ASAP
EAST AFRICA

A Systems Approach to Air Pollution – East Africa: Synthesis Report

ASAP-East Africa Research Team

February 2020

ASAP brings together leading UK and East African researchers in air pollution, urban planning, economic geography, public health, social sciences and development studies to provide a framework for improved air quality management in three East African cities: Addis Ababa (Ethiopia), Kampala (Uganda) and Nairobi (Kenya).

This timely and responsive programme of activity will enhance local decision-making abilities to improve urban air quality, reduce the effects of air pollution upon human health, and allow for sustainable development to proceed without further deterioration in air quality.

Central to the project's aims are strengthening research capabilities and technological expertise in East Africa, with local stakeholders and experts involved in the conception, implementation, and uptake of the programme and its outcomes.

asap-eastafrica.com

Contents

Urbanisation and air quality in East Africa

The global urban population has grown rapidly from an estimated 751 million in 1950 to 4.2 billion in 2018. Around 55% of the world's population is believed to reside in urban areas, a proportion expected to increase to 68% by 2050 (UN, 2018). While the pace and pattern of urban growth and urbanisation varies, the vast majority of the growth is expected to take place in the global south. More specifically, it is in poor informal or slum settlements on the peri-urban interface that growth is expected to be greatest. Indeed, poverty in low and middle income countries (LMICs) is becoming increasingly urban. The growth of informal settlements, slums or poor residential neighbourhoods is a global phenomenon accompanying the expansion of urban populations. An estimated 25% of the world's urban population live in informal settlements, with 213 million informal settlement residents added to the global population since 1990 (UN-Habitat, 2013). Data from East African cities illustrates these trends, with the ASAP-East Africa focus cities Nairobi, Addis Ababa and Kampala, witnessing significant growth.

*Table 1: **Urbanisation statistics for study cities (UNDESA, 2016; UN-HABITAT, 2016; UN-HABITAT, 2014)***

	Addis Ababa (Ethiopia)	Kampala (Uganda)	Nairobi (Kenya)
Population of Urban Agglomeration (2015)	3,316,000	2,012,000	4,070,000
Population of Urban Agglomeration (2030)	5,851,000	3,939,000	7,140,000
Projected % increase in population (2015-2030)	80.69	103.46	82.37
Rate of change of the urban population 1995-2015 (% per year)	4.47	4.91	4.36
City Density (population/km²)	8,300/km²	3600/km²	8500/km²
Contribution to national GDP	-	Ca. 60%	Ca. 60%
Estimated % of national urban population living in slums (2014)	74	54	56

Rapid urbanisation has the potential to improve the well-being of societies, yet urbanisation also presents a number of human development challenges. With a significant proportion of urban expansion predicted to take place in informal settlements, economic disparities in urban areas will likely be exacerbated, indeed, migration and urban growth are leading to a shift in the locus of global poverty that has been referred to as the 'urbanisation of poverty' (UN-Habitat, 2003; Duflo et al., 2012). Rapid urbanisation may also exacerbate environmental risk with exposure determined by a number of technological, environmental, and behavioural factors. Key environmental health issues in the global south include poor water and sanitation, flooding, indoor air pollution from solid fuels and urban ambient air pollution.

In the context of this report, air pollution is the focus, both household and ambient. Whilst various estimates of mortality associated with air pollution exist, the WHO asserts that there are 4.2 million premature deaths every year as a result of exposure to ambient (outdoor) air pollution and 3.8 million annually as a result of household (indoor) exposure primarily related to smoke from cooking and heating[1]. The World Health Organisation (WHO) concludes that more than 80% of people living in urban areas are exposed to air quality levels that exceed their recommended (WHO) limits[2], threatening lives, productivity and economies. The Lancet Commission, drawing on the Global Burden of Disease study (2015), estimates annual global premature deaths due to air pollution risk factors at between 5.7-7.3 million - equivalent to one in ten premature deaths (Cohen et al., 2017). This figure is broadly equal to the death toll associated with AIDS, malaria, tuberculosis, malnutrition, road accidents and war and murder combined. It also highlights an epidemiological transition from communicable to non-communicable disease associated with economic development.

Urban air pollution is thus a pressing and multi-sectoral development challenge, representing a major health, economic and social threat to cities globally. It is inextricably linked to how we plan, manage and live in our cities. Poor air quality acts as a brake on development through increasing market costs including higher expenditure on health, loss of labour productivity, the impact of illness on education, and reduced agricultural yields. It also leads to greater non-market costs by increasing disutility of illness and mortality (World Bank and IHME, 2016). Due to its different sources and removal processes, air pollution concentrations in cities, and the surrounding peri-urban and rural areas, are highly heterogeneous.

The economic cost of air pollution is also significant. According to the World Bank, the cost of premature deaths to the global economy in foregone labour income each year equates to $225 billion (World Bank and IHME, 2016). These costs increase significantly if morbidity is taken into account with consequent loss of labour and education. In recent years, an increasing amount of research has focused on links between cognition and mental health, including dementia (Shehab and Pope, 2019). The links between air quality and mental health are currently insufficiently proven to produce robust cost estimates. If verified the economic cost of air quality will rise dramatically. Despite the high costs associated with air pollution, stakeholders (public, private and civil society) often fail to assign sufficient attention to the issue. This may be driven, in part, by the existence of contemporaneous concerns (for example, tackling poverty, addressing inequality and driving economic growth) and the challenge of associating current air pollution levels with future impacts. Available evidence suggests that air pollution will worsen in coming years and exert an increasing toll on public health in many cities of the global south, especially in sub-Saharan Africa (SSA). Renewed efforts are therefore required to sensitise individuals to the scale of the air pollution challenge and to encourage action to address the issue. At its heart, this involves three key elements:

---

[1] https://www.who.int/airpollution/en/
[2] The WHO sets a limit of $PM_{2.5}$ 25 µg/m^3 24-hour mean

- **Air Quality Monitoring**: This involves monitoring the level of common air pollutants in both indoor and outdoor settings. Sensor based instruments and air quality monitoring systems are used widely in outdoor ambient applications though their cost can vary considerably.
- **Air Quality Modelling**: This provides predictive capacity and involves mathematical simulations of how air pollutants disperse and react in the atmosphere to affect ambient air quality. Technical capacity and hardware availability are often limited in the global south undermining the capacity of countries to undertake modelling.
- **Air Quality Management**: This requires input from the monitoring and modelling. It refers to the activities individuals and institutions undertake to help protect human health and the environment from the harmful effects of air pollution.

Air Quality in East Africa

Efforts to ascertain air quality across East Africa has historically been undermined by the absence of air quality monitoring in key areas. Whilst there exists a paucity of air quality data, available information illustrates that air quality is an issue of particular concern with air pollution threatening to undermine the development of inclusive, safe, resilient and sustainable cities. Long term visibility measurements can be used for a proxy for air pollution (see figure 1). Visibility data is routinely collected at airports throughout East Africa (in some cases from the 1950s to present day). Historic visibility in the three study cities is inversely proportional to the amount of particulate matter present in the air i.e. declining visibility correlates closely with increasing levels of air pollution. These results suggest that increased populations, the crowding of motorised traffic onto roads and increased economic activity in focus countries has been accompanied by a gradual but steady decline in air quality. Using visibility as a proxy, since the 1970s to present, air pollution is estimated to have increased by 162, 182, and 62% in Kampala, Nairobi and Addis Ababa, respectively (Singh et al., 2020)

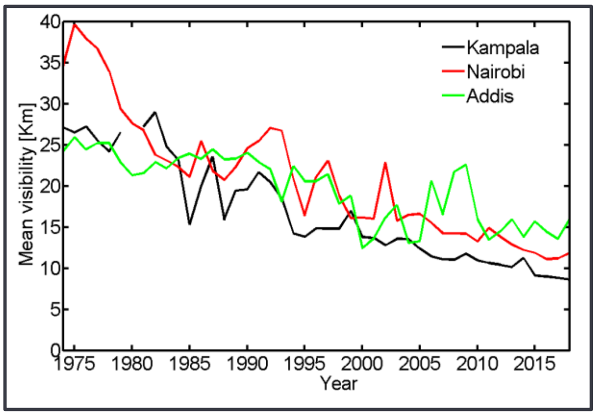


*Figure 1: **Long term visibility measurements from Addis Ababa, Kampala and Nairobi from 1970-2010**.*

It is also important to note that, whilst air quality is often a product of activities undertaken in urban areas, the impacts of air pollution are felt beyond the city. Modelling results emphasise that the three East African cities cannot be considered in isolation from the larger East African airshed[3]. Indeed, poor urban air quality impacts beyond administrative or economic boundaries and highlights that efforts to address air pollution must be cognisant of how urban centres relate to wider regional units and wider regional economies. This involves understanding the interface

[3] An airshed is a part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions. It typically forms an analytical or management unit. It can also refer to a geographic boundary for air-quality standards.

between local (city), regional (state/county), national (country) and international institutions. Governance factors will thus exert a significant impact, constraining or enabling effective initiatives to address air quality. ***Figure 2*** provides example model $PM_{2.5}$ data over the urban domains of the three focus cities (Nairobi, Addis Ababa, Kampala).

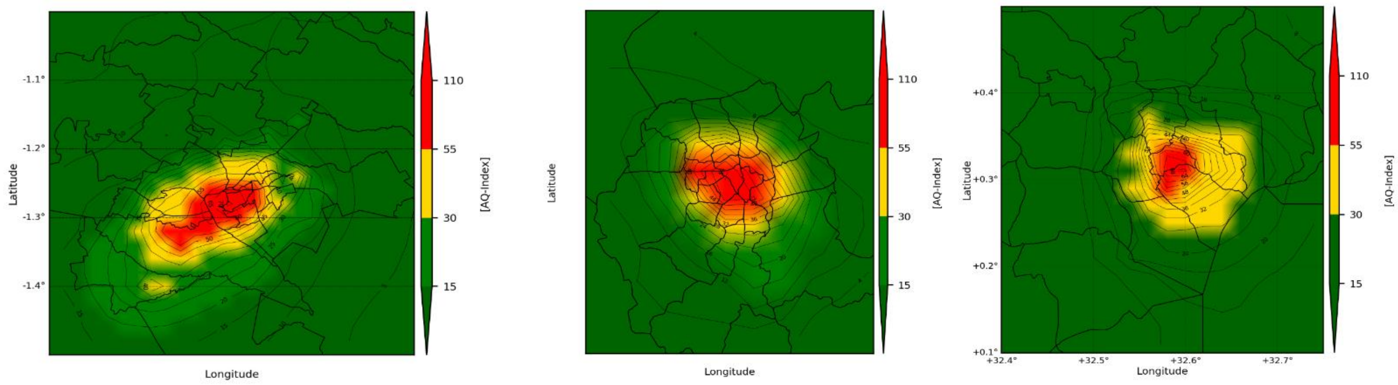


Figure 2: ***$PM_{2.5}$ Average Concentrations and relative Air Quality (AQ) Index levels for the period 14th February – 15th March 2017 (regions surrounding Nairobi, Addis Ababa, Kampala)***

The ASAP-East Africa research programme has supported the development of a comprehensive approach that identifies emission sources and articulates mechanisms for their control, reduction or elimination. This includes the development of a repository of recommendations focussed on a number of pollution sources. These include restriction on open burning, curbs to industrial pollution, accompanied by regulations that seek to reduce emissions from power generation. The most critical and effective efforts to address outdoor urban air pollution must be focused on reducing vehicle emissions, in particular poorly maintained matatus and boda bodas are responsible for much of the vehicular exhaust emissions. Improvements in indoor pollution will be achieved from transitioning from smoky biomass fuels, to cleaner fossil fuels (e.g. gas and ethanol) to universal electricity provision. Alongside those issues that can be addressed at local, regional or national scales, increased pressures exerted by global population growth and economic development are also important.

