Measuring Air Quality for Advocacy in Africa (MA3):

Feasibility and practicality of longitudinal ambient PM2.5 measurement using low-cost sensors

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ABSTRACT

Introduction: Ambient air pollution in urban cities in sub-Saharan Africa (SSA) is an important public health problem, given the magnitude of health effects attributable to the latter. On most global air quality index maps, however, information about ambient pollution from Africa is scarce. African physicians with interest in air quality monitoring (AQM) thus set out to evaluate the feasibility and practicality of longitudinal ambient $PM_{2.5}$ measurement using Purple Air-II-SD device, a low-cost AQM sensor, with the aim of assessing the efficiency of its data recovery rate, comparing averages and identifying challenges experienced.

Methods: Following an AQM workshop in Dar Es Salaam, Tanzania in June 2019, Purple Air-II-SD devices were given to all the sixteen participants. Thirteen physicians from seven countries (Gambia, Kenya, Uganda, Cameroon, Benin Republic, Burkina Faso, and Nigeria) eventually installed the instruments and participated in data collection throughout July 2019. The data was downloaded from the SD memory cards, and alongside the documented operational challenges, zipped and emailed to the principal investigator weekly.

The data was cleaned and analysed, with the percentage of time data was logged (or data recovery rate) taken as the primary outcome variable. The time drift on the devices and the daily and hourly averages at all sites were also computed.

Results: There was only one site with a 100% data recovery rate (Nairobi, Kenya), with Abakaliki Road-Enugu-Nigeria and Kampala-Uganda sites having 98.6% and 95.5% recovery rates respectively for $PM_{2.5}$ logging. Bariga-Lagos-Nigeria site had the least data logging - 72.1%. Kampala-Uganda, Bariga-Lagos-Nigeria, Nnewi-Nigeria, and Nairobi-Kenya sites all had daily $PM_{2.5}$ averages above the WHO $PM_{2.5}$ safety threshold of 25μg/m^3, with Kampala-Uganda and Nnewi-Nigeria recording values > 250μg/m^3. Fajara-Gambia and Ouagadougou-Burkina Faso sites had daily averages below the WHO daily thresholds. All sites recorded hourly averages above 10 μg/m^3. Power outages, SD memory card issues, internet connectivity problems and device safety concerns were important challenges experienced in the process of use of the Purple Air-II-SD sensors.

Conclusion: Even though its use is froth with some surmountable operational challenges, it was reasonably practicable and feasible to measure $PM_{2.5}$ in sub-Saharan African countries using the Purple Air-II-SD device.

Keywords: Air pollution, Ambient, Measurement sensor, Low-cost **Word Count:** 350

INTRODUCTION

Exposure to ambient air pollution is increasingly becoming a significant health-related environmental issue (1). The Lancet commission on air pollution (2) published recently emphasized that approximately 92% of pollution-related deaths occurred in low-and-middle-income countries (LMICs). However, the magnitude of the risk attributable to ambient air pollution has not been well documented for the African continent thus making the figure almost entirely based on data obtained from LMICs outside Africa or data from household air pollution in SSA.

It is estimated that three billion people, *i.e.* 40% of the world's population, are exposed daily to air pollution with a majority living in LMICs (1,3). Air pollution originates largely from incompletely combusted solid fuels used in households (4,5,6). In urban areas in Africa, ambient air pollution also arises from emissions from old and poorly maintained vehicles, high sulphur fuels, dust and fumes from industries, smoking and roadside refuse burning (7). The overall morbidity related to air pollution is further increased by its independent effect on obstructive lung diseases (5,8,9).

Inhalable, thoracic and respirable fractions of particulate matter (PM) have documented health effects associated with them (10). These health effects are determined to a large extent by the concentration, surface area, chemical constituents and the biological activity of the particles (10,11). Some of these health effects are Chronic Obstructive Pulmonary Disease (COPD), asthma, lung cancer, heart disease, stroke, arterial thrombosis, hypertension to mention a few (10,12). Measuring ambient PM 2.5 will help identify the main sources, foster citizen science and quantify the extent of the pollution to enact advocacy, which will eventually lead to the establishment and reinforcement of strict air quality regulation in the sub-Saharan African region (13). These data will assist in supporting African governments to implement evidence-based policies and programmes and could also influence behavioural change in some communities/countries i.e. some countries can copy and replicate successful programmes from others.

Measuring ambient air pollutants has traditionally been done with expensive gold standard instruments (14). Examples include the gravimetric measuring cyclone device, optical measuring devices (TSI Sidepak, Apex pump, RTI MicroPEM, etc) and the Tapered Element Oscillating Microbalance popularly known as TEOMs (15). The advent of less expensive yet efficient air quality monitoring (AQM) instruments had made air quality measurement more affordable and accessible to scientists and non-scientists alike, making citizen science a reality (16). Studies comparing the performance of newer less expensive AQM instruments to the more expensive gold standard instruments have revealed very promising results (17,18). Applying these low-cost technologies offers a tremendous opportunity for long-term exposure measurements and determination of drivers/sources of air pollution at scales needed for regions or population-based research.

In the 'Measuring Air Pollution in Africa for Advocacy' or MA3 study, we set out to measure ambient particulate matter 2.5 in seven sub-Saharan African countries with the use of a low-cost AQM sensor-Purple Air II SD sensor. Over four weeks, we sought to find out how practical and feasible it was to execute an air quality measurement primary study (ambient $PM_{2.5}$ measurement) with a large geographical coverage to gather data on ambient air pollution utilising low-cost particle sensors deployed across sub-Saharan Africa. The specific objectives were (a) to assess the data recovery rate for low-cost ambient $PM_{2.5}$ measurement devices placed over a four-week period in thirteen sites across seven sub-Saharan African countries (Benin Republic, Burkina Faso, Cameroon, The Gambia, Kenya, Nigeria and Uganda) using a low-cost air quality measurement device (Purple air II SD sensor), (b) compare the average ambient $PM_{2.5}$ pollutant levels in each country with the WHO air quality standard threshold for ambient $PM_{2.5}$ and identify the challenges associated with collecting ambient PM2.5 across the thirteen sites.

METHODOLOGY

Study Preparation

The idea for the study was discussed with like-minded scientists with interest in exposure science. A committee of four people was then formed to contribute to the planning of the study. The operational aspect was led by Babatunde Awokola (BA), assisted by Gabriel Okello (GO). Sean Semple (SS), Kevin Mortimer (KM), Chris Jewel (CJ) and Annette Erhart (AE) provided oversight for the project. This committee met at the University of Aberdeen, Scotland on 27th February 2019. This venue was chosen because the field expert, Prof Sean Semple (SS), resides and works in Scotland. The director of the African Centre for Clean Air (ACCA), Gabriel Okello (GO), was also a member of the committee. The deliberation achieved the following: an agreement on the eventual focus of the MA3 study, selection of the countries and participating scientists, choice of the low-cost equipment to use, identification of the source of the funds to use to procure the instruments, ordering of the instruments and details of the training in the use and maintenance of the instruments.

Purple Air II SD was the instrument that was identified as the most ideal for the measurement of ambient particulate matter 2.5mm. Even though MA3 did not seek to measure carbon monoxide, the opportunity was taken to teach this also and Lascar® logger was the instrument chosen for carbon monoxide measurement. Seventeen Purple Air II SD devices, seventeen 20,000mAH Anker® power banks, and ten lascar loggers were procured online from the United States and shipped to Liverpool, United Kingdom in preparation for the Air Quality Measurement (AQM) training. Sixteen sites spread across nine sub-Saharan African countries were identified based on the air quality measurement scientists that showed interest in participating in the study. The cohort was chosen from among the Physician-researchers participating in the International Multidisciplinary Programme Against Lung Diseases and Tuberculosis in Africa (IMPALA)/Pan African Thoracic Society Methods in Epidemiologic, Clinical and Operations Research (PATS MECOR) course for 2019 (18). This was a combined event held on 9th and 10th June 2019 in Dar Es Salaam, Tanzania in East Africa. In order to maximize the opportunity, the cohort identified had a two-day training on Air Quality Measurement. This training commenced one day before the main event to have uninterrupted hours of knowledge transfer. The program of events and pictures are attached herewith (Appendix A).

During this training, most participants were found to be new to Air Quality Monitoring and as such the concepts were thought from first principles. The faculty (SS, BA, GO) focused on particulate matter, carbon monoxide and ambient air pollution. The use of Purple Air-II-SD sensor and Lascar logger were also focused on. Ultimately, the MA3 study was introduced, explained in detail and thrown open for participants to commit to being a part of it. The ethical waiver letter from the Liverpool School of Tropical Medicine (Appendix B) and the study protocol (Appendix C) were later circulated among the participants. All participants opted to participate. In the end, each participant was given one Purple Air II SD device and one Anker® power bank. A few people were also given Lascar® logger for use for separate research-related purposes.

In order to ease the process of transporting the air quality measurement equipment from Tanzania to the respective home countries of the AQM scientists, an individualised customs information letter was written for each person by the executive assistant to the director of the Liverpool School of Tropical Medicine (Appendix D).

A WhatsApp® mobile chat group was also created by BA to ease the process of communicating, coordinating and supporting the physicians in the process of installing, maintaining and downloading data from the PurpleAir II SD equipment.

Study Design

The study was a four-week multi-centric longitudinal air pollution monitoring to evaluate the air quality in thirteen sites across seven countries across sub-Saharan Africa using low-cost sensors. Data on ambient PM2.5 were collected continuously.

The Physicians that participated in the African Centre for Clean Air (ACCA)-facilitated AQM training in Dar Es Salaam, Tanzania in June 2019 carried out the $PM_{2.5}$ measurement in the following locations:

1. Cotonou, Benin Republic
2. Ouagadougou, Burkina Faso
3. Douala, Cameroon
4. Fajara, The Gambia
5. Nairobi, Kenya
6. Bariga, Lagos, South-Western Nigeria
7. New Haven, Enugu, Eastern Nigeria
8. Goshen, Enugu, Eastern Nigeria
9. Abakaliki Road, Enugu, Nigeria
10. Trans-Ekulu, Enugu, Eastern Nigeria
11. Awka, Anambra, Nigeria
12. Nnewi, Anambra, Nigeria and
13. Kampala, Uganda

Due to health-related and local permission reasons, Khartoum in Sudan, Mbeya in Tanzania and two other locations in Nairobi, Kenya were unfortunately unable to take part in the MA3 feasibility study.

Sampling Strategy

Sampling Tool/Instrument: Purple Air-II-SD sensor

The Purple Air-II-SD is a ubiquitous AQM tool that performs quite well at both low and high particulate matter (PM) concentration. It is an optical particle counter that can be used for measuring household PM, personal PM exposure and ambient PM (20). Some unique properties of Purple Air-II-SD sensor are: It is wifi enabled and is thus able to upload in real-time to the Purple Air website server via wi-fi or mobile phone hotspot and it is also able to log data to an SD card and so data is always recoverable if a wi-fi signal is lost for any reason.

The instrument is cone-shaped, made of a combination of plastic and metal and weighs one pound (approximately 0.5kg). The plastic-covered top is the sensor surface which must be exposed to the atmosphere always to pick up the particulate matter readings. On the side, there is a sturdy metal panel with two perforations attached. This serves to aid the mounting of the instrument. When Purple Air-II-SD is turned upside down, it has a twin metal chamber within it (sensor A & B) which functions to maintain the internal integrity/internal quality assurance. On the extreme sides of the sensors, the microSD card slot is present on one side while the USB power cable point is present on the other side. The power cable and adapter are connected to the device through the latter. Where alternating current power source is unavailable, the power bank is also connected through this same USB power cable point. The pictures of the PurpleAir-II-SD sensor are in figures 1 and 2 below.

