30th November 2020

AFRICA: citizen science using sensor data to tackle deadly environmental dangers by producing actionable information

Collaborators: CfA's (Code for Africa) civic data communities and infomediary initiatives.

Sustainable Development Goals Covered

SDG 3.9:

By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination

SDG 11.6:

By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

SDG 12.4:

By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

Countries: Kenya, Uganda, Nigeria, Tanzania

Data Types:

Time Series Data

Technologies:

Air quality Sensors monitoring Particulate Matter 2.5 and Particulate Matter 10

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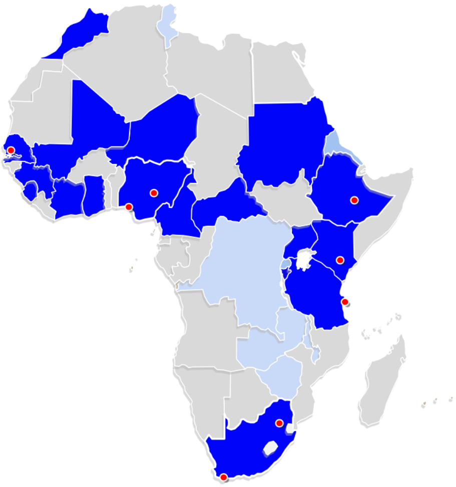
About

Code for Africa (CfA) is the continent's largest non-profit network of indigenous civic technology and open data labs, with full-time staff in 20 African countries in Burkina Faso, Burundi, Cameroon, Central African Republic, Côte d'Ivoire, Ethiopia, Ghana, Guinée, Kenya, Morocco, Mali, Niger, Nigeria, Sénégal, Sierra Leone, South Africa, Sudan, Tanzania, Uganda and Zimbabwe.

CfA's labs work to build open source digital democracy and citizen science tools and data that help Africans make better informed decisions about their lives, communities and economies.

Our labs do this by building shared infrastructure such as the continent's largest non-government open data portal, open.AFRICA, along with the commons.AFRICA repository of civic technologies and the continent's largest repository of evidentiary documents at source.AFRICA. CfA also seed-funds, incubates and accelerates initiatives such as Africa's largest civic drone network, africanDRONE, Africa's largest misinformation fighting fact-checking network, PesaCheck, the continent's leading investigative environmental journalism watchdog, the Oxpeckers Centre, the 11 country InfoNile water advocacy network, and the WanaData women data science community.

Most relevant to this study, CfA incubates the sensors.AFRICA citizen science initiative that uses low-cost remote sensing technologies to monitor air, water, sound and radiation.



Project Objective

Air pollution is a fast rising but often invisible public health crisis across Africa that impacts on communities who often don't have the infrastructure or other resources to quickly identify or combat the problem. CfA is therefore conducting ongoing experimentation and research with low-cost technologies that help grassroots communities and civic watchdogs track and analyze, in near real-time, granular data on local air quality in select African countries, including Kenya, Nigeria, South Africa and Tanzania.

CfA has for the purposes of this report worked only with existing available data, drawing on data from citizen science initiatives it seed-funded or otherwise supported in the past, as well as from additional independent projects at development agencies and research institutes elsewhere on the continent. Specifically, this report seeks to provide insights on the following objectives:

1. Identifying the most useful data sources/indicators from existing citizen science sensor networks that may offer potential complementary/comparative air quality insights in the Africa Region to inform the Bank's efforts to realize SDGs 3.9, 11.6, and 12.4

2. Identifying new low-cost citizen science-driven data collection and evaluation methods focused on air quality to help share the Bank's policy development strategies and wider efforts to mitigate impacts of air pollution.

3. Providing comparative analysis of the current low-cost hardware solutions used by citizen science networks to help the Bank evaluate potential synergies or alignment with efforts to monitor air quality by government, and other partners

4. Collating the existing air quality data from citizen science networks, and structuring this into a consolidated private repository that updates in real-time, and is accessible only by the Bank team (adhering to any recommendations by the Bank's Office of Information Security and Access to Information Committee) for granular analysis and review.

Executive Summary

Reliable, up-to-date air quality data is scarce in Africa. There are few official air quality monitoring services on the continent, and the existing citizen science or academic initiatives are fragmented and often sporadically offline.

This report therefore serves as a scoping study for what is missing, as much as what exists. CfA identified **20** substantive citizen science or academic air quality networks on the continent. It also profiled a major United Nations Environmental Program (UNEP) initiative to aggregate both citizen science and official air quality data, as an important additional civic resource.

Only a fraction of these sources however provide access to their data, and even fewer offer open APIs (application program interfaces) for automated access and analysis. CfA was able to use the four available open APIs to aggregate over 19 million data points from 1,085 sensors at 381 nodes across the continent. The resulting data repository is over 13gig in size.

We note in our findings that it is important to note that not all sensors are online at any one time, with many offline for months at a time. Anecdotal feedback indicates that resources are a major constraint in maintaining sensors, and keeping them connected to communication grids.

The most common indicator measured by the sensors in this study is Particulate Matter, primarily PM10 and PM2.5. Some sensors also measure Temperature, Relative Humidity (RH), Noise levels, and GPS location. A small number of networks measure Ozone and PM1.0, but these are not part of our primary focus as their coverage is not extensive. All the networks aggregated into the research repository for this study provide both current and previous data at the respective sites. The four data sources included in the repository are Air QO, OpenAQ (Open Data Durban), Purple Air and sensors.AFRICA. The OpenAQ data had to be scraped, as no API was available.

As indicated in our recommendations, the number of data sources can be substantially increased with fairly modest software engineering support to help citizen science networks develop usable APIs.

Making data more easily accessible has big impacts. Our literature review of citizen science case-studies records how grassroots shantytown communities in Nairobi used data from low-cost air sensors provided by sensors.AFRICA to challenge local factories before the Kenyan Environmental Tribunal, winning official sanctions and protection. We also note how OpenAQ created courseware and education resources to embed their sensors into shantytown schools in South Africa’s KwaZulu Natal province, with teachers and pupils serving as custodians of the hardware and with the data used

by local community activists to lobby for curbs on pollution. The sensors have remained online, long after the project's original funding ended.

The major challenge faced by citizen science pioneers project went further ahead and did a comparative analysis of the different existing low-cost hardware kits within these networks thus identifying the strong points of each network which assist a lot with the data output of the repository.

An interactive courseware and training material on how to develop and use low cost sensors using open source firmware and easily available hardware was also developed.

Some data was brought together and structured in a private repository.

Methodology

Our approach to aggregate data on citizen science initiatives in Africa was done using these methodologies as indicated in the following steps, however, not all the steps were followed due to various challenges.

Step 1: Surveying all current sources for air quality data in Africa on existing global open data portals, on GitHub and on air monitoring websites and reviewing case-studies and methodology used on the African Continent and elsewhere around the world.

Step 2: Deconstructing and analysing the most common low cost sensors hardware kits currently in use by citizens science sensor initiatives in Africa, for side-by-side comparative analysis.

Step 3: Establishing streamlined team-to-team communication channels with the Bank's urban team/partners for immediate feedback and/or inputs.

Step 4: Developing interactive courseware with supporting training material on ways to use low-cost hardware and open source software tools to collect and evaluate new air quality data. We will do this by collating existing courseware for air quality data projects focused on Africa, as well as a number of international best-practice benchmarks, finally followed by testing with citizen science networks on the continent.

Step 5: Consolidating all the insights into a detailed report that captures findings, case studies, and recommendations arising from this research project to inform GP SURR operational teams about possible new low-cost data collection and evaluation methods for air quality in the African Region.

Step 6: Assist the Bank to develop policy notes that highlight key pollution challenges, and their implications for city livability and productivity in Africa. We will do this in response to requests by the Bank team, leveraging input from our university and citizen science networks .

