling Grounds of Dueling Creek, Bostwick, George Washington House, Hilltop Manor, Market Master's House and William Hilleary House or Hilleary Magruder House. It has a total area of 1.01 square miles with 1.00 square miles as land and 0.01 square miles as water. It shares borders with Edmonston on the north, Hyattsville on the northwest, Cottage City and Colmar Manor on the southwest, and Cheverly on the southeast.

Approximately 9,148 people, 3,542 households and 1,960 families in Bladensburg (2010 Census). Also, there are 12.6% White, 65.6% African American, 0.5% Native American, 2.0% Asian, 16.6% from other races and 2.7% from two or more races [239]. However, Hispanic or Latino were 26.9% of the population. These statistics reveal that residents of Bladensburg are predominantly of African Americans and/or Hispanic heritage. Air pollution from the location of the concrete block plant is of utmost importance because the plant is open for six days a week excluding Sunday.

1.2 Description of The Concrete Block Plant

The concrete block plant is on a property, which belongs to Ernest Maier, Inc. and is close to some historic sites in Bladensburg – Peace Cross, Battle of Bladensburg Memorial, Anacostia River and Bladensburg Waterfront Park [227]. The plant is located at 4700 Annapolis Rd, Bladensburg, MD 20710

Figure 2. Ernest Maier Inc., concrete block plant, Bladensburg (Google maps)

2. Mapping Your Data

2.1 Recruitment

Weekly meetings will be held with the residents of Bladensburg in February 2018. Volunteers will be recruited and identified in the meetings and feedback will be gotten from residents on the monitoring locations.

2.2 Training

All volunteers in the study will be trained on the handling of AirBeams and atmotubes and conducting traffic counts at each of the monitoring locations. Training will include use of data sheets and sampling procedures. This will ensure community participation and lead to the community's capacity to conduct scientific research. Volunteers will be given access to the data sheets and schedules during meetings. There will be a practical training session on set up and handling of Airbeams and Atmotubes, as well as, traffic counting. The training will include the importance of starting all monitoring sessions at a uniform time, adhering to the schedule, taking notes about equipment issues and observations about monitoring location (construction) which could affect data collection.

PERSONAL MONITORING

AirBeams and Atmotubes will be deployed site by side throughout the project. Sensors will be worn by volunteers in their breathing zone.

Figure 1. Residents using AirBeams

3. MEASURING PARTICULATE MATTER (PM) WITH AIRBEAMS

3.1 AIRBEAMS

AirBeams are wearable air monitor that maps, graphs, and crowdsources air pollution exposures in real-time via the AirCasting android app. Also, it measures fine particulate matter, $PM_{2.5}$ by utilizing a light scattering method which is registered by a detector and converted into measurements that estimate the number of particle in the air. The measurements are sent through Bluetooth to the app on the android device which creates maps and graphs in real time on the device. At the end of the session, it is sent to the AirCasting website where the data is crowdsourced to generate heat maps indicating where $PM_{2.5}$ concentrations are highest and lowest.

3.2 WHY DO WE MEASURE PM?

PM has been associated with various adverse health outcomes, such as, asthma, respiratory illnesses, lung cancer, cardiovascular diseases, premature mortality, low birth weight, blood pressure and stroke. It is produced via industrial processes (concrete block plant) and road transport (diesel truck and commuter traffic).

3.3 HOW TO USE AIRBEAMS

3.31 CONNECTING THE AIRBEAM TO THE AIRCASTING APP

a. Download the AirCasting app on your android device.

b. Turn on the AirBeam, the LED indicator will start blinking.

c. On your android device, turn on your Bluetooth and press the menu button, then press settings.

d. Press external devices, then select the AirBeam from the list of paired devices. Select yes when prompted to connect. You will be redirected to the sensors dashboard.

e. Measurements from the AirBeam will be displayed on the screen in 5 to 20 seconds and the blinking red light on the AirBeam will become solid red. This means that you are connected.

3.32 AT THE MONITORING LOCATION TO BEGIN AIRCASTING

a. At the monitoring location, turn on the AirBeam and connect it to the AirCasting app via Bluetooth.

b. Your GPS should be turned on so that you can see your location on the map.

c. Wear the Airbeam around your neck placing it in your chest area which is your breathing zone.

d. Verify your location and press the start recording button to commence a new AirCasting session.

e. The Airbeam and the android device should be within 10 feet.

f. Walk around the location and record the observed data on the AirBeam data collection sheet (Appendix A).

g. At the end of the monitoring session, press the stop recording button. Then press save session to save the data using this format: Site number/ shift number/ date/ UMD. Site number and shift number can be found on Appendix D, Table 4.

h. Turn off AirBeams and recharge them for the next shift.

3.33 VIEWING AIRCASTING DATA

The AirCasting app allows you to view your data in three ways:

a. Sensors dashboard which is the default view. You can tap the sensor tiles once to hide/show the peak and average values for your session. Also, you can tap the tiles twice to pause the stream. If you will want to map or graph a sensor stream, long press the tile, then drag it and place it on the map or graph areas at the top of the screen. You can rearrange the sensor tiles by long press, drag and drop method.

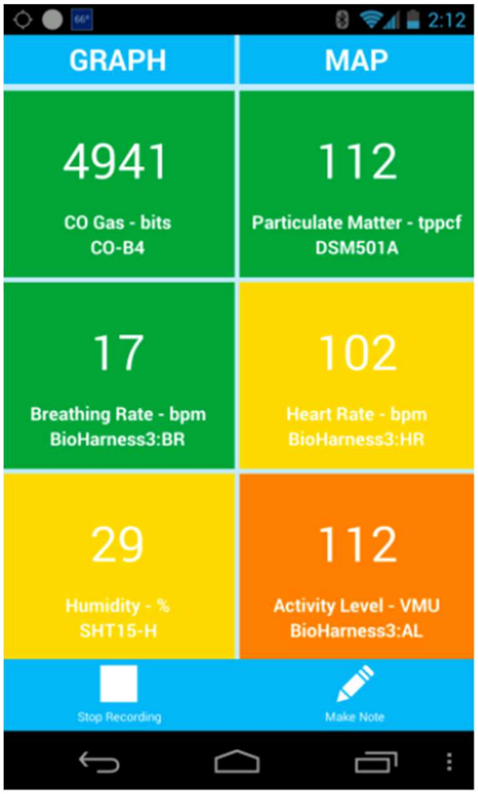


Figure 3. Sensors dashboard for AirCasting app

b. The map displays your current location by a colored dot with a white outline. The color of the dot shows the intensity of a reading, which is explained by the heat legend found at the top of the screen. You can view AirCasting data from all contributors by pressing the CrowdMap button. The color of each square reflects the average intensity of all recordings in that area.

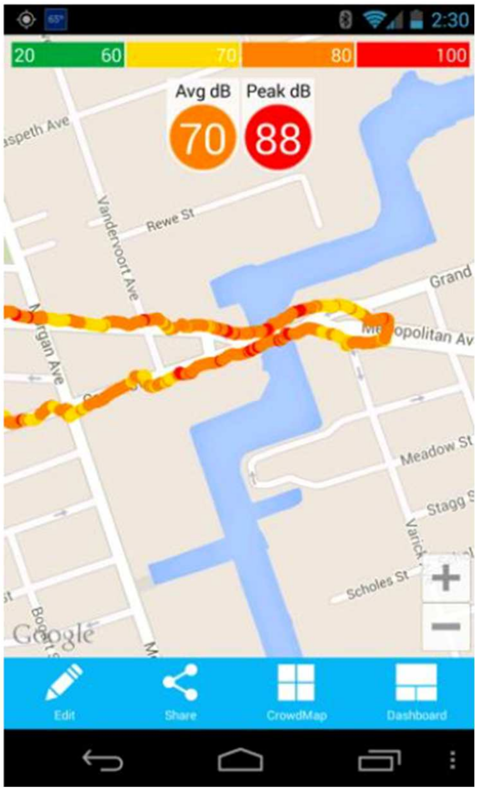


Figure 4. Map display by AirCasting app

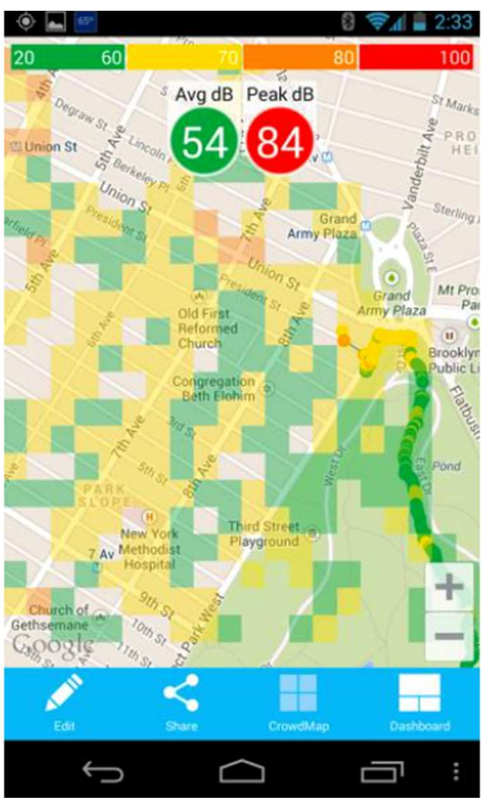


Figure 5. CrowdMap button display for AirCasting app

c. Graph shows your readings over time. You can zoom in and out for details and swipe to pan through the data.

