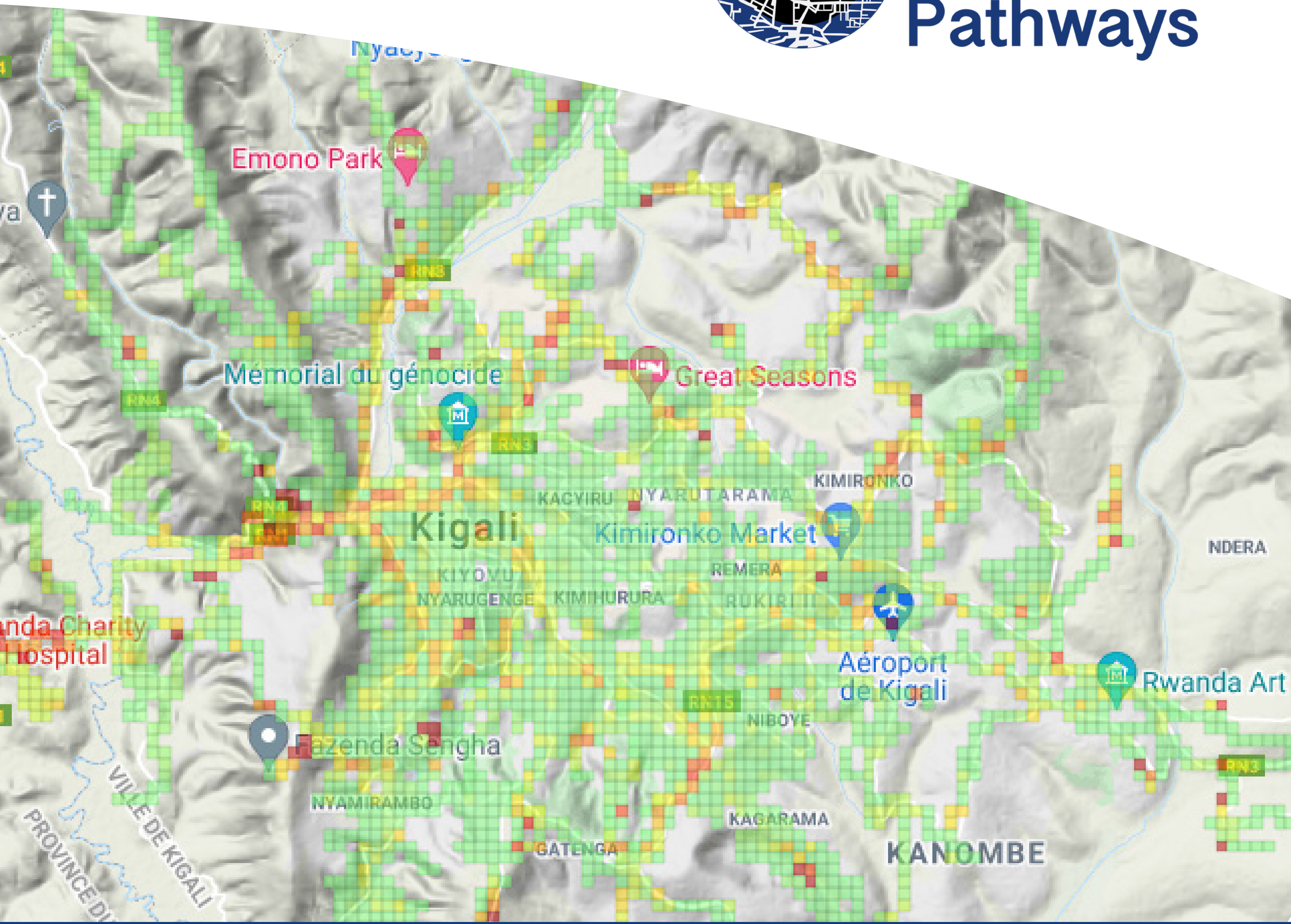
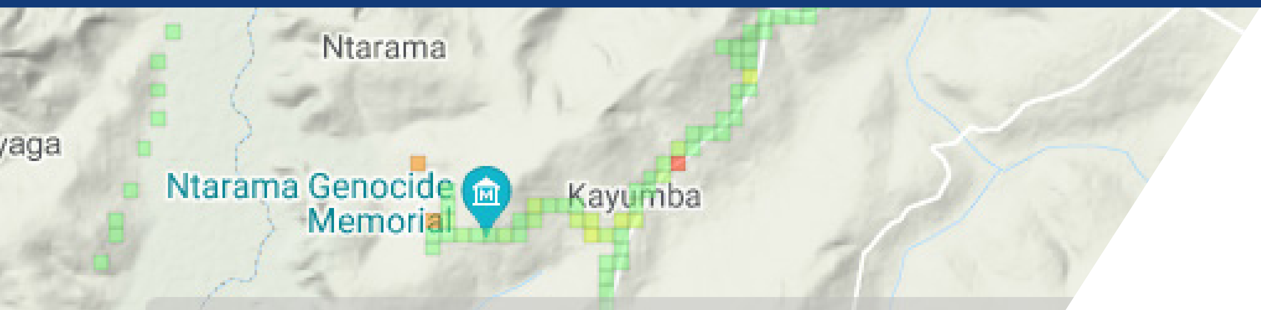
Urban Pathways



KNOW THE AIR YOU BREATHE

Mapping air quality in Kigali



Imprint

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Title
Know the air you breathe: Mapping air quality in Kigali

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Executive Summary

Air pollution already causes 7 million premature deaths every year, according to the World Health Organisation. With the predicted rise in population and rapid motorisation rates in many low- and middle-income cities, **an urban health crisis is anticipated if no action to lower pollution levels is taken.** The Government of Rwanda has recognised this pressing issue and implemented the Air Quality and Climate Change Monitoring Project. To support current efforts and initiatives, the deployment of mobile air quality sensors has the potential to supplement monitoring stations and to fill in spatial and temporal gaps in air quality data. Results can then lay the ground for evidence-based policies and strategies to appropriately control air quality and support the transition to a more sustainable urban mobility.