Key Terminologies and Abbreviations

AQ - Air Quality

AQI - Air Quality Index

CH_2O - Formaldehyde

CO - Carbon monoxide

CO_2 - Carbon monoxide

FEM - Federal equivalent method

FRM - Federal reference method

NO_2- Nitrogen Dioxide

0_3 - Ground level Ozone

PM - Particulate Matter

Low cost sensors - LCS

RH - Relative humidity

SO_2 - Sulphur dioxide

TVOC - Total volatile organic compound

US EPA - United States Environmental Protection Agency

US EPA AQI - United States Environmental Protection Agency - Air quality index

Introduction

Citizen science is the involvement of citizens in scientific research and/or knowledge production. Projects that involve citizen scientists are burgeoning, particularly in ecology and the environmental sciences, although the roots of citizen science go back to the very beginnings of modern science itself (Silvertown, J. (2009)[1].

It is through citizen science that low-cost sensors are being deployed to monitor air quality in various parts of the world(R. Piedrahita et al, 2014)[2]. They provide indicative measurements thus also assisting in engaging and raising awareness among citizens (De Souza et al, 2017)[3]. The sensors are affordable, compact and in spite of manufacturers having different calibration methods, they have proven to be moderately accurate (Li er al 2020)[4].

The growing problem of air quality in African Cities needs to be urgently addressed. Unfortunately, faced by an unending list of modern day challenges, most cities do not have this as one of their priority items and thus lack air quality monitoring systems (Desouza et al, 2017)[5]. Low cost sensors are proving to have the potential of bridging this gap. However, with a growing number of low cost sensors on the continent, it is important that only those that perform well in the conditions of the region are promoted (Amegah, 2018)[6].

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[1] Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, *24*(9), 467–471. https://doi.org/10.1016/j.tree.2009.03.017

[2] Piedrahital, R. (2014). The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. *Atmospheric Measurement Techniques*, 3325–3336. https://doi.org/10.5194/amt-7-3325-2014

[3] deSouza, P. (2017). A Nairobi experiment in using low cost air quality monitors. *Clean Air Journal*, *27*(2), 12–42. https://doi.org/10.17159/2410-972x/2017/v27n2a6)

[4] Li, J., Mattewal, S. K., Patel, S., & Biswas, P. (2020). Evaluation of Nine Low-cost-sensor-based Particulate Matter Monitors. *Aerosol and Air Quality Research*, *20*(2), 254–270. https://doi.org/10.4209/aaqr.2018.12.0485

[5] deSouza, P. (2017). A Nairobi experiment in using low cost air quality monitors. *Clean Air Journal*, *27*(2), 12–42. https://doi.org/10.17159/2410-972x/2017/v27n2a6

[6] Amegah, A. K. (2018). Proliferation of low-cost sensors. What prospects for air pollution epidemiologic research in Sub-Saharan Africa? *Environmental Pollution*, *241*, 1132–1137. https://doi.org/10.1016/j.envpol.2018.06.044

Air Quality Index (AQI) Basics

The US AQI is like a yardstick that shows the level of air pollution in a place. Higher values represent more hazardous environments while lower values are indicators of good air quality.

The US AQI has six categories which correspond to different levels of health concern.

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Source: Airnow.gov

Major Air Pollutants

Criteria Air Pollutants - while there are many environmental pollutants plaguing Africa, US EPA suggests six key pollutants to watch. Hereafter referred to as criteria pollutants. For this report, I.e from an Afrocentric perspective but also from a global health perspective, we will focus on the these six pollutants:

1. Ground-level Ozone - O_3
2. Particulate Matter - PM
3.Carbon Monoxide - CO
4. Lead - Pb
5. Sulfur Dioxide - SO_2
6.Nitrogen Dioxide - NO_2

Of primary concern to this report would be Particulate Matter, as it is a catch-all pollutant resulting from an amalgamation of the other 5 (and more) pollutants. Having reviewed various global burden of disease (GDB) reports, it is likely that this is the best indicator / measure of cause of death (COD). Of course, focusing only on crude death rates would be misleading, as Disability Adjusted life years (DALYs) and Years Lived with Disability (YLDs) play a huge role in air pollution's impact on the African continent's population and have far reaching economic impacts.

Ground-level ozone

Ozone is a gas that occurs both in the Earth's upper atmosphere and at ground level. It is harmful at ground level as it is the main ingredient in smog. In urban environments it can reach unhealthy levels and cause health problems including chest pain, coughing, throat irritation, and airway inflammation. Ozone can also reduce lung function, harm lung tissue, worsen bronchitis, emphysema, and asthma.

Particle pollution

This is also known as particulate matter. Particulate matter, or PM are tiny hazardous solid and liquid particles suspended in the air. They can consist of sulphate, nitrates, ammonia, sodium chloride, and black carbon. These can be either organic or inorganic, including dust, pollen, soot, smoke, and liquid droplets. It includes $PM_{1.0,}$ PM 2.5 and PM. 10. Their sizes vary and therefore PM_{10} is particulate matter 10 micrometers or less in diameter, $PM_{2.5}$ is particulate matter 2.5 micrometers or less in diameter. PM.10 is roughly one-seventh the diameter of a human hair. **PM 2.5** is often considered even more dangerous to human health because of its ultrafine size (about 1/30th the average width of a human hair). These pollutants are produced by polluting fuels and technologies, and are known to exceed WHO-recommended levels by a factor of 100 in poorly ventilated dwellings, along streets polluted by vehicular emissions, within neighbourhoods close to industrial sites and within industrial zones.

Carbon monoxide, Nitrogen dioxide, Sulphur Dioxide

Carbon monoxide (CO) is a colorless and odorless gas but very harmful when inhaled in large amounts. Sources of CO include unvented kerosene and gas space heaters, leaking chimneys and furnaces, and gas stoves at household level. Nitrogen Dioxide (NO_2) is part of a group of gases called nitrogen oxides (NOx). No_2 is of the greatest concern within this group due to its effects on human health. Sulphur dioxide (SO_2) is part of the group of gases called Sulphur oxides SOx. The largest source of SO_2 is the burning of fossil fuels by power plants and other industrial facilities. These gasses are common pollutants but do not form part of this study.

Data sources/indicators from existing citizen science sensor networks

We identified data sources/indicators from existing citizen science sensor networks, as well as other African air quality dataglobal open data portals, on GitHub and on air monitoring websites.

There were a few other networks but our focus is primarily on those that have an Open API access as this enables us to be able to get both current and previous data for analysis and interpretation.

Please see a separate document regarding international case studies and methodologies.

Source	African Countries Covered	Type of Access	Source of Data	Type of Data Available
Sensors.Africa	Kenya, Tanzania, Uganda, South Africa, Nigeria.	Open API	sensors.AFRICA's Low cost air quality sensors (LCS) manufactured, maintained, and deployed by NGO,Code for Africa via a network of non-paid partnerships i.e collaborations with: grassroot citizens' movements, e.g CSOs, civil rights NGOs, investigative media houses, state run schools entities, research based academic institutions e.t.c	Pollutants: $PM_{1.0}$, $PM_{2.5}$, and PM_{10} Atmospheric parameters: Temperature, Relative humidity (RH). Geolocation: GPS data.
Purple Air	Kenya, Uganda, South Africa, Madagascar, Angola, DRC, Ghana Côte d'Ivoire, Sierra Leone, Morocco, The Gambia, Senegal and Cape Verde	Open API	Low-cost air quality sensors commercially manufactured by the manufacturer i.e PurpleAir.	Pollutants: $PM_{.1.0}$, $PM_{2.5}$ and PM_{10} Atmospheric parameters: Temperature and Relative Humidity(RH)
IQAir	Ghana, Côte d'Ivoire, Mali, Cape Verde, Algeria, Chad, Ethiopia, Kenya, Uganda, Madagascar, South Africa, DRC, Mauritius	Limited API Access	AirVisual manufactures and sells semi-low-cost sensors IQAir to various customer segments including: individuals, corporations, NGOs and government. The site is also a community driven data aggregator where sensor units are added from third party monitors from: community run units as well as from Federal regulatory monitors (FRMs) & Federal equipment reference monitors (FEMs) such as those deployed by US state departments in US embassies across Africa.	Pollutants: $PM_{1.0}$, $PM_{2.5}$, PM_{10}, Total volatile organic compound (TVOC), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2 Ground level Ozone $O_{3,}$ Atmospheric parameters:Temperature, and Relative humidity (RH), Wind speed, Rain, Pressure Coming soon: Formaldehyde (CH_2O)