To guide discussions of air pollution, the ASAP-East Africa research team have adapted the US Environmental Protection Agencies (US EPA) Air Quality Index Scale to illustrate how different levels of air pollution contribute to different health impacts amongst different groups. The ambient air quality standards most often utilised include those developed by the European Union, the United States and the WHO. The WHO air quality standards (25 $\mu g/m^3$ 24 hour mean) are not legally binding, rather they represent a guideline for countries and are significantly tougher than those suggested by others. ***Table 2*** provides a guide to different levels of exposure to $PM_{2.5}$ over a 24 hour period, health implications associated with that level of exposure and includes a cautionary statement identifying those groups likely to be affected.

Table 2: ***Air Quality Index scale as defined by the US EPA (2016)***

$PM_{2.5}$ μg/m³ (24 hour average)	***Air Pollution Level***	***Health Implications***	***Cautionary Statement for $PM_{2.5}$***
0.0-12.0	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.	None
12.1-35.4	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion
35.5-55.4	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion
55.5-150.4	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may begin to feel more serious health effects.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
150.5-250.4	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
250.4-500.4	Hazardous	Health alert; everyone may experience more serious health issues.	Everyone should limit outdoor exertion.

Nairobi (Kenya)

Air quality monitoring

Efforts to assess air quality in Nairobi are challenged by the city's limited air quality monitoring network and lack of long-term data required to ascertain variations in air pollution both temporally and spatially. The city has one active long term monitoring site (**http://aqicn.org/**) located at Nairobi Alliance Girls High School with plans to establish a wider network currently in development. That data which is available suggests that air pollution in the city consistently exceeds World Health Organisation guideline limits for Particulate Matter ($PM_{2.5}$) 24-hour mean[4]. $PM_{2.5}$ data collected by ASAP-East Africa indicates that air quality in Nairobi is typically at levels considered *'unhealthy for sensitive groups'* to '*unhealthy'* (***Figure 3***). The ASAP-East Africa team have supplemented available long term air quality monitoring with spot measurement campaigns at selected sites including outdoor (Moi Avenue and Dandora) and indoor (school and household) locations. Alongside this, analysis of visibility data has been

[4] $PM_{2.5}$ and PM_{10} are particulate matter with diameters less than 2.5 and 10 microns, respectively. The World Health Organization (WHO) recommends that $PM_{2.5}$ and PM_{10} daily mass concentrations do not exceed 25 and 50 μg/m³, respectively.

undertaken to fill historical data gaps and suggests that air quality levels are poor and declining within the city (***Figures 4a and b***).

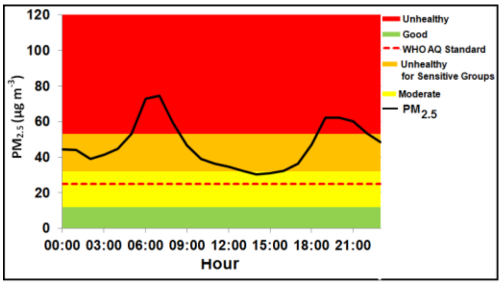


Figure 3 *Hourly averaged $PM_{2.5}$ concentrations in Nairobi at WHO air quality standard, derived from two month (Jan-Feb 2017) data. Here, different colour backgrounds show the EPA air quality index for health.*

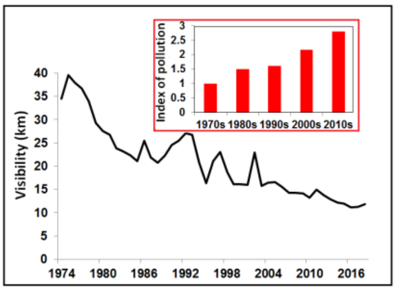


Figure 4 a) *Annual visibility trends and* ***b)*** *index of pollution level at Nairobi derived from 45 years of hourly visibility data (1974-2018). The air pollution index is referenced to the levels observed in the 1970s.*

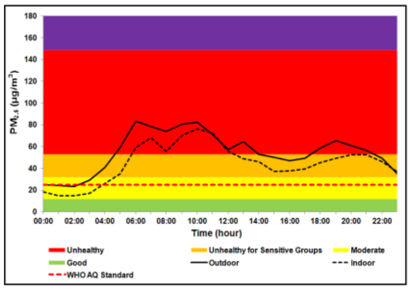


Figure 5 *Hourly averaged $PM_{2.5}$ concentrations Moi avenue primary school (July / August 2018) Indoor and Outdoor*

Low cost particle sensors: ASAP simultaneously monitored $PM_{2.5}$ and PM_{10} at multiple sites in Nairobi; urban background (American Wing building, University of Nairobi), urban roadside (Nairobi's Central Business District) and rural background (outskirts of Nanyuki town). Comparison of sites has facilitated an understanding of PM variation between urban background, urban roadside and rural areas.

Visibility and satellite data: ASAP-East Africa researchers have collated hourly visibility data for the period 1974-2018 alongside meteorological factors (relative humidity, temperature and wind) at Jomo Kenyatta International Airport to investigate long term historical air quality trends. A clear trend of decreasing annual visibility (0.52 km year^{-1}) was observed in Nairobi between 1974 and 2018 (***Figure 4a***). Findings suggest that air pollution levels have increased by 182% between the 1970s and 2010 (***Figure 4b***).

Household and other additional studies: Household studies and spot measurement campaigns have been implemented across Nairobi to explore spatial and temporal variation of air quality in the micro-environments where people spend significant periods of time. A study of Moi Avenue Primary School, located in Nairobi's Central Business District, highlighted that school air quality was an issue of concern (***Figure 5***). Classroom PM concentrations, in the $PM_{2.5}$ size range, were measured to be on average 43 ± 19 µg m^3 and peaked at 47 ± 14 µg/m^3 during school days. Outdoor levels of $PM_{2.5}$ recorded larger concentrations, averaging 54 ± 22 µg/m^3 and peaking at 61 ± 21 µg/m^3, which is consistently at an unhealthy level. Studies in the vicinity of Dandora dump site recorded average levels of $PM_{2.5}$ to be 47.4 ± 9.5 µg/m^3 and peak concentration was 94.5 ± 32.6 µg/m^3 during the monitoring period, highlighting the potential impact of solid waste management (or the lack of) on air pollution.

Air quality management

The federal government of Kenya developed Air Quality Regulations for the country in 2014. However, policy implementation has been limited and currently fails to address air pollution issues. Urban air pollution remains concerning despite high levels of institutional awareness and action. The City County Government, in partnership with UN Environment and other stakeholders, have developed Nairobi City's first Air Quality Action Plan (2019-

2023). The action plan identifies four broad overlapping actions to build the scientific evidence base for policy interventions for air quality management; raising public awareness on the health and environmental impacts of air pollution; developing effective approaches for air quality management and building an effective implementation and enforcement programme for air quality legislation. Alongside this, a number of NGOs (e.g. the Kenya Air Quality Network) and professionals have collectively taken actions to push government to tackle air pollution in Kenya holistically.

Despite these efforts, successful interventions will only emerge with the development of a holistic approach cognisant of the socio-economic and cultural context of the country. Currently, the focus of action for air quality management has been driven by demands for information provision and capacity building with little to no attention to the socio-economic factors that can motivate people to change environmental behaviours. The development of an action plan shows the importance of bringing governance to the people but challenges are posed by the nature of political power in Kenya and the dominant role played by national government in the provision of urban infrastructure.

The state of air quality management in Nairobi is indicative of the inconsistencies in policy and practice. The development of air quality regulations took a number of years before being approved, yet after its emergence it became a political document for referencing purposes; this may set a negative precedence because actions may be driven by political expediency, rather than addressing the underlying societal issues. The above highlights the likely challenge the city government may face in implementing the action plan. The role of national government in infrastructure provision also raises concerns as to how county and national governments will work together to achieve the goal of developing clean and affordable urban infrastructure for the people.

Addis Ababa (Ethiopia)

Air quality monitoring

Efforts to assess air quality in Addis Ababa are challenged by the city's limited air quality monitoring network and lack of long-term data required to ascertain variations in air pollution both temporally and spatially. The city has one active monitoring site (**airnow.gov**) established in 2017 at the US Embassy, with plans to establish a wider network currently in development. That data which is available suggests that air pollution in the city consistently exceeds World Health Organisation guideline limits for Particulate Matter ($PM_{2.5}$) $\mu g/m^3$ 24-hour mean[5]. Archived $PM_{2.5}$ data indicates that air quality in Addis is typically at levels considered *'moderate'* to '*unhealthy for sensitive groups'* (***Figure 6***) according to the United States Environment Protection Agencies Air Quality Index. The ASAP-East Africa team have supplemented available long term air quality monitoring with spot measurement campaigns at selected sites including outdoor (Addis Ababa National Bus Station) and indoor (household) locations and mobile monitoring

[5] $PM_{2.5}$ and PM_{10} are particulate matter with diameters less than 2.5 and 10 microns, respectively. The World Health Organization (WHO) recommends that $PM_{2.5}$ and PM_{10} daily mass concentrations do not exceed 25 and 50 $\mu g/m^3$, respectively.

(buses). Alongside this, analysis of visibility data has been undertaken to fill historical data gaps and suggests that air pollution levels are plateauing within the city see (***Figures7a and b***).

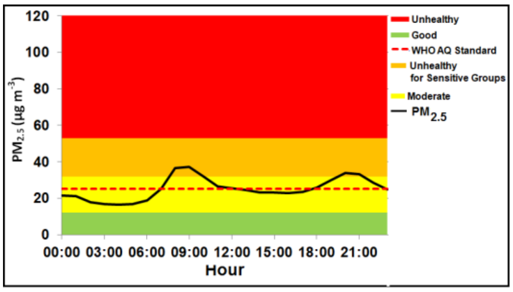


Figure 6 *Hourly $PM_{2.5}$ concentrations in Addis and WHO air quality standards, where different colour backgrounds show the EPA air quality index for health.*

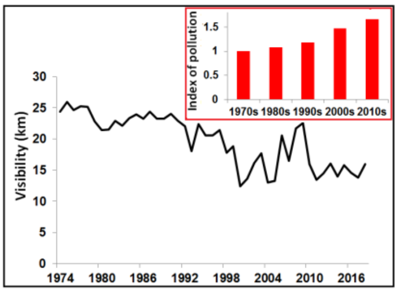


Figure 7a) *Annual visibility trends and* ***b)*** *index of pollution level at Addis derived from 45 years of hourly visibility data (1974-2018). The air pollution index is referenced to the levels observed in the 1970s.*

Figure 8 *Bus air quality monitoring study linking pollution data with GPS*

<u>**Low cost particle sensors:**</u> ASAP simultaneously monitored $PM_{2.5}$ and PM_{10} at multiple sites in Addis Ababa; urban background (The Ethiopian Public Health Institute), urban roadside (Commercial Bank of Ethiopia, Teklehaimanot square) and rural background (Geferssa Mental Health Rehabilitation Centre in Geferssa). Comparison of sites has facilitated an understanding of PM variation between urban background, urban roadside and rural areas.

