Air Quality Research in Africa: trends and prospects

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Agenda

1. What's air pollution?
2. Air quality guidelines
3. Particulate matter
4. Scale of monitoring
5. Air pollution monitoring
6. Air pollution and impacts
7. Trends in research and gaps in Africa

Part 1

What's air pollution?

Introduction

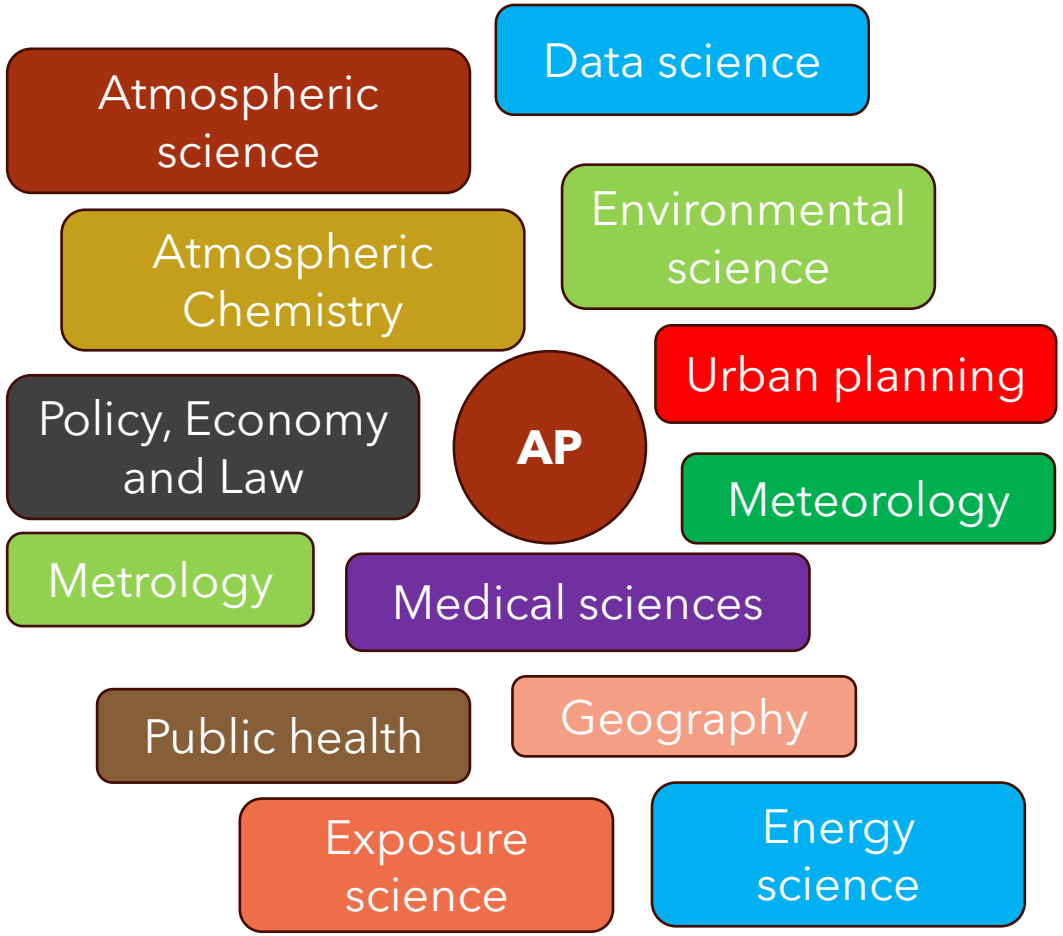
Question 1 – What's air pollution?
Presence of harmful substances…

- **Air pollution** is the contamination of air due to the presence of harmful substances (called pollutants) in the atmosphere… Air pollution is also the contamination of the indoor or outdoor environment either by chemical, physical or biological agents that alters the natural features of the atmosphere.
- Air pollutants are of many different types: gases, particulates (organic or inorganic) and biological molecules and are generated by both by human activities and natural phenomena.
- Air pollution has economic, environmental, social and health impacts. It can cause diseases, allergies and even deaths; it can also cause harm to other living organisms such as animals and crops. It can cause damage to the environment, the climate and to materials (acid rain for instance).

Introduction

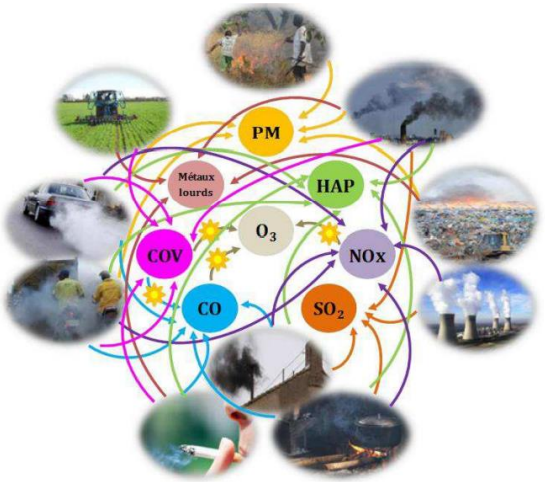
Question 2 – What's air pollution science made of? A complex and interdisciplinary field…

- **Air pollution science** covers a very complex and interdisciplinary scientific area, where aspects of policy and regulation, urban planning, public health, epidemiology, toxicology, and decision-making mix together with aspects like metrology, sensing and monitoring, data analysis and assimilation techniques, chemical schemes, modelling and forecasting, computational efficiency and performance, coupling with the meteorology and many others.
- It aims to describe the generation, transportation, dispersion, physical and chemical transformation, and the impact of various categories of substances that are identified and classified as air pollutants via the environmental legal framework and the scientific community.
- APS is a topic that is progressing very fast in the past two decades, attracting the interest of various groups and initiatives worldwide.



Atmospheric pollutants

Question 1 – What are pollutants?
Different categories – particles, gaseous, VOC, HAP…



Solid pollutants
Particles of very small size, aerodynamic diametre of few µm…

Gaseous pollutants
- Ozone (O_3)
- Sulphur dioxide (SO_2)
- Nitrogen oxides (NOx)
- Carbon monoxide (CO)

HAP (hazardous air pollutants)
Toxic air pollutants, popularly known as 'air toxics' or as 'hazardous air pollutants (HAPs)', are known or suspected to cause serious health effects including cancer, reproductive and birth defects, or to cause adverse environmental effects. The US EPA identifies about 187 air toxics).

Atmospheric pollutants

Question 1 – What are pollutants? Different categories – particles, gaseous, VOC…

Volatile organic compounds (VOCs)
VOCs are organic compounds with vapour pressure high enough to be vaporized into the atmosphere under normal conditions.
In addition to anthropogenic sources, these are emitted by a variety of living organisms, including plants and microorganisms.

Biogenic volatile organic compounds (BVOCs). BVOCs are classified according to their structure and biosynthetic origin. These include isoprenoids (isoprenes and monoterpenes) as well as alkanes, alkenes, carbonyls, esters, ethers, alcohols and acids.

Biopollutants
Various microorganisms with biological origin: bacteria, molds, mildew, viruses, house dust, mites, cockroaches, and pollen.

- Pollens originate from plants;
- viruses are transmitted by people and animals;
- bacteria are carried by people, animals, and soil and plant debris;
- Standing water, water-damaged materials, or wet surfaces also serve as a breeding ground for molds, mildews, bacteria, and insects.

Atmospheric pollutants

Question 1 – What are the sources?
Different origins: biogenic or natural, anthropogenic, mixed

Biogenic emission sources (are from natural origin) include:

- Sahara dust, sea sprays,
- volcanic emissions,
- vegetation, grassland fires,
- soils , etc.

Anthropogenic sources (are from human activities) include:

- Combustion of fuels (fossil, biomass…),
- Household activities,
- Open burning of solid municipal waste (SMW),
- Agricultural activities and bush fires,
- Construction works,
- Industrial processes,
- Mining activities,
- …

Part 2

Air Quality Guidelines

Air quality guidelines

Question 1 – What's criteria pollutant?
Six pollutants: $PM_{2.5}$, PM_{10}, CO, O_3, NO_2, SO_2…

- **Particulate matter (PM) – PM2.5 and PM10:** PM is a common proxy indicator for air pollution. There is strong evidence for the negative health impacts associated with exposure to this pollutant. The major components of PM are sulfates, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water.

- **Carbon monoxide (CO):** a colourless, odourless and tasteless toxic gas produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, charcoal, natural gas and kerosene.

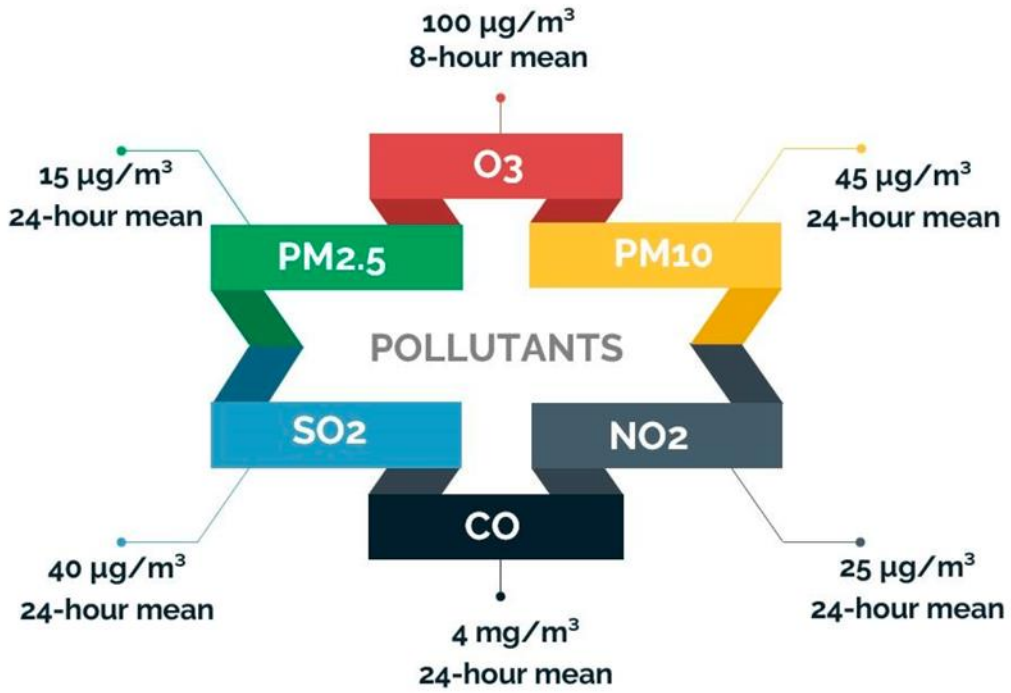
- **Ozone (O_3):** Ozone at ground level, is one of the major constituents of photochemical smog and it is formed through the reaction with gases in the presence of sunlight.

- **Nitrogen dioxide (NO_2):** a gas that is commonly released from the combustion of fuels, in the transportation and industrial sectors.

- **Sulfur dioxide (SO_2):** a colourless gas with a sharp odour, produced from the burning of fossil fuels (coal and oil) and the smelting of mineral ores that contain sulfur.

Air quality guidelines

Question 2 – What's air quality guideline? For different pollutants…by WHO



Recommended 2021 air quality guideline (AQG) levels and 2005 AQG - WHO

Source: Essamlali, I.; Nhaila, H.; El Khaili, M. Supervised Machine Learning Approaches for Predicting Key Pollutants and for the Sustainable Enhancement of Urban Air Quality: A Systematic Review. Sustainability 2024, 16, 976. https://doi.org/10.3390/ su1603097

Table 0.1. Recommended AQG levels and interim targets

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	–	–	60
	8-hour[a]	160	120	–	–	100
NO_2, µg/m³	Annual	40	30	20	–	10
	24-hour[a]	120	50	–	–	25
SO_2, µg/m³	24-hour[a]	125	50	–	–	40
CO, mg/m³	24-hour[a]	7	–	–	–	4

[a] 99th percentile (i.e. 3–4 exceedance days per year).
[b] Average of daily maximum 8-hour mean O_3 concentration in the six consecutive months with the highest six-month running-average O_3 concentration.

Air quality guidelines

Question 3 – What's air quality guideline?
AQG set by countries …

- **Air quality threshold limits from the European commission and the WHO**

	Time Interval	EU 2008	EU 2030	WHO 2005	WHO 2021
$PM_{2.5}$	Annual mean	25 µg/m³	10 µg/m³	10 µg/m³	5 µg/m³
	24 hours mean	NA	25 µg/m³	25 µg/m³	15 µg/m³
PM_{10}	Annual mean	40 µg/m³	20 µg/m³	20 µg/m³	15 µg/m³
	24 hours mean	50 µg/m³	45 µg/m³	50 µg/m³	45 µg/m³
NO_2	Annual mean	40 µg/m³	20 µg/m³	40 µg/m³	10 µg/m³
	1 hour mean	200 µg/m³	200 µg/m³	NA µg/m³	NA µg/m³
	24 hours mean	NA	50 µg/m³	NA µg/m³	25 µg/m³
O_3	8-hour mean	120 µg/m³	120 µg/m³	100 µg/m³	100 µg/m³

- **Air quality threshold limits from the WHO and Senegal**

Polluants	Moyenne temporelle	Valeurs limites (en $\mu g\ m^{-3}$)		
		Directives OMS 2005 (2021)	NS 05-062 (2003)	NS 05-062 (2019)
Dioxyde de soufre (SO_2)	10 minutes Journalière	500 20 (40)	– 125	500 50
Dioxyde d'azote (NO_2)	Horaire Annuelle	200 40 (10)	200 40	200 40
Ozone O_3	8 heures	100	120	100
Monoxyde de carbone (CO)	Horaire 8 heures	30 000 10 000	– 30 000 (24 h)	30 000 10 000
Particules $< 10\ \mu m$ (PM_{10})	Journalière Annuelle	50 (45) 20 (15)	260 80	150 40
Particules $< 2{,}5\ \mu m$ ($PM_{2.5}$)	Journalière Annuelle	25 (15) 10 (5)	– –	75 25
Plomb (Pb)	Annuelle	0,5-1,0	2	0,5

Air quality guidelines

Question 4 – What's air quality index (AQI)? Differed from one place to another (breakpoints and methods)…

2023 AQI for Fine Particle Pollution (*Breakpoints are in micrograms per cubic meter*)			
AQI Category and Index Value	**Previous AQI Category Breakpoints**	**Updated AQI Category Breakpoints**	**What changed?**
Good (0 – 50)	0.0 to 12.0	0.0 to 9.0	EPA updated the breakpoint between Good and Moderate to reflect the updated annual standard of 9 micrograms per cubic meter
Moderate (51 – 100)	12.1 to 35.4	9.1 to 35.4	
Unhealthy for Sensitive Groups (101 – 150)	35.5 to 55.4	35.5 to 55.4	No change, because EPA retained the 24-hour fine PM standard of 35 micrograms per cubic meter.
Unhealthy (151 – 200)	55.5 to 150.4	55.5 to 125.4	EPA updated the breakpoints at the upper end of the unhealthy, very unhealthy, and hazardous categories based on scientific evidence about particle pollution and health. The Agency also collapsed two sets of breakpoints for the Hazardous category into one.
Very Unhealthy (201 – 300)	150.5 to 250.4	125.5 to 225.4	
Hazardous (301+)	250.5 to 350.4 and 350.5 to 500	225.5+	

AQI can be based on one or several pollutants and varies from one country to another .

- The Air Quality Index (AQI) is a simplified process of assessing air quality. It offers a convenient way for individuals to understand the level of air pollution in their vicinity.
- AQIs are numerical values that correspond to different degrees of pollution, where higher numbers indicate poorer air quality.
- Although each country may have its own specific AQI standard, the US EPA standard is widely adopted and encompasses six levels of health concern.

Part 3

Particulate matter

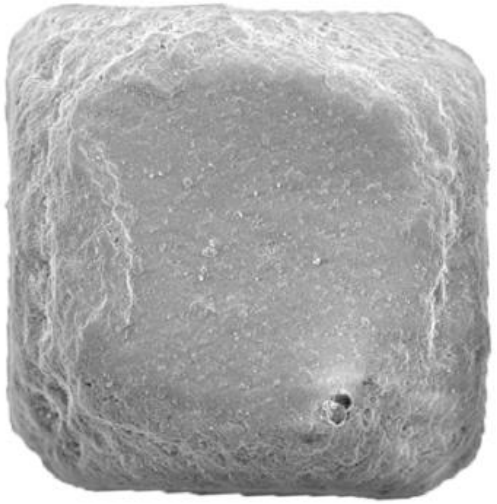
Particulate matter

Question 1 – What are particulate matter (PM)? PM have different sizes or categories and different origins

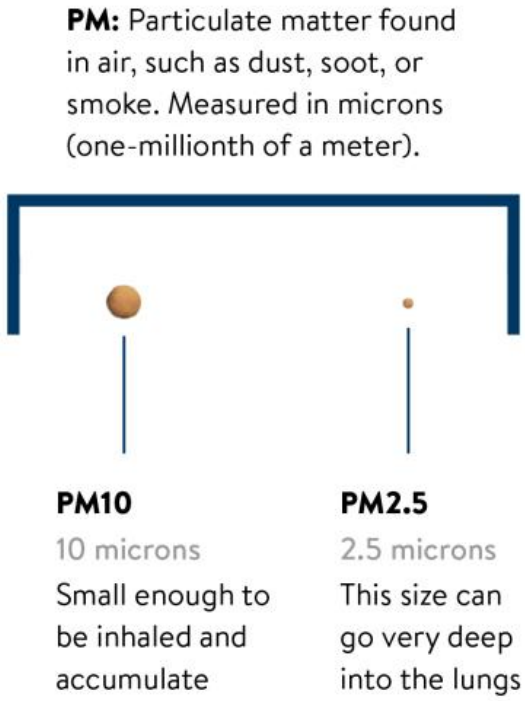
PM are 'inhalable particles' with an aerodynamic diameter of less than or equal to 10 µm (PM_{10}; $D_p \leq 10$ µm).

