Strengthening Air Quality Management in Accra, Ghana

FINAL REPORT

IMPROVED POLLUTION MANAGEMENT AND REDUCED ENVIRONMENTAL HEALTH RISK IN ACCRA-TEMA METROPOLITAN AREA (P164417)

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WORLD BANK GROUP

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Acronyms & Abbreviations

AP	Air Pollution
MoU	Memorandum of Understanding
AAP	Ambient Air Pollution
AQ	Air Quality
AQM	Air Quality Management
AQMP	Air Quality Management Plan
ASA	Advisory Services and Analytics
BETF	Bank Executed Trust Fund
CEA	Country Environmental Analysis
DAP	Data Acquisition Plan
DQO	Data Quality Objectives
EPA	Environmental Protection Agency, an agency of MESTI
GAMA	Greater Accra Metropolitan Area
GHG	Greenhouse Gas
GoG	Government of Ghana
GRA	Ghana Revenue Authority
HAP	Household Air Pollution
LUSPA	Land Use and Spatial Planning Authority, an agency of MESTI
MDAs	Ministries, Departments and Agencies of GoG
MESTI	Ministry of Environment, Science, Technology and Innovation
MLGRD	Ministry of Local Government and Rural Development
MMDAs	Metropolitan, Municipal and District Assemblies
MTR	Mid-Term Review (of AQMP)
MoF	Ministry of Finance and Economic Planning
MoTI	Ministry of Trade and Industry
PM	Particulate Matter
PMEH	Pollution Management and Environmental Health
QA	Quality Assurance
QAPP	Quality Assurance Project Plans
QC	Quality Control
SCD	Systematic Country Diagnostic
SOPs	Standard Operating Procedures
TP	Training Plan
WB	World Bank
WBG	World Bank Group

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Executive Summary

Ambient concentrations of fine particulate matter, or $PM_{2.5}$, are high and remain a key driver of the deleterious health effects of air pollution. Various estimates of $PM_{2.5}$ across the Greater Accra Metropolitan Area (GAMA) are increasingly available as a result of long-term monitoring by the Ghanaian Ministry of Environment, Science, Technology and Innovation's (MESTI's) Environmental Protection Agency (EPA Ghana) as well as a number of air pollution monitoring campaigns by academic and international partner agencies.

Current air quality conditions present an unacceptable health burden for the population of GAMA and are not in line with international guidelines for air quality. Current WHO guidelines for ambient concentrations of $PM_{2.5}$ recommend no higher than 10 µg/m³ on an annual average basis and 25 µg/m³ averaged over a 24-hour period, although these levels are set to be updated later this month. As the data in Table 1 and Figures 1 and 2 show, ambient concentrations are typically 2 to 10 times these values depending on location and season, with the Harmattan periods resulting in very significant increases in ambient concentrations. As a result, air pollution is Ghana's number one environmental risk, responsible for about 8 percent of total annual mortality, which is disproportionately borne by infants and the elderly.

The economic (welfare) cost of air pollution is estimated at US$2.5 Billion or roughly 4.2% of the country's 2017 Gross Domestic Product (GDP). The cost of air pollution in Ghana's two largest cities, Accra and Kumasi, is estimated at $264 million/year. A recent cross-sectional analysis of cost of health care found that, depending on the disease, a significant fraction of health care costs related to treatment of air pollution-related illness falls to patients.

To address the global challenge of pollution mitigation, The Pollution Management and Environmental Health (PMEH) multi-donor partnership was established in 2014 to make links between air pollution, human health, climate change, and growth priorities, through overarching analytical work and country specific support. The PMEH pilot in Accra was focused on a strategically selected subset of initiatives that would fill monitoring and planning gaps and to strengthen capacity of EPA Ghana to build upon their past practice, to sharpen their technical capacity and to strengthen the analytical pillars for air quality management (AQM) planning.

Unique among PMEH pilots, the GAMA pilot is conducted in collaboration with several other development partners who have and continue to support EPA Ghana in their AQM planning efforts. While the PMEH program had a mandate to establish a "full-scale" air quality management plan for each city that consisted of a list of core components of air quality management planning, such as monitoring, inventory, health impact assessment, source apportionment, stakeholder engagement, policy design and implementation, many of these elements were already underway or being supported by other international partners at the time the pilot was established. This report highlights AQM planning achievements that resulted directly from the PMEH-funded activities, but also features several AQM planning advances that occurred through coordination and participation of other international partners working toward a common objective of advancing AQM planning for GAMA.

This report is intended to summarize the achievements of Ghana's PMEH Program. Since the many deliverables should be viewed collectively in how they achieve the overall objectives of the PMEH program, this report has been drafted primarily for the benefit of communicating the impact of the PMEH project more effectively. The report begins with an introductory chapter that provides context on air pollution in Ghana and the Greater Accra Metropolitan Area, specifically. It draws mostly on academic research and recent World Bank analysis conducted for the *Ghana Country Environmental Analysis* that was supported in part, through PMEH activities. A short chapter follows that provides some context on the PMEH program and the Accra pilot. Then the core outputs and resulting outcomes of the PMEH activities are presented with supporting details to show how each aspect contributed to the next iteration of the GAMA air quality management plan mid-term review that is currently underway. Finally, several sets of recommendations are presented that draw from the World Bank as well as several other development partners that have been working on Air Quality in Ghana to provide a comprehensive view of how this important work can be taken forward as EPA Ghana continues to address the challenges that air quality presents for a sustainable future in Accra and across Ghana.

Further, support of EPA Ghana will help to solidify EPA Ghana as a regional leader in air quality measurement and management that will allow dissemination of expertise within West Africa and sub-Saharan Africa as a whole. The efforts undertaken through the PMEH project have provided insight into the most important and critical next steps that need to be taken in support of EPA Ghana's air quality management efforts in Accra. These include:

- Assess and compare new, continuous methods with filter-based, manual sampling methods to identify potential issues and provide solutions to correct these issues in a way that will allow EPA Ghana to have more consistently accurate particle measurements from the full range of monitoring methods deployed.
- Determine which datasets or groupings of datasets will be used to assess regulatory compliance, analyze health impacts, or otherwise understand air quality burdens within the city and to establish regulatory guidance for the use of both gravimetric and continuous monitoring technologies in their compliance networks.
- Overhaul Ghana EPA's analytical chemistry laboratory equipment consistent with international air quality measurement best practices (e.g; X-ray fluorescence instead of atomic absorption spectrometry).
- Develop an integrated air pollution prevention and control program focusing on key sectors (transport, waste and biomass burning or clean cooking) to reduce emissions. The program should place a special emphasis on how to coordinate financing and policies across three sectors most closely linked to the mitigation of air pollution—environment, transport, urban development and energy—and how to reconcile the sometimes-conflicting objectives and demands of these sectors to achieve environmental improvement.

Supporting EPA Ghana with their work in Accra will help to create a model that the agency can use and apply in other major cities with air quality concerns, including Kumasi and Takoradi, where there is interest in better understanding ambient pollution.

1. INTRODUCTION

1.1. Air Quality in Ghana

Ambient concentrations of fine particulate matter, or $PM_{2.5}$, are high and remain a key driver of the deleterious health effects of air pollution. $PM_{2.5}$ poses a significant and even fatal health risk where long-term exposure exists. Illnesses associated with $PM_{2.5}$-related mortality include lung cancer, ischemic heart disease, stroke, acute lower respiratory infection, and chronic obstructive pulmonary disease (COPD) (e.g., bronchitis, emphysema). Various estimates of $PM_{2.5}$ across the Greater Accra Metropolitan Area (GAMA) are increasingly available as a result of long-term monitoring by the Ghanaian Ministry of Environment, Science, Technology and Innovation's (MESTI's) Environmental Protection Agency (EPA Ghana) as well as a number of air pollution monitoring campaigns by academic and international partner agencies. Table 1 provides a range of values that provide a solid basis for estimating the current toll that air pollution is taking on the GAMA population, while also leaving room for improved monitoring practice to reduce uncertainties moving forward.

The temporal pattern of ambient air pollution is significantly influenced by the Harmattan winds that carry high levels of mineral dust from the Sahara Desert across the city during December –March. Field measurements from 2020 demonstrated the significant enhancement of ambient concentrations during this time period which raised ambient $PM_{2.5}$ levels between 56 and 71 μg/m^3 (Alli et al. 2021, See Figure 1). While 2020 was a pandemic year that may have reduced the anthropogenic fraction of air pollution, there is no reason to believe that the Harmattan was affected, and prior studies also show this magnitude of enhancement.

Table 1. Estimates of annual average fine particle pollution ($PM_{2.5}$) across the GAMA.

Source	Year	Estimated annual average PM2.5 (µg/m3)	Comments
Arku et al.(2008)	2006	20-40	Short-term sampling over 3 weeks; 4 low-income residential neighborhoods
Dionisio et al. (2010)	2007-08	30-70 (residential) 40-50 (roadside)	4 low-income residential neighborhoods (non-Harmattan)
Mudu (2021)	2014-2015 2010-2016	49 (ground-level) 25-50 (satellite)	Satellite data processed through the DIMAQ Model (Shaddick and Wakefield, 2002).
EPA Ghana, personal communication	2015-2020	46-127	Every 6-day gravimetric sampling at 12 metropolitan sites across Accra
Southerland et al. (2021)	2015-2019	52-67	Global dataset of satellite derived annual average PM2.5 concentrations in urban areas
Alli et al. (2021)	2020	37 (commercial/business) 36 (high density residential) 28 (medium density residential) 26 (peri-urban) 89 (Harmattan) 23 (non-Harmattan)	Rotating measurements at 55 sites across GAMA with seasonal adjustments. Note that 2020 was a pandemic year.
EPA Ghana, personal communication	2020	73 (Roadside) 88 (Residential) 69 (Commercial/Business)	Every 6-day gravimetric sampling at 12 metropolitan sites across Accra. Note 2020 was a pandemic year
U.S. Embassy FEM monitor	2020	64 (Harmattan) 21 (Non-Harmattan)	Continuous monitoring results from US Embassy in Accra. Note 2020 was a pandemic year

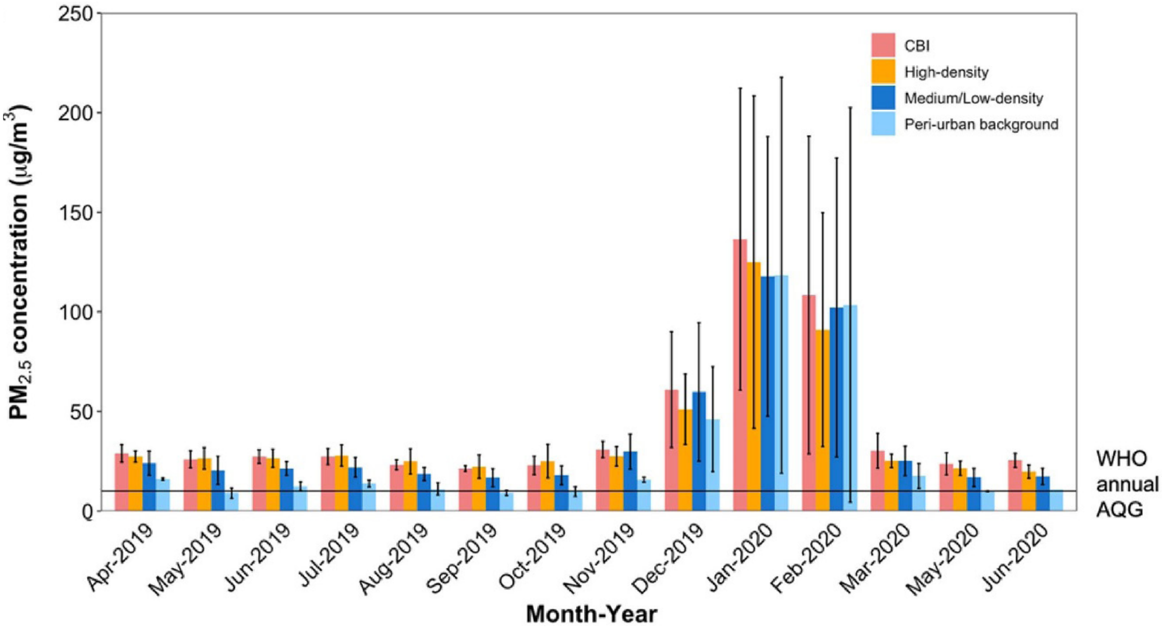

Figure 1. Weekly integrated $PM_{2.5}$ concentrations at the fixed sites averaged by site-types across measurement months. Bars are standard deviations of the weekly measurements in that month. The horizontal line in (A) shows the WHO annual AQG of 10 $\mu g/m^3$. Reproduced from Alli et al. 2021.

The spatial pattern of air pollution is becoming better understood with increased AQ monitoring providing an increasingly consistent picture of elevated levels of air pollution running North to South through the core of Accra with additional enhancement near Tema. Figure 2 shows three recent analyses of the estimated spatial pattern of pollution across GAMA. (note that the MESTRI spatial interpolation lacked ground monitors in Tema).

Current air quality conditions present an unacceptable health burden for the population of GAMA and are not in line with international guidelines for air quality. Current WHO guidelines for ambient concentrations of $PM_{2.5}$ recommend no higher than 10 µg/m3 on an annual average basis and 25 $\mu g/m^3$ averaged over a 24-hour period (WHO 2005), although these levels are set to be updated later this month. As the data in Table 1 and Figures

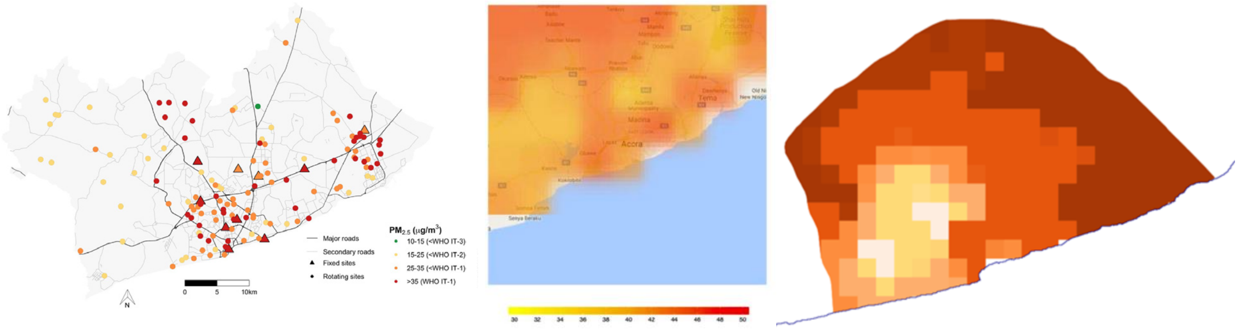

Figure 2. Estimated spatial pattern of ground-level air pollution based on (a) rotating surface site measurements, (b) modelled average values using a satellite-ground monitor data fusion algorithm and (c) spatially interpolated data from ground-level measurements. Sources: Alli et al. 2021; Mudu 2021; MESTRI 2017.

1 and 2 show, ambient concentrations are typically 2 to 10 times these values depending on location and season, with the Harmattan periods resulting in very significant increases in ambient concentrations. In 2018, EPA Ghana proposed its own national standards for 24-hour average concentrations of $PM_{2.5}$ at 35 µg/m³ but did not propose an annual standard, given difficulties in separating the mostly natural Harmattan contribution to PM during the December to March time period, significantly affecting annual average concentrations.

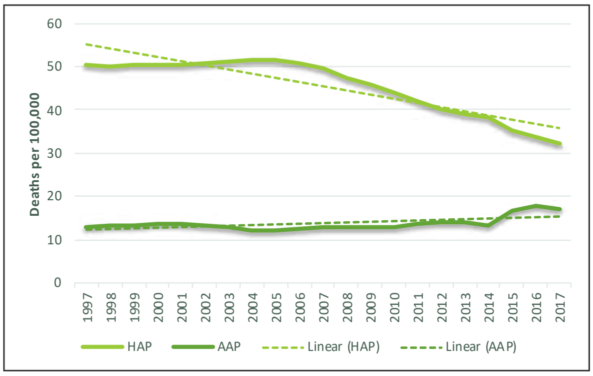

Figure 3: Rate of death associated with HAP and AAP (Global Burden of Disease database). Source: Ghana CEA, World Bank, 2020.