<u>**Visibility and satellite data:**</u> ASAP researchers have collated hourly visibility data for the period 1974-2018 alongside meteorological factors at Addis Bole International Airport to investigate long term air quality trends. A clear trend of decreasing annual visibility (0.26km $year^{-1}$) was observed in Addis between 1974 and 2018 (***Figure 7a***). Findings suggest that air pollution levels have increased by 76% between the 1970 and 2010 (***Figure 7b***).

<u>**Household and other additional studies:**</u> Household studies and spot measurement campaigns have been implemented across Addis Ababa to explore spatial and temporal variation of air quality in the micro-environments where people spend significant periods of time. Findings obtained from these studies have highlighted that air quality at bus stations and on buses is a matter of concern *(Figure 8)*. At Addis Ababa Stadium bus station, air quality ($PM_{2.5}$) was on average at a level considered *'unhealthy'* (113 ± 99 µg/m^3). Across buses studied, air quality levels for $PM_{2.5}$ ranged between $PM_{2.5}$ 49 ± 19 µg/m^3 and 105 ± 45 µg/m^3. According to the US EPA air quality index, this range entails air quality that is consistently '*unhealthy for sensitive groups'* or '*unhealthy'*. Household monitoring highlights that indoor air pollution is also an issue of concern, with a large proportion of households reliant on a fuel mix that involves charcoal and firewood. Measurements illustrate that air quality during cooking in many households is at an alarming level.

Air quality management

Whilst Addis Ababa city government currently lacks an Air Quality Management Plan, the government of Ethiopia has recognised the need for one. The Ministry of Environment, Forest and Climate Change (MEFCC) developed an Urban Air Quality Management guidance framework in 2016 with the support of the Centre for Society and Environment in India and is currently developing evidence based Air Quality Management Plans (AQMP) for all major cities. The MEFCC is also currently implementing a roadmap to develop an evidence based countrywide AQMP. The Addis Ababa city administration, with the support of US EPA, have developed a draft Air Quality Management Plan for the city. Whilst this effort is commendable, it is doubtful the plan will be sufficient to address urban air quality issues considering existing city infrastructure and broader policy implementation issues.

Initiatives to improve air quality include the development of a light rail corridor for mass transit and an ongoing US$ 300 million Transport Systems Improvement Project (TRANSIP) funded through international development assistance. The latter aims to design and implement an Intelligent Transport System Master Plan (2016-2023), an integrated program for traffic management and pedestrian safety. The plan calls for the development of bus rapid transport and extension of light rail transport in the city.

However, other initiatives essential for the improvement of air quality are currently missing. Emissions control of the increasing number of vehicles in the city is required. Presently, no significant policy actions to control importation of vehicles have been developed. In addition, the national government exerts control over most policies related to transport and energy infrastructure in the city. Whilst the city administration are entitled to formulate city based environmental laws and AQMPs, the inability of regional government to manage transport and energy related issues responsible for air pollution may hinder the implementation of citywide regulations.

Whilst the first national environmental policy emerged in the 1990s, progressive integration of the policy into all development practices has been limited and ineffective. Contradictions are evident in the prioritisation of investment in transport infrastructure versus management of urban air pollution. While the adoption of a light rail system is a welcome clean air development, inaction on vehicle emissions monitoring and control undermines potential gains. Summarily, whilst local action towards air quality management is commendable, maintaining momentum is required.

In terms of household air quality improvement, the national government is implementing a National Improved Cookstoves Program (2013-2030). The program is aligned with the Growth and Transformation Plan. Whilst, reports show that government has distributed 11 million improved cookstoves (2017), many are still dependent on biomass and unable to afford stoves.

Attempts to improve air quality in Addis Ababa are commendable, but there are grey areas that might make the process unsustainable. Political factors often make investment in air quality monitoring systems impossible. Further to this, the localisation of control measures to improve air quality in the city are also an issue.

Kampala (Uganda)

Air quality monitoring

Efforts to assess air quality in Kampala are facilitated by the city's extensive air quality monitoring network. However, the city lacks long-term data required to ascertain changes in air pollution both temporally and spatially. The Greater Kampala Area has over fifteen active monitoring sites (**http://aqicn.org/**) with plans to establish a wider network of

25 outdoor sensors (operated by KCCA) currently in development. Available data suggests that air pollution in the city consistently exceeds World Health Organisation guideline limits for Particulate Matter ($PM_{2.5}$) µg/m^3 24-hour mean[6]. Archived $PM_{2.5}$ data collected from the US Embassy indicates that air quality in Kampala is typically at levels considered *'unhealthy for sensitive groups'* to *'unhealthy'* (***Figure 9***) according to the United States Environment Protection Agencies AQI. The ASAP-East Africa team have supplemented available long term air quality monitoring with spot measurement campaigns at selected outdoor (Uganda National Road Authority Headquarters) and indoor (household) locations and mobile monitoring on motorcycle taxis (Boda Boda). Alongside this, analysis of visibility data has been undertaken to fill historical data gaps and suggests that air quality levels are poor and declining (***Figures 10a and b***).

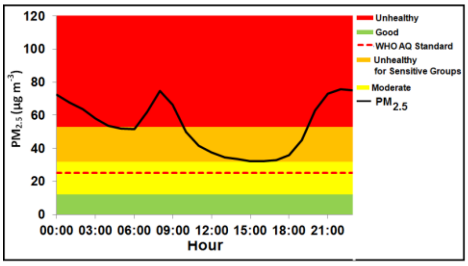


Figure 9 Hourly $PM_{2.5}$ concentration at WHO air quality standard, where different colour backgrounds show the EPA air

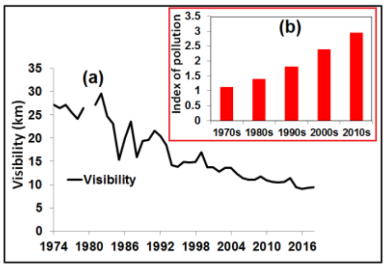


Figure 10a) *Annual visibility trends and* ***b)*** *index of pollution level at Kampala derived from 45 years of hourly visibility data (1974-2018). The air pollution index is referenced to the levels observed in the 1970s.*

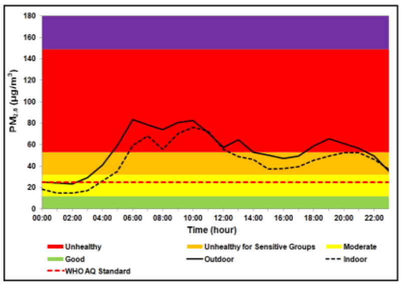


Figure 11 *Boda Boda air quality monitoring study linking pollution data with GPS*

<u>**Low cost particle sensors:**</u> ASAP are simultaneously monitoring $PM_{2.5}$ and PM_{10} at multiple sites in Kampala; urban background (Business Studies building, Kampala campus of Ndejje University), urban roadside (Uganda National Road Authority Headquarters) and rural background (Engineering Building at Ndejje University, Luweero campus). Comparison of sites has facilitated an understanding of PM variation between urban background, urban roadside and rural areas.

<u>**Visibility and satellite data:**</u> ASAP researchers have collated hourly visibility data for the period 1974-2018 alongside meteorological factors (relative humidity, temperature and wind) at Kampala Entebbe International Airport to investigate long term historical air quality trends. A significant loss (0.45km year^{-1}) in visibility was observed in Kampala between 1974 and 2018 (***Figure 10a***). Findings suggest that air pollution levels have increased by 162% between the 1970s and 2010 (***Figure 10b***).

<u>**Household and other additional studies:**</u> Household studies and spot measurement campaigns have been implemented across Kampala to explore spatial and temporal variation of air quality in the micro-environments where people spend significant periods of time. Household monitoring highlights that indoor air pollution is an issue of concern with a large proportion of households reliant on a fuel mix that includes charcoal and firewood. Measurements highlight that air quality during cooking in many households reaches an alarming level. Average

[6] $PM_{2.5}$ and PM_{10} are particulate matter with diameters less than 2.5 and 10 microns, respectively. The World Health Organization (WHO) recommends that $PM_{2.5}$ and PM_{10} daily mass concentrations do not exceed 25 and 50 µg/m^3, respectively.

levels of air quality monitored across households was 205 μg/m^3 24-hour mean (*very unhealthy levels*). Mobile air quality monitoring on-board Boda Boda indicates that certain occupations, particularly transport providers, spend significant periods of time (up to 25% of journey times) in locations where air quality is at a level considered '*unhealthy'* (***Figure 11***).

Air quality management

Government in Uganda, at both national and city levels, are taking actions to develop Air Quality Regulations, reflective of an awareness of poor air quality in the country's cities. However, actions taken at national level, to date, will fail to address air quality issues sufficiently. At the national level, drives to address air quality issues are limited and rhetorical. No cohesive or cross-sectoral plan to develop Air Quality Regulations for the country exists. It is evident that the recognition accorded to poor air quality management in the country is more of a political discussion than indicative of any concerted political action. This is not to say that government does not have plans to address air quality in the country, but rather that air quality management is not a priority. The efforts of technical officers to ensure the development of evidence based air quality management have been undermined by a lack of political will. Similarly, international development partners' support lacks sustainability or continuity. An example of this is the inability to pass the National Environmental Act Bill, 2017 into law. The stalling of environmental policy is common in Uganda, despite claims that the country has good policies.

At the city level, the Kampala Capital City Authority (KCCA) is developing an Air Quality Information Management System to inform the development of an Air Quality Management plan for the city. The efforts of the city government are commendable as they are currently taking holistic actions to develop an air quality monitoring and management framework (for example, integrating air quality with climate strategy and public health considerations), as well as enhancing the technical capacity of the authority to monitor air quality. The Kampala Air Quality Management Project is one component of Kampala Climate Change Action Plan supported by the European Union. Through this international assistance, the authority has development an action plan, which should soon become operational. The efforts of the city authority highlight the significance of local government in taking local action to address urban air pollution. Among current actions to improve air quality in Kampala, the authority are installing 25 air quality monitoring stations with 5 stations in each Division of Kampala. This will provide real time air quality information. The city government are also promoting the development of alternative sustainable transport systems.

Both national and city governments are taking actions, driven by city growth and deteriorating transport infrastructure. However, more needs to be done to improve the state of urban infrastructure in the city to complement significant ongoing investment in technical skills and capacity building for air quality management. Proactive interventions such as improved and cleaner public transport, promotion of active travel and pedestrianisation initiatives could make a significant difference in a city that currently lacks sustainable alternatives to polluting vehicles. In addition, the recognition by the national government of the poor state of air quality needs political action rather than politicising issues that affect citizens. Whist the actions of city government may develop an effective air quality action plan, the national government exerts a significant influence over the implementation of control measures that are also central to the promotion of good air quality in the city. In Uganda, significant efforts are needed to address policy silos and institutional disconnects that political disputes exacerbate.

East Africa Air quality modelling

The ASAP-East Africa research team investigated air pollution using numerical modelling approaches. This enabled the reproduction of the main meteorological patterns, anthropogenic pollution emissions related to different sectors and the chemical and transport processes acting in the atmosphere**.** Efforts have focused on the following objectives:

1. Manipulation of the available open source emissions inventories for East Africa to create a new up-to-date emission inventory.
2. Quantitative analysis of the impact of each anthropogenic emission sector.
3. Simulation of the main regional and local meteorological processes and air pollutant dispersion patterns for focus countries and cities.
4. Creation of reduced emissions scenarios, with a focus on the improvement of the urban road network, including: regular road maintenance, upgrading of urban road paving, and progressive electrification of the vehicle fleet.