According to their type of source and mode of generation, PM_{10} are further stratified into different size fractions, including:

- Coarse particles ($PM_{2.5-10}$; $2.5 < D_p < 10$ µm),
- Fine particles ($PM_{2.5}$; $D_p \leq 2.5$ µm)
- Ultrafine particles ($PM_{0.1}$; $D_p \leq 0.1$ µm) particles.



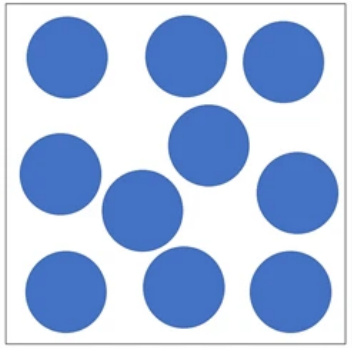
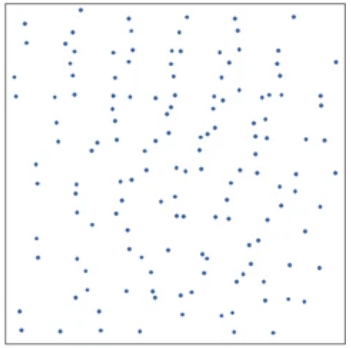
Average grain of table salt
330 microns / .33 mm



Particulate matter

Question 1 – What are particulate matter (PM)?
PM have different sizes or categories and different origins

Comparison of the surface area of particles with different diameters.

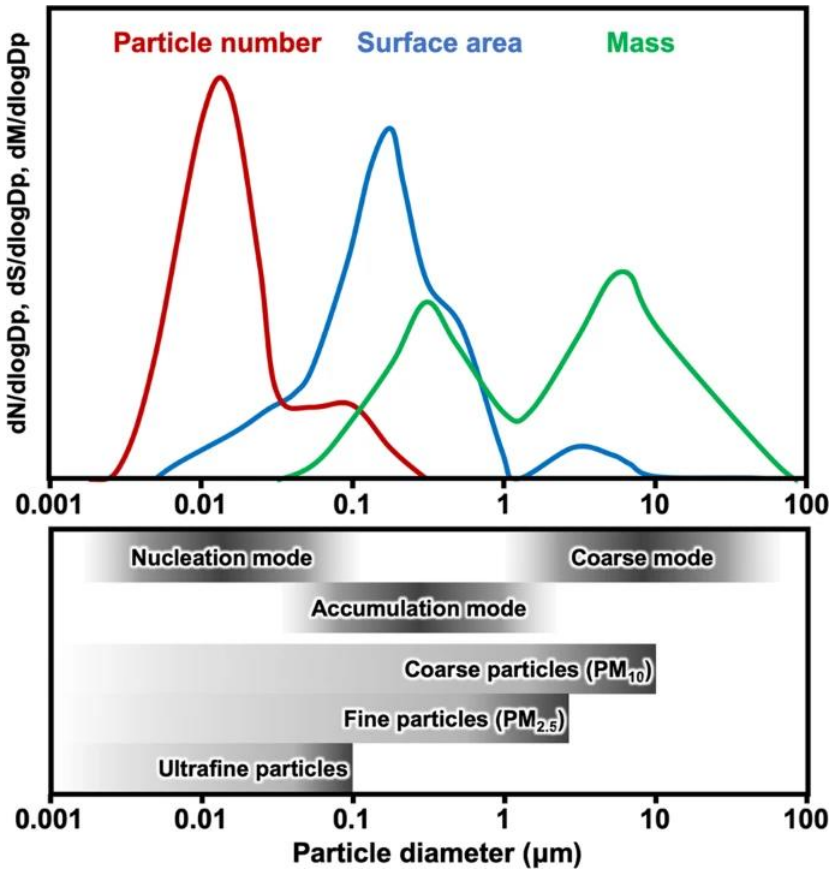
	10 µm (Coarse)	2.5 µm (Fine)	0.1 µm (Ultrafine)
			
Total mass	1	1	1
Particle number	1	64	1,000,000
Surface area per particle	1	0.0625	0.0001
Total surface area per mass	1	4	100
	• Filtered in proximal airway • May irritate skin, mucosa	• Reaches peripheral airway • Cannot enter systemic circulation	• Higher adsorbed toxic material on surface • May enter systemic circulation

Source: Kwon et al. Ultrafine particles: unique physiochemical properties relevant to health and disease, Experimental & Molecular Medicine (2020) 52:318–328 https://doi.org/10.1038/s12276-020-0405-1

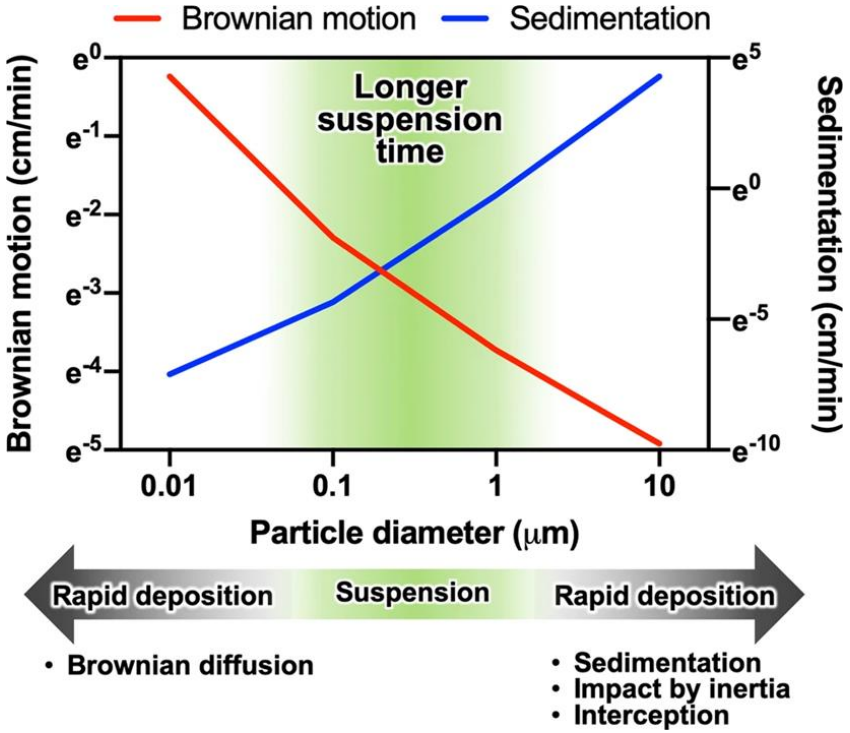
Particulate matter

Question 1 – What are particulate matter (PM)?
PM have different sizes or categories and different origins

Particle-size distribution of atmospheric PM.



Deposition modes of particles according to size distribution



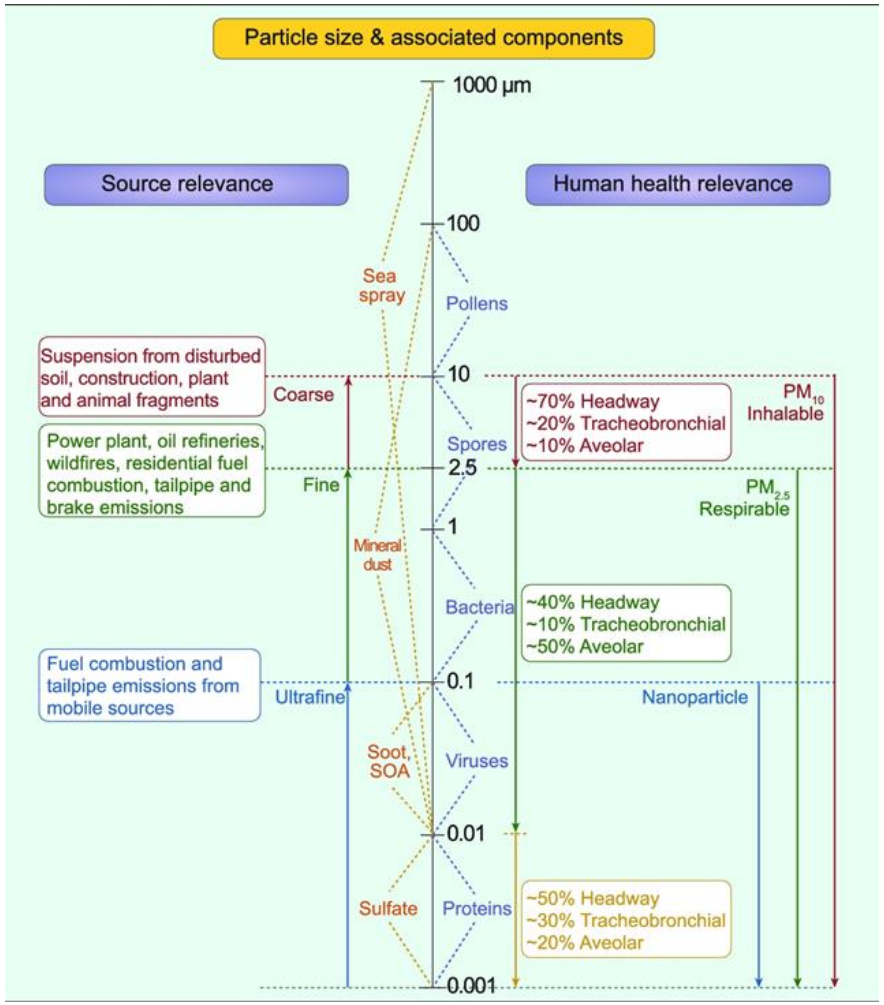
Source: Kwon et al. Ultrafine particles: unique physiochemical properties relevant to health and disease, Experimental & Molecular Medicine (2020) 52:318–328 https://doi.org/10.1038/s12276-020-0405-1

Particulate matter

Question 1 – What are particulate matter (PM)?
PM have different sizes or categories and different origins

Size distribution of atmospheric PMs and associated components with implications for emission sources and inhalation exposure.

Natl Sci Rev, Volume 4, Issue 4, July 2017, Pages 593–610, https://doi.org/10.1093/nsr/nww079



Part 4

Definition of the Scale of monitoring

Air pollution studies

Question 1 – Which scale?
Global, regional, local, microenvironments…

Global

Regional

Local

Air pollution studies

Question 2 – Outdoor / indoor air pollution? different microenvironments and sources…

- **Urban/ambient air pollution**: road traffic, airport, burning of MSW, Sahara dust, industrial processes, etc.
- **Indoor air pollution**: car cabin, homes, hospitals, offices, commercial buildings, schools, etc.

Road traffic

Open burning of solid waste

Schools…

Markets place

Healthcare facilities

Part 5

How do you monitor air pollution?

Air pollution monitoring

Question 1 – How do you monitor air pollution? different pollutants and various techniques …

REMOTE SENSING

GROUND INSTRUMENTS

MOBILE MONITORING

Various techniques and technologies are available to measure air pollution levels…

- Remote sensing using satellites…
- Ground measurements use static or mobile devices.

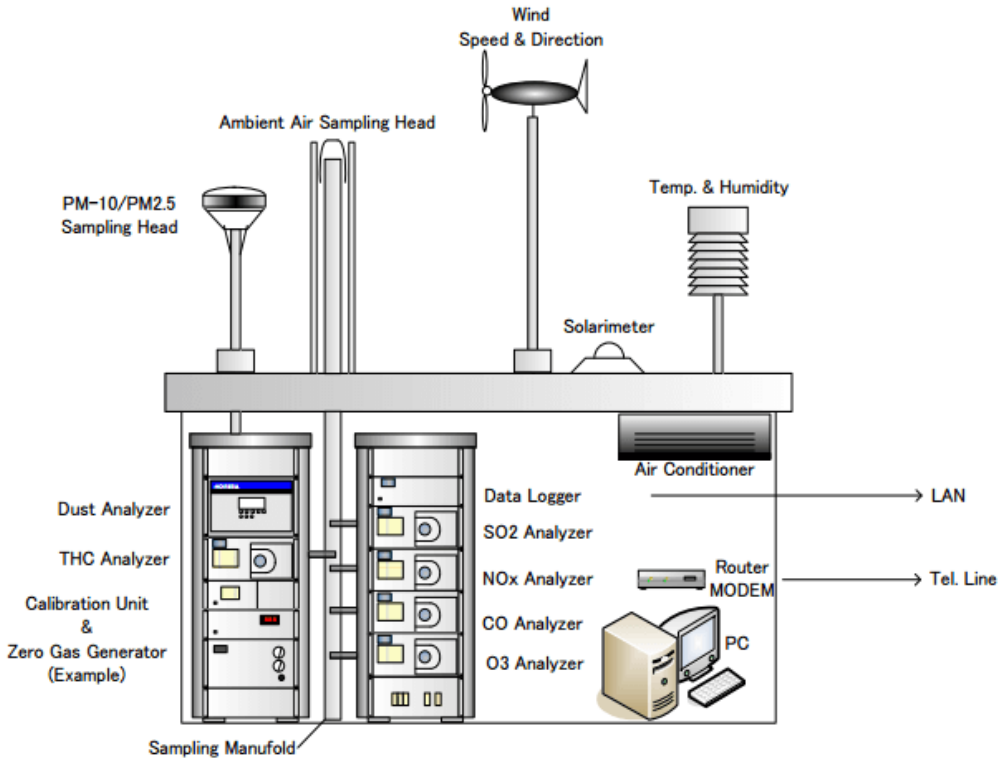
- Static include one or several instruments fixed on the ground, on a wall or on a mat..

- Mobile monitoring uses aircraft, drones or cars.

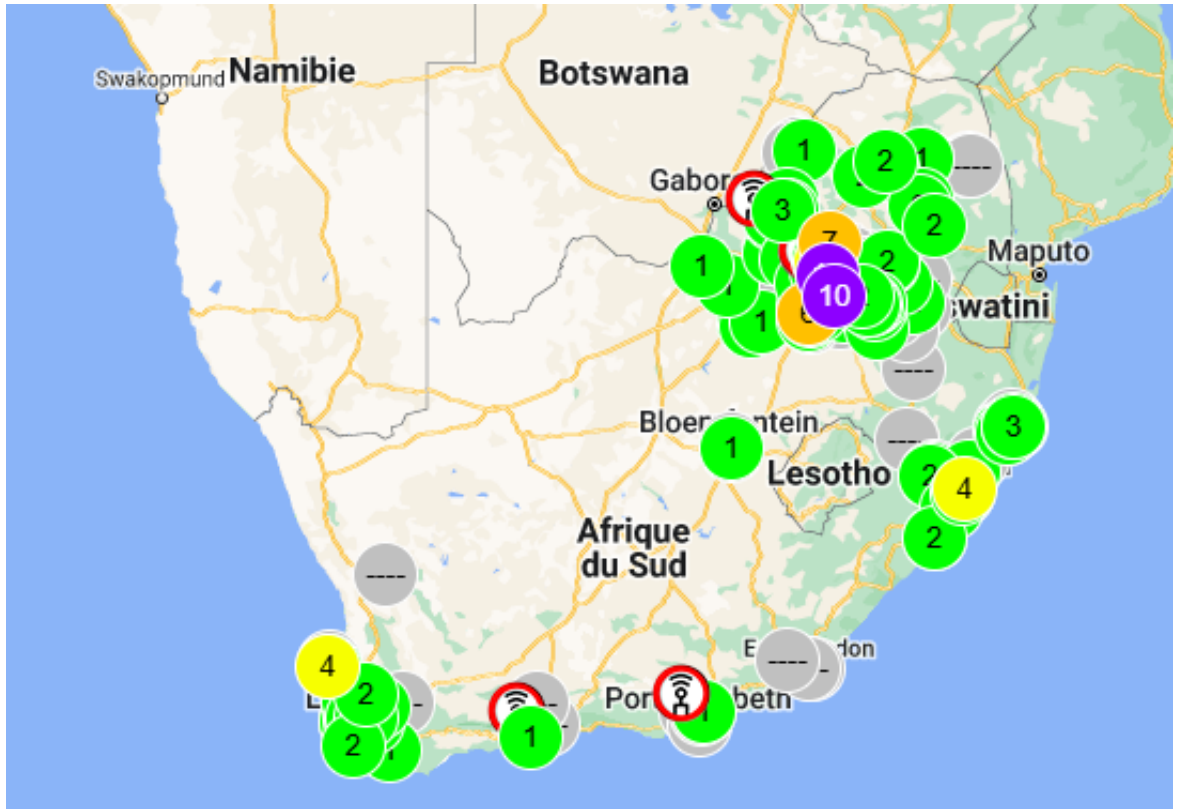
Air quality monitoring

Question 1 – How do you monitor air pollution?
Use of reference and high-grade instruments …

An air quality monitoring station has a set of instruments: PM monitor, gas analyzers… are installed to form a network in a specific area.