Air pollution is Ghana's number one environmental risk, responsible for about 8 percent of total annual mortality (World Bank CEA 2020). According to the World Bank *Ghana Country Environmental Analysis* (2020) that was supported, in part, through PMEH activities, air pollution was the sixth-ranked overall risk for death in 2017. In Ghana, air pollution was responsible for approximately 16,000 premature deaths that year, with about 8,500 in urban areas and 7,500 in rural areas (See Figure 3), thus rapid urbanization presents Ghana with a challenge in air quality management. Total annual mortality attributed to ambient air pollution (AAP) in urban Ghana (including all cities, even those not in GAMA) was estimated to be about 4,600 cases and about 2,600 cases were estimated in rural Ghana. Total annual mortality attributed to household air pollution (HAP, which includes emissions within and nearby residential households) in urban Ghana were estimated at 3,900 cases and approximately 5,000 cases in rural Ghana. However, over the past two decades, HAP has shown a dramatic decrease in its associated rate of death, which may be in part due to government efforts to replace traditional three-stone fires with LPG cookstoves. AAP has shown a slight increase. The Ghana Environmental Protection Agency (EPA) estimated that in 2015 about 2,800 lives were lost due to air pollution in the GAMA alone (EPA 2015). That represents 61% of national urban deaths, yet the population of GAMA is only about 4% of the national population. This number is projected to increase to approximately 4,600 by 2030 if no action is taken to reduce the current and projected future burden of air pollution.

Air pollution's disease burden is disproportionately borne by infants and the elderly (See Figure 4). Figure 2's left panel demonstrates how the elderly experience most AP-related premature deaths because this age demographic is most sensitive to some of the key health endpoints exacerbated by air pollution, such as heart attack and stroke. Similarly, the right panel shows that a greater proportion of non-fatal illness is borne by young children, who are most susceptible to acute lower respiratory tract infection (ALRI), such as pneumonia. The increase in risk of these diseases – resulting in the large burden of disease discussed in the prior paragraph – results in a further erosion of human capital in the country.

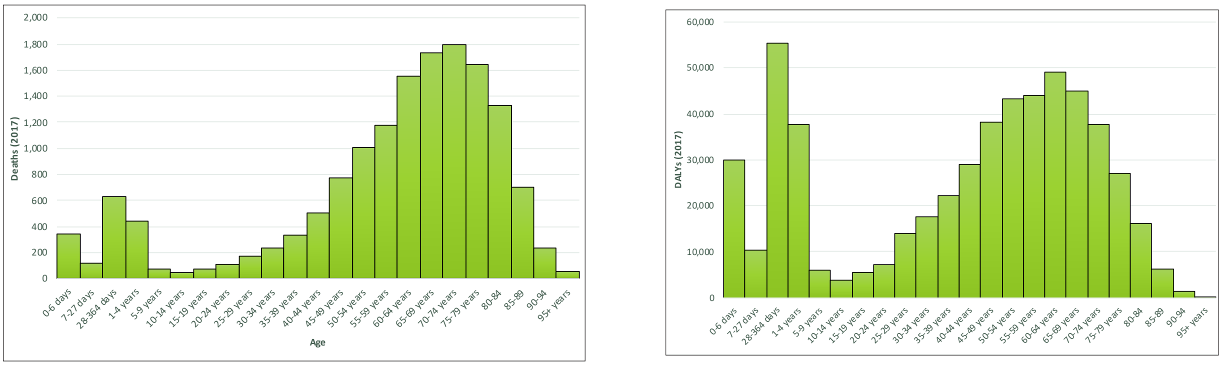

Figure 4: Premature deaths (left) and illness (right, in disability-adjusted life years (DALYs) associated with air pollution risk in Ghana (Source, Ghana CEA, World Bank, 2020).

Air pollution in the GAMA is generated by a diverse set of sources including point sources (e.g., industrial sites), mobile sources (e.g., vehicles), and area sources (e.g., residential cooking and lighting, agricultural, open dump burning or small-scale commercial enterprise emissions, etc.). Origin of air pollution includes both from naturally occurring (Harmattan wind-blown Saharan dust and sea salt along the coastal regions) and man-made (cook stoves and open burning of wastes, etc.). Transportation, burning of solid waste and commercial and residential burning of solid biomass fuels (e.g. wood, charcoal) are among the main sources of air pollution in GAMA (Zhou et al. 2013).

The economic (welfare) cost of air pollution is estimated at US$2.5 Billion or roughly 4.2% of the country's 2017 Gross Domestic Product (GDP) (World Bank CEA, 2020). Of this economic burden, ambient air pollution is currently slightly less costly than household air pollution, but as the government moves to address HAP (see later sections on consideration of a HAP guideline) and with increased rates of urbanization, this may not hold for long. The cost of air pollution in Ghana's two largest cities, Accra and Kumasi, is estimated at $264 million/year (World Bank CEA, 2020).

Financial costs of treatment of air pollution-related diseases are also high. A recent cross-sectional analysis of the health care costs of treatment found that, depending on the disease, a significant fraction of health care costs related to treatment of air pollution-related illness falls to patients (Santos et al. 2020). Even those with insurance (approximately 40% of the population) still had only a fraction of medical costs covered (e.g. 65%, 79%, 73% and 84% respectively for treatment of ischemic heart disease, lung cancer, stroke and pneumonia in children). These medical costs (after insurance) represent the equivalent of twice the annual earnings of some patients (Santos et al. 2020). Only patients with chronic obstructive pulmonary disease (COPD) had the cost of treatment fully covered by available insurance. Additionally indirect costs associated with lost earnings result in very high financial impacts on many of the patients and families least able to afford it. The study found that 45 percent of the patients in the sample came from the first (poorest) and second (poor) quintiles of socioeconomic status (Santos et al. 2020).

The impacts of climate change and deteriorating air quality threaten to erode development gains and worsen the health of Ghanaians. This calls for relevant actors to share results and experiences of their efforts and make air quality data more easily accessible and understandable to the public. This report documents recent efforts by EPA Ghana, the World Bank and several international donors and partner organizations to do just that through several supportive activities.

The Government of Ghana (GoG) has made efforts to measure and address the consequences of air pollution. The EPA has a long history of monitoring air quality in Accra. EPA Ghana established an air quality monitoring network in the Greater Accra Metropolitan Area between 1997 and 2001, EPA Ghana partnered with World Bank to monitor particulate matter less than ten microns in diameter (PM_{10}), total suspended particulates, black carbon, sulfur dioxide, and carbon monoxide. In 2005, EPA Ghana partnered with the U.S. Environmental Protection Agency (USEPA) and U.S. Agency for International Deelopment (USAID) to monitor PM_{10}, sulfur dioxide, carbon monoxide, nitrogen dioxide, lead, manganese, and ozone.

Over the next ten years, they added limited $PM_{2.5}$ samplers into the network, measuring air quality at roadside, residential, and industrial sites. In 2018, EPA Ghana worked with the USEPA to deploy a network of low-cost sensors measuring $PM_{2.5}$ at sites across the city. Ghana is already implementing several policies and plans to improve air quality and reduce Greenhouse Gas (GHG) emissions. These efforts are targeted at ultimately making sure that economic development takes place in a sustainable manner to ensure the well-being of the citizens now and in future.

A legal and regulatory framework to address air pollution exists. The main laws that govern air quality in Ghana are the Environmental Protection Agency Act 1994 (Act 490), and the Environmental Assessment Regulations 1999 (LI 1652), which regulates industrial activities. Ghana published standards for Environment and Health Protection – Requirements for Ambient Air Quality and Point Source/Stack Emissions (GS 1236) in 2019, and for motor vehicle emissions (GS 1219) in 2018. In 2018 EPA Ghana launched the (GAMA) Air Quality Management Plan (AQMP) to address air pollution-related health impacts via policies to reduce emissions from vehicles, electricity generating units, industrial point sources, open burning of solid waste, neighborhood impacts of cookstoves, and other anthropogenic sources (Environmental Protection Agency Ghana, 2018). The AQMP identified areas where capacity gaps can and should be addressed to further enhance their ability to implement the monitoring plan and emissions reduction performance. The AQMP identified the need to have a more refined understanding of human exposure across GAMA and an improved appreciation for the sources contributing to this exposure. The air quality monitoring system in GAMA requires further enhancement to more effectively assess certain emissions and to provide a continuous monitor capacity that can better inform the public in "real-time" during critical air pollution episodes (or used as an early warning system).

There are still areas where monitoring quality, data analysis and data management require strengthened procedures. Data on air pollution in Accra are not easily accessible, though it has to be recognized that Accra is in a better position compared with other African cities, because of the existence of a long tradition of measurements and analysis of air pollution data (Schwela 2012). Currently, the official EPA-Ghana website for Accra does not report data on ambient air pollution. In addition, EPA Ghana needs continued support in developing technical justifications for policy actions that can help improve air quality. These justifications must be accessible to decision makers and stakeholders with the authority to act on recommendations. However, Ghana faces continuing gaps in capacity, including national air quality monitoring capabilities and governance, environmental health surveillance and assessment of risks attributable to both ambient and household air pollution, and a national policy framework specific to the impacts of poor air quality.

This report is intended to summarize the achievements of Ghana's Pollution Management and Environmental Health (PMEH) Program. Since the many deliverables should be viewed collectively in how they achieve the overall objectives of the PMEH program, this report has been drafted primarily for the benefit of communicating the impact of the PMEH project more effectively.

2. POLLUTION MANAGEMENT AND ENVIRONMENTAL HEALTH PROGRAM

To address the global challenge of pollution mitigation, The Pollution Management and Environmental Health (PMEH) multi-donor partnership was established in 2014 to make links between air pollution, human health, climate change, and growth priorities, through overarching analytical work and country specific support. Over 5 years, the Ghana pilot aimed to achieve three main objectives:

1. Strengthen air quality management support for developing countries to significantly reduce air pollution through pollution management planning and investment.
2. Strengthen analytics and raise awareness on pollution and its health impacts in urban, rural areas.
3. Promote awareness of PMEH issues among policymakers, business partners, city leaders, and the general public through effective knowledge management and cooperation.

To achieve these objectives, the PMEH supports cooperation and knowledge exchange between low- and middle-income countries (LMICs), and currently implements technical assistance for air quality management and climate change mitigation in China, Egypt, Ghana, India, Nigeria, South Africa, and Vietnam. These countries were chosen to pilot city or regional level air quality management programs and build the capacity of governments to expand air quality monitoring on a national level. Activities are focused on air quality management, toxic site management, and research to assist local governments in achieving their climate targets. The PMEH has enabled countries to contribute to improved environmental health conditions for an estimated 240 million people in those cities over the five-year period that the AQ pilots were carried out.

PMEH Ghana Pilot

The objective of the Bank Executed Trust Fund (BETF) PMEH pilot project in Ghana is to improve capacity to address ambient air-pollution and support development of a full-scale AQMP for the Greater Accra Metropolitan Area (GAMA). The GAMA pilot was focused on a strategically selected subset of initiatives that would fill monitoring and planning gaps gaps as well as strengthen the capacity of EPA Ghana to build upon their past practice, to sharpen their technical capacity and to strengthen the analytical pillars for air quality management (AQM) planning. Concretely, the four objectives of the analytical work going into Ghana's PMEH program[1] were to:

i. to enhance and improve the existing regulatory structure and ambient monitoring network, secure new locations and update quality assurance project plans (QAPP) for the Accra and Tema municipalities to include additional species – including continuous and speciated $PM_{2.5}$ and black carbon;
ii. to develop Household Air Pollution (HAP) guidelines and HAP exposure test methods;
iii. to increase capacity for aspects of AQM planning through training on new measurement techniques and the development and application of source apportionment or other modeling that leads to a full-scale AQM plan (PM sampling and chemical composition analysis and source apportionment); and finally
iv. to establish a robust and secure system fordata management that allows for public access to air quality and other environmental information.

Activities of the PMEH in Ghana are well aligned with the recently updated Ghana Systematic Country Diagnostic (SCD) which recognizes air pollution as a major development challenge causing economic losses. A new Country Partnership Framework (CPF) 2020-2026 is under preparation and this project responds to the *Focus Area 3: Promoting Sustainable and Resilient Development.* The World Bank launched the latest Country Environmental Analysis (CEA) for Ghana that contained a specific focus on air pollution and includes several recommendations that are aligned with and supported by the updated AQMP.

[1]As set out in the project concept note, March 2018.

In July 2019, the World Bank and the EPA Ghana completed a memorandum of understanding (MoU) which allows the World Bank's technical contractor to lead a consortium of local and international organizations and experts to address the Air Quality Management (AQM) component of the PMEH program. The MoU also outlined how the contractor would improve EPA Ghana's technical and institutional capacity to address air pollution issues by collaborating in the collection of air quality information for GAMA and the conformation of the air quality monitoring system to international best practices.

While the PMEH program had a mandate to establish a "full-scale" air quality management plan for each city that consisted of a list of core components of air quality management (AQM) planning, such as monitoring, inventory, health impact assessment, source apportionment, stakeholder engagement, policy design and implementation, many of these elements were already underway or being supported by other international partners at the time the WB ASA was established. Unique among PMEH pilots, the GAMA pilot is conducted in collaboration with several other development partners who have and continue to support EPA Ghana in their AQM planning efforts. This report highlights AQM planning achievements that resulted directly from the PMEH-funded activities, but also features several AQM planning advances that occurred through coordination and participation of other international partners working toward a common objective of advancing AQM planning for GAMA.

This report provides a synthesis of the key project outputs and outcomes of the PMEH Advisory Services and Analytics (ASA) in GAMA, before briefly exploring recommendations and initiatives that could potentially serve as a basis for continued collaboration with the WBG or other international partners.

3. PROGRAM OUTPUTS AND OUTCOMES

As a result of this report and the support of the PMEH multi-donor trust fund, AQM planning in GAMA has advanced significantly. The following sections walk through the outputs and corresponding outcomes across a variety of areas that have strengthened AQM planning capacity at EPA Ghana and within other partner institutions working with EPA Ghana to reduce air pollution in Accra and other cities and towns of Ghana.

Enhanced Capacity

Outputs: Through a technical support contract, a program of training and capacity building provided a range of training for EPA Ghana staff on AQ monitoring procedures and protocols related to:

- Gravimetric $PM_{2.5}$ sampling and analysis,
- Continuous $PM_{2.5}$, Black Carbon (BC) and meteorological measurement,
- Laboratory analysis of metals by Atomic Absorption Spectroscopy (AAS), ions by Ion Chromatography (IC) and organics by Gas Chromatography with Mass Spectrometry (GCMS),
- Receptor modeling using Positive Matrix Factorization (PMF) statistical software, and
- Data management, including validation

This training had initially been planned as a series of live in-person workshops and trainings using mostly international expert training; but was modified due to the COVID -19 pandemic restrictions on travel to utilize on-the-ground expertise based at the University of Ghana, combined with virtual implementation of video and zoom instruction to achieve project objectives in a timely manner.

Outcomes: EPA Ghana now has an enhanced understanding of the importance of rigorous attention to standard operating procedures and quality assurance protocols necessary for high quality gravimetric analysis. They have improved understanding of the temporal and spatial patterns of air pollution across GAMA and the role of various emission sources and natural events in contributing to poor air quality. EPA Ghana has not mastered source apportionment but has advanced in their capacity to analyze additional constituents of fine particulate matter and to use PMF receptor model software so that as they continue to collect and analyze additional samples, they will be able to conduct ongoing source apportionment and better understand the sources contributing to air pollution now and be able to identify any changes in the future.