Two modelling systems have been adopted for this purpose. The Highway Development and Management version 4 (HDM-4) reproduces the ground state conditions of the road network and enables the creation of several alternative scenarios, according to the implementation of maintenance standard for road network and modification in the vehicle fleet. Also, the model returns an economic analysis for the implementation of any possible scenario. The meteorological and chemical dispersion patterns are simulated by a modelling system made up by coupling the Weather and Research for Forecast model with the chemistry-transport model CHIMERE (hereafter WRF-CHIMERE).

The modelling system WRF-CHIMERE has simulated weather and the main pollutant dispersion patterns for all three cities. The modelling system, despite the small amount of historical input data, has demonstrated confidence in reproducing real world air pollutant concentrations, see ***Figure 12***. It has also been able to reproduce almost all the exceedance values of $PM_{2.5}$ daily levels according to the WHO limits. Heat Maps relating the average concentrations of PM_{10} with the local regional county borders show how the majority of the urban areas of the three cities are affected by concentrations of PM_{10} higher than the WHO limits.

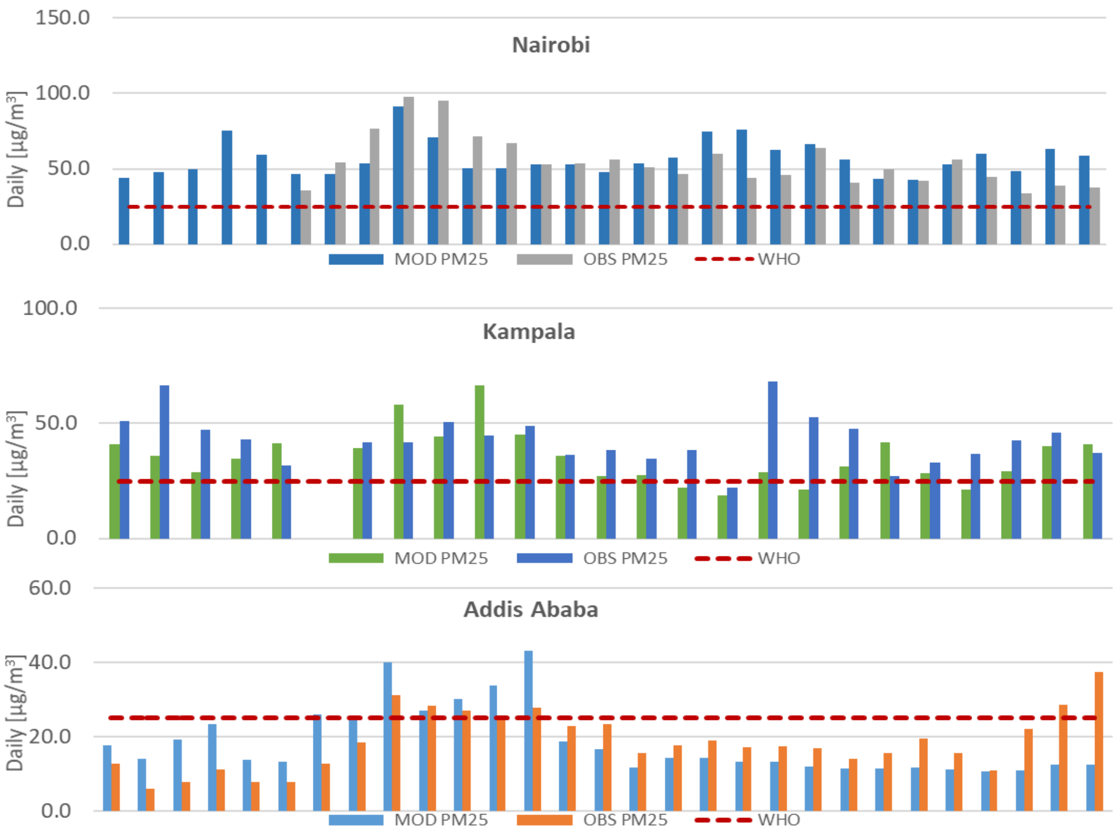


Figure 12: ***Daily time series relative to PM2.5 concentrations from modelled data and from different observation sources: PM2.5 for Nairobi comes directly from measurements made by the WP2 of the ASAP project, while PM2.5 daily values for Addis Ababa and Kampala have been obtained by the local US Embassies.***

The results suggest air quality levels in urban East Africa can be modelled effectively. Going forward, more effort is required to improve the accuracy of the input data, which would result in improved model outputs. The high levels of air pollution observed and the extension of the poor air quality areas in the three cities highlight the importance of further scientific focus on the extent of the transport of air pollutants by local meteorology.

Calibration of the HDM-4 model with an improved emissions inventory has allowed for analysis of the road transport emissions in each study city under a range of scenarios, including: systematic maintenance of the urban road network, paving of all unpaved roads, electrification of the vehicle fleet (from gasoline/diesel), see ***Figure 13***. The analysis of each scenario has been complemented with an economic analysis relative to the economic saving projected for the period 2017 – 2036 connected with each scenario relative to the upgrading of the unpaved road.

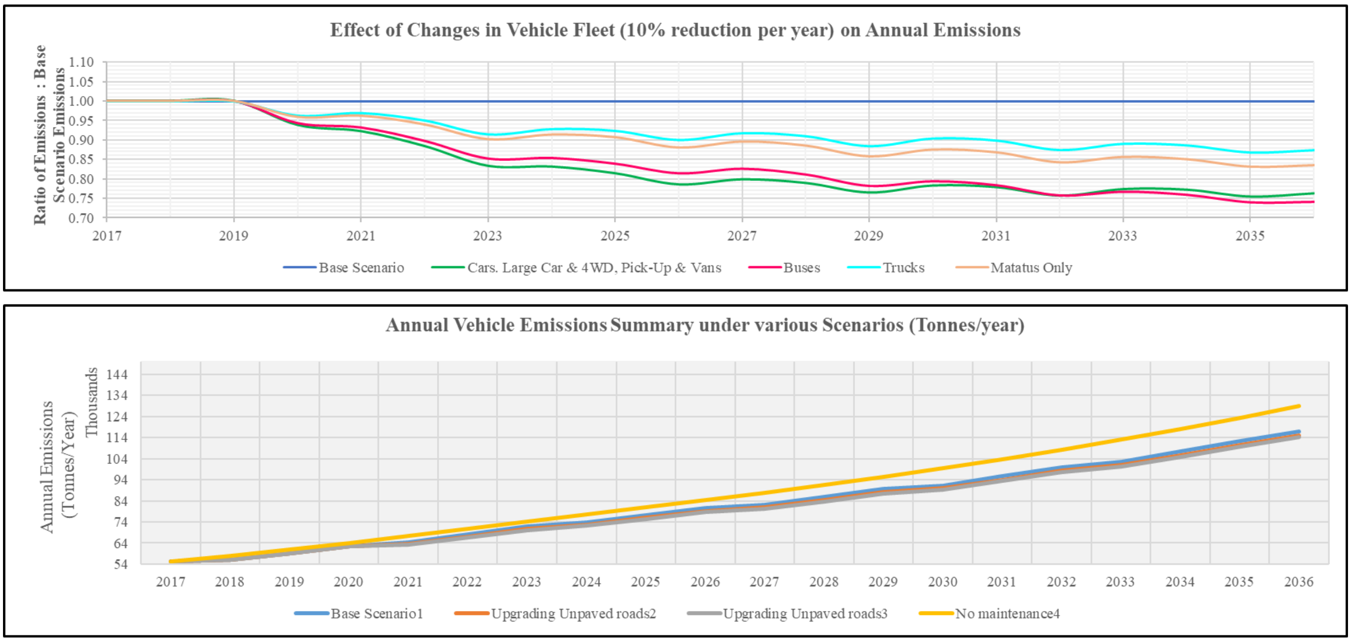


Figure 13: ***Graphs showing the results of the scenarios produced using HDM-4 calibrated for the city of Nairobi, Kenya.*** *The top panel shows the effect of vehicle fleet progressive substitution from gasoline/diesel based to electric engines. The bottom panel provides the annual change in vehicle emissions under various scenarios connected with the systematic maintenance and progressive paving of all the urban road network. Both scenarios have been created from the base year 2017 with a 20 year of extension, to 2036.*

In conclusion, the ASAP atmospheric modelling activities have provided an up-to-date emissions inventory for East Africa. This has allowed, for the first time, the use of a chemistry-transport model to predict the levels of air pollution in the cities of Nairobi, Kampala and Addis Ababa. Despite the low quantity and quality of input data available for the work, the modelling system WRF-CHIMERE has shown good capabilities in reproduction of real-world air pollution levels. Additional input data from different research environments, as well as the training of local researchers in monitoring and modelling, represents a feasible option for increasing knowledge of and expertise in air pollution in East Africa.

Technological innovations in Air Quality

There are several current trends in air quality monitoring and modelling that should be embraced by various sectors, including academia, governance and businesses, including 1. Low cost sensors, 2. Cloud computing, and 3. Data science techniques.

The use of low cost sensors is now globally pervasive with many sensor networks running in East Africa, and they have been widely used in the ASAP project. The sensors offer indicative measurements of air quality at a price point significantly lower than regulatory grade equipment, sometimes at a cost of 1% of the regulatory price.

However, it is important to note that the sensors are typically not calibrated for local conditions and care has to be taken in the interpretation of their data.

Cloud computing is in essence computation on remote computer servers, accessed via the internet, on a pay per need basis. This removes the large overheads associated with the purchase and maintenance of the sophisticated computer servers required for large scale air quality modelling, for example that needed for the WRF-CHIMERE model.

The field of data science is evolving and growing rapidly; techniques such as machine learning and artificial intelligence offer the potential to fuse disparate and sparse data sets together to generate continuous spatial and temporal outputs. This has great potential in East Africa where air quality data sets are sparse.

To encourage the use of technological innovation in air quality, there is need to develop capacity and capability. There are notable islands of excellence in the East African academic sector and these should be further developed and extended to government institutions. The data sets and other outputs from these new technologies should be made publicly available, thereby promoting democrat and decentralized digital solutions that stakeholders can utilize.

Vulnerability and air pollution

Common approaches to assessing the impact of air pollution have tended to assume an equal vulnerability, sensitivity or susceptibility to air pollution (Stilianakis, 2015). This assumption masks differences in exposure and risk across populations, locations and occupations with air quality in cities varying both spatially and temporally (Kathuria and Khan, 2007). Although average changes in risk associated with exposure to air pollution are considered small, some individuals or groups can be considered more vulnerable or susceptible than others (Avis and Khaemba, 2018). Understanding how and why certain population groups are more vulnerable than others is an important input into policy decisions about setting acceptable levels of risk.

Understanding vulnerability to air pollution presents a unique challenge for researchers. Authors commonly refer to vulnerability as the level of exposure of human life, property and resources to the impact from hazards (in this case air pollution) (Fussel, 2007; O'Brien et al., 2009). Factors, such as sex, age, education, and occupational exposure can modify the relationship between hazards and mortality (Kan et al., 2008). Further to this, the effects of air pollution exposure on health are considered greater in people from lower socioeconomic backgrounds (O'Neil, 2003). According to Stilianakis (2015), exposure to air pollution may have different effects on individuals and population groups due to differences in innate and acquired characteristics and their relationship with other risk factors e.g. smoking. Innate characteristics are mainly biological and physiological and reflect the capacity of the human body to respond to exposure. Acquired factors, such as socioeconomic status, are those that affect social coping or adaptive capacity and do not allow the individual or the population group to minimise exposure. The ASAP programme has adopted the WHO's (2004) definition of vulnerability i.e. "the likelihood of being unusually severely affected by air pollutants either as a result of susceptibility to the effects of these substances or as a result of a greater than average exposure".