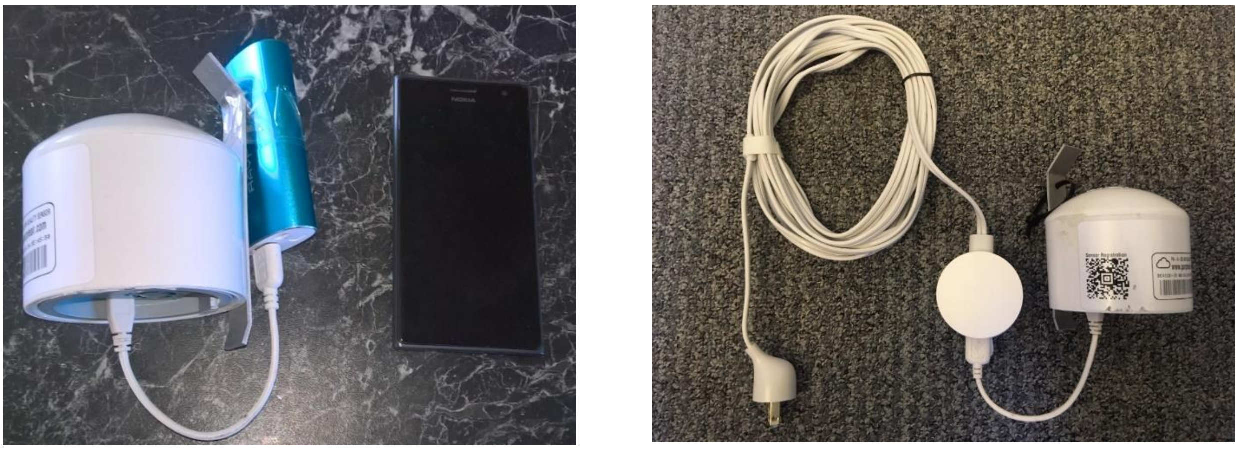

Figure 1: Purple Air-II-SD sensor with a powerpack (left) and with an alternating current

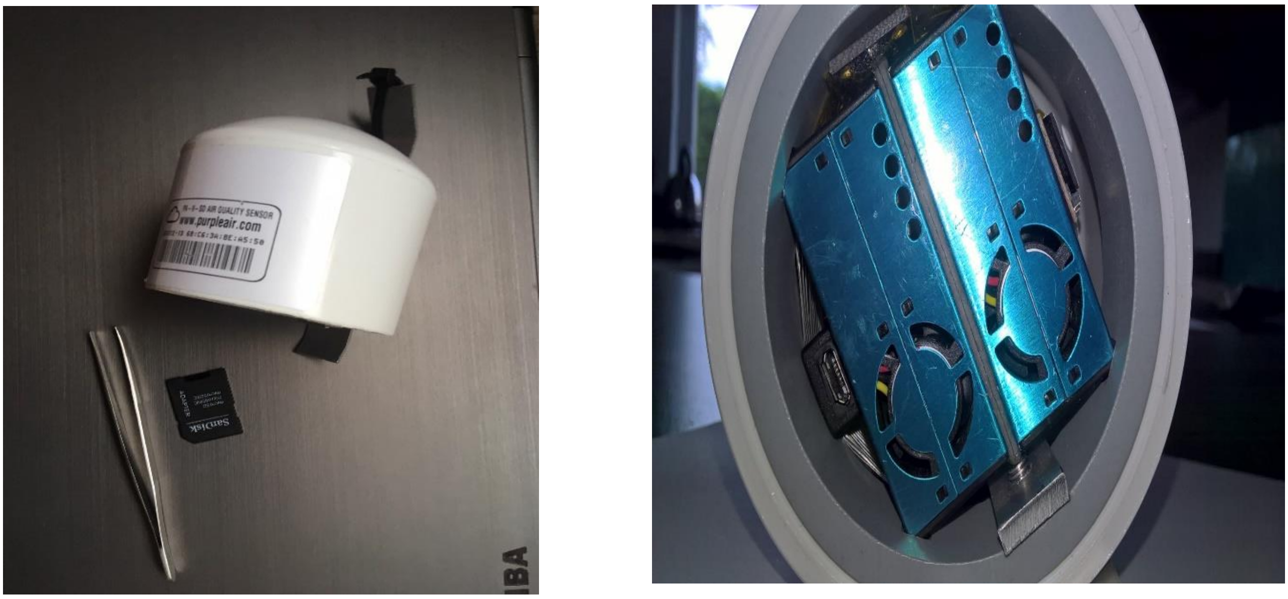

Figure 2: Purple Air-II-SD sensor with a tweezer & SD card (left) and turned upside

Independent evaluation data has shown that Purple Air-II-SD sensor has good agreement with gold standard instruments ($R^2 = 0.979$) (17).

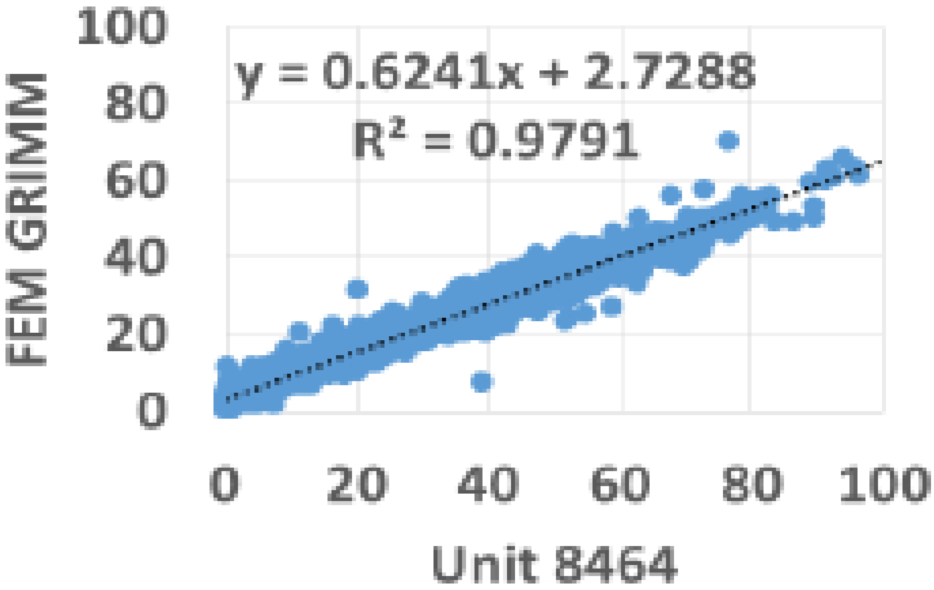

Figure 3: Performance of the GRIMM reference method versus Purple Air sensor (named unit 8464 in the field evaluation). $PM_{2.5}$ five-minute mean, measured in µg/m^3.
Source: http://www.aqmd.gov/docs/default-source/aq-spec/field-evaluations/purple-air-pa-ii---field-evaluation.pdf?sfvrsn=4 (Page 7)

When Purple Air-II-SD is used at high PM concentrations, it also performs quite well. (18) Figure 4 reveals Purple Air's good performance at high PM levels as compared with Sidepak, an older and well-known optical PM measuring device, at a 97% level of agreement.

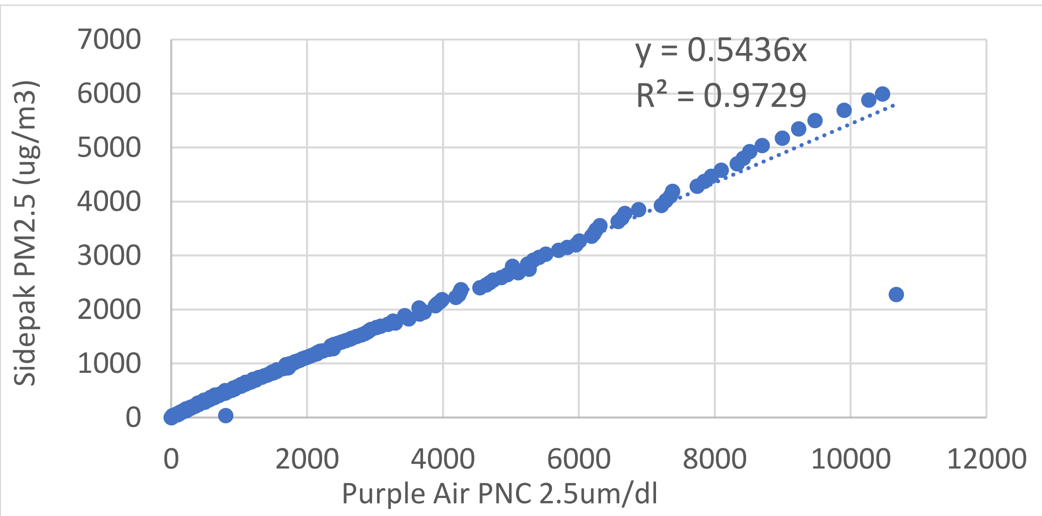

Figure 4: Performance of Sidepak versus PurpleAir in the measurement of $PM_{2.5}$

Regarding the cost, simpler low volume samplers for personal and microenvironmental monitoring of PM2.5/PM10 costs less than $1,000. Commercial medium or low volume AQM sampling systems cost $5,000-8,000. The automated continuous monitoring systems cost $20,000-25,000 (21) The tapered element oscillating microbalance instrument (TEOM) costs over £10,000 GBP (22).

The AQM instruments using gravimetric and optical methods costs between $400 and over $6,000 for hardware only, not mentioning the cost of filter analysis for the gravimetric ones, while the Purple Air-II-SD sensor costs $250 and requires no filter analysis in special laboratories. Examples of the optical AQM instruments are TSI Sidepak AM510, TSI Dustrak, RTI MicroPEM, Dylos DC1700 and the Berkeley PATS+ (15).

In order to understand the implications of the readings derived from the Purple Air sensors, the United States Environmental Protection Agency (EPA) Air Quality Index, which signifies the breakpoints for PM2.5 was designed. This is summarised in the table below:

Table 1: United States Environmental Protection Agency (EPA) Air Quality Index

$PM_{2.5}$ mg/m^3	**AQI**	**Advice**
0-12	Good	Air quality is satisfactory and poses little or no health risk.
12.1-35.4	Moderate	People who are unusually sensitive to particle pollution may experience respiratory symptoms.
35.5-55.4	Unhealthy for sensitive groups	Heart/lung disease and elderly/ children advised reducing prolonged exertion
55.5-150.4	Unhealthy	Heart/lung disease/elderly/children avoid prolonged exertion; everyone reduces prolonged exertion
150.5-250.4	Very unhealthy	Heart/lung disease avoid all physical activity; everyone avoids prolonged exertion
250.5+	Hazardous	Heart/lung disease remain indoors; everyone avoids physical activity

Also, the World Health Organization (WHO) air quality guidelines stipulate that the safe annual mean threshold for $PM_{2.5}$ is 10μg/m^3 while the 24-hour mean is 25μg/m^3(23).

MA3 study chose to use Purple Air -II-SD sensors due to the properties earlier highlighted which makes it accessible, affordable and relatively easier to maintain. Regarding the current published knowledge of ambient air pollution in sub-Saharan Africa, there is a big gap in our knowledge of ambient air pollution in sub-Saharan Africa. The map below shows the state of what is known about $PM_{2.5}$ globally, with sub-Saharan Africa (within the red circle) having sparse data. We hope to contribute significantly to the fount of knowledge on ambient $PM_{2.5}$ using Purple Air -II-SD sensors.

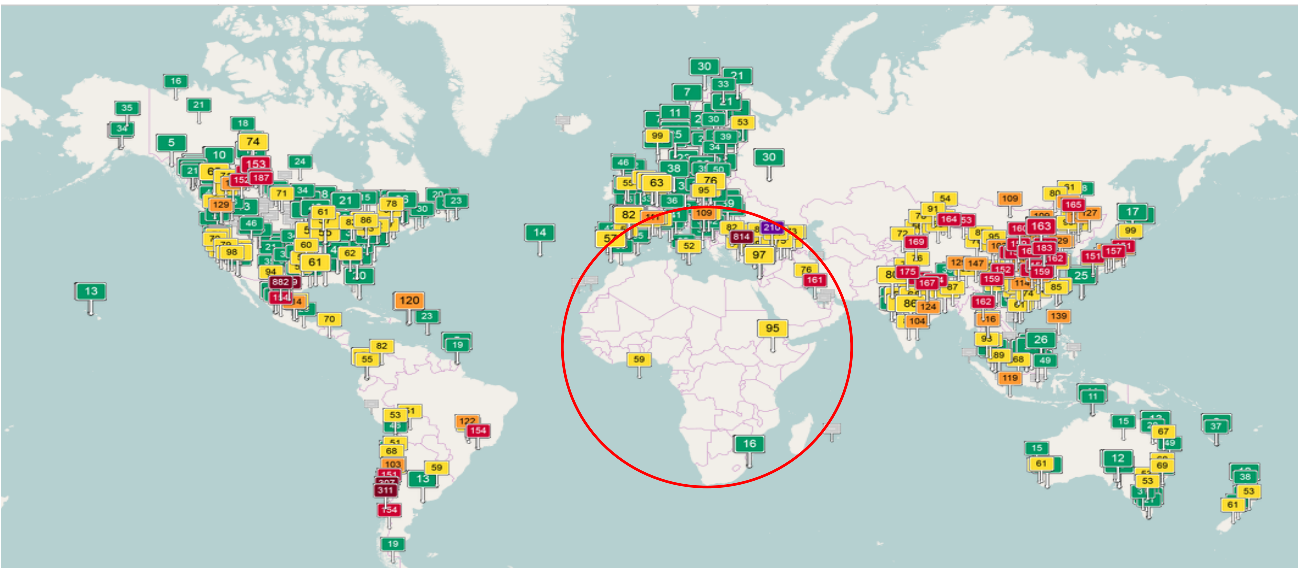

Figure 5: Map showing the gap in the knowledge of ambient air quality index in sub-Saharan Africa ***Source:*** www.onairschools.org/2017/09/07/air-quality-real-time-map

Further details about the sampling tool, the sampling frame, sampling item, and sampling sequence are found in pages 4 to 6 in the MA3 project protocol (Appendix C)

Variables

Outcome variable: The primary outcome variable is the percentage of $PM_{2.5}$ data logged by each device, given the total number of minutes in July 2019.

Secondary outcome variables are challenges experienced during the installation, use, maintenance, and data download from the Purple Air -II-SD devices used.

Exposure variables : Sampling site (urban/semi-urban city in sub-Saharan Africa) ; Meteorological conditions: dry and rainy season, road dust (unpaved roads, living on the roadside, road capacity), traffic (high traffic area, traffic flow, fuel type, age of cars) , sources of domestic energy (coal/charcoal and other biomass fuel), solid waste combustion, bush burning, commercial activities (food preparation, street vendor, vehicular/motorbike taxi driver) , tree cutting and construction activities .