In the City of Kigali, Rwanda, the Urban Pathways project enabled the **deployment of 20 low-cost, mobile air quality monitoring devices** provided by open-seneca, mounted on 16 Ampersand electric motorcycle-taxis and 4 bicycles used by volunteers. Beyond the question of the average severity of air pollution in the City of Kigali, the project aimed to more precisely identify areas with particularly severe air pollution, the so-called "hotspots". To raise awareness among participants about their personal exposure to air pollution and health effects, a user survey was shared with the motorcycle taxi drivers and cyclists on the use of the sensors and their feedback on possible sources of higher particulate matter values.

After four weeks of data collection in September 2021, the participants had gathered 6.6 million valid data points over a total area of 162 km². The median baseline for the entire collection period in Kigali was found to be **31.0 µg/m³ overall, which is about 6 times higher than recommended as annual average by the WHO,** which is of annual exposure of 5µg/m3. Daily exposure should not exceed 15µg/m3, according to the WHO air quality guidelines updated in 2021.

After processing the data and removing the pollution baseline of the city, the project was able to **identify air pollution hotspots across the city** (map). A particularly warning hotspot was found around the highly frequented Nyabugogo bus station area, on the intersection of RN1 and KN7 Rd. Other hotspots were identified, including but not limited to: Ruyenzi (RN1), Kicukiro (KK 15 Rd), south of Nyarugenge (eastern side to KN75 St near Camp Kigali School), Mumena (KN159 St), Nyamirambo (KN250 St) and the western part of Muyange (KK 23 Ave). Peaks of air pollution could be identified in the morning between 7:00 am and 9:00 am, hinting toward a link with traffic rush hours, and in the evening between 7:00 pm and 10:00 pm.

Initial recommendations were made, based on the dataset and drivers' feedback. They include:

- alongside the confirmed largest hotspot around Nyabugogo's bus terminal (RN1/KN7 Rd), a need to further analyse and discuss the other hotspots. A collaborative identification process is recommended, for instance during a workshop on a Car Free day.

- recommended targeted mobility interventions in the hotspots, which should be identified as "air quality management areas". Possible measures include the promotion of walking, cycling, public transport, and the reduction of fossil-fuel motorization. For instance, the hotspot identified in the south of Nyarugenge (eastern side to KN75 St, Camp Kigali School, SABE- School of architecture and Built Environment of University of Rwanda) could be addressed via extending the cycle lane network south of the Central Business District, as proposed by ITDP Africa and the SolutionsPlus project.

- further work needed to understand the causes of air pollution. The study was not conclusive on a possible association between air pollution and the status of roads as paved or unpaved. Further research is needed in this regard.

- required further analysis of the health consequences to schools and hospitals found in the hotspots. A ban on vehicle engines idling outside schools and hospitals during drop-off and pick-up is recommended. Further recommendations include the deployment of infrastructure facilitating cycling and walking around schools and the support of collective transportation via cleaner vehicles, such as electric school buses or vehicles respecting higher emission standards.

- continuation of ambitious sustainable urban mobility measures in Kigali, including the support of electric mobility initiatives.

- required interventions in other secondary or satellite cities to Kigali, such as Ruyenzi showing high levels of air pollution.

- further recommendations on modalities to implement air quality monitoring and control projects. These include the relevance of mobile sensors, the importance of situating local ownership and expertise at the heart of the project, the consideration of local needs and conditions to deploy the sensors, and a focus on community education and citizen engagement.

Urban Pathways and its sister project **SOLUTIONSplus** will continue to support the City of Kigali and institutions of the Government of Rwanda in their efforts towards improved air quality and sustainable urban mobility.

Abbreviations

μg/m³	Microgram per cubic meter
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BRT	Bus Rapid Transit
CAT	Central Africa Time zone
COE	Center for Global Equality
CO	Carbon monoxide
FMI	Finish Meteorological Institute
Hz	Hertz
ICE	Internal Combustion Engine
IKI	International Climate Initiative
ITDP	Institute for Transportation and Development Policy
LMICs	Low- and middle-income countries
MINEDUC	Ministry of Education
MININFRA	Ministry of Infrastructure
NDC	Nationally Determined Contribution
NO2	Nitrogen dioxide
PM	Particulate matter
REMA	Rwanda Environment Management Authority
SD Card	Secure Digital Card
UEMI	Urban Electric Mobility Initiative
UP	Urban Pathways
UR-CST	University of Rwanda-College of Science and Technology
WHO	World Health Organisation

Urban Pathways

Committed to monitor and reduce air pollution

The Urban Pathways project (https://www.urban-pathways.org) has the objective to make an active contribution to delivering on the Paris Agreement at the city level in the context of the New Urban Agenda and the Sustainable Development Goals. Its aim is to make a direct contribution to sustainable urban development by focusing on implementation projects in the areas of mobility, energy, and resource management. The project is funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and is implemented by UN-Habitat, the Wuppertal Institute and UN Environment. Urban Pathways started in four pilot countries (India, Brazil, Kenya and Vietnam) to develop a Living Lab framework, which is then intended to be replicated across the partner regions. As of now, Urban Pathways has stretched its activities far beyond those countries, being active in 10 pilot cities and replicating activities in more than 15 cities.