airqo	Uganda	Limited Access API	Low-cost air quality sensors fabricated and deployed by Airqo in Uganda.	Pollutants: PM 2.5, PM 10, Atmospheric data: temperature, atmospheric pressure, relative humidity Geo-location data: GPS location data
openaq	South Africa, Uganda, Kenya, Nigeria	Open API	Aggregated data from different sources with a primary focus on Federal reference monitors (FRM) and Federal equivalent methods (FEM)	Pollutants: $PM_{2.5}$, PM_{10}, NO_s, SO_s, CO, BC
aqicn	Morocco, Cape Verde, Senegal, Mali, Côte d'Ivoire, Ghana , Chad, Ethiopia, Kenya, Uganda, Angola and South Africa. There are also sensors at the Canary Islands (Spain) and Reunion (France)	Limited Access	Aggregated data sources from different sources mostly focusing on Federal reference monitors. (FEM)	Pollutants: Pollutants: $PM_{2.5}$, PM_{10}, Temp, Rel Humidity (in Africa) Form, aldehyde (CH_2O), Total volatile organic compound (TVOC), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2) (other parts of the world eg Asia)
Open data Durban	South Africa	Open API	Low-cost sensors developed and deployed by Open data Durban sensors	Pollutants: $PM_{1.0}$, $PM_{2.5}$ and PM_{10}. Sensors are located in weather stations collecting other atmospheric data..
Air Now	Algeria, Guinea, Mali, Côte d'Ivoire, Kenya, Ethiopia, Uganda and Sudan	Limited Access API	US embassies and consulates	$PM_{2.5}$ and PM_{10}.
South African Air Quality information System	South Africa	Limited Access API		N/A
Richards Bay Clean Air Association	South Africa	Data Scraping		TBD
Alphasense	Kenya		Research	No information.
Breezometer	Kenya, Uganda , South Africa			
Clarity	Kenya, Uganda, Sengal, Guinea, Côte d'Ivoire, Ghana, Sudan. Ethiopia, Angola, Madagascar	Paywall	Governments, Businesses, Communities, NGOs	P.M1, PM 2.5, P.M 10, tVOC, NO2
Dylos -SEI	Kenya		Research Study	
Open Seneca	Kenya		Research Study	
RAMP	Kenya			
SmartCitizen	Kenya, South Africa, Nigeria, Burkina Faso, Tanzania, Equatorial	Limited API		Pollutants (AF): N02, CO, Atmospheric data:

	Guinea, Niger, Morocco,			Temperature, Relative humidity (RH), Light, Noise.
UNEP	Kenya, Uganda	Limited API		N/A
Weather Underground	Kenya, Uganda, Nigeria, South Africa, Ethiopia, Côte d'Ivoire, Sierra Leone, Ghana, Gambia, Senegal, Cape Verde, Niger, Soul Buoy (Null Island), DRC, Madagascar, Morocco			P.M. 2.5 and PM 10
Luftdaten	Kenya, South Africa, Liberia	Open API		Pollutants: P.M. 2.5 and PM 10, Atmospheric data: Temperature, Relative humidity

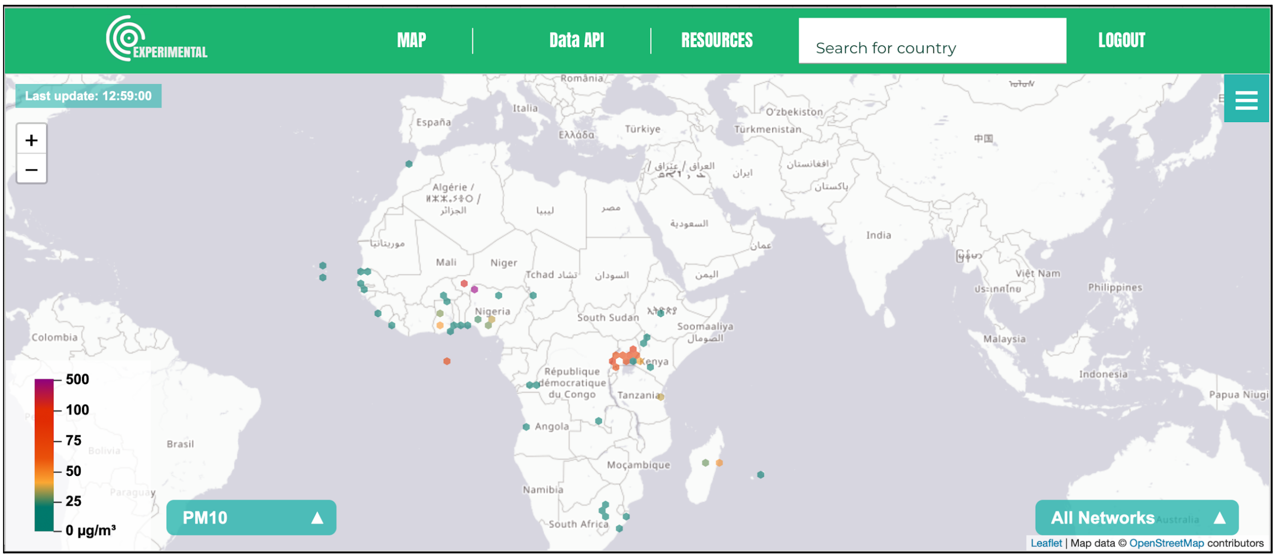
Commentary on the different Air Quality Sensors on the Continent

From our study, there are slightly over 25 African countries that have active citizen science networks collecting air quality data. This is very low when one considers that the continent has 54 countries. The data that is collected is mainly particulate matter (PM) for PM_{10}, $PM_{2.5}$, and PM_{1}. Some monitors are also collecting data on Temperature, Relative humidity (RH), Noise levels and to a lesser extent Ozone and Formaldehyde (CH_2O).

Sensors use different methods to collect this data but the one that is highlighted is laser scattering that is induced when particles go through the detection area of a monitor (more of this is available in the 'hardware comparison section). These networks are also established with different objectives including academic study, neighbourhood/ community advocacy, global studies and analysis etc but a common trend is that of engaging ordinary citizens in the data collection process and having data (to different degrees) publicly available.