Data Collection

Baseline data about the sampling site was collected using the questionnaire in Appendix 1 of the MA3 protocol -Appendix C. Information regarding the challenges faced during installation, use, maintenance, and data download from the PurpleAir-II-SD device was collected using the form in Appendix 2 in the MA3 protocol. $PM_{2.5}$ concentration was be sampled as already highlighted under the sampling sequence section. Every week, the Microsoft excel CSV files bearing the ambient $PM_{2.5}$ data were manually downloaded by the site exposure scientist and zipped up in preparation for sending. The filled out forms and the Microsoft excel CSV files from the device SD cards were sent by email to bawokola@gmail.com cc gabrielokello@gmail.com. In the sites where the devices were connected to wifi, the $PM_{2.5}$ data were downloaded from the Purple Air website (24).

Following the steps outlined in the protocol for time drift or shift of time stamp on the device (Appendix E), a deliberate attempt was made at calculating how much time the device in-built Real-Time Clock (RTC) loses when not connected to the internet. This RTC needs to connect to an internet clock continuously or at least intermittently for it to stay accurate. In situations where there is no internet wifi, the RTC loses its accuracy.

Data preparation and statistical analysis

At one-week intervals, zipped folders containing the excel comma-separated value (CSV) files having the $PM_{2.5}$ data are received from all the participating sites. One CSV file contains $PM_{2.5}$ data logged at 80 seconds-120 seconds interval for one full day (24 hours). The interval of logging depends on the version of the firmware in the device. These folders were unzipped, the CSV files extracted and kept in a pre-labelled folder on the study personal computer. This was done until the end of the data collection period (July 1, 2019, to July 31, 2019). In the ideal situation, 31 CSV files were expected in each site folder at the end of the data collection period.

Each file was next screened for error bars and glitches which were removed when seen. Following this, each site folder was run through a 'Purple Air Cleaner' or pa cleaner software. This was designed by Dr. Ruaraidh Dobson and Prof Sean Semple of the Institute for Social Marketing at the University of Stirling, Stirling, Scotland to extract daily $PM_{2.5}$ averages by date and create just one CSV file per study site from a folder containing multiple CSV files from each site.

The percentage number of hours for which $PM_{2.5}$ data were logged during the study period was calculated for each study site using the formula below:

$$\left[\frac{\text{Number of logged data}}{\text{PurpleAir device time periods}} \times 100\%\right]$$

The number of logged data is the count of the number of $PM_{2.5}$ data readings found in the CSV files. Purple Air device time period was derived from multiplying 31 days by 24 hours, converting this to seconds by multiplying by 3600. This is then divided by the interval (in seconds) at which that device logs. Some devices log every 80 seconds and some log every 120 seconds. This percentage number of hours was referred to as the data recovery rate. In addition to the recovery rate, summary statistics counts at various $PM_{2.5}$ thresholds, bar charts and line graphs were computed within the Microsoft Excel environment.

The files sent from each participating site following the time drift test were accompanied by the time the investigators disconnected the devices from power and when they reconnected them to the power source. The CSV files were then examined for the time the ‘bug' sign was seen, which signifies when the device came on according to its Real-Time Clock (RTC). The drift in the time stamp was then calculated by the difference between this device ‘bug' sign time and the actual location time that the exposure scientist switched the device back on. The ‘bug’ sign is three vertical bars within a single Microsoft excel cell.

The next step in analysis is being planned. These were not done due to the short duration of data collection in this feasibility study and time constraint. On the single CSV file generated per study site, trends and associations in the data will be investigated using longitudinal data methods (autoregressive time-series models, hierarchical modelling for time-series data). We will then calculate the probability that our $PM_{2.5}$ measurements exceed the current WHO standard for ambient $PM_{2.5}$, to generate data that quantifies the magnitude of air pollution in these sub-Saharan African countries.

Timeline Followed

The timeline followed for the various phases of the MA3 feasibility and practicality project of July 2019 is as in the Gantt chart below in table 2.

Table 2: Gannt Chart showing the MA3 feasibility study timeline

	June 7-16	June 17-30	July 1- 30	August 1-7	August 7-21	August 22-30	Sept. 1-10
AQM Training							
Set up of PurpleAir at home countries							
Four weeks of data capturing							
Data upload							
Final Data upload							
Data preparation & Analysis							
Manuscript Write-up							

RESULTS

Eighteen physicians spread across nine [9] sub-Saharan African countries participated in the AQM workshop. At the execution stage, 13 physicians representing seven [7] sub-Saharan African countries participated in data collection. Three physicians had challenges getting permission locally to set up the instruments while the last person had a near-fatal motor vehicular accident. The sites were either urban or semi-urban and the study was executed during the wet season. The details of the participating sites and countries are contained in table 3.

Out of the 13 devices used at the sites that participated in the data collection, only two (Nairobi, Kenya and Fajara, The Gambia) were permanently connected to the wifi. The devices in these two countries thus had two options for data download: download from the Purple Air website or manual data download from the SD cards in the devices. All the other devices placed at the other 11 sites were not connected to wifi and data could only be downloaded from them manually. Details of these can be found in table 4.

Table 3: Details of participating countries and sites in the MA3 study of July 2019

Country	Town & City	Town description	Season	Place the device was placed
Benin Republic	Cotonou	Urban	Wet	Hospital premises
Burkina Faso	Ouagadougou	Urban	Wet	Residential premises
Cameroon	Douala	Urban	Wet	Hospital premises
The Gambia	Fajara	Urban	Wet	Residential premises
Kenya	Ngong Road, Nairobi	Urban	Wet	Residential premises
Nigeria	Bariga, Lagos	Urban	Wet	Hospital premises
Nigeria	New Haven, Enugu	Urban	Wet	Residential premises
Nigeria	Abakaliki Rd, Enugu	Semi-Urban	Wet	Residential premises
Nigeria	Trans-Ekulu, Enugu	Urban	Wet	Residential premises
Nigeria	Goshen, Enugu	Urban	Wet	Residential premises
Nigeria	Nnewi, Anambra	Urban	Wet	Residential premises
Nigeria	Awka, Anambra	Urban	Wet	Residential premises
Uganda	Ntinda, Kampala	Urban	Wet	Office premises

Table 4: Wifi connectivity and data download methods for the MA3 study sites

Country	Town & City	Wifi Yes/No	Real-time Yes/No	Data download method
Benin	Cotonou	Wifi no	No	SD card manually
Burkina Faso	Ouagadougou	Wifi no	No	SD card manually
Cameroon	Douala	Wifi no	No	SD card manually
The Gambia	Fajara	Wifi yes	Yes	Purple Air website
				SD card manually
Kenya	Ngong Road, Nairobi	Wifi yes	Yes	Purple Air website
				SD card manually
Nigeria	Bariga, Lagos	Wifi no	No	SD card manually
Nigeria	New Haven, Enugu	Wifi no	No	SD card manually
Nigeria	Abakaliki Rd, Enugu	Wifi no	No	SD card manually
Nigeria	Trans-Ekulu, Enugu	Wifi no	No	SD card manually
Nigeria	Goshen, Enugu	Wifi no	No	SD card manually
Nigeria	Nnewi, Anambra	Wifi no	No	SD card manually
Nigeria	Awka, Anambra	Wifi no	No	SD card manually
Uganda	Ntinda, Kampala	Wifi no	No	SD card manually

The percentage of minutes of $PM_{2.5}$ logged over the one-month study period (also referred to as the data recovery rates) is displayed in table 5. Only one study site (Nairobi, Kenya) had a 100% data recovery rate. Abakaliki Road, Enugu, Nigeria (98.6%) and Kampala, Uganda (95.5%) followed that of the Nairobi site. The least rate was obtained in Bariga, Lagos, Nigeria (72.1%) while the others had between 90 and 94.4% data recovery rate.

Table 5: Percentage of minutes of $PM_{2.5}$ logged over the one month per device in each study site in the MA3 study

Country	Town & City	Number of Records logged	PA time periods	Percentage of minutes of $PM_{2.5}$ logged Data recovery rates (%)
Benin Republic	Cotonou	30799	33480	92.0%
Burkina Faso	Ouagadougou	21142	22320	94.7%
Cameroon	Douala	*	33480	0.0%
The Gambia	Fajara, Greater Banjul	20636	22320	94.7%
Kenya	Ngong Road, Nairobi	22320	22320	100.0%
Nigeria	Bariga, Lagos	24148[#]	33480	72.1%
Nigeria	New Haven, Enugu	31241	33480	93.3%
Nigeria	Abakaliki Rd, Enugu	32999	33480	98.6%
Nigeria	Trans-Ekulu, Enugu	31139	33480	93.0%
Nigeria	Goshen, Enugu	35322[ϕ]	33480	105.5%
Nigeria	Nnewi, Anambra	21078	22320	94.4%
Nigeria	Awka, Anambra	31500	33480	94.1%
Uganda	Ntinda, Kampala	21312	22320	95.5%

* *The data collected at Douala, Cameroon from July 1 to July 31, 2019, was corrupted due to firmware/device software errors. The data was not interpretable and could not be utilized*

[ϕ] *In a bid to search for wifi for its real-time clock (RTC), the device in Goshen logged every 30 seconds instead of every 80 seconds due to it not being connected to wifi.*

Table 6: Comparison of $PM_{2.5}$ averages from each site with selected $PM_{2.5}$ thresholds

Country	Site	Records	#MM>10	#MM>25	#MM>250	%MM>10	%MM>25	%MM>250
Burkina Faso	Ouagadougou	**21142**	16026	4647	1	**75.80**	**21.98**	**0.00**
The Gambia	Faraja	**20636**	11455	1644	78	**55.51**	**7.97**	**0.38**
Nigeria	Enugu, New Haven	**31241**	29569	18811	4	**94.65**	**60.21**	**0.01**
Nigeria	Anambra, Nnewi	**21078**	20500	16944	173	**97.26**	**80.39**	**0.82**
Nigeria	Anambra, Awka	**31498**	29343	20003	18	**93.16**	**63.51**	**0.06**
Kenya	Nairobi	**22320**	21322	14256	11	**95.53**	**63.87**	**0.05**
Uganda	Kampala, Ntinda	**21312**	21293	19605	276	**99.91**	**91.99**	**1.30**
Benin	Cotonou	**30799**	29262	9178	3	**95.01**	**29.80**	**0.01**
Nigeria	Enugu, Abakaliki	**32998**	30437	15972	13	**92.24**	**48.40**	**0.04**
Nigeria	Enugu, TransEkulu	**31138**	28428	15178	28	**91.30**	**48.74**	**0.09**
Nigeria	Enugu, Goshen	**35322**	32512	18084	4	**92.04**	**51.20**	**0.01**
Nigeria	Lagos, Bariga	**24148**	24062	23113	22	**99.64**	**95.71**	**0.09**

= Number | % =Percentage | *MM = Measurements in $\mu g/m^3$

Table 6 shows the comparison of the purple air device $PM_{2.5}$ loggings at each site with selected PM thresholds. These thresholds comprise 10, 25 and 250 all in $\mu g/m^3$. Overall, the sites with the highest recorded readings as revealed by readings greater than 250 $\mu g/m^3$ were Kampala-Uganda, Nnewi-Anambra-Nigeria, and Fajara-The Gambia sites. Those with the most readings above the WHO daily average threshold (25 $\mu g/m^3$) were Bariga-Lagos, Awka-Anambra-Nigeria, Kampala-Uganda, and New haven-Enugu-Nigeria. The lowest number of recordings > 250 $\mu g/m^3$ were observed at Ouagadougou-Burkina Faso, Cotonou-Benin Republic, New

Haven-Enugu and Goshen-Enugu sites. Also, the lowest number of loggings >25 µg/m^3 were recorded at Fajara-Gambia, Ouagadougou-Burkina Faso and Cotonou-Benin Republic sites.

Figure 6 to figure 17 below comprises bar charts showing the daily $PM_{2.5}$ concentration in each of the MA3 feasibility study participating sites. A red line showing the World Health Organization (WHO) $PM_{2.5}$ safety threshold for daily levels (25µg/m^3) was added to each bar chart to show study side $PM_{2.5}$ levels in comparison with this WHO safe level. Kampala-Uganda, Nairobi-Kenya, Bariga-Lagos-Nigeria, and Nnewi-Nigeria showed daily values that were above the WHO threshold (figures 8, 9, 11 and 16 respectively). Awka-Nigeria, Abakaliki Rd., Enugu-Nigeria, Goshen-Enugu-Nigeria, and New Haven-Enugu-Nigeria had values that were borderline in comparison to the standard. The sites with $PM_{2.5}$ concentration lower than the WHO safety limits are Cotonou-Benin Republic, Fajara-Gambia, Ouagadougou.