Enhanced Understanding of Spatial and Temporal Patterns of Air Pollution Through Continuous AQ Monitoring

Outputs: EPA Ghana has worked with the World Bank and local academics from the University of Ghana to install two new continuous monitoring sites, measuring $PM_{2.5}$, PM_{10}, black carbon, and meteorological variables. These sites are located at University of Ghana in East Legon and at St. Joseph's School in Adabraka and were chosen based on EPA Ghana's monitoring objectives and the ability to collect representative air quality samples at the appropriate spatial scale (Figure 5). Table 2 provides a detailed description of the equipment installed at each continuous site.

Improved Knowledge of Health and Economic Impacts of Air Pollution in GAMA

PMEH in collaboration with EPA Ghana organized a dissemination workshop on Air Quality Management in Ghana. The event brought together government officials, academia, researchers, NGOs, CSOs and the media to discuss the growing problem of air pollution in Ghana and how the World Bank is supporting Ghana in Tackling Air Pollution. The workshop enhanced the knowledge of NGOS, CSOs and media to carrying out environmental campaigns, advocacy and awareness raising activities. One of the key outcomes of the workshop is the initiative to establish a coalition of researchers, NGOs, CSOs and the media platform on Environmental and Air Quality in Ghana.

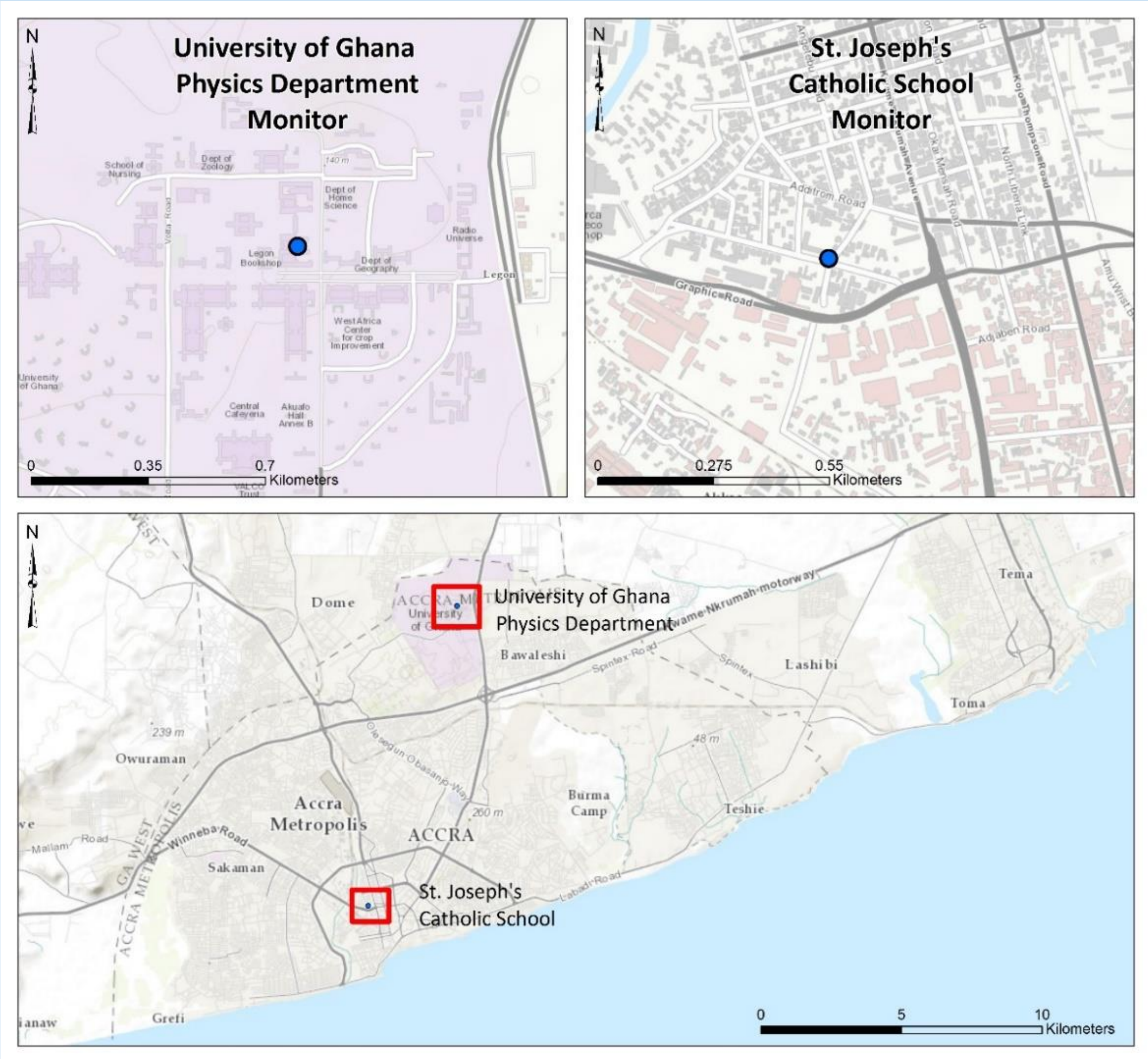

Figure 5: Location of continuous monitoring sites. Source: Greater Accra Metropolitan Areas Air Quality Management Plan, 2018.

Table 2: Instrumentation installed at University of Ghana and Adabraka.

Air Quality Dataset	Supplies	Justification
$PM_{2.5}$, PM_{10}, and $PM_{10-2.5}$	Teledyne API T640	Highly regarded as the next-generation of regulatory monitoring for $PM_{2.5}$. Certified as a Federal Equivalence Method (FEM)- for $PM_{2.5}$ (while also providing non-FEM PM_{10} and $PM_{10-2.5}$ measurements), the T640 provides high accuracy and reliability with limited maintenance compared to alternative analyzers. STI, with the USEPA, developed an SOP for this instrument.
Black Carbon (BC)	Magee Scientific AE33	While there isn't an FRM or FEM designation for BC instruments, as the USEPA does not regulate BC as a criteria pollutant, the AE33 is trusted by research and regulatory groups alike when accurate and long-term BC measurements are needed.
Wind speed and wind direction	R. M. Young 5305V	A robust, widely-adopted, accurate, and field calibratable anemometer, the RM Young 5305V meets or exceeds both the USEPA and World Meteorological Organization (WMO) specifications for wind speed and wind direction measurements.
Temperature and relative humidity	R. M. Young 41382VC	The R.M. Young 41382VC is a high accuracy temperature and relative humidity probe that meets or exceeds both the USEPA and WMO specifications for temperature and relative humidity measurements.

In addition to the deployment of the two continuous monitors and three gravimetric samplers, EPA Ghana has worked with the U.S. Environmental Protection Agency (USEPA) to build upon Accra's existing air monitoring system and deploy a series of low-cost sensors.[2] These efforts included relocating eight active sensors to the neighborhoods of Jamestown (six) and Chorkor (two) to better understand air quality throughout the Neighborhood Pilot intervention project (implemented by E360 in 2019). The sensors relocated to Jamestown originated from Dansoman (two), North Industrial Area (two), and EPA Ghana (two). The sensors relocated to Chorkor originated from East Legon (two). Figure 6 shows the locations of the eighteen air quality sensors in Accra pre- and post-relocation. Sensor locations are classified by whether they were in the Jamestown or Chorkor neighborhoods, or whether they were 'Elsewhere' within Greater Accra.

[2]The low-cost sensors utilized were Clarity Node sensors which measure pollutant levels via a Laser Particle Counter (LPC). Air quality measurements were recorded by the Clarity sensors every minute, in what is considered near real-time, and hourly and daily $PM_{2.5}$ concentrations were estimated as the average of the minute-by-minute data

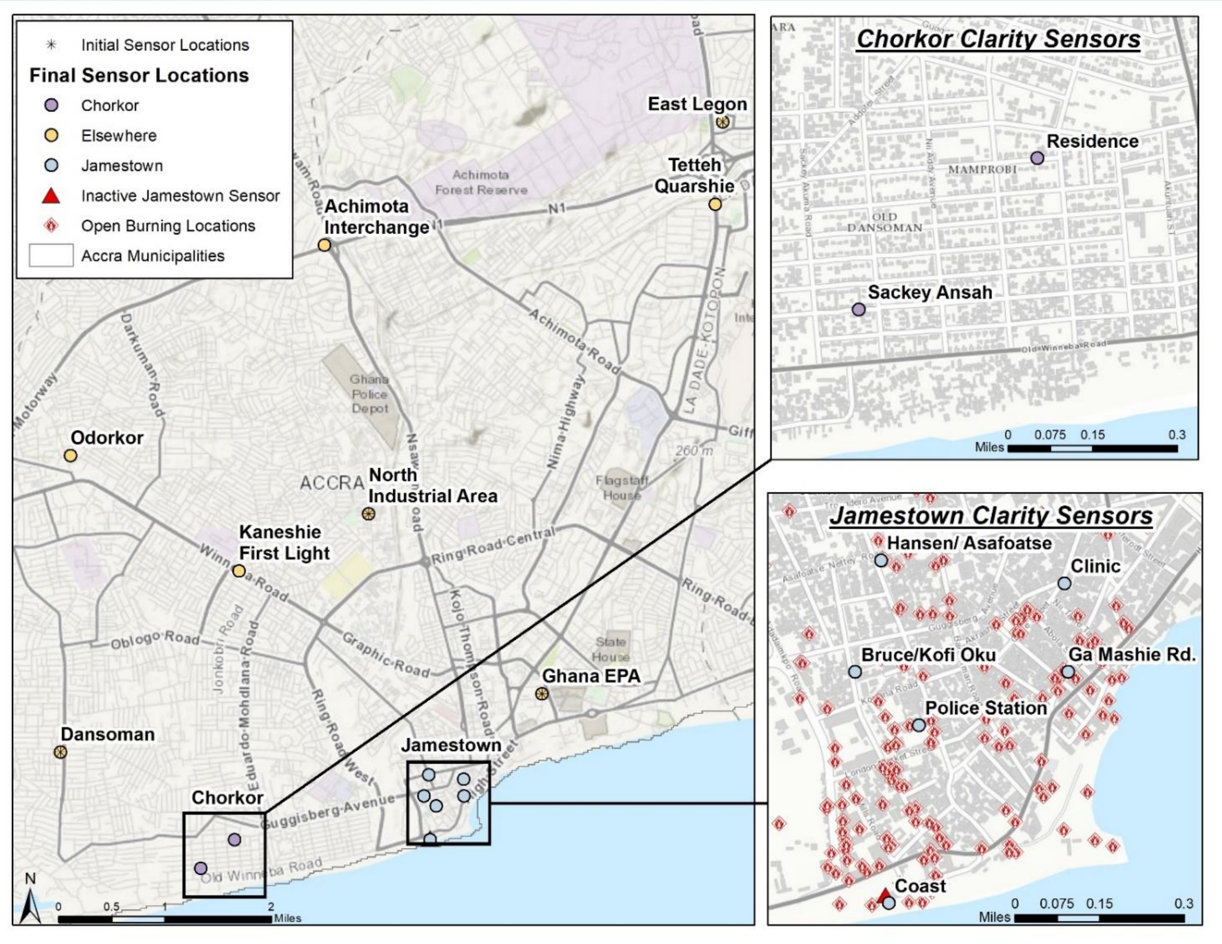

Figure 6: EPA Ghana air quality monitoring network in Greater Accra;
Source: Greater Accra Metropolitan Areas Air Quality Management Plan, 2018.

Air quality monitoring was carried out from July 2018 through February 2020. A gap in data availability for relocated Clarity sensors exists for the timeframe during which they were relocated, April 28th to May 3rd, 2019. A total of 18 sensors collected data during the study period, seven more than in 2015. Additionally, six of the 2015 sites are no longer active: South Industrial Area, Labadi T-Junction, Mallam Junction, Graphic Communication Group Co., Weija, and Kasoa. The estimated annual averages from 2018 – 2020 vary between 16 and 118 ug/m^3 by year and by site, but generally consistent with the values in Table 1. While the low-cost sensor data from this time period has not been calibrated against a reference grade monitor, several of the sensors continue to operate and appear to show results generally consistent with the three FEM monitors in GAMA during 2021. Their co-location during 2021 provided an opportunity to back-calibrate the 2018-2020 sensor data to improve estimates across the city.

Separately from EPA Ghana's monitoring efforts, a continuous $PM_{2.5}$ monitor was installed at the US Embassy in Accra and began recording hourly $PM_{2.5}$ concentrations on January 30th, 2020. The US Embassy data is uploaded automatically to AirNow, an online international air quality data management system.[3] We will be able to use this data in combination with the newly installed continuous data to better understand the distribution of air pollution within Accra and as part of a QA/QC check of the 2020 gravimetric measurements. Figure 7 shows the location of the US Embassy monitor in relation to EPA Ghana's T640 monitors.

[3]https://www.airnow.gov/international/us-embassies-and-consulates/#Ghana$Accra

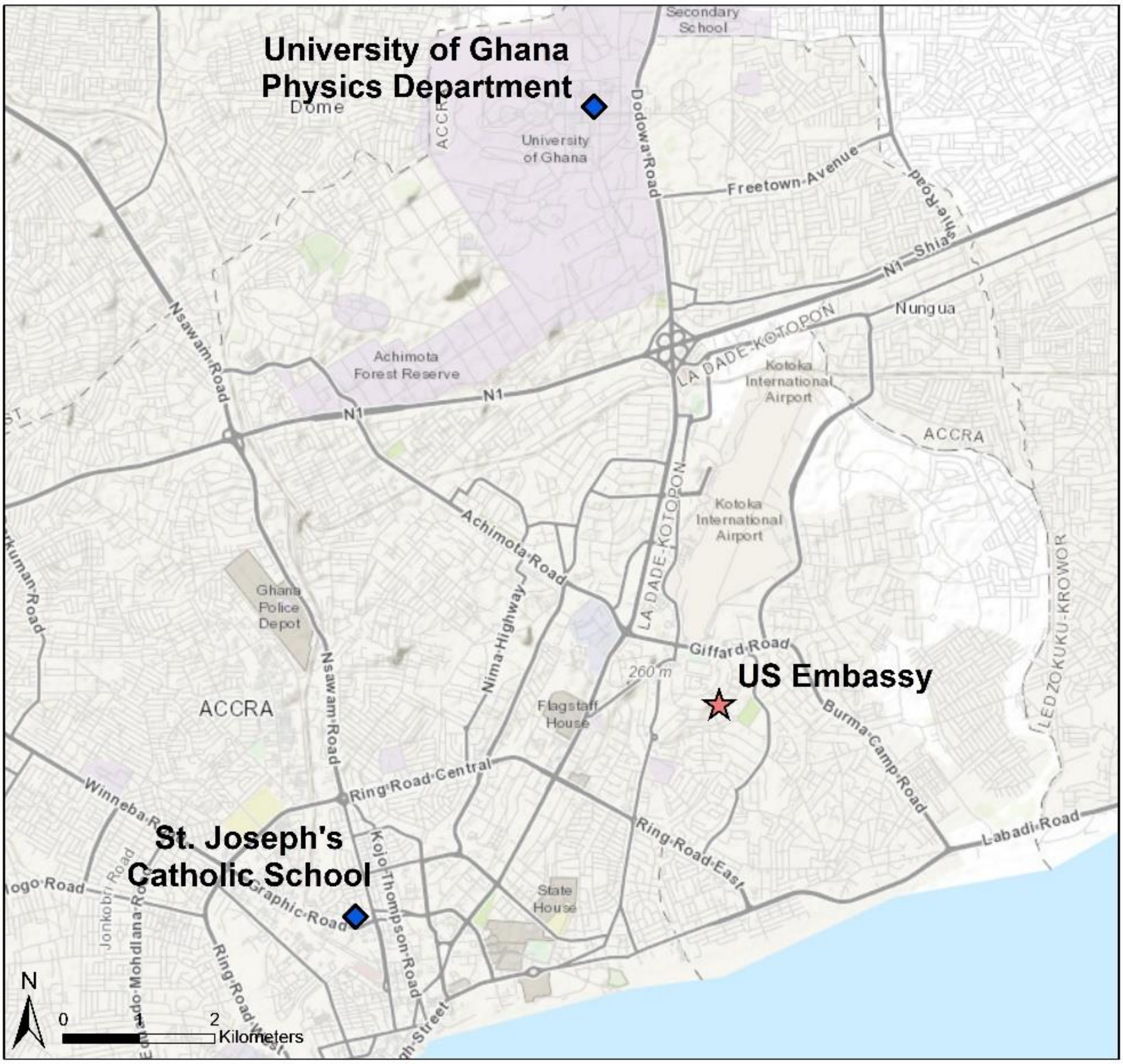

Figure 7: US Embassy and EPA Ghana continuous monitor location.
Source: Greater Accra Metropolitan Areas Air Quality Management Plan, 2018.