Collating Air Quality Data from Existing Networks into a Private Experimental Repository with Real Time Updates

Attempt at Collating Data of African AQ Networks (Real Time)

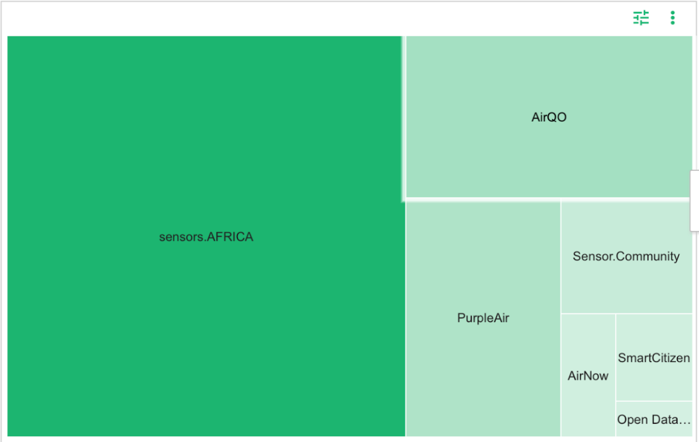


20,367,729

air quality measurements

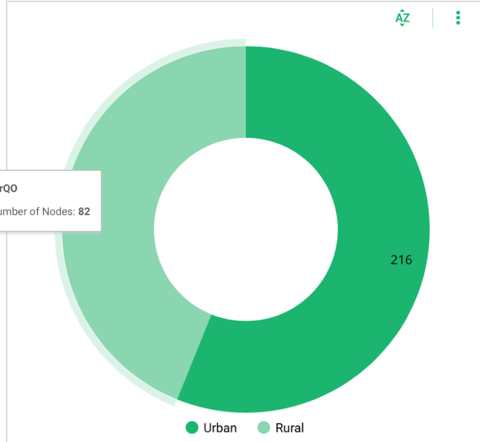
This experimental dashboard tracks air quality data aggregated via API or regular manual data uploads from independent citizen science or academic research networks across Africa. The dashboard is intended to give users an overview of existing network coverage and data trends, as well as gaps in coverage. It offers researchers insights into that challenges grassroots AQ networks face in keeping sensors online, and the wide disparities in data standards and quality.
All information in the repository is open data. sensors.AFRICA is custodian of the dashboard.
We are happy to explore suggestions for adding new networks to the repository.

1,183	483	82	28	6
sensors	nodes	cities	countries	networks



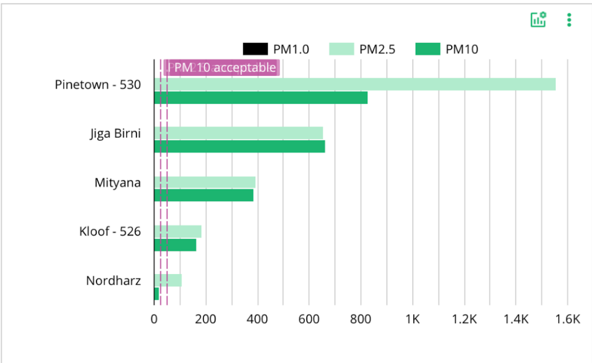
Network Coverage

The number of AQ nodes operated by each network monitored by this dashboard.



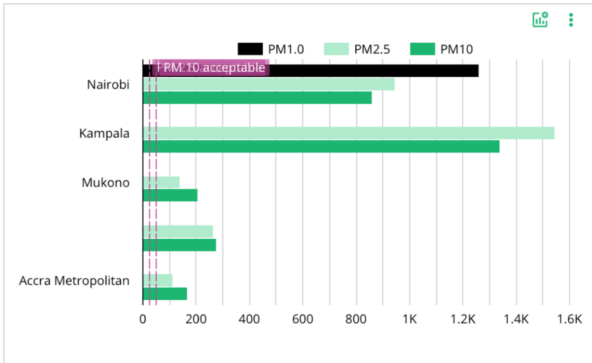
Urban/Rural

An estimate of AQ nodes based on geo-location data shared by sensors. Locations are classifed as urban if in an area with over 500,000 people.



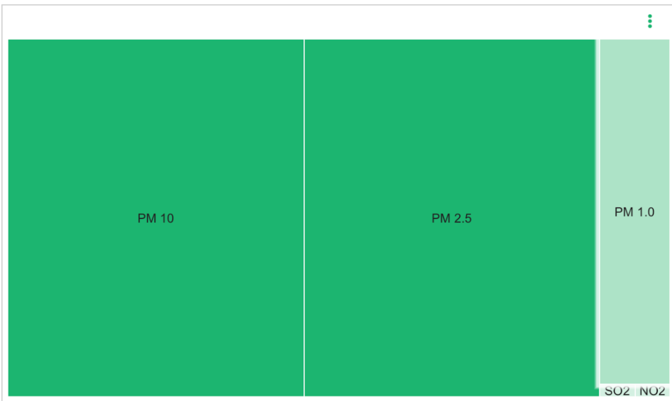
Worst Nodes

The top five nodes that measured the highest (worst) levels of PM1, PM 2.5 and PM10 over the past four weeks.



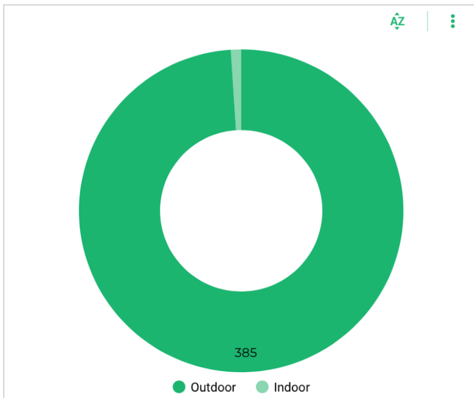
Best Nodes

The top five nodes that measured the lowest (best) levels of PM1, PM 2.5 and PM10 over the past four weeks.



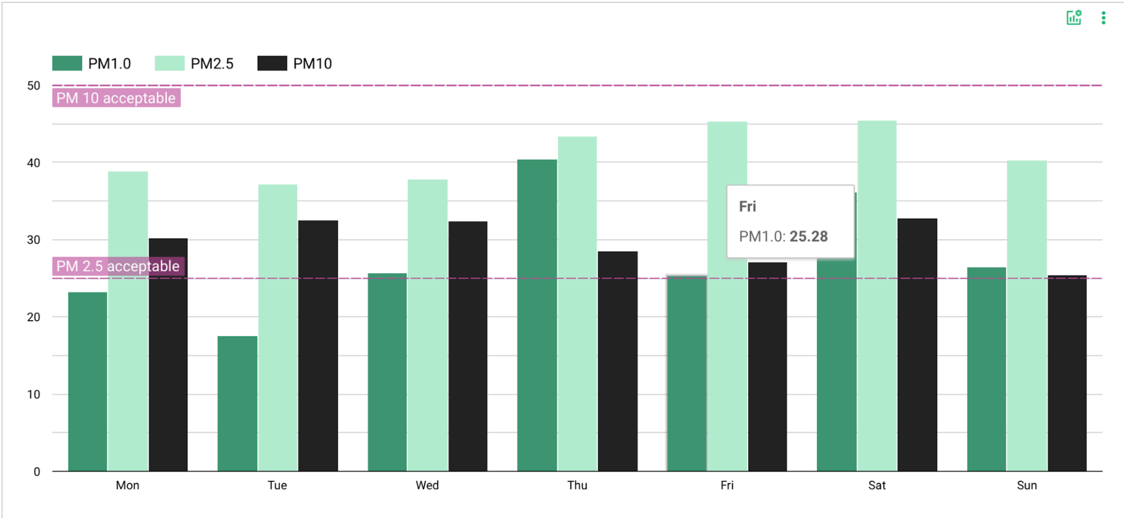
What is being measured

An indication of what AQ pollutants are being measured by the sensors monitored by this dashboard.



Indoor/Outdoor

An estimate, based on metadata sent from sensors monitored by this dashboard, on the in/outdoor placement of AQ nodes. Not all sensors share this metadata.



Air Quality Day Trend

An overview of AQ trends over an average week, measuring daily PM1, PM2.5 and PM10 levels, over a four week period.

https://data4sdgs.sensors.africa/dashboard

The map shows real time Air Quality Readings in twenty seven countries: Kenya, South Africa Uganda, Chad, Nigeria, Ethiopia, Burkina Faso, Ghana, Sudan, Mali, Ivory Coast, Guinea, Algeria, Mauritius, Cabo Verde, Liberia, Togo, Gambia, Sierra Leone, Namibia, Sénégal, Congo, Angola, Tanzania, Madagascar, Bénin from 6 different air quality networks.