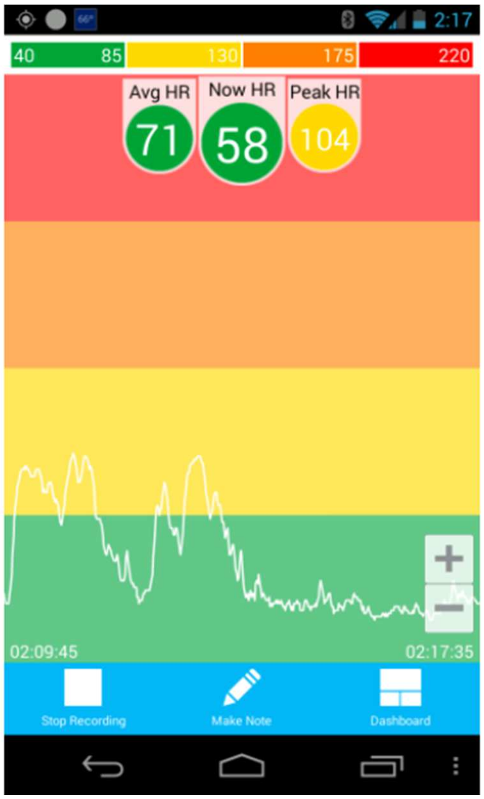


Figure 6. Graph display of AirCasting app

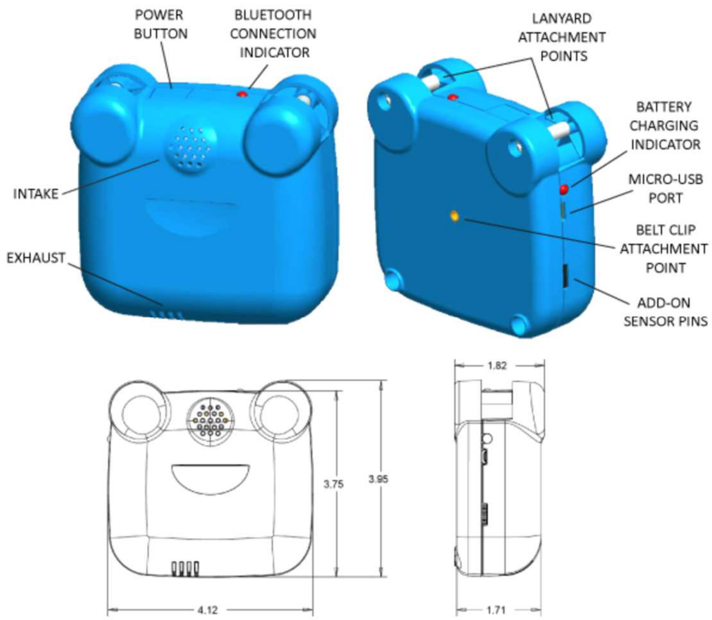


Figure 7. Schematics of AirBeam

4 MEASURING VOLATILE ORGANIC COMPOUNDS (VOCs) WITH ATMOTUBES

4.1 ATMOTUBES

Atmotube is a wearable, portable device which measures the presence of VOCs in the real-time via Air Quality Score android app. Measured data are sent via Bluetooth low energy (LE) protocol to your mobile phone. The device has an LED color which represents the Air Quality Score and alerts you whenever the air is unsafe. Also, measurements are uploaded to a secure cloud and is aggregated on the air quality map.

4.2 WHY DO WE MEASURE VOCs

Exposure to VOCs has been associated with irritation, sensory effects, headache, eye irritation, skin irritation and airway irritation, damage to the liver, kidneys and central nervous system, asthma and respiratory effects. Also, it may lead to lung, blood, liver, kidney and biliary tract cancers, and negative impacts on reproductive systems or birth defect.

4.3 HOW TO USE ATMOTUBES

a. Download the Atmotube app on your android and iOS device.

b. At the monitoring location, turn on the Atmotube and connect it to the Atmotube app via Bluetooth.

c. Wear the Atmotube around your neck placing it in your chest area which is your breathing zone.

d. Walk around the location and record the observed data on the Atmotube data collection sheet (Appendix B, Table 2).

e. At the end of the monitoring session, save the data using this format: Site number/ shift number/ date/ UMD. Site number and shift number can be found on Appendix D, Table 4.

f. Turn off Atmotubes and recharge them for the next shift.

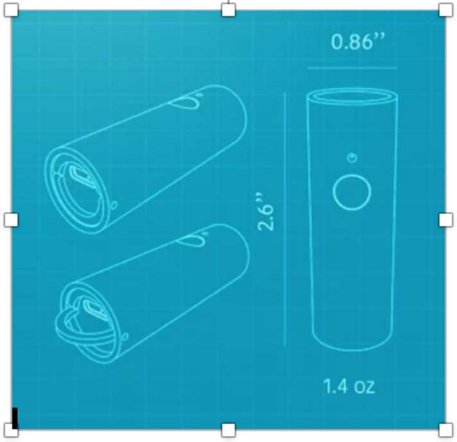


Figure 8. Schematics of Atmotube

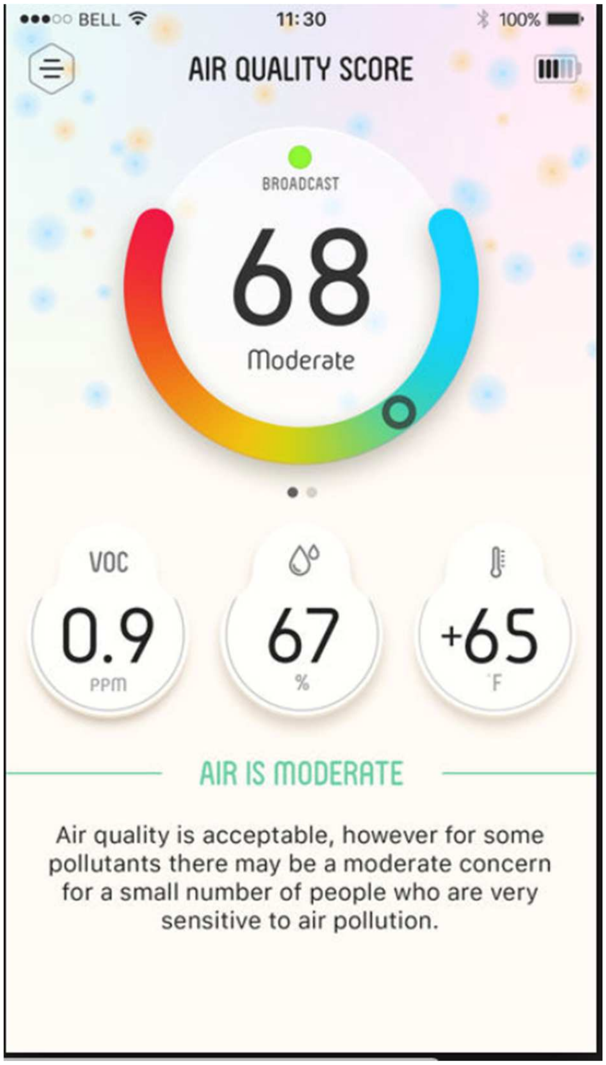


Figure 9. App for Atmotube

5. TAKING PM AND VOC MEASUREMENTS

PM and VOC measurement needs to be done precisely and air monitoring should begin at the same time at all locations to ensure consistency.

a. Arrive at least 10 minutes before sampling time to set up the sensors.

b. A maximum sample time of 30 minutes is recommended.

c. Make notes of your observations of the surroundings such as, nearby parks, buildings, stores and so on.

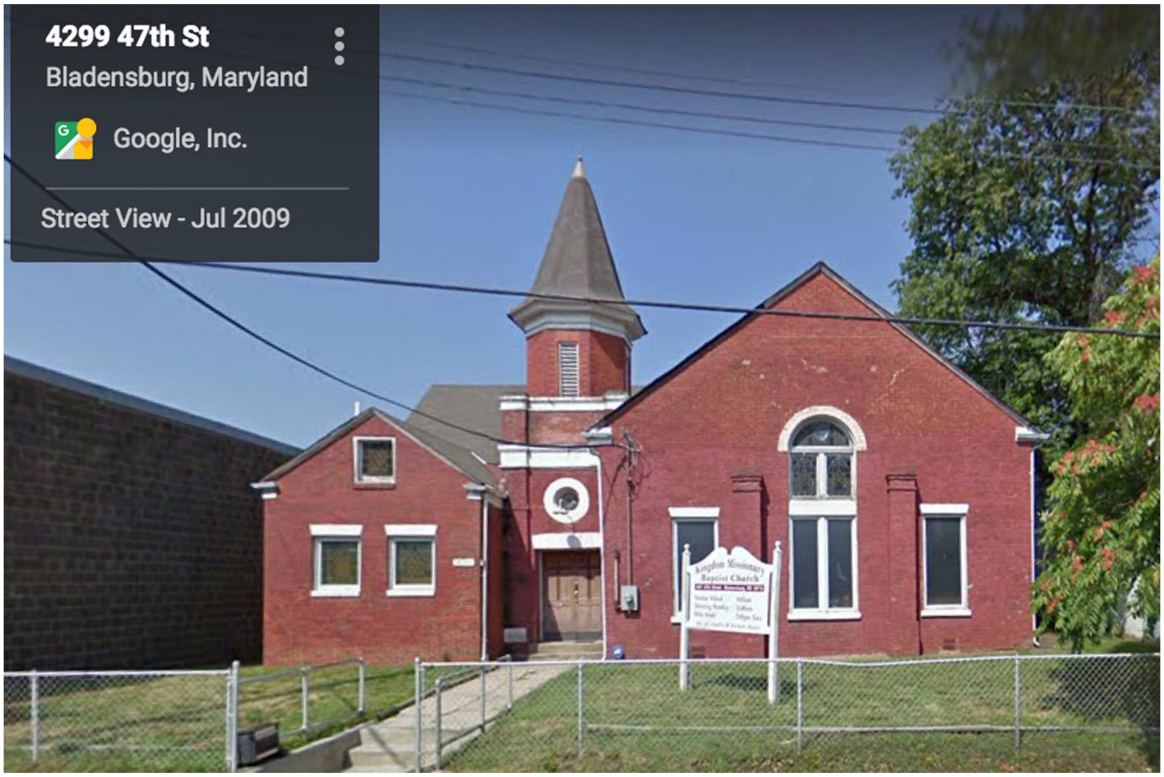


Figure 10. Kingdom Missionary Baptist Church (Google map)