Identifying the considerable environmental risk of rising air pollution in numerous cities across the globe, and urban health crises linked with increased population and motorization rates, the Urban Pathways project saw the need to promote Air Quality Sensing powered by Citizen Science. Urban Pathways has supported air quality projects in Addis Ababa, Ethiopia, and Nairobi, Kenya. To pursue the efforts to monitor air pollution and engage citizens, the Urban Pathways project selected three further cities for implementation in 2021: Kigali (Rwanda), Quito (Ecuador), and Kathmandu (Nepal), in which a total of 60 mobile air quality low-cost sensors would be deployed.

Urban Pathways project partners include:

UN-Habitat. UN-Habitat is the United Nations programme working towards a better urban future. The Urban Basic Services Branch of UN-Habitat will work with international partners and highly motivated cities in Asia, Africa and Latin America on the implementation of the New Urban Agenda focusing on urban energy, mobility and resources systems. This will build directly on a broad range of activities by UN-Habitat in the respective sectors and on the dedication to sector integration.

UN-HABITAT
FOR A BETTER URBAN FUTURE

UN Environment. UN Environment provides technical advice on the effective implementation of the Paris Agreement. Its mission is to identify emission reduction opportunities, timely and quantified progress towards emission reduction strategies and additional mitigation actions. UNEP assists by facilitating dialogue with the ministerial level and assessing the implementation readiness of the pilot project concepts as well as helping to identify suitable funding agencies for the scaled-up implementation phase.

UN
environment

Wuppertal Institute. The Wuppertal Institute supports Urban Pathways by developing implementation-ready concepts for sustainable urban development, bringing together local demand, technical expertise and policy advice with financing institutions. In close cooperation with a network of international project partners, the institute works on closing the implementation gap between applied research and policy action to foster sustainable urban development in Europe, Asia, Africa and Latin America.

Wuppertal
Institut

1. Setting the scene

1.1 Reducing air pollution: an urgent need

Anthropogenic air pollutants from motor vehicles, heating, construction, and industry are a significant contributor to climate change and many health problems experienced today. In fact, atmospheric fine particulate matter (PM2.5), especially black carbon, is affiliated with the main driving forces of global warming. Air pollution causes 7 million premature deaths every year, according to the World Health Organisation (WHO)[1]. This is a particular concern in African countries, where data is lacking.

PM2.5 is usually monitored using large and expensive reference stations, which require costly calibration and maintenance. However, reference stations only provide air quality data from one fixed location, which generally is neither representative for an entire city nor for the experience of individuals moving around the city. In low- and middle-income countries (LMICs), where reference stations are often unaffordable, there is very limited data assessing air quality available, which results in a general lack of appropriate policies to control air quality and a lack of awareness about the negative health effects associated with the often-alarming levels of air pollution experienced by ordinary citizens. With the predicted rise in population and rapid motorisation rates in many LMIC cities, an urban health crisis is anticipated if no action to lower pollution levels is taken.

In order to support the development of sustainable urban mobility plans in LMICs, collecting finely grained air quality data of urban areas is essential to provide evidence for transitioning towards efficient and clean mobility systems. The use of low-cost air quality monitors has the potential to supplement existing monitoring stations (if any) by deploying affordable, rapid sensor networks across the city that can fill in spatial and temporal gaps in air quality data.

Moreover, the flexibility of deployment of these low-cost mobile sensors enables measuring the impact of intervention activities aimed at improving air quality at a far lower geographical scale than would normally be possible, fomenting their replication and scale-up at the local, national, and global level. Combining the hyper-local air quality data provided by these low-cost devices with air quality modelling tools, provides cities with a powerful city decision support tool to control air pollution and identify the best sustainable urban mobility plans.

1 https://www.who.int/airpollution/data/cities/en/

Identifying the stringent issue of air pollution, Urban Pathways supported corresponding projects in the East-African region. In Nairobi, Kenya, the project spearheaded by UN-Habitat joined hands with the University of Nairobi's Maker Space Lab, open-seneca and the University of Cambridge in a project called "open-seneca Nairobi – Air Quality Monitoring powered by citizen science". A pilot was started to build low-cost mobile sensors in order to map out air pollution in Kenya's capital city. To ensure interactions, a workshop enabled participants to learn how to build sensors with open-source hardware and software, but also to interpret the air quality data. Devices were mounted on different transport modes: Uber taxis, matatus (minibuses), boda-bodas (motorcycle taxis) and bicycles. In Addis Ababa, Ethiopia, Urban Pathways, led by UNEP, set up 7 static air pollution monitoring sensors to collect and analyze data. This data resulted in the city banning medium sized trucks to lower the peak of pollution levels in rush hour.

To pursue the efforts to monitor air pollution and engage citizens, the Urban Pathways project selected three further cities for implementation in 2021: Kigali (Rwanda), Quito (Ecuador), and Kathmandu (Nepal), in which a total of 60 mobile air quality low-cost sensors were deployed.

1.2 The Urban Pathways air quality project in Kigal

Context

Kigali, located in the geographical centre of Rwanda, is the administrative and commercial capital and the largest city of the country. The 2018 population for Kigali was approximately 1.5 million and is forecasted to grow to approximately 3.8 million in 2050, according to the Kigali Transport Master Plan revised in 2020. Air pollution is identified as an environmental health risk in this master plan. Measures to reduce air pollution are identified, including restrictions around importing older vehicles, investing in public transport systems and reducing emissions from bus fleets.

