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CLEAN AIR CATALYST

Understanding Nairobi's Air

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PREAMBLE

Kenya's capital city of Nairobi has experienced accelerated growth in both population size and economic output in the last two decades, driven by its role as an international and regional hub for commerce, transport, regional cooperation, and economic development. Its population has increased from 1.4 million in the 1990s to more than 5 million in 2022 and this is projected to grow to more than 7 million by 2030. On the economic front, the city's contribution to the national GDP as of 2020 was slightly above 20%. Like many other rapidly expanding cities, the Nairobi City Government faces serious challenges in meeting the needs of the city residents, leading to delays and reduced service provision. This is evidenced by the number of people living in informal settlements, which currently stands at more than 70% of the city's population.

This rapid expansion has taken an environmental toll on the city, which is evident in the worsening environmental footprint of the city. Air pollution is among the major environmental challenges that are worsening in the city. If no action is taken, this challenge is expected to increase as the city's population and economic importance continue to grow.

EXECUTIVE SUMMARY

Introduction

Globally, air pollution is the top environmental cause of disease and is estimated to cause at least 7 million premature deaths annually (WHO, 2022). It is also estimated that 99% of the global population lives in areas with air pollution levels above the WHO recommended limits. Most air pollution impacts are experienced in low- and middle-income countries. In Africa alone, ambient air pollution was estimated to cause close to 400,000 premature deaths in 2019, while indoor air pollution caused more than one million premature deaths in the same year (UNEP, 2021). Some of the leading air pollution-related ailments that contribute to these premature deaths include pneumonia, heart disease, stroke, diabetes, chronic lung disease, and lung cancer. Despite indoor air pollution being the current leading cause of premature deaths in Africa, evidence suggests that its importance in urban areas is reducing while, at the same time, the importance of ambient pollution is on the rise (UNEP 2021; Fisher et al. 2021; WHO 2022).

The ambient air pollution challenge is particularly important in urban areas where the demand for energy, transport, and other amenities drive activities that significantly alter atmospheric composition. The East Africa region is fast urbanizing, and this will lead to the worsening of air pollution in the coming years if no action is taken to address the challenge (Fisher et al. 2021; WHO 2022).

In addition to health effects, air pollution has also been shown to have negative impacts on both terrestrial and aquatic ecosystems, including soil and vegetation for crop production (Gallego et al. 2009; Huijbregts et al. 2000; Jonson et al. 2017). For example, air pollutants such as ground-level ozone have a negative effect on agriculture, with estimates indicating that it has the potential to reduce crop yield by 2.2% -5.5% for maize and between 3.9% to 15% for wheat (Avnery et al. 2011; Wilkinson et al. 2012).

Air pollution also has a considerable negative impact on the economy; in 2013, both indoor and outdoor air pollution were estimated to cost the global economy approximately USD 5.11 trillion in welfare losses (World Bank Group, 2016). In addition, the health costs from air pollution in 2015 were estimated to be USD 21 billion. If no urgent and significant actions are taken, this figure is projected to rise to USD 176 billion by 2060, representing 1% of the global GDP (OECD 2016a). The same report projects that the annual international welfare costs associated with premature deaths from outdoor air pollution will rise from USD 3 trillion in 2015 to USD 18-25 trillion in 2060. In Africa alone, the healthcare costs of pollution attributable to particulate matter were estimated at USD 445 billion in 2013, and they are expected to rise significantly as the continent's population grows (OECD 2016b).

Therefore, air pollution is a critical environmental policy issue with implications for society, ecosystems and economies that warrant urgent attention. Despite the urgency, action to reduce air pollution, particularly in Africa, has yet to receive commensurate attention (UNEP 2021). This is further evidenced by the low amount of global donor funding towards air pollution actions; in Africa, the entire continent received less than 0.2% of the estimated USD 155 million raised for air pollution globally between 2015 and 2019 (Clean Air Fund, 2021).

Air pollution in Nairobi

As cities like Nairobi expand in both population and economic output, so do their ecological footprints. This growth can result in increased energy and transportation demand and more use of fossil fuels which contribute to air pollution, compounding the preexisting challenges faced by city leaders (Amegah and Agyei-Mensah, 2017). The rapid expansion of Nairobi has taken an environmental toll on the city, which is evident in the worsening air pollution levels. Since 1970, based on visibility data from the Jomo Kenyatta International Airport, air pollution levels have increased by more than 180% (Singh, Avis, and Pope 2020). This is one of the most extreme increases in the region, compared to other East African cities such as Kampala and Addis Ababa which have registered increases of 56% and 34%, respectively (Singh, Avis, and Pope 2020). These increases in air pollution levels are not evenly distributed and tend to be higher in informal settlements, where more than 70% of Nairobi's residents live, thus exacerbating air quality disparities in the city (UN Habitat, 2016.

The available research, although limited, reveals concentrations of air pollutants above the WHO recommendations in Nairobi (Gaita et al., 2014; Kinney et al., 2011; Muindi et al., 2016). The specific air pollutants of concern in Nairobi include nitrogen oxide, sulfur dioxide, ozone, carbon monoxide, volatile organic compounds, and particulate matter 2.5 and 10 (Pope et al., 2018). Pollution concentrations are unevenly distributed, with higher concentrations in the central business district and along the roadways, especially intersections and major transport corridors (Shilenje et al., 2016).

Despite the existing evidence of air pollution, its impacts, and the urgent need to take action, there is a lack of appropriate remedial response being taken by policymakers and the general public. Additionally, the city has inadequate air quality monitoring networks, with most monitoring being monitored by low-cost-sensors and very minimal (less than 4) reference grade monitors, further hindering research efforts which would serve to inform substantive remedial actions.

This report aims at establishing the current state of air pollution in Nairobi, in terms of what has been done towards increasing understanding of the major pollutants and their sources, and more importantly, identifying the major gaps in understanding the air pollution landscape in the city. This will inform researchers and policymakers on the data and evidence gaps that need to be filled to facilitate the development of comprehensive actions to address air pollution problems in the city. We present a systematic review of existing monitoring studies and conclude with a call-to-action on urban air quality in Nairobi. Future versions of this report are intended to include additional information when it is available.

1. CURRENT STATE OF KNOWLEDGE

1.1 Ambient Air Quality Monitoring

Despite the considerable health and environmental impacts of air pollution, the subject remains understudied in Nairobi and most of the available data is mainly derived from short term studies, which are insufficient to fully characterize air pollution impacts on the city (Kirago et al., 2022; López-Ballesteros et al., 2018). In the few long-term studies conducted in Nairobi, particulate matter has been identified as a pollutant of concern with annual concentrations averaging 18 µg m^{-3} which is over three times higher than the WHO recommended safe limit of 5 µg m^{-3} (Gaita et al., 2014; Kirago et al., 2022). Visibility data has also been used to estimate long term concentration of particulate matter in the city, in one such study Singh et al (2020) found that particulate matter concentrations in the city increased at an average rate of 4.1% per year.

From one of the few studies that monitored air quality for one year, Kirago et al (2022) reported that PM2.5 was always elevated and above the WHO recommended limits, with an average concentration of 27± 6 µg m−3. During the one-year monitoring period, seasonal variability of PM2.5 concentration was observed to be minimal, with the dry season showing a relatively higher concentration compared to the rainy season. The speciation of the PM2.5 showed that carbonaceous aerosols contributed approximately ⅔ of the PM2.5 mass, with organics and black carbon contributing approximately 50% and 15% of the PM2.5 mass loading respectively (Kirago et al., 2022). In this study, Kirago et al (2022) used the C-14 method on the EC component of a one-year time series of high-volume 24-hour samples collected from the university rooftop location (i.e. regionally representative- not a hot spot) and determined that on average 85% of the EC was from fossil fuel and 15% from biomass burning. From these studies BC is one of the air pollutants of concern in the city with considerable health and climate implications. It is worth noting that these measurements were carried out at a height of 17 meters above ground level, which could misrepresent the concentrations at the ground-level breathing zone . This change in concentration based on monitoring height was studied by Kinney et al. (2011) where it was found that at a height of 1.5 meter on a curbside (urban site) the concentration of PM2.5 reduced from 110 µg m^{-3} to 43 µg m^{-3} at a 17 meters height.

Air pollution in the city also varies spatially with elevated levels being reported in the informal settlements, where waste burning and industrial influence are significant. For the limited studies carried out in informal settlements, air pollution levels have been shown to exceed the WHO safe limits by several levels of magnitude. In one such study, the PM2.5 concentrations were observed to average between 67-166 µg m^{-3} in the informal settlement located next to a major waste dumpsite and close to industrial areas. During midday periods when traffic emissions were expected to be minimal the average concentration spanned between 59 - 146 µg m^{-3}, with peak levels as high as 214 µg/m^{-3} during morning and evening peak hours, also suggesting a strong traffic influence (Egondi et al., 2016).

In addition to the few long term studies, the US State Department has been monitoring PM2.5 at the US embassy in Nairobi since 2021 (Airnow, 2023); data from this site indicates relatively low concentrations with an average of 16.8 µg m$^{−3}$ for 2022, however it is worth mentioning that the location is considered urban background, which means the concentrations are more diluted compared to what would be recorded in source-rich areas within the city.

Coarse particulate matter (PM10), another highly prevalent air pollutant in the city, is especially high on roadside environments. In a study by Pope et al. (2018) it was established that PM10 mass concentration when monitored at the urban roadside was high and ranged between 79–94 µg m^{-3}, while those at urban background and rural background sites were 53.0 and 19.5 µg m^{-3}, respectively.