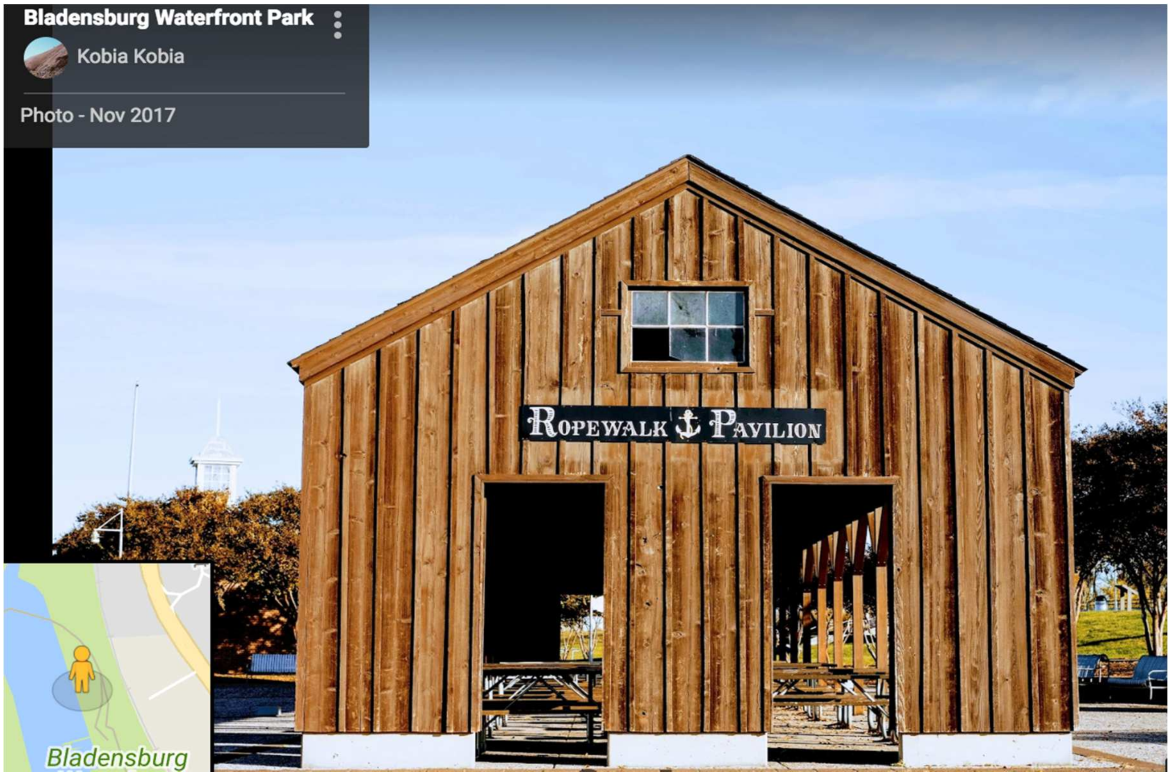


Figure 11. Bladensburg Waterfront Park (Google map)

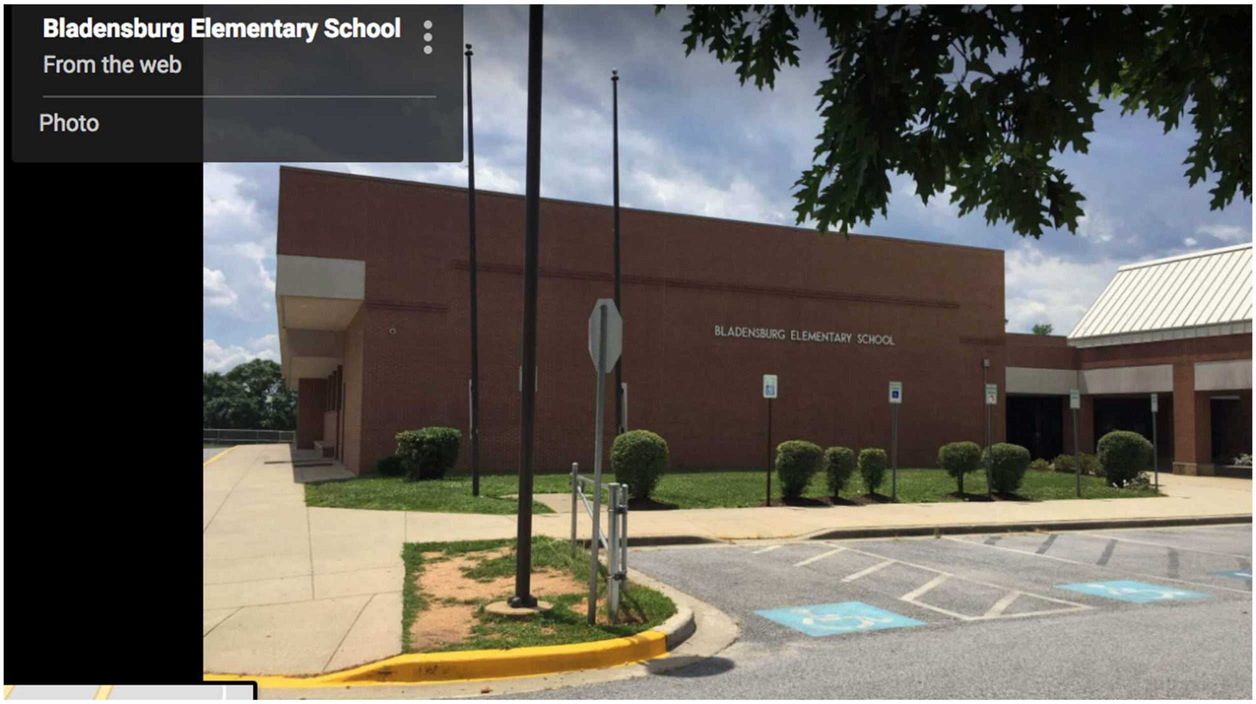


Figure 12. Bladensburg Elementary School (Google map)

Figure 13. Hillcrest Village Apartments (Google Map)

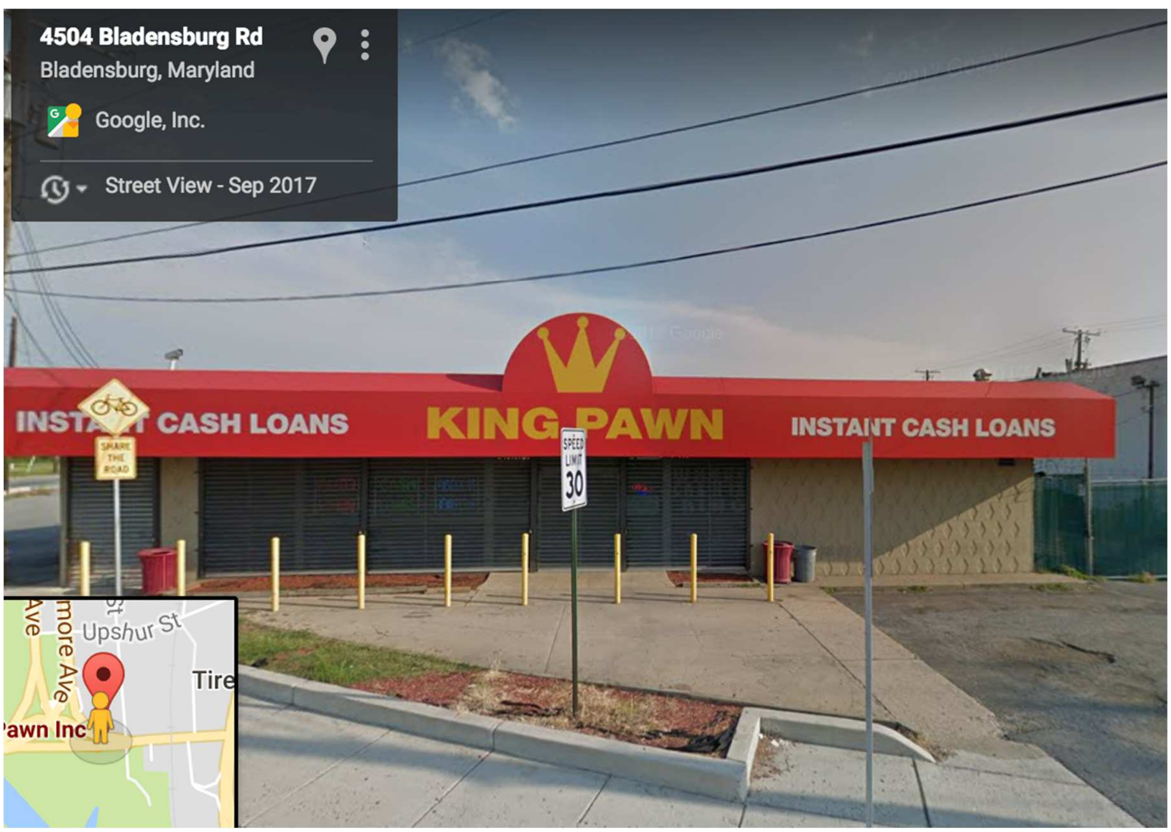


Figure 14. Confluence Area (King Pawn Auto Shop) (Google map)

Figure 15. Residential area at 4213 Edmonston Rd, Bladensburg, MD 20710 (Google map)

6. TRAFFIC COUNT

Traffic count will be done at the monitoring locations while PM and VOC monitoring is going on. This will involve counting the number of motor vehicles, including cars, buses, vans, trucks and so on that drive past during the sampling period. Heavy duty trucks will comprise of trucks larger than pick-up trucks, while vans and sport utility vehicles were counted as cars. Traffic count data sheets (Appendix C, Table 3) will be utilized.

FIXED MONITORING

7. MEASURING PARTICULATE MATTER (PM) WITH PURPLE AIR

7.1 PURPLEAIR

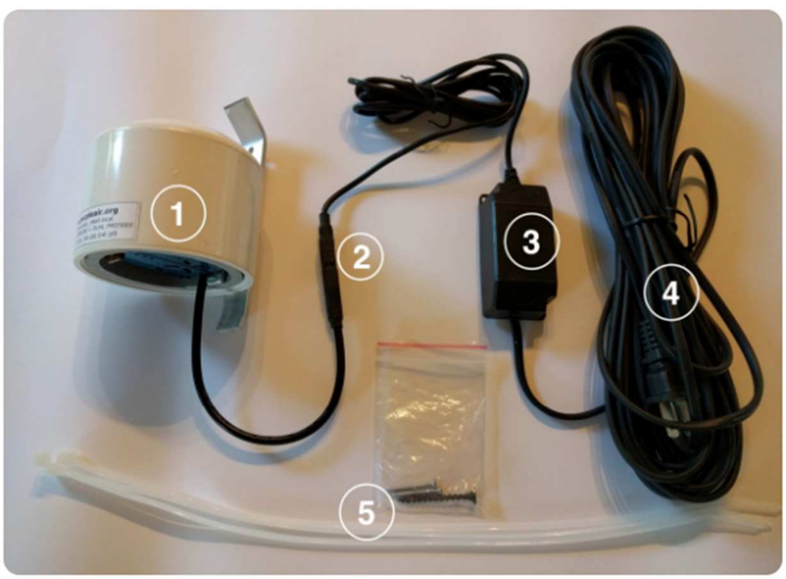
Purple Air sensors are fixed sensors which utilize laser beams to detect PM (PM_1, $PM_{2.5}$ and PM_{10}) particles by their reflectivity and calculate their weights from the counts. The performance of the Purple Air sensors were tested against University of Utah's sensors during an inversion, it was observed that readings from the Purple Air were correlated but slightly lower than the readings from the University of Utah's sensors. The sensors are placed in locations which portray the air we breathe such as neighborhoods, side of houses and a few feet above our heads. The data obtained is saved on the cloud.