The Government of Rwanda clearly recognises the pressing issue of air pollution. The Ministry of Education (MINEDUC) and Rwanda Environment Management Authority (REMA) have been implementing the Air Quality and Climate Change Monitoring Project since 2017. In this context, 22 air quality monitoring low-cost sensors and one reference air quality station have been deployed across the country, providing real-time information about the Air Quality Index. On the event of the International Day of Clean Air for blue skies on 7 September 2021, they launched a new website and mobile application (https://aq.rema.gov.rw/). Furthermore, in order to better understand the causes of air pollution, an inventory study of sources of air pollution was conducted (REMA, 2018), identifying road traffic as a large contributor to air pollution in Kigali City.

This concern is translated into policy directions and measures. Rwanda Standards Board in 2019 approved the introduction of the European Emission Standard EURO 4, and Rwanda's Nationally Determined Contribution (NDC) in the context of the Paris Agreement, updated in 2020, announced measures related to vehicle emissions standards, including tax incentives, scrappage of older vehicles, and inspection. The National Transport Policy and Strategy for Rwanda, revised in 2021, completes this ambition by focusing on public transport, non-motorised transport, announcing a strong support towards the introduction of electric vehicles. The use of air pollution monitoring devices is used to assess the performance of the policy in achieving the reduction of ambient air pollution levels.

In spite of these measures, the City of Kigali stands in front of a considerable challenge as private motorization levels, a recognised source of air pollution, are expected to significantly rise between now and 2050, in a business-as-usual scenario. The modal share of non-motorised transport is expected to decline from a level of 52% of trips in 2017 to 21% in 2050 in a scenario without a Bus Rapid Transit (BRT) system, while the number of motorised trips via private cars are expected to sharply increase. The policy measures identified in the city and national transport documents to support active, public, shared and clean urban mobility hence appear all the more important.

Objectives

In this context, the Air Quality project aimed at two main objectives:

1. Collect data to identify air pollution hotspots in Kigali

In Kigali, the Urban Pathways project enabled the deployment of 20 low-cost, mobile air quality monitoring devices, to obtain air quality data with a high spatial and temporal resolution. The project aims to contribute to ongoing efforts and decision-making by Rwanda and Kigali environmental, transport and education authorities, by completing existing static monitoring stations with an extensive coverage of the territory of Kigali via the use of mobile sensors. The project also aspires to raise awareness among citizens about their personal exposure to pollution and health effects to trigger behavioural change.

Beyond the question of the severity of the air pollution issue in Kigali – What is the level of air quality in Kigali? –, the project had a strong spatial component, aiming to identify air pollution hotspots – In which places is the ambient air in Kigali particularly good or bad? –. This identification of places should provide support to locally specific recommendations.

Alongside the data collection, the project intended to promote a collaborative approach across different types of stakeholders, as well as inform and engage decision makers about the usefulness of integrating low-cost sensors in their air quality monitoring system, and about the applications of the collected air quality data in land use planning, mobility, and urban design.

2. Model future levels of air quality based on transport forecasts by 2050

In addition, the University of Helsinki together with the Finish Meteorological Institute (FMI) completed this first phase by forecasting future levels of air quality, depending on the evolution of transport by 2050. To do so, the University of Helsinki and FMI modelled current traffic behaviours and atmospheric dispersion, as well as expected traffic volume increase in Kigali in 2050 and predictions of PMx, NO2 and CO in 2030 and 2050.

The resulting "air quality decision support system" aims to support decision-makers with information on how transport patterns influence air quality and, consequently, allow them to identify transport measures needed to reduce air pollution stemming from transportation.

On this basis, four future transport scenarios were identified: business-as-usual, sustainable, low electrification, and high electrification. The project was able to model the levels of CO2 and NOx in all these four scenarios, and to identify subsequent recommendations addressed to decision-makers. Methodology and findings of this second part are detailed in Report Part II.

Methodology

To achieve the two main objectives of this project, the following steps were followed:

- Stakeholder identification
- Deployment of the mobile air quality sensor network
- Community engagement
- Air quality data analysis and recommendations
- Modelling air quality and transport scenarios.

Stakeholder identification

This air quality project, supported by Urban Pathways, was implemented by a grouping of international and local stakeholders selected for their complementary expertise in air pollution, modelling, transport planning and knowledge of mobility in Kigali (see table 1).

UN-Habitat selected organisations tasked to provide the mobile air quality sensors and to realise the modelling exercise. open-seneca, one initiative of the Center for Global Equality (CGE), based at the University of Cambridge, was tasked to provide the sensors. The University of Helsinki, in coordination with the Finish Meteorological Institute (FMI), led the modelling exercise of future air pollution levels based on various transport scenarios. UN-Habitat and the Urban Electric Mobility Initiative (UEMI) coordinated the implementation of the project.

In a second step, local organisations were identified to lead the initiative on the ground, help organise workshops, find transport providers or volunteer citizens for data collection. The identification of local stakeholders was led by the Urban Pathways team, which has built long-standing relationships with the local government and other stakeholders in Kigali. Once the relevant stakeholders were identified, regular meetings with open-seneca, the Urban Pathways city representatives and local stakeholders were organised to coordinate the remaining activities, maintain the sensor network and ensure local appropriateness of the project.

Local stakeholders involved include:

- **Air quality and transport experts** to manage the air quality sensor network, facilitate procurement and shipment, ensure local appropriateness and provide expertise on findings. Dr. Egide Kalisa, Postdoctoral Researcher, Expert in Air Pollution and Environmental Science and Health, University of Toronto, as well as Lecturer at the College of Science and Technology , University of Rwanda, was identified as the "air quality local champion". Having the University of Rwanda at the heart of the project was key to local ownership of the project. Dr. Alphonse Nkurunziza, Lecturer at the University of Rwanda, College of Science and Technology and a senior Transport Planning Expert , provided expert review from a transport perspective.
- **Transport drivers and citizens** to mount the sensors on vehicles. Sensors were deployed on 16 motorcycles used for taxi services, and 4 were used by cyclists on their private bicycles.
- **Ampersand,** the first company offering electric motorcycle-taxis to drivers and charging services in Kigali. Ampersand's motorcycles, also supported in the context of Urban Pathways' sister project SolutionsPlus, reduce carbon emissions by more than 95% and tailpipe emissions by 100%, while increasing driver's incomes by more than 40% through cost savings. Committed to tackling poor air quality in Kigali, Ampersand accepted to mobilise 16 of its drivers to deploy sensors on their motorcycles, and financially compensated these drivers for their involvement in the project.