Black carbon (BC) has also been monitored in Nairobi by a few researchers, and its ambient concentration is consistently high. This has been attributed to vehicle traffic emissions as BC concentration reduces significantly as distance grows from major traffic routes (Kinney et al., 2011; Gatari et al., 2019;). In a study by Shilenje et al., (2016) the concentration of black carbon was monitored in three locations representing inner city transport corridors (Ladhis Road), busy city highway (Nakumatt Junction) and a major roundabout (Pangani Roundabout). The BC concentration at the inner-city transport corridor was reported to be above the instruments set limit (50 µg m^{-3}) and in the other two sites the BC concentration was above 14 µg m^{-3}. Gatari et al., 2019 carried out a curbside measurement campaign of 11-hour samples of PM2.5 and BC. From the study, BC concentration in the central business district averaged between 20 – 42 µg m^{-3}, and between 17–79 µg m^{-3} on the major roads. The study noted that BC in these samples accounted for around 50% of the PM2.5 mass, indicating that traffic is a predominant source of PM2.5 in the city. Furthermore, the study confirmed the accuracy of their optical BC measurement by determining that elemental carbon (EC by thermal optical method) and BC were roughly equivalent in collocated samples.

Although there is limited data available on gaseous pollutants, among the reported gaseous air pollutants are SO_2, CO, NO_x, NO_2, and O_3. These pollutants and their ambient concentrations have been reported to be below the limits set by the Kenya Ambient Air Quality Standards, which are 60µg m^{-3} (annual average), 5 mg m^{-3} (8 hours), 80µg m^{-3} (annual average), 150µg m^{-3} (annual average), and 120 µg m^{-3} (8 hours) respectively (Shilenje et al., 2016). However, it is worth noting that in the same study, PM2.5 concentrations reported from the four sites were significantly lower than the previously discussed studies. Absent justification for the quality control and quality assurance of the data collected, it is difficult to draw conclusions from this limited data. Figure 1 below shows the average NO2 concentration in the city, from satellite data obtained in January 2016.

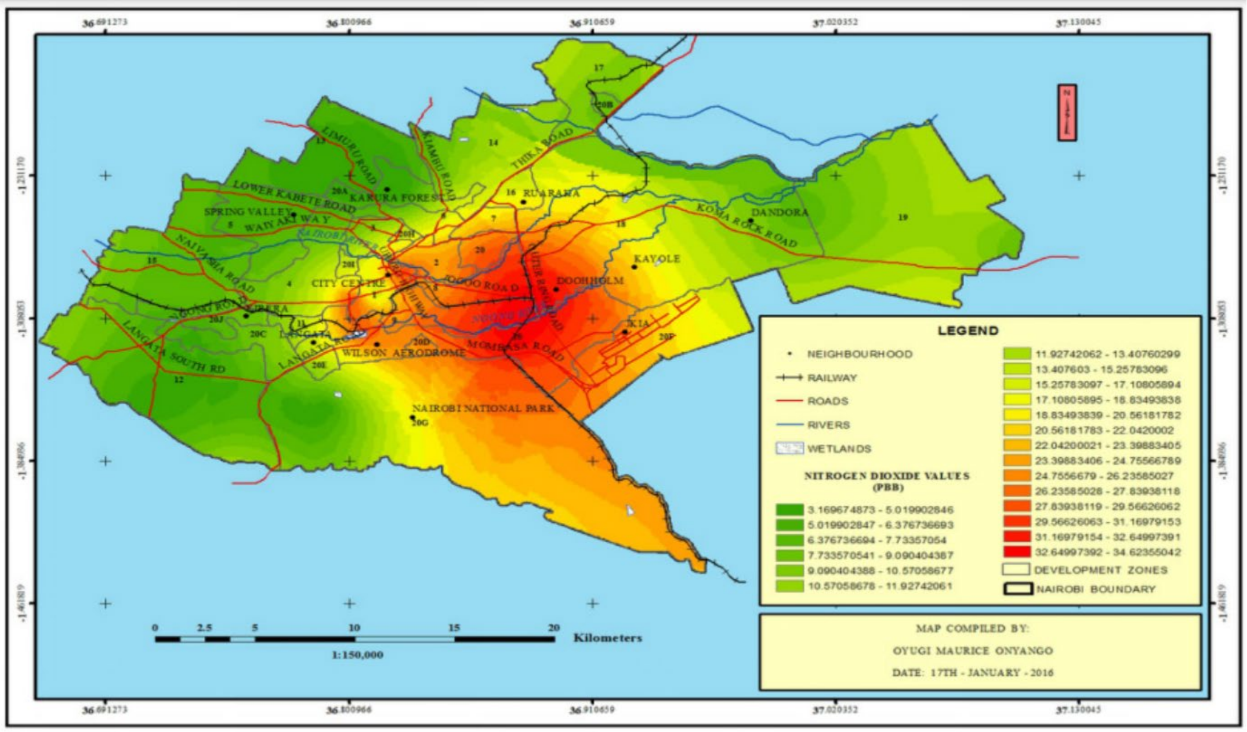

Figure 1: Spatial Distribution of Nitrogen Dioxide Concentration in the City adapted from (Oyugi 2021)

From the few studies on air pollution in the city, the most important emission sources are vehicular emissions, industries, and open burning of waste. However, most of these studies were focused on understanding the influence of these sources to air pollution in the city and therefore, the existing studies do not fully reflect the importance of other sources of air pollution and their relative drivers in the city (Gaita et al., 2014; George and Awange, 2010; Kiai et al., 2021; Kinney et al., 2011; Shilenje et al., 2016).

To triangulate the information from literature with the experiences of air quality practitioners in the city, a stakeholder's forum was organized to further examine these findings, the forum brought together more than 40 organizations working in the air quality space in Nairobi (Clean Air Catalyst, 2022). Based on the judgment of experts attending this forum it was concluded that Nairobi's air pollution stems from several different sources, including motorized transport-related emissions, open waste burning and inefficient incinerators, industrial emissions, and household pollution (including cookstoves). PM2.5 is the most studied air pollutant in Nairobi (as per the references herein), and consistent with the references above BC is expected to be a main contributor to PM2.5 (USEPA, 2011). The city's BC largely originates from the transport sector, deriving from fossil fuel combustion emissions that come from heavy traffic congestion and lower fleet fuel economy. Nairobi's fleet accounts for more than one third of the 3.1 million registered vehicles in Kenya–many of which are imported, second-hand, and fuel inefficient–and the city has an ineffective traffic policy, leading to highly congested roads. Nairobi's high altitude compounds these factors as the lower oxygen levels negatively impact combustion efficiency. Black carbon exposure levels were found to be highest at curbsides and bus terminals within the city limits of Nairobi, meaning that all of the city's residents are at risk of experiencing the negative health effects of black carbon (Kirago et al., 2022).

Despite the calls for action supported by the evidence from the studies, the city authorities have no continuous air quality monitoring networks in Nairobi and the existing monitoring sites (see figure 2 below) are run by third parties with the city having minimal access to the data. The City can only access reference grade data from the US Embassy. Numerous studies have been able to monitor air quality only in specific locations for a limited period of time due to cost restrictions and study periods limits (Rai et al., 2017). To be able to assess and manage air quality in a developing city such as Nairobi, it is paramount that a measuring network be established. Long-term high-resolution data is required for such cities as Nairobi. Petkova et al. (2013) argues that Nairobi is in the vanguard of air pollution measurements for sub-Saharan Africa (SSA) but lacks continuous long-term calibrated measurements of PM and other air pollutants. The constraints to making measurements are the high cost of purchasing and operating research-grade air quality monitoring equipment with appropriate calibration and certification practices. Exploring the potential of low-cost sensors for air quality monitoring networks is a possibility that the city may consider (Lewis et al, 2016; Rai et al., 2017). In the recent past the city has collaborated with AirQo to increase the distribution of low-cost sensors in the city and currently there are more than 15 sensors under this partnership[1], in addition to the AirQo sensors the city also has several LCS run by third parties and the data is accessible through OpenAQ[2].

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[1] AirQO. Accessed May 10, 2023. https://platform.airqo.net/.

[2] OpenAQ. "Home." OpenAQ. Accessed May 10, 2023. https://openaq.org/#/countries/KE.

AirQo , a member of the research and data committee of N-AIR recently identified and mapped the Air Quality Monitoring network in the City of Nairobi. These sites measure Particulate matter and CO. They are summarized in the table below.