The World Bank team can view different pollution and weather characteristics including:

- PM 2.5
- PM 10
- Temperature
- Humidity
- Air Quality according to the AQI-US Scale

Data on the map can be viewed by pollutant, country (specific to 5 countries) or by air quality network.

Sensor.AFRICA's interactive dashboard, accessible **here**. The dashboard was developed to allow users to explore the comparisons between the different air quality networks: **Sensors.Africa, Purple Air, AirQuo, Smart Citizen, Open data Durban, Sensors.Community.** The dashboard has over 20 million data points collected, from 1,184 sensors, and 485 nodes. It allows one to observe the most and least polluted areas in the different counties that have air quality monitors (using the international map **here**), or download historical data for further research (using the application program interface, or API, **here**) and observe ongoing changes/trends in air quality in these particular areas. It has interactive infographics that for the moment are updated on a weekly basis.

The user can utilize the visualizations on the dashboard in order to have a better understanding of the data. Some of the information available includes:

- Country Coverage of the air quality monitors (by node/sensor coverage).
- Sensor Location: Rural vs Urban by percentage.
- Network coverage: Node/Sensor Coverage.
- Country coverage - broken down to city level and number of nodes per city/town.
- What is being measured (showing the number of nodes).

The visualizations are developed to portray quantities of variables in order for the user to have an immediate understanding.

Commentary and Key Questions on the Experimental Repository

a. How do you do the data pull from the various repositories and what is the planned frequency of updates? Are there duplicates? If so, how do you reconcile?

We've focused on a repository with documented APIs for now. We've created one service per repository to pull in data to the main sensorsAFRICA repo. These services are scheduled to run from once per day to once per hour for frequently updated repos. Repos do not provide all the necessary information to actually say this is 100% duplicate of that and hence we use ownership to track where data comes from and hopeful the intelligence to detect duplicates from different networks is something that can be built into the main sensorsAFRICA repo e.g. OpenAQ doesn't give any hardware information about the sensor used to collect data.

b. How do you ensure that no data is lost?

We have daily automatic backup for the main sensors.AFRICA repository running. When pulling in data, the next run of a service always checks where the previous run successfully ended. If there were any errors, the process will be retried.

c. How are the measures from the various sensor sites comparable, or are there any transformations that would be required for comparability?

The measures are comparable or at least we've focused on the measurements that are common to most sensor networks: PM2.5 and PM10 measurements. However how this data is measured and provided differs. For example some networks give you hardware information and sampling frequency such as sensorsAFRICA but others such as OpenAQ averages the results and only give you the averaging frequency per hour. Again, a bit of intelligence needs to be built into the main sensors.AFRICA repo to handle/transform all these mismatches into something readily useful.

Comparative analysis of low-cost sensor hardware kits used by citizen science air quality data initiatives

As cities grow demographically, they also face a greater risk of increased air pollution (Castel et al). It is common in developed cities to have networks of reference monitoring stations giving real time reports on air quality. The air quality is conducted for legislation and scientific purposes. These monitoring stations come at a cost, and are not common to find in lower and middle income countries. However, progress is being made in the development of low-cost technology and this is changing the conventional approach of real-time monitoring (Mattewal, et al).

The low cost , use friendly air pollution platforms have led to a new trend worldwide where air quality is monitored beyond the traditional monitoring stations.(castell et al). These have also enabled the engagement of citizens in the environmental monitoring process and through this addressing data gaps in regions that have limited monitoring (Johnson et al, 2018). Some of these, like PurpleAir PA-II-SD, have demonstrated good linearity against reference instruments (Kelly et al, 2017). We have identified 6 such networks on the African Continent with 7 different models of AQ monitors. This report gives a comparative analysis of the hardware that is used for these monitors.

The Sensors

Networks and their respective monitors

- Sensors Africa: SDS 011
- Purple Air: PA-II, PA-II-SD and PA-I-Indoor
- Air Qo: Air Qo Monitor
- IQ Air: Air Visual Pro
- Open Data Durban

Sensors Africa: SDS 011

The sensors.africa SDS 011 monitor collects both PM 10 and PM 2.5

Purple Air PA-II

General Features:

The PA-II measures PM 2.5.It has a built in wifi which enables it to transmit data to the Purple Air Map. It is white in colour, available for both indoor and outdoor use but has no internal storage. It weighs 332 g and has the following dimensions: 85 mm x 85 mm x 125 mm. It comes with a Power Supply that weighs 12.6 oz (357 g). A/C input is 100-240V AC, 50/60Hz, 1.5A and A/C output 5V DC, 3A. The Sensor input 5V DC, 0.18A continuous, 600mA peak. Weather resistance: IP68,

Features of the wireless system:

- Wireless Networks 802.11b/g/n @ 2.4GHz, (WPA2 pre-shared key or open networks)
- Certificates: FCC/CE/ TELEC/SRRC
- Tx Power 802.11 b: +20 dBm; 802.11 g: +17 dBm; 802.11 n: +14 dBm
- Rx Sensitivity: 802.11 b: -91 dbm (11 Mbps), 802.11 g: -75 dbm (54 Mbps), 802.11 n: -72 dbm (MCS7)
- Antenna Type 2 dBi on-board PCB antenna

Characteristics of the Laser Particle Counters

- Type(2): PMS5003
- Range of measurement: 0.3, 0.5, 1.0, 2.5, 5.0, & 10 µm.
- Counting efficiency is 50% at 0.3µm & 98% at ≥0.5µm
- Effective range (PM2.5 standard)*0 to 500 µg/m³
- Maximum range (PM2.5 standard)*≥1000 µg/m³.
- Maximum consistency of error (PM2.5 standard): ±10% at 100 to 500µg/m³ & ±10µg/m³ at 0 to 100µg/m³
- Standard Volume 0.1 Litre
- Single response time is ≤1 second while Total response time is ≤10 seconds.

Characteristics of the Pressure, Temperature, & Humidity Sensors

- Type: BME280,
- Temperature range:-40°F to 185°F (-40°C to 85°C)
- Pressure range: 300 to 1100 hPa
- HumidityResponse time :(τ63%): 1 s
- Accuracy tolerance: ±3% RH
- Hysteresis: ≤2% RH

Purple Air PA-II-SD

The PA-II-SD is an air quality sensor that measures real-time PM2.5 concentrations for residential, commercial, or industrial use. Built-in WiFi enables the sensor to transmit data to the PurpleAir map, where it is stored and made available to any smart device. For locations with limited or no WiFi access, the PA-II-SD incorporates an SD card and real-time clock, allowing the sensor to record and store data locally.

General Features:

It is White in colour with the following dimensions: 3.5 in x 3.5 in x 5 in (85 mm x 85 mm x 125 mm) and weighs 12.4 oz (352 g) It is Intended for both Outdoor and indoor use, has WiFi connectivity and internal storage via a 16GB micro SD.