Deploying sensor deployment with the help of professional motorcyclists assured high efficacy in terms of data collection in the short time frame of the project. As a result, the data collected represents the largest dataset ever collected by open-seneca.

- **Cyclists.** Four individuals, kindly put in contact with UEMI by the European Union Delegation in Rwanda, volunteered to deploy the sensors on their bicycles, used for commute or leisure trips.
- **Local government:** to inform policy makers and ensure usability of the data. Throughout the project, the city of Kigali has been directly involved, represented by Francois Zirikana, E-mobility specialist at the city of Kigali.

Table 1. Overview of stakeholders in the Kigali project

Tasks	Organisation	Staff
International Partners		
Coordination	UN-Habitat	Stefanie Holzwarth
Coordination	UEMI	Emilie Martin
Provision of sensors and data analysis	open-seneca	Christoph Franck
Air quality and transport modelling	University of Helsinki	Dr. Andrew Rebeiro-Hargrave, Andres Huertas
Air quality modelling	Finnish Meteorological Institute	John Backman
Local partners		
Local air quality champion	University of Rwanda	Dr. Egide Kalisa
Local transport planning expert	University of Rwanda	Dr. Alphonse Nkurunziza
Sensors' deployment and data support	UEMI	Moise Bitangaza
Company providing vehicles to mount the sensors	Ampersand	Brady Grimes, Clive Irambona, Joseph Tuyishime
City representative	City of Kigali	François Zirikana

Further information on implementing partners can be found in Annex I.

2. Mapping current air quality in Kigali

2.1. Deploying air quality mobile sensors

The low-cost, mobile air quality sensors were provided by open-seneca. These sensors are open-source and transmit geo-tagged particulate matter (PM2.5), temperature and humidity data to a visualisation platform, where an automated data-processing pipeline generates aggregated city maps. These maps are shared with local communities and policymakers alike to drive the search for solutions that can be implemented at both individual and city level.

The open-seneca sensor

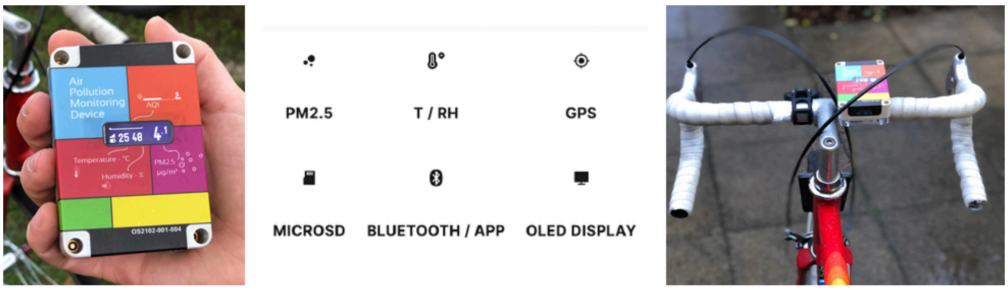
The open-seneca air quality monitor is a low-cost, small, portable sensor that measures

- PM2.5 / PM10 (Sensirion SPS30 Particulate Matter Sensor)
- Temperature and humidity (Sensirion SHT31)
- GPS location (u-blox GPS module)

at a sampling rate of 1 Hz.

The sensor can be either carried on a wrist band or mounted on various vehicles through the integrated, standardised Garmin-style mount, ensuring secure operation. The live readings are displayed on an on-board display to allow the user to identify air pollution hotspots immediately.

Figure 1. open-seneca air quality sensor, with main characteristics and mounting mechanism



Two main modes for data transfer are possible:

- Connect to a smartphone app via Bluetooth protocol to autonomously send the gathered pollution data to the open-seneca platform for processing. By connecting the device to the open-seneca app, live data as well as historic user data can be visualised on a map and sources of pollution can be reported by the user.
- Save data locally in an SD card, that can be extracted from the device and the data manually transferred to a computer and uploaded to the open-seneca platform. This was the option selected in Kigali as the motorcycle-taxi drivers have limited access to data plans.

Data quality

The open-seneca particulate matter sensor is pre-calibrated and shows excellent inter-sensor comparability. Previous field tests showed that when open-seneca sensors are co-located, i.e.placed in the same location for an extended period of time to compare the readings reported by each individual sensor, the measurements are within ± 0.6 μg/m³. This allows to compare readings of sensors moving around the city and identify which areas are more polluted than others (understanding spatial distribution of PM2.5 and finding hotspots of pollution), as well as comparing PM2.5 levels before, during, and after intervention activities aimed at reducing air pollution.

In order to provide accurate PM2.5 absolute values i.e., knowing the exact concentration of PM2.5 in a specific location instead of performing relative comparisons, an additional calibration step with a reference monitoring station in the city is necessary. This step is only possible if the city already has existing air quality monitoring reference stations and could be performed post-deployment. Due to the time restrictions of the project, it was agreed with the local stakeholders that the calibration would be performed after the deployments.