TABLE 1: MONITORING SITES IN NAIROBI CITY COUNTY

Location	Status	Description	Manufacturer	Ownership	Parameters
UoN Parklands Campus	Online	Reference Grade Monitor	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter
University of Nairobi	Online	Reference Grade Monitor	Met One Instruments, Inc.	UoN	Particulate Matter
UNON Fuel Station	Online	Low Cost Sensor	Sailhero/AirQo	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
ANWA Junior Academy	Online	Low Cost Sensor	Purple Air	Unknown	Particulate Matter
Dagoretti Corner	Online	Low Cost Sensor	Unknown	Unknown	Unknown
The Banda school	Offline	Low Cost Sensor	Unknown	Unknown	Unknown

Wasaa Road	Online	Low Cost Sensor	Purple Air	Unknown	Particulate Matter
Kasarani Stadium	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
Premier Industries Ruaraka	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
EIK Offices/ Highway Mall	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
Naivas Westlands	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
Nyayo Sports Complex	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide

Nairobi National Park	Online	Low Cost Sensor	Sailhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
Bins Nairobi Industrial Area Nairobi	Offline	Low Cost Sensor	Unknown	Unknown	Unknown
7th Landmark Plaza	Offline	Low Cost Sensor	Unknown	Unknown	Unknown
Safaricom Care Centre (Moi avenue)	Online	Low Cost Sensor	IQAIR	UNEP/NCCG/SEI	Particulate Matter
Mbagathi Hospital	Online	Low Cost Sensor	IQAIR	UNEP/NCCG/SEI	Particulate Matter
Kibera Drive	Offline	Low Cost Sensor	Unknown	Unknown	Particulate Matter
Safaricom Care Centre(Westlands)	Online	Low Cost Sensor	IQAIR	UNEP/NCCG/SEI	Particulate Matter

JKIA	Offline/Unknown	Low Cost Sensor	Unknown	Unknown	Unknown
All Saints Cathedral Primary School	Offline	Low Cost Sensor	Unknown	Unknown	Unknown
St. Scholastica Catholic school	Offline	Low Cost Sensor	Unknown	Unknown	Unknown
St. Peter Claver's Catholic Church	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
Baba Dogo Primary School	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
Nairobi Primary School	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
NCC Embakasi Primary School	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter

Lunga Lunga Health Centre	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
Karen C Primary School	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
Nairobi US Embassy	Online	Reference Grade Monitor	Teledyne Technologies	US Mission Nairobi/AIRQO	Particulate Matter
County Government Of Nairobi	Online	Low Cost Sensor	AirQo	AIRQO/NCCG	Particulate Matter
Thigiri Lane	Online	Reference Grade Monitor	Met One Instruments, Inc.	UNEP/AIRQO/Code4Africa/SEI	Particulate Matter/Carbon Monoxide/ NO2/SO2
Chandaria Industries	Online	Low Cost Sensor	IQAIR	UNEP/NCCG/SEI	Particulate Matter
Safaricom Shop JKIA JCC Shop	Online	Low Cost Sensor	IQAIR	UNEP/NCCG/SEI	Particulate Matter

The Kenya Alliance of Resident Associations (KARA)	Online	Low Cost Sensor	Sailhero/IQAIR	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
World Agroforestry Centre (Icraf)	Online	Low Cost Sensor	Sailhero/IQAIR	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
UNEP HQ	Online	Low Cost Sensor	Salhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
United Nations Environment Programme (UNEP)	Online	Low Cost Sensor	Salhero	UNEP/NCCG/SEI	Particulate Matter/Carbon Monoxide
Moi Avenue Primary School	Online	E-Sampler	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter
St. Bakhita Primary School	Online	E-Sampler	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter

Heshima Road Pr. School	Online	E-Sampler	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter
RIRUTA HGM PRI SCH	Online	E-Sampler	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter
James Gichuru Primary School	Online	E-Sampler	Met One Instruments, Inc.	GEOHealth Hub	Particulate Matter

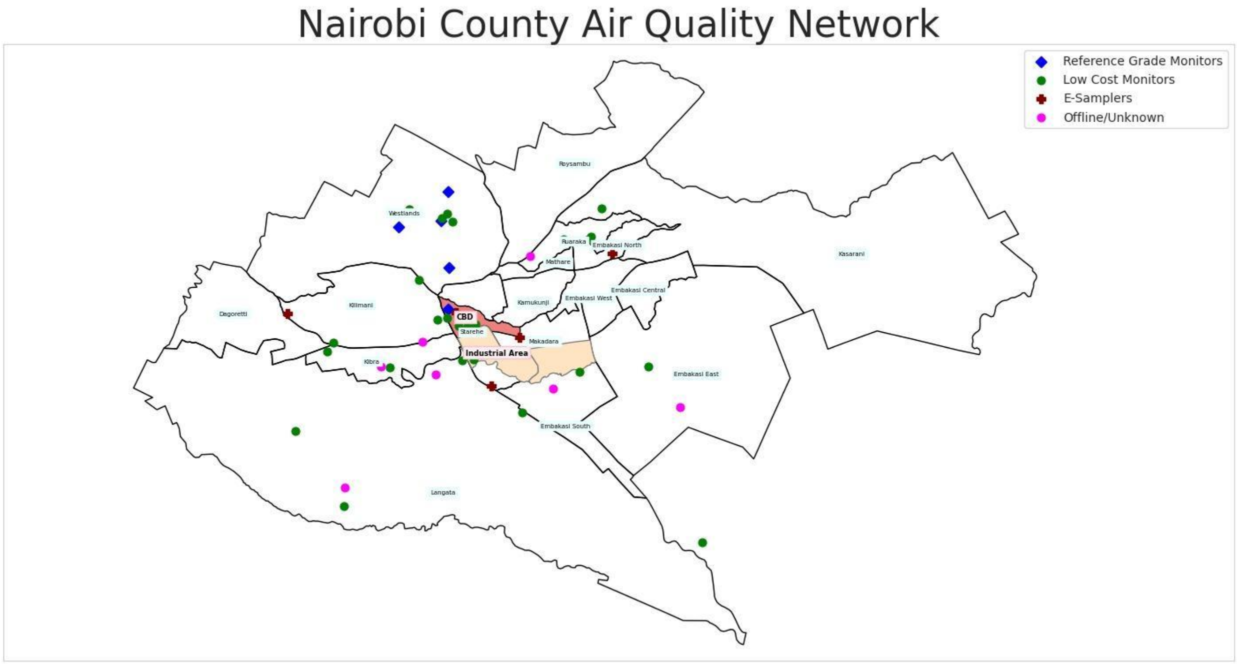

Figure 2: Distribution of air quality monitoring stations in Nairobi- The County can only access data from the US Embassy reference monitor. (AirQo)

1.2 Air Quality Modeling

Studies on the distribution of air pollution within Nairobi, though limited, are complemented by global and regional modeling studies that provide information on the state of air quality and possible trends for Kenya (e.g., Lacey et al., 2017; Marais et al., 2019; Shindell et al., 2022; Kumar et al., 2022). However, the results are generally presented and discussed at the national level, limiting the ability to accurately sync these results with findings from the studies and effectively address the state of air quality in Nairobi specifically. These global and regional modeling efforts can provide context for urban air quality in Nairobi; however, they are difficult to use for air quality management and improvement as they lack specificity to Nairobi's context. Regional modeling has also explored the ability to simulate trace gas concentrations from biomass burning and the impact this has on air quality in East Africa. From this study, the WRF-chem simulated the seasonality of NO2 and CO but estimates of the gas abundances contained biases, where NO2 was overestimated and CO underestimated throughout all the seasons (Opio et al., 2022).

Only one study was found in the literature review that applied a chemical transport model to the urban pollution in Nairobi (Mazzeo et al., 2022). WRF-CHIMERE was developed, run, and evaluated at high spatial resolution (2 km x 2km) over three cities in East Africa (Kampala, Addis Ababa, and Nairobi) from 14 February – 14 March 2017. The model output was evaluated against one roadside site (Tom Mboya Street) in Nairobi and one rural background site (Nanyuki). Figure 3 displays the Nairobi model domain. Nairobi has high simulated PM2.5 concentrations, with elevated concentrations also seen on the outskirts of the city. Figure 4 displays the political divisions in Nairobi (Figure 4a) and the simulated average hourly PM2.5 concentrations during the study period (Figure 4b). Fig.4 highlights that the urban center was simulated to have the highest PM2.5 levels and thus PM pollution is an issue throughout the city. Twenty-four exceedances of the 24- hour PM2.5 WHO guideline (25 µg m^{-3}) were simulated during the study period, which aligned with the observed data from Tom Mboya Street station.

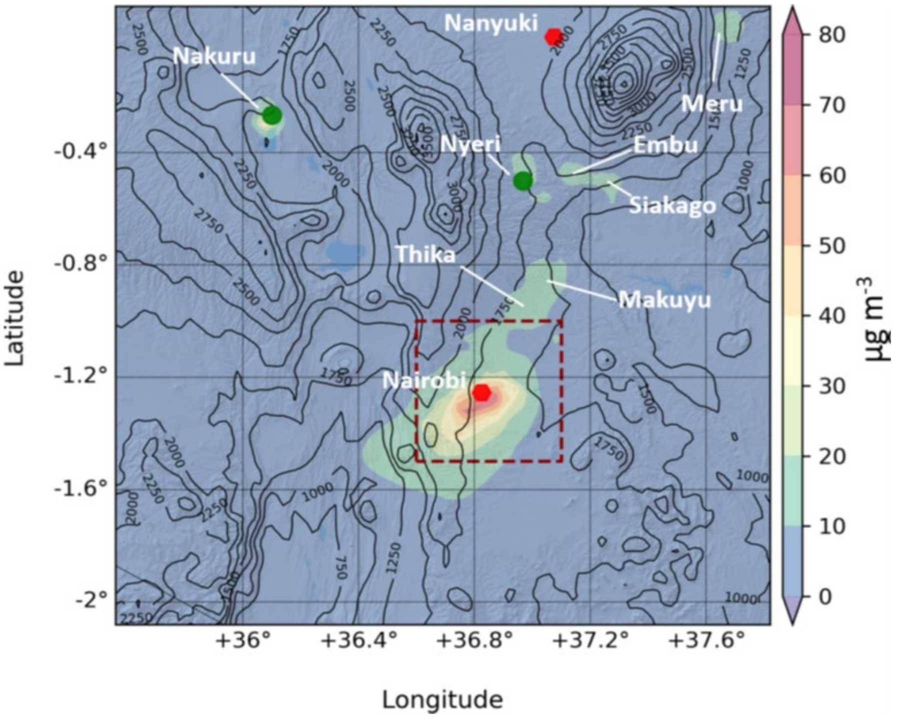

Figure 3: The simulated average PM2.5 concentration for the study period over the Nairobi modeling domain at 2 x 2 km spatial resolution. The red dashed square shows the urban domain for Nairobi (taken from Mazzeo et al., (2022).