Findings from vulnerability scoping studies illustrate that efforts to improve air quality and minimise health impacts associated with air pollution must acknowledge significant differences in exposure across locations and risks across groups. The development of policy recommendations must in turn be cognisant of such differences.

Air Pollution Exposure and Vulnerable Populations

Air pollution is considered to impact on all groups, especially when exposed over prolonged periods of time. However, some population groups are considered more susceptible than others. Further to this, different pollutants may affect groups in varying ways. Building on the WHO (2004) assertion that vulnerable groups include young children, the elderly, people with certain underlying diseases, foetuses and groups exposed to other toxicants that interact with air pollutants and those with low socio-economic status, ASAP considers that it is also important to move towards a less pre-conceived notion of vulnerability to a stance that incorporates individual and context specific vulnerability. Such an approach takes account of physiological vulnerability (e.g. foetus and children's organ development) and social vulnerability due to high exposures (e.g. occupational groups) and co-morbidities.

Young children are among the most susceptible to the effects of air pollution (WHO, 2006; WHO, 2005, Schwartz 2004). Children have higher breathing rates than adults and therefore a higher intake of air pollutants per unit of body weight. They also spend more time outdoors than adults, thereby adding to their exposure potential (WHO, 2005). The developing lung may also have a limited metabolic capacity to address the inhalation of toxic substance. Schwartz (2004) notes that 80% of alveoli are formed postnatally and changes in the lung continue throughout adolescence. Exposure to air pollutants, thus, poses a serious risk to this population group. Some children are especially vulnerable, for example, those with underlying chronic lung conditions such as asthma and cystic fibrosis. Exposure of pregnant women to high levels of air pollution may also impact on the development of foetuses with the potential for health impacts later in life.

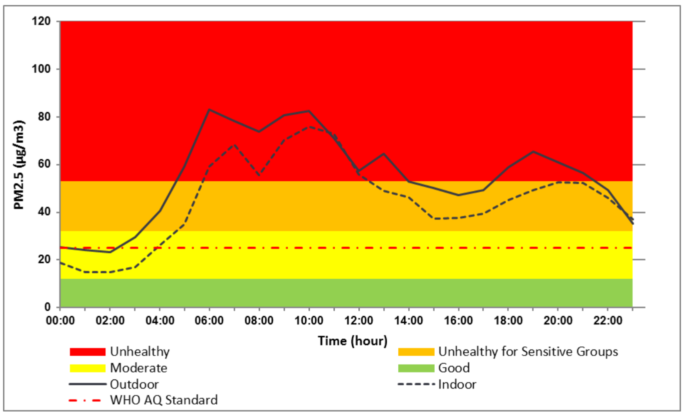


Figure 14 ***Average school day concentration of PM2.5 in Moi Avenue Primary School (indoor and outdoor)***

ASAP East-Africa explored air pollution in an inner city Nairobi primary school, next to a major road, via the deployment of low cost PM sensors in both indoor and outdoor settings. Data gathered during the school based study indicates that air pollution levels in both indoor (classroom) and outdoor (school ground) settings regularly exceeds WHO guideline amounts of 25 µg m^3. Classroom PM concentrations, in the $PM_{2.5}$ size range, were measured to be on average 43 ± 19 µg m^3 and peaked at 47 ± 14 µg m^3 during school days[7]. Further to this, air pollution levels tended to peak during school hours consistently reaching unhealthy levels for sensitive groups levels between school hours of 08:00-16:00. Outdoor levels of $PM_{2.5}$ recorded larger concentrations, averaging 54 ± 22 µg m^3 and peaking at 61 ± 21 µg m^3, which is consistently at an unhealthy level.

Older people are another group likely to be more affected by air pollution due to generally weaker immune systems, or undiagnosed respiratory or cardiovascular health conditions. As people age, their bodies are less able to compensate for the effects of environmental hazards. Exposure to air pollution of elderly populations may lead to higher morbidity and mortality predominantly as a result of cardiovascular and respiratory disease (Hoek et al. 2013). Many physiological changes associated with aging may increase susceptibility to particle effects. Virtually all components of the respiratory system are affected by aging, including spirometry, diffusing capacity for oxygen, lung elastic recoil, chest wall compliance and inspiratory muscle strength. The elderly may also be more susceptible to particle exposure because of lifetime chronic exposure to PM, as well as previous respiratory infections, airway damage and loss of lung capacity. Exposure to air pollution of this group can aggravate and increase baseline risk of heart disease and stroke, lung diseases such as COPD and asthma. The increases in mortality associated with particulate air pollution are thus greatest among the elderly adult population.

ASAP-East Africa explored household air pollution in homes that included a resident aged 55 or above. Data gathered during the home based study indicates that air pollution levels in indoor settings regularly exceed WHO guideline amounts of 25 µg m^3. Indoor PM concentrations, in the $PM_{2.5}$ size range, were measured to be on average 205 µg m^3 and peaked at 1076 µg m^3. Air pollution levels tended to peak during cooking periods, reaching levels well beyond the US EPA air quality index. Air quality was particularly poor in those households that reported using charcoal or firewood as primary fuel source. Household exposures are not only high in concentration they can also be of long duration, hence indoor activities can lead to the greatest air pollution exposures.

The studies also probed perceptions of school pupils and older people regarding air pollution. Findings underscore the vulnerability of the young and the old to air pollution in locations where they spend significant periods of time. Both studies also suggest that those from low socioeconomic backgrounds are likely to face a dual burden of exposure both at home and in other locations e.g. school environments.

Survey findings suggest that Moi Avenue Primary School pupils are relatively cognisant of their inherent vulnerability to air pollution, perceiving their vulnerability on a scale of 1-5 at an average of 3.73/5 (five indicating extreme levels of vulnerability). This may in part be explained by survey participant's membership of the school environmental club and previous sensitisation regarding issues of pollution. Older residents of Addis Ababa considered themselves less vulnerable, on average, than school pupils reporting an average score of 3.16/5. Interestingly, both studies highlighted a degree of geographic variance in reported vulnerability to air pollution suggesting that location of residence mediated perception of risk to air pollution.

[7] PM2.5 particles (sometimes termed fine particles) are those with a diameter less than 2.5 µm in diameter.

Both school pupils and older people demonstrated a mixed understanding of the potential sources of air pollution, though this is to be expected given the relative lack of knowledge regarding air pollution in many societies. These studies underscore that good air quality in home and school environments is central to the provision of a safe, healthy, productive, and comfortable environment for the young and the old. Given the inherent vulnerability of different age groups to air pollution exposure, coupled with the significant proportion of time spent in indoor environments (whether at home or at school), it is clear that there is a need to develop policies that protect certain populations from exposure to unhealthy levels of air pollution in such settings.

Air Pollution Exposure and Vulnerable Occupations

Despite a growing body of evidence of the health impacts of exposure to air pollution, relatively little attention has been given to the effects of occupational exposures (Fang et al., 2010). Exposure to air pollution can result from occupational factors (e.g. outdoor work) and exposure to high concentrations of certain air pollutants. Certain types of work (e.g. in transport or construction) may lead to higher exposure (Rotko et al., 2000). Further examples of hazardous work can include those who live on waste dumps and make a living from sorting and selling waste products. The presence of hazardous waste and smoke from burning of waste is considered to pose serious health risks (SIDA, N.D).

Occupational exposure differs from general ambient exposures in both particle type (e.g., composition), as well as exposure frequency (e.g. environmental exposures are relatively constant while occupational exposures are more variable), duration (e.g. a work-shift and working lifetime vs. an entire day and lifetime), and intensity or concentration (i.e. occupational exposures are generally higher than ambient levels) (Fang et al., 2010).

ASAP-East Africa explored the exposure of waste pickers to air pollution in Dandora dumpsite (Nairobi) via the deployment of a low cost PM sensor located in an outdoor setting. Data gathered during this study indicates that air pollution levels in Dandora exceed WHO guidelines 100% of the time. PM concentrations, in the $PM_{2.5}$ range, were measured to be on average 47.4 ± 9.5 µg/m^3 and peak concentration was 94.5 ± 32.6 µg/m^3 during the monitoring period. Further to this, air pollution levels demonstrated a high degree of variability, though consistently reaching unhealthy levels on weekdays (Monday-Friday). Whilst air pollution levels recorded during weekends were lower, they suggested that air pollution is consistently at levels considered unhealthy for sensitive groups in and around Dandora.

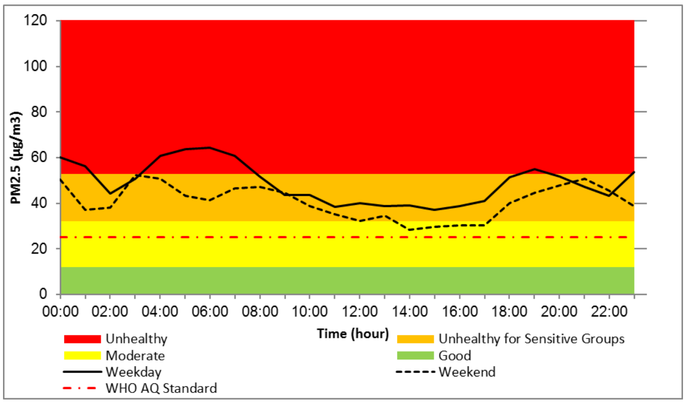


Figure 15 ***Average weekday and weekend concentration of PM2.5 at Dandora dumpsite***

Occupational exposure was also explored amongst Boda Boda drivers in Kampala, street vendors and bus drivers in Addis Ababa, and commercial canteens in Rwanda. These studies highlight that those who earn their living in locations where air pollution is likely to be higher are at risk of prolonged exposure to particularly harmful levels of air pollution.

Survey findings suggest that waste pickers, whilst relatively cognisant of their exposure to air pollutants, recorded a relatively low perception of vulnerability to air pollution. On a scale of 1-5, the average score of respondents was 2.24/5. This may in part be explained by survey participants' views of their inability to access alternative livelihoods, resources to minimise exposure or support. In Addis Ababa, street vendors reported a vulnerability score of 3.5 and bus drivers 4.7/5. Differences between occupational groups will be probed in the final phase of the project. These studies underscore that broader efforts to address air pollution must intersect with other urban initiatives including transport provision and solid waste management (SWM) and support alternative or improved livelihoods that will concomitantly improve air quality or reduce risk of exposure. Given the inherent vulnerability of certain occupations to air pollution exposure, coupled with the overlap of work and home environments, it is clear that there is a need to develop policies that simultaneously address broader livelihood issues and air pollution in such settings.

Air Pollution Exposure and Vulnerable Locations

There are a number of factors that may increase an individual's exposure to air pollution including time-activity patterns, modes of transport, recreational activities and, pivotally, proximity to sources of air pollution such as major roads or polluting industries. Despite this acknowledgment, risk assessment studies often ignore within city variations of air pollutants. Air quality measurements that rely on background monitoring stations (e.g. US Embassy monitoring sites in Kampala and Addis) may underestimate exposure levels in road side locations where variation in levels of air quality is particularly marked. Such locations are referred to as 'hotspots' and require further exploration.