While this section outlines a plethora of continuous monitoring that has occurred over the past three years; (summarized and assessed in a separate data report (See Annex A), the project faced challenges in aligning the timelines for this monitoring, given delays in procurement, shipping and finally due to several lockdowns as a result of the COVID 19 pandemic. Despite the fact that not all monitoring has occurred simultaneously, the abundance of data from continuous monitoring has provided a vastly improved understanding of the temporal and spatial patterns of air pollution across GAMA as shown below.

Outcomes:
Figure 8 shows the hourly, daily and seasonal variation in $PM_{2.5}$ concentrations at the Adabraka and University of Ghana sites for January through June 2021 and at the US Embassy site for January 2020 – June 2021. These data provides an obvious enhancement to the temporal understanding of pollution episodes over the 6-day, 24-hour integrated sampling that EPA Ghana had utilized prior to the project. In addition, the ability to calibrate and utilize low-cost sensors, as illustrated in the introduction, vastly improves the spatial understanding of where pollution is greatest and where communities are most exposed.

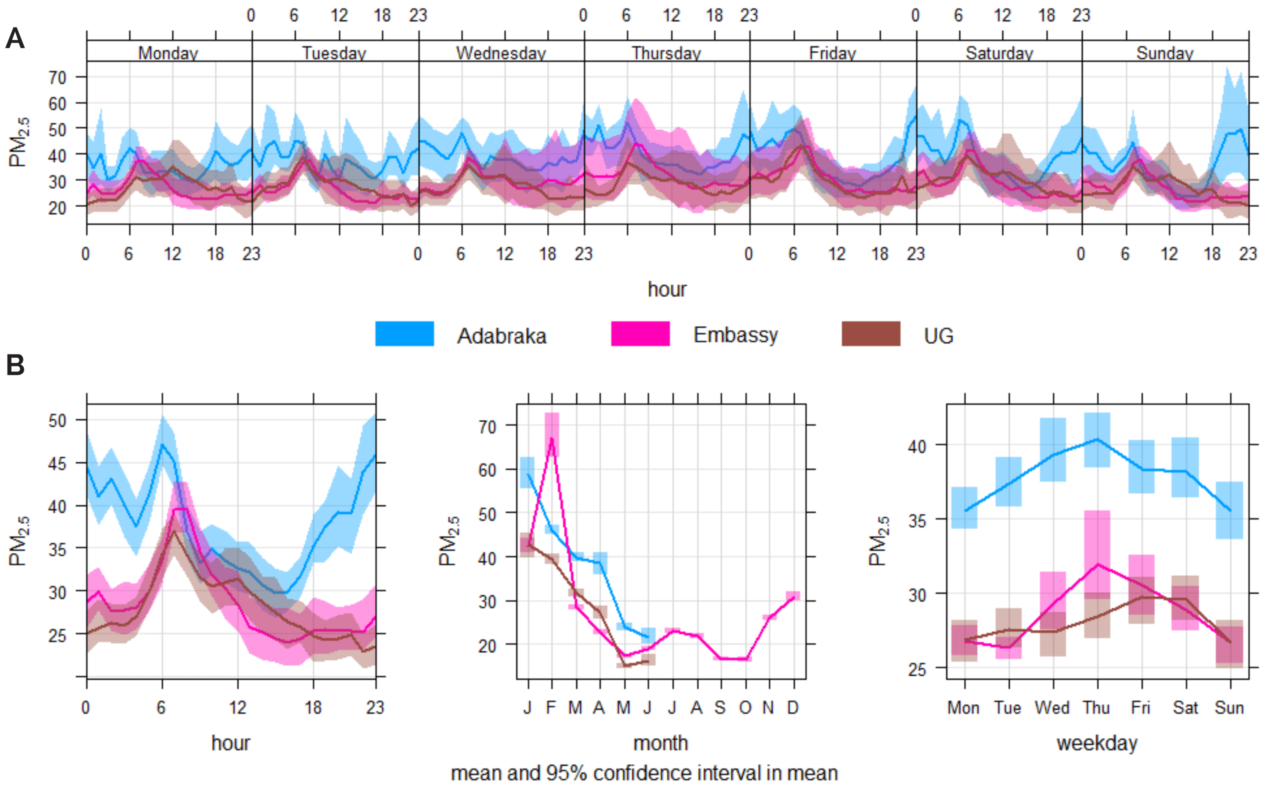

Figure 8. Hourly, daily and seasonal variability in PM2.5 continuous monitor concentrations. Source: World Bank 2021.

Table 3 presents the monthly average $PM_{2.5}$ concentrations across the three monitor locations for the overlapping months of available data. Overall, it appears that the US Embassy monitor records lower $PM_{2.5}$ concentrations. However, this may reflect that the US Embassy measurements are available at hourly intervals while the EPA Ghana measurements for the same months are available at minute-by-minute intervals.

Table 3: 2021 Monthly Average $PM_{2.5}$ concentrations across 3 continuous monitoring sites in Accra

Month	Average $PM_{2.5}$ (µg/m³)		
	EPA Ghana: University of Ghana	EPA Ghana: Adabraka	US Embassy
January 2021	56.9	62.2	41.5
February 21	39.4	46.1	32.0
March 21	31.7	39.8	28.1
April 21	27.1	34.1	24.7
May 21	13.7	23.7	11.2
2021 YTD Average	**32.9**	**40.4**	**29.0**

Note: The two EPA Ghana monthly averages were calculated from minute-by-minute measures while the US Embassy monthly average was calculated from hourly measures.

AQ Monitoring Quality Improvements

Outputs: EPA Ghana has established a Quality Assurance Project Plan (QAPP) consistent with data quality objectives (DQOs) established by EPA Ghana. Standard operating procedures and training consistent with those objectives and audits have been performed to ensure that DQOs are being met. In addition, a data management system has been put in place with validation procedures that enable staff to quickly identify and correct problems before significant data loss occurs and to ensure the routine collection of high-quality data.

For quality control purposes, four additional mini-vol gravimetric samplers were deployed and rotated between each of the three targeted $PM_{2.5}$ gravimetric sampling sites every four weeks. Two of the additional samplers are equipped with quartz filters held in URG Corporation $PM_{2.5}$ impactors and run at 2.0 lpm. The other two samplers are equipped with URG Corporation $PM_{2.5}$ cyclone inlets to sample with Teflon filters at 5.0 lpm. Due to the fact that the four additional mini-vol samplers are different models compared withthe mini-vols that were deployed as part of this project, the filters collected for each filter-type from each of the three mini-vols at a targeted site can be used to analyze both the equipment and the analytical laboratory process. Quartz filters continue to be sent to the University of Colorado Boulder for organics audit; while the Teflon filters continue to be sent to the audit lab at the University of Denver for metals audit.

Outcomes: New measurement methods have been employed and analysis has occurred that has identified several potential quality issues that need to be addressed in order to meet the established DQOs. As shown in Figure 9, new continuous methods of measurement and low-cost sensors show significantly lower ambient concentrations relative to gravimetric measurements (particularly on Quartz filters). A review of existing operational procedures - to be addressed through strict adherence to new SOPs and QA protocols - is critical to identifying the reason for any discrepancy and achieving DQOs established for these measurements. EPA Ghana is committed to understanding these issues and conducting studies to resolve and eliminate operational issues that contribute to systematic biases between methods and improve overall accuracy to achieve DQOs.

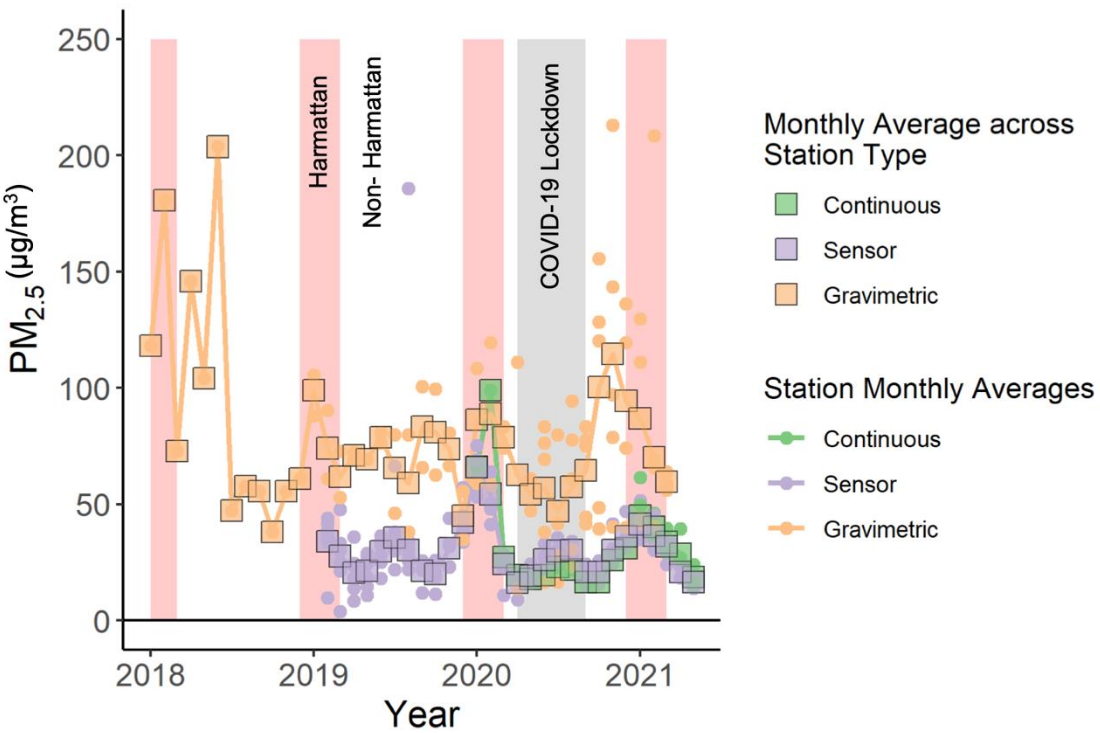

Figure 9. Monthly average $PM_{2.5}$ concentrations by station type for Accra network. Source: World Bank 2021.

The data for the continuous monitors maintained by EPA Ghana can be accessed through the Konect system online (Exhibit 6.1). [12]You must have a Konect account authorized by EPA Ghana to access this data.

With PMEH support, EPA Ghana has established a cloud-based Campbell Konect data management system to upload, store and query the continuous equipment for measures of BC, $PM_{2.5}$, PM_{10}, relative humidity, wind speed and direction, and temperature across the Adabraka and University of Ghana locations at varying time steps and temporal scales. These queries can be viewed directly on the site as tables, graphs, and charts or can be downloaded for external analysis. The Konect system also allows the user to set up and manage alerts triggered by outlying data, quality assurance checks, or validation requirements. Figure 10 shows an example query. A detailed Standard Operating Procedure (SOP) document has been developed with detailed instructions on how to perform a query, with an expanded description of query options.

This system will also support the real-time production of an online AQI for public dissemination of air pollution levels for all continuous data after validation and authorized release.

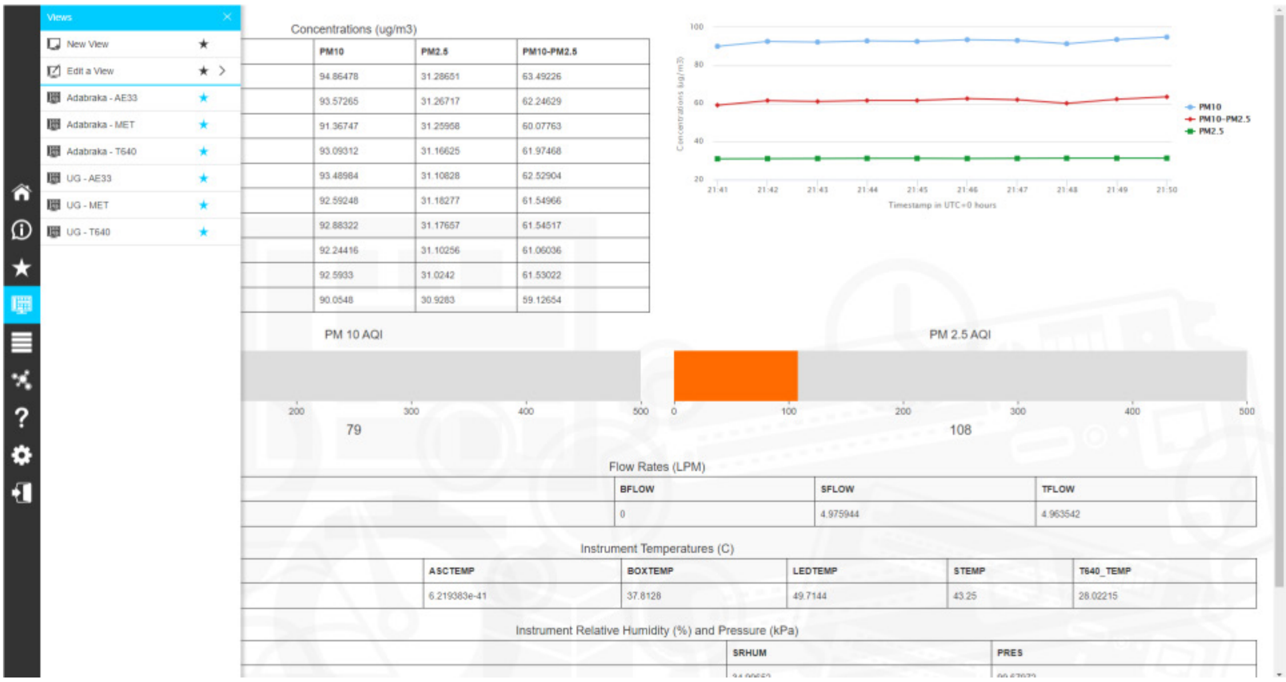

Figure 10. Screen view of Campbell Konect data management system for review and validation of continuous air quality data. This figure shows an example of Adabraka PM concentrations as tables, graphs and AQI's along with corresponding meteorological measurements. Source: World Bank 2021.

Understanding Key Sources of Air Pollution Through Source Apportionment Analysis

Outputs: EPA Ghana, with World Bank PMEH support, has pursued a number of actions to improve their understanding of which sources contribute to air pollution quantitatively. EPA Ghana maintains a laboratory with a gas chromatograph/mass spectrometer (GC-MS), ion chromatograph (IC), and atomic absorption spectrometer (AAS). These analytical devices require consistent tending, maintenance, and consumable supplies, including access to gases like Helium to consistently keep the GC-MS in vacuum for optimal function. Due to funding and access constraints and having received these devices secondhand, EPA Ghana has struggled to keep consumables in stock and therefore have struggled to keep the equipment functioning in a way that would facilitate quick and efficient analysis of gravimetric samples.

As part of our ongoing capacity building with EPA Ghana and its laboratory team, some of the previously non-functional analytical devices critical for processing atmospheric samples have been brought online in the EPA Ghana laboratory and are anticipated to facilitate source apportionment analyses on past, current, and future gravimetric datasets. At the time of this report draft, we are presenting the partial speciation results of sampling efforts performed in 2019. These results include measures for:

- Elemental Carbon (EC) and Organic Carbon (OC) fractions using a Sunset Analyzer;
- Trace organic species using gas chromatography with mass spectrometry (GC-MS) quantification methods; and
- 46 emissions source molecular markers using the Positive Matrix Factorization (PMF) tool.