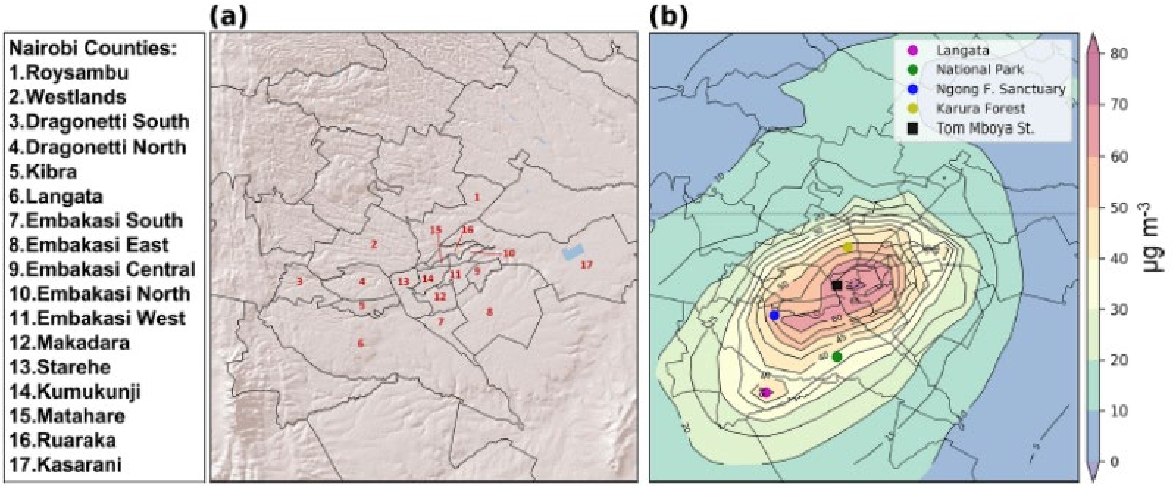

Figure 4: Taken from Mazzeo et al. (2022). Map showing the Nairobi urban domain shown in the red box in Figure 3. a) Counties within Nairobi (data source openAFRICA), b) average hourly concentrations of PM2:5 over the study period (taken from Mazzeo et al., (2022)

Emissions inventories (EIs) are key inputs into air quality modeling. While there are global and regional inventories available that can be used, many are at coarse resolution. Many are available online[3]. In addition, there are inventories developed for Africa that focus on improving the characterization of sources such as the charcoal industry (Bokarie et al., 2020) and diffuse and inefficient combustion (DICE-Africa[4]; Marais and Wiedinmyer, 2016).

A higher-resolution emissions inventory was developed for the WRF-CHIMERE runs described previously (Mazzeo et al., 2022). This EI combined DICE-Africa 0.1° x 0.1° for 2013 (Marais and Wiedinmyer, 2016) and EDGAR v4.3.2 0.1° x 0.1° for 2012 (Crippa et al., 2018), and then downscaled the emissions and extrapolated to 2017. This anthropogenic emissions inventory is available (Mazzeo, 2021). Detailed local road and vehicle data (e.g., Mbandi et al., 2019) were used to develop the Highway Development and Management version 4 (HDM-4) model (Waiguru, 2017; Mazzeo et al., 2019.). As transport is an important sector for air pollution in Nairobi, these data and the emissions simulated could be further used and expanded in the Clean Air Catalyst work to improve the representation of vehicle emissions.

Community-based sources (e.g., solid or liquid fuel for cooking and heating, waste burning in communities, unpaved roads) are often poorly represented in global emissions inventories due to the high spatial heterogeneity, complex activity data and patterns, as well as the variable emission factors. Local studies that have investigated sources of pollution in low-income settlements (e.g. West et al., 2020; Dianati et al., 2019) could be evaluated to develop improved bottom-up inventories of community-based sources.

Another potential EI tool for the Clean Air Catalyst is found in the Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa (SDM[5]; UNEP et al., 2022). This Assessment provides historical and future emissions data for three policy scenarios: the baseline scenario, the SLCP scenario, and the agenda 2063 scenario. The scenarios outline 37 total mitigation actions across the non-baseline scenarios–20 related to the agenda 2063 scenario and 17 related to SLCP reduction–that have co-benefits for

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[3] "Emissions of Atmospheric Compounds and Compilation of Ancillary Data." ECCAD. Accessed May 10, 2023. https://eccad.aeris-data.fr/.

[4] This includes emissions from solid biofuels (wood, crop residue, charcoal), charcoal production, kerosene, backup generators, cars, motorcycles, gas flaring, and ad hoc oil refining

[5] Summary for Decision Makers

climate and air quality. Relating to air quality, the scenarios model annual average exposure to outdoor PM2.5 exposure, premature mortality due to PM2.5 exposure, exposure to outdoor annual mean 8hr maximum ozone concentrations, and premature mortality due to ozone exposure in Africa's major subregions using data from 2019 and projecting until 2063. If implemented, the 37 measures can account for significant reductions in CO2 and methane emissions, SLCPs, PM2.5 exposure, and air pollution-related illnesses/deaths. The input data and emissions should be investigated to determine their usefulness and if they can be used to improve the emission inventories used in the Clean Air Catalyst work.

While local modeling and emission studies do exist, there are very few. This gap can serve as a baseline to work from in the Catalyst project. Improving emission estimates would align with Nairobi Air Quality Action Plan objective 1 (Nairobi City Council, 2019). Under the CAC project, EI for a number of sub-sectors is under consideration with some of the major community activities that are major sources will be developed, such sources will include, industries, open burning of waste, eateries, household energy demand and transport. This EI could be compared with other EIs through a modeling exercise in comparison with existing regional emission inventories. As part of the Clean Air Catalyst's work in Nairobi, a Catalyst partner, Map-AQ, will conduct source attribution modeling. The first round of modeling will rely on regional emissions inventory data to identify the source contributions from key sectors. As new, fine scale emissions inventories are developed by the Clean Air Catalyst, older models will be updated with local emissions inventory data. The purpose of the Catalyst modeling work is to raise awareness of the major sources of air pollution in Nairobi and provide estimates of exposure to impacted communities by the priority sources of air pollution.

1.3 Source Identification

As in the case of air monitoring and analysis, a limited number of exposure studies and source apportionment research are available to identify the major sources of air pollution in Nairobi. The air pollutants in Nairobi have diverse sources such as vehicular transport, open burning of waste, eateries and industrial sources. However, vehicular transport has been identified as a major source of most of the air pollutants (Kirago et al., 2022, Dsouza, 2017). The literature for Nairobi reveals that there is a higher concentration of air pollutants along major roads and intersections (Kinney et al. 2011; Shilenje et al., 2016; Gatari et al., 2019). In addition, the central business district is also highly polluted due to a high volume of human and vehicular activities. The diurnal variation of the pollutants also shows that the peaks correspond to the city's daily traffic cycle, where the concentrations are highest in mornings and evenings, see Figure 5 below.