7.2 HOW TO USE THE PURPLE AIR

1. Configure and set up PurpleAir on www.purpleair.com and install device at the fixed monitoring locations (APPENDIX E, Table 5).

2. Mount sensors in a shady spot out of direct sun, away from vents and other sources of pollution.

3. Mount power supply and connect to a power outlet. Connect Purple Air to power supply and turn it on. The sensor will monitor for 24 hours every day.

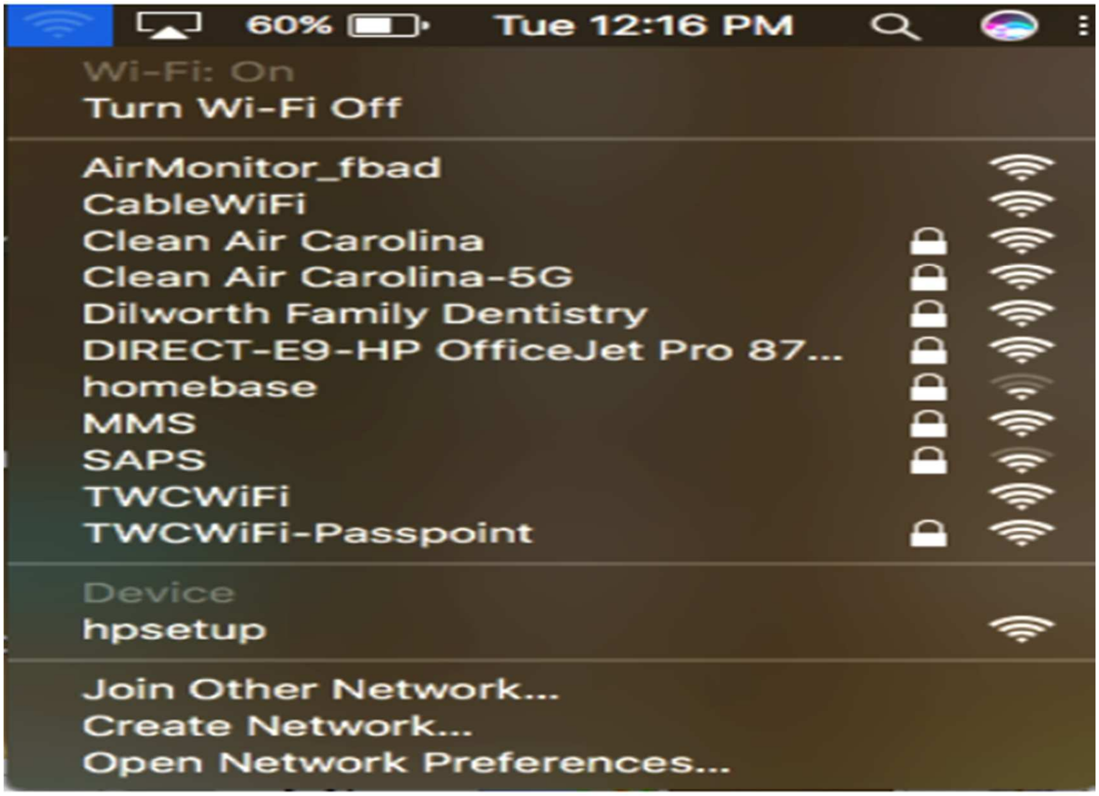


1) PA-II Dual Laser Sensor.
2) Micro USB connector.
3) 5V 2A USB Outdoor Power Supply.
4) 17 foot power cable.
5) Zip Ties for mounting.

Figure 16. Purple Air sensor

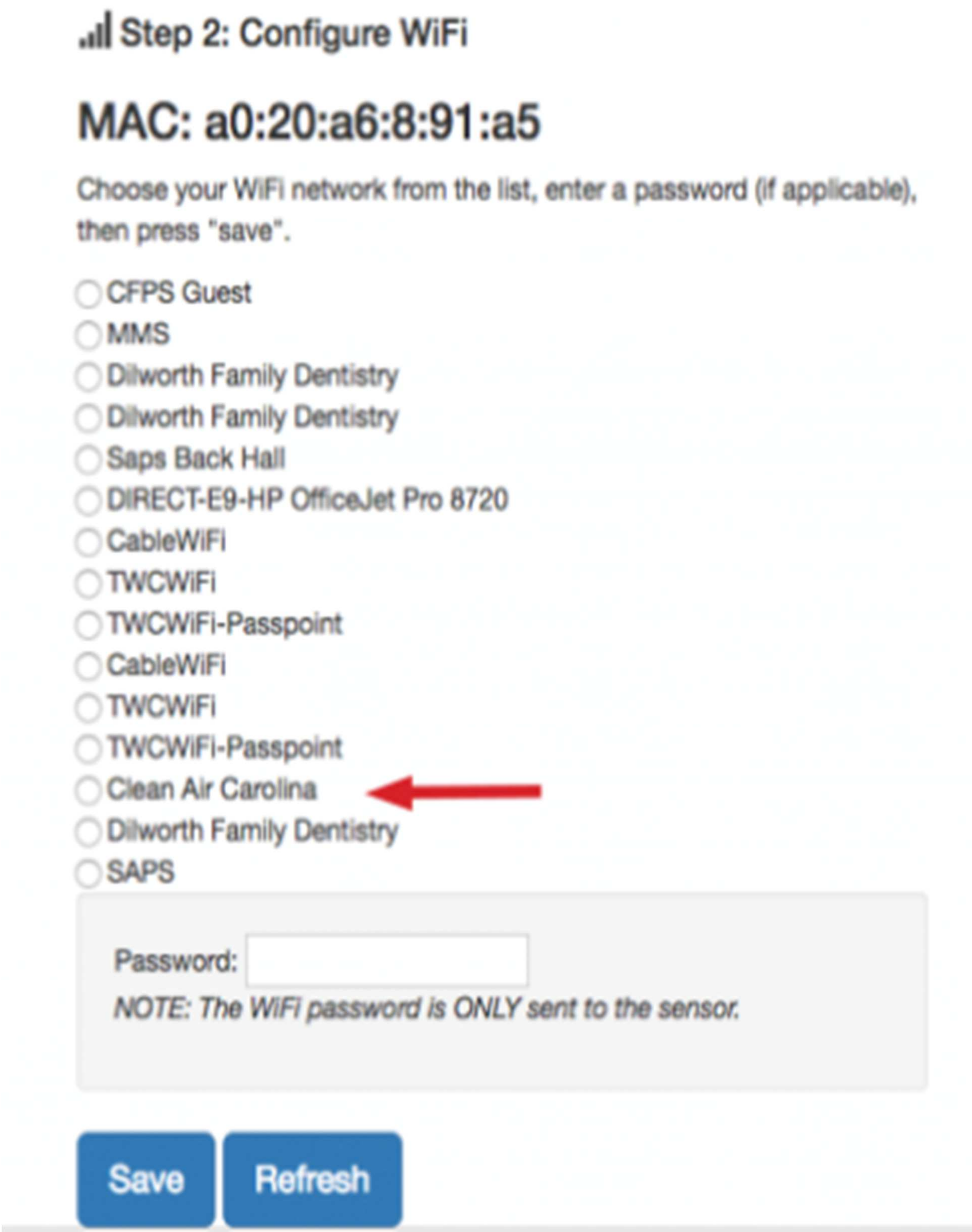
Configure WIFI

1. Connect your phone, tablet, or computer to a Wi-Fi network called “AirMonitor_xxxx”. The “xxxx” is specific to your sensor.