It comes with a white power supply that weighs 25.0 oz (709 g) and has a length of 17 ft (5 m). The power supply has an A/C input 100-240V AC, 50/60Hz, 1.5A and an A/C output of 5V DC, 3A. The sensor has an input 5V DC, 0.18A continuous, 600mA peak

Weather resistance: IP68

Features of the wireless system:

- Wireless Networks 8 02.11b/g/n @ 2.4GHz (WPA2 pre-shared key or open networks)
- Certificates: FCC/CE/ TELEC/SRRC
- Tx Power: 802.11 b: +20 dBm, 802.11 g: +17 dBm, 802.11 n: +14 dBm
- Rx Sensitivity: 802.11 b: -91 dbm (11 Mbps), 802.11 g: -75 dbm (54 Mbps), 802.11 n: -72 dbm (MCS7)
- Antenna Type: 2 dBi on-board PCB antenna

Characteristics of the Laser Particle Counters

- Type: (2) PMS5003
- Range of measurement: 0.3, 0.5, 1.0, 2.5, 5.0, & 10 µm
- Counting efficiency: 50% at 0.3µm & 98% at ≥0.5µm
- Effective range(PM2.5 standard)*: 0 to 500 µg/m³
- Maximum range (PM2.5 standard)*: ≥1000 µg/m³
- Maximum consistency error (PM2.5 standard): ±10% at 100 to 500µg/m³ & ±10µg/m³ at 0 to 100µg/m³
- Standard Volume 0.1 Litre
- Single response time ≤1 second
- Total response time ≤10 seconds

Characteristics of the Pressure, Temperature, & Humidity Sensors

- Type: BME280
- Temperature range: -40°F to 185°F (-40°C to 85°C)

- Pressure range: 300 to 1100 hPa
- Humidity Response time: (τ63%): 1 s
- Accuracy tolerance: ±3% RHHysteresis: ≤2% RH

SD Card Reader & Real-time Clock

- Real-time Clock (RTC): DS3231
- SD Card 16GB micro SD card included takes micro SD cards up to 64GB
- SD Card FormatFAT32
- SD Card Data Access: Remove micro SD card with tweezers & connect to computer to download csv data files

Purple Air PA-I-Indoor

With the PA-I-Indoor's full-color LED, the resulting glow indicates air quality at a glance from across the room. Sporting a simple design that sits comfortably on a counter or tabletop, the PA-I-Indoor measures real-time PM2.5 concentrations. Built-in WiFi enables the sensor to transmit data to the PurpleAir map, where it is stored and made available to any smart device.

General Features:

The sensor has the following dimensions: 4.25 in x 3 in x 2.25 in (108 mm x 67 mm x 57 mm) and has a weight of 6.4 oz (181 g)
Its power supply length is 3.2 ft (1 m), it is Translucent in colour white with real-time AQI colored LED light.

The sensor comes with a power supply that has an A/C input of 100-240V AC, 50/60Hz, 1.5A and A/C output 5V DC, 3A.

The Sensor has an input of 5V DC, 0.18A continuous, 600mA peak

It is strictly for Indoor use only.

Features of the wireless system:

- Wireless Networks: 802.11b/g/n @ 2.4GHz (WPA2 pre-shared key or open networks)
- Certificates: FCC/CE/ TELEC/SRRC
- Tx Power: 802.11 b: +20 dBm, 802.11 g: +17 dBm, 802.11 n: +14 dBm
- Rx Sensitivity: 802.11 b: -91 dbm (11 Mbps), 802.11 g: -75 dbm (54 Mbps), 802.11 n: -72 dbm (MCS7)
- Antenna Type:2 dBi on-board PCB antenna

Characteristics of the Laser Particle Counters

- Type: (1) PMS1003
- Range of measurement: 0.3, 0.5, 1.0, 2.5, 5.0, & 10 µm
- Counting efficiency: 50% at 0.3µm & 98% at ≥0.5µm
- Effective range (PM2.5 standard)*: 0 to 500 $\mu g/m^3$
- Maximum range (PM2.5 standard)*: ≥1000 $\mu g/m^3$
- Maximum consistency error (PM2.5 standard): ±10% at 100 to 500$\mu g/m^3$ & ±10$\mu g/m^3$ at 0 to 100$\mu g/m^3$
- Standard Volume: 0.1 Litre
- Single response time: ≤1 second

- Total response time: ≤10 seconds

Characteristics of the Pressure, Temperature, & Humidity Sensors

- Type: BME280
- Temperature range: -40°F to 185°F (-40°C to 85°C)
- Pressure range: 300 to 1100 hPa
- HumidityResponse time: (τ63%): 1 s
- Accuracy tolerance: ±3% RH
- Hysteresis: ≤2% RH

AirQo

Air Qo Monitor

The AirQo monitor is designed to monitor PM 2.5, and PM 10, location details, internal and external temperature,atmospheric pressure, and humidity.

It transmits data over 2G network that is predominately available in many parts of Africa. The device is very portable and can be deployed statically or mounted on mobiles like motorcycle taxis and vehicles to provide spatio-temporal pollution snapshots.

The device is built locally and uniquely designed to withstand the physical environmental conditions such as dust and extreme weather conditions and optimised to work in settings characterised by unreliable power and intermittent internet connectivity, typical in a sub-Saharan African setting.

The device has also been co-located with BAM1020 at the US Embassy in Kampala and they correlate well with R2 value between 0.87 and 0.90.

IQ Air

Air Visual Pro

Air visual Pro’s advanced laser technology provides highly accurate readings of tiny fine particles (PM2.5) down to 0.3 microns.

It enables one to compare Indoor Air Quality with the nearest monitoring station as well as discover sources of pollution so one can breathe clean air – both indoors and out.

AirVisual Pro has an internal battery and data-storage capability. It allows for wireless download of data or access via the AirVisual website or mobile app for analysis (where one can set up alerts via a smartphone).

Key Features:

- Requires a constant power/electricity connection.
- Can monitor either indoors or outdoors

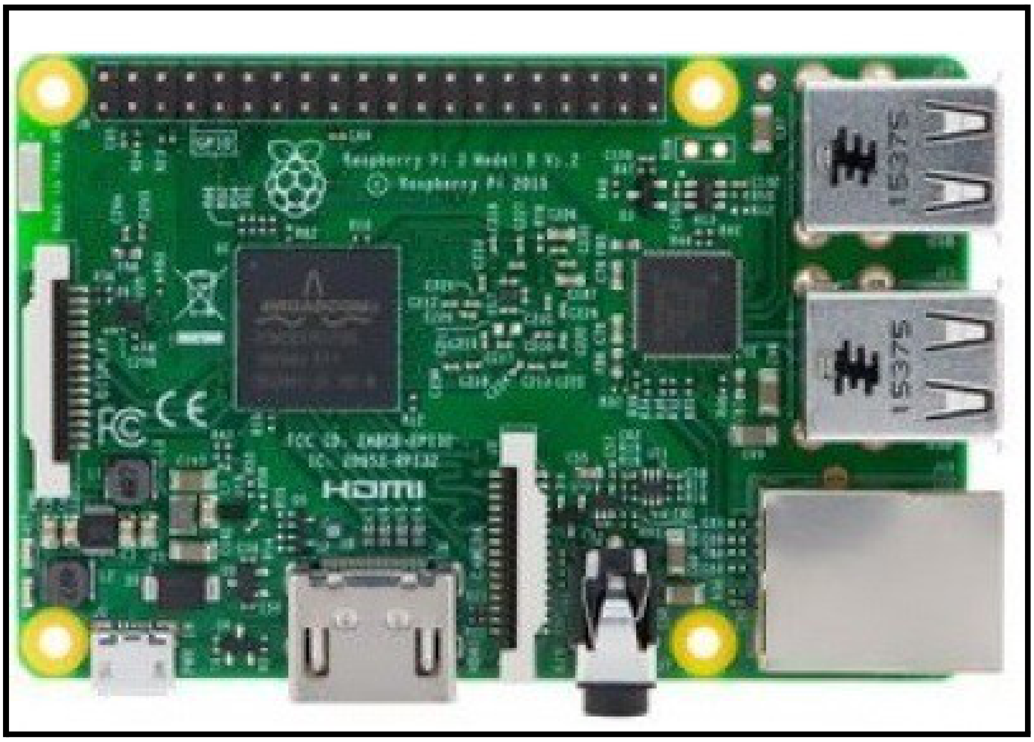
Open Data Durban

The sensor is a Raspberry Pi based weather station that measures temperature, humidity, wind-speed and direction, the presence of harmful gases and the amount of microscopic dust particles in the air.

The station has an onboard storage space using a memory card, this ensures that data is not lost in case the internet connection breaks down.

Below is a table showing the various sensors utilized in the station and the parameters they measure.