Further, low-income populations often live in areas likely to experience increased exposure to air pollutants – notably in locations of high pollution and low quality housing (e.g. proximity to high traffic areas or factories). Studies that have included socio-economic factors have identified poor and less affluent population groups as most exposed to environmental risk in their place of residence (WHO, 2010).

The WHO (2010) highlight that inequalities were reported for environmental risks experienced within the dwelling (such as exposure to biological and chemical contamination, noise, temperature extremes and absence of sanitary facilities), as well as the residential environment (lack of urban amenities, proximity to pollution sites or polluted areas, exposure to traffic related pollution). Housing market dynamics in land use decisions may also explain why certain populations experience both poor socio-economic status and heightened air pollution exposure. As good housing and environmental quality are in high demand in urban areas, they command a financial premium and can be rented for higher prices (WHO, 2010). Consequently, poor and less affluent population groups tend to be affected to a greater extent by inadequate housing conditions, higher household density and higher environmental burden in their residential environments (WHO, 2010).

Egondi et al. (2016) undertook an air quality monitoring study in two urban informal settlements of Nairobi (Korogocho and Viwandani). The authors found average $PM_{2.5}$ levels of 166.4 μg/m^3 (Korogocho) and 67.2 μg/m^3 (Viwandani). Egondi et al. (2016) concluded that residents in both informal settlements are exposed to $PM_{2.5}$ levels exceeding hazardous levels according to WHO guidelines. The study showed a marked disparity between the two areas situated 7 km apart indicating the local situation and sources exert an important influence on exposure to $PM_{2.5}$.

The ASAP-East Africa team explored air pollution exposure in a number of locations thought to increase risk. In Addis Ababa, air quality was monitored at Addis Ababa Stadium bus station and on buses via the deployment of a low cost PM sensor located in an outdoor setting (bus station) and on buses. Data for on bus monitoring was linked to GPS data to show how urban mobility and exposure are linked. PM concentrations measured at the bus station, in the $PM_{2.5}$ size range, were found to be on average 113 ± 99 μg/m^3 and peaked at 323 ± 203 μg/m^3. Further to this, air pollution levels tended to peak during early morning and late evening hours, consistently reaching unhealthy levels throughout the day. Measured levels of $PM_{2.5}$ on buses ranged between $PM_{2.5}$ 49 ± 19 μg/m^3 and 105 ± 45 μg/m^3 on journeys monitored (see ***Figure 16***).

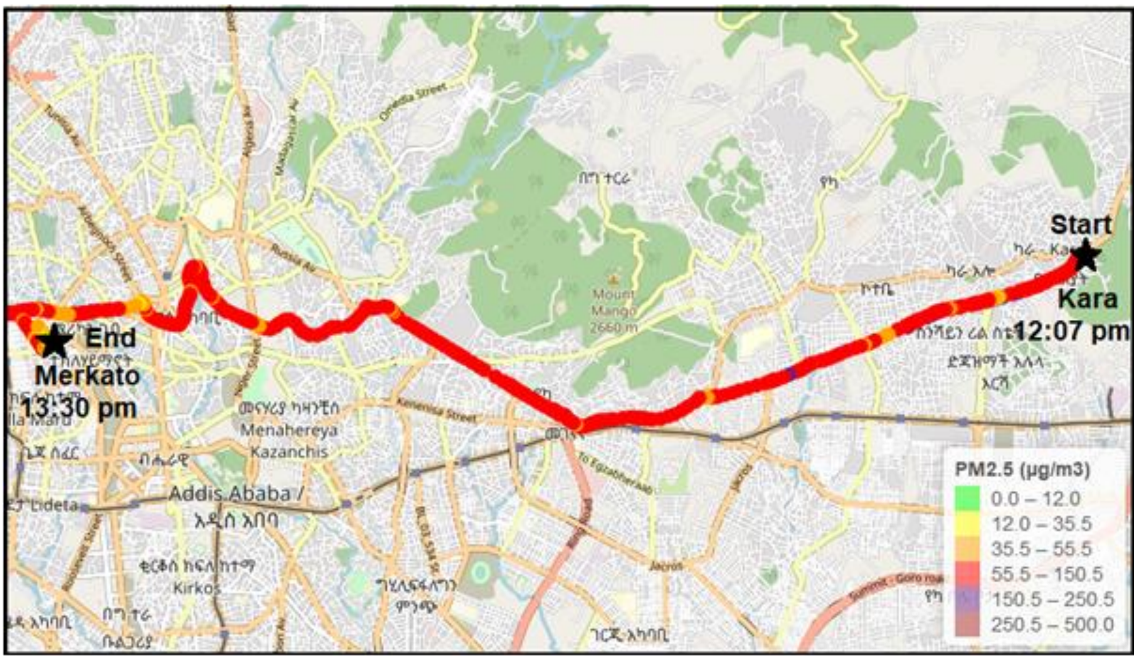


Figure 16: ***Bus Monitoring Campaign (Addis Ababa)***

The ASAP-East Africa research team also explored indoor air pollution exposure in low income households of Namuwongo in Kampala, and Kibera in Kenya via the deployment of a low cost PM sensor located in houses. Data gathered during this study indicates that air pollution levels in indoor (household) regularly exceed WHO guideline amounts. Average PM concentrations, in the $PM_{2.5}$ size range, were measured to be 72.61 ± 64.42 in households that used charcoal and firewood compared to 43.46 ± 33.44 for households that reported using LPG and electricity. This highlights that between households in the same area, fuel usage influences exposure.

ASAP EAST AFRICA

Survey findings suggest that survey respondents across both studies are relatively cognisant of their inherent vulnerability to air pollution. Households in Namuwongo perceived their vulnerability at a level of 3.08/5, suggesting a relatively high perception of vulnerability. In the Addis study, reported perception of vulnerability was 3.87/5. This may in part be explained by the prolonged periods of time spent in locations with poor air quality (both at bus stations and on buses).

Figure 3: ***Survey respondent's perceptions of vulnerability according to cooking fuel type and household ownership status***

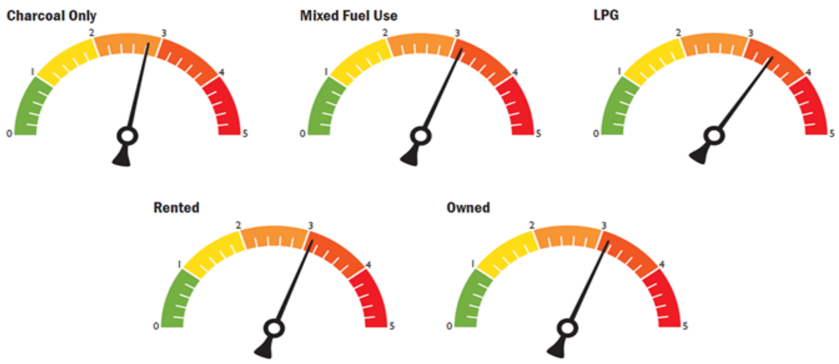


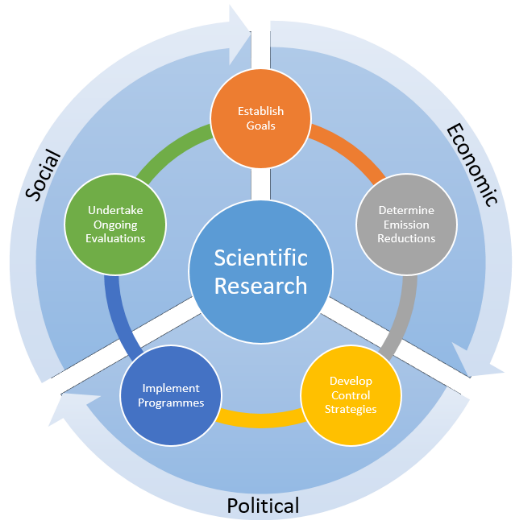
Figure 17: ***Survey respondents' perceptions of vulnerability by cooking type and household ownership status***

Air quality management

Air quality management involves a continuous review and assessment of goals and strategies based on their effectiveness. All parts of this process are informed by scientific research that provides air quality managers with essential understanding of how pollutants are emitted, transported and transformed in the air and their effects on human health and the environment. It is imperative that agencies of government work closely with the scientific community to support the development of air quality interventions.

Despite concerted efforts to manage air quality globally, air pollution still remains a significant environmental health risk (Longhurst et al., 2016). The 2018 UN Climate Change Conference Report, stresses that "more than 90% of air pollution-related deaths occur in low- and middle-income countries, mainly in Asia and Africa". A holistic approach is therefore required for effective intervention which considers the different sources of air pollution and addresses the related socio-economic, political and health problems. Urban air pollution and vulnerability to exposure are not natural but constructed and shaped by the character of development, governance and management structures as well as complex social, economic and political processes. Indeed social, economic and political factors not only influence air pollution levels but also exert a profound impact on air quality management plans (***Figure 18)***.

Figure 18 **Dynamic air quality management processes**



Whilst Ethiopia, Kenya and Uganda have established air quality regulations and indicative emission reduction targets, these have often been developed in abstract from air quality monitoring and modelling studies. Without robust scientific knowledge it is difficult to develop control strategies for air pollutants, to implement programmes or to evaluate the success of these strategies. More efforts are required to enhance the capacity of the scientific community to assess air quality and to use this data to inform air quality. The emergence of initiatives such as Air Qo, hosted by Makerere University, provide a model that could be replicated in other cities. More attention also needs to be focused on the extent to which social, economic and political factors impact on air quality and air quality management more broadly.

Emerging trends in air quality management recommend that effective air quality management requires not only diagnosing and modelling air pollutants, but the development of a holistic approach where the spatial nature of air pollutants, socio-economic and institutional factors are integrated. Air quality management policies are expected to protect public health and to remove many of the adverse socio-economic impacts that are associated with air pollution. However, evidence continues to show that air quality management policies are failing, even in the global north, despite strong commitments at different scales of government (Brunt et al., 2016). In addition, air quality needs to be addressed as other non-communicable risk factors are, suggesting that there is a need to engage with the health professional community too. Challenges of air quality management are more pressing in East Africa, frustrated by a lack of institutional focus and competition between departments of government alongside challenges pertaining to technical expertise, human resolve and financial resources, as well as a lack of political will. An article in the journal 'Regional Studies' co-authored by ASAP researchers, published in October, 2019, discusses these challenges further, and posits strategies for the implementation of air pollution policies in East Africa and beyond in the future.

Findings from the ASAP-East Africa programme illustrate that there is no *one-size-fits-all* urban strategy for addressing air pollution. Urban policy priorities and choices depend on a variety of factors - including the scale, speed and source of urbanisation, the size of cities and the stage of urban development. Intergovernmental relationships are also key to successful urbanisation and efforts to address air quality. National, regional and city governments need to be connected and share a similar vision. Local governments will need technical and managerial skills, the ability to engage with the public and strong capacities to design, implement, monitor and evaluate policies and air quality management. There is clear potential for the sharing of best practise within East African countries, with pockets of excellence providing learning across national boundaries.