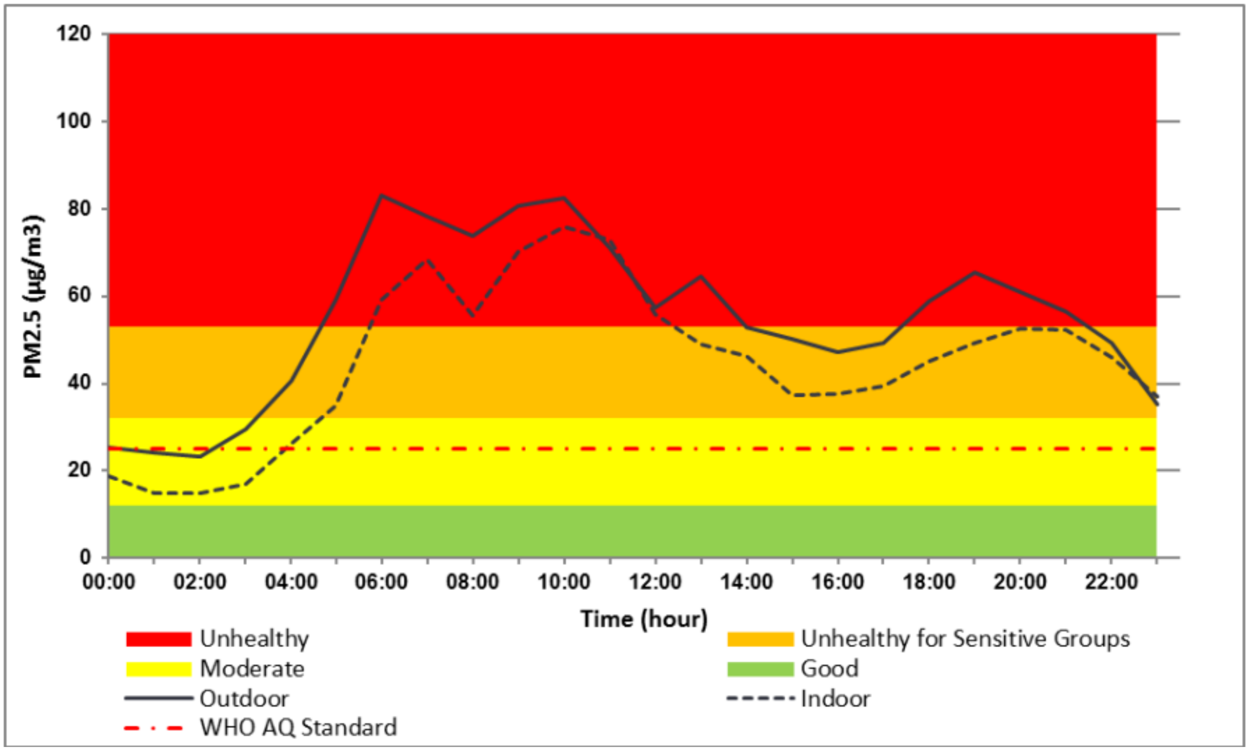


Figure 5: Diurnal pattern of air pollution in one of the schools located in Nairobi CBD, the colors indicate the air quality index as defined by the USEPA (Adopted from Avis Et al., 2020).

Along with emissions from vehicular transport, waste management is a continuous challenge the city is struggling with, resulting in many informal settlements, and even hospitals, opting to conduct open burning of waste. Open burning of waste emits gaseous pollutants, and particulate matter, including metals and smoke particles.

Industries also contribute significantly to the city's air pollution, and as current laws on emission monitoring are not heavily enforced, effluents and carbon fuels continue to be emitted (Kinney et al. 2011). Ngo et al. (2015) measured 8-hour average occupational exposure levels of PM2.5, black carbon (BC), ultraviolet active-particulate matter (UV-PM), and trace elements in individuals who work alongside roadways in Nairobi, specifically bus drivers, garage workers, street vendors, and women who work in informal settlements. The authors found that BC and re-suspended dust were important contributors to PM2.5 levels. This suggests traffic emissions are an important air pollution source for these occupational groups who work outside. The study also found biomass emissions and trash burning markers were common in Nairobi's low-income areas and open-air garages. Other important anthropogenic sources include household use of carbon fuels, city construction and land use change. About 70% of Nairobi residents live in informal settlements. Approximately 69.7% of Nairobi residents use paraffin and charcoal as a source of fuel at the household level for domestic purposes, which in turn results in poor indoor air quality (Dianati et al., 2019). Construction within the city is constantly increasing with the growth of the population, and the movement of heavy machines and vehicles on bare land stirs up and contributes to particulate matter air pollution (Muindi et al., 2016. Increasing human activity is constantly contributing to air pollution in Nairobi. This highlights a need to sustainably monitor and manage the major sources to address these challenges. (Dianati et al., 2019).

During the stakeholders' engagement, eateries were also identified as an important source of air pollution in the city. Their contribution is mainly driven by the fuel used which is mainly biomass-based, mainly for roadside eateries and mid-level hotels.

1.4 Climate, Health and Gender Impacts of Air Pollution

1.4.1 AIR POLLUTION AND CLIMATE

Aerosols and trace gasses that are adverse to human health also have impacts on the climate. Black carbon, for example, is an absorbing aerosol and thus a warming agent that some have claimed is the second most important warming agent after CO2 (Bond et al., 2013). It is a by-product of incomplete combustion of fossil and biomass fuels such as wood burning, diesel fuel combustion, and coal combustion. Several other aerosol species, such as sulfates, nitrates, and some organics, are scattering agents and thus have a cooling impact on climate. Some organic aerosols are known as "brown carbon" for their absorbing nature similar to black carbon and are an ongoing area of research (Laskin et al., 2015). Surface O3 is a warming agent and is formed from the reaction of VOCs and NOx is the presence of sunlight. Collectively, many of these compounds are referred to as Short-

Lived Climate Pollutants (SLCPs), owing to their relatively short lifetimes (e.g., for aerosols, about 1 week). Oftentimes, trace gasses such as methane and hydrofluorocarbons are lumped into SLCPs, despite having relatively longer lifetimes (~9 years for methane), though still at least an order of magnitude shorter than CO2 (lifetime of 100 to 1000 years), see Figure 6 below. Methane is important as a warming agent with a greater efficacy than CO2 and is also a major precursor to surface ozone which harms human health.

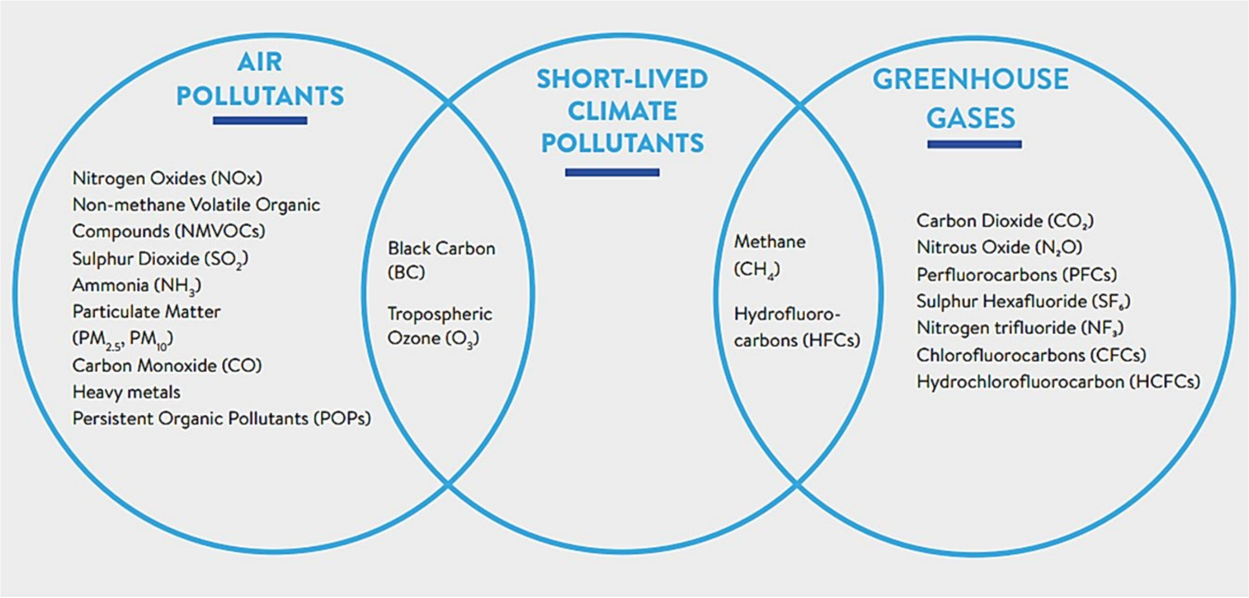


Figure 6: A summary of pollutants that are classified as air pollutants, short-lived climate pollutants and greenhouse gasses (Source: CCAC)

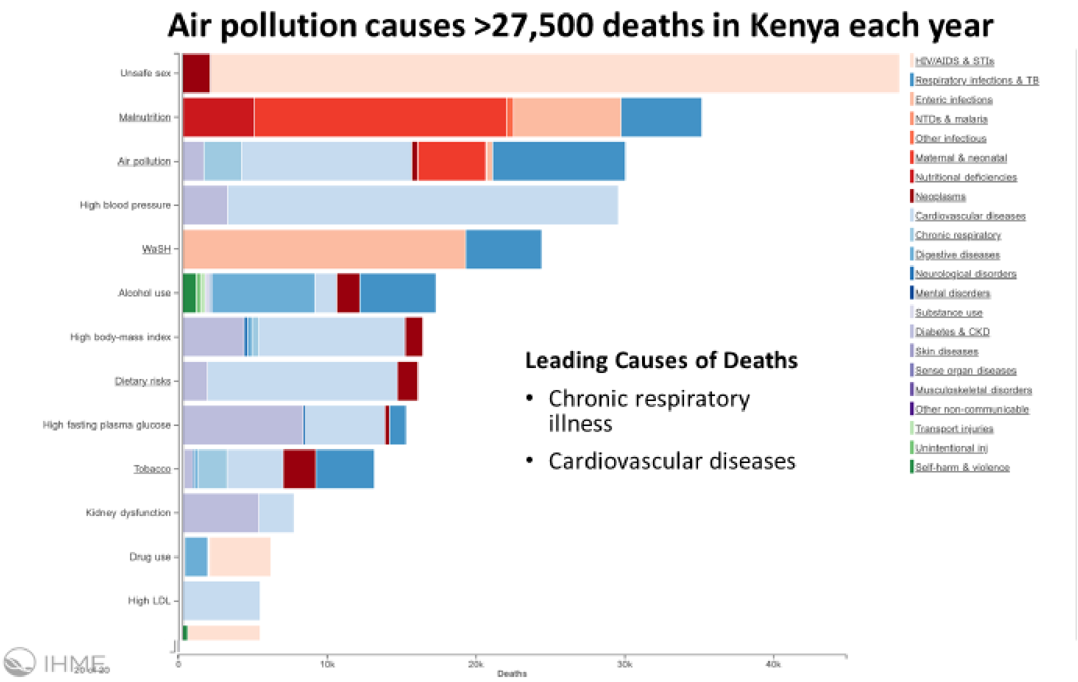
Curbing both black carbon aerosol and methane has been touted as a potential “win-win” scenario both for human health and climate (Shin dell et al., 2012). This is because removal of these pollutants reduces PM2.5 and O3 at the surface but also removes powerful warming agents from the atmosphere. BC is often co-emitted with other species, so understanding the specific sources (such as diesel fuel) is of critical importance if one wishes to specifically target warming agents and reduce the health burden of air pollution. Reductions of aerosols that have large negative impacts on human health but reflect incoming sunlight and thus cool the surface of the earth (e.g., sulfate and nitrate aerosols from power plants) will have the unfortunate unintended consequence of actually causing an increase in global warming (Westervelt et al., 2015). Therefore, climate and air quality mitigation strategies should be developed synergistically to identify “win-win” mitigation measures, or as integrated packages that result in overall health and climate benefits.