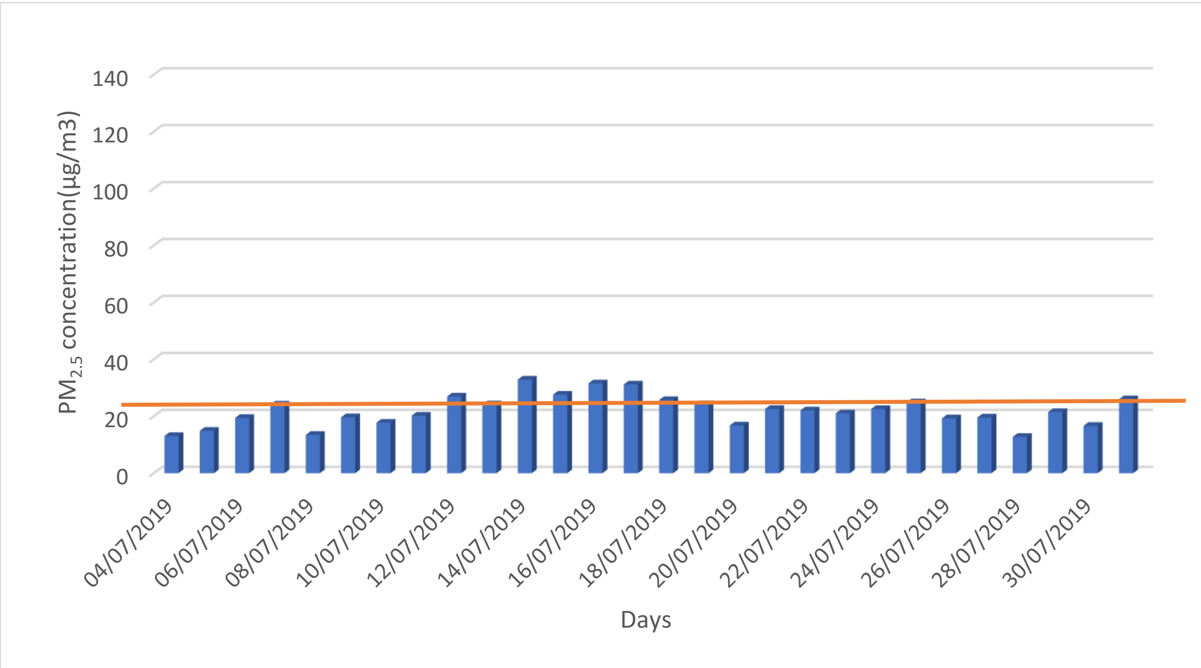

Figure 6: Daily $PM_{2.5}$ concentration in Cotonou, Benin Republic

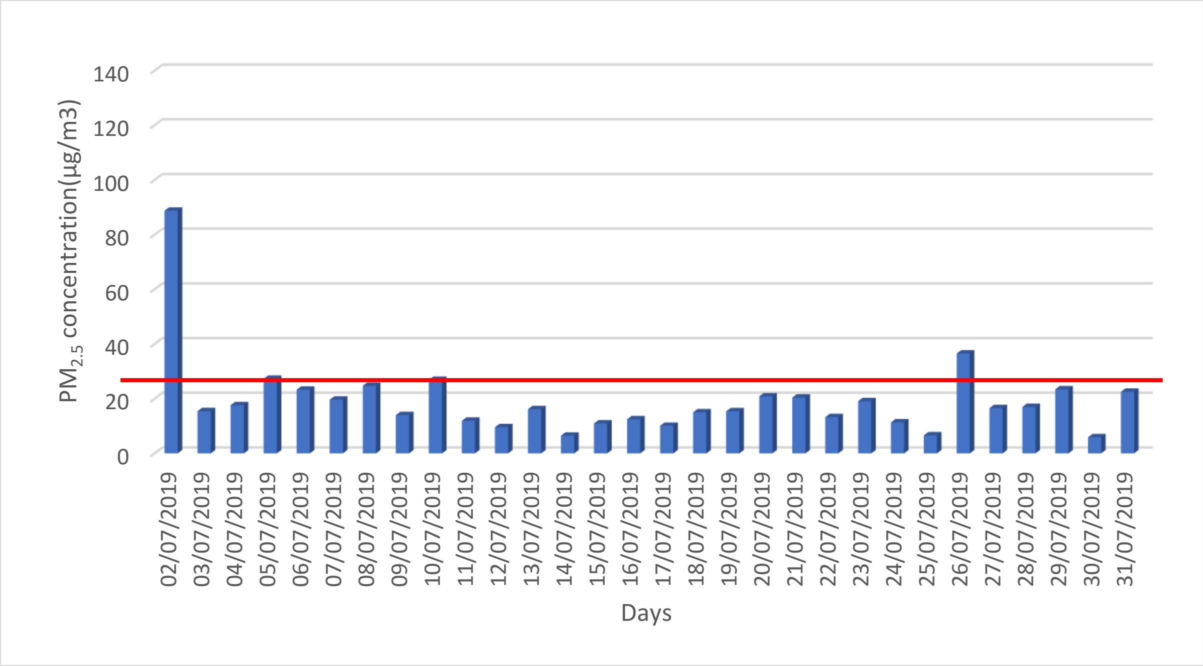

Figure 7: Daily $PM_{2.5}$ concentration in Fajara, The Gambia

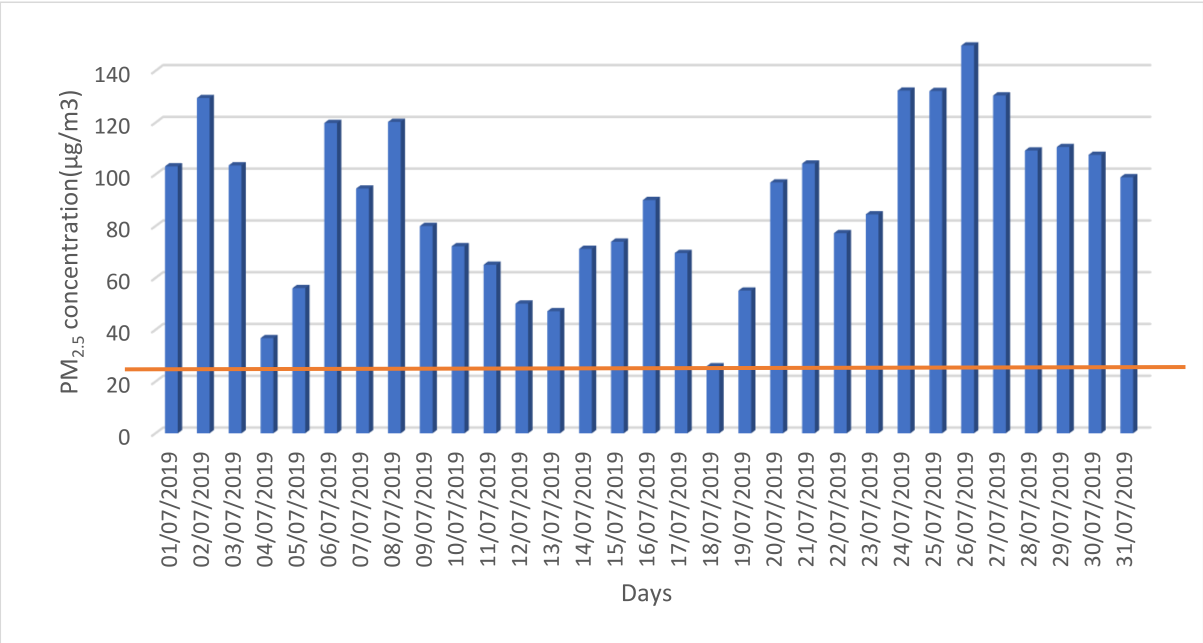

Figure 8: Daily $PM_{2.5}$ concentration in Kampala, Uganda

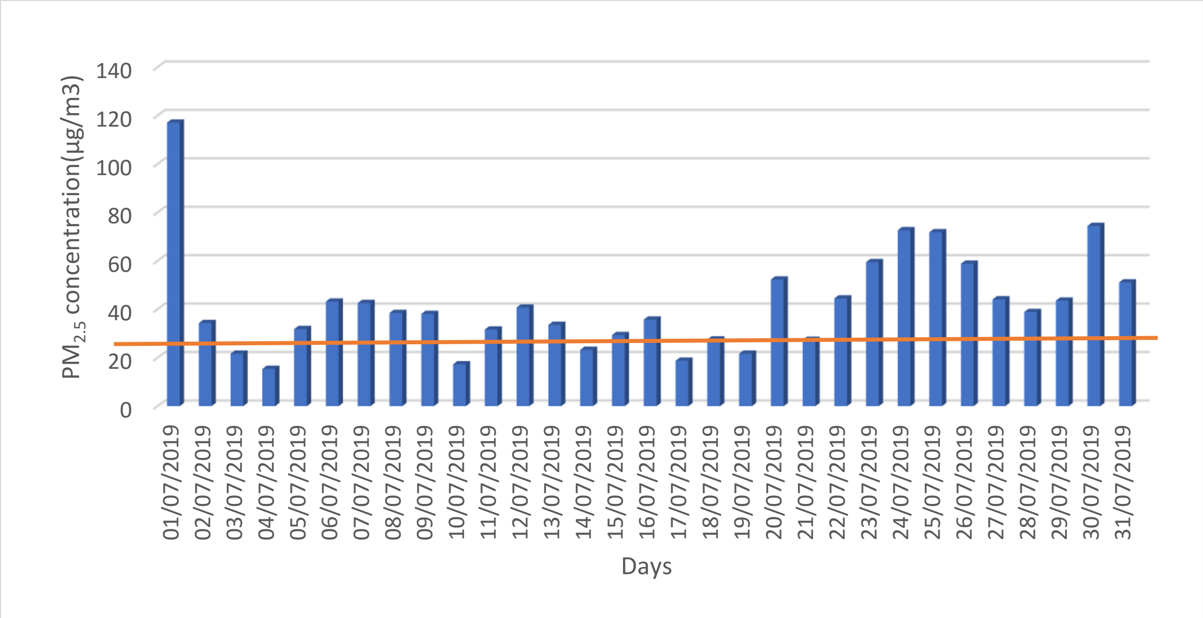

Figure 9: Daily $PM_{2.5}$ concentration in Nairobi, Kenya

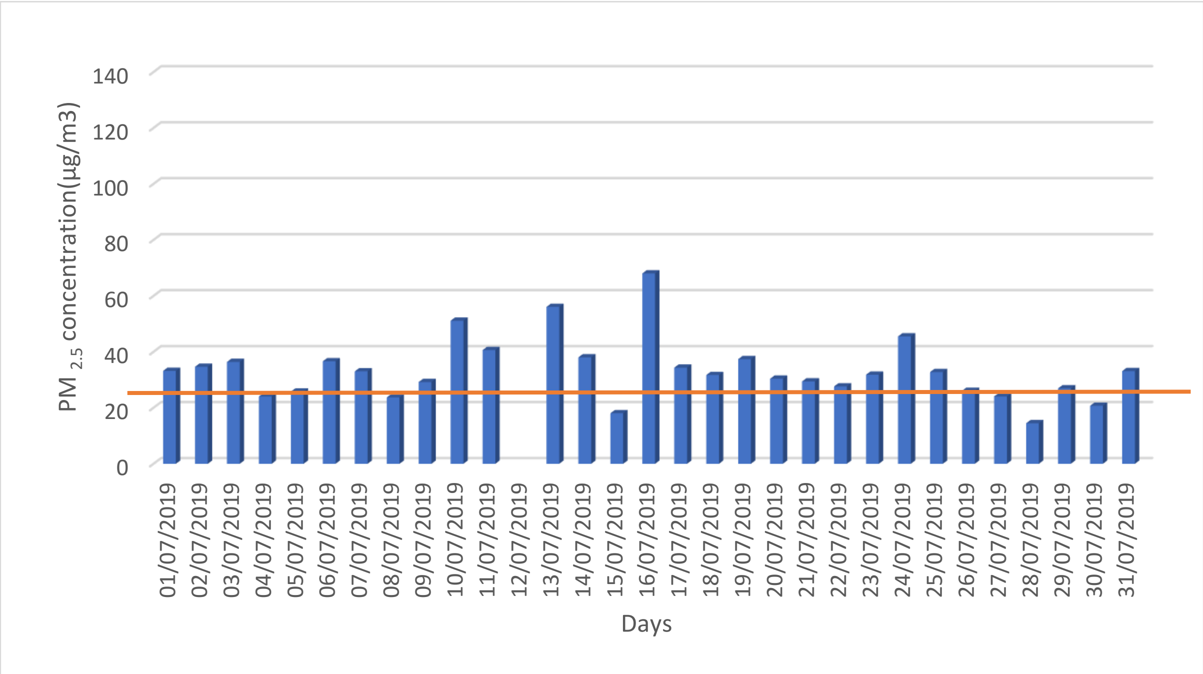

Figure 10: Daily $PM_{2.5}$ concentration in Awka, Nigeria

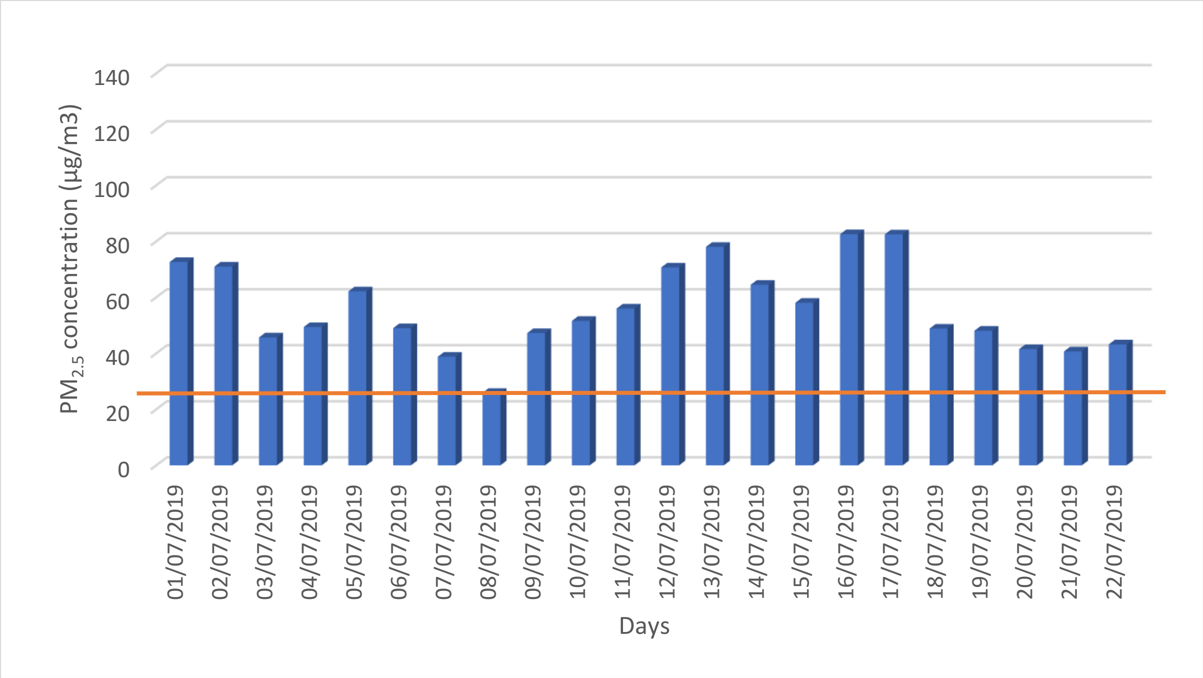

Figure 11: Daily $PM_{2.5}$ concentration in Bariga, Lagos, Nigeria

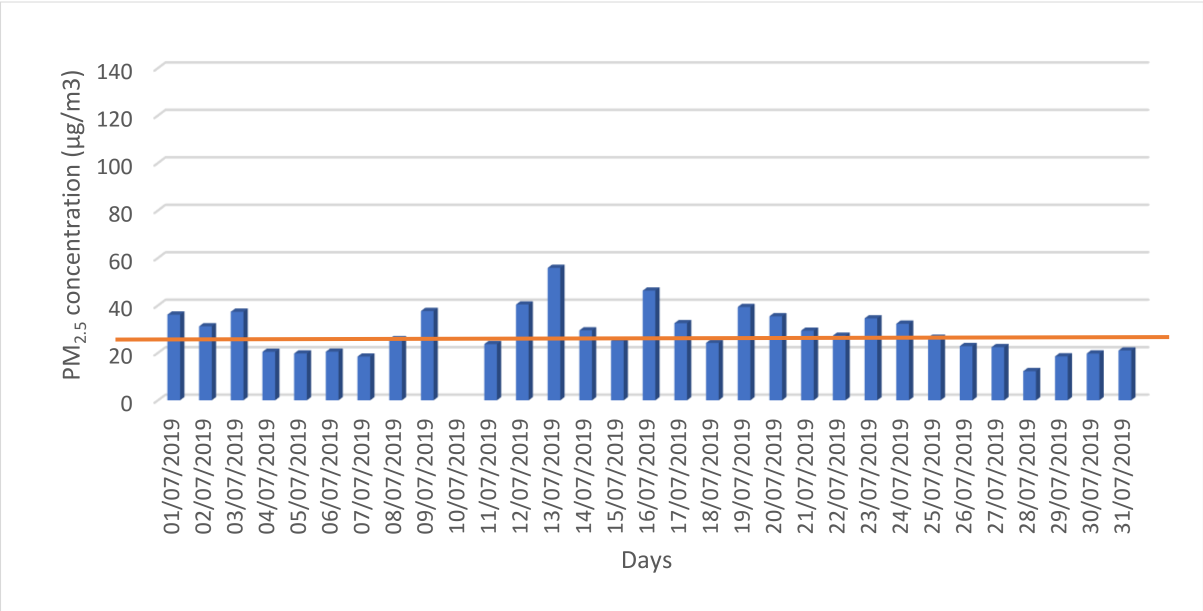

Figure 12: Daily $PM_{2.5}$ concentration on Abakaliki Road, Enugu, Nigeria

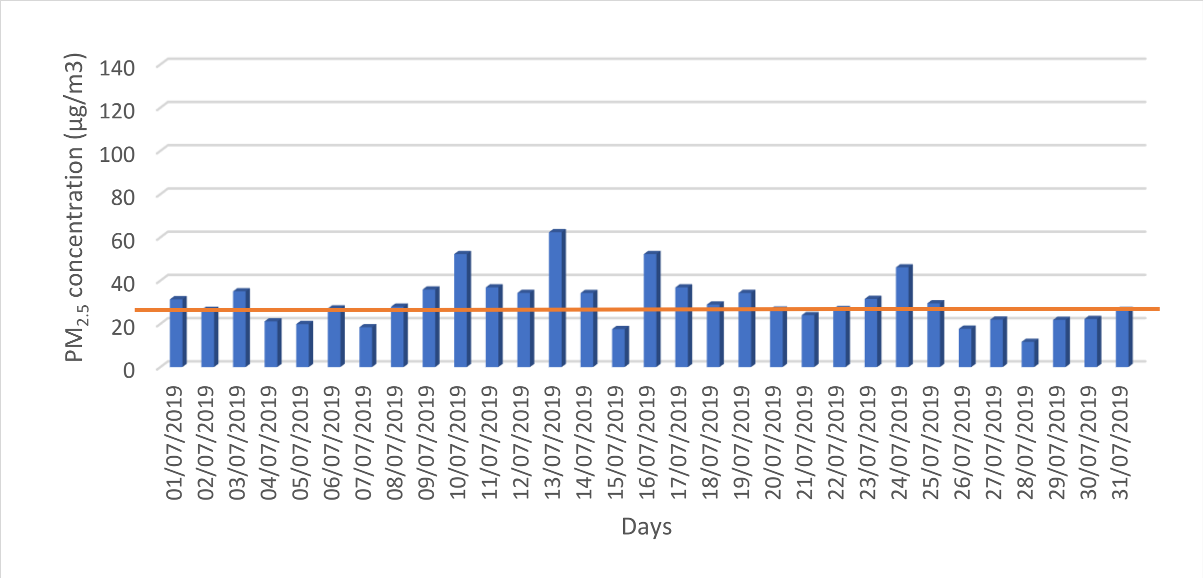

Figure 13: Daily $PM_{2.5}$ concentration in Goshen, Enugu, Nigeria

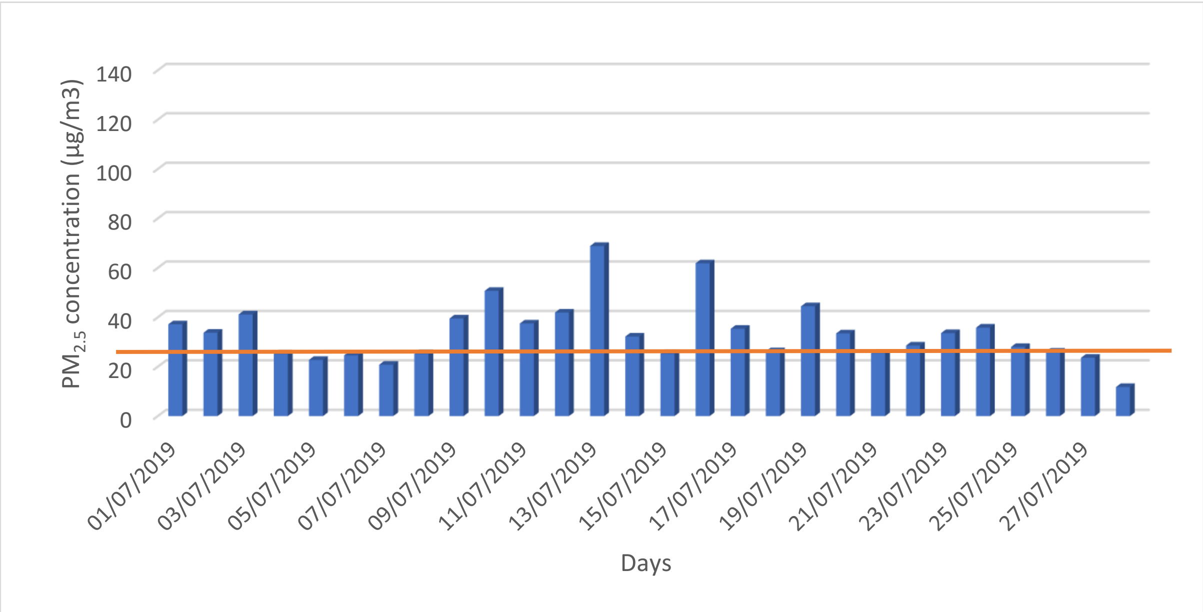

Figure 14: Daily $PM_{2.5}$ concentration in New Haven, Enugu, Nigeria

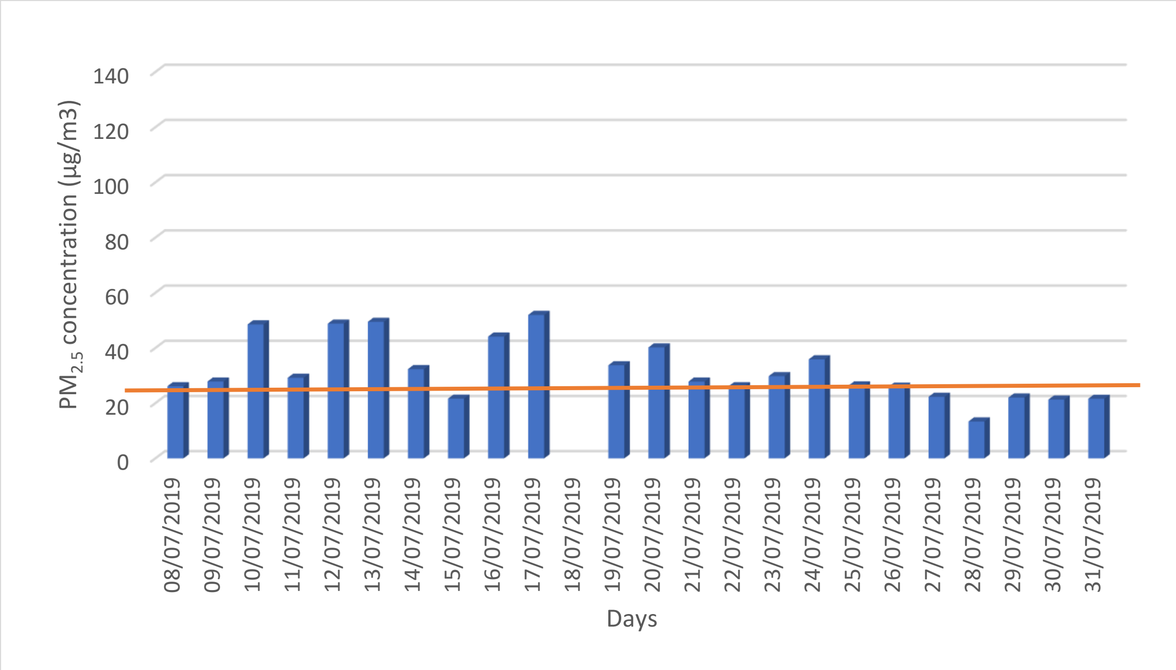

Figure 15: Daily $PM_{2.5}$ concentration in Trans Ekulu, Enugu, Nigeria

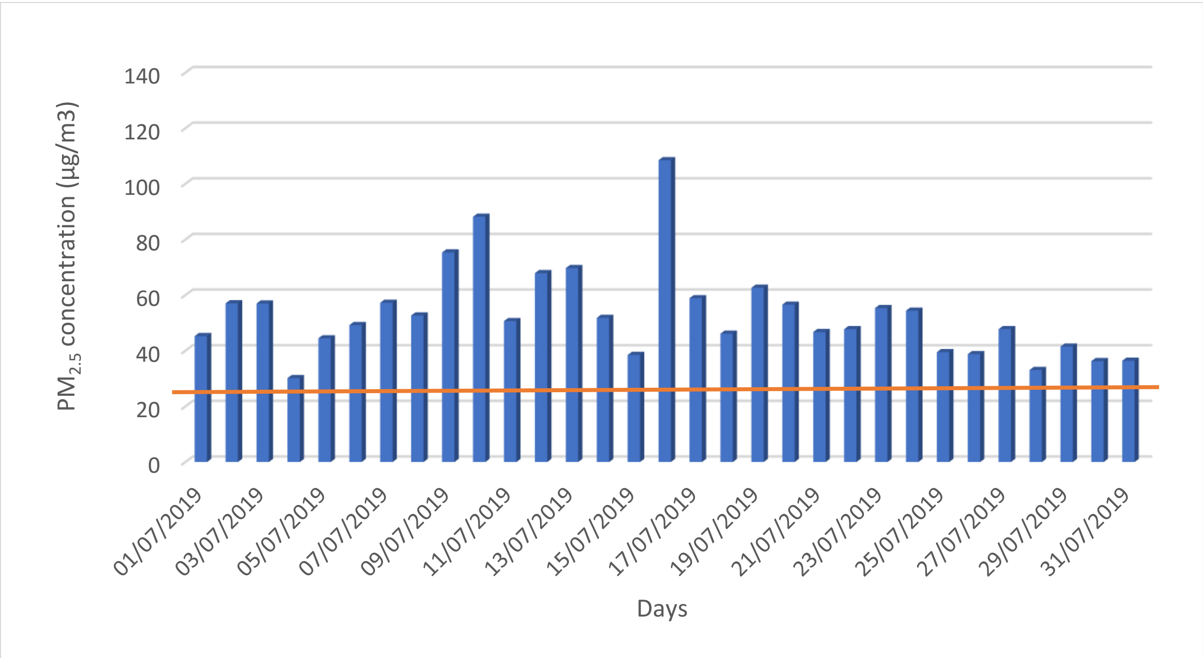

Figure 16: Daily $PM_{2.5}$ concentration in Nnewi, Nigeria

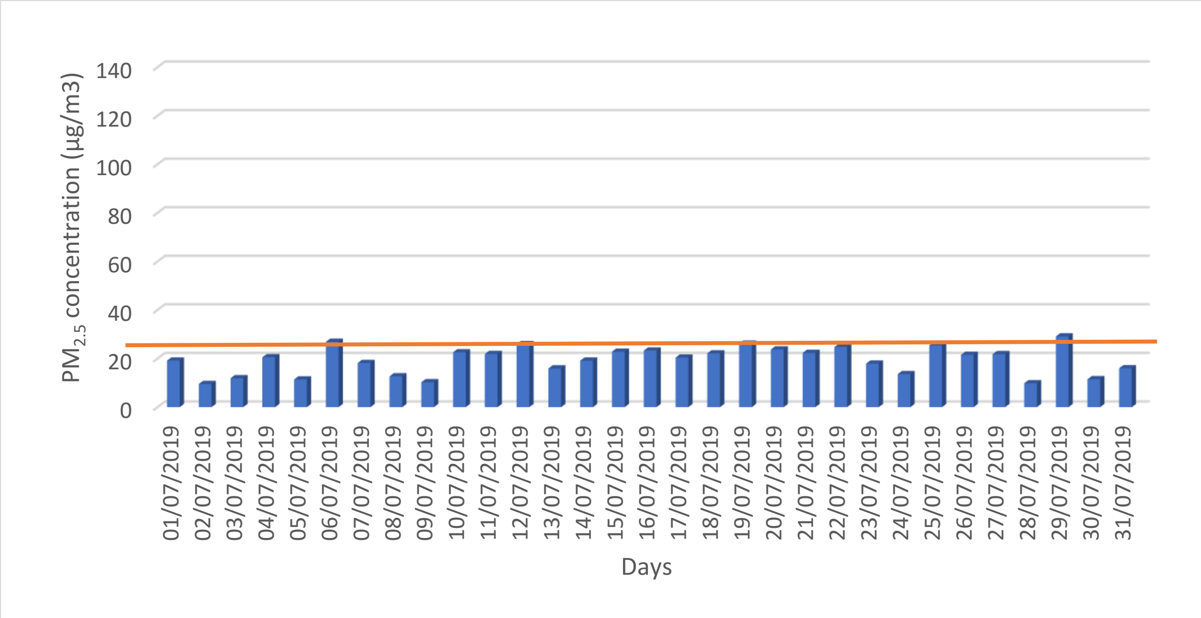

Figure 17: Daily $PM_{2.5}$ concentration in Ouagadougou, Burkina Faso

The hourly averages across each hour of the day for the study period of July 1 to July 31, 2019, were computed and displayed as a line graph in figure 18. Overall, all sites involved in the MA3 feasibility study had hourly averages higher than 10 µg/$m^{3.