Procurement and deployment in Kigali

Open-seneca shipped 20 air quality monitors to the University of Rwanda in Kigali on 8th August 2021. This shipment included Garmin-compatible motorbike mounts and USB charging cables. As the restrictions related to Covid19-pandemic did not allow for a local in-person assembly workshop, usually done to increase local participation, sensors were shipped pre-assembled. This also enabled an accelerated deployment of the network due to time constraints.
Prior to the shipment, the respective documentation to release the shipment from customs was prepared in accordance with Rwandan law n°37/2012 of 09/11/2012 to assure rapid processing and release. The shipment arrived in Kigali on 18th August 2021. Upon approval of the Rwandan Ministry of Education, which was gathered by the project's local champion Dr. Egide Kalisa, the customs office released the sensors on 31st of August 2021. The project's UEMI local stakeholder, Moise Bitangaza, organised their transfer from the airport to the Ampersand office.

The data collection period was chosen to be four weeks (1st September 2021 - 1st October 2021), with 16 sensors mounted on Ampersand's electric motorcycles and four sensors on private bicycles.

Figure 2. Fitting of open-seneca sensors. Left and middle: open-seneca sensors are placed on the Ampersand electric motorbikes during the capacity building and deployment workshop at Ampersand's Kigali Office, 1 September 2021. Right: open-seneca sensor mounted on a private bicycle. Picture Credit: Moise Bitangaza.

Based on previous multilateral discussions between open-seneca, Ampersand and UEMI, it was decided that the data will be collected offline on the sensor's SD card, as the drivers did not have access to a smartphone or sufficient data plan to upload data on the go. This required manual uploading to the open-seneca data platform, kindly facilitated by Moise Bitangaza once a week.

Following the end of this period of four weeks, sensors are currently stored at the University of Rwanda, owned by the University and to be deployed locally for further projects.

2.2. Methodology

A. Data collection

The collected geo-tagged pollution data is aggregated by open-seneca into meaningful air quality city maps. The collected air pollution data is aggregated temporally and spatially:

- **Temporal variations of PM2.5**: the data from the whole city is aggregated daily to obtain the baseline PM2.5 concentration of the city, calculated as the median in 24h periods, and analyse how this baseline varies over time. This baseline is not affected by localised spikes in air pollution that users might experience while they commute in the city, and rather gives an understanding of the city background pollution, which strongly depends on meteorological conditions and other external conditions, such as long-range transboundary particulate pollution.

- **Spatial variations of PM2.5:** the data is aggregated over the whole data collection period to provide city pollution maps that highlight which areas are more polluted than others. Two types of maps are generated:
  - **Absolute PM2.5 maps:** they display the spatial distribution of measured PM2.5 concentrations. It is important to note that sufficient data needs to be collected in the whole city every day to provide a realistic view of the air pollution distribution in the city. If the coverage is not sufficient, these maps could be highly skewed by the city baseline. As an example, if one part of the city was mapped on days with higher baseline, it would look more polluted than others mapped on days with low baseline. Therefore, the absolute PM2.5 map should not be used to understand spatial variations of PM2.5 in the city, and instead, the hotspot map (PM2.5 with baseline subtracted) should be used.

  - **Hotspot maps:** they display PM2.5 concentrations in the city once the cities' PM2.5 background is subtracted, effectively highlighting which areas of the city are more polluted than the average (hotspots) or which areas are less polluted ("cold spot"). This visualisation technique corrects for city-scale PM2.5 clouds (e.g., fog) that macroscopically moves across the city and can cause all active sensors to record "false" local hotspots. The PM2.5 background is calculated as the 15-minute moving-median value of all PM2.5 readings across the city. To facilitate the visualisation of these maps, the colour scale is set so that areas that have average pollution levels are shown in green, and areas that consistently exceed the city background will be highlighted in red. For example, in a hotspot map, a zone that displays a value of 15 $\mu g/m^3$ means that its particulate pollution levels are 15 $\mu g/m^3$ above the median value of all sensors that submitted PM2.5 data within the last 15 minutes. If that zone consistently records higher PM2.5 than the background, then it is classified as a hotspot. These hotspots can be filtered according to a chosen set of validation criteria: e.g., a minimum number of datapoints, minimum number of independent users or unique time periods that measure high PM values in the same area.

- **Temporal variation of city pollution maps:** if sufficient data is collected regularly throughout the day and the city, pollution maps can be generated for shorter time frames than the total data collection period. For example, maps can be generated for different hours of the day or different days of the week to understand how changes in traffic behaviours impact different parts of the cities.

Additionally, other important information can be obtained by analysing the collected air quality data, such as at what times of the day the data was collected, or how PM2.5 varies at different times of the day according to traffic conditions and rush hours.

B. Community engagement

The deployment of open-seneca sensors involves citizens in all the phases of the project (see Figure 3): sensor assembly, data collection and interpretation, as well as identification of solutions to improve air quality. This holistic and inclusive approach not only helps build local capacity on how to assemble, deploy, manage, and maintain the sensor network; but it leverages the power that engaged communities can have in driving change and bringing value to the collected air quality datasets.

Figure 3. Community engagement in all the phases of the air quality monitoring process.

In order to involve local stakeholders and citizens, a series of workshops were organised in Kigali:

- **Train-the-trainers workshop:** on the 15th of July 2021, a first collective meeting of open-seneca, Ampersand, Universities of Rwanda and Helsinki, UN-HABITAT and UEMI, was held, discussing the general outline of the project in Kigali. In this meeting, the Kigali partners were briefed by open-seneca on air pollution and the open-seneca sensors. The purpose of this meeting was to transfer knowledge about the open-seneca sensor technology and operation, as well as on how to build, deploy, manage, and maintain networks of these mobile sensors. In addition, on 9th September 2021, an internal workshop between open-seneca and Moise Bitangaza was conducted to discuss minor hardware related issues as well as to implement an update of the sensor software.