Ambient Air Quality Monitoring Station



Air quality monitoring

Question 1 – How do you monitor air pollution? Use of reference and high-grade instruments …

Particulate matter monitors …

Method Component	T640	T640x
Inlet	T-API custom inlet	EPA-approved omnidirectional PM_{10} inlet
Sample Flow	5 lpm	16.67 lpm (total) 5 lpm to monitor
Sample Conditioning	Aerosol Sample Conditioner (ASC) where a heater is used to ensure that the measured aerosol's RH does not exceed 35%.	
Measurement Method	Broadband spectrometry using 90° white-light scattering with Polychromatic LED. T640 calculates the aerodynamic mass fraction of $PM_{2.5}$ and PM_{10} aerosol based on an algorithm which converts the measured light scattering signal from 64 channels (combined from 256 channels) to $PM_{2.5}$ and PM_{10} mass concentrations.	
Sample Period	1 – hour data are reported. Each 1 – hour period is based on sixty 1 - minute averages that use a 10-min rolling average of the PM mass concentration	
Resolution	0.1 µg m^{-3}	
Approvals	$PM_{2.5}$ FEM *(PM_{10}LC data is available and may be reported for AQI)*	$PM_{2.5}$ FEM PM_{10} FEM $PM_{10-2.5}$ FEM

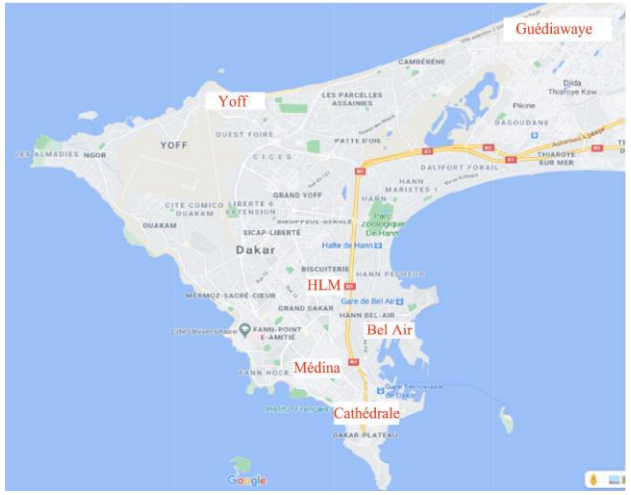
Teledyne T640

Beta attenuation mass (BAM)

Air quality monitoring

Question 1 – How do you monitor air pollution? Use of reference and high-grade instruments …

The city of Dakar, has 6 fixed stations…



Source: Sow et al., Monitoring of Atmospheric Pollutant Concentrations in the City of Dakar, Senegal, Open Journal of Air Pollution, 2021, 10, 18-30

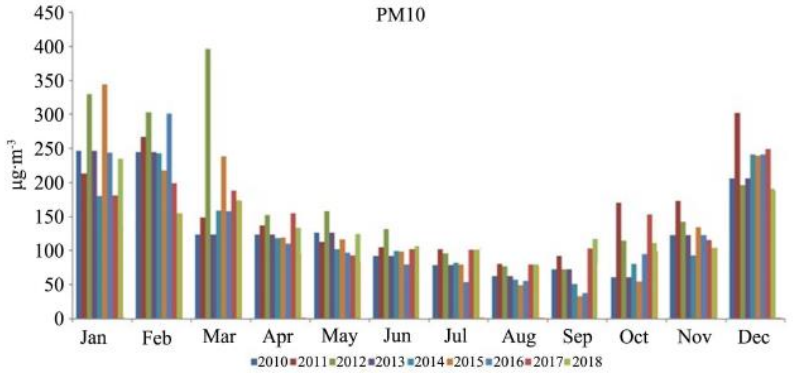


Figure 3. Monthly averages of PM_{10} concentrations over the period from 2010 to 2018 (Source: CGQA).

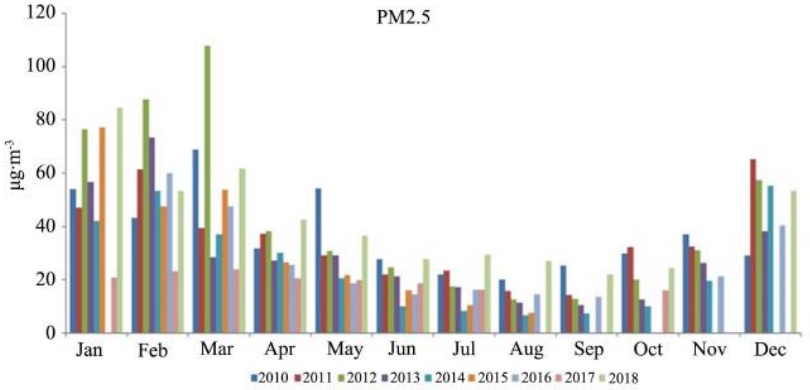
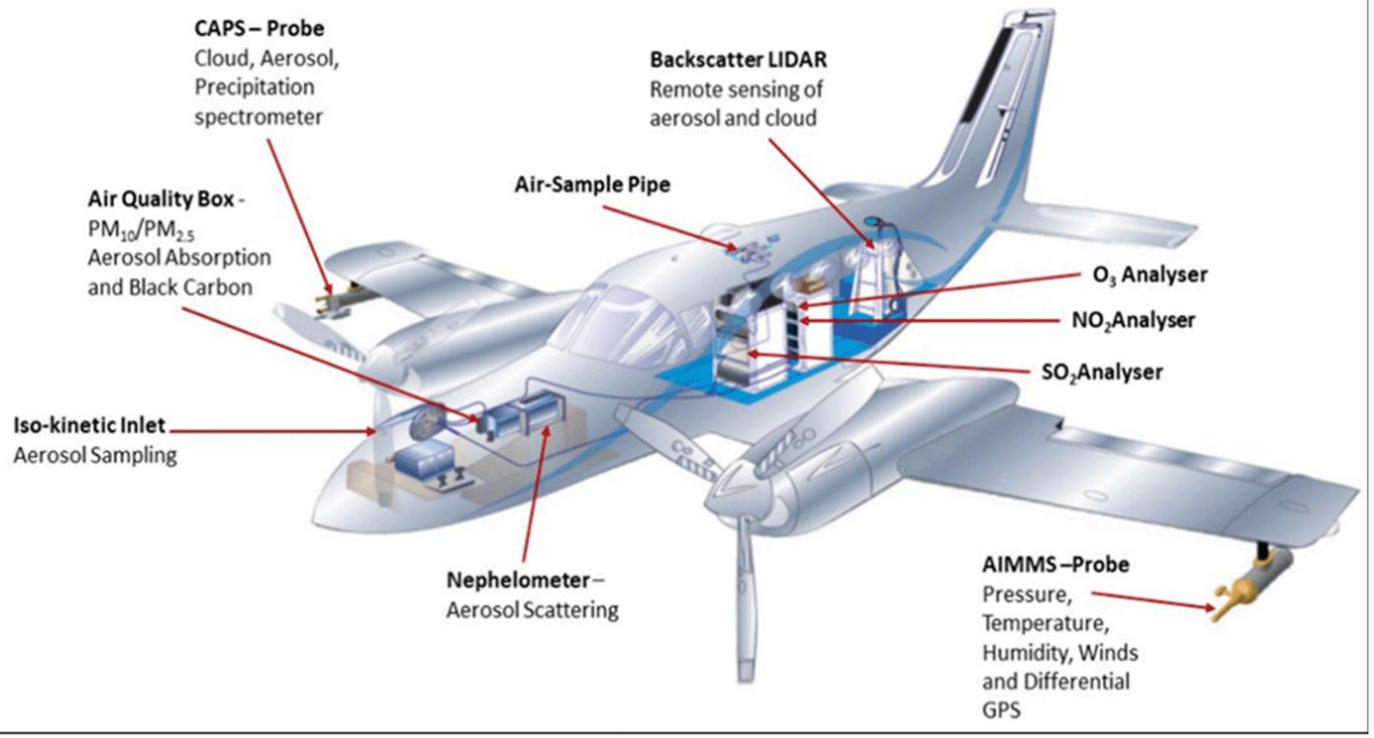


Figure 4. Monthly averages of $PM_{2.5}$ concentrations over the period from 2010 to 2018 (Source: CGQA).

Air pollution monitoring

Question 1 – How do you monitor air pollution?
Use of an aerial vehicle with embedded instruments …

Crew	1 pilot, 1 mission scientist, optional second pilot/observer
Flight endurance	Approximately 4 hours
Pressurised Cabin	Yes. Max cabin alt is 10,000 ft
Nominal science speed	85 ms^{-1}
Max alt	25,000 ft whilst operating in UK airspace
Min alt	500ft, dependent on airspace restrictions, geography and meteorology
Ascent rate	800 ft per minute
Decent rate	1000 ft per minute
Effective horizontal sampling scale (1 Hz)	85 m
Effective vertical sample scale (1 Hz)	4 m (ascent), 5 m (descent)



The Met Office Atmospheric Survey Aircraft, with instrumentation.

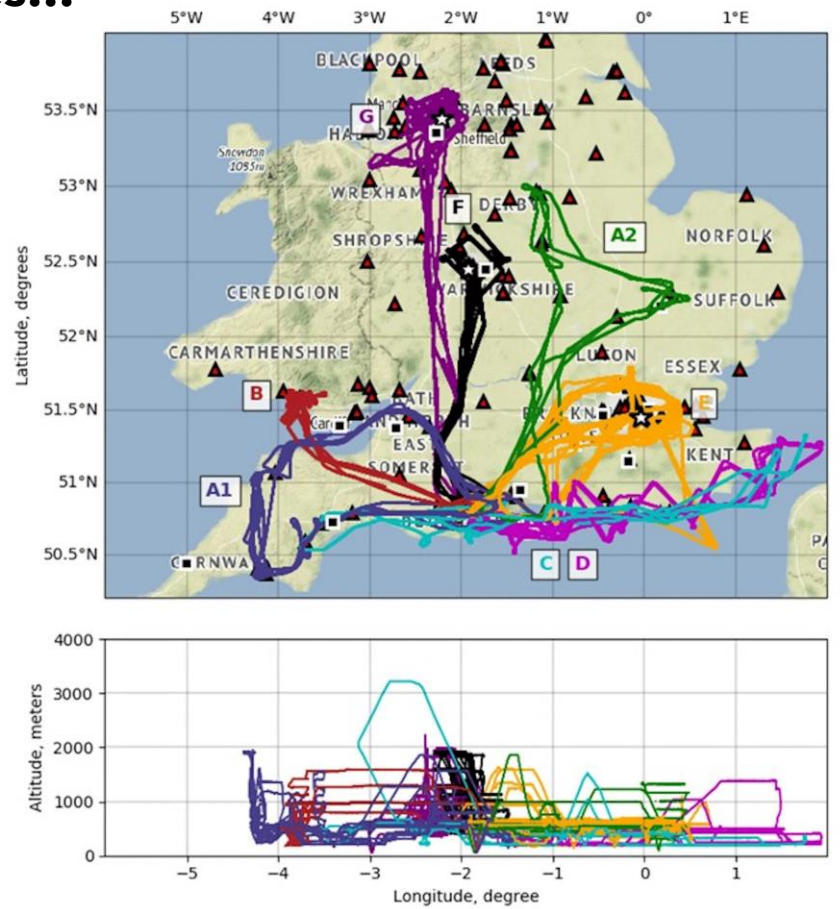
Source: Angela Mynard et al., Long-term airborne measurements of pollutants over the United Kingdom to support air quality model development and evaluation, AMT, 16, 4229–4261, 2023, https://doi.org/10.5194/amt-16-4229-2023

Air pollution monitoring

Question 1 – How do you monitor air pollution?
Use of an aerial vehicle with embedded instruments …

The embedded instruments…

Horizontal (top) and vertical(bottom) profiles…



Source: Angela Mynard et al., Long-term airborne measurements of pollutants over the United Kingdom to support air quality model development and evaluation, AMT, 16, 4229–4261, 2023, https://doi.org/10.5194/amt-16-4229-2023

Air quality monitoring

Question 1 – How do you monitor air pollution?
Use of UAV with embedded instruments …

Small sensors mounted on drones (UAV).

- Horizontal and vertical profiles
- One or several sensors
- Limited flying time
- Need for authorization
- Skills needed to flight the UAV
- Limited load

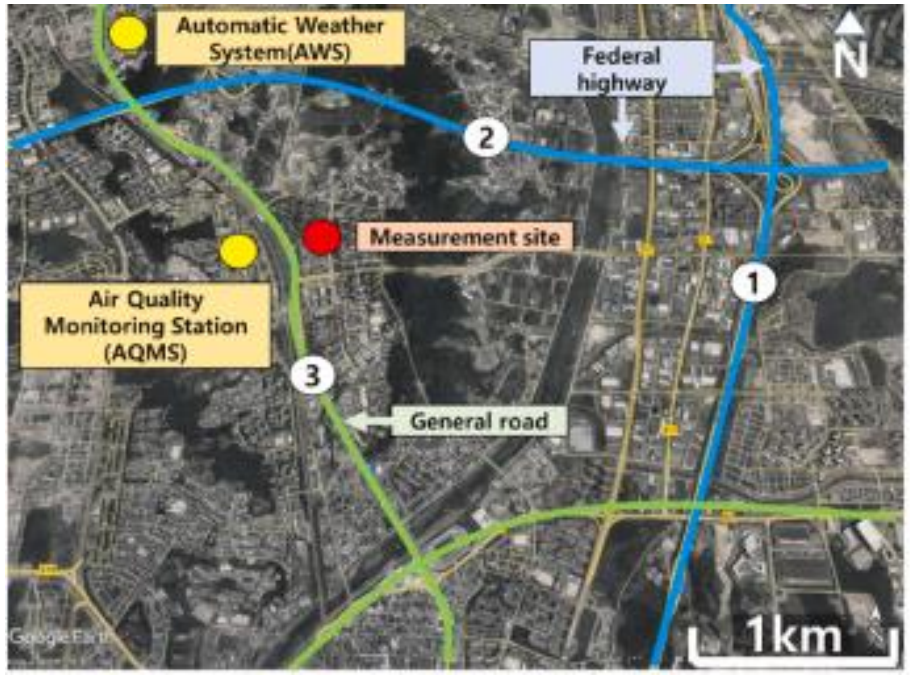
Characeritsics:

- multicopter drone with eight propellers (dimensions: 950 × 950 × 500 mm)
- a maximum take-off weight: 9 kg,
- Maximum heigth: 92 m
- Flying duration: < 10 min
- measurement devices such as: Sidepak AM520 for **PM2.5**, Series 500 for **O_3**, microAeth® MA200 for **black carbon (BC),** HL-1D for **temperature and humidity**

Source: Lee et al., Vertical measurements of roadside air pollutants using a drone, Atmospheric Pollution Research 13 (2022) 101609

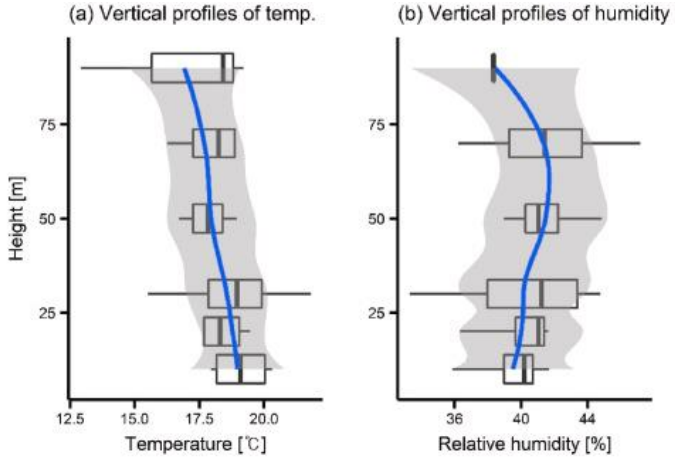
Air quality monitoring

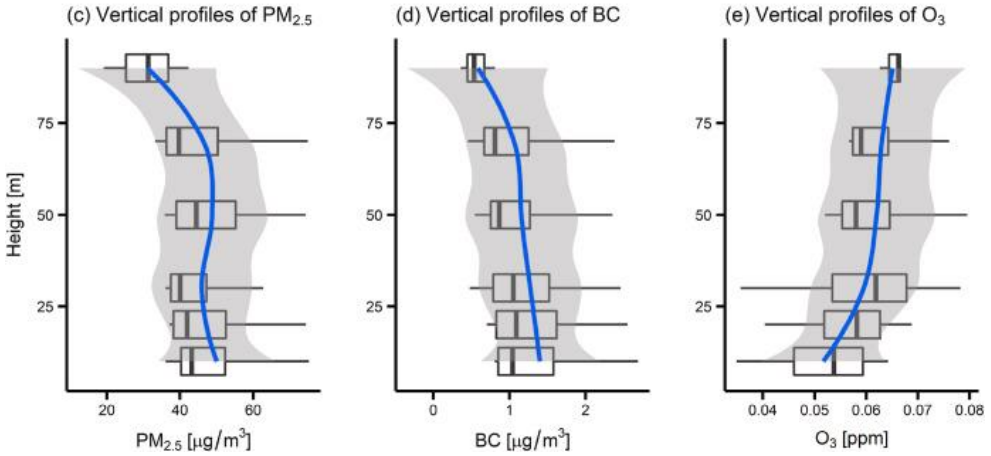
Question 1 – How do you monitor air pollution?
Use of UAV with embedded instruments …



Map of the investigated area

Vertical profiles





Source: Lee et al., Vertical measurements of roadside air pollutants using a drone, Atmospheric Pollution Research 13 (2022) 101609

Part 6

Why should we monitor air pollution?