What is clear is that air pollution is not an unavoidable consequence of economic growth. With committed leadership at local, regional and national levels, cities can decouple development from pollution and help countries of the global south avoid the issues associated with air pollution in other regions such as South Asia. The technical, economic, and political feasibility of pollution control is demonstrated in many contexts where there have been significant curbs to ambient air pollution. Effective strategies include establishment and enforcement of air quality standards, reduction of emissions from stationary sources via a requirement for transition to clean fuels and renewable energy sources, banning of use of polluting fuels in urban centres, improvement to access to public transportation, mandating of fuel efficiency standards for cars, trucks and buses, and restriction of access to private vehicles. Urban planning initiatives that reduce sprawl, decrease motorised journey times and encourage increased walking and cycling, such as new zoning laws and construction of bicycle paths, creation of pedestrian infrastructure, and introduction of bicycle rental programmes represent additional low-cost strategies for air pollution control. As an example of the potential for building on such initiatives, there appears to be a sound framework on which planners and policy makers may build active travel options. In Nairobi, one of the case study cities, around half of daily travellers already make walking trips despite a lack of dedicated infrastructure. This suggests there is a firm basis upon which increased levels of walking may be encouraged through well-maintained pavements, green walking routes, optimized pedestrian phases at intersections and other facilitators of easy walking trips (Rajé et al., 2018)

Whilst many East African countries, have developed comprehensive legislation requiring air quality control, they often struggle to enforce the legislation effectively and link it to the other economic, urban and political challenges. Indeed not only is the development of scientific understanding and engineering advances challenging, but protracted legal, social, and political processes also potentially slow implementation of the required emission controls.

Effective air pollution control efforts also require concerted action over the entire airshed. This proves difficult in contexts where there are multiple actors often with competing agendas – this includes tensions between different levels of government. What is often required is the development of air quality management interventions that regulate all stationary emission sources within a given region in a consistent and comprehensive manner. Such decisions must be supported by government officials, industry managers, and the public to maintain concerted pollution control efforts in future years.

Accordingly, understanding whether and what type of policies a city adopts involves attention to what Lavers and Hickey (2015) call ‘policy coalitions’, which help explain how policy processes operate in specific policy domains within particular political settlements. The ASAP-East Africa team adapt and apply an approach to analysing the influence exerted by political settlements on development interventions developed by Kelsall et al. (2016). Kelsall et al (2016) note that the political settlement is the underlying balance of power and institutions on which the political order is based. Knowing how the political settlement affects political commitment to air quality helps design strategies that result in policy pathways, funding solutions and governance arrangements that not only complement each other but also either build on the strengths of the political settlement or help mitigate its weaknesses.

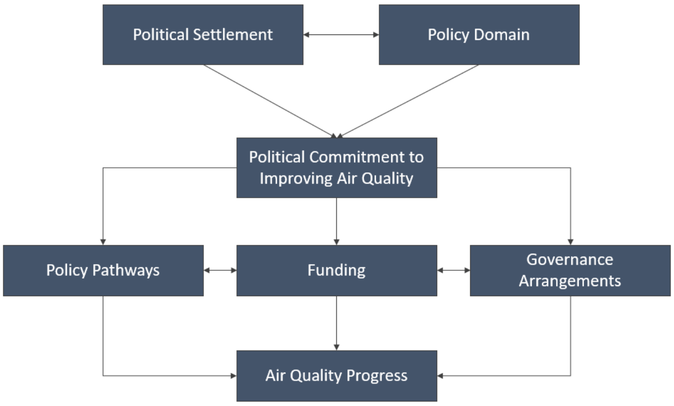


Figure 19: ***Political Settlements and Improved Air Quality (adapted from Kelsall et al, 2016: 11)***

Expanding on the model outlined above, Kelsall et al. (2016) comment that the policy domain is understood as the realm of ideas, interest groups and coalitions concerned (in this instance) specifically with air quality issues. The nature of the political settlement and policy domain interact to drive a certain level of political commitment to air quality, which manifests in a variety of policy pathways to improved air quality. It also drives a certain level of public funding, and also particular governance arrangements, such as how air quality regulations are managed and enforced, how key polluters are monitored and held accountable – all of which will affect implementation, and ultimately improved air quality progress.

Addressing air pollution is thus both a technical and political issue. Improvements to air quality involve re-framing the debate, identifying and creating political opportunities, and mobilising resources. Reforms inevitably involve political trade-offs, conflicts and negotiations because these reforms redistribute resources across both sectors and households. Such an approach to Political Settlements Analysis can provide an insight into a cities commitment to improving air quality and the ambitiousness of its efforts to achieve it. Further, it can provide some broad indications of the kinds of ‘strategies for change’ and reform coalitions air quality advocates should focus on in different types of city. Such an analysis can provide a guide to the places in which policymakers are most likely to find transferrable lessons.

Recommendations

The final phase of the ASAP-East Africa will develop country and city specific '***Agendas for Action'***. These will sit alongside current (country and city level) policy interventions but acknowledge the social, economic and political factors that have influenced their development. ***Agendas for Action*** will be aspirational documents that highlight both strengths and weaknesses in these interventions but also opportunities to augment action and empower individuals and communities to work with government to tackle air pollution. These Agendas will highlight the need for multi-stakeholder action across geographic and sectoral silos to address air quality. They will also be positioned to encourage a reframing of current approaches to city planning which adopt an approach based on 'predict and provide' to one that seeks to 'decide and provide' i.e. deciding on a vision for a future equitable and sustainable city and investing to deliver this. ***'Agenda's for Action'*** will build on the recommendations below:

Individuals

While effective policies to reduce emissions at their source must be the focus, some evidence supports the effectiveness of individual action to reduce exposure and minimise health risks. Individuals often have little or no say in where they work or the periods of time they spend in highly polluted environments. This is, in part, a product of the location of affordable or accessible properties, available livelihood opportunities or the transport infrastructure that connects the city. This makes individuals particularly dependent on actions taken by others to minimise exposure to air pollution (i.e. transport and infrastructure initiatives and governmental policies). Despite this, knowledge and attitudes towards air pollution can enhance the adoption of adaptive strategies and encourage others to change their behaviours.

Personal exposure to air pollution can be reduced by avoiding locations with poor air quality or minimising periods of time spent in such locations. As noted this is often challenging when one's occupation or travel needs necessitate working near or passing through air pollution hotspots. In order to most effectively adjust behaviour, individuals must be able to anticipate when and where air pollution is likely to be elevated above levels thought to increase risk. This requires providing individuals with the information they need to make informed decisions. Such information would allow individuals to better understand when and where exposure is likely to be highest and whether they are more likely than the general population to be susceptible to the harmful effects of air pollutants. This would require publically available air quality data in near real time.

Efforts must also be made to improve environmental health literacy. Environmental health literacy is a measure of individual understanding of specific risks, which then leads to broader personal knowledge, including strategies that empower people to eliminate, reduce or minimise environmental exposures harmful to health. Individual choices could include transitioning to alternative and cleaner fuels (e.g. briquettes), prioritising non-motorised or public transport or adopting other mechanisms to minimise exposure. These strategies would imply a cost which may deter use, as well as there being cultural determinants which may also reduce uptake.

Organisational

Whilst the ability of organisations to address air pollution or minimise exposure may be limited or constrained, there are a number of opportunities available to organisations (e.g. civil society groups, public transport providers etc.) to support air quality improvement and minimise the impact of air pollution, while also reducing air pollution at hotspots yielding broader societal benefits. The ability to act is often dependent on financial resources and broader support from local and national governments is often a central component of this.

Organisations can play a significant role in sensitising the wider community to the causes and consequences of air pollution. Education is considered a key factor in developing public knowledge and awareness about issues such as air pollution. Studies show that many lack sufficient environmental knowledge, despite possessing positive attitudes towards taking actions to improve air quality. By encouraging organisations to include air quality issues as part of their advocacy activities, they, and the individuals they represent, may become more knowledgeable about air quality issues, play a role in sensitising others and, ultimately, become agents of change. In contexts where knowledge is limited, organisations could become a significant community resource. In some contexts, such organisations can play a public information role regarding air pollution levels. ASAP-East Africa research partners ACT Together, the Ethiopian Elderly and Pensioners National Association and Anbessa Bus Company could all play such roles.

Organisations can highlight the increasing evidence of the links between poor air quality, exposure to air pollution and public health issues, most importantly links with NCDs. Advocacy organisations can play a key role in promoting healthy living and tackling the key risk factors linked to air pollution from all sources. In particular, groups such as ACT Together and the Ethiopian Elderly and Pensioners can support the collection of health data to provide a fuller picture of the impact of household air pollution in informal settlements or amongst older people. Given the paucity of data currently available, it is important to expedite such initiatives.

Governmental

Given the multi-scalar and interdependent nature of urban air pollution, it is clear that government must play a key role in supporting efforts to address this issue. The rapidly growing populations will make solutions to air pollution increasingly difficult if action is not taken as soon as possible. The focus must be on integrated planning for future urban growth, promoting efficient urban accessibility pathways based on compact, public transport and active travel-oriented city forms, as well as supporting household transitions to cleaner fuels. Such city-level policy initiatives must be complemented by concerted efforts at a national and sectoral level.

It is important to underline here the complexity and dynamics of city-region economies. This is to call for a research and policy focus on the development of an integrated or systemic approach to understanding the city-region plexus. Such an approach appreciates the interconnected nature of city-region liveability and livelihood. It also acknowledges some of the perverse consequences or negative feedback loops that are the outcome of interactions between different systems. Bryson (2019) identifies three elements to be included in this type of analysis:

1. First, such an analysis must acknowledge the importance of understanding decisions made by individuals, households and firms. All city-regions are shaped by these decisions and the outcomes and legacies of decisions made in the past.
2. Second, is to understand system or process interdependencies. Partly, this is about identifying problems that need to be overcome and partly about understanding how to prioritise policy interventions.
3. Third, the development of an integrated or systemic understanding of place should acknowledge place-based distinctiveness and try to enhance inimitability[1].

Efforts must be made to link national and local initiatives that address rapid urban growth by focusing on the implementation of Integrated Development Plans. A challenge here is effective implementation and prioritisation of interventions for short, medium and long term. These plans must ensure coordination at multiple levels and a balanced focus between the city centre and peripheral areas to ensure that growth is orderly and that viable and affordable options are available. The development of transportation infrastructure can be used to guide urban growth through the establishment of mass transport skeletal services (e.g. bus services could be established along future BRT, LRT, and MRT routes).

Policy integration across urban planning, design and transport is frequently compromised by sectoral and disciplinary silos, fragmented governance and a lack of coordination between national and local policy frameworks for urban form and transport. This fragmented landscape must be addressed and efforts to think of cities of systems of systems should be encouraged.

Government should encourage greater cooperation between agencies. Oversight and enforcement at national, regional, and local levels are needed to ensure better urban environments. Regional and local actors interested in creating healthier environments can benefit from the application of scientific knowledge, technical expertise and environmental data. Government environmental agencies should cooperate closely with other departments to better manage city development. While recognising that one of the biggest challenges in this context is the need to make decisions now which have impacts far into the future, horizon scanning is important to the city development process. It can also uncover sources of potential conflict, allowing these unintended consequences to be addressed as part of the planning, rather than the implementation, stage. In addition, with the growing imperative to consider climate change in planning, agencies influencing infrastructure development need to ensure air quality challenges are central to decision-making processes. It is helpful to think of climate change and air quality as two sides of the same coin, with many climate forcing agents also being air pollutants, for example particulate matter and ozone.

Ideally, infrastructure developments will be directly linked to strategic planning policy, which in turn informs local planning and regulation. While this approach to planning is commonly adopted in the global north, it is far less effective in the global south, where there is typically limited institutional capacity and a high degree of informal urban growth.