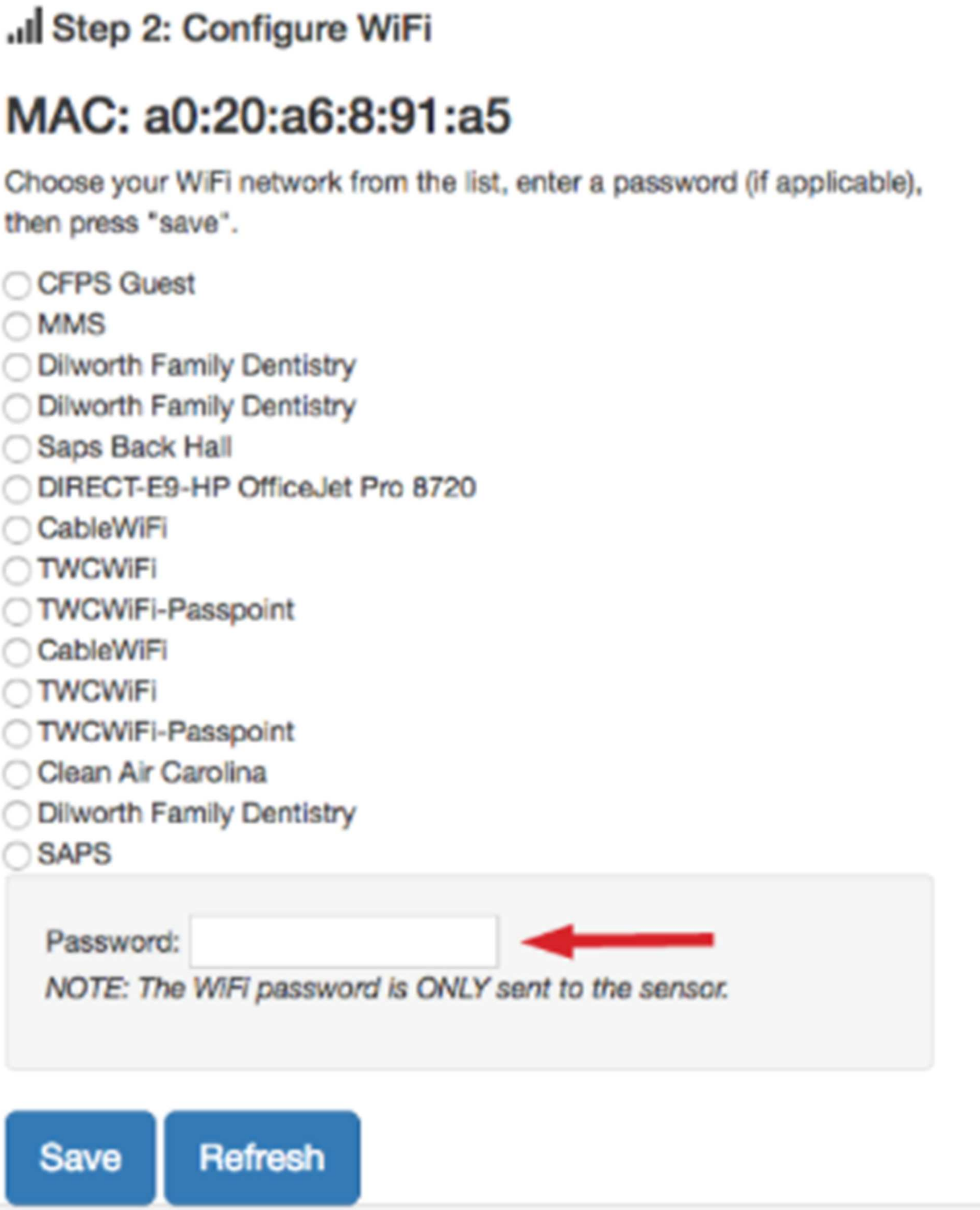


2. Connect to sensor

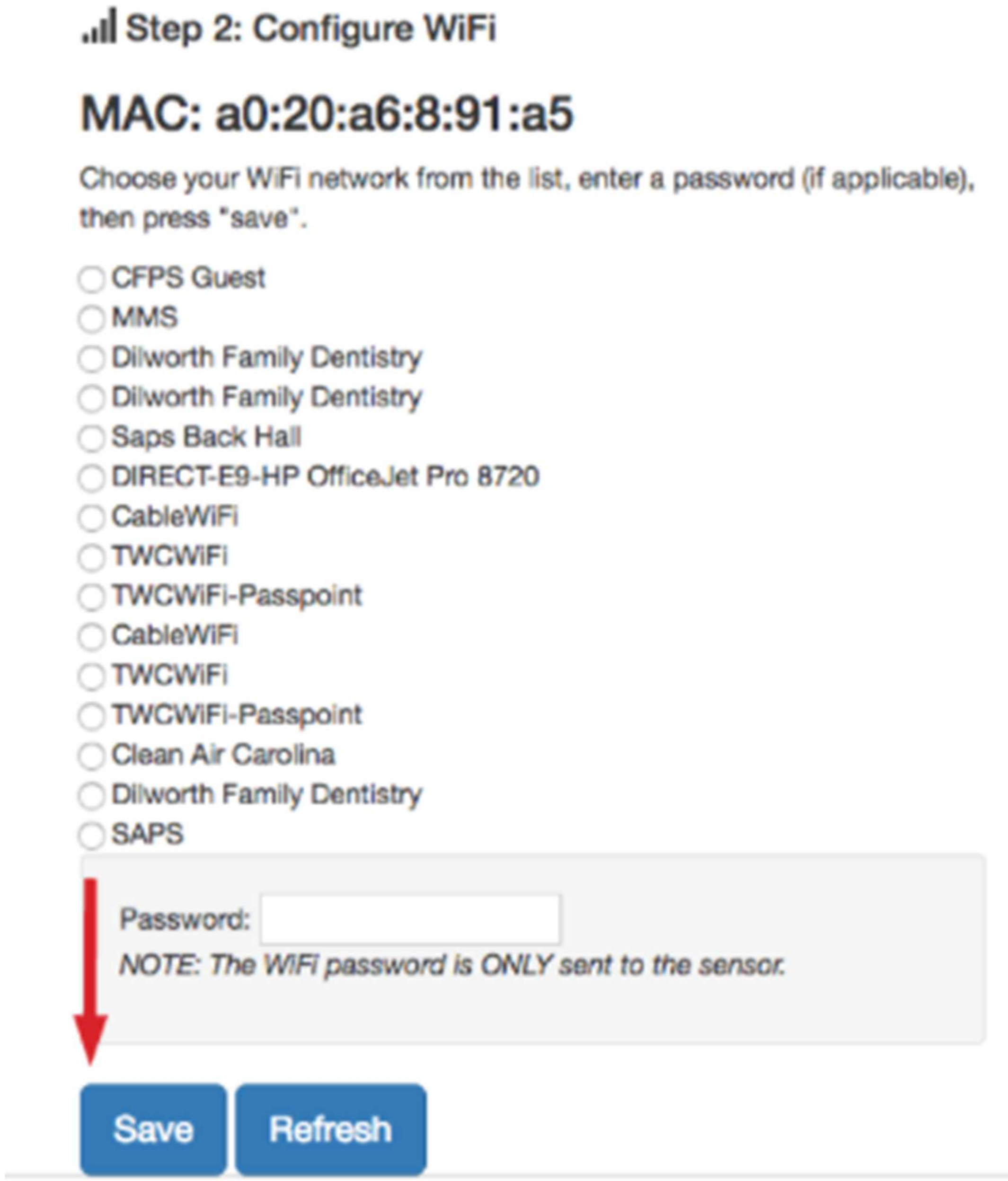
3. Select your home Wi-Fi network



4. Type in your home Wi-Fi password


Step 2: Configure WiFi
MAC: a0:20:a6:8:91:a5
Choose your WiFi network from the list, enter a password (if applicable), then press "save".
CFPS Guest
MMS
Dilworth Family Dentistry
Dilworth Family Dentistry
Saps Back Hall
DIRECT-E9-HP OfficeJet Pro 8720
CableWiFi
TWCWiFi
TWCWiFi-Passpoint
CableWiFi
TWCWiFi
TWCWiFi-Passpoint
Clean Air Carolina
Dilworth Family Dentistry
SAPS
Password:
NOTE: The WiFi password is ONLY sent to the sensor.
Save
Refresh

5. Click save.



6. A confirmation screen will appear on the web page with your sensor's information.

7. Finally connect the Purple Air sensor to the map.

Figure 17. Port Towns Community Development Corporation (Google map)

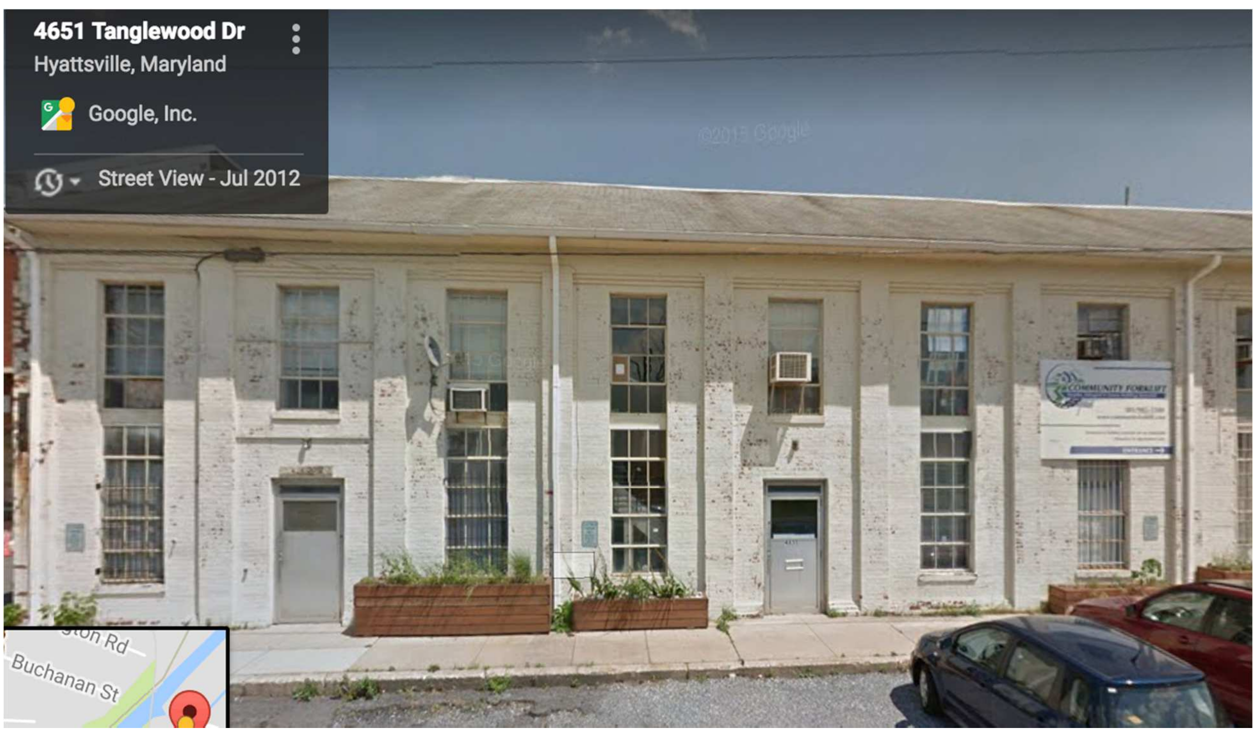


Figure 18. Community Forklift Nonprofit Reuse Warehouse

Figure 19. Bladensburg Public Library (Google map)

8. Air Quality

8.1 Air Quality Index

Air quality describes the amount of pollution present in the air. EPA has developed the Air Quality Index (AQI) that acts as a guide for citizens, in which pollutant concentrations and health concerns have been provided for common pollutants [262]. The sensors will detect pollutant concentrations in $\mu g/m^3$ and represent them in colors explained by the AQI. A detection limit is the lowest concentration of a pollutant in the environment that a sensor or other instrument can routinely detect. The expected range for ambient VOCs concentrations in the United States is 5-100$\mu g/m^3$, while for PM concentrations it is 0-100$\mu g/m^3$ for 24 hours [262]. AQI translates pollution into the potential for adverse effects in individuals and is used to report daily air quality. AQI is calculated from air pollution data which is averaged over 1, 8 or 24 hours based on the pollutant. This is due to the different effects of various pollutants on the human body.