In addition to the aerosol impact on surface temperature, the impact of aerosols on precipitation and circulation is an important synergy that could be explored. High aerosol loadings generally lead to a suppression of precipitation, through decreased convection and evaporation, longer cloud lifetime, and other effects. The impact that emissions local to Nairobi and larger East Africa have on precipitation has largely not been systematically studied to our knowledge. However, impacts of dust emissions, and emissions of aerosols from industrialized nations, have been found to have a statistically significant impact on precipitation rates in Africa in both the east and west Sahel region (Westervelt et al., 2018). In one of the few studies to look at local emissions in East Africa, Berhane and Bu found a negative correlation between historical Aerosol Optical Depth (AOD) loading and precipitation over Eritrea (Berhane and Bu, 2021).

Additionally, major emission sources of greenhouse gasses are also major sources of air pollutants such as transport and energy generation from fossil fuels. Strategies advocated by air pollution managers, such as increasing energy efficiency and increased use of renewable energy sources, could also bear major benefits in reducing greenhouse gasses. Kenya's GHG emissions reduction commitments, as stipulated in the Nationally Determined Contribution (NDC), are anchored on the country's Green Economy Strategy and Implementation Plan (GESIP). Under this strategy, the country aims to promote a development pathway that reduces the country's ecological footprint. This focus is also expected to yield substantial benefits in improving the country's air quality.

1.4.2 AIR POLLUTION AND HEALTH

Exposure to high concentrations of air pollutants and in particular PM2.5 for any length of time can cause short-term and long-term negative health outcomes, including hospital admissions due to asthma, and premature death from chronic obstructive pulmonary disease, cardiovascular disease, lung cancer, and lower respiratory infection, and work loss days, among others. Both indoor and outdoor air pollution can contribute to furthering these health impacts. There are very few studies in Nairobi that try to quantify the burden of disease associated with air pollution in the city. However, the Global Burden of Disease (GBD) study conducted by IHME provides a comprehensive picture of diseases in Kenya, see Figure 7 below.



Air pollution causes >27,500 deaths in Kenya each year

Leading Causes of Deaths

- Chronic respiratory illness
- Cardiovascular diseases

Figure 7: Major causes of mortality in Kenya (data adopted from IHME, 2023)

The Nairobi City County Government also collects regular health data from the health facilities across the city and uploaded into the Kenya Health Information System (KHIS). From these data, it is notable that the leading driver of morbidity in the city is upper and lower respiratory diseases as shown in figure 8 below. From the figure, health ailments associated with upper and lower respiratory diseases have been on the rise in the city, with a notable decline in 2020 which is mainly associated with the COVID-19 lockdown, that limited the number of people visiting health facilities and significantly reduced air pollution emitting activities in the city. This finding is also corroborated by the 2021 Kenya National Economic Survey which estimated that 16.5 million Kenyans were suffering from respiratory ailments that are exacerbated by poor air quality (KNBS, 2021).

Air pollution is widely understood to have adverse impacts on human health and ecosystems. Human health impacts occur on differentiated timescales. For instance, at shorter timescales, exposure to air pollution is closely correlated with cough, shortness of breath, wheezing, asthma exacerbations, and high rates of hospitalization. In the long-term exposure to air pollution is associated with chronic asthma, pulmonary insufficiency, cardiovascular diseases, cardiovascular mortality, infertility, gestational diabetes, dementia, metabolic syndrome, higher risks of osteoporosis, cancer, cardiovascular disease, and chronic obstructive pulmonary disease (Manisalidis et al., 2020; Miller, 2020; Schraufnagel et al., 2019).

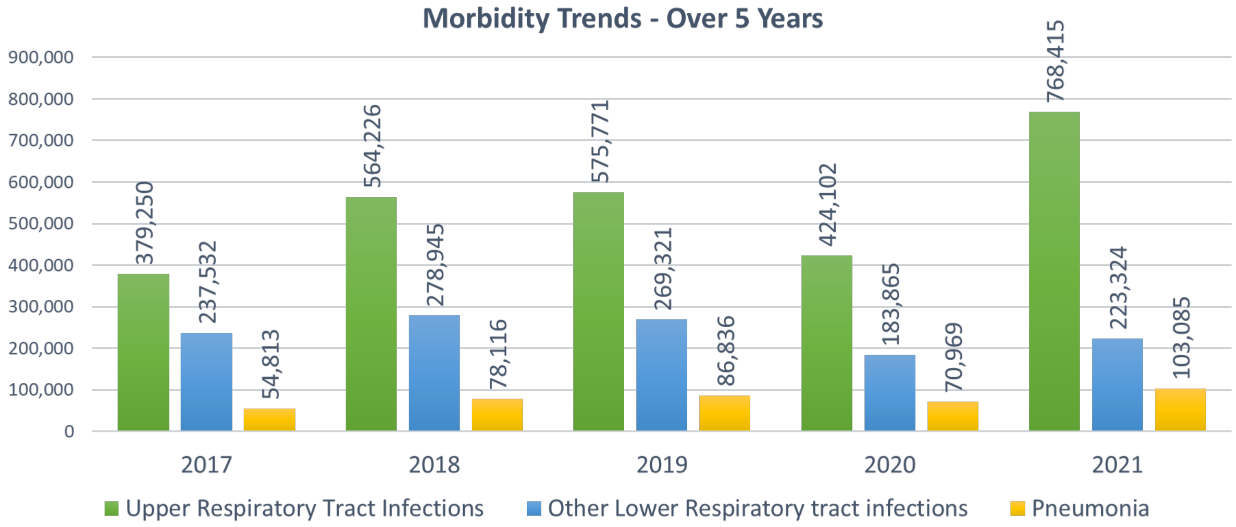


Figure 8: Morbidity trends associated with upper and lower respiratory tract infections. (Kenya Health Information System)

Additionally, short, and long-term exposures have also been linked to premature mortality and reduced life expectancy (Kelly and Fussell, 2015; Lelieveld et al., 2020; Manisalidis et al., 2020). In the recent past, evidence has also emerged linking air pollution to increased cases of dementia and preterm mortality (Hamad et al., 2020; Han, 2019; Paul et al., 2019). Moreover, following the global COVID-19 pandemic, evidence has emerged linking higher COVID-19 fatalities in communities exposed to high levels of air pollution (Wu et al., 2020).

Exposure to air pollution, even at very low concentrations, can still result in negative impacts. For instance, a study conducted by Weichenthal et al. (Pope, 2022) found a strong correlation between (PM2.5) concentration and the risk of premature death. The study followed approximately 7.1 million adults living in areas with low ambient PM2.5 concentration and found a strong correlation between low concentrations of PM2.5 (below 5 ugm^{-3}) and premature deaths in the long term. These studies, among others, prompted the WHO to revise the ambient PM2.5 recommended standards to 5 ugm^{-3}). These effects make air pollution the top environmental cause of morbidity and mortality, with estimates indicating that air pollution is responsible for more than 8 million deaths across the globe each year (Lelieveld et al., 2020; WHO, 2022).

1.4.3 AIR POLLUTION AND GENDER

The effects of climate change and air pollution are not felt equally by everyone. Women and girls are disproportionately vulnerable to the negative impacts of climate change and air pollution as compared to men, as these impacts often exacerbate the pre-existing gender inequities that plague global societies. Poor air quality and its associated health outcomes tend to have a disproportionate effect on women and other marginalized communities as these groups have limited climate resiliency (due to limited access to basic services and key resources and the prioritization of more privileged groups over marginalized groups when it comes to access to health services). Furthermore, the health effects of climate change and air pollution exacerbate pre-existing conditions (which tend to impact marginalized communities more than non-marginalized communities) and puts more stress on the already strained mental and physical realities of people living in marginalized environments (CAC, 2022).

In Nairobi, as many other cities in the developing world, air pollution affects women and children disproportionately, due to cultural norms and occupational hazards. Most low-income households reside in the city's informal settlements and use solid fuels to meet their household energy demands. These solid fuels are burned in inefficient cookstoves, translating to increased emission and aggravated indoor air quality especially in the many homes with poor ventilation, with some studies showing pollution levels multiple times higher than the WHO standards. Due to the cultural norms where women and children spend a lot of time around these cooking areas, their exposure to this emission is considerably higher compared to other groups. In addition, women make up a bigger proportion of food vendors in the city and most of the food vendors are located close to major transport hubs, where emissions from both the cooking and from the transport sector exacerbate their exposure. Even though women have a greater probability of exposure to unsafe air, gender segregated air pollution impacts data is not available. Therefore, more work is needed on gendered, and sex differentiated impacts of exposure from known and suspected sources of air pollution including open burning, waste separation in landfills, waste-water discharges, transport and industrial sites.