The 2019 analytic results include only organic species as measured on quartz filters from gravimetric samplers using GC-MS at the University of Colorado Boulder (CU Boulder). The 2019 results do not include an analysis of the inorganic ions and target metals contributions. While we did not attain complete analysis and understanding of other mass sub-fractions of the $PM_{2.5}$, the carbonaceous and organics analysis still provides valuable groundwork and proof of concept for future source apportionment efforts from within EPA Ghana's air monitoring division.

In terms of sample collections, 71 24-hour quartz fiber filter samples were collected between January 26 and May 26, 2019 at five roadside monitoring sites in greater Accra (Figure 11). EPA Ghana and CU Boulder analyzed these samples for organic carbon, elemental carbon (similar to black carbon) and several organic markers by GC-MS. We measured average concentrations of $PM_{2.5}$ across the five sites to be 74.4 μg/m^3. Figure 12 shows individual site concentrations and compositions. The average OC and EC concentrations across all sites were 15.4 μg/m^3 (21%) and 8.3 μg/m^3 (11%), respectively. Although non-carbonaceous matter composes a majority of the $PM_{2.5}$ mass at all sites, we observe that the sampling sites in Kaneshi, Tetteh Quarshie, and Mallam Junction experience elevated EC concentrations compared to the sites in Tantra Hill and Amasaman.

Figure 11. 2019 Roadside source apportionment sampling sites in Accra (Stars denote site locations) . Source: World Bank 2021.

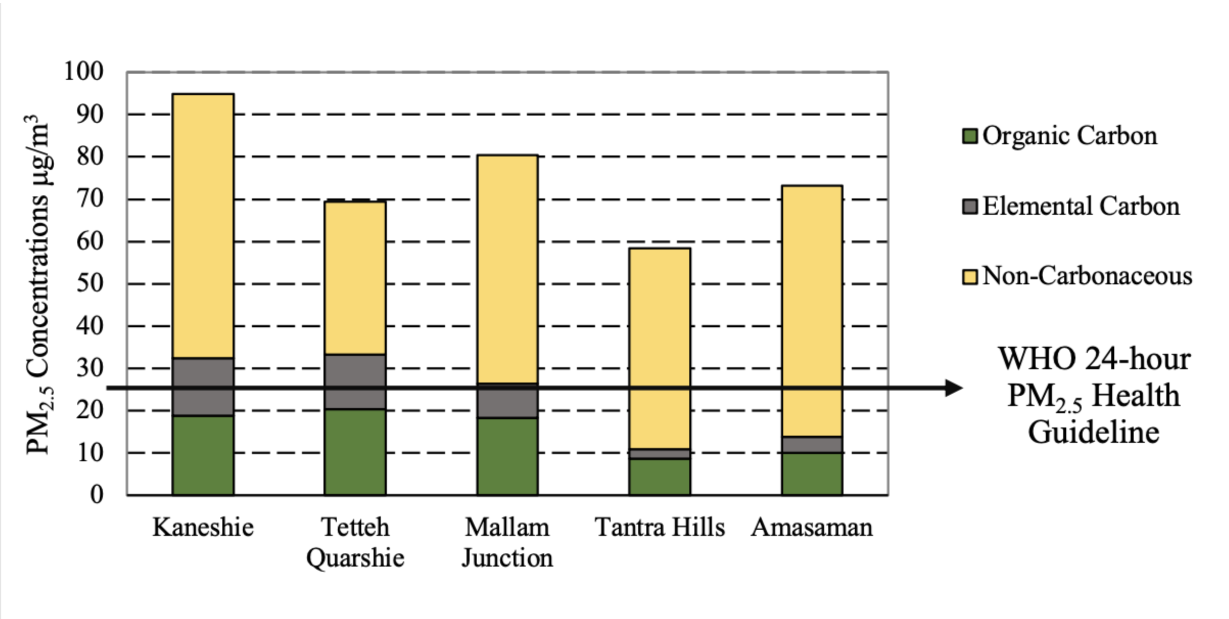

Figure 12. 2019 PM2.5 concentrations and fractional composition by site at five roadside sites. Source: World Bank 2021..

From the extractable fraction of OC, CU Boulder was able to quantify the mass concentrations of 46 molecular markers for use in the apportionment of specific sources contributing to the carbonaceous fraction of roadside $PM_{2.5}$. Target compounds were selected for monitoring and estimating emission activity from vehicle activity, wood combustion, biogenic emissions, and various types of potential open- burning of waste. CU Boulder used the EPA's PMF 5.0 tool (Norris et al. 2014) which mathematically identifies correlation between the molecular tracers within the dataset and creates source profiles that can reliably explain their concentrations across the samples. A final six-factor solution was selected that represented the best statistical fit while also based on known emission sources surrounding the sampling sites. That solution identified wood combustion, plastic waste burning, two separate vehicle profiles, an unidentified but strong source of Bisphenol-A (BPA), and a factor that contained potential signatures from meat cooking and smoldering waste (Mixed Sources). Figure 13 shows the resulting factor median contributions to OC and EC at each of the five sites.

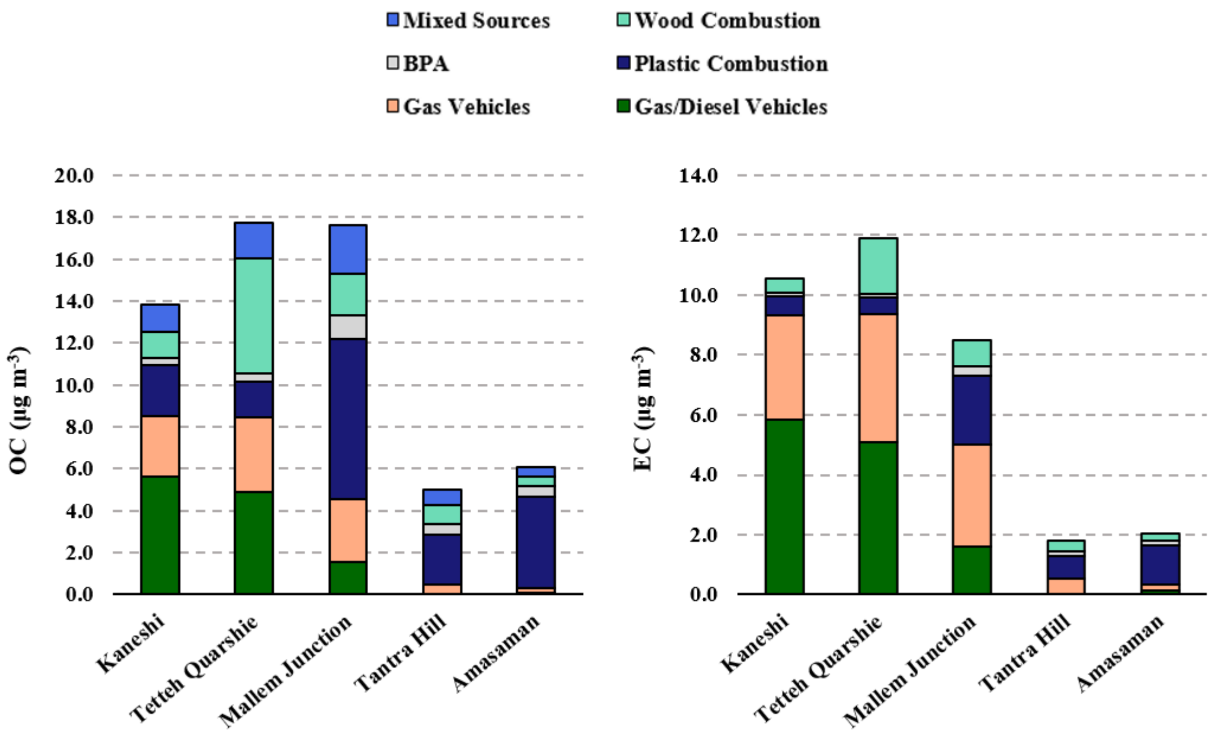

Figure 13. Potential source contributions to carbonaceous fraction of $PM_{2.5}$ at roadside sites in Accra, Ghana in 2019. Source: World Bank 2021.

In addition, three new gravimetric $PM_{2.5}$ samplers were deployed at the Adabraka, University of Ghana, and Dansoman sites (Figure 14) to collect filter samples necessary for source apportionment analyses at these non-roadside sites. EPA Ghana deployed one ARA N-FRM mini-vol (16.7 liters per minute flow rate) gravimetric integrated samplers and one Airmetrics MiniVol (5.0 liter per minute flow rate) gravimetric integrated samplers at each site to collect $PM_{2.5}$ on both Teflon and quartz filters. These samplers collect a 24-hour sample every six days and continue to be collected, stored, and analyzed in the laboratory at EPA Ghana to identify metallic, organic, and ionic species collected.[4] In conjunction with gravimetric samples (mostly PM_{10}) that EPA Ghana has been collecting since 2005, these samples will be analyzed via chemical speciation to determine emissions sources related to ambient $PM_{2.5}$ concentrations.

To date, CU Boulder has received and analyzed 36 24-hour quartz fiber filters for the carbonaceous fraction of $PM_{2.5}$. The filters analyzed were collected between August 7, 2020 and May 16, 2021 from the three non-roadside monitoring sites, two of which are located alongside a Federal Reference Monitor (FRM) shown in Figure 14. At the time of this report, we present the EC and OC concentrations from these samples.

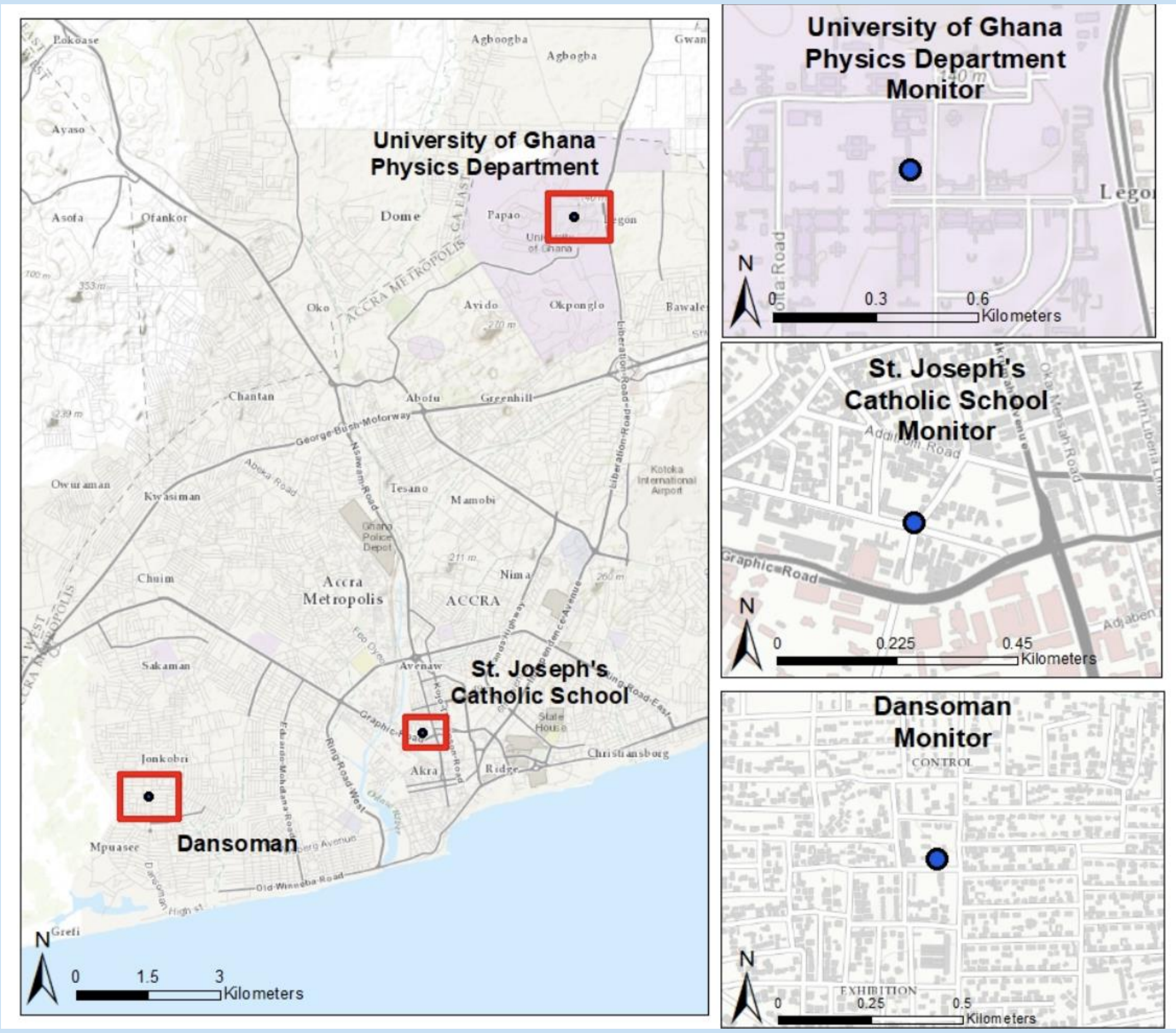

Figure 14. 2020 non-roadside source apportionment sampling sites. The St. Joseph's School site is also referred to as Adabraka, the neighborhood in which it is located. Source: World Bank 2021.

[4]Metallic species quantified may include: Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Br, Rb, Sr, Zr, As, Mo and Pb. Ionic species quantified will include: NO_3^-, SO_4^{2-}, Cl^-, Na^+, NH_4^+, and K^+. Organic species categories will include: Alkanes, Alkanoic acids, PAHs, Hopanes, Methoxyphenols, and plastic burning tracers

Average concentrations of the 2020 collected $PM_{2.5}$ across the three sites is 120.1 μg/m³, individual site concentrations and bulk compositions are plotted in Figure 15. The average OC and EC concentrations across all sites are 5.8 μg/m³ (4.8%) and 1.2 μg/m³ (1.0%) respectively. Note that four samples (two at Adabraka and two at University of Ghana) are excluded from these calculations as they are missing the total $PM_{2.5}$ mass concentrations. As with the 2019 roadside results, the non-carbonaceous matter composes a majority of the $PM_{2.5}$ mass at all sites. While Dansoman and University of Ghana present comparable OC (0.53 μg/m³ and 0.67 μg/m³, respectively) and EC (4.8 μg/m³ and 4.2 μg/m³, respectively) concentrations, Adabraka displays elevated OC concentrations (11 μg/m³) and EC (3.3 μg/m³) Average concentrations of the 2020 collected $PM_{2.5}$ across the three sites is 120.1 μg/m³, individual site concentrations and bulk compositions are plotted in Figure 15. The average OC and EC concentrations across all sites are 5.8 μg/m³ (4.8%) and 1.2 μg/m³ (1.0%) respectively. Note that four samples (two at Adabraka and two at University of Ghana) are excluded from these calculations as they are missing the total $PM_{2.5}$ mass concentrations. As with the 2019 results, the non-carbonaceous matter composes a majority of the $PM_{2.5}$ mass at all sites. While Dansoman and University of Ghana present comparable OC (0.53 μg/m³ and 0.67 μg/m³, respectively) and EC (4.8 μg/m³ and 4.2 μg/m³, respectively) concentrations, Adabraka displays elevated OC concentrations (11 μg/m³) and EC (3.3 μg/m³).