Impacts of air pollution

Question 1 – Why should we monitor air pollution?
Negative impacts …

Environment

- Reducing visibility and blocking sunlight,
- Sulfur can lead to excess levels of acid in lakes and streams, and damage trees and forest soils;
- Atmospheric nitrogen can reduce the biodiversity of plant and harm fish and other aquatic life;
- Ozone damages tree leaves and negatively affects scenic vistas in protected natural areas…

Health

- Increase the risk of heart and respiratory diseases, as well as lung cancer and strokes
- Ozone is a major factor in causing asthma
- Nitrogen dioxide and sulfur dioxide can also cause asthma, bronchial symptoms, lung inflammation and reduced lung function.
- Fine particles (PM2.5) a leading cause of cancer.
- Est. 8 millions deaths p.a

Economy

- Healthcare expenditures
- Decreased workplace productivity
- Environmental damage and lost of ecosystem services
- Decreased tourism
- Decreased power plant production
- Decreased crop production
- Est. USD 3 – 5 Trillion p.a

Air pollution and health effects

Question 1 – Why should we monitor air pollution?
Negative impacts on health…

All parts of the body are affected: skin, eyes, lungs, heart, kindneys, etc.

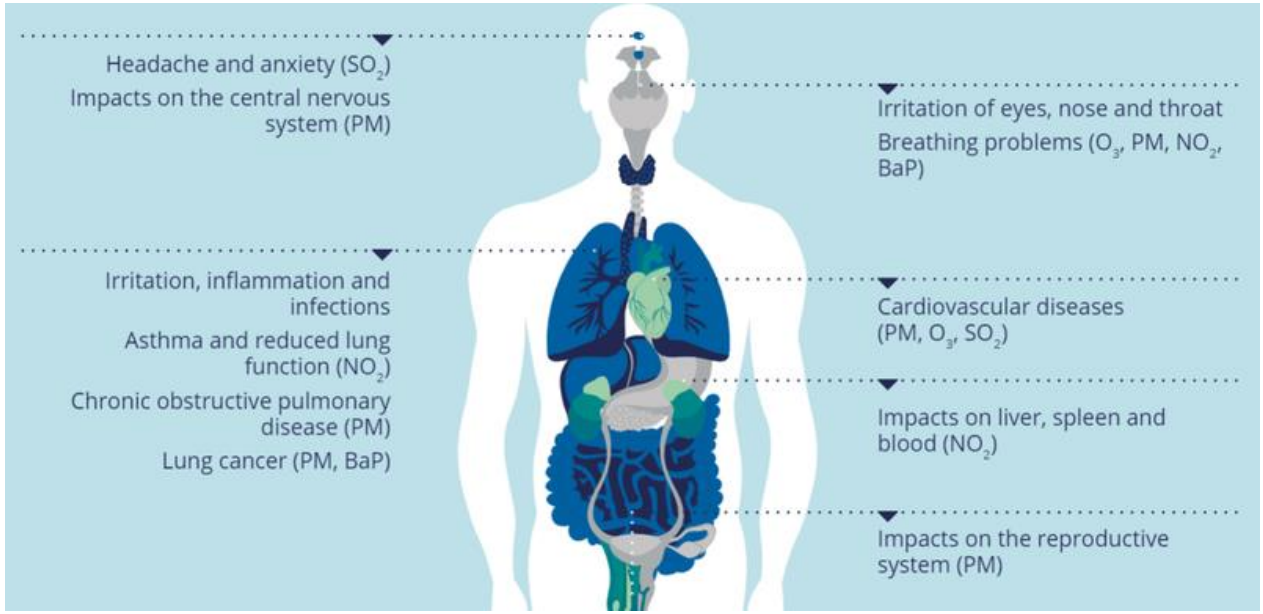
The effects of air pollution on human body vary depending on the type of pollutant, the length and level of exposure, and other factors, including a person's individual health riks and the cumulative impacts of multiple pollutants or stressors.

- Source: SoGA,2024 /, fig 9

Air pollution and health effects

Question 1 – Why should we monitor air pollution? Negative impacts on health…

Known air pollutants can have different but cumulative effects on the body…



Source: www.eea.europa.eu

Table 1. Summary table of the major pollutants, their sources and their impact on human health.

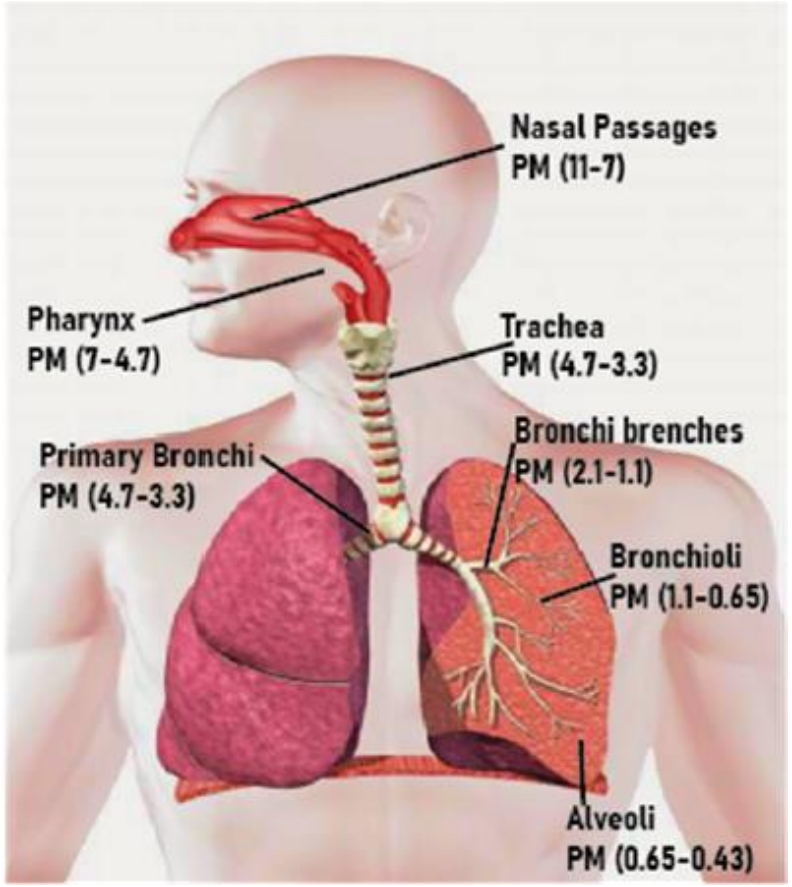
Pollutant	Sources	Health Impact
PM10 PM2.5 Ultrafine PM	• Resuspension of soil of industrial dust • Coal or oil combustion • Diesel engines (90% of PM2.5 emissions) [6] • Transformation products of NO_x, SO_2 and organics • Anthropogenic	• Premature death if heart or lung diseases are present, nonfatal heart attacks and irregular heartbeat • Asthma, decreased lung function and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing • Hypertension [7] • Depressive symptoms [8]
NO_2	• Photochemical reaction of NO with O_3	• Aggravates respiratory symptoms, especially for children, older adults, and asthmatics
O_3	• Formed via UV (sunlight) and pressure of other key pollutants	• Worsening of bronchitis, emphysema, and asthma • Reduction in lung function and inflammation of the lining of the lungs • Long exposure: can permanently damage lung tissue
SO_2	• Combustion of coal or oil • Factories pertaining to chemicals, paper, or fuel	• Asthmatics are the sensitive category (coughing, wheezing, and chest tightness) • Long exposure affects everybody
CO_2	• Anthropogenic • Deforestation and the burning of fossil fuels, such as coal, oil, and natural gas	• Low: dizziness and headaches • High: unconsciousness and dyspnea
VOCs	• Fuel combustion, gasoline evaporation or solvents • Cooking • Floor surface materials (PVC/vinyl, linoleum) [9]	• All effects related to O_3 (VOC involved in O_3 formation) • Some toxic per se (e.g., causing cancer)
CO	• Engines burning fossil fuels • Emitted from vehicles, furnaces, and heaters	• Sensation of dizziness, fatigue, and headache • Dangerous for people with heart disease

Air pollution and health effects

Question 1 – Why should we monitor air pollution? Negative impacts on health…

Particles of different sizes (UFP, FP, CP) and effects …

- Fine particulate matter ($PM_{2.5}$), is mostly absorbed through the respiratory system, where it can infiltrate the lung alveoli and reach the bloodstream.
- In the respiratory system, reactive oxygen or nitrogen species (ROS, RNS) and oxidative stress stimulate the generation of mediators of pulmonary inflammation and begin or promote numerous illnesses.
- Fine particulate matter, is responsible for nearly 4 million deaths globally from cardiopulmonary illnesses: heart disease, respiratory infections, chronic lung disease, cancers, preterm births, and other illnesses.



Source: Bernasconi, S.; Angelucci,A.; Aliverti, A. A Scoping Review on Wearable Devices for Environmental Monitoring and Their Application for Health and Wellness. Sensors 2022, 22, 5994. https://doi.org/10.3390/s22165994

Air pollution and health effects

Question 1 – Why should we monitor air pollution? Chemical composition of fine particles…

Different sources and various components…

Source		Components
Natural	Biomass	Potassium (K)
	Sea spray aerosols	Sodium (Na)
	Coal burning	Aluminium (Al), Selenium (Se), Cobalt (Co), Arsenic (As)
	Soil and road dust	Aluminium (Al), Silicon (Si), Calcium (Ca)
	Volcanic dust particles and wild land fire particles	Potassium (K), Zinc (Zn), Lead (Pb)
Anthropogenic	Diesel, petrol and coal combustion	Elemental carbon (EC), Sulfates (SO_4)
	Oil burning	Vanadium (V), Nickel (Ni), Manganese (Mn), Iron (Fe)) Organic carbon (OC)
	Heavy industry—high temperature combustion	Iron (Fe), Zinc (Zn), Copper (Cu), Lead (Pb), Nitrates (NO_3)
	Fertilizer and animal husbandry	Ammonium (NH_4)
	Volatile organic compound (VOC) emissions	Benzene, Ethylene glycol, Formaldehyde, Methylene chloride, Tetrachloroethylene, Toluene, Xylene, and 1,3-Butadiene

Source: Thangavel et al., Recent Insights into Particulate Matter (PM2.5)-Mediated Toxicity in Humans: An Overview, Int J Environ Res Public Health. 2022 Jun; 19(12): 7511.

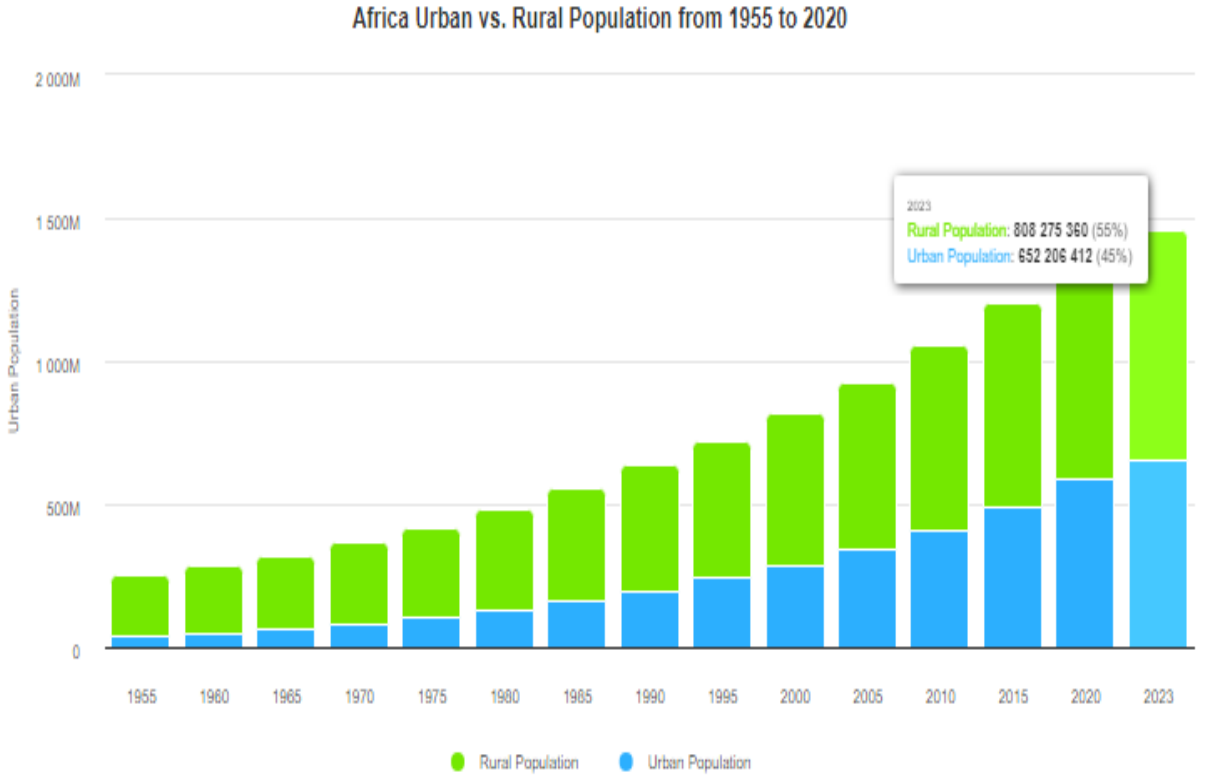
Part 7

What's the situation in Africa?

The context

Growing population of Africa from 1955 to 2023

(Source: https://www.worldometers.info/demographics/demographics-of-africa/)

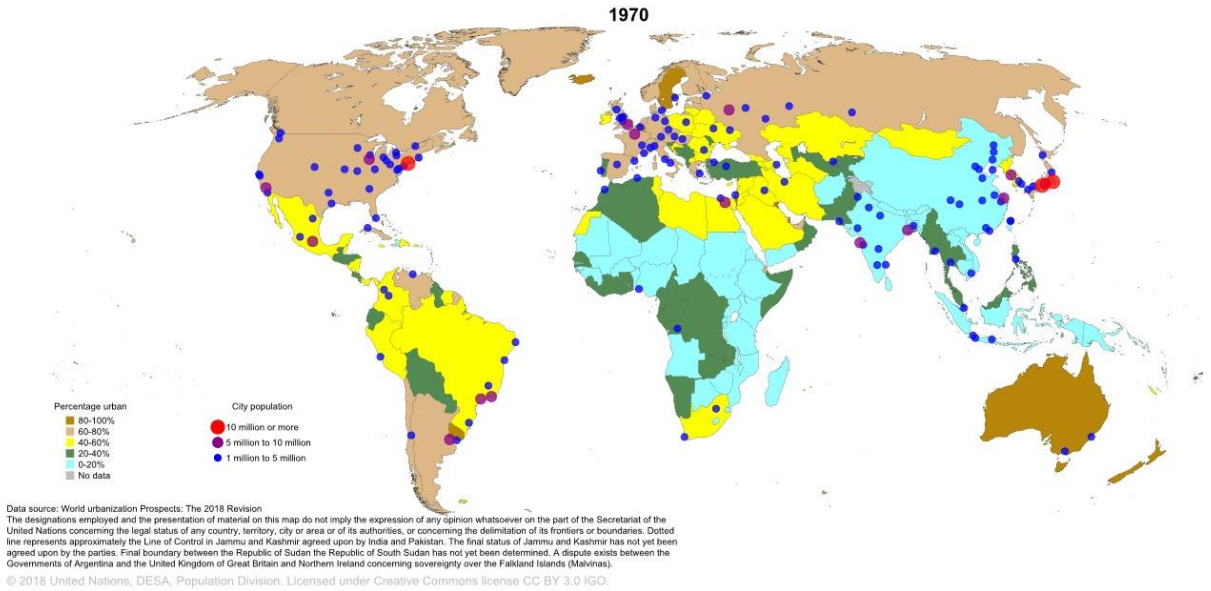


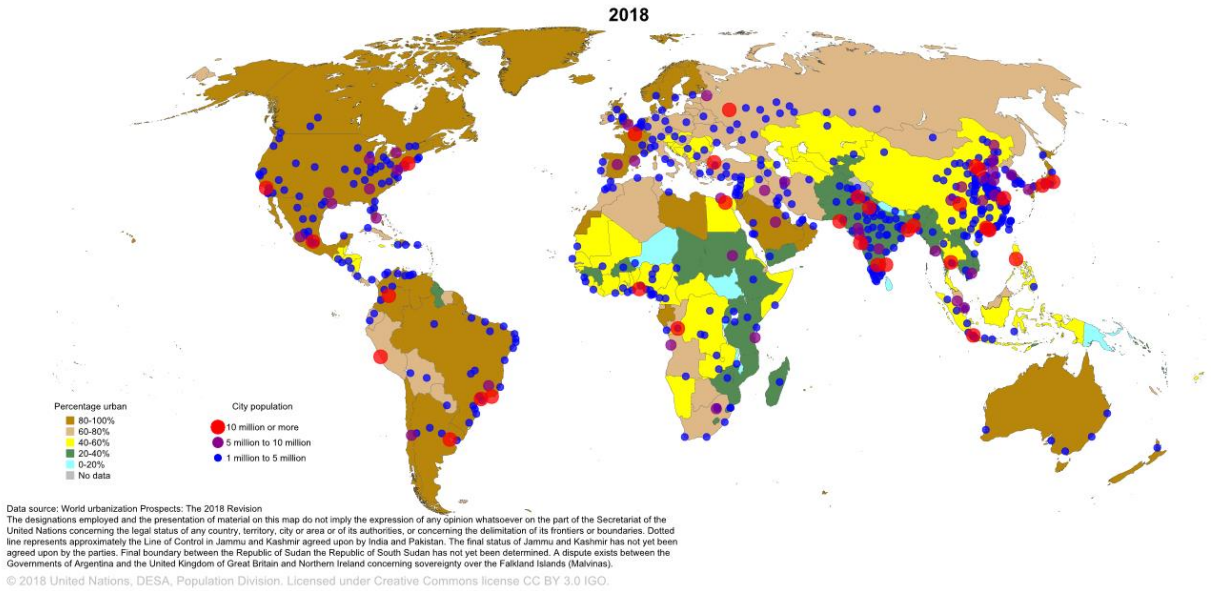
The African population is growing rapidly (~2.3% p.a) and ~18% of the world population.