- **Sensor assembly and distribution workshops: once trained,** the local stakeholders can deliver workshops to engage citizens in both the assembly and use of the open-seneca sensor. Following the delivery of the open-seneca sensors to Ampersand, a capacity building and deployment workshop was held on 1st September 2021 in Ampersand's Kigali office. During this workshop, 16 air quality sensors were fitted to the Ampersand electric motorbike fleet and four devices were fitted to private bicycles. he local stakeholders, including Moise Bitangaza, Clive Irambona and the Ampersand delivery drivers, resolved mounting issues by organising rubber spacers from a local shop, as the mounting arm was too wide to fit the motorbike's handlebar. The handlebar mounting position was chosen over various other suggested locations on the motorcycle to prevent compromises of the driver's safety while riding and to avoid splash water damaging the electronics of the sensor.

During the workshop, the drivers were briefed on the basic operation of the open-seneca device, e.g., collecting data, charging as well as mounting, and received an introduction to the different parameters collected by it. As Ampersand's electric motorbikes are powered by battery, the open-seneca sensors were connected via USB to the motorbike, which made the continuous operation of the monitor possible and enabled the collection of air pollution data in unprecedented spatial and temporal resolution. Motorcycle-taxi drivers were asked to operate the sensor constantly during the business hours.

- **Data interpretation workshop:** once the data is collected, an essential component is to bring meaning to the air quality maps. For this, local knowledge of the city dynamics and additional information is critical. The maps were shared with the local stakeholders to help identify hotspots and sources of pollution. In the cities where extra datasets were available, such as a map of paved/unpaved roads, the air quality data was linked to the provided datasets. Volunteers carrying a sensor contributed by answering questions about their experience during the data collection period. The questions were asked by the local stakeholders and answered in a conversational manner, therefore some quotes are available. Example survey questions were:

- How was the traffic when the sensor showed high values of PM2.5?
- How was the traffic when the sensor showed low values of PM2.5?
- What do you think are the main sources of particulate pollution in your city?
- What situations caused the sensor readings to spike?
- What did you learn during the experience?
- Did seeing your personal exposure to pollution cause any change in your perception or behaviour?

- **Presentation of results to policy makers:** the air quality city maps, together with the data analysis and University of Helsinki's modelling were presented to Rwanda authorities on the 15th of November during an online event, with the Rwanda Environment Management Authority and Rwanda's Ministry of Infrastructure invited. This aimed to inform them on the power of using a combination of low-cost air quality sensors and air quality modelling to provide evidence for a transition to cleaner mobility and support decision-making. During this workshop, initial recommendations or solutions that can be implemented in the city to reduce air pollution in the identified hotspots, identified by the team and Dr. Egide Kalisa, were presented to them.

Because the dataset collected is significant, further events will be planned to collaboratively interpret results and identify recommendations, where the general public will have the opportunity to interact with the data and interpret the results with the help of local knowledge. This will be key in understanding the findings and pollution phenomena in the Rwandan capital and allow for citizens from all walks of life to learn about the air quality situation in their hometown.

2.3. Results of air quality data collection

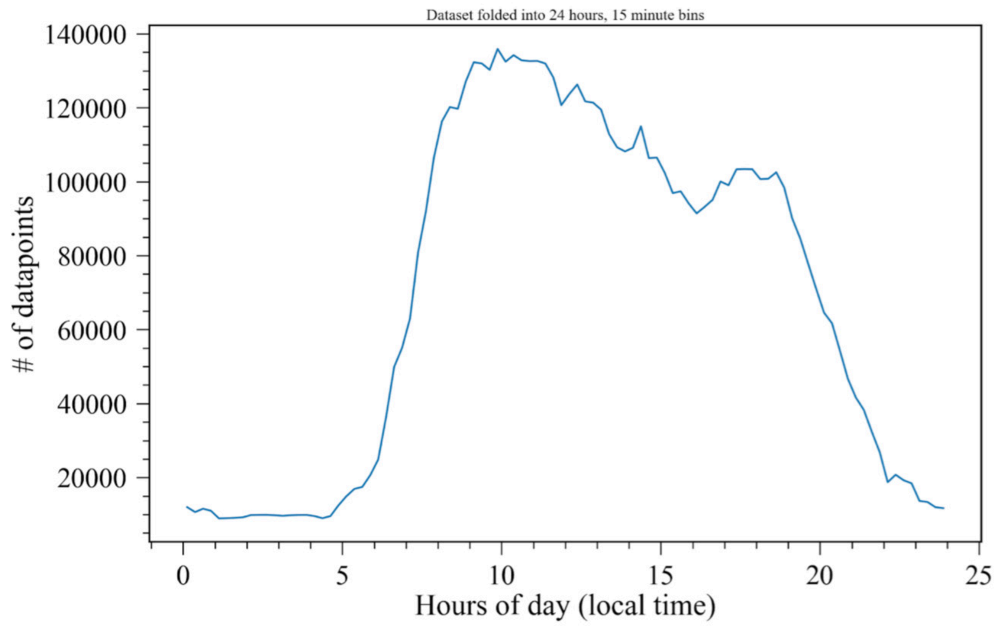
A. Current air quality levels in Kigali

Dataset characteristics

After four weeks of data collection, the volunteers had gathered 6.6 million valid data points, each corresponding to an individual air quality measurement at a specific location.

Thanks to the high mobility of the motorcyclists providing taxi services to passengers, a total area of 162 km² was geotagged with air pollution data, corresponding to over 40,000 data points per km². As expected, the sensors were mostly operated during the drivers' business hours between 5 am and 11 pm CAT, with activity maxima at 10 am and 6 pm (Figure 4).