1.4.4 IMPACTS ON WOMEN

While air pollution has definitive impacts on the health of humans as a whole, women and men of varying socio-economic status, age, and occupations are exposed to differing levels of air pollution and as such suffer different consequences (OECD, 2021). Available evidence suggests that globally, women experience more exposure to indoor air pollution from solid fuel use, increased harm from poor sanitation and waste burning, and higher exposure to toxic airborne chemicals in occupation. Compounded by biological differences and social circumstances like poverty, gender inequality and discriminatory gendered cultural norms, studies link air pollution to irregular menstruation, infertility, gestational diabetes, dementia, metabolic syndrome and polycystic ovary syndrome as well as higher risks of osteoporosis, cancer, cardiovascular disease, chronic obstructive pulmonary disease and stroke. At the societal level, higher levels of air pollution perpetuate the gender pay gap as the need to care for dependent family members falls disproportionately on women (OECD 2021).

1.5 Broader Intersectional Impacts

In Nairobi, over half the population lives in informal settlements with poor housing made with tin/corrugated iron roofing and mud or tin/corrugated iron sheet walls, limited access to proper sanitation, unpaved roads, open burning of refuse and the near absence of public services (Ngo et al. 2015; Muindi 2017; Dianati et al. 2019;). Slums are also in close proximity to sources of air pollutants, such as highways, industrial zones, or open dumpsites (Dianati et al. 2019). Health researchers investigating the burden of disease in these settlements have documented a high prevalence of respiratory illness, asthma, and acute respiratory infections among children, including seasonal mortality among under-five children with a high peak during the cold season (Egondi et al. 2013). Emerging health concerns for slum residents also include injuries, infectious diseases such as dengue (Ezeh et al., 2016), and cardiovascular disease (van de Vijver et al., 2013). In one study focused on the vulnerability of school age children, researchers found children from low socioeconomic backgrounds may face a dual burden of exposure both at home and in school environments. Data gathered during that study indicates that air pollution levels in both indoor (classroom) and outdoor (school ground) settings regularly exceed WHO guideline amounts (Avis et al. 2019).

Women are more likely to be unemployed or involved in informal employment selling street foods or groceries and scavenging at dumpsites, exposing themselves to a higher cumulative level of air pollutants (Muindi 2017). Researchers have also found higher rates of maternal mortality associated with severe air pollution (Ziraba et al., 2009). Although slum areas are not homogeneous with varying economic activity and environmental factors, a Rapid Care Analysis carried out by Oxfam in 2016 in the Mukuru area (informal settlement close the Nairobi industrial area) confirmed that childcare is extremely difficult due to constraints against outdoor play and disease outbreaks as a result of industrial effluent and open sewers (Maina and Kimani 2019).

1.6 Indoor or Household Air Pollution

Perception- based research also indicates a lack of source awareness by people living in slum areas. Hazardous levels of indoor PM2.5 are found in 86% of households within Nairobi informal settlements households (Muindi 2017). These households tend to rely on kerosene for cooking and lighting as well as charcoal or wood for cooking. The use of plastic waste, cloth rags, and other unconventional fuels has also been reported (Dianati et al. 2019).

One study investigating indoor air pollution in the Korogocho and Viwandani slum areas of Nairobi found despite having windows, some people chose not to open them even during cooking times because of structural limitations, security and privacy concerns. (Muindi et al. 2016). Muindi et al. also found lamps were widely used in the evening, and the reliance on kerosene for lighting, especially for the open-wick lamp, was also a major contributor of indoor fine particles. Many participants felt poverty was to blame for the state of indoor air quality, as it constrained people from using cleaner fuels. Further, the lack of knowledge of the consequences of using dirty fuels was cited as a factor contributing to the poor state of indoor air quality, compounded by the fact that many informal settlements are characterized by many houses crowded together in small areas (Muindi 2017).

Across the country, cooking fuel and household air pollution are well-recognized problems and focus of attention. The Kenya Government expects to achieve universal access to clean cooking by 2028, two years ahead of SE4ALL schedule (Clean Cooking Alliance 2019).

1.7 Exposure from Gender Differentiated Mobility

Severe traffic congestion, especially during the extended peak hours, contributes to local air pollution and leads to significant economic losses. The city is also reported to have one of the longest average journey-to-work times in Africa (Rajé, Tight, and Pope 2018). A large fraction of Nairobi residents are regularly exposed to on-road and roadside pollution through driving, walking or working on the street, working in buildings or living in apartments above high-traffic roads, especially motorists, pedestrians, traffic police, street vendors, downtown workers in buildings adjacent to busy roads (Kinney et al. 2011).

Walking is the most common mode of transport in Nairobi, often because people cannot afford other means of transport. Pedestrians are the city's poorest residents, suggesting that this population group may suffer from disproportionate exposure to, and subsequent effects from, air pollution. These residents typically have limited access to healthcare, so it is more likely that the health impacts of emissions will go untreated.

Vulnerability and mobility are also both inextricably linked with gender. Women who work in informal settlements could be exposed to BC from diesel emissions, as walking is the primary means of commuting in these areas, as well as from smoke from cook stoves, kerosene lamps or trash burning which are common in these areas (N. S. Ngo et al. 2015). A study by Ngo, Kokoyo, and Klopp (2015) found women living in the Mathare slum in Nairobi experienced high levels of PM2.5 as roadside mechanics and street vendors, populations already considered at-risk since they spend their workday in close proximity to roadway emissions.

The burden of reduced mobility is borne disproportionately by women and children (Salon and Gulyani 2010). Mobility and transit choice are very closely linked to income levels and employment. Men are more likely than women to go to work and are more likely to travel by matatu, privately owned mini buses used as shared taxis. Women are more likely to be employed in informal and domestic work (Emina et al. 2011). This gender gap in transit choice is attributed in large part to the cost and expectations around childcare as the presence of children in the household does not affect men's employment status (Pinchoff et al. 2021).

1.8 Solid Waste Management/Dump Sites

Nairobi's solid waste management is characterized by low coverage and collection, pollution from uncontrolled dumping, inefficient or lacking waste management infrastructure, and unregulated and uncoordinated private sector operations (Avis, Gatar, and Ng'ang'a 2018). Cost is a significant driver of the waste problem and influenced by household monthly income, household size and education level of the household head (Ndunda 2018).

Findings from the ASAP-East Africa Vulnerability Scoping Study Dandora dumpsite air pollution monitoring campaign highlight that air quality levels ($PM_{2.5}$) at outdoor locations exceed WHO guidelines at all times. Other studies of those living and working in, or near, Dandora have reported significant health issues including respiratory tract issue, chronic bronchitis, asthma, fungal infections, allergic and unspecified dermatitis/pruritus – inflammation and itchiness of the skin (Avis, Gatari, and Ng'ang'a 2018). Workers and surrounding populations also face an increased cancer risk due to exposure to dioxins and furans from waste burning (Shih et al. 2016).

Women waste-pickers live close to the dumpsite and spend most of their working hours at the dumpsite scavenging for valuable waste as the main source of their household income in an environment that has affected their health due to presence of toxic metals such as lead, and mercury released during waste combustion (Kimani 2021). Despite the presence of security officers, criminal groups exert a significant influence and control materials recovered and onward sale to recyclers (Muindi et al. 2022)

1.9 Occupational Exposure in Factories

In addition to individuals who worked along roadways in Nairobi, a few studies document disproportionate exposure to pollutants in work environments. In a cross-sectional study in the industrial area of Nairobi, in five different types of factories' production, workers in the selected factories had reduced lung function that could be attributed to the high levels of PM_{10} concentration in their working environment (Musumba, Ng'ang'a, and Kombe 2018). Very high concentrations of benzene and toluene in the breathing zone of spray painters was also found in small-scale informal auto garages in the Embakasi study area (Mwatu et al. 2019).

1.10 A Lack of Source Awareness

A number of low-cost monitoring, participatory science-based initiatives have incorporated perception surveys and participatory mapping to identify local sources and evaluate residential source awareness. A study (N. Ngo, Kokoyo, and Klopp 2015) on risk perceptions and understandings of air pollution in poor Nairobian neighborhoods, found that less than half of the respondents explicitly considered health in their definition of air quality. Another monitoring study, (Egondi et al. 2013) conducted in two urban informal settlements of Nairobi (Korogocho and Viwandani) concluded that residents in both informal settlements are exposed to PM2.5 levels exceeding hazardous levels according to WHO guidelines. Residents, however, commonly just associated odor with air pollution sources despite being exposed to air pollution in their place of work or to at least two sources of air pollution (Egondi et al. 2013). Less than 20% of respondents in both areas mentioned sources related to indoor pollution. In this study, duration of stay, age and gender were not significantly associated with perceived health risk related to air pollution, but marital status, education level, and occupation were (Egondi et al. 2013). Those who had not heard information about air pollution were associated with low perceived risk in both areas.