The context

Percentage urban and urban agglomerations by size class

Source: https://population.un.org/wup/Maps/





The context

Growing population of Africa from 1955 to 2023 ~2.3% per annum

High urbanization rate ~4.5% per annum (fast growing cities)

Demands: growing needs in all sectors!

- Education & health,
- Energy & water supply,
- Food supply & waste management,
- mobility & transport…

Adverse effects

- Pressure on resources and the environment
- Deteriorating air quality with adverse consequences

Air pollution in the news

Question 1 – An emerging crisis in African cities?
Public media – the role they play

Air Pollution in South Africa: The Silent Killer That Demands Urgent Action

Joan Igamba
22 November 2023 • 0 Comments

ARAB NEWS

SAUDI ARABIA | MIDDLE EAST | WORLD | BUSINESS | MEDIA | LIFESTYLE | OPINION

LATEST NEWS / Sport — Argentina reach Copa America semifinals, beating Ecuador 4-2 on penalty kicks afte

Home / Is Cairo the world's most polluted city? 'No' says the government, 'probably' say its suffering residents

Is Cairo the world's most polluted city? 'No' says the government, 'probably' say its suffering residents

'There is no escape': Nairobi's air pollution sparks Africa health warning

Pollution in the Kenyan capital is 'beyond imagination'. With Africa's predicted rise in population – and a constant stream of dirty secondhand cars from Europe and Japan – this urban health crisis could kill 1.5 million within a generation

NATURE AND ENVIRONMENT | AFRICA

Africa's fight against urban air pollution

Martina Schwikowski | Ngala Killian Chimtom
04/06/2024

Cities are growing rapidly in Africa, but many countries lack effective technologies to measure the associated air pollution. Experts are finding new ways to track air quality in hopes of reducing health risks.

! Issues related to air pollution in africa are reported by foreign media.

Why little interest from local media?

7.1 Indoor air pollution

Indoor air pollution

Question 1 – Are our homes polluted?
Indoor sources and outdoor infiltration…

Several pollutants sources found indoor…

Indoor pollutants and sources

- Fuel combustion
- Cooking activities
- Building Materials and Furnishings
- Excess moisture
- Tobacco Products
- Incense Smoke
- Insecticides
- Household Cleaning Products
- Type of Flooring
- Pets and Animals
- Outdoor air
- …

IEQ (Indoor environmental quality)
PM2.5: <15 µg/m^3 (WHO)
PM10: <15 µg/m^3 (WHO)
Temperature : ~25 °C
Relative humidity : 40-60 %
Carbone dioxide : <1000 ppm

Indoor air pollution

Question 1 – Are our homes polluted?
In-kitchen pollution…

Biomass combustion: a leading cause of indoor pollution

1. Cooking activities generate atmospheric pollutants…
2. Most Africans use biomass in the form of firewood, with inefficient ovens. The three-stones fire is the most popular…
3. Other forms of biomass: charcoal, sawdust, biogas, biochar…
4. Biomass is the primary fuel because of its availability and cost. It is the cheapest fuel…
5. On market or along the streets there are some cooking activities…

Indoor air pollution

Question 1 – Are our homes polluted?
In-kitchen pollution…

Solutions or alternatives to polluting biomass and inefficient ovens..

1. Charcoal: better (energy & weight) than fired wood
2. Biogas: clean fuel, but difficult to implement.
3. Biochar: being progressively implemented
4. Butane and propane or (LPG) : clean fuel but the cost and availability are issues.
5. Kerosene: pollute more than gas
6. Improved biomass cooking stoves:

Indoor air pollution

Question 1 – Are our homes polluted?
In-kitchen pollution…

Other factors

the way you cook , what you cook and the duration matter…

Are you cooking indoor or outdoor?

Street food is common in many places…
If you are cooking out, you are less exposed…
Cooking indoor needs appropriate ventilation conditions…

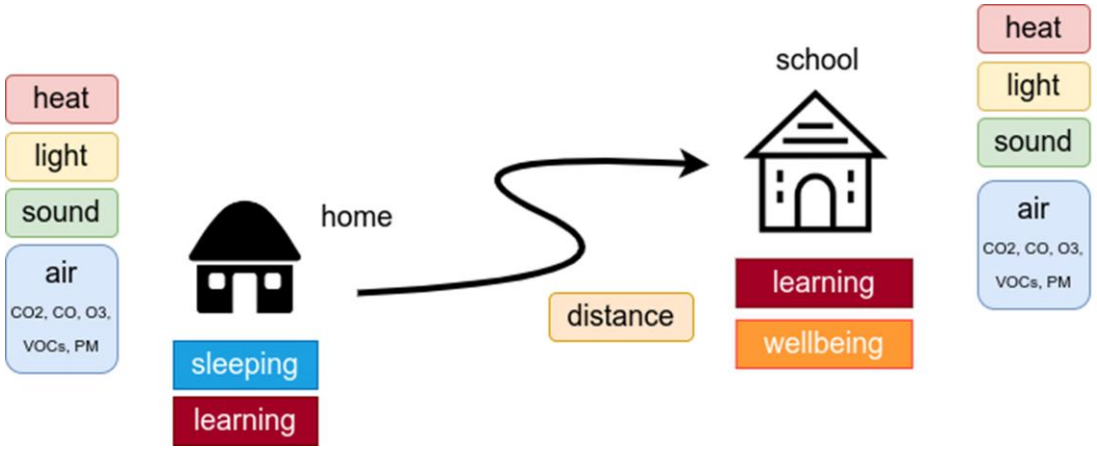
Indoor air pollution

Question 2 – Are our schools, offices, and hospitals polluted? Indoor sources and outdoor infiltration…

The comfort in our buildings is to be investigated, very few work till now…

Poor air quality impacts negatively the productivity …

Children and students are exposed but very research on this issue…



Indoor air pollution

Question 3 – Is our vehicle polluted?
Comfort in transport, traffic, mass transportation…

The air quality in our car deteriorate, esp. if stuck in the traffic or overcrowded buses…

SENEGO

ACCUEIL ACTUALITÉS POLITIQUE JUSTICE CÉLÉBRITÉS

Accueil » Actualités » Dakar Dem Dikk et la forte canicule, les passagers s'évanouissent…

Dakar Dem Dikk et la forte canicule, les passagers s'évanouissent…

El Malick SECK 29 mai 2024 à 11:09

Dakar Dem Dikk and the strong heatwave, the passengers faint… (translation)

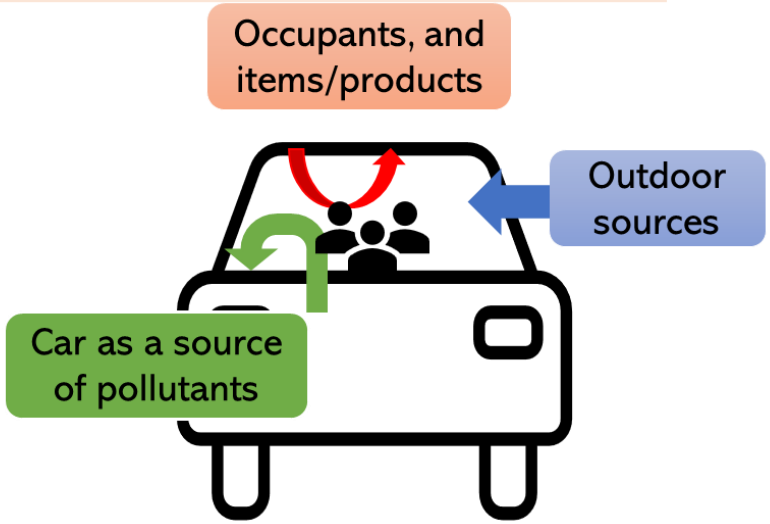
Indoor air pollution

Question 3 – Is our vehicle polluted?
Comfort in transport, traffic, mass transportation…

Various pollutants from different origins flow in the cabin… and the situation can become critical.

- Occupants : behaviours, and even the breath (level of CO2 in the cabin)
- products brought in the vehicle (cosmetics, deodorants, food, papers…)
- tobacco smoke contains particles and chemicals

- Cars are assembled from materials (plastics, fibers, adhesives, paints, and lubricants) may release VOCs into the cabin over time.
- exhaust fumes contain dangerous pollutants
- Tires degradation
- Oil pipes, brakes…

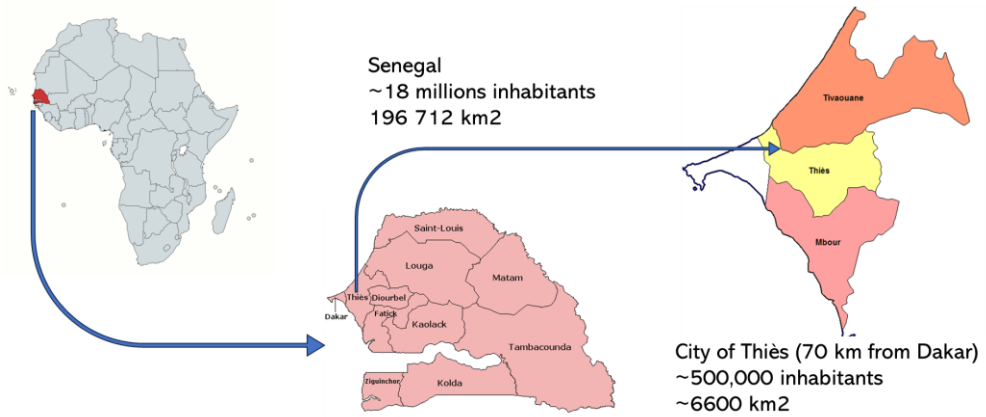


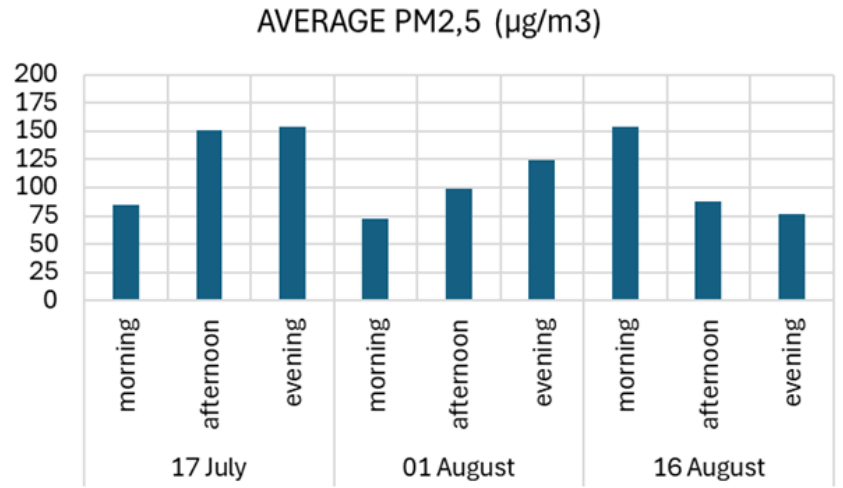
Outdoor sources
- climatic conditions (temperature, dust storms…)
- roadside activities (construction works, burning of waste, etc.),
- exhaust fumes from other cars…
- Road and tires degradation
- Construction works
- Waste degradation

Indoor air pollution

Question 3 – Is our vehicle polluted?
Comfort in transport, traffic, mass transportation…

The indoor environmental quality (IEQ) in buses in the city of thiès, Senegal… (on-going study)





7.2 Ambient air pollution

Industries, mines, construction works

Question 1 – What are the industrial sources? Factories, power plants, mines…

Industrial air pollution is when factories and mines release harmful substances into the air.

Mines release particles that pollute the air, soil and water in remote areas…

Karpowership plants in coastal areas…

Fuel oil fired power plants …

Coal fired power plants in South Africa…

SÉNÉGAL : une usine de farine de poissons pollue l'air dans la commune de Gandiol

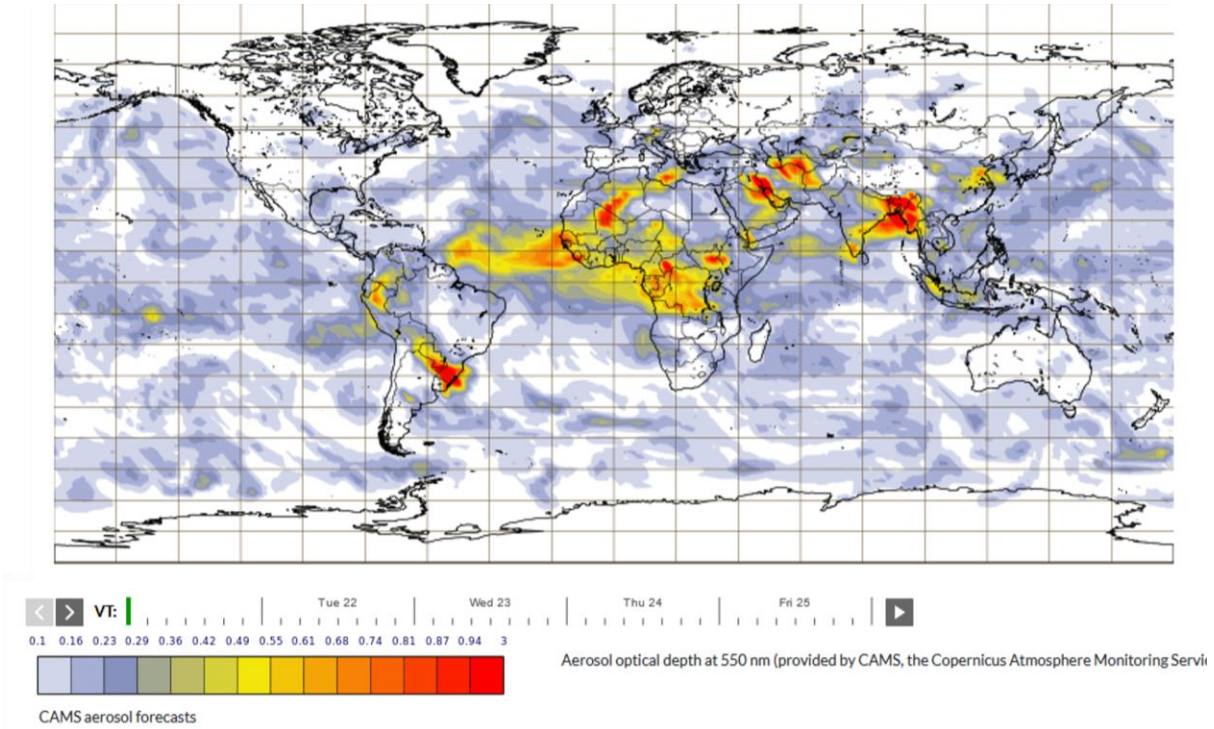
Par **Boris Ngounou** - Publié le 20 novembre 2019 / Modifié le 20 novembre 2019

Industries, mines, construction works

Question 2 – What is Sahara dust?
Dust storm from the Sahara desert…

Sahara dust…

- Saharan dust (also African dust, yellow dust, or Sahara dust storms) is an aeolian mineral dust from the Sahara, the largest hot desert in the world.
- The desert spans just over 9 million square kilometers, from the Atlantic Ocean to the Red Sea, from the Mediterranean sea to the Niger River valley and the Sudan region in the south



Feb. 21, 2022.
The Copernicus Atmosphere Monitoring Service (CAMS) tracks dust transport from the Sahara Desert and has been closely tracking episodes of dust originating from the Sahara Desert since mid-January 2022.