COMPONENT	**PARAMETER**
MQ-135 gas sensor	Benzene, alcohol and smoke
Nova PM SDS011	PM 2.5 and PM 10
Maplin anemometer	Wind speed and direction
DHT22 sensor	Temperature and humidity



Source: Medium.com

Network	sensors.africa	Purple Air	Purple Air	Purple Air
Web	Sensors Africa	Purple Air	Purple Air	Purple Air
Model	SDS 011	PA-II	PA-II-SD	PA-I-Indoor
Web info on specific model.		PA-II	PA-II-SD	PA-I-Indoor
Data Collected	PM10 and PM 2.5	PM2.5	PM 2.5	PM 2.5
Location	Outdoor	Indoor and Outdoor	Indoor and Outdoor	Indoors
Wifi	Built in	Built in	Built in	Yes
Intended use	Outdoor	Outdoor and indoor		indoor use
Internal Storage	None	None	incorporates an SD card and real-time clock, allowing the sensor to record and store data locally	Yes, 16GB micro SD

Network	Air Qo	Air Now	IQ Air	Open Data Durban
Web	Air Qo	Air Now	IQ Air	Open Data Durban
Model	AirQo monitor		AirVisual Pro	Nova PM SDS011
Model web	AirQomonitor		AirVisual Pro	
Data Collected	PM 2.5, and PM 10, location details, internal and external temperature,atmospheric pressure, and humidity,		PM 2.5, CO_2, Temperature and Humidity	PM 2.5, PM 10, Smoke, Benzene, Temperature and Humidity.
Location	Outdoors and mobile eg. motorbikes		Indoor and Outdoor	Outdoor
Wifi			Yes	Yes
GSM	Works with 2 G Networks			
Intended use	Outdoor		Indoor and outdoor	Outdoor
Internal Storage				Yes

**Information on 'Air Now' Sensors is not available (these are located at US Embassies*

Summary Points on Side to side Analysis

1. Working environment
2. Parameters
3. Storage capability
4. Sensor-used
5. Data transmission

Working Environment

Some sensor kits are capable of collecting either indoor or outdoor air quality data while others are able to do both. The Open Data Durban, AirQo and SensorsAFRICA sensor kits are meant for outdoor air quality data collection. The PA-I-Indoor is strictly meant for Indoor air quality measurement while the IQAir, PA-II and the PA-II-SD can be used for both Indoor and outdoor air quality measurement.

Parameters Measures

The sensor kits measure various air quality parameters. The PA-II, PA-II-SD and PA-I-Indoor measure PM2.5, temperature, humidity and atmospheric pressure. The sensorsAFRICA sensor kit measures PM2.5, PM10, temperature and humidity. The AirQo is able to measure PM2.5, PM10, humidity as well as internal and external temperature. The IQAir is capable of measuring PM2.5, CO_2, temperature and humidity. The open Data Durban sensor kit on the other hand entails an outdoor weather station and in addition to PM2.5 and PM10 is capable of measuring smoke, benzene, alcohol levels as well as atmospheric temperature and humidity.

Storage Capability

All the sensors are able to transmit data to a remote server while some have an additional feature of being able to also store data locally. Through the remote server, the data is stored and can be both analysed and visualized.

The PA-II-SD, IQAir and Open Data Durban have data storage capabilities and hence no data loss occurs when the internet connection breaks down. On the other hand, the sensorsAFRICA sensor kit, PA-II, PA-I-Indoor and AirQo do not have data storage capabilities and only transmit the collected data directly to a remote server. This might lead to loss of data collected when the internet connection goes down.

Data Transmission

The sensor kits also use various methods to send data out to the various servers where they are stored. The PA-II, PA-II-SD, PA-I-Indoor, IQAir and Open Data Durban use WiFi for data transmission. The AirQo sensor uses GSM for data transmission while sensorsAFRICA has sensor kits that use either WiFi, GSM or Sigfox for data transmission. WiFi networks are however prone to downtime hence the data collected during these periods is not transmitted. GSM and Sigfox networks on the other hand are more stable leading to reliable data transmission.

Particulate Matter Sensor Type

The sensors kits use various Particulate matter sensor modules. The PA-II, PA-II-SD and sensorAFRICA use the PMS5003. The PA-I-Indoor uses the PMS1003 while the Open Data Durban sensor kit uses the SDS011. The PMSx003 family of sensors do produce better results in terms of repeatability and reproducibility between units (coefficient of variation) due to the atmospheric environment ("AE") correction factor implemented in them (Badura, M., et Al. 2018).[7]

	WORKING ENVIRONMENT		**PARAMETERS MEASURED**						
	Indoor	Outdoor	PM2.5	PM10	temp.	humid	Atmos. pressure	CO2	smoke, benzene, alcohol levels
Open Data Durban,		■	■	■					■
AirQo		■	■	■	■	■			
SensorsAFRICA		■	■	■	■	■			
PA-II,	■	■	■		■	■	■		
PA-II-SD	■	■	■		■	■	■		
PA-I-Indoor	■		■		■	■	■		
IQ Air	■	■	■		■	■		■	

	STORAGE CAPABILITY		**DATA TRANSMISSION**			**PARTICULATE MATTER SENSOR TYPE**		
	Inbuilt Storage	Transfer to remote Server	Wifi	GSM	SigFox	PMS5003	PMS1003	SDS011
Open Data Durban,	■	■	■					■
AirQo		■		■				
SensorsAFRICA		■	■	■	■	■		
PA-II,		■	■			■		
PA-II-SD	■	■	■			■		
PA-I-Indoor		■	■				■	
IQ Air	■		■					

[7] Badura, M., Batog, P., Drzeniecka-Osiadacz, A., & Modzel, P. (2018). Evaluation of Low-Cost Sensors for Ambient PM2.5 Monitoring. *Journal of Sensors*, *2018*, 1–16. https://doi.org/10.1155/2018/5096540

Interactive courseware and supporting training materials

The team developed interactive courseware and teaching materials on how to use low-cost hardware and open source software tools to collect and evaluate air quality data.

These will enable the World Bank team or any other interested party to be able to put together low cost sensors using readily available hardware, upload the necessary (open-source) firmware and access the data collected by the monitors.

LINK TO COURSEWARE

The courseware covers the following important areas:

- **Obtaining open source firmware.**

  The objective here is to use open source software (hereafter referred to as 'firmware*') to program and assemble air quality sensors.

- **Developing Low Cost Sensor Hardware**

  This is hardware that is relatively affordable, easily available with components that can be easily replaced and have recognized levels of accuracy

- **How to load the firmware**
- **Access and Analysis of the data**
- **Maintaining the sensor**

**courseware consists of 37 explanatory slides*

Risk mitigation

Risk mitigation is a critical part of any project and as with most projects, we did experience some risk and had to figure out how to navigate them in order to mitigate the issues as effectively as possible.

Did you need to address any risks?

Yes, we did have to address a number of risks

If yes, what were the risks and how were they managed or Mitigated?

- We would have preferred to have access to many more networks but as some do not have open APIs and others have a paywall, we had to do without these as our priority is to ensure access to data that is openly available to all. There are also not very many sensors deployed in African countries compared to other parts of the world.
- It has been difficult to get all the data from some of the open API networks. This has been due to the magnitude of the data, which is difficult to work with, considering that we are also collecting historical data.
- Some networks do not have historical data and therefore we are only able to get access to real time data eg sensors.community. Others do not list their measurements, others have their data in the form of files while some networks do not give raw values.
- We noted that in some cases, some sensors had not collected data in a long time, probably due to maintenance challenges. This brought about a problem to the validity of the data. We have tried to keep these particular sensors out of the dashboard. Where possible, we have also contacted the concerned parties to have a look at the sensors.
- Towards the end of the project our main technical person had to go on medical leave. This held us back for several weeks as we had to get new staff on the project based on their availability. This caused a delay in the finalization of the repository.