}$ There was also a slight 'dip' in PM levels between 12noon and 6 pm, followed by a slight rise in the evenings (between 9 pm and 11 pm). Kampala-Uganda, Abakaliki Rd-Enugu-Nigeria, and Bariga-Lagos sites had the highest hourly averages. Fajara-Gambia and Ouagadougou-Burkina Faso sites had the lowest hourly averages.

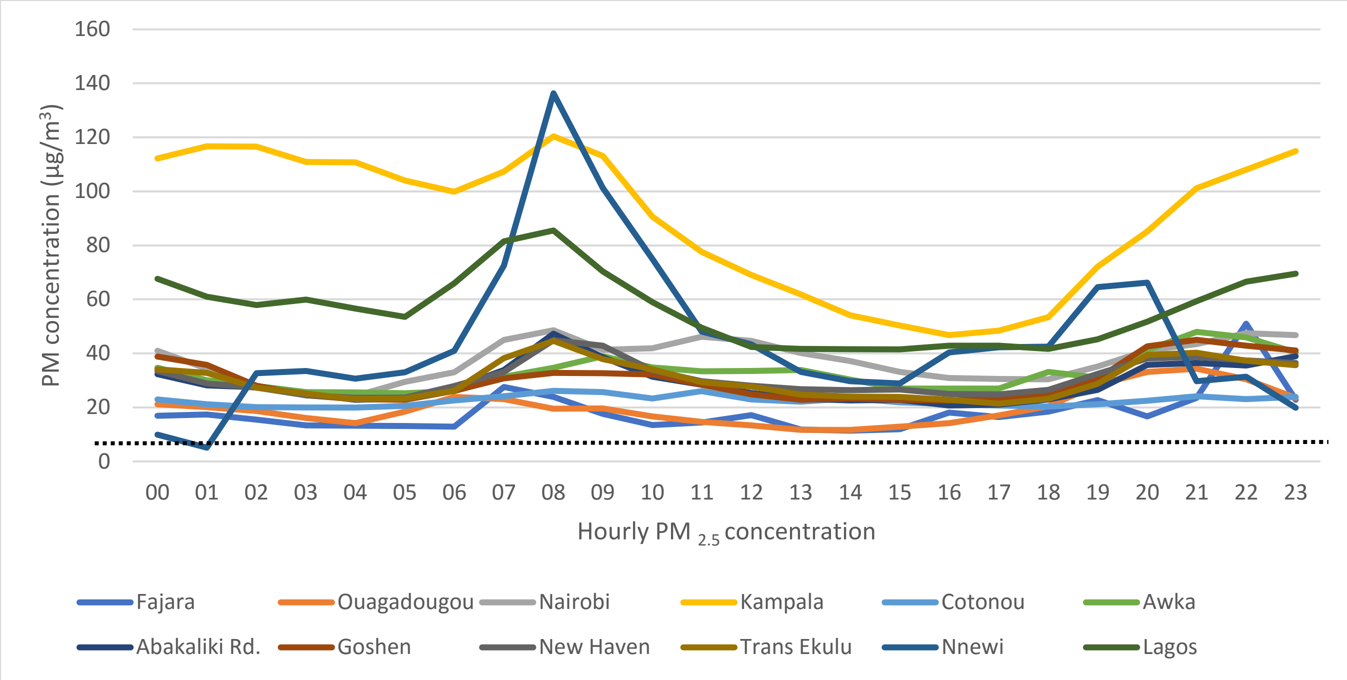

Figure 18: Hourly $PM_{2.5}$ concentration averages at all participating MA3 sites

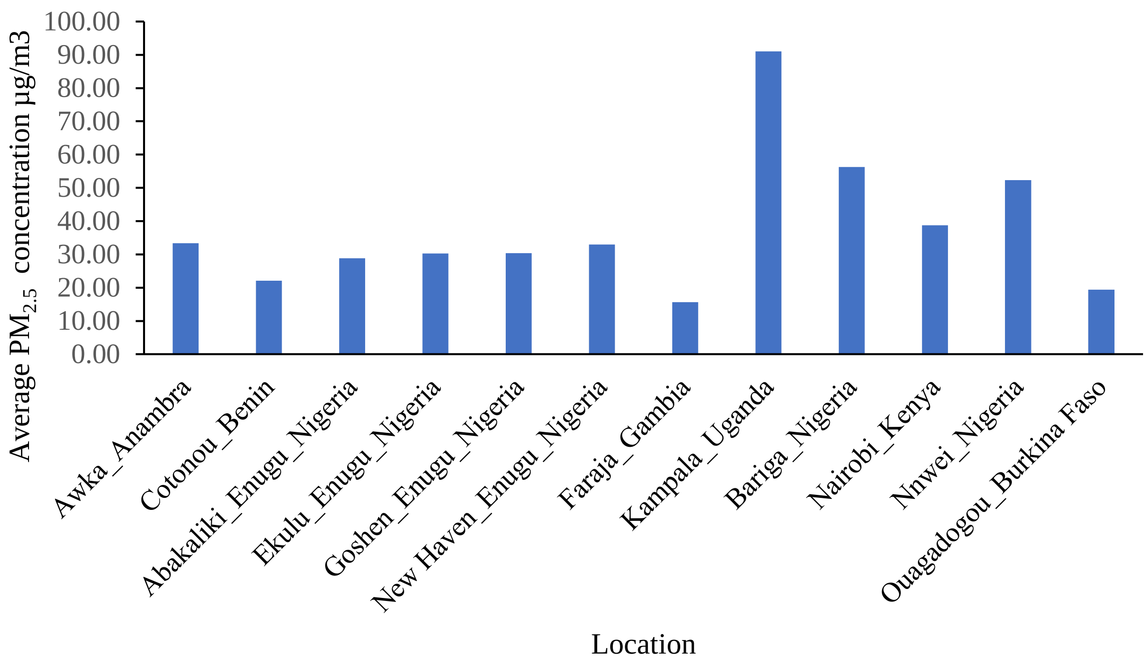

Figure 19: $PM_{2.5}$ period average in µg/m^3 measured in six sub-Saharan African countries in the MA3 feasibility study from 1st to 31st July 2019

The sites with the highest average $PM_{2.5}$ are Kampala-Uganda, Bariga-Lagos, Nnewi-Lagos, and Nairobi-Kenya. The sites with the lowest averages are Fajara-Gambia, Ouagadougou-Burkina Faso and Cotonou-Benin. The bar chart in figure 19 above gives details of this.

The time drift experienced by the devices used in the MA3 study is detailed in table 7 below. The devices in Fajara, Kampala and Abakaliki Road-Enugu-Nigeria had the least time drift (4 to 5½ minutes). The highest times drifts were experienced at the Nigerian sites in Goshen, Awka, and Nnewi sites (17½ to 24 minutes). The other sites had time drifts ranging between 9 and 12 minutes.

Table 7: Time drifts in minutes on the timestamp of the devices used in the MA3 feasibility study.

Country	**City**	**Date drift test was done**	**Time Off**	**Time On**	**'Bug' sign on CSV file**	**Drift (minutes)**
Burkina Faso	Ouagadougou	29th July 2019	3:33:00 PM	3:34:30 PM	3:46:20 PM	**00:11:50**