Road transport

Question 1 – What is traffic related pollution?
All modes pollute: ships, cars, railways, aircrafts…

TRAP is due to several factors:

1. low road density and traffic congestion due to lack of human resources and funds
2. high proportion of unpaved, poorly designed or/and maintained
3. lack of refineries and massive imports of low-quality fossil fuels (petrol & diesel)
4. fast growing fleet due to surge in imports of second-hand 4-w vehicles and motor bikes, poorly maintained
5. Road and tire degradation

7.3 Air quality monitoring

Air quality monitoring in Africa

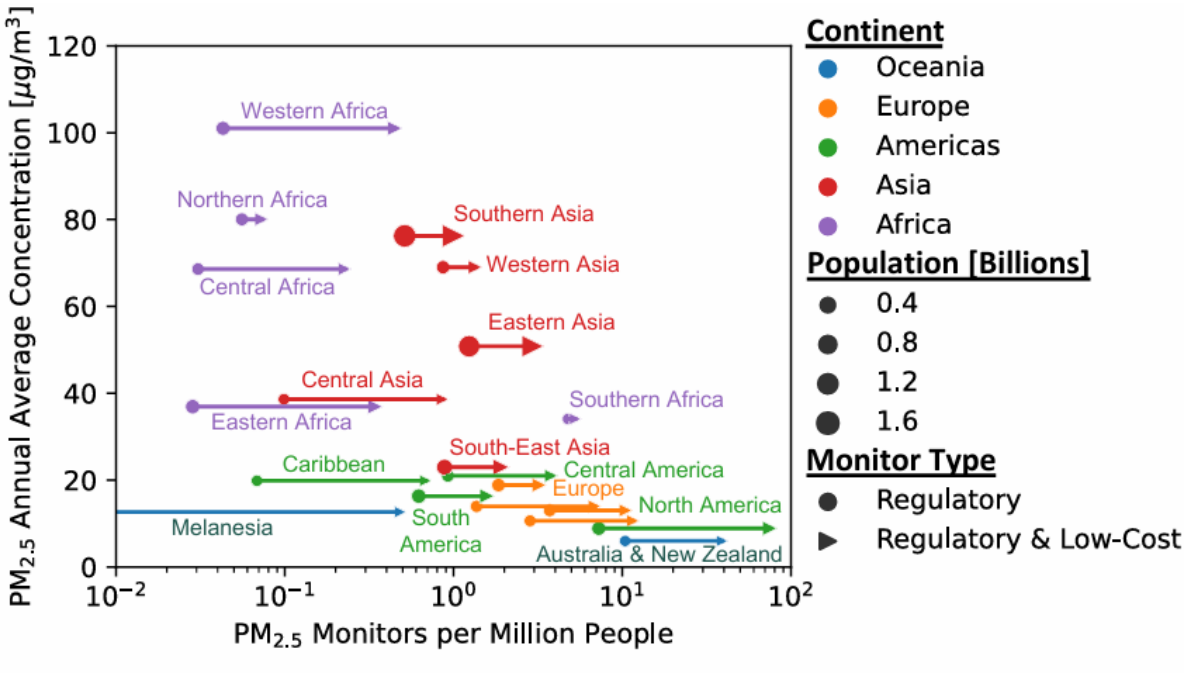
Question 1 – What issues are surrounding air quality monitoring in Africa? Infrastructure, funds, human resources…

Issues surrounding air quality monitoring in Africa:

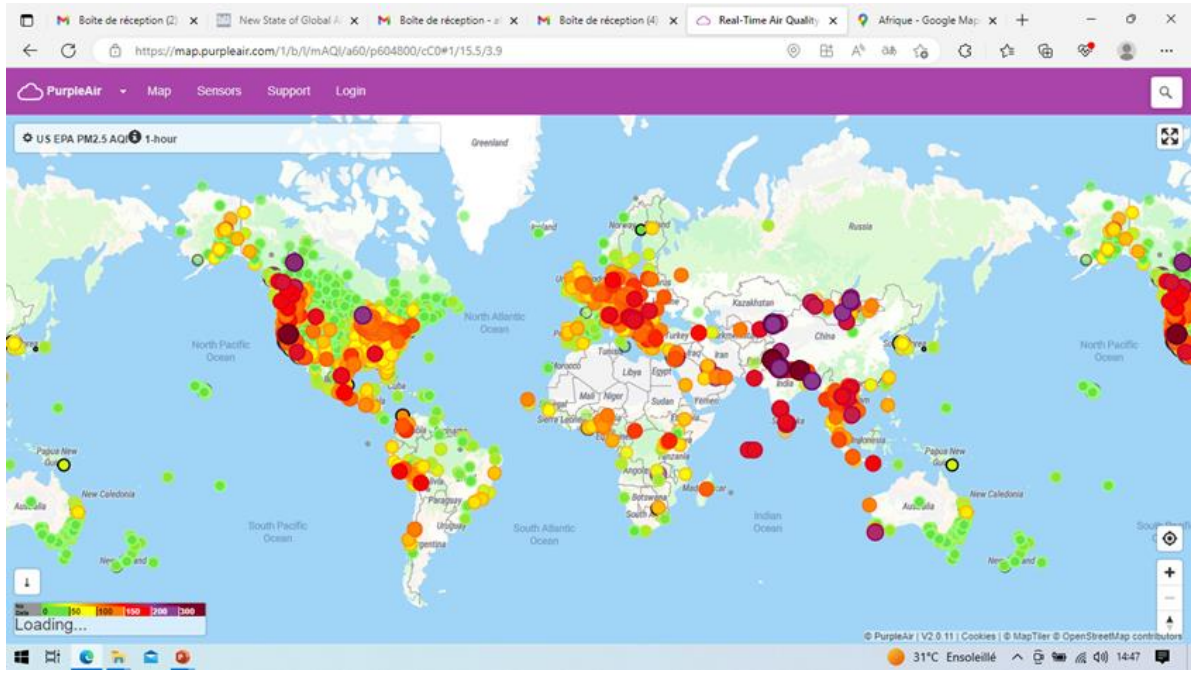
- Low public awareness among population
- Air quality data are scarce
- Very few monitors in most places
- High upfront cost of reference monitors
- Lack of human and financial resources
- Lack of collaboration in some places
- No strict regulation
- Law enforcement

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Lack of air quality data…



The Global Air Quality Data Gap



Global map of PurpleAir sensors

Source: Malings et al. (2022) Forecasting with the GEOS-CF System and Other NASA Resources to Support Air Quality Management. Proceedings of the International Conference on Air Quality in Africa.

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
New opportunities with small IoT-based air sensors…

Handheld portable air quality monitors are interesting for personal exposure assessment…

airSniffler - USD 70
NO2, ozone, VOCs, ambient temperature, relative humidity, and UV
Source: https://www.airsniffler.com/

Atmotube PRO – USD 150
PM (PM1, PM2.5,
and PM10 pollutants, VOCs,
Temperature, humidity and barometric pressure)
Source: https://atmotube.com/

Eco-DEYI Air Quality Meter
$PM_{0.3}$ - PM_{10} , 3/6 channels
Cost : EUR 142

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
New opportunities with small IoT-based air sensors…

Clarity NodeS
(USD 1300)

Davis
(USD 300)

Airnote
(USD~150)

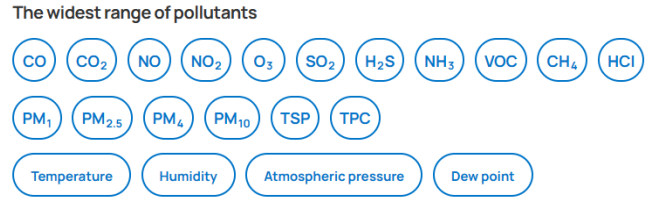
PurpleAir
(USD 300)

Small sensors usually measure one or several air parameters and weather parameters…

AQMesh air quality monitor

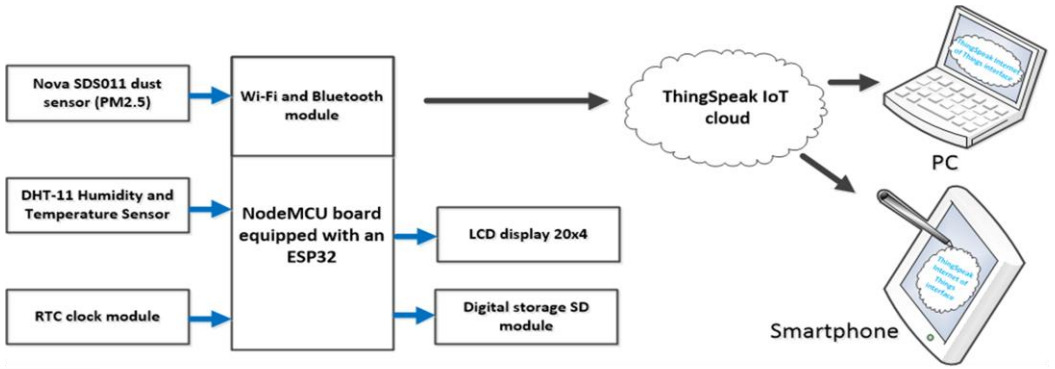
- NO, NO2, O3, CO, SO2, H2S, TVOC and CO2
- PM1, PM2.5, PM10, TPC and TSP (up to 30 µm)

Kunak
(USD > 5,000)



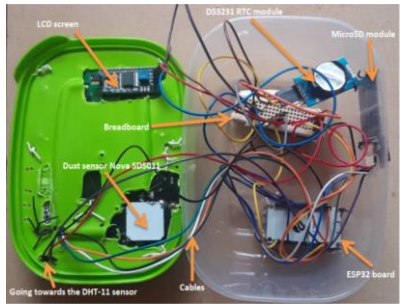
Air quality monitoring in Africa

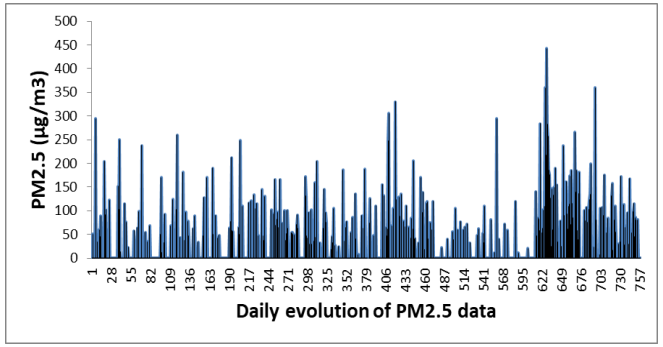
Question 2 – What issues surrounding air quality monitoring in Africa?
New opportunities with small IoT-based air sensors…



ITEMS	Cost (€)
SDS011 sensor	31.10
DHT-11 Sensor	3.05
SD card	3.81
RTC module	3.81
LCD 20x4	6.10
SD support	3.81
ESP32	15.24
Jumper	3.05
Box	0.76
Test plate	3.80
TOTAL	74.53

Buy or design your own air quality monitor at a low cost…Need knowledge in microelectronics and programming…





Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Need to train researchers on these techniques…

Air quality monitoring in Africa

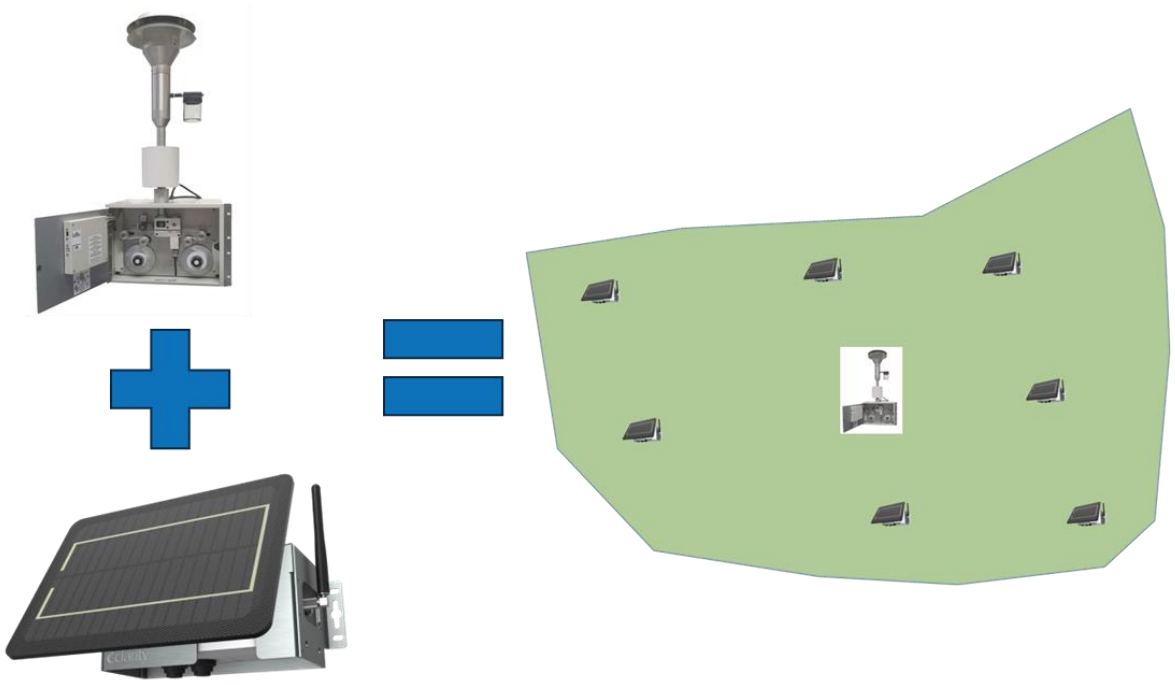
Question 2 – What issues surrounding air quality monitoring in Africa?
Hybrid networks with small IoT-based air sensors…

Hybrid networks for AQ monitoring

Hybrid networks integrate reference grade and small airs sensors:

- Reference monitors are accurate but expensive
- Low-cost air sensors are easy to deploy, cheap but data are questionable
- A combination offers an optimal design

BAM 1020 (USD ~25,000)
Clarity NodeS (USD ~1,200)



Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Need for calibration for small IoT-based air sensors…

- **Small sensors are inaccurate and need calibration… two types: lab calibration vs field calibration.**
- **Field calibration uses co-location of small air sensors with a reference monitor…**

Air quality monitoring in africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Need for hybrid networks and calibration…

Table 2. Comparability of LCS for indoor measurements and reference instrumentation.

Concept	Low-cost sensor	Reference-grade instrument
Cost (indicative range)	100–2500 €	10000–75000 €
Operating cost	Relatively inexpensive	Expensive
Location	Portable or fixed (also organized in sensors network)	Typically fixed location
Staff Training	Little or none (monitor) Some training (research)	Some training (monitor) High training (instrument)
Analysis skills	None (if data are provided by the sensor system) High (research)	None (monitor) High skills (instrument)
Data quality	Depends on sensor and analysis procedure. Not complying with AQ directive (Directive 2008/50/EC)	Known and stable. Repeatable and reliable, complying with AQ directive (Directive 2008/50/EC)
Selectivity	May suffer from interferences with environmental parameters and other contaminants	High selectivity
Lifetime	1–2 years + drift	> 10 years
Development degree	Research	Advanced
Accessibility to data	In real-time	In real-time (monitor) Usually not in real-time (instrument)
Area coverage	High	Low
IoT applications	Yes	No
For regulatory monitoring	No	Yes
End user	Research, policymakers, building managers	Local government, citizens

Source: Milagros Ródenas García, et al., (2022) Review of low-cost sensors for indoor air quality: Features and applications, Applied Spectroscopy Reviews, 57:9-10, 747-779, DOI: 10.1080/05704928.2022.2085734

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Need for standards and certification for small air sensors…

The number of small air sensors available on the market and users are demanding standard to compare them…

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

No standard but few performance evaluation centres…

- Air quality sensors performance evaluation center

Site: http://www.aqmd.gov/aq-spec/home

- Airparif

Site: https://www.airparif.fr

- Air quality Sensor Evaluation and Training centre for West Africa

Site: https://www.afriset.org/

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Lab performance assessment for small air sensors…

Lab performance evaluation using an aerosol chamber

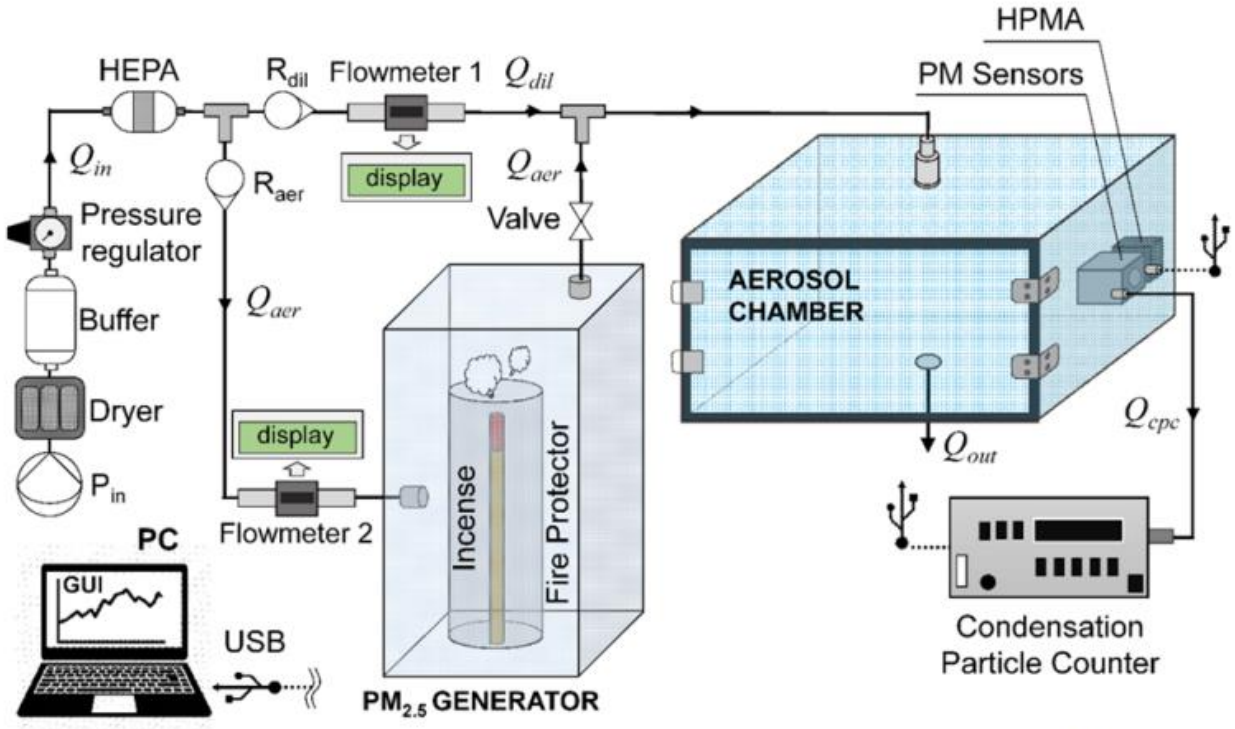


Fig. 1. Experimental setup to characterize the aerosol chamber and evaluate the PM sensors.