Output indicators

Have there been any final results or outcomes in which data or methods have allowed data to be produced: faster; more cheaply; at a higher resolution or granularity, or where there was no data before? If yes, please describe.

The main product from this work is the development of a private experimental repository of air quality data that is readily available (accessible only by the Bank team). The experimental repository was to collate data from air quality networks around the continent and use infographics and diagrammatic representations to be able to compare the data. The project was only able to pull data from seven networks: Sensors.Africa, Air Qo, Purple Air, AirNow, Smart Citizen, and Open Data Durban and Sensors.Community uploaded to the repository.

Has the project contributed to the production and/or use of data disaggregated by a) sex b) disability c) age, d) geography (or other)? If yes, please summarize the types of disaggregated and the context.

The project has gathered data disaggregated by geography. The project looks into air quality networks in different African countries. The main countries of focus for this project are Kenya, Uganda, South Africa and Nigeria. There are a number of other countries that have been included where possible. Some countries, like Tanzania, do not have many sensors.

Data on ambient air quality from these countries being collected by different networks is available on the experimental repository.

Has the project contributed to the use and/or production of gender statistics? If yes, please describe.

No, the project has not contributed to the use or production of gender statistics.

Lessons Learned

There are several lessons that this study has brought out both for Code for Africa and the relevant programme partners. The lessons in line with some of the specific activities related to this include:

1. *Work closely with GPURL and DECDG with respect to any needed interactions with selected stakeholders to identify potential complementary air quality data in Kenya, Nigeria, South Africa and Tanzania, that may already be available and useful for this research project;*

   Though we managed to identify a number of air quality networks on the continent, and also added one more country to our sources, it was clear that there isn't a lot of air quality data available on the African continent when compared to other continents. There are not many sensor networks, these are only available in a few counties and most of the sensors are located near major urban areas.

   However, we also noted that a number of networks have emerged over the last few years, which was one of the factors that led us to include Uganda in our study, where networks like Sensors.Africa and AirQo have developed presence.

   Another major concern was that some of the networks/sensors do not have up to date data.

2. *Participate in knowledge exchange activities to contribute to similar engagements led by the urban team, for example in Uganda.*

   This was not done as we had challenges pulling together the data from the different networks that we would need to use for the knowledge exchange activities.

3. *Create a private repository of air quality data that is readily available (accessible only by the Bank team) mobilized under this project for review by the World Bank's Office of Information Security (and as relevant by the Bank's Access to Information Committee).*

   We made some progress in developing the repository but were hampered by a number of challenges. This included the fact that there are very few Open API networks on the continent which we initially intended to use for the repository.

   Where we were able to access the data, the volume of data proved to be a hindering factor as the large volumes of data led to the system crashing thus hampering the working progress.

   The importance of having an easy to understand dashboards in order to increase the awareness on the importance of good air quality. The AQI Scale is very helpful with this as it gives a visual impression of the existing situation.

Repository Ranking: Though we managed to have a graph showing trends and country ranking on the repository, we would have prefered to show specific sensor rankings with location details so as to be able to do some deeper analysis on causes, demographics, health data, environment and land use.

4. *Develop training materials on various ways to collect and evaluate new air quality data methods.*

   These were developed and shared and are available for people to view.

5. *At the request of the World Bank team, develop policy notes that highlight key pollution challenges and their implications for city livability and productivity*

   These were not requested.

6. *Work in concert with GPURL and DECDG to produce a detailed and relevant report to capture insights, findings, case studies, and recommendations arising from this research project to inform GPSURR operational teams about possible new data collection and evaluation methods with respect to air quality in the Africa Region.*

   This report has been prepared in accordance with the guidelines provided.

   Other Lessons:

   Personnel Challenges: Our main technical person had to go on extended medical leave. This held us back for several weeks as we had to get new staff on the project based on their availability. This caused a delay in the finalization of the repository.

   The increasing importance of low cost sensors in order to have readily available data Eg the scenario in Kenya where reference data on air quality has to be purchased from the meteorological authorities.

Advantages and Disadvantages of the Private Repository.

Advantages:

1. Select data from some of the Air Quality Networks is available through the experimental repository.
2. In the case where there is an area of concern concerning Air Quality it is very easy to have sensors installed at that location.
3. With the different networks that the repository captures data from, there can be a wider spatial spread that is covered for this data collection
4. The Dashboard shows different trends and comparisons of real time Air Quality Data.
5. Changes can be made to the dashboard depending on the requirements of the researcher.

Disadvantages:

1. Some areas are not covered e.g. parts of Nairobi and Lagos that are highly polluted do not have monitors and this has a negative effect on possible interventions.
2. Some sensors within networks do not have up to date data due to lack of maintenance concerns, power supply issues or other challenges.
3. A lot of the focus tends to be in urban and metropolitan areas and not rural areas, of which some might have air quality concerns eg near mining areas.
4. The data takes a long time to obtain e.g one network can take up to 7 days or more to pull and upload on the experimental repository.
5. In the past some professionals e.g. academics have expressed their displeasure over data from low cost sensors versus reference data over accuracy concerns..
6. There might be some inconsistencies in data collection and calibration across the different networks, when this happens it inevitably raises concerns over the accuracy of the data.

Potential of replicability and scalability.

1. With the development of the experimental repository covering these 4 countries (Kenya, Uganda, Nigeria and South Africa) there is opportunity to add a few other countries who these networks are already present at e.g. Ghana, Tanzania and Ethiopia.
2. As these networks increase their sensors in the respective countries, the experimental repository can adapt to the increased number of sensors, thus giving more real time information on the status of air quality on the continent.
3. This can be replicated in other environmental fields where necessary eg riverine water quality, noise pollution or other areas of concern that monitoring can be done.
4. There is a need for deployment of more environmental monitoring sensors on the continent in order to fully capture the extent and impact of air pollution and other environmental damage within major urban centres on the continent. The urban development is on the rise as well as the levels of pollution in urban centres.
5. Linkage between land use and monitors - eg industrial areas, residential, even within the networks themselves is beneficial for decision makers.

Way Forward

In the course of this project we were able to get a great view of opportunities that can come from doing more work in this space. We have identified and outlined these opportunities in this section as a way forward for expanding the project. They include:

1. Where possible the data can be used for advocacy purposes in urban centres where air quality is a major concern and issue among the population (this is particularly for publicly available data).
2. Recognizing the data gaps and absence of sufficient AQ data on the continent has proven to be an opportunity for further development and improvement of existing AQ networks within our reach by advocating for more low-cost sensors to be deployed on the continent. This can go a long way in securing rights of citizens towards a better and livable environment though citizen science driven approaches.
3. Data from the experimental repository will be used to develop policy notes that highlight key pollution challenges and their implications for city livability and productivity in Africa.

Conclusions

The project aimed at conducting research on methods that can be used to mobilize, monitor and analyze near real time data on air quality in different African countries.

Through the course of the project we were able to identify different networks collecting real time AQ data in Africa and attempt to collate the data into a single repository. Additionally, we were able to do a side by side comparison of the hardware that is used to collect data. Training courseware on how to use open source software and easily available hardware was also developed.

The project faced a number of challenges which hampered us from being able to access the data from air quality networks either due to heavy load of data or due to lack of access keys to the APIs. As a result of this, it was also difficult to have a functional repository as intended as well as to organise knowledge activities with networks from other countries.

In a nutshell, we can say that less than half of the countries on the African continent have active citizen science networks collecting data. The project therefore identified the need for more investment in citizen science projects on the continent that will enable better access to open data on Air Quality. This will provide readily available data on the status of air quality in urban areas as well as showcase signals to problem areas that require immediate attention in the continent. In doing so, there can be a pulling together of such data to be used for advocacy purposes where air quality is an issue of concern.

Final outputs

- **LINK TO COURSEWARE**
- LINK TO DASHBOARD AND EXPERIMENTAL REPOSITORY

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