These findings are similar to another study that found odorous drainage channels and toilets frequently cited as a source of air pollution (Muindi et al. 2014). The feeling of helplessness attributed to the lack of voice among the residents to approach their leaders and to demand action as well as their informal residential status, poverty and lack of alternatives may inhibit collective action against pollution (Muindi et al. 2014).

Another study investigating perceptions of personal exposure to air pollution among informal settlement dwellers of Makuru found that residents were able to identify new hyperlocal, potential sources of pollution exposure even though the resident questionnaire found limited evidence of change in people's knowledge about air pollution over the duration of the project. The study also found no change in how polluted the residents thought the air was (either indoor or outdoor) (West et al. 2020). A study commissioned by the CAC project to gauge the air pollution awareness in the city corroborated previous findings: close to 85% of Nairobi residents associated air pollution with odors and bad smells.

2. REGULATORY LANDSCAPE AND AIR QUALITY STAKEHOLDERS

2.1 Current action on air pollution management

Under the Kenya Constitution, issues related to air pollution were fully devolved to the county governments and therefore the counties have full jurisdiction of addressing air pollution and controlling emissions within their boundaries. The air pollution issue in Nairobi has been recognized as a major challenge by the city authorities and several plans and interventions have been put in place to address this. However, due to capacity and financial constraints the city has not rolled out a comprehensive plan to address the challenge. Some of the initial steps the city authorities have taken-are described below.

The Nairobi Air Quality Action Plan (NCCG, 2022) outlines the actions the city will take between 2019 and 2023 to address air pollution. It is designed to tackle air pollution by enhancing AQ governance, setting out to lay the foundation for current and future AQ management and regulation. The Plan aims to achieve this through capacity building, public awareness, and legislation. It features several key actions, including improving the capacity of city staff, installing AQ monitors, analyzing future climate change trends, developing a more robust GHG inventory, creating a communications strategy and awareness materials, and implementing an effective AQ. Key milestones set in the action plan that have already been met include:

4. Enhancing the capacity of the city air quality managers to take action in addressing air pollution.

5. Develop an air quality management policy for the city, which was enacted in 2020 (NCCG, 2020).

6. Development of the legal framework under which to anchor air quality management in the city among others. The Act was passed by the county assembly in 2021.

Other additional efforts aimed at reducing air pollution in the city include the Integrated Urban Development Masterplan for the City of Nairobi, the County Integrated Development Plan (2022-2027), the Climate Change Action Plan, and other mitigation measures (such as sector-based policies and awareness campaigns).
At the national level air quality challenges have also been recognized as an issue of major concern and this prompted the development of the first Ambient Air Quality Standards for the country in 2014, under the Clean Air Regulations. These regulations provided for the prevention, control and abatement of air pollution to ensure clean and healthy ambient healthy ambient air and are anchored under the Environment Management and Coordination Act (EMCA, 2014) and enforced by the National Environment Management Authority. To further characterize the state of policies and regulations surrounding air quality in Nairobi, a political economy analysis was undertaken.

2.2 Political Economy Analysis Recap

The political economy analysis (ARIN, 2023) was undertaken in Nairobi to explore and understand the sectoral sources of air pollution in Nairobi and identify intersections and relations among different sectors. The analysis also aimed to understand the governance processes that are behind air quality management, and their accompanying challenges and opportunities. Moreover, the PEA aimed to identify strategic and specific areas for intervention that could promote effective, equitable and gender-responsive air quality management systems. The PEA identified several areas for direct policy action, as well as potential cross cutting interventions. The working group, through the Catalyst, can strategically target the top decision makers in the city to be the key ambassadors and champions of clean air in Nairobi, enabling them to gain political goodwill and thus effectively execute the necessary interventions. From the gender perspective, the PEA recommended a deep dive gender analysis and the formation of a gender working group that focuses on air quality. The PEA can be accessed here.

3. RECOMMENDATIONS FOR CURRENT AND FUTURE MONITORING RESEARCH

There are clear research and monitoring gaps in Nairobi hindering the ability to implement actionable policies for air quality management. Transport, waste and energy have been identified as major polluting sectors in the city, and gender, climate and health have been identified as social and environmental issues most impacted by air pollution. With more robust research and monitoring, the sectors with the most prevalent sources of pollution can be understood and addressed. Most available data in Nairobi have originated from short term studies, which do not allow for a complete profile of air pollution impacts on the city. The city is lacking a continuous air quality monitoring network, which would serve to effectively characterize the state of Nairobi's air pollution. The following section lays out the recommendations for current and future monitoring research in the city, beginning with the Catalyst's plan for air quality monitoring.

3.1 Clean Air Catalyst Monitoring and Assessment

Evidently, air pollution is a pressing issue in Nairobi. This report has identified vehicular emission and open burning of waste to be some of the major sources, and ambient levels of air pollutants have been established to be well above WHO recommended limits. As the NCCG has no continuous air monitoring networks in place in Nairobi, the Catalyst plans to install air monitoring equipment, and provide trainings on instrumentation, operations, quality assurance, data analysis and how air monitoring supports air quality management policy. The Nairobi pilot team will thus focus on monitoring particulate matter and black carbon with reference-grade monitors in two sites, which will be co-selected by the CAC partners and the Nairobi City Authorities. Currently, 12 sites have been identified and 5 have been reviewed by the site selection committee, made up of members from WRI, AirQo, HEI, Vital Strategies, JKUAT, the County government and NEMA. This site review was conducted on March 20th, 2023. A second site review occurred on April 12th, and as of April 13th, the National Parliament will tentatively be the host of site one, pending approval from the National Assembly. Site two has been tentatively selected to be in an industrial area managed by the Kenya Pipeline Corporation (KPC). After site selection, the Catalyst plans to monitor these sites in Nairobi with reference-grade monitors. The site at KPC is relatively open and the aim is to place the monitor on a rooftop that is approximately three meters above ground, which will give a well-mixed representation of emissions in the industrial area. The Nairobi team has also identified several other sites where AirQo, a member of N-AIR, will be placing low-cost sensors.

The Catalyst's modeling work will be led by Map-AQ using WRF-Chem, which will be based on updated local emissions inventory tracers to quantify the contributions of sources within Nairobi as opposed to contributing sources from areas around or outside Nairobi. This method will allow the data to be specified to the local area and allow for a deep analysis of pollution sources and quantities.

MapAQ's modeling will be complemented by methodologies developed to map the sources of air pollution and exposure risks in Nairobi, which mainly utilized satellite retrievals. They used multi-layer GIS maps to understand the nature of Nairobi County's emissions, including vulnerable communities and neighborhoods. The GIS mapping allowed us to visualize various factors affecting AQ, including Nairobi's dumpsites, land use and land cover changes, population distribution, ambient air pollution, and major air pollutants (Ongo, 2022).

Through mapping, we have gained an understanding of the air pollutants that affect Nairobi's air–including carbon monoxide, nitrogen oxides, sulfur dioxide, ozone, PM, and lead–ultimately finding that PM2.5 is the dominant pollutant. The Thika super-highway and Mombasa Road are large contributors to NO2 emissions and CO is largely concentrated around the Thika super-highway. Formaldehyde levels are high in metropolitan Nairobi–including Kiambu, Kajiado, bulbul, and Ngong–and lower in the outskirts. Similarly, methane is concentrated in Nairobi and parts of Kiambu. Ozone, which thrives in sunnier and drier environments, is largely found in semi-arid regions in Kenya, which include the southern region of Muranga, parts of Thika, and most of Machakos.

With this information, we are able to visualize where various pollutants are concentrated which ultimately allows us to begin to identify hotspots, sources of pollution, and eventually take steps towards developing solutions.

4. ANNEX

The Clean Air Catalyst will work with the following government organizations and Commissions among others:

- Climate Change Directorate (CCD)
- Kenya Meteorological Department (KMD)
- Kenya Medical Research Institute (KEMRI)
- Kenya Industrial Research Development Institute (KIRDI)
- Ministry of Environment and Forestry
- Ministry of Health
- Ministry of Transport
- Nairobi City County Government (NCCG)
- Nairobi Metropolitan Area Transport Authority (NAMATA)
- National Environment Management Authority (NEMA)
- National Transport and Safety Authority (NTSA)
- National Gender and Equity Commission (NGEC)*

The Catalyst also will work with the following private/non-profits/NGOs and academic organizations:

- Airqo
- C40 Cities
- Climate and Clean Air Coalition
- Code for Africa
- EED Advisory (Pan-African consulting firm)
- Environmental Compliance Institute (ECI)
- Global Environmental and Occupational Health Hub project (GEOHUB)
- Groots Kenya*
- Groundwork
- Health Care Without Harm
- Health Effects Institute
- Jacaranda Health

- Jomo Kenyatta University of Agriculture and Technology (JKUAT)
- Kenya Association of Manufacturers (KAM)
- Kenya Alliance of Residence Association (KARA)

- Kenya Climate Change Working Group (KCCWG)Kenya Private Sector Alliance (KEPSA)
- Muungano Wa Wanavijiji*
- Pan African Climate Justice Alliance (PACJA)
- SERVIR, including Regional Center for Mapping Of Resources For Development (RCMRD)
- Slum Child Foundation
- Slum Dwellers International-Kenya*
- Strathmore University
- Stockholm Environment Institute (SEI)
- United Nations Environment Programme (UNEP)
- University of Leicester
- University of Nairobi
- Wangari Maathai Institute for Peace and Environmental Studies
- World Health Organization (WHO)

*Indicates gender and/or equity organization:

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