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

Figure 20. The Air Quality Index levels of health concern, numerical values and meanings [262]

8.2 Interpreting the AQI

The time period over which the pollutant is measured is an important factor for interpreting the AQI. For instance, the daily (24 hour) $PM_{2.5}$ standard is 35 ug/m^3. This standard is based on the average of hourly monitoring measurements over a 24-hour period. A single $PM_{2.5}$ measurement taken over a few minutes, or even hours, above 35 ug/m^3 should not be viewed as poor air quality. By using the AQI calculator on the EPA website, you can learn that a 24-hour average measurement of $PM_{2.5}$ of 35 ug/m^3 is “yellow,” or moderate air quality, and a 24-hour average measurement of 50 ug/m^3 is “orange,” or unhealthy for sensitive groups. The concentration entered in the calculator should be an average value over a longer time period, (such as, over 24 hours) not just a single reading taken over the span of a few minutes or hours.

9 Quality Control

9.1 Calibration

Sensors have been calibrated by the manufacturers, however, checks will be conducted on the sensors before each monitoring session to ensure the collection of accurate data. Also, sensors will be examined twice a week to ensure that there are no physical damage on them.

9.2 Data Review

Data obtained from each monitoring session will be valid and acceptable for use, if the sessions took place at during the initial monitoring period and last for 30 minutes as outlined in the monitoring protocol. After each session, each sensor’s data will be downloaded, converted to a Microsoft Excel file and reviewed. Data will be reviewed for consistency across sensors and presence of outliers. Also, after review and utilizing the time stamp across the sensors, the individual files will be combined into a single spreadsheet. This is important because it will aid to identify potential problems or reveal problems with any of the sensors.

APPENDIX C

TABLE 1. AIRBEAM DATA COLLECTION SHEET

Date											
Location											
Airbeam #											
Shift …A	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
PM											
Humidity											
Temp											
Noise											
Shift …B	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
PM											
Humidity											
Temp											
Noise											
Shift …C	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
PM											
Humidity											
Temp											
Noise											
Shift …A	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
PM											
Humidity											
Temp											
Noise											

Notes: ADD DESCRIPTION OF THE SITES AND OBSERVATIONS ABOUT SITE DURING MONITORING DURING SPECIFIC SHIFT

APPENDIX D

TABLE 2. Atmotube data collection sheet

Date											
Location											
Atmotube #											
Shift …A	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
VOC											
Humidity											
Temp											
CO											
Shift …B	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
VOC											
Humidity											
Temp											
CO											
Shift …C	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
VOC											
Humidity											
Temp											
CO											
Shift …A	Start time..				End time						
	Time 0	1min	5min	10min	15min	20min	25min	30min	Min	Max	Mean
VOC											
Humidity											
Temp											
CO											

1. Notes: ADD DESCRIPTION OF THE SITES AND OBSERVATIONS ABOUT SITE DURING MONITORING DURING SPECIFIC SHIFT

APPENDIX E

TABLE 3 TRAFFIC COUNT DATA SHEET

Date			
Location			
Volunteer		Address	Phone number
Shift			
Direction			
5 minute Increment		Count (Use hatch marks to record vehicles)	
Start	End	Cars	Trucks

APPENDIX F

TABLE 4 SCHEDULE OF SITE NUMBER AND SHIFT NUMBER FOR PERSONAL MONITORING

Site	Site Description	Shift	Time	Traffic
Site 1	Kingdom Missionary Baptist Church	Shift 1a	0700 - 0900	Heavy traffic
	4107 47th Street Bladensburg MD 20710	Shift 1b	1100 - 1300	
		Shift 1c	1600 - 1800	
Site 2	Bladensburg Waterfront Park	Shift 2a	0700 - 0900	Light traffic
	4601 Annapolis Road, Bladensburg MD 20710	Shift 2b	1100 - 1300	
		Shift 2c	1600 - 1800	
Site 3	Elementary school	Shift 3a	0700 - 0900	Heavy traffic
	4915 Annapolis road, Bladensburg MD 20710	Shift 3b	1100 - 1300	
		Shift 3c	1600 - 1800	
Site 4	Hillcrest Village Apartments	Shift 4a	0700 - 0900	Light traffic
	4101 53rd Avenue, Bladensburg MD 20710	Shift 4b	1100 - 1300	
		Shift 4c	1600 - 1800	
Site 5	Confluence area	Shift 5a	0700 - 0900	Heavy traffic
	4504 Annapolis Rd, Bladensburg, MD 20710 (King Pawn Auto Shop)	Shift 5b	1100 - 1300	
		Shift 5c	1600 - 1800	
Site 6	Residential area	Shift 6a	0700 - 0900	Light traffic
	4213 Edmonston Rd, Bladensburg, MD 20710	Shift 6b	1100 - 1300	
		Shift 6c	1600 - 1800	

APPENDIX G

TABLE 5. SITE NUMBERS FOR FIXED LOCATIONS

Site	Site Description
Site 1	Kingdom Missionary Baptist Church
	4107 47th Street Bladensburg MD 20710
Site 2	Hillcrest Village Apartments
	4101 53rd Avenue, Bladensburg MD 20710
Site 3	Port Towns Community Development Corporation,
	4930-A Annapolis Rd, Bladensburg, MD 20710
Site 4	Community Forklift Nonprofit Reuse Warehouse,
	4671 Tanglewood Dr, Hyattsville, MD 20781
Site 5	Bladensburg Elementary school
	4915 Annapolis road, Bladensburg MD 20710
Site 6	Bladensburg Branch Library, PGCMLS
	at 4820 Annapolis Rd, Bladensburg, MD

APPENDIX H
DESCRIPTIVE STATISTICS FOR PM CONCENTRATIONS

Location	Day	Shift	Mean	Median	Mode	Std Deviation	Variance	Range	IQR	Minimum	Maximum
Church	Wednesday 0606	Morning	28.87	22.22	7.5	22.55	508.5	123.05	28.1	2.77	125.82
		Afternoon	27.93	19.81	14.95	23.22	539.53	162.45	21.16	4.28	166.73
		Evening	30	19.42	22.33	31.07	965.76	184.46	21.33	3.98	188.44
Waterfront Park		Morning	3.71	3.69	3.05	0.86	0.75	5.22	1.3	1.82	7.04
		Afternoon	4.51	4.35	3.91	1.02	1.03	6.57	1.35	2	8.57
		Evening	5.86	5.03	3.4	3.07	9.44	16.57	3.87	1.82	18.39
Elementary School		Morning	3.84	3.47	3.54	1.71	2.91	11.94	1.22	1.48	13.42
		Afternoon	4.06	4.06	4.2	0.81	0.65	5.04	1.11	2	7.04
		Evening	3.4	3.19	3.12	1.3	1.7	10.88	1.19	1.27	12.15
Hillcrest Apartments		Morning	3.27	3.19	3.12	0.69	0.48	3.88	0.99	1.38	5.26
		Afternoon	2.89	2.84	2.91	0.64	0.41	3.89	0.82	1.22	5.11
		Evening	3.21	3.12	3.62	0.92	0.85	6.99	1.18	1.43	4.42
Confluence		Morning	7.21	6.19	5.26	3.34	11.14	22.58	3.54	2.25	24.83
		Afternoon	8.75	7.42	6.11	4.25	18.07	21.24	6.14	2.12	23.36
		Evening	4.41	3.91	3.4	1.83	3.34	11.92	1.7	1.88	13.8
Church	Thursday 0607	Morning	27.44	19.23	14.48	23.34	544.82	144.85	14.19	9.1	153.95
		Afternoon	20.67	14.02	9.17	18.62	346.64	135.64	14.21	4.5	140.14
		Evening	11.73	5.19	3.69	15.94	254.16	123.45	9.96	1.94	125.39
Waterfront Park		Morning	9.39	9.32	9.25	1.08	1.16	7.84	1.43	6.26	14.1
		Afternoon	7.6	7.5	7.19	1.43	2.06	8.24	2.15	3.62	11.86
		Evening	4.06	3.98	3.91	0.96	0.92	5.91	1.25	1.82	7.73
Elementary School		Morning	11.39	11.41	11.26	1.04	1.08	6.92	1.4	8.03	14.95
		Afternoon	7.5	7.5	6.96	1.15	1.33	7.21	1.69	4.13	11.34
		Evening									
Hillcrest Apartments		Morning	9.24	9.25	9.17	1.25	1.56	6.93	1.73	6.26	13.19
		Afternoon	5.65	5.8	5.8	1.48	2.2	7.95	2	2.12	10.07
		Evening	4.1	3.98	3.83	1.06	1.12	6.49	1.18	2	8.49
Confluence		Morning	10.47	10.22	10.52	1.79	3.19	12.29	1.94	6.65	18.94
		Afternoon	6.68	6.65	6.73	1.81	3.29	11.21	2.38	2.51	13.72
		Evening	4.58	4.43	4.28	1.01	1.02	6.72	1.36	2.38	9.1
Church	Saturday 0609	Morning	27.74	20.51	16.23	19.91	396.38	121.67	12.39	12.23	133.9
		Afternoon	18.18	14.64	12.97	11.22	125.97	81.37	8.31	7.96	89.33
		Evening	7.02	6.88	6.34	1.18	1.39	7.5	1.46	3.76	11.26
Waterfront Park		Morning	12.69	12.67	12.52	1.322	1.75	7.62	1.94	9.02	16.64
		Afternoon									
		Evening									
Elementary School		Morning	17.62	17.5	18.03	1.79	3.22	10.19	2.45	13.65	23.84
		Afternoon	18.18	14.64	12.97	11.22	125.97	81.37	8.31	7.96	89.33
		Evening	6.27	6.19	6.11	0.95	0.89	6.52	1.23	3.33	9.85
Hillcrest Apartments		Morning	11.14	11.19	11.56	1.24	1.53	9.88	1.56	6.19	16.07
		Afternoon	8.66	8.72	8.87	1.17	1.37	6.44	1.68	5.34	11.78
		Evening	7.82	7.73	7.27	1.69	2.84	10.55	2.14	3.47	14.02
Confluence		Morning									
		Afternoon	12.69	12.67	12.52	1.32	1.75	7.62	1.94	9.02	16.64
		Evening									
Church	Wednesday 0613	Morning	28.36	15.62	184.49	33.76	1140	176.69	13.6	7.8	184.49
		Afternoon	25.14	16.81	10.89	24.12	581.99	182.79	15.39	7.27	190.06
		Evening	22.38	17.5	16.39	21.03	442.19	155.23	3.2	12.82	168.05
Waterfront Park		Morning	10.53	10.45	10	1.34	1.81	7.77	2.01	7.34	15.11
		Afternoon	11.94	11.93	12	1.15	1.34	8.1	1.63	7.8	15.9
		Evening	18.93	18.76	18.57	1.5	2.26	11.56	1.87	14.18	25.74
Elementary School		Morning	10.75	10.6	10.52	1.34	1.8	9.59	1.64	6.8	16.39
		Afternoon	11.68	11.34	11.56	2.31	5.33	19.59	2.08	7.5	27.09
		Evening	9.5	9.5	9	3.55	12.57	12	3.5	3	15
Hillcrest Apartments		Morning	10.22	10.07	9.78	1.38	1.91	10.76	1.65	5.88	16.64
		Afternoon	13.09	12.82	12.3	2.73	7.48	29.98	1.87	3.69	33.67
		Evening	16.5	16.5	16	1.6	2.57	5	2	14	19
Confluence		Morning	10.22	10.15	9.55	1.29	1.68	10.3	1.49	7.11	17.41
		Afternoon	13.08	12.82	12.08	1.65	2.74	11.12	1.87	9.7	20.82
		Evening	17.69	17.67	17.85	1.39	1.95	8.31	1.84	13.57	21.88