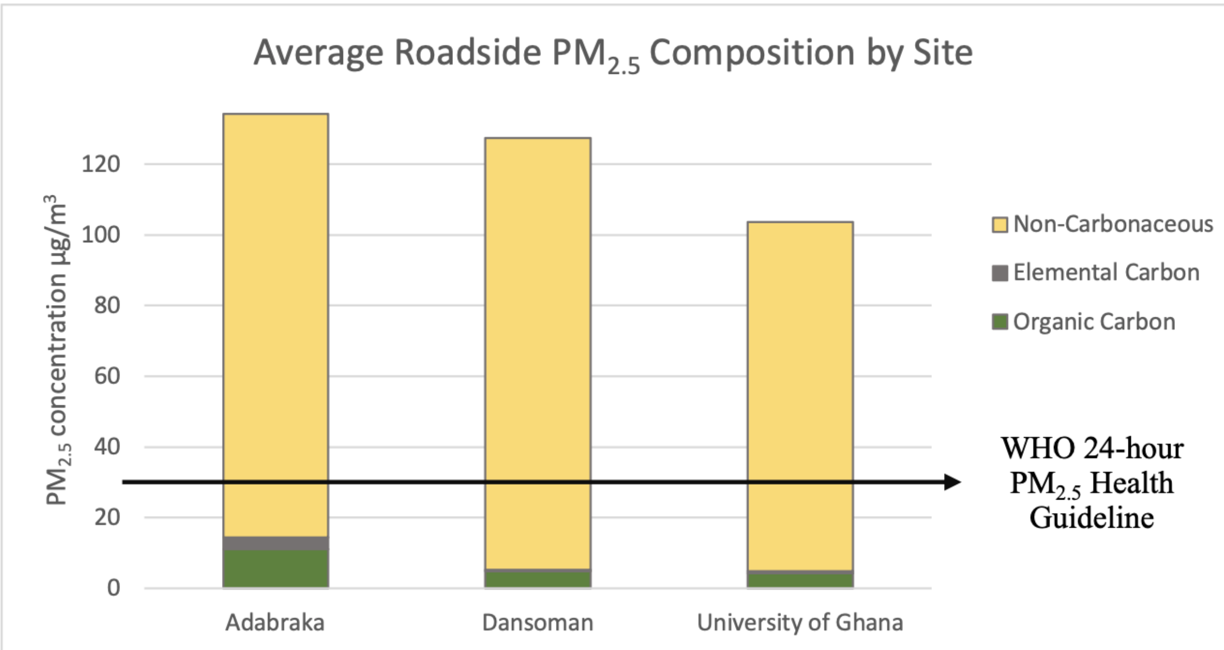

Figure 15. 2020 $PM_{2.5}$ concentrations and fractional composition by site at three non-roadside sites. Source: World Bank 2021.

The elevated EC and OC concentrations observed at Adabraka likely reflect increased traffic in the area, as well as increased e-waste and refuse burning, compared to the sites further from Accra's city center at Dansoman and University of Ghana. The lighter traffic density experienced at the University of Ghana and Dansoman sites, which reduces the influence of vehicle emissions, is also reflected by the higher OC to EC ratios (6.7 and 8.5) than is seen in Adabraka (3.7). As with the Tantra Hill and Amasaman sites in 2019 the higher ratios of OC to EC at Dansoman and University of Ghana are likely caused by mixing and transport of OC from secondary formation and from other combustion sources with varying ratios of primary OC and EC emissions.

Because larger datasets provide great robustness for PMF analysis, we combined the quantified results from samples collected during this project with those quantified from EPA Ghana's roadside filter collection network. The samples quantified from the two filter collection networks span different, non-overlapping sampling periods. We thus make the assumption that emission sources contributing to the organic fraction of PM did not deviate too greatly between the two time periods, and that source apportionment analysis can still provide meaningful insights into common, non-seasonal, emitters in Accra. We obtained a five factor PMF solution using the complete dataset of speciated organic tracers. Chemical profiles were resolved and are shown in Figure 16. Because a majority of the dataset fed into the PMF analysis was from the roadside filter collection network, the profiles from this analysis are similar to those from the PMF analysis of the roadside filters. No substantial changes to the resolved profiles are noted due to the addition of filter samples from Adabraka, University of Ghana, and Dansoman. The only substantial change in the analysis was the presence of a stronger correlation between BPA and the vehicle and plastic burning tracers in the 2020 filters, resulting in a stronger fit of the five factor solution where BPA did not emerge as an independent source.

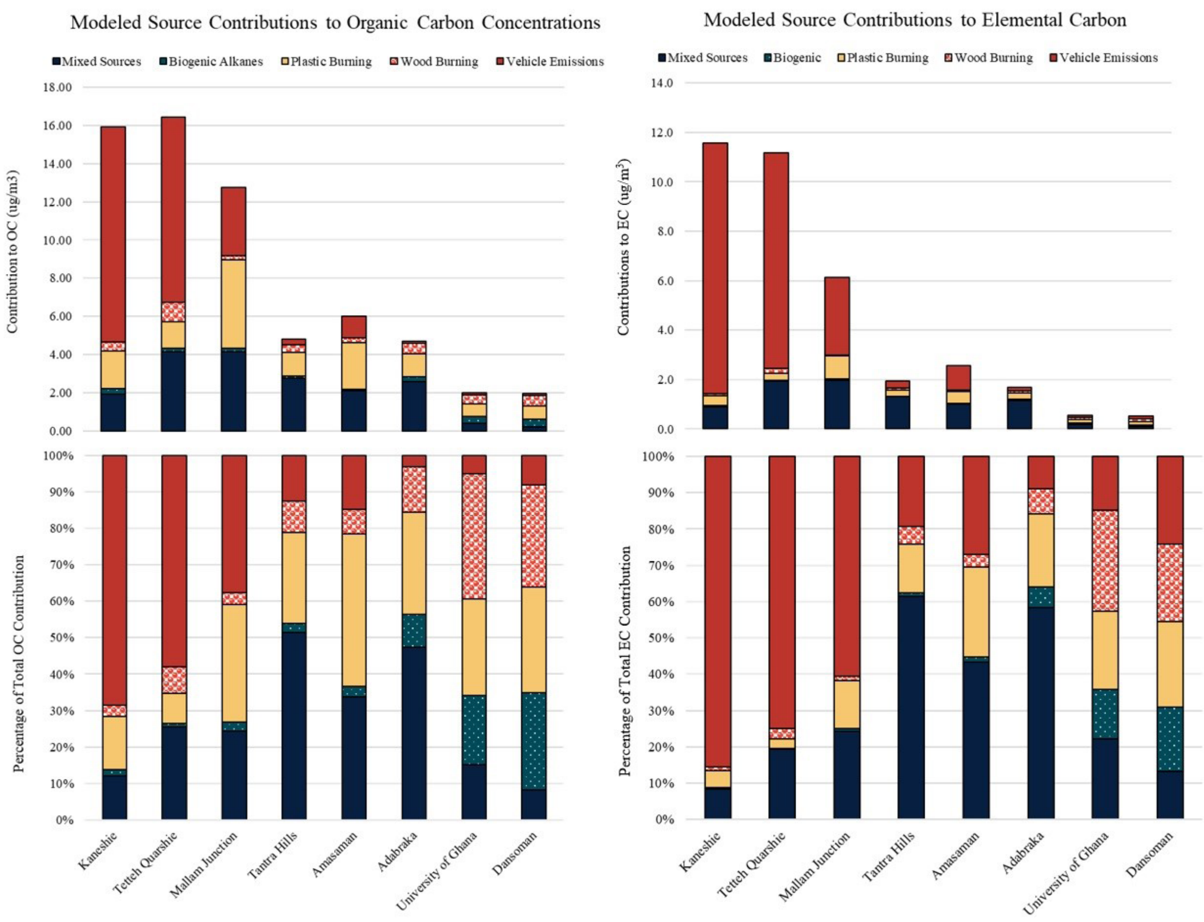

Figure 16. Source contributions to organic carbon (left) and elemental carbon (right) across the eight filter collection sites in Accra.
Source: World Bank 2021.

Outcomes: Source apportionment analyses for samples collected from roadside sites in 2019 indicate the majority of $PM_{2.5}$ concentrations are derived from standard petrol combustion and diesel vehicle combustion. The fraction of EC at each site is related to primary elemental particles from combustion while the fraction of OC at each site is related to secondary formation of organic particles. Mallam Junction experiences a larger fraction of particles due to waste burning than the other sites, as this monitor is located approximately 100 meters upwind of a major dump site.

Preliminary source apportionment analyses of filters collected at the Adabraka, UG, and Dansoman sites in 2020/2021 find that the ratio of elemental carbon (EC, which is similar to "black carbon" or BC) to organic carbon (OC) is highest at the Adabraka site and lower at the UG and Dansoman sites, indicating more primary emissions near Adabraka than the other non-city center sites.

A combined analysis of all sites between 2019 and 2021 shows that though individual days showed specific profiles contributing larger fractions to the overall OC and EC, on average no singular emission source was identified as a major contributor at these sites. Adabraka, which in general has higher measured concentrations of carbonaceous PM, showed the greatest contribution to OC and EC from the mixed sources profile, while University of Ghana and Dansoman both showed greatest contribution from wood burning. With the exception of Kaneshie, Tetteh Quarshie, and Mallam Junction, the sites in this network are located away from any dominating pollution source, and represent a potential assessment of the background carbonaceous PM in Accra. However, the non-carbonaceous fraction that cannot be analyzed as part of EC/OC make up the majority of particles at each of these sites. Ongoing analysis of metals and ions will help identify the origin of the non-carbonaceous fine particulate.

EPA Ghana continues to collect source apportionment samples and has enhanced capacity to assess all components of PM2.5 and perform receptor modeling on the results moving forward.

Household Air Pollution

Outputs: A key contributing factor to AAP in Accra is household air pollution (HAP), which has been shown to cause the same harmful health effects as AAP including cardiovascular, and respiratory diseases and premature death. With HAP being responsible for over 11,000 premature deaths in Ghana alone, it is imperative that policy and decision-makers consider a course of action that will promote adoption and sustained implementation of cleaner fuels and more energy efficient technology within homes (GBD/ State of Global Air 2020). These health effects cost 2.3 percent of Ghanaian gross domestic product (GDP) yearly – or the equivalent of $1.4 billion U.S. dollars (CEA, World Bank 2020). As part of PMEH support, a review was carried out on clean cooking intervention implementation factors and limitations in transitioning from traditional to cleaner energy technologies in support of reducing HAP exposures in Accra. The review assesses current knowledge and provides perspective on setting effective HAP guidelines in the local Accra context. Based on the review of current peer-reviewed literature on HAP, a recommendation that EPA Ghana consider setting an initial HAP guideline for Accra to promote improved ambient and household air quality has been included within the AQMP mid-term review recommendations.

The Kintampo Health Research Centre and Ghana Health Service, in collaboration with Researchers at Columbia World Projects, Columbia University, and the University of California (USA) conducted *The Ghana Energy Use Survey* in all 16 regions of Ghana between 19 February and 27 March, 2021. The survey instrument was designed to capture pertinent household demographics and important determinants of cooking fuel usage, as observed in previous studies in Ghana and around the world. Key areas of focus included cooking fuels and technologies, energy costs, and energy needs. We also investigated household knowledge and perceptions about cooking, health, and new cooking technologies. These data will help inform the efforts to promote a sustainable, equitable transition to clean household energy in Ghana.

The WHO Urban Health Initiative (UHI) also developed an integrated framework to enable local policymakers to evaluate and identify evidence-based strategies to reduce the burden of air pollution. Based on the results of WHO UHI training workshops on using available tools at that workshop conducted by the Household Energy Group in Ghana 3–6 July and 13–16 August 2018, the UHI team developed a report providing an evidence-based framework to compare the impacts of different urban policies on health and provide an assessment of whether current efforts are likely to achieve policy goals over the next 10 years.

Outcomes: Based on the range of new data and analytics available on residential energy use and the implications of reducing solid biomass combustion in homes, EPA Ghana is set to evaluate the magnitude of impact of interventions, perform a risk bias evaluation and assess the certainty of evidence used in the proposed new guideline, which has been based on an improved local database and knowledge of HAP impacts and costs relative to what was available prior to the PMEH program.

Improved Knowledge of Health and Economic Impacts of Air Pollution in GAMA

Ouputs: As part of the routine review of environmental issues that the World Bank undertakes with all client countries, the 2020 Ghana Country Environmental Analysis (Ghana CEA, World Bank 2020) included a specific chapter on air pollution during this cycle. This work included a baseline assessment of air quality and the mortality and morbidity burden of air pollution in both urban and rural settings across the country. This project thus enabled a Cost of Environmental Degradation analysis that quantifies and monetizes the impact of air pollution on the population. The report also included a review of the role that household air pollution plays in contributing to ambient air pollution in both urban and rural settings and illustrated the distributional impacts of air pollution, which is often at its worst in the poorest neighborhoods. Finally, a review of the air pollution governance framework highlighted both opportunities as well as gaps and challenges for the government in addressing air pollution nationally.

Outcomes: The recommendations from the CEA are provided below in Chapter 4 and serve as a key input for the GAMA AQMP mid-term review. These recommendations are broken down by timeframe and have been incorporated into recommendations for the AQMP implementation matrix that will guide AQM planning in GAMA over the next two and half years until the next scheduled AQMP update.

Improved Stakeholder Engagement on AQ Management

Outputs: Both before and after the August 2018 launch of the AQMP, many local and international stakeholders became involved in air quality management work in Accra. Industrial Economics, Inc., has provided support to the USEPA and World Bank for their engagements with EPA Ghana to first draft the AQMP and to install new air quality monitors to expand EPA Ghana's air quality monitoring network. Since the time of the AQMP launch, the World Bank has hosted quarterly calls with organizations involved in local air quality management. The purpose of these calls was to share the work that each institute has been engaged in to allow for collaboration and to reduce redundancy of efforts, acknowledging the resources required by local government staff to manage projects with external groups. These stakeholder meetings have included project team members from the USEPA, World Bank, World Health Organization, ICLEI, UN Habitat, UN Environment, Columbia University, University of Colorado Boulder, Stockholm Environment Institute (SEI), University of Cape Coast, University of Ghana, Sonoma Technology, Carnegie Mellon University, University of Massachusetts, C40 Cities, Climate and Clean Air Coalition, Environment 360, and the U.S. Embassy in Accra.

Outcomes: Coordinated air quality improvement efforts within the city include:

- Climate and Clean Air Coalition/WHO's Urban Health Initiative, working with EPA Ghana and the Accra Metropolitan Authority to understand the impact of air pollution on the local community's health;
- Environment 360's open burning intervention in Jamestown, working to provide education to the local community to reduce open burning of waste;
- USEPA, Carnegie Mellon, and Columbia University's deployment of a low-cost sensor network;
- University of Massachusetts Amherst's air quality measurement project, which has collected continuous measurements of $PM_{2.5}$, NOx, and black carbon at 150 sites across Ghana, working to generate high-resolution land use regression models to understand local health impacts and to analyze the relationship between

air pollution exposure and respiratory infections in children born to exposed mothers;

- C40's Climate Change Resilience Plan, Climate Action Plan and Air Quality in Climate Action Planning Project (CAP-AQ), which is supporting Accra by estimating the air quality and health implications of Accra's climate change mitigation scenarios, as recently published in the city's Paris-compatible Climate Action Plan;
- SEI, supported the development of emissions inventory specific to the city of Accra; and
- World Bank and Industrial Economics, working with EPA Ghana deploy continuous (at two sites) and gravimetric (at three sites), air quality monitors providing training and maintenance of laboratory instruments necessary for gravimetric analysis of filter-based air quality samples, and support data management, analysis, and source apportionment efforts.

Many of the products of this activity are featured in this report and have been incorporated to various extents into the mid-term review process of the GAMA AQMP.

A new partner, The Clean Air Fund, has launched an African Air Quality Initiative that is poised to potentially continue support for enhanced AQM planning in Accra, including many of the recommended actions listed in Chapter 4. In addition, the U.S. Department of State is pursuing support on a regional scale and is considering various grantees and many of the partners currently working with EPA Ghana listed above are in contention for this funding.