The Gambia	Fajara	5th Aug. 2019	1:07:00 PM	1:08:00 PM	1:12:04 PM	**00:04:04**
Uganda	Kampala	25th July 2019	7:22:00 PM	7:23:21 PM	7:27:21 PM	**00:04:00**
Kenya	Nairobi	5th Aug. 2019	5:35:48 AM	5:37:49 AM	5:47:48 AM	**00:09:59**
Nigeria	Anambra, Nnewi	30th July 2019	5:51:00 AM	5:56:33 AM	6:14:18 AM	**00:17:45**
Nigeria	Anambra, Awka	29th July 2019	8:20:08 PM	8:22:40 PM	8:42:09 PM	**00:19:29**
Nigeria	Enugu, Abakaliki Rd.	30th July 2019	1:27:23 PM	1:27:41 PM	1:33:20 PM	**00:05:39**
Nigeria	Enugu, Trans Ekulu	27th July 2019	8:17:20 AM	8:18:40 AM	8:29:58 AM	**00:11:18**
Nigeria	Enugu, New Haven	25th July 2019	12:02:32 PM	12:03:52 PM	12:14:32 PM	**00:10:40**
Nigeria	Enugu, Goshen	26th July 2019	5:24:00 PM	5:25:11 PM	5:49:06 PM	**00:23:55**

NB: Cotonou-Benin and Douala-Cameroon sites did not carry out a time drift test for logistic reasons

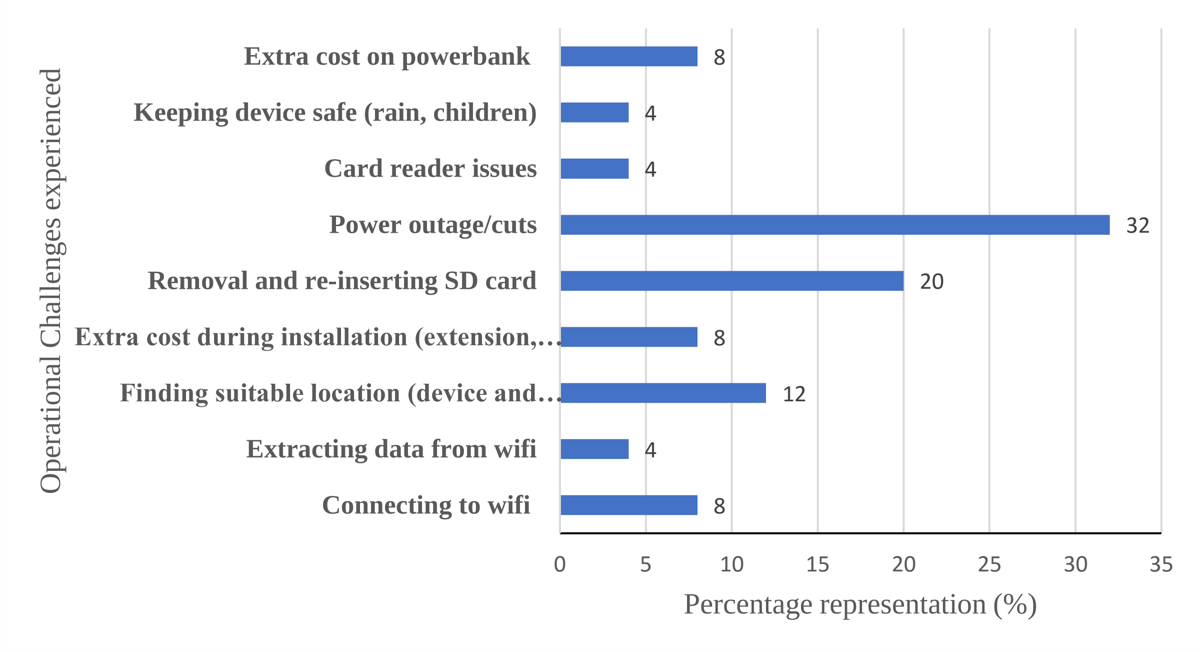

Figure 20: Summary of the operational challenges experienced with the use of PurpleAir II SD AQM sensor during MA3 in July 2019

Figure 20 displays information about the challenges experienced with the use of the Purple Air device during the MA3 study. Power outages were cited as the greatest challenge faced by the participating investigators (32%). This was followed by difficulties with the removal and re-insertion of the SD card within the device (20%) and finding a suitable location to mount the device (12%). Other challenges described were installation costs, wifi connectivity, cost procuring extra power banks, card reader issues, and device safety.