Church	Thursday 0614	Morning	33.91	22.55	22.55	27.96	781.71	143.2	25.93	4.13	147.33
		Afternoon	42.62	33.85	27.09	26.07	679.79	152.84	31.79	10.07	162.91
		Evening	14.85	12	15.9	12.26	150.19	93.35	11.07	1.43	1.43
Waterfront Park		Morning	3.37	2.84	2.71	1.69	2.84	9.38	1.95	0.99	10.37
		Afternoon	2.07	2	1.94	0.63	0.4	3.79	0.73	0.94	4.73
		Evening	2.11	2	2.06	0.64	0.41	3.83	0.86	0.9	4.73
Elementary School		Morning	4.55	3.76	2.98	2.45	5.99	17.85	2.81	1.38	19.23
		Afternoon	7.4	5.57	2.38	6.4	40.92	47.83	5.62	0.94	48.77
		Evening	3.65	3.4	2.98	1.3	1.69	7.96	1.64	1.59	9.55
Hillcrest Apartments		Morning	3.29	2.84	2.64	1.7	2.9	16.37	1.03	1.48	17.85
		Afternoon	2.94	2.64	2.19	1.23	1.5	8.57	1.21	1.13	9.7
		Evening	3.1	2.91	2.57	1.13	1.28	9.72	1.16	1.32	11.04
Confluence		Morning	2.75	2.64	2.51	1	1.01	7.78	1.14	0.86	8.64
		Afternoon	2.42	2.31	2.12	0.68	0.47	4.03	0.9	1.08	5.11
		Evening	2.2	2.06	2.06	0.67	0.45	5.16	0.75	1.03	6.19
Church	Saturday 0616	Morning	46.71	22.67	195.93	51.26	2627	188.74	48.48	7.19	195.93
		Afternoon	21.2	11.41	6.11	30.74	944.99	195.55	14.94	2.12	197.67
		Evening	8.06	2.91	2.51	18.58	345.24	134.01	1.73	0.82	134.83
Waterfront Park		Morning	8.4	8.34	7.73	1.16	1.34	8.02	1.6	4.5	12.52
		Afternoon	2.8	2.77	2.71	0.66	0.44	4.18	0.95	1.08	5.26
		Evening	2.79	2.77	2.64	0.62	0.39	3.98	0.81	1.13	5.11
Elementary School		Morning	8.45	8.42	8.11	1.25	1.55	8.09	1.6	4.73	12.82
		Afternoon	3.64	3.47	3.4	0.94	0.89	5.83	1.29	1.82	7.65
		Evening	3.87	3.54	3.05	1.44	2.07	9.58	1.52	1.54	11.12
Hillcrest Apartments		Morning	7.38	7.15	6.57	1.83	3.33	14.14	2.23	3.62	17.76
		Afternoon	5.69	4.28	3.69	5.72	32.68	57.62	1.72	1.88	59.5
		Evening	3.3	3.12	3.19	0.97	0.94	7.69	1.12	1.48	9.17
Confluence		Morning	5.72	5.57	4.65	1.21	1.46	8.08	1.54	3.26	11.34
		Afternoon	3.17	3.05	2.71	0.97	0.94	7.09	1.32	1.48	8.57
		Evening	3.88	3.54	3.05	1.46	2.14	9.28	1.37	1.54	10.82

APPENDIX I
DESCRIPTIVE STATISTICS FOR VOC CONCENTRATIONS

Location	Day	Shift	Mean	Median	Mode	Std Deviatior	Variance	Range	IQR	Minimum	Maximum
Church	Wednesday 0606	Morning	0.48	0.36	0.29	0.26	0.07	0.65	0.51	0.25	0.9
		Afternoon	0.35	0.18	0.6	0.18	0.03	0.45	0.31	0.15	0.6
		Evening	0.32	0.23	0.19	0.17	0.03	0.42	0.3	0.18	0.6
Waterfront Park		Morning	0.14	0.14	0.14	0.02	0.0003	0.08	0.01	0.11	0.19
		Afternoon	0.14	0.13	0.11	0.06	0.003	0.3	0.02	0.11	0.41
		Evening	0.22	0.22	0.22	0.001	2.56E-06	0.01		0.21	0.22
Elementary School		Morning	0.32	0.3	0.28	0.05	0.002	0.17	0.06	0.27	0.44
		Afternoon	0.34	0.3	0.29	0.09	0.009	0.32	0.02	0.28	0.6
		Evening	0.27	0.28	0.28	0.028	0.0008	0.12	0.03	0.17	0.29
Hillcrest Apartments		Morning	0.28	0.27	0.26	0.04	0.002	0.21	0.03	0.26	0.47
		Afternoon	0.29	0.29	0.29	0.03	0.0007	0.09	0.02	0.25	0.34
		Evening	0.23	0.22	0.22	0.03	0.0009	0.12	0.03	0.17	0.29
Confluence		Morning	0.15	0.14	0.14	0.06	0.004	0.3	0.03	0.11	0.41
		Afternoon	0.13	0.12	0.11	0.05	0.003	0.3	0.03	0.11	0.41
		Evening	0.19	0.22	0.22	0.05	0.002	0.11		0.11	0.22
Church	Thursday 0607	Morning	0.28	0.23	0.18	0.15	0.02	0.42	0.11	0.18	0.6
		Afternoon	0.36	0.28	0.2	0.19	0.04	0.5	0.3	0.2	0.7
		Evening	0.2	0.15	0.13	0.12	0.02	0.54	0.07	0.11	0.65
Waterfront Park		Morning	0.12	0.11	0.11	0.02	0.0004	0.06	0.03	0.11	0.17
		Afternoon	0.13	0.12	0.11	0.02	0.0003	0.06	0.02	0.11	0.17
		Evening	0.2	0.19	0.17	0.05	0.003	0.16	0.05	0.15	0.31
Elementary School		Morning	0.28	0.26	0.26	0.03	0.0007	0.1	0.03	0.26	0.36
		Afternoon	0.23	0.22	0.18	0.04	0.001	0.11	0.07	0.18	0.29
		Evening	0.13	0.11	0.11	0.02	0.0005	0.07	0.03	0.11	0.18
Hillcrest Apartments		Morning	0.28	0.28	0.29	0.04	0.002	0.22	0.04	0.23	0.45
		Afternoon	0.22	0.21	0.2	0.02	0.0003	0.06	0.03	0.19	0.25
		Evening	0.4	0.4	0.4	0.07	0.005	0.28	0.08	0.25	0.53
Confluence		Morning	0.12	0.12	0.12	0.004	0.00002	0.01		0.11	0.12
		Afternoon	0.11	0.11	0.11					0.11	0.11
		Evening	0.16	0.17	0.17	0.01	0.0002125	0.04	0.02	0.14	0.18
	Saturday 0609	Morning	0.63	0.6	0.6	0.05	0.002	0.1	0.09	0.6	0.7
		Afternoon	0.38	0.38		0.14	0.02	0.42	0.22	0.18	0.6
		Evening	0.65	0.65	0.6	0.1	0.01	0.3	0.1	0.5	0.8
		Morning	0.64	0.65	0.68	0.05	0.003	0.13	0.03	0.55	0.68
		Afternoon	0.16	0.12	0.12	0.05	0.003	0.1	0.1	0.12	0.22
		Evening	0.46	0.48	0.49	0.05	0.003	0.18	0.07	0.38	0.56
		Morning	0.37	0.37	0.37	0.04	0.001	0.1	0.07	0.32	0.42
		Afternoon	0.34	0.35	0.35	0.03	0.0008	0.08	0.02	0.27	0.35
		Evening	0.29	0.23	0.23	0.12	0.01	0.3	0.27	0.19	0.49
		Morning	0.42	0.39	0.36	0.06	0.004	0.14	0.1	0.36	0.5
		Afternoon	0.36	0.38	0.38	0.06	0.003	0.18	0.015	0.23	0.41
		Evening	0.17	0.18	0.18	0.02	0.0004	0.07	0.03	0.13	0.2
		Morning	0.68	0.68	0.68	0	0	0	0	0.68	0.68
		Afternoon	0.13	0.13	0.13	0.007	0.00005	0.02	0.01	0.11	0.13
		Evening	0.16	0.17	0.17	0.01	0.0002	0.04	0.02	0.14	0.18
	Wednesday 0613	Morning	0.24	0.21	0.14	0.11	0.01	0.58	0.11	0.13	0.71
		Afternoon	0.25	0.24	0.23	0.03	0.001	0.12	0.05	0.2	0.32
		Evening	0.33	0.33	0.3	0.03	0.001	0.15	0.05	0.29	0.44
		Morning	0.2	0.21	0.21	0.02	0.0003	0.07	0.02	0.16	0.23
		Afternoon	0.17	0.17	0.17	0.02	0.0004	0.08	0.02	0.12	0.2
		Evening	0.25	0.25	0.21	0.04	0.001	0.11	0.06	0.21	0.32
		Morning	0.28	0.29	0.32	0.04	0.002	0.12	0.07	0.21	0.33
		Afternoon	0.19	0.17	0.16	0.05	0.002	0.16	0.05	0.15	0.31
		Evening	0.25	0.23	0.23	0.047	0.002	0.18	0.05	0.19	0.37
		Morning	0.21	0.2	0.17	0.05	0.002	0.14	0.03	0.17	0.31
		Afternoon	0.16	0.16	0.15	0.02	0.0003	0.06	0.02	0.14	0.2
		Evening	0.17	0.2	0.2	0.04	0.001	0.1	0.09	0.11	0.21
		Morning	0.32	0.26	0.23	0.18	0.03	0.97	0.08	0.2	1.17
		Afternoon	0.16	0.16	0.16	0.02	0.0005	0.07	0.03	0.11	0.18
		Evening	0.4	0.39	0.29	0.12	0.01	0.42	0.14	0.27	0.69