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4. LESSONS LEARNED, RECOMMENDATIONS AND CRITICAL NEXT STEPS

The efforts undertaken through the PMEH project have provided insight into the most important and critical next steps that need to be taken in support of EPA Ghana's air quality management efforts in Accra. Supporting EPA Ghana with their work in Accra will help to create a model that the agency can use and apply in other major cities with air quality concerns, including Kumasi and Takoradi, where there is interest in better understanding ambient pollution. Further, support of EPA Ghana will help to solidify EPA Ghana as a regional leader in air quality measurement and management that will allow dissemination of expertise within West Africa and sub-Saharan Africa as a whole.

World Bank Country Environmental Analysis Recommendations

The 2020 CEA explored several aspects of AQM planning that could serve the GoG in advancing environmental management nationally and recommendations have been broken down by time-frame in Box 1 below.

Box 1. Recommendations to Improve Air Quality (Source: Ghana Country Environmental Analysis, World Bank, 2020).

Short-term Recommendations (1-2 years)

- Improve enforcement of existing air pollution regulations (MESTI/EPA)*
- Finalize the draft AQM policy (Cabinet, MESTI)
- Create a multi-stakeholder platform to coordinate AQM planning across public, pri vate, non-profit sectors (Cabinet)
- Reinforce/recruit staff with proper training and expertise in AQM to document levels of air pollution, monitor trends, and quantify improvements (MESTI/EPA)
- Make the case for clean air policies as an avenue to protect human capital and develop economic opportunities (MESTI/EPA)
- Establish a robust data management and public data dissemination system that can support decision-making and provide information to the public on when to take self-protective measures (MESTI/EPA)
- Support behavior-change communication that helps households, especially women, to adopt practices that reduce health risks from HAP (MESTI/EPA)

Medium-term Recommendations (2-5 years)

- Bolster the institutional framework in a way that facilitates achievement of AQM policy objectives, e.g. creation of a "Clean Air Czar/Commissioner" (Cabinet, MESTI)
- Enhance AQM regulatory and enforcement authority of the EPA (Parliament, MESTI)
- Author HAP/AAP guidelines, regulations, by-laws that account for socioeconomic and cultural differences across neighborhoods and rural/urban settings (Parliament, MLGRD/MMDAs)
- Maintain collaboration with Nigeria and other Economic Community of West African States countries to reduce vehicle emissions: setting limits for sulfur in fuels at <50 ppm‡ (MESTI)
- Lower import duties on environmentally friendly cars; raise duties on higher-emission secondhand vehicles (MoF/GRA)
- Transition away from solid biofuels; establish HAP guidelines for clean cookstoves to regulate residential combustion levels (MESTI/EPA, MoTI)
- Analyze causes and effects of trash burning in Accra, other major urban areas and develop suitable policies and mechanisms to prohibit/control it; encourage public-private partnerships to finance municipal services for waste collection, disposal, recycling (MESTI/EPA, MLGRD/MMDAs, MSWR)

Long-term Recommendations (5+ years)

- Improve understanding of air pollution sources; work with universities, research institutes to use existing expertise and build future capacity for analysis of pollution issues (MESTI)
- Provide sustained funding to hire/retain qualified staff to deliver on AQM goals (MESTI, MoF)
- Mainstream and coordinate AQM policy planning, implementation, and enforcement across national, regional, local levels of Government (MDAs, MLGRD/MMDAs)
- Quantify air pollution costs and AQM benefits using natural capital accounting (at macroeconomic level) and cost-benefit analysis (at project level) to target priority sectors for action (MESTI, MoF)
- Given the high personal exposures observed in households using solid biomass fuels, provide air quality monitoring in rural settings to address HAP (Wiedinmyer et al., 2017) (MESTI/EPA)
- Impose sufficient distances between industrial, commercial, residential zones in city planning (MESTI/LUSPA43, MLGRD/ MMDAs)
- Design LPG cookstove interventions for rural and urban communities; study supply chains and market conditions to identify incentives for LPG distribution companies and clean cookstove manufacturers/suppliers; target subsidies to transition away from solid biomass fuel use; employ results-based financing to reach program goals (e.g. World Bank, 2016) (MESTI, MoTI)

Notes:
*Acronyms for all agencies and departments are provided in the acronyms list at the front of this document.
ǂSetting limits for sulfur in fuels at 50 ppm or lower (by 2020) will enable Ghana to follow through on the 2015 Transportation Policy Roadmap, which calls for adopting EURO emission standards for automobiles and diesel trucks.

AQMP Mid-Term Review Recommendations

Based on the CEA recommendations, the achievements of the PMEH program, and other AQM planning efforts undertaken by international partners and described within the AQMP MTR Recommendations deliverable (See Annex A), EPA Ghana is poised to move their AQM planning efforts forward on several fronts. Here, we highlight some of this potential in terms of project outcomes that are consistent with the overall Project Development Objective (PDO), as broken down by the five goals that EPA Ghana has established for AQM planning in GAMA:

- ***Goal 1: Ambient Concentrations of Air Pollutants Comply with the New Ambient Air Quality Standard & Regulations (for PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3) in the Greater Accra Region as a Result of Emission Reductions:*** Stemming from new data and research, the MTR recommends:
    - establishing a guideline for HAP to complement existing $PM_{2.5}$ standards.
    - a review and potentially updates of the level and form of existing standards for $PM_{2.5}$ and PM_{10} based upon new baseline AQ data.
    - consideration of a new separate standard for BC as a component of $PM_{2.5}$.
- ***Goal 2: Collaborative Governance in the Implementation of the AQMP:*** The MTR will consider new objectives around clean cooking and Municipal Solid Waste (MSW) collection.
- ***Goal 3: Air Quality Management in the Greater Accra Region is Supported by Effective Systems and Tools:*** The MTR includes new continuous methods for AQ monitoring and recommends:
    - EPA Ghana should build on the Campbell Konect data management system to develop, implement and support a real-time, online AQI after validation and authorized release.
    - additional QA/QC studies to operationalize and achieve DQOs and align various measurement methods for $PM_{2.5}$
    - additional monitoring in Tema Metropolitan Area and other

major cities in Ghana. The presence of the harbor and the industries located at Tema has substantial impacts on respirable air particulate matter (APM) concentrations.
- further integration of climate and AQM planning efforts via downscaled (municipal level) decision support tools and studies.
- updated health benefits research including baseline health incidence and population data.

- ***Goal 4: Air Quality Decision-making is Informed by Sound Research:***
  The MTR recommends:
  - enhancing capacity within EPA Ghana for use of decision support tools (LEAP-IBC and Pathways-AQ) for policy analysis with multiple benefits assessments.
  - the improvement of specific laboratory capabilities to perform source apportionment tasks.

- ***Goal 5: Knowledge and Understanding Amongst Decision-Makers,Stakeholders, and the General Public in the Greater Accra Region is Enhanced:***
  - The mid-term review recommendations document results of the E360 pilot on open waste burning and collection efforts, the Urban Health Initiative's outreach and communications efforts with health workers, C40's climate action planning and the CCAC Breathe Life campaign's efforts at awareness raising around air pollution generally.
  - Publicly disseminate online AQI of air pollution levels on EPA Ghana website or Met Services website.

To the extent that these findings and recommendations are adopted by EPA Ghana for inclusion in the AQMP MTR, they become an effective part of GoG AQM planning and established objectives for the next compliance period under their AQMP. This represents a significant outcome toward improving air quality across GAMA and a basis for replication throughout the country.

Other International Partner Recommendations

World Health Organization and Urban Health Initiative Partners

Analysis by the WHO and other CCAC partners as part of the Urban Health Initiative has provided significant analysis regarding the cost effectiveness and health benefits of action in the areas of reducing municipal solid waste burning, transportation emissions and HAP. Their findings are available elsewhere (Mudu et al. 2021, Essel and Spadaro 2021 and Edwards et al. 2021) but key recommendations are provided here:

Municipal solid waste (from Mudu et al. 2021): Three scenarios were modelled – ceasing waste burning; expanding composting and recycling; landfill gas capture – that were found to reduce emissions of GHGs and SLCPs compared with the BAU scenario and that had a range of health benefits commensurate with the level of $PM_{2.5}$ reduced.

Suggested policy interventions:

- Build political will and commitment to include health and well-being issues in SWM by considering HIA.
- Encourage the decrease of waste production (restrict the import of waste from developed countries and limit the use of plastic).
- Create and/or enforce regulatory frameworks on waste burning and indiscriminate dumping.
- Support waste prevention and communal recycling initiatives.
- Encourage public participation in environmental management issues.
- Regulate urban land use, land ownership and improve urban planning.
- Increase population data collection to guide local and national planning.
- Consider extended producer responsibility.

Suggested actions:

- Increase waste collection and waste treatment.
- Facilitate the separation and collection of waste.
- Improve waste treatment infrastructure.
- Increase equipment and operational funds to support waste management activities.
- Collect reliable waste generation data to assist with planning of waste management programmes

Transportation (from Essel and Spadaro 2021): The UHI examined three future transportation scenarios relative to a reference scenario in which the demand for transport is predicted to increase three-fold, personal car ownership is expected to double, and there will be greater utilization of the public transport system. Three alternatives focused on existing and planned actions, a transit-oriented development (TOD) focused strategy and a future with increased use of electric public transit, walking and cycling.

In order to achieve the large health and economic benefits that could accrue under the various alternative scenarios (e.g., up to 5,500 averted premature deaths from improvements in air quality plus an additional 33,000 saved lives due to increased physical activity during the time period between now and 2050 for Scenario 3), it will be necessary to improve the efficiency and effectiveness of transport infrastructure and services. In particular, consumers need greater access to greener vehicle technologies, a more comprehensive and decarbonized public transportation system, such as the BRT and light rail is needed in GAMA. Appropriate government incentives and financial investments are needed to facilitate the transition to sustainable transport modes. Investments in walking and cycling infrastructure, as well as other sustainable alternatives will be required to eliminate emissions, improve urban air quality, improve quality of life, and reduce the mortality risk among all age groups in the population of GAMA.

The current transportation system in GAMA, which remains in the hands of sole proprietor operators who mostly operate paratransit and minibus services through informal operations, needs to be properly regulated. Government efforts should aim to develop regulations for urban transport that ensure oversight and responsibility-sharing and prescribe standards for operations of all commercial road transport services.

Household Air Pollution (from Edwards et al. 2021): A household energy working group under the UHI projected changes over the next 10 years under current policies (business-as-usual scenario), and under moderately progressive and more aggressive scenarios, which led to reductions of both HAP exposure as well as the HAP contribution to AAP and provided a double benefit to cooks in the GAMA region.

At a household level, a main barrier to successful clean cooking interventions is communication which when unchecked inhibits the widespread adoption of clean household energy. Better documentation on the evidence surrounding beliefs around food taste and LPG safety would provide the basis for effective media communication campaigns, in addition to targeted campaigns to promote LPG as an aspirational fuel.

Other key elements of a strategic master plan would include addressing the widespread availability of unregulated and cheap charcoal in urban areas, economic modelling of pricing structures to increase penetration of LPG in lower income populations combined with targeted incentives programs for LPG refills. Similarly, economic modelling of electricity pricing structures to increase penetration of induction cookstoves would assist in transitioning the population to clean household energy. In addition, long-term plans to improve LPG cylinder recirculation models for households, as well as piping of LPG into residential communities, would ensure reliability of supply chains, and reduce the need for charcoal as a secondary fuel. Finally, quality assurance for clean cooking technologies and monitoring of impacts would be key to obtaining objective information on the effectiveness of policies and programs.

C40 Climate Action Planning

Finally, it is worth noting that C40 Cities Leadership Group has been assisting the Accra Municipal Assembly with climate action planning and has launched both a resilience plan and a climate action plan that would reduce GHG emissions by 73%, aiding GAMA on its way to achieving carbon neutrality by 2050. By fully implementing the ambitious scenario, Accra can reduce $PM_{2.5}$ by 21 μg/m^3 in 2050. The sectors that have the highest potential to reduce $PM_{2.5}$ in that year are switching away from the open burning of waste, new residential energy efficiency for cooking and water heating, (as a result of decreased solid fuel use), modal shift to BRT buses and walking, together with a switch to cleaner on-road fuels, followed by industrial energy efficiency measures. These actions are expected to prevent over 500 premature deaths per year in 2050, as a result of reduced exposure to ambient $PM_{2.5}$. The majority of health benefits are expected to accrue from a reduction in open burning within the waste sector, changes in new residential buildings (cooking and water heating improvements) and a shift in various modes of on-road transport, with the use of cleaner fuels.

While the recommendations within the CAP apply only to Accra proper, they represent a model for other parts of GAMA to achieve the health climate benefits that have been identified for Accra across the region. The Ambitious Scenario described by the C40 reports calls for the following actions:

Solid Waste:

- Universal waste collection - to achieve 100% waste collection, which will eliminate indiscriminate waste disposal and eradicate open burning in the long term. Source separation of municipal solid waste will reduce the collection of mixed waste to the barest minimum.
- Develop efficient and effective waste treatment and processing systems (such as recycling and composting) - to divert waste from final disposal sites, which will extend the life of landfills. Diverting organic waste (such as food waste, paper and cardboard) from landfills will reduce greenhouse gas emissions.
- Providing safe waste disposal infrastructure (for solid waste and wastewater) - to ensure Accra has adequate capacity for the disposal and treatment of all waste streams, and to facilitate progression up the waste hierarchy.

Energy/Buildings:

- Affordable electricity – reducing the cost of electricity and ensuring sustainable access for all citizens, including by increasing investments in renewable generation
- Building permitting – an efficient building permitting process that incentivizes energy efficient and resilient buildings, in new developments as well as retrofitting old buildings
- Energy efficient appliances – transition to energy efficient appliances in residential and commercial buildings, and improve efficiency in industrial processes

Transportation:

The mitigation of air pollution from road transport will require appropriate investments and initiatives such as:

- Urgent reduction of rush hour congestion by making public transport options attractive to commuters;
- Investment in sustainable mass public transportation systems;
- Establish a non-motorized transit network, in particular to connect public transport hubs and commercial/ institutional facilities (e.g. schools);
- Improve the quality of sidewalks including tree-planting for shade;
- Prepare for a transition from fuel to electric vehicles (to absorb excess electricity generation capacity in Ghana);
- Encourage car-sharing and car-pooling schemes.

Land Use:

- Enhance service delivery within Accra Metropolitan Assembly, in particular to protect environmentally sensitive areas and to better serve socio-economically deprived communities.
- Contribute to raising Ghana's ranking on the World Bank Ease of Doing Business Index by expediting development planning and building permitting from the current 90 day-cycle to an improved 30- day cycle.
- Improve the efficiency of revenue collected from property rates through an electronic billing system.

- Improve spatial planning awareness and capacity development for staff of the Physical Planning Department

Mainstream Climate Change in Development Processes:

- Transparent, responsive and accountable governance
- Effective Local Government structures
- Improved access to finance for Local Governments
- Partnerships between Local Government, businesses, and other actors

Conclusion and Next Steps

The Task Team recommends consideration of additional efforts and the following next steps:

Monitoring and Laboratory Methods Audit: Concerns regarding the significant difference between gravimetric sampler-based measurements and continuous measurements of both PM_{10} and $PM_{2.5}$ indicate a need for a thorough audit of EPA Ghana's monitoring, filter handling, storage, and laboratory analysis system for managing gravimetric data. This process include a number of steps that are sensitive to external factors, including the availability of consistent power for consistent flow rate at the measurement device, use of oven and compressed air to ensure quartz filters can be measured without retaining additional water from the humidity in the air or allowing gas phase reactions of pollution in the air (or, better, preferential use of the more expensive Teflon filters for use with gravimetric mass measurements over quartz), storage within a freezer at the appropriate temperature and use of desiccant to remove excess humidity, proper filter handling, and standard weighing techniques. An in-person audit will help to identify potential issues and provide solutions to correct these issues in a way that will allow EPA Ghana to have more consistently accurate particle measurements.