DISCUSSION

Ambient air pollution measurement is an important topical issue that needs to be given its due attention. Most of the air quality measurement efforts in the developing world have been largely focused on household air pollution. While the latter is important, the former is equally important especially due to the relatively younger, active populations in developing countries who get exposed to air pollution as they go about their daily work. Seeking effective and affordable ways to quantify the magnitude of ambient air pollution is a step in the right direction. The utopia here is the attainment of clean air through citizen science and advocacy. Measuring Air Pollution in Africa for Advocacy (MA3) study is our step in that right direction.

The magnitude of planning, coordination, and logistics that went into the MA3 study was significantly huge. First, bringing busy academics together in one room for a strategic meeting was quite challenging, yet very rewarding. In the light of competing genuine interests, a few meeting dates earlier suggested were cancelled. Due to the unequivocal belief in everyone that this is an important topical issue worthy of a solution, the strategic meeting eventually held, which helped to kick-start the process. The issue of funds came up next. Through a combination of creative thinking, utilization of earlier established networks and a deep understanding of what is allowable or permissible with currently running grants, some funds were identified for the MA3 project. This proved to be the lifeline for the project because, without funds to procure the instruments, the study would have not held.

Procuring the Purple Air-II-SD, Lascar® carbon monoxide loggers and the Anker® power banks and shipping them from the United States to Liverpool, United Kingdom (UK) was straightforward. The logistic challenges occurred when it was time to transport the equipment from the United Kingdom to Tanzania and from Tanzania to other sub-Saharan African countries. Under aviation rules regarding the air transportation of long-acting cells containing lithium, there is a restriction on how much each passenger can fly with. The IMPALA administrator could therefore not fly with 17 Anker® Lithium Power bank batteries alone. She divided these power banks up among five scientists flying from the UK to Tanzania and then collated the power banks again at Tanzania. She also experienced significant delays at the security exit at Tanzania due to the number of Purple Air sensors and Lascar loggers in her check-in luggage. Learning from this experience, she requested the Liverpool School of Tropical Medicine to draft individual letters for everyone that would receive equipment to make customs and airport security passage easier for the AQM scientists. Despite this, some physicians still had difficulties convincing the customs in most countries of the innocuous nature of the sensors. They were viewed with utter suspicion and one person was taken into a private room for interrogation and thorough searching. All participating physicians however successfully transported the Purple Air sensors back to their home countries after careful explanation, presentation of the LSTM letters and a lot of patience.

Power-related issues were a major practical challenge experienced by over a third of the investigators in our study. The participating countries all have inherent challenges with uninterrupted power supply for its citizenry and this affected the ease with which the investigators could power the Purple Air devices (25,26,27) Even though we procured and distributed an Anker® 20,000 mAh power bank with each device, the challenge lies in being able to recharge the power bank when its charge got used up while at the same time keeping the device running so as not to lose data. The above-named Anker power bank was chosen because it lasts for 72 hours when used from a full charge. A previous study on the practical challenges of setting up an electronic medical record system in a Nigerian hospital also cited constant power outages as a significant challenge (28). With the benefit of hindsight, each Purple Air device should be accompanied by two Anker power banks, leaving the investigator enough time and resource to power the device continuously.

Issues surrounding the removal and re-insertion of the Purple Air device SD memory card also posed a significant challenge to some investigators. The SD memory card slot was designed in such a way that removal is very deliberate. This is so because the card slot is partially hidden in the under-side of the sensor, partly covered by a protective rubber rim. This protects the SD card from natural elements and tampering by the uninitiated. Removal and re-insertion are only possible with the aid of a metal tweezer as the human fingers are too big to enter the space around the slot. Extra caution, however, needs to be taken because the power needs to be disconnected before card removal and the card re-inserted before reconnecting the power. If this sequence is not followed, the risk of a device firmware (software) corruption increases significantly. This might have been the case at the Douala, Cameroon site where the data captured at the site was thoroughly corrupted and unusable. Furthermore, the memory chip lines on the card must align with the chip lines in the card slot at card re-insertion. Irreversible data loss occurs if the SD card is inserted the wrong way, accounting for why the Bariga, Lagos site lost data between the 23^{rd} of July 2019 and 31^{st} July 2019 (figure 11). The need to check and re-check before carrying out an SD card re-insertion cannot be overemphasized.

Device safety also posed a challenge for some physicians. In communities where poverty fueled petty thefts are common, ensuring that the devices are placed in places where the likelihood of them being stolen is low becomes very imperative. Also, placing them out of the reach of inquisitive children and rain is important. Good knowledge of the local security status becomes quite crucial here. The availability of internet connectivity at the participating sites and the ease of coupling the device with this was also complained about. In line with the same trend regarding electricity supply, stable broadband internet supply is still a real struggle for many sub-Saharan African countries (28). Where is it available, the cost is prohibitively high. This already known reality informed the purchase of the PurpleAir -II-SD sensors and not the PurpleAir sensors without inbuilt SD cards.

The proportion of data logged over the study period at each participating site is a function of a balance of how all the identified challenges played out and how well these were managed. Overall, there was at least a 92% data recovery rate in all sites except the Bariga-Lagos site where the wrong placement of the SD card led to an inadvertent loss of data, leading to a 71% data recovery rate. This means that at most participating sites, the device captured at least 92% of the expected $PM_{2.5}$ longitudinal data during the entire study time period. This is a reasonably good performance given the number of challenges that needed to be surmounted to achieve this. One site attained 100% data recovery (Nairobi, Kenya), with six other sites attaining a

94% and above recovery rate (Burkina Faso, Gambia, Uganda, Nnewi-Nigeria, Awka-Nigeria, and Abakaliki Road-Enugu-Nigeria.). This has proven that when used properly, this instrument can measure $PM_{2.5}$ satisfactorily well.

The time stamp on the in-built Real-time clock (RTC) within the Purple Air devices used experiences a lag or delay which is proportionate to the amount of time it stays without being connected to the internet. This lag or delay is known as the time drift. Starting from its time on the manufacturer's shelf before procurement till when it was eventually installed, this time drift can be in minutes or days. When the device is connected to the internet, the RTC connects to an internet clock and updates its timestamp (18). The two study sites that were permanently on wifi had time drifts of 4 minutes. The other sites that were not connected to the internet had time drifts as much as 10 minutes in the minimum. At locations where continuous internet connectivity is not available, connecting the Purple Air sensor to the internet a few minutes a week will help to update the RTC time. A mobile phone hotspot can serve this purpose when a wireless internet system is unavailable.

Based on the daily $PM_{2.5}$ averages computed for each site in comparison with the daily WHO $PM_{2.5}$ safety threshold, Ntinda Road in Kampala-Uganda, Bariga in Lagos, Nigeria, Nnewi-Anambra, Nigeria and Nairobi, Kenya were the most polluted locations in our study. This comes as no surprise knowing the level of emission from old worn engines, indiscriminate burning of refuse, commercial activities involving burning of wood or charcoal (commercial roadside cooking, frying or smoking of food) that goes on at these locations (7). Awka-Nigeria, Abakaliki Road, Enugu-Nigeria, Goshen-Enugu-Nigeria, and New Haven-Enugu-Nigeria had borderline average daily $PM_{2.5}$ emissions considering the WHO threshold. Fajara, The Gambia and Ouagadougou in Burkina Faso were the least polluted locations. Fajara in The Gambia has had a lot of trees planted all around over the last 40 years, contributing immensely to the level of clean air available. Besides, indiscriminate open refuse burning outside designated refuse dumps is generally discouraged. Dusty winds blowing from the Sahara have been identified to contribute significantly to the air pollution in Burkina Faso (29). Given that our study occurred during the wet season when the Sahara dust would be washed down quickly, the low PM levels captured might be plausible.

The hourly averages followed a similar trend as the daily $PM_{2.5}$ averages with regards to site average values. The notable finding here was that all sites recorded PM levels higher than $10\mu g/m^3$. There was also an afternoon dip in the PM levels, with a subsequent rise in the night and the mornings. This trend fits into the urban lifestyle whereby most people will be settled into their place of commercial activity by noon and are back on the road for a commute back home in the evenings. The early morning household and commercial cooking coupled with the work commute rush hour all likely contribute to the morning PM level rise observed.

The MA3 study has been able to show the strengths of utilising the Purple Air-II-SD sensor: it is an affordable device that is portable, readily available for procurement, easy to self- install and easy to maintain. Also, the data can be downloaded with minimum stress in a comma-separated value (CSV) format that makes it easy to either clean and analyse or load into a statistical package for analysis. Besides, the data can be uploaded onto the Purple Air website if the wifi internet is available. The use of this instrument is not without weaknesses. The numerous challenges experienced along the way can be a bit discouraging. The lack of a warning signal when things are not done properly is a notable weakness. The loss of data following SD card misplacement at the Bariga study site helps drive home this point. Investigator pro-activeness will be needed to overcome this device's weakness.

The ability of the Purple Air -II-SD sensor to measure particulate matter in real-time provides a unique opportunity to utilize ‘live' evidence to engage policymakers on the need for policies in favour of clean air. Also, the simplicity of the Purple Air makes it most suitable for citizens to use them to explore their local environment and learn about air quality thus promoting citizen science. This hastens the journey towards a world with cleaner air. Perceived threats to the above are the time drift experienced by the devices and firmware corruption that can also occur. Taking due diligence to connect the device to the internet once a week and handling the same as per protocol will help mitigate these threats.

Concerted efforts need to be put in place to advocate for cleaner air in our communities in sub-Saharan Africa. Ambient air pollution quantification needs to be widespread so that the actual level of pollution at each location is mapped out and documented. Using this information as an advocacy tool, there is then a need to engage both the citizens and the policymakers on the issue of formulation and enforcement of legislation promoting cleaner air. This will include, but not restricted to, banning of importation of cars or machines with worn engines, indiscriminate burning of refuse, smoking in public places and use of dirty fuels for cooking. All these must be done with the involvement of the citizenry and at a cost that every country can afford to sustain at every level of its development.

TRANSLATION

A PowerPoint has been prepared (Appendix F), waiting to be sent to INSPIRE following the grading of this manuscript. This is to be included in the INSPIRE resource bank for Air Quality Monitoring scientists and Physicians to use as a resource for practice, research, teaching, and advocacy.

LIMITATIONS

There were not enough funds and logistic strength to cover all countries in sub-Saharan Africa. Also, the choice of the study site was opportunistic and was determined by the country and town that the participating physicians were from. This led to a country having multiple sites (Nigeria) while some other countries were not represented at all e.g. Mali, Sierra Leone, Liberia, etc. It would be very informative and ideal to be able to cover most, if not all sub-Saharan African countries where ambient air pollution levels are unknown.

AREAS OF FURTHER STUDY

A follow-up MA3 study has been planned to run over one calendar year. This will enable us to execute spatial-temporal analysis and reveal the effects of seasonality on air pollution. Furthermore, this would generate the largest repository of published continuous ambient $PM_{2.5}$ data globally.

REFERENCES

1. World Health Organization. How air pollution is destroying our health. 2018. Available at https://www.who.int/air-pollution/news-and-events/how-air-pollution-is-destroying-our-health. Retrieved at 6:51 pm on 15th August 2019.
2. Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N., Nil, Baldé, et al. 2017. The Lancet Commission on pollution and health. Lancet. https://doi.org/10.1016/S0140-6736(17)32345-0.
3. Chen H, Goldberg MS, Villeneuve PJ. A systematic review of the relation between long-term exposure to ambient air pollution and chronic diseases. *Rev Environ Health*. 2008; 23(4):243-97. PubMed PMID: 19235364.
4. Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet*. 2017 13;389(10082):1907-18. PubMed PMID: 28408086.
5. Hoek G, Krishnan RM, Beelen R, Peters A, Ostro B, Brunekreef B, et al. Long-term air pollution exposure and cardio-respiratory mortality: a review. *Environ Health*. 2013 28;12(1):43. PubMed PMID: 23714370. Pubmed Central PMCID: 3679821.