Source: Hapidin et al., Aerosol Chamber Characterization for Commercial Particulate Matter (PM) Sensor Evaluation, Aerosol and Air Quality Research, 19: 181–194, 2019

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Calibration models for small air sensors…

Models

- Linear and quadratic regression models
- Gaussian process models
- Clustering model
- Artificial neural network model
- Hybrid random forest and linear regression models

Linear regression models

- Main advantages:
- ease of implementation and calibration, as well as their ability to be readily interpreted.
- Main disadvantage:
- inability to compute complicated relationships between input and output which are beyond that of a second-order polynomial.

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Calibration models for small air sensors…

Univariate linear regression models

The general equation :

$$y = a_0 + a_1 x + \epsilon$$

y : dependent variable (reference monitor response)

x : independent variable (one of the sensor outputs, eg mass concentration or number of particles for size bins or bins combination)

ε is a random term. Regression coefficients: a_0 (the intercept) and a_1 (the slope) estimated by ordinary least squares procedure.

Multivariate linear regression models

Linear additive models with several independent variables

The general equation :

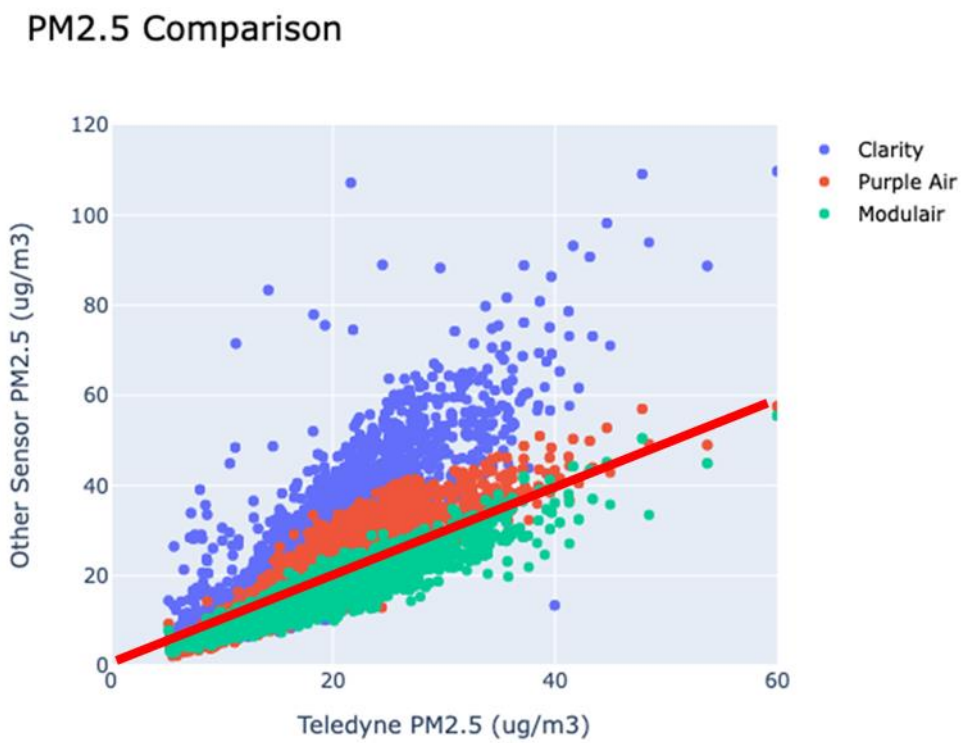
$$y = a_0 + a_1 x_1 + a_2 x_2 + \cdots + \epsilon$$

where k is the number of independent variables ($x_1 \ldots x_k$) and $a_0 \ldots a_k$ are the regression coefficients.

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Calibration models for small air sensors…

Data analysis and visualization



Performance metrics: Is your sensor good?

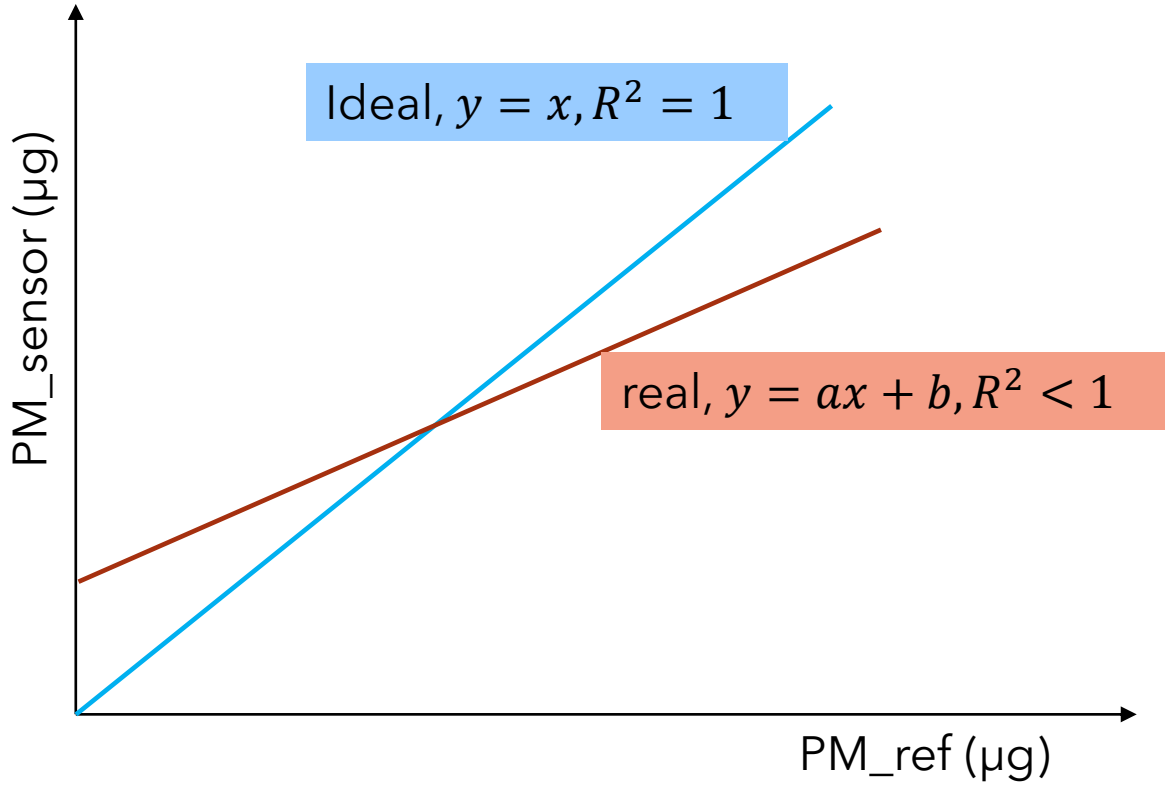
Use tools to perform statistical analysis:

- Coefficient of correlation (r)
- Coefficient of determination (R^2)
- Standard deviation (SD)
- Coefficient of variation (CV)
- Root mean square error (RMSE)
- Mean absolute error (MAE)
- …

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Calibration models for small air sensors…

Simple linear regression



Performance metrics: Is your sensor good?

- Slope (U.S. EPA slope of 1.0 ± 0.35 for SLR.)
- Intercept (U.S. EPA: range of [−5 ; +5] for SLR)
- Coefficient of determination (U.S. EPA: $R^2 > 0.7$)

$$R^2 = 1 - \frac{\sum_i^N (y_i - x_i)^2}{\sum_i^N (y_i - y_{moy})^2}$$

- Root Mean Square Error - RMSE (U.S. EPA: target $RMSE \leq 7 \frac{\mu g}{m^3}$.)

$$RMSE = \sqrt{\frac{\sum_i^N (y_i - x_i)^2}{N}}$$

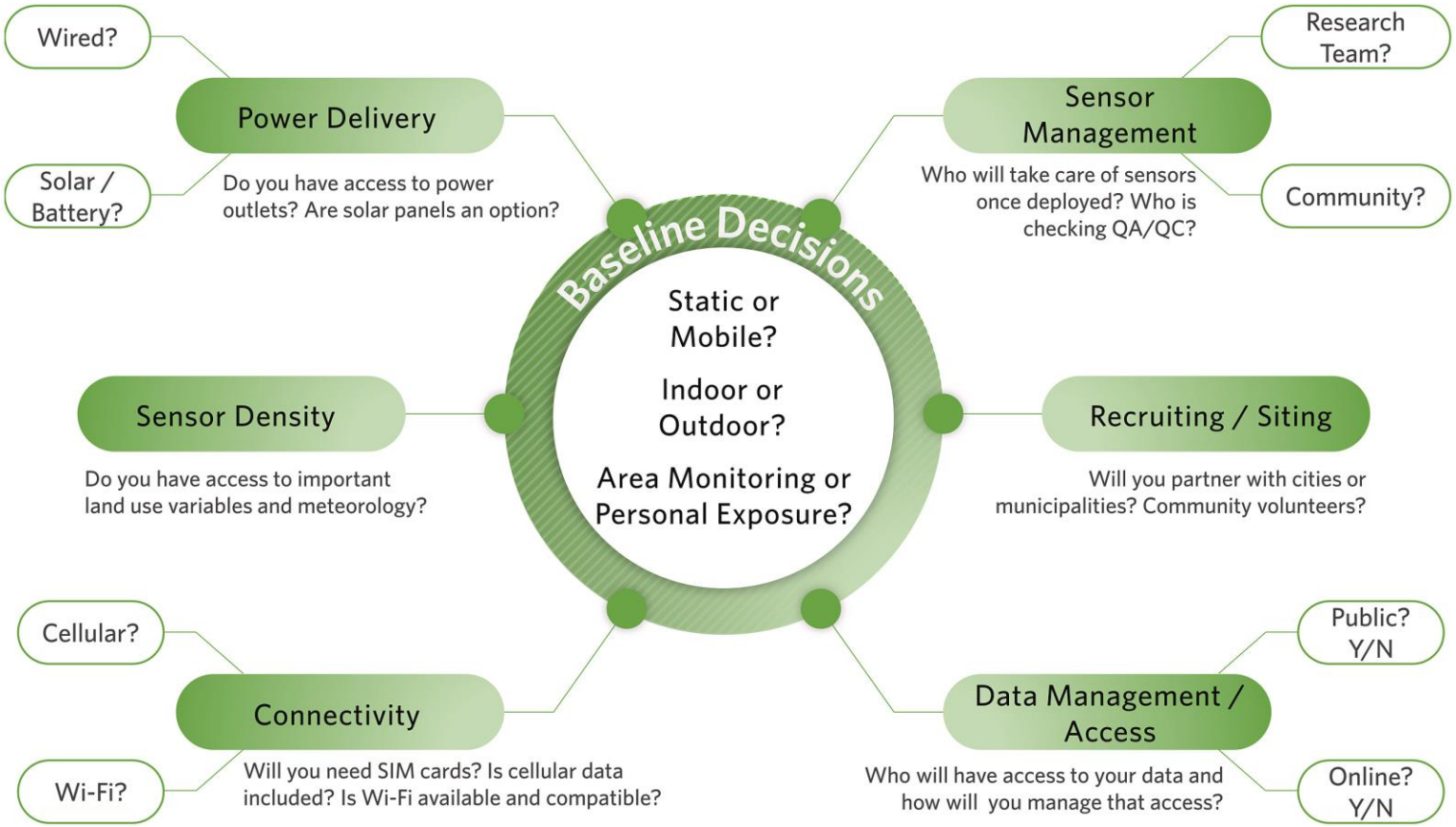
- Mean absolute error (MAE)

$$MAE = \frac{\sum_i^N |y_i - x_i|}{N}$$

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
Prerequisites for the deployment of small air sensors…

A number of questions need to be addressed before you deploy your sensors …



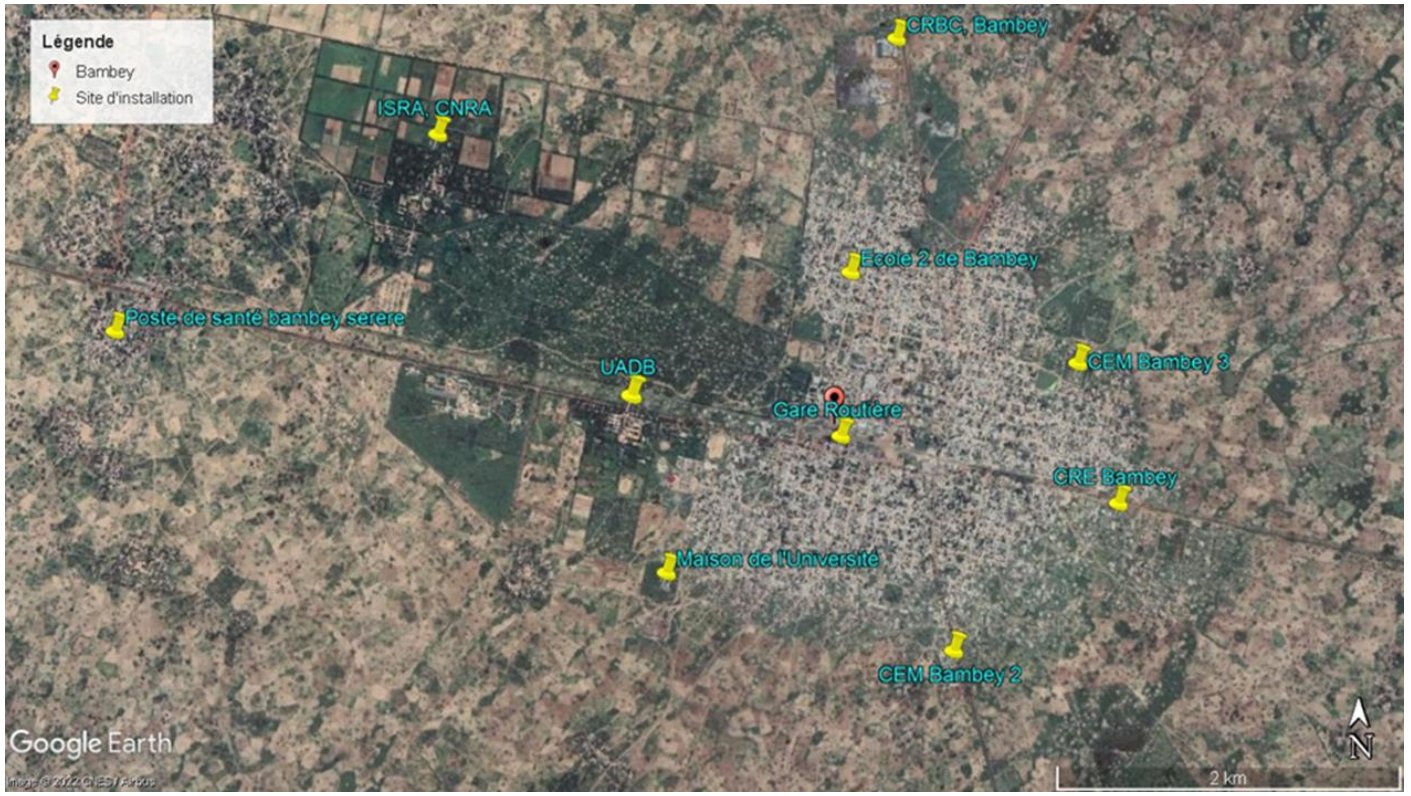
Source: Zimmermann, 2022

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
The deployment of small air sensors…

Case of an area study…

- Sensors designed or selected
- Sensors are calibrated,
- Area is selected,
- Locations of sensors known,
- Data management system,
- Choose the monitoring period an start
- Maintenance and security,
- Frequent look at the data and quality check