Government at national and local levels can support innovations or interventions that improve the environmental performance of vehicles such as adoption of new technologies or improved fuels. Cities, in particular, have the opportunity to improve the environmental performance of vehicle fleets involved in municipal services such as waste collection and public transport. They can also encourage moves to more efficient commercial and private vehicles through regulatory and fiscal measures. Policy measures such as fleet emission regulations foster economies of scale, and thereby contribute to reducing the production cost of new technologies. For public bodies, implementation of regulatory measures is cost-effective, whereas upfront investments for the purchase of new public transport fleets may be prohibitive. From the perspective of the transport operator, enhancements can be cost-effective under specific conditions (i.e. dependent on retail and fuel costs).

For users, the health and environmental benefits of investment must be balanced against economic costs. However, such benefits tend to be excluded from benefit cost calculations of individual users (Bartle et al., 2016). A menu of options is available for policy makers drawn from global experience and can include vehicle: emission standards, fuel quality standards, scrappage programs, and tax incentives. When adopting these, it is important to develop a national policy road map for cleaner vehicles and fuels that provides a clear and predictable course for technology and fuel adoption by private and public stakeholders. Such interventions must be accompanied by communication and education campaigns that highlight the co-benefits of such programmes. Within urban transport policy, three key principles are commonly recognised - usually summarised as 'avoid, shift, improve' (UNEP, 2011):

- **Avoid**: reduce travel intensity in cities through greater physical proximity and co-location of different urban functions;
- **Shift**: move from spatially inefficient and energy intensive private motorised modes to public, shared and non-motorised transport;
- **Improve:** improve the efficiency of road-based vehicles.

To these UNEP principles, the ASAP team suggests that active travel should be recognised as an important intervention.

Government at national, regional and local levels can develop policy interventions to enhance growth in less polluting transport options. The impacts of motorized transport in the study cities can be seen in congestion, accidents, community severance and, of particular relevance to the current study, air pollution. To provide an environment where cleaner air, simple trip-making and access to key facilities, services, workplaces and social activities can be accomplished with ease, there needs to be a more socially equitable hierarchy of road users which moves away from favouring the car and other motorised modes. Movement towards this future vision may be achieved through holistic planning and policy interventions which, over time, erode car dependency and lessen the use of highly polluting vehicles, while providing clean, sustainable alternative mobility options. Building on the urban transport policy suggestions in the previous section, policies to decrease transport's contribution to emissions could be comprised of interventions such as:

- **Enabling mode shift**, including restrictions on cars, promotion and provision of integrated public transport, installation of rapid transit, bike lanes and safe and attractive walking routes through green space

- **Enhancing road quality and conditions**, especially of routes away from the city centre, to encourage use by freight transport
- **Improving public transport options** for local people and discouraging private transport (e.g. through pricing mechanisms such as road user and workplace parking charges
- **Lowering emissions to improve local air quality** [e.g. through regulated emissions standards, mandatory vehicle inspections, improved road conditions within the urban area and technology (e.g. alternative fuels)]
- **Developing land use strategies** to encourage higher densities and limit urban sprawl

ASAP EAST AFRICA

Annex 1: Bibliography

Avis, W. and Khaemba, W. (2018). Vulnerability and air pollution. ASAP-East Africa Rapid Literature Review. Birmingham, UK: University of Birmingham. **https://www.asap.uk.com/s/ASAP-EastAfrica-VulnerabilityandairpollutionRapidLitReviewFinal-2.pdf**

Bartle, C. et al., (2016). The Economic Benefits of Sustainable Urban Mobility Measures Independent Review of Evidence: Summaries. European Platform on Sustainable Urban Mobility Plans. **https://www.eltis.org/sites/default/files/report_summary_reviews_of_measures.pdf**

Bryson, J., (2019). City-Regions: Towards an Integrated or Systematic Approach. ASAP-East Africa Rapid Literature Review. Birmingham, UK: University of Birmingham.

Brunt, H. et al. (2016). Local air quality management policy and practice in the UK: The case for greater public Health integration and engagement, Environmental Science & Policy, 58, 52–6. **https://doi.org/10.1016/j.envsci.2016.01.009**

Cohen, A.J., Brauer, M., Anderson, H.R., Frostad, J., Estep, K., et al. 2015. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Disease Study 2015. *The Lancet*. 389(10082), 1907. **https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(17)30505-6.pdf**

Duflo, E. et al., (2012). Improving Access to Urban Services for the Poor: Open Issues and a Framework for a Future Research Agenda. Poverty Action Lab. **https://www.povertyactionlab.org/sites/default/files/publications/USI%20Review%20Paper.pdf**

Egondi, T. et al (2016). Household Air Pollution: Sources and Exposure Levels to Fine Particulate Matter in Nairobi Slums. Toxics 4, 12: 1-13. **https://doi.org/10.3390/toxics4030012**

Fang, S. et al. (2010). A Systematic Review of Occupational Exposure to Particulate Matter and Cardiovascular Disease. Int. J. Environ. Res. Public Health. 7. 1773-1806. **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2872342/pdf/ijerph-07- 01773.pdf**

Fussell, H. (2007). Vulnerability: A generally applicable conceptual framework for CC research. Global Environmental Change. 17(2): 155– 167. **http://www.riesgoycambioclimatico.org/biblioteca/archivos/DC1089.pdf**

Hickey, S. (2013). Thinking about the politics of inclusive development: Towards a relational approach. ESID. **https://assets.publishing.service.gov.uk/media/57a08a2a40f0b64974000466/esid_wp_01_hickey.pdf**

Hoek, G., Krishnan, R.M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B. and Kaufman, J.D., 2013. Long-term air pollution exposure and cardio-respiratory mortality: a review. Environmental Health, 12(1). **https://ehjournal.biomedcentral.com/track/pdf/10.1186/1476-069X-12-43**

Kan, H. et al. (2008). Season, sex, age, and education as modifiers of the effects of outdoor air pollution on daily mortality in Shanghai, China: The Public Health and Air Pollution in Asia (PAPA) Study. Environ Health Perspect 116. 1183–1188. **https://www.ncbi.nlm.nih.gov/pubmed/18795161**

Kathuria, V. and Khan, N.A. (2007). Vulnerability to Air Pollution: Is There Any Inequity in Exposure? Economic and Political Weekly. 3158-3165. **https://www.jstor.org/stable/4419846?seq=1#page_scan_tab_contents**

Kelsall, T. et al. (2016). Political settlements and pathways to universal health coverage. ODI. **https://www.odi.org/sites/odi.org.uk/files/resource-documents/10382.pdf**

Lancet Commission (2017). The Lancet Commission on pollution and health. Lancet. Vol. 391, No. 10119. **https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(17)32345-0.pdf**

Lavers T. and Hickey S., (2015). 'Investigating the political economy of social protection expansion in Africa: At the intersection of transnational ideas and domestic policies', ESID Working Paper 47. **https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2598114**

Longhurst, J. et al. (2016). Progree with Air Quality Management in the 60 Years Since the UK Clean Air Act, 1956. Lessons, Failures, Challenges and Opportunities. Int. J. Sus. Dev. Plann. Vol. 11, No. 4. 491–499. **https://media.proquest.com/media/hms/PFT/1/nZcAA?_s=p1tNah5eYjsAPN39NfQwIZAEwRE%3D**

O'Brien, K. et al. (2009). Vulnerability interventions in the context of multiple stressors: lessons from the Southern Africa Vulnerability Initiative (SAVI). Environmental Science and Policy. 12. **https://doi.org/10.1016/j.envsci.2008.10.008**
https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(17)30505-6.pdf

O'Neill, M. et al. (2003). Workshop on Air Pollution and Socioeconomic Condition Health, wealth, and air pollution: advancing theory and methods. Environ Health Perspect 111. 1861–70. **https://pdfs.semanticscholar.org/a180/e2bb97e6671eef84994fccd91c86e3bc0a37.pdf**

Rajé, F., Tight, M., and Pope, F. D. (2018). Traffic pollution: a search for solutions for a city like Nairobi. *Cities*, *82*, 100-107. **https://www.sciencedirect.com/science/article/pii/S0264275117312933**

Rotko, T. Koistinen, K. HAeNNINEN, O.T.T.O. and Jantunen, M. (2000). Sociodemographic descriptors of personal exposure to fine particles (PM2. 5) in EXPOLIS Helsinki. Journal of Exposure Science and Environmental Epidemiology, 10(4), p.385. **https://www.nature.com/articles/7500342.pdf**

Schwartz, J. (2004). Air pollution and children's health. Paediatrics. 113. 1037– 1043. **http://pediatrics.aappublications.org/content/pediatrics/113/Supplement_3/1037.full.pdf**

Singh A., Avis W. and Pope F.D., (2020), Historical visibility trends in Africa: a proxy for PM pollution. *Environment Research Letter* (*Under review*)

Shehab, M., and Pope, F.D. (2019) Effects of short-term exposure to particulate matter air pollution on cognitive performance. *Scientific Reports*. 9, 8237. **https://www.nature.com/articles/s41598-019-44561-0**

SIDA (ND.). Air pollution. Copenhagen. SIDA.
https://www.sida.se/contentassets/5bf5b0b77cfd4491857db2c08bf6e0aa/13547.pdf

Stilianakis, N. (2015). Susceptibility and vulnerability to health effects of air pollution: The case of nitrogen dioxide. EU. **http://publications.jrc.ec.europa.eu/repository/bitstream/JRC98587/lb-na-27634-en-n%20.pdf**

UNDESA (2016). The World's Cities in 2016 – Data Booklet. UNDESA. **https://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf**
UN-HABITAT (2016). World Cities Report in 2016. Nairobi: UN-HABITAT. **http://wcr.unhabitat.org/main-report/**

UN-HABITAT (2014). Proportion of urban population living in slums and urban slum population by country, 1990-2014. UN-HABITAT. **https://undatacatalog.org/dataset/proportion-urban-population-living-slum-1990-2014**

UN-Habitat. (2013). Streets as public spaces and drivers of urban prosperity. Nairobi: UN-Habitat. **http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3513**

UNEP (2011). Towards a Green Economy: Pathways to sustainable development and poverty eradication. UNEP. https://sustainabledevelopment.un.org/content/documents/126GER_synthesis_en.pdf

UN- HABITAT (2003. The Challenge of Slums: Global Report on Human Settlements 2003. United Nations Settlements Programme (UN-Habitat).

US EPA (2016). Technical Assistance Document for the Reporting of Daily Air Quality – the Air Quality Index (AQI). US EPA. https://www3.epa.gov/airnow/aqi-technical-assistance-document-may2016.pdf

WHO (2010). Environment and health risks: a review of the influence and effects of social inequalities. WHO. http://www.euro.who.int/__data/assets/pdf_file/0003/78069/E93670.pdf

WHO (2006). Air Quality Air Quality Guidelines Global Update 2005. World Health Organisation. http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf?ua=1%201/23/17

WHO (2005). Effects of air pollution on children's health and development: a review of the evidence. WHO Regional Office for Europe. http://apps.who.int/iris/bitstream/handle/10665/107652/E86575.pdf?sequence=1&isAllowed=y

WHO (2004). Health Aspects of Air Pollution. WHO. http://www.euro.who.int/__data/assets/pdf_file/0003/74730/E83080.pdf?ua=1

World Bank and Institute for Health Metrics and Evaluation, (2016). The Cost of Air Pollution Strengthening the Economic Case for Action. Washington DC: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/25013/108141.pdf?sequence=4&isAllowed=y

Disclaimer Statement

This material has been funded by UK aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.