Thursday 0614	Morning	0.11	0.11	0.11	0.01	0.0001	0.06	0	0.11	0.17
	Afternoon	0.34	0.35	0.37	0.07	0.005	0.27	0.09	0.25	0.52
	Evening	0.17	0.12	0.11	0.09	0.008	0.31	0.09	0.11	0.42
	Morning	0.14	0.14	0.15	0.01	0.0002	0.05	0.02	0.11	0.16
	Afternoon	0.15	0.14	0.13	0.03	0.0008	0.1	0.02	0.11	0.21
	Evening	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Morning	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Afternoon	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Evening	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Morning	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Afternoon	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Evening	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Morning	0.12	0.12	0.11	0.005	0.00003	0.01	0.01	0.11	0.12
	Afternoon	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Evening	0.11	0.11	0.11	0	0	0	0	0.11	0.11
Saturday 0616	Morning	0.45	0.44	0.43	0.06	0.003	0.21	0.05	0.38	0.59
	Afternoon	0.35	0.33	0.28	0.08	0.007	0.32	0.08	0.28	0.6
	Evening	0.13	0.11	0.11	0.07	0.005	0.37	0	0.11	0.48
	Morning	0.19	0.2	0.15	0.03	0.001	0.09	0.06	0.15	0.24
	Afternoon	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Evening	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Morning	0.35	0.34	0.39	0.04	0.002	0.13	0.06	0.26	0.39
	Afternoon	0.24	0.22	0.21	0.05	0.003	0.13	0.08	0.19	0.32
	Evening	0.23	0.25	0.18	0.04	0.001	0.08	0.08	0.18	0.26
	Morning	0.3	0.31	0.31	0.03	0.0009	0.1	0.04	0.24	0.34
	Afternoon	0.17	0.17	0.17	0.01	0.0002	0.05	0.01	0.14	0.19
	Evening	0.14	0.14	0.13	0.01	0.0003	0.06	0.02	0.13	0.19
	Morning	0.17	0.16	0.14	0.03	0.0006	0.07	0.04	0.14	0.21
	Afternoon	0.11	0.11	0.11	0	0	0	0	0.11	0.11
	Evening	0.12	0.11	0.11	0.04	0.001	0.19	0	0.11	0.3

APPENDIX J

DESCRIPTIVE STATISTICS FOR TRAFFIC COUNTS

Date	Shift	Vehicles	Sites	Mean	SD
Wednesday 0606	Morning	Cars	Church	7.92	1.93
		Trucks		1.25	0.75
	Afternoon	Cars		6	2.34
		Trucks		3.33	2.02
	Evening	Cars		2.75	2.22
		Trucks		0.17	0.58
	Morning	Cars	Waterfront Park	122.2	131.82
		Trucks		10.7	11.52
	Afternoon	Cars		162.2	26.71
		Trucks		9.8	2.59
	Evening	Cars		169.33	46.42
		Trucks		17.33	19.88
	Morning	Cars	Elementary School	50.17	7.99
		Trucks		17.5	5.01
	Afternoon	Cars		72	15.03
		Trucks		16.5	3.02
	Evening	Cars		135	15.74
		Trucks		26.17	3.43
	Morning	Cars	Hillcrest Apartments	3.33	2.5
		Trucks		1	1.55
	Afternoon	Cars		0.67	1.21
		Trucks		0.17	0.41
	Evening	Cars		5.83	2.79
		Trucks		1	1.1
	Morning	Cars	Confluence	210.71	55.67
		Trucks		11.58	3.32
	Afternoon	Cars		185.14	25.81
		Trucks		12.86	3.18
	Evening	Cars		185.83	25.38
		Trucks		9.83	4.88
Thursday 0607	Morning	Cars	Church	6.58	1.56
		Trucks		1.92	0.9
	Afternoon	Cars		9.33	3.11

		Trucks		2.25	1.14
	Evening	Cars		4.1	1.19
		Trucks		1.5	0.58
	Morning	Cars	Waterfront Park	2.17	1.47
		Trucks		1.4	0.55
	Afternoon	Cars		2.31	0.57
		Trucks		1	
	Evening	Cars		2.2	1.1
		Trucks			
	Morning	Cars	Elementary School	57.67	9.05
		Trucks			
	Afternoon	Cars		66.67	10.21
		Trucks		22	8.07
	Evening	Cars		136.5	7.12
		Trucks		25.83	4.02
	Morning	Cars	Hillcrest Apartments	1.5	1
		Trucks			
	Afternoon	Cars		1	
		Trucks			
	Evening	Cars		3.6	1.67
		Trucks		1	0
	Morning	Cars	Confluence	185.43	25.75
		Trucks		16.29	2.69
	Afternoon	Cars		184.5	18.84
		Trucks		14.17	2.99
	Evening	Cars		192	27.03
		Trucks		6	1.73
Saturday 0609	Morning	Cars	Church	11.25	3.62
		Trucks		1.17	0.83
	Afternoon	Cars		6.33	3.45
		Trucks		0.17	0.39
	Evening	Cars		2	1.41
		Trucks			
	Morning	Cars	Waterfront Park	39.75	27.67
		Trucks		9.63	3.81
	Afternoon	Cars		137.83	36.64
		Trucks		4	1.26
	Evening	Cars		3	1.67

		Trucks			
	Morning	Cars	Elementary School	53.17	10.15
		Trucks		16	2.82
	Afternoon	Cars		87.5	21.32
		Trucks		13.17	2.93
	Evening	Cars		94.17	11.3
		Trucks		14.83	3.13
	Morning	Cars	Hillcrest Apartments	1.4	0.89
		Trucks		1	1.55
	Afternoon	Cars		1.4	0.55
		Trucks			
	Evening	Cars		2.75	1.5
		Trucks		2	
	Morning	Cars	Confluence	73	16.49
		Trucks		9.17	3.92
	Afternoon	Cars		177.17	34.67
		Trucks		4	3.22
	Evening	Cars		81	17.46
		Trucks		3	
Wednesday 0613	Morning	Cars	Church	9.75	3.7
		Trucks		0.67	0.89
	Afternoon	Cars		6.83	3.51
		Trucks		1.08	1.62
	Evening	Cars		1.92	1.73
		Trucks		0.08	0.29
	Morning	Cars	Waterfront Park	1.83	1.83
		Trucks			
	Afternoon	Cars		2.67	1.63
		Trucks			
	Evening	Cars		2.17	0.98
		Trucks			
	Morning	Cars	Elementary School	56.17	3.82
		Trucks		17.67	3.5
	Afternoon	Cars		51.67	5.64
		Trucks		19.5	5.54
	Evening	Cars		119.67	10.58
		Trucks		24.17	6.74

	Morning	Cars	Hillcrest Apartments	1.17	0.98
		Trucks			
	Afternoon	Cars		1.67	1.37
		Trucks		1	
	Evening	Cars		4.83	2.64
		Trucks		2	1.73
	Morning	Cars	Confluence	159.83	56.29
		Trucks		13.83	3.06
	Afternoon	Cars		183.83	10.57
		Trucks		12	1.1
	Evening	Cars		247.5	26.2
		Trucks		5.33	1.37
Thursday 0614	Morning	Cars	Church	9.33	3.08
		Trucks		1.64	0.81
	Afternoon	Cars		9.58	2.02
		Trucks		1.83	0.83
	Evening	Cars		3.25	2.22
		Trucks			
	Morning	Cars	Waterfront Park	2.17	1.17
		Trucks		1	0.71
	Afternoon	Cars		4.17	1.33
		Trucks		1	0
	Evening	Cars		2.4	1.14
		Trucks			
	Morning	Cars	Elementary School	52	14.18
		Trucks		14.33	2.25
	Afternoon	Cars		60.83	10.87
		Trucks		12	2.83
	Evening	Cars		124.5	17.51
		Trucks		26.33	6.31
	Morning	Cars	Hillcrest Apartments	3.2	1.3
		Trucks		1.6	0.55
	Afternoon	Cars		2.5	1.22
		Trucks		1	
	Evening	Cars		5.5	4.14
		Trucks		1.33	0.58
	Morning	Cars	Confluence	90.17	11.32

		Trucks		13.83	3.13
	Afternoon	Cars		80.83	13.93
		Trucks		15	2.9
	Evening	Cars		203.33	22.04
		Trucks		6.83	3.31
Saturday 0616	Morning	Cars	Church	13.75	4.27
		Trucks		1.6	0.89
	Afternoon	Cars		9.83	4.17
		Trucks		1.29	0.49
	Evening	Cars		1	0
		Trucks		1	
	Morning	Cars	Waterfront Park	5.17	2.93
		Trucks			
	Afternoon	Cars		4.5	2.95
		Trucks			
	Evening	Cars		7	3.58
		Trucks			
	Morning	Cars	Elementary School	52.33	7.61
		Trucks		10.33	4.32
	Afternoon	Cars		76.33	19.54
		Trucks		15.4	5.41
	Evening	Cars		119.33	17.57
		Trucks		1.25	0.5
	Morning	Cars	Hillcrest Apartments	3.8	0.84
		Trucks		1	
	Afternoon	Cars		3.2	2.28
		Trucks		1.67	1.15
	Evening	Cars		4.6	3.58
		Trucks		2	1.41
	Morning	Cars	Confluence	165.83	47.05
		Trucks		7	4.76
	Afternoon	Cars		228.17	21.71
		Trucks		6.33	2.88
	Evening	Cars		209.33	36.81
		Trucks		3	0.82

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