6. Smith KR. Fuel combustion, air pollution, exposure, and Health: the situation in developing countries. *Annual Review of Energy and Environment*. 1993; 18; 529-566.
7. Okello , Devereux , Semple . Women and girls in resource-poor settings experience much greater exposure to household air pollutants than men: Results from Uganda and Ethiopia. *Environment International* 2018; 119:429- 437.
8. Gordon SB, Bruce N , Grigg J, Hibberd P , Kurmi O , Lam K , Mortimer KJ et al. Respiratory risk from household air pollution in low and middle-income countries *Lancet Respir Med* 2014; 2: 823-60
9. Katoto PDM , Byamungu L, Brand A , Mokoya J, Strijdom , Goswami , Patrick D , Nawrot T , Nemery . Ambient air pollution and health in Sub-Saharan Africa: Current evidence, perspectives, and call to action. *Environmental Research* 2019; 173: 174-188
10. The United States Environmental Protection Agency. Particulate Matter (PM) pollution. Health and environmental effects of Particulate Matter. 2018. Available at https://epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm. Retrieved at 7:45 am on 15th August 2019.
11. The United States Environmental Protection Agency. Particle pollution and your health. 2003. Available at https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1001EX6.txt.Retrieved at 1:09 pm on 16th August 2019.
12. World Health Organization. Non-Communicable Diseases. 2018. Available at https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases. Retrieved at 4:24 am on 12th May 2019
13. Inspire: Health advocates for clean air. Take Action: Think global, act local. Available at https://inspirecleanair.org/take-action

14. Health and Safety Executive (HSE). General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols. 2014. Available at http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf.Retrieved at 6:37 pm on 31st July 2019

15. Amaral SS, de Carvalho JA, Martins Costa MA, Pinheiro C. An overview of Particulate Matter Measurement Instruments. *Atmosphere* 2015; 6:1327-1345. Doi:10.3390/atmos6091327

16. PurpleAir: Real-Time Air Quality Monitoring. Available at www2.purpleair.com. Retrieved at 8:50 pm on 12th August 2019

17. Air Quality Sensor Performance Evaluation Centre: AQ-SPEC. Field Evaluations. South Coast AQMD: 2019. Available from http://www.aqmd.gov/aq-spec/evaluations/field Retrieved on 31st July 2019 at 10:23 GMT

18. Semple S. Using Purple Air for the Monitoring Air Pollution in Africa for Advocacy project. Air Quality Measurement Workshop presentation at the IMPALA scientific meeting, Dar Es Salaam, Tanzania. June 2019

19. International Multidisciplinary Programme to Address Lung Health & TB in Africa (IMPALA). NIHR Global Health Research Unit on Lung Health and Tuberculosis in Africa at Liverpool School of Tropical Medicine. Available at lstmed.ac.uk/impala. Retrieved at 7:02 pm on 30th August 2019.

20. Air Quality Sensors-Purple Air. Available from www2.purpleair.com/collections/air-quality-sensors

21. World Health Organization (WHO) Measuring particulate matter (PM10 and PM2.5) in Europe. Report on a WHO workshop. Berlin, 1997. World Health Organization Regional Office for Europe. Available from

www.euro.who.int/_data/assets/pdf_file/0004/118417/E58139.pdf. Retrieved at 3:15 pm on 26th August 2019

22. Queensland Government. Tapered Element Oscillating Microbalance. Available from https://www.qld.gov.au/environment/pollution/monitoring/air/air-monitoring/measuring/oscillating-microbalance; March 2017. Retrieved at 3:15 pm on 2nd July 2019
23. World Health Organization. Occupational and Environmental Health Team. (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: global update 2005: summary of risk assessment. World Health Organization. Available at https://apps.who.int/iris/handle/10665/69477. Retrieved at 11:34 pm on 26th August 2019.
24. Purple Air Online data. Available at https://www.purpleair.com/sensorlist. Retrieved at 7:38 pm on 28th August 2019
25. Amadi HN. Impact of Power Outages on Developing Countries: Evidence from Rural Households in Niger Delta, Nigeria. Journal of Energy Technologies and Policy 2015; 5:3
26. Ngechu W. Kenya power announces power outages across the country from tomorrow. Citizen Digital. Available from https://citizentv.co.ke/news/kenya-power-announces-power-outages-across-the-country-from-tomorrow-232953/. Retrieved at 3:34 pm on 5th September 2019
27. Gaye M. NAWEC resumes severe power outages. Freedom Newspaper. Available from https://www.freedomnewspaper.com/2018/12/26/gambia-nawec-resumes-severe-power-outages/. Retrieved at 4:51 pm on 4th September 2019.
28. Awokola BI, Abioye-Kuteyi EA, Otoru OO, Oyegbade OO, Awokola EO, Awokola JA, Ezeoma IT. Practical Challenges of Setting Up an Electronic Medical Record

System in a Nigerian Tertiary Hospital: The Wesley Guild Hospital Experience. *Middle East Journal of Family Medicine* 2012; 10:2

29. Air pollution in Ouagadougou in Burkina Faso'. Available from http://urbanemissions.blogspot.com/2011/06/air-pollution-in-ouagadougou-burkina.html. Retrieved at 5:13 pm on 12th August 2019.

APPENDICES

APPENDIX A
IMPALA Air Quality Monitoring Workshop
PATS MECOR 2019

Date: June 9-10, 2019
Location: Dar es Salaam, Tanzania
Type of meeting: International
Number of anticipated attendees: 15

Faculty:
Sean Semple, PhD
Gabriel Okello, PhD
Babatunde Awokola FWACP, ATSF

Objectives: To teach PATS MECOR researchers the basics of measuring exposure to air pollution with particular emphasis on household air pollution research and to provide hands-on experience with equipment to enable them to make exposure measurements on return to their home institutions.

SUNDAY JUNE 9, 2019

Time	Topic	Speaker	Duration
9:00 AM – 9:15 AM	Welcome and introductions	All	15 minutes
9:15 AM – 10:30 AM	Overview of air pollution and health	Sean Semple	75 minutes
10:30 AM - 11:00 AM	**Coffee/Tea Break**		**30 minutes**
11:00 AM – 11:45 AM	Measuring household air pollution in Africa	Gabriel Okello	45 minutes
11:45 AM – 12:30 PM	How to measure particulate matter concentrations	Sean Semple	45 minutes
12:30 PM – 13:30 PM	**Lunch**		**60 minutes**
13:30 PM – 14:00 PM	Measuring carbon monoxide	Gabriel Okello	30 minutes
14:00 PM – 15:00 PM	Introduction to MA3 project and the Purple Air device	Babatunde Awokola and Sean Semple	60 minutes
15:00 PM – 15:20 PM	**Coffee/Tea Break**		**20 minutes**
15:20 PM – 16:10 PM	Hands-on tutorials on using the Purple Air and Lascar instruments	Sean Semple and Gabriel Okello	50 minutes
16:10 PM – 16:30 PM	Discussions around the MA3 project and the African Centre for Clean Air	Gabriel Okello, Babatunde Awokola, Sean Semple	20 minutes
16:30 PM – 17:00 PM	Short trip to install purple air devices at an outdoor location nearby	Sean Semple	75 minutes

MONDAY JUNE 10, 2019 (workshop starts after evening dinner)

Time	Topic	Speaker	Duration
13:00 PM – 13:30 PM	Any questions during lunch	-	30 minutes
19:15 PM – 20:30 PM	Looking at the data from yesterday and then thinking about using your MA3 data for advocacy in your country	Sean Semple	75 minutes
20:30 PM – 21:30 PM	Individual appointments with MA3 project participants (10 mins each)	Gabriel Okello and Sean Semple	60 minutes

APPENDIX B

LSTM
LIVERPOOL SCHOOL OF TROPICAL MEDICINE
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Dr Babatunde Awokola
Liverpool School of Tropical Medicine
Pembroke Place
Liverpool
L3 5QA

Monday, 17 June 2019

Dear Dr Awokola,

Re. Research Protocol (19-061) *Measuring Air Quality in Africa for Advocacy (MA3)*

On behalf of LSTM Research Ethics Committee, it is acknowledged that LSTM REC approval is not required for the above-named study, as the project seeks to gather environmental air quality data and will not involve collection of any human data.

Approval from building owners should be secured prior to installation of air quality monitoring devices.

Please send a copy of the approval to the LSTM Research Governance and Ethics Office via lstmrec@lstmed.ac.uk

Should you wish to contact LSTM REC in relation to this study in the future, please contact Brian Slater, Secretary, Research Ethics Committee at lstmrec@lstmed.ac.uk.

Yours sincerely,

Angela Obasi

Dr Angela Obasi
Chair
Research Ethics Committee

APPENDIX C (Attached herewith)

APPENDIX D

LSTM
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13 June 2019

To Whom It May Concern

Please note that Dr Babatunde Awokola is travelling to Manchester, UK on Saturday 15th June 2019. Dr Awokola attended the Air Quality Measurement (AQM) workshop at the annual International Multidisciplinary Programme to Address Lung health and TB in Africa (IMPALA) conference in Dar es Salaam, Tanzania. Subsequently, he will travel from Manchester, UK on Monday 1st July 2019 to The Gambia where he will do field work for a research project using equipment he received during the training above.

Dr Awokola will be carrying the following equipment that was used at the AQM. This equipment will, at all times, remain in the ownership of the Liverpool School of Tropical Medicine.

- ANKER battery pack x 5
- PurpleAir data collector x 4
- USB cable x 4
- LASCAR x 3

Please contact me if you have any queries.

Yours faithfully

Annmarie Hand

Executive Assistant to Professor David Lalloo
Director Liverpool School of Tropical Medicine
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APPENDIX E

MEASURING AIR QUALITY FOR ADVOCACY IN AFRICA (MA^3)

Protocol for checking the time stamp on purple air device operating without a wifi connection

Introduction

The emergence of low-cost air quality devices offers new opportunities to simultaneously gather spatial and temporal air quality data in near-real-time, as well as engage citizens in active environmental monitoring in sub-Saharan Africa (SSA). This subsequently provides more capabilities in the assessment of human exposure to air pollution and identifying the factors leading to pollution in the various areas in SSA.

Sensor platforms are currently available to monitor a range of air pollutants and new devices are continually being introduced (Piedrahita et al., 2014). We are therefore going through a paradigm shift in how and who is monitoring air quality (Lewis and Edwards, 2016). There has been an introduction of devices that are relatively lower in cost, easier to use and less bulky than traditional equipment, and offer the prospect for citizens and communities to monitor their local air quality that may affect their health (Snyder et al., 2013).

Significance:

Data quality is a pertinent concern, especially in citizen science applications, where citizens are collecting and interpreting the data. Operating any piece of technology usually comes with some challenges. The capability to manage and overcome these challenges determines the success of projects involving the use of these tools in the long run.

Extremely accurate DS3231 real-time clock (RTC) in the Purple Air II SD incorporates a battery backup and maintains accurate timekeeping when main power to the device is interrupted, however, there's a possibility of shifting of time stamps on devices that are operational but not connected to wifi.

Objective:

The overall objective is to check whether there's a shift in time (minutes lost) when the Purple Air-II-SD devices are operated without connection to wifi.

Hypothesis

"The timestamp of the purple air device may shift when the device is not connected to wifi during measurement".

Sampling Tool

Purple Air II SD sampling sensor (check purple air website or MA^3 protocol for specifications)

Method for checking shift in time stamp on Purple Air II SD

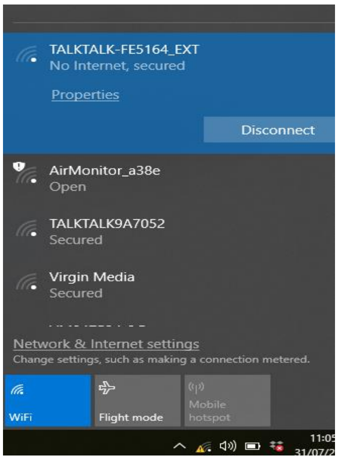
1. Set up the Purple air II SD sampling sensor.
2. Connect the Purple air SD sampling sensor to a power source.
3. If the device is already operational, switch off the sensor by disconnection from a power source at a specific time for 10 to 20 seconds and.

4. Record the time the disconnection was done.
5. Connect the device to power source again, measure for five more minutes, then download and send the file to bawokola@gmail.com and copy gabrielokello@gmail.com
6. For devices where time shift has occurred, it will require logging on to the internet using wifi or phone hotspot for five minutes.

Procedure for connecting to wifi

Connect Purple air to wifi if available. To connect to a wifi network:

a. Open a browser with the page
   http://www.purpleair.com/configure
b. Next, disconnect your laptop or pc from your office/home wifi. The easiest way to do this is to switch the wifi off for the next step.
c. Connect to 'Air Monitor_XXXX' via your laptop wifi. XXXX is unique to each specific purple air device.



d. Once you reconnect to the wifi, you might see messages such as 'No internet, open' or 'Unable to connect t theo internet'. Do not worry about this.
e. Return to the browser and the 'configure' page
f. Press 'connect to sensor'
g. Configure wifi by choosing your wifi network from the list of options, entering the password (if applicable) and then pressing save
h. The device will only be connected for five minutes and then disconnected.
i. Measurement will then continue without connection to wifi

NOTE: In case of any challenges, a step by step procedure will be carried out with Babatunde at a prior agreed and scheduled time.

References

1. Lewis, A., Edwards, P., 2016. Validate personal air-pollution sensors. Nature 535 (7610), 29–31.
2. Piedrahita, R., Xiang, Y., Masson, N., Ortega, J., Collier, A., Jiang, Y., Li, K., Dick, R.P., Lv, Q., Hannigan, M., Shang, L., 2014. The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. Atmos. Meas. Tech. 7, 3325–3336.
3. Snyder, E., Watkins, T., Solomon, P., Thoma, E., Williams, R., Hagler, G., Shelow, D., Hindin, D., Kilaru, V., Preuss, P., 2013. The changing paradigm of air pollution monitoring. Environ. Sci. Technol. 47, 11369–11377.

APPENDIX F (Attached herewith)