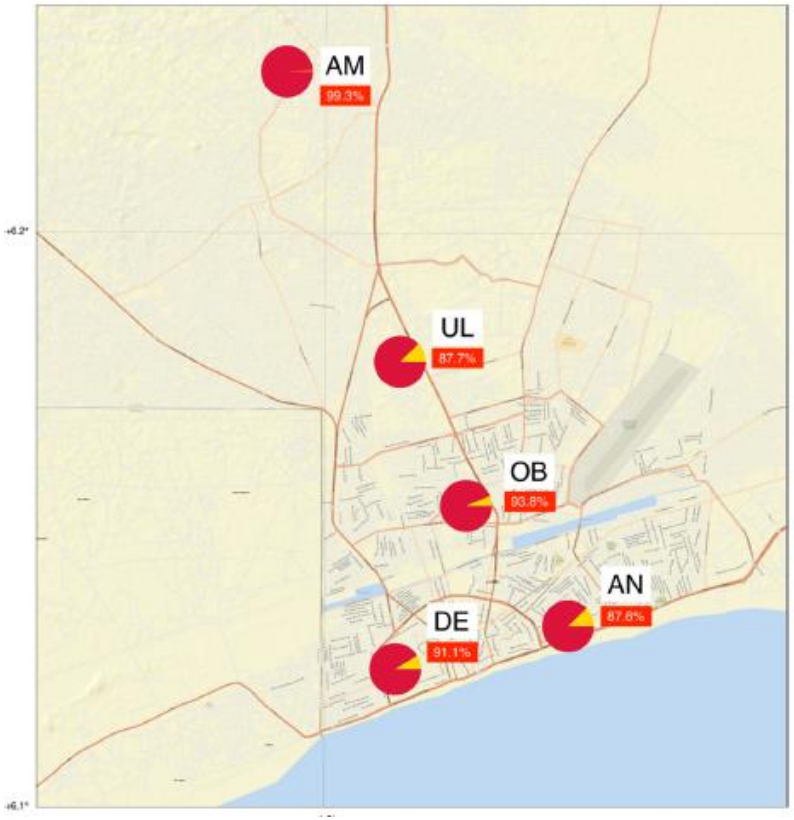


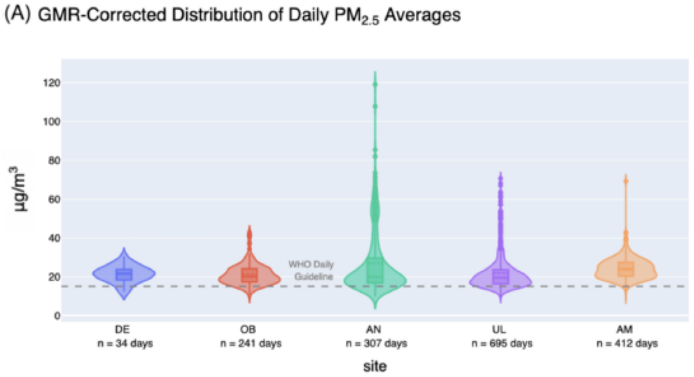
Air quality monitoring in Africa

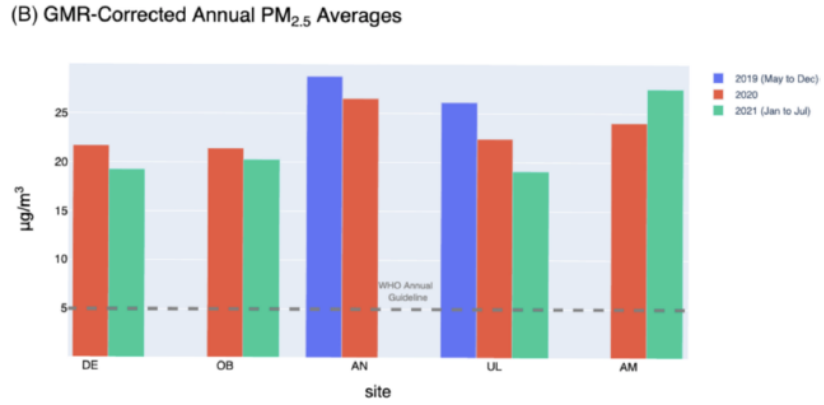
Question 2 – What issues surrounding air quality monitoring in Africa?
The deployment of small air sensors…

Case study: Lome, Togo

A few purlpleAir sensors (2019-2021)







Source: Raheja et al. , A Network of Field-Calibrated Low-Cost Sensor Measurements of PM2.5 in Lomé, Togo, Over One to Two Years, ACS Earth Space Chem. 2022, 6, 1011−1021, Doi: https://doi.org/10.1021/acsearthspacechem.1c00391

Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
The deployment of small air sensors…

Case study: Brazzaville (Congo) and Kinshasa (DR Congo)

A few purlpleAir sensors (2018-2020)

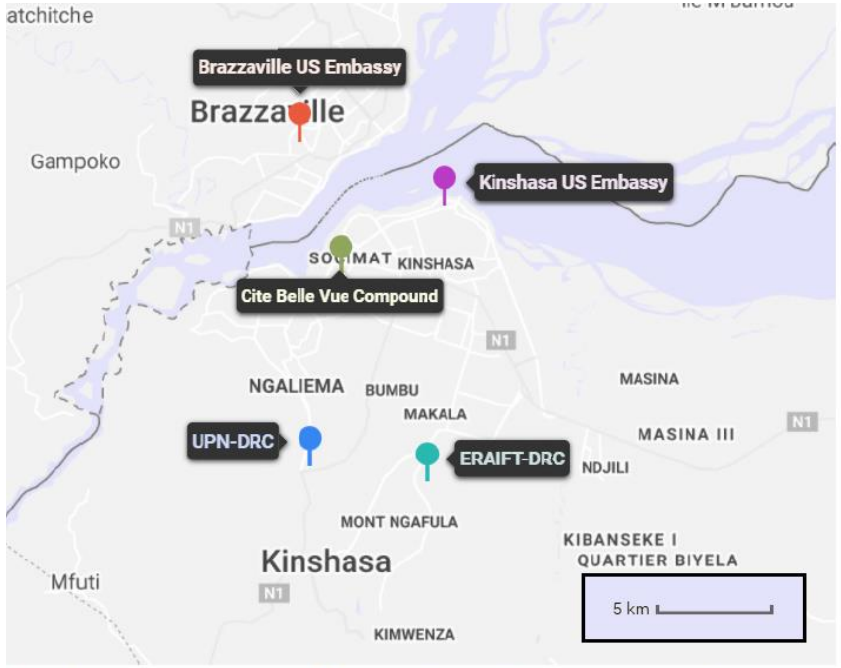


Fig. 1. Map of sensor locations in Kinshasa and Brazzaville. Background map © Google, 2020.

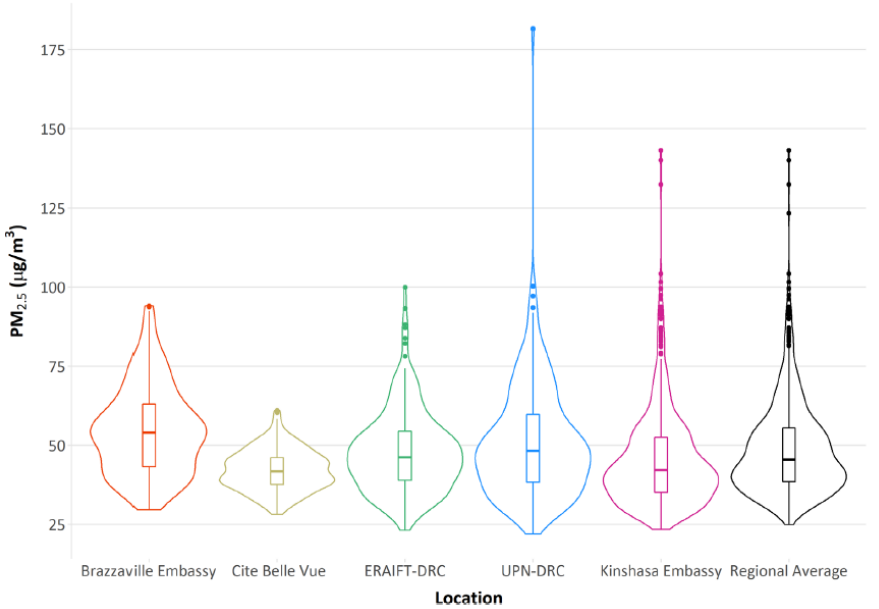


Fig. 7. Violin plot of daily averaged $PM_{2.5}$ values for the entire dataset at each location and for the site-wide average. Boxes represent median and interquartile range.

$$PM_{2.5} = \beta_0 + \beta_1 \times \text{PurpleAir } PM_{2.5} + \beta_2 \times T\,(°C) + \beta_3 \times RH\,(\%)$$

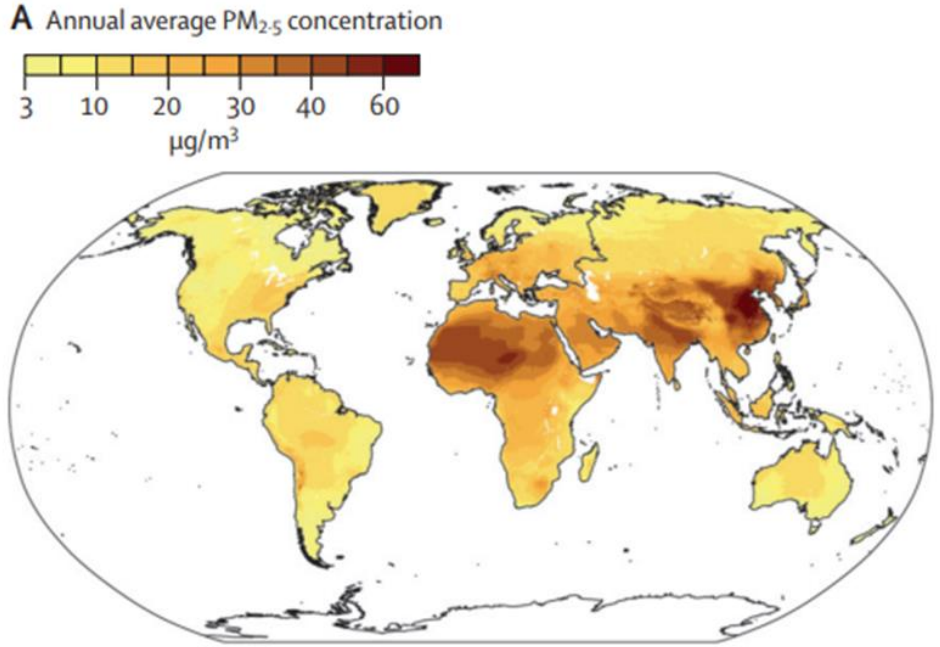
Source: McFarlane et al., (2021). First Measurements of Ambient PM2.5 in Kinshasa, Democratic Republic of Congo and Brazzaville, Republic of Congo Using Field-calibrated Low-cost Sensors. Aerosol Air Qual. Res. 21, 200619. https://doi.org/10.4209/aaqr.200619

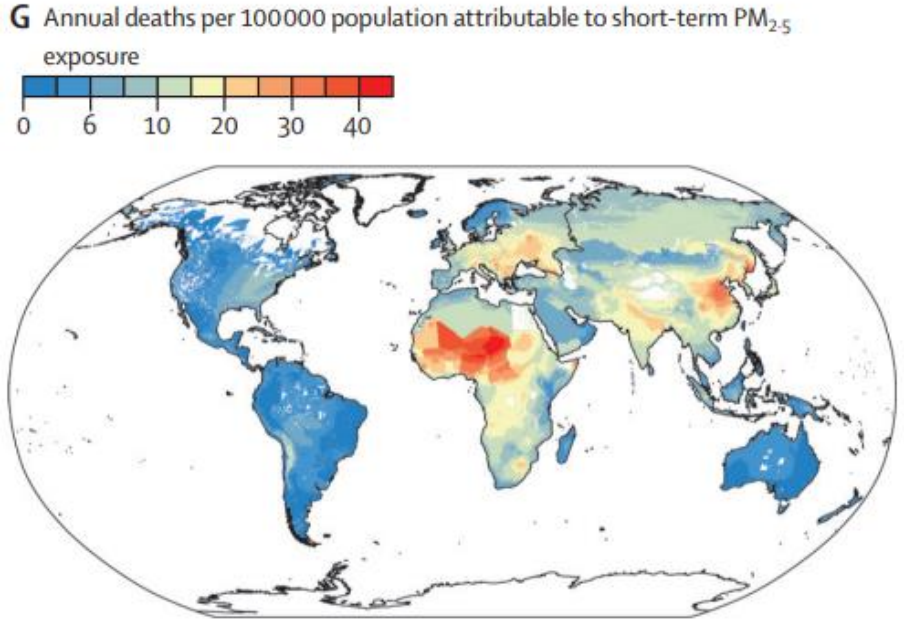
Air quality monitoring in Africa

Question 2 – What issues surrounding air quality monitoring in Africa?
The burden of disease and the need for deployment of small air sensors…

Short-term exposure (hours to days) to PM2·5 contributes a substantial global mortality burden, particularly in Asia and Africa, as well as in global urban areas.

Approximately 1 million (95% CI 690 000–1·3 million) premature deaths per year





Source: Yu et al., Estimates of global mortality burden associated with short-term exposure to fine particulate matter (PM2·5), The Lanceth the Planetary Health, vol. 8, issue3, p. 146-155, 2024

7.4 Efforts being done...

Collaboration

Question 1 – What collaboration in Africa?
Most of the work are done in collaboration with the North…

TROPOS
Leibniz Institute for Tropospheric Research

HEI HEALTH EFFECTS INSTITUTE

NASA

COLUMBIA CLIMATE SCHOOL
LAMONT-DOHERTY EARTH OBSERVATORY

Laero
Laboratoire d'Aérologie

NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE UNIVERSITY

UADB
UNIVERSITE ALIOUNE DIOP de BAMBEY

UNIVERSITY OF GHANA

UNIVERSIDADE CABO VERDE
uniCV

airqo
Breathe Clean

MAKERERE UNIVERSITY

POPULI SAPIENTIA POPULO

UNIVERSITY OF LAGOS
IN DEED AND IN TRUTH

MAKERERE UNIVERSITY

Networks

Question 2 – Any networks or groups in Africa?
A few groups exist…

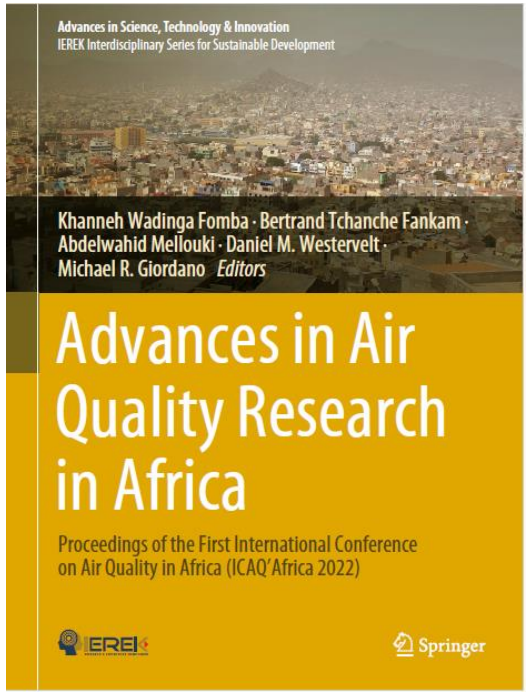
More networks or groups and events

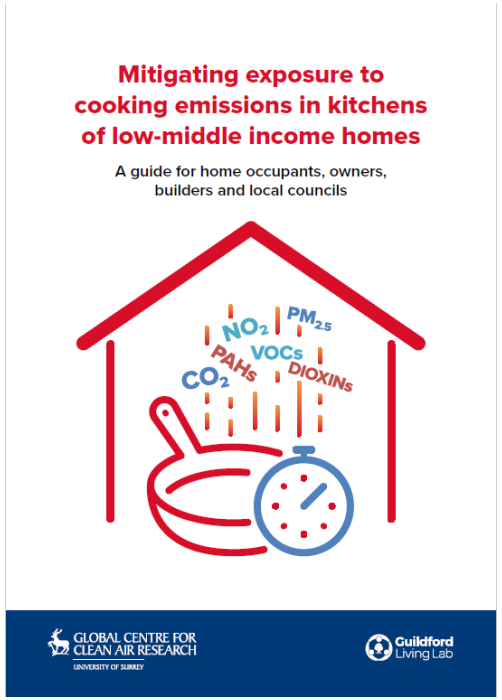
- ASAQ (African Society for Air Quality)
- ANGA (African Group on Atmopheric Science)
- AirQo
- The Clean Air Monitoring and Solutions Network (CAMS-Net)
- AfriqAir

- **Conferences, workshops, trainings, forums, webinars**
- First international Conference on Air Quality in Africa (11-14 October 2022, ICAQ'Africa2022)
- Follow up workshop on a pilot design for air quality in Africa, (17-19 Jan 2023, Kigali - Rwanda)
- AfriqAir and CAMS-Net General Meeting (7-10 March 2023, Kigali - Rwanda)
- Workshop on Air Pollution and its Health Impacts in Africa, 28th to 30th June 2023, Kigali- Rwanda
- Air sensors international conference, October 17-19, 2023, Accra – Ghana (ASIC Ghana)
- International workshop on Air quality and IoT-based air sensors, 13-15 march 2024, Bambey – Senegal.

More readings…

Question 3 – Publications on air quality monitoring in Africa?
Increasing number of papers, reports…





Conclusion…

- As Africa is developing, we expect a continuous deterioration of the air quality …

- Efforts are needed at all levels to change the trend…

- Air pollution is a fast growing field of research where we lack expertise in Africa while a lot is still to be investigated…

The Way to Get Started is to Quit Talking and Begin Doing.

[*Walt Disney*]

Thank you for tour attention.

Q&A?