Air Quality Datasets: EPA Ghana should assess the relative reliability of each measurement, following completion of audits of sampling and analysis and implementation of any required corrective actions to improve data quality, along with current research on the reliability of each method. This will help them to determine which datasets or groupings of datasets they will use to assess regulatory compliance, analyze health impacts, or otherwise understand air quality burden within the city and to establish regulatory guidance for the use of both gravimetric and continuous monitoring technologies in their compliance networks.

Laboratory Equipment Overhaul: An overhaul of EPA's laboratory equipment will allow them to improve their measurement system to be consistent with international air quality measurement best practices. EPA Ghana has struggled to keep their Gas Chromatography Mass Spectrometry (GC-MS), Ion Chromatography (IC), and Atomic absorption spectroscopy (AAS) functioning. These instruments were given to EPA Ghana second-hand over many years, putting them into varying states of functionality. Similar to limitations with availability of consumable supplies within the monitoring process, laboratory equipment requires an array of consumables, including access to gases like Helium to create a vacuum within the GC-MS system to allow proper functionality, proper vials to allow auto-sampling within the IC, and element-specific lamps within the AAS so that it may analyze different metallic compounds.

Integrated Air Pollution Prevention and Control Program for Ghana: The need for Ghana to develop an integrated air pollution prevention and control program focusing on key sectors (transport, waste and biomass burning or clean cooking) to reduce emissions. The program should place a special emphasis on how to coordinate policies across three sectors most closely linked to the mitigation of air pollution—environment, transport, and energy—and how to reconcile the sometimes-conflicting objectives and demands of these sectors to achieve environmental improvement. This will enhance and support potential applications for Climate Investment Funds or Global Climate Fund applications.

The solutions to air pollution challenges are likely to require continuing investment of dedicated resources, which could potentially be linked to specific policy and institutional reforms to improve project effectiveness and potentially be replicated nationally. The ability to implement other recommendations on AQM planning and effectiveness may be critically dependent upon establishing a "next phase" development program in one of these areas with an included AQM component.

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ANNEX: LIST OF PROJECT OUTPUTS

This Annex presents an overview of the deliverables for the *Improved Pollution Management and Reduced Environmental Health Risk in Accra-Tema Metropolitan Area (P164417)* as related to the capacity support to Ghana Environmental Protection Agency to strengthen AQM in Accra. The descriptions below describe each activity and how they complement each other in order to attain the overarching goal of comprehensive AQM planning for GAMA, as well as how they have influenced EPA Ghana's thinking on AQM planning more broadly.

Deliverable 1: Review of air pollution ground-level monitoring system. PMEH conducted a technical review of laboratory equipment, field monitoring, and continuous sampling equipment in Ghana. The review carried out a gap analysis and proposed a pathway for strengthening ground-level monitoring for GAMA. The technical review concluded that while manual PM10 compliance ambient monitoring capacity is comprehensive and robust, source-based analysis with chemical filter sampling is lacking. Partly based on this report, EPA Ghana and the WB team agreed to shape the PMEH Program around strengthening the capacity of understanding the sources of pollution. The addition of a source apportionment network and the enhanced focus on Short-lived Climate Pollutants (SLCP) and GHGs also has influenced the training activities to achieve sustainability for these multiple objectives after the conclusion of PMEH support.

Deliverable 2: Data Acquisition Plan (DAP). PMEH worked closely with the EPA Ghana to develop an air quality monitoring Data Acquisition Plan which addresses some of the gaps laid out in the 2018 GAMA AQMP. Specifically, the plan provides details on monitor operation, monitor siting, detection limits, and data quality objectives. The plan provided the framework necessary to generate air quality datasets using the required instrumentation. It then describes a plan for instrument deployment, calibration, maintenance, and operations tasks and schedules. It also describes the process for co-locating some already-deployed low-cost sensors with monitors verified as US Federal Reference Monitors (FRMs). Again, it describes the data management and quality assurance procedures needed to generate air quality datasets and recommends a plan for data validation and verification. The plan is currently being implemented and has enabled the deployment of continuous instrumentation (including Black Carbon) with a quality assurance plan and standard operating procedures (SOPs) for all equipment. This has resulted in an improved database of information to update EPA Ghana's 2018 GAMA AQMP.

Deliverable 3: Training Plan (TP). PMEH worked closely with the EPA Ghana to develop an air quality monitoring Training Plan. The plan describes the capacity building and expertise required to generate the air quality datasets introduced in the DAP, including the objectives related to each facet of the overall air quality management strategy in Accra. It also provides a training schedule with dates relative to completion of in-country deployment of continuous air quality monitors. The plan details each of the topics of the training and capacity building materials with respect to installation, calibration, operation, and maintenance of field monitoring and laboratory analysis instruments and techniques. Using the TP, PMEH has provided capacity building and training for the EPA for air monitoring and laboratory source attribution analyses.

Deliverable 4: COVID-19 Training Contingency Plan. The global pandemic occurred mid-implementation of the DAP and TP, requiring a radical restructuring of equipment deployment and TP activities. This memorandum describes how project consultants were able to rely on greater use of local consulting partners, remote and virtual training programs and to refocus efforts toward EPA Ghana training in a way that enabled the project to remain on schedule despite the many challenges this presented. This required diligence on the part of the team to ensure that our client and local partners continued to support the monitoring campaign in a manner consistent with the signed MoU yet respecting public health conditions on the ground in Ghana.

Deliverable 5: Standard Operating Procedures (SOPS) for Deployment and Startup of Filter Sampling Equipment. A range of equipment was deployed to improve the underlying database for air quality for Accra. This includes enhancements to the existing AQ monitoring system and source apportionment capacity of EPA Ghana. Carefully documented SOPs (9 in all) were created that are specific to the equipment that EPA Ghana is utilizing to improve that database of AQ measurements. The specific SOPs are complemented by instrument manuals and laboratory forms. A critical element of the enhancement is the addition of a cloud-based data management system that enables EPA Ghana to house all AQ measurements in a single location and ensure resilience of the dataset to loss from fire, theft, or vandalism of local computer equipment.

Deliverable 6: Quality Assurance Project Plan. This document proposes a Quality Assurance (QA) Plan to support EPA Ghana's air quality monitoring plan for GAMA in accordance with several monitoring goals included in their 2018 AQMP for GAMA. This QA Plan describes the processes needed to maintain the quality of air quality datasets, as introduced in the DAP (deliverable 2 above). This QA Plan covers data collected through continuous monitoring and gravimetric sampling and affiliated laboratory and data management analyses; it does not cover data collected through the use of low-cost sensors or personal exposure monitors (e.g. for HAP). EPA Ghana may expand this document to include data collected using these other instruments at another time. A QA handbook from USEPA is also provided to help with QAPP implementation.

Deliverable 7: Household Air Pollution Guideline. As the Bank is precluded from developing regulatory or legislative products for client countries, this draft memorandum is intended to provide background context and recommendations for EPA Ghana to consider as they embark on their regulatory process of developing and adopting a guideline for the control of Household Air Pollution (HAP), which is one of the largest contributors to Ambient Air Pollution in GAMA. The report reviews implementation factors and limitations in transitioning from traditional to cleaner energy technologies in support of reducing HAP exposures in Accra and assesses current knowledge on setting effective HAP guidelines. Based on the review of current peer-reviewed literature on HAP, this report recommends EPA Ghana consider setting an initial HAP guideline for Accra to promote improved ambient and household air quality.

Deliverable 8: Air Quality Data Report. The PMEH project aimed to expand the scientific evidence supporting air quality policies, efforts, and analyses in Accra by providing additional high-quality air quality measurements for use by EPA Ghana. This report includes a spatial and temporal characterization of air pollution in Accra based on six months of continuous measurements implemented through contract funds. It addresses key questions such as, 'what air quality was observed and with what air quality measurement system before the PMEH project?', 'how has this work changed the status of air quality management in Accra?', 'how has this project pushed forward the efforts that were started via US EPA Megacities partnership?', 'what type of analyses are possible now that were not possible 3 years ago?' The report recommends that EPA Ghana performs standard checks of the data to flag unreliable measurements in accordance with the Data Acquisition Plan (DAP) and with equipment and laboratory-specific SOPs. The report shows that source apportionment analyses for samples collected from roadside sites in 2019 indicate the majority of PM10 concentrations are derived from standard petrol combustion and diesel vehicle combustion. The fraction of elemental carbon (EC) at each site is related to primary elemental particles from combustion while the fraction of OC at each site is related to secondary formation of organic particles.

Deliverable 9: GAMA AQMP Mid-Term Review Recommendations. Similar to the HAP guideline, this report provides recommendations for EPA Ghana to consider as it undertakes its Mid-Term Review (MTR) of the 2018 GAMA AQMP. This provides updated text, data and analysis for consideration by EPA Ghana to include in each section of the existing (preliminary) 2018 AQMP. It attempts to capture the PMEH funded work as well as the large body of other air quality monitoring and AQ management planning activity that is ongoing in Accra with the support of a wide range of donors and academic institutions. To the extent that this is now reflected in recommendations for the AQMP MTR, EPA Ghana can achieve the goal of improving the underlying database upon which the 2018 AQMP was based. A key chapter of the report is the revised Implementation Matrix, which benefits from new policies and actions for the GoG to consider based upon the updated data and analysis, as well as AQM recommendations contained in the World Bank 2019 Ghana Country Environmental Analysis that featured a special chapter on air quality.

1. AQ monitoring network review performed by DRI	PMEH Recommendations for Accra, Ghana Prepared by John G. Watson[a] Judith C. Chow[a] Richard J. Tropp[a] L.W.- Antony Chen[b] [a]Desert Research Institute, Reno, Nevada, USA [b]University of Nevada, Las Vegas, Nevada USA Prepared for Pollution Management and Environmental Health (PMEH) Program The World Bank Washington, DC
2. Data Acquisition Plan (DAP, 2a) w/appendices (2b)	IEc Air Quality Monitoring Data Acquisition Plan Revised Draft Report | November 7, 2019 prepared for: The World Bank Group prepared by: Industrial Economics, Incorporated 2067 Massachusetts Avenue Cambridge, MA 02140 617/354-0074 Contact: Dr. Stefani Penn, spenn@indecon.com

3. Training Plan (TP)

IEc

Air Quality Monitoring Training Plan

Final Report | December 30, 2019

prepared for:

The World Bank Group

prepared by:

Industrial Economics, Incorporated

2067 Massachusetts Avenue

Cambridge, MA 02140

617/354-0074

4. COVID-19 Training Contingency Plan

PMEH COVID-19 Contingency Plan for Virtual Installation and Training

Continuous Monitoring Team	Virtual	Levi Stanton, STI, Stefani Penn, Henry Roman, Raphael Arku
	In Person	Dr. Hughes, EPA Ghana Field Team
Gravimetric Sampling Team	Virtual	David Pfotenhauer, Michael Hannigan, Stefani Penn, Henry Roman
	In Person	Dr. Hughes, EPA Ghana Field Team
Laboratory Analysis Team	Virtual	David Pfotenhauer, Michael Hannigan, Stefani Penn, Henry Roman
	In Person	Dr. Osei-Twum, EPA Ghana Lab Team
Source Apportionment Team	Virtual	David Pfotenhauer, Michael Hannigan, Stefani Penn
	In Person	Dr. Osei-Twum, EPA Ghana Lab Team

We will perform installations and training in five phases, including:

Phase 1. Gravimetric sampler installation

Phase 2. Continuous monitor and meteorological equipment installation

Phase 3. Laboratory training and introductory source apportionment

Phase 4. Methods demonstration and quality checks

Phase 5. Source apportionment training

Phases 1, 2, 3, and 5 will be comprised of:

1. EPA Ghana trainee team studying preparatory materials, including SOPs, instrument manuals, and appropriate sections of the QA Plan, and creating a list of questions or comments to be addressed by the trainers;
2. A webinar hosted by the appropriate trainer team to train hands-on the instruments, including a Q&A session and troubleshooting; and
3. Follow-up materials prepared by training participants to demonstrate skills and knowledge acquired, including written, photograph, and video.

Phase 4 will consist of the EPA Ghana team demonstrating methods acquired in the field and in the laboratory, including quality checks, to determine if there are any issues. The availability of our on-the-ground advisory team members, Dr. Hughes and Dr. Osei-Twum, are crucial to the success of this virtual

5. Standard Operating Procedures (SOPs)
   a. through o.

This includes a database of several individual SOPs for specific equipment, equipment manuals and operational notes to aid in the use of all equipment in the AQ monitoring network

6. Quality Assurance Project Plan for Accra Monitoring Network (QAPP)

IEc

Air Quality Monitoring
Quality Assurance Project Plan: Version 2.0

Draft for EPA Ghana Consideration and Finalization | May 15, 2020

Prepared for:

EPA Ghana Consideration and Finalization

Prepared by:

Industrial Economics, Incorporated under contract to the World Bank Group

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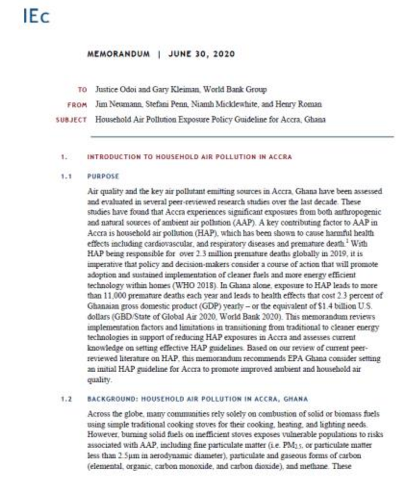
<table>
<tr><td>7. HAP Guideline Recommendation Report</td><td>
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MEMORANDUM | JUNE 30, 2020

TO Justice Odoi and Gary Kleiman, World Bank Group
FROM Jim Neumann, Stefani Penn, Niamh Micklewhite, and Henry Roman
SUBJECT Household Air Pollution Exposure Policy Guideline for Accra, Ghana

1. INTRODUCTION TO HOUSEHOLD AIR POLLUTION IN ACCRA

1.1 PURPOSE

Air quality and the key air pollutant emitting sources in Accra, Ghana have been assessed and evaluated in several peer-reviewed research studies over the last decade. These studies have found that Accra experiences significant exposures from both anthropogenic and natural sources of ambient air pollution (AAP). A key contributing factor to AAP in Accra is household air pollution (HAP), which has been shown to cause harmful health effects including cardiovascular, and respiratory diseases and premature death.[1] With HAP being responsible for over 2.3 million premature deaths globally in 2019, it is imperative that policy and decision-makers consider a course of action that will promote adoption and sustained implementation of cleaner fuels and more energy efficient technology within homes (WHO 2018). In Ghana alone, exposure to HAP leads to more than 11,000 premature deaths each year and leads to health effects that cost 2.3 percent of Ghanaian gross domestic product (GDP) yearly – or the equivalent of $1.4 billion U.S. dollars (GBD/State of Global Air 2020, World Bank 2020). This memorandum reviews implementation factors and limitations in transitioning from traditional to cleaner energy technologies in support of reducing HAP exposures in Accra and assesses current knowledge on setting effective HAP guidelines. Based on our review of current peer-reviewed literature on HAP, this memorandum recommends EPA Ghana consider setting an initial HAP guideline for Accra to promote improved ambient and household air quality.

1.2 BACKGROUND: HOUSEHOLD AIR POLLUTION IN ACCRA, GHANA

Across the globe, many communities rely solely on combustion of solid or biomass fuels using simple traditional cooking stoves for their cooking, heating, and lighting needs. However, burning solid fuels on inefficient stoves exposes vulnerable populations to risks associated with AAP, including fine particulate matter (i.e. $PM_{2.5}$, or particulate matter less than 2.5μm in aerodynamic diameter), particulate and gaseous forms of carbon (elemental, organic, carbon monoxide, and carbon dioxide), and methane. These</td></tr>
<tr><td>8. AQ Monitoring Data Report</td><td>
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Accra Air Quality Data Report: 2018-2021

Draft Report | 30 June 2021

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<tr><td>9. GAMA AQMP Mid-Term Review Recommendations</td><td>Discussion draft available now. To be finalized by Ghana EPA</td></tr>
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