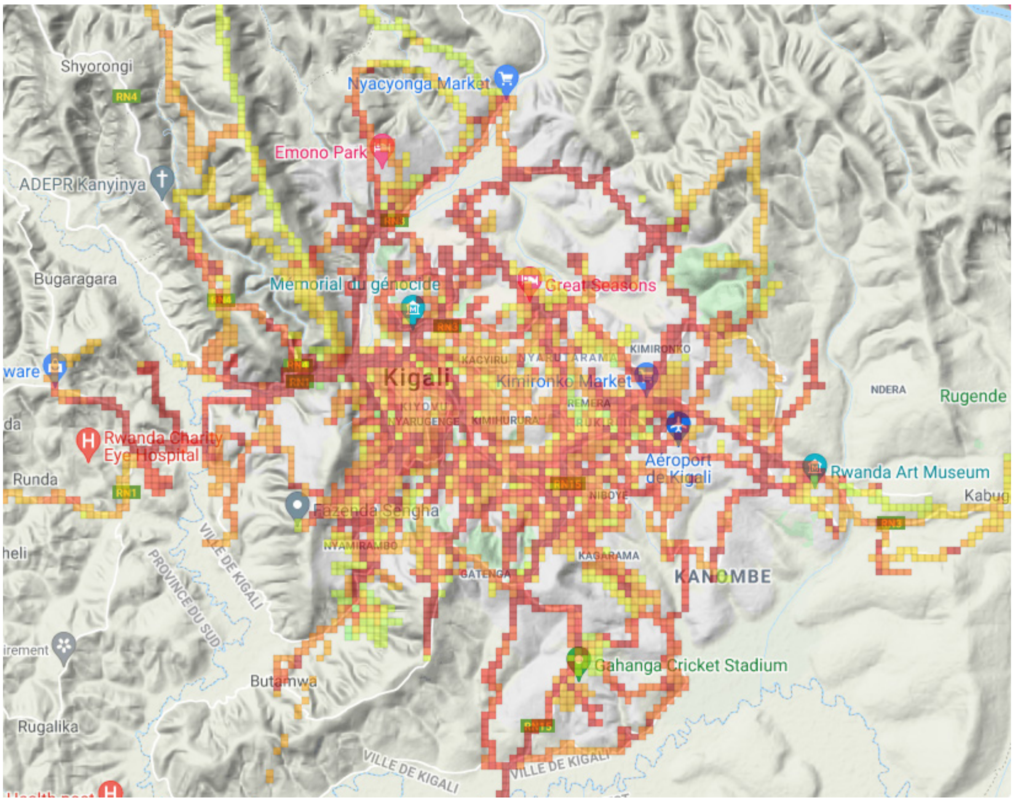
Figure 4. Histogram of data point collection with regards to time of the day. The sensors were mostly used during the business hours of 5 am to 11 pm CAT, with a maximum usage around 10 am CAT.



Absolute air quality results

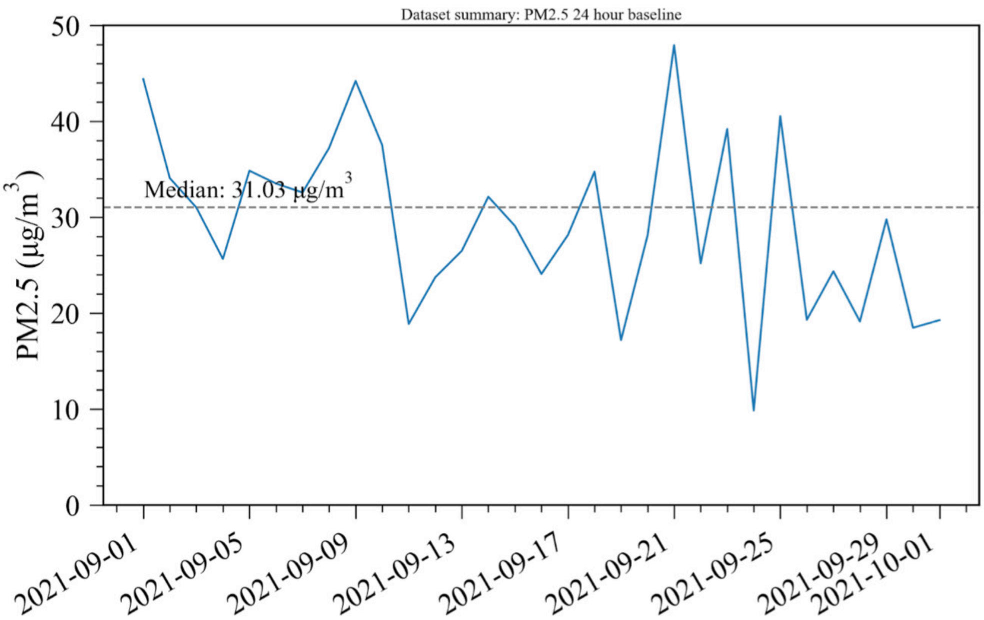
Figure 5 shows the map of PM2.5 absolute levels, displaying the aggregated, geotagged PM2.5 pollution data collected over four weeks with the open-seneca sensors ("absolute PM2.5 map", see the part above on the methodology). The median baseline for the entire collection period in Kigali was found to be 31.0 μg/m³ overall, which is about 6 times higher than recommended as annual average by the 2021 WHO air quality guidelines, which is of annual exposure of 5μg/m3. Daily exposure should not exceed 15μg/m3.

Figure 5. Air pollution map of Kigali. The map shows the aggregated, geotagged PM2.5 pollution data collected over four weeks with the open-seneca sensors.



The temporal PM concentration in Kigali varies greatly, with levels being significantly below the baseline some days and strongly exceeding it on other days, as shown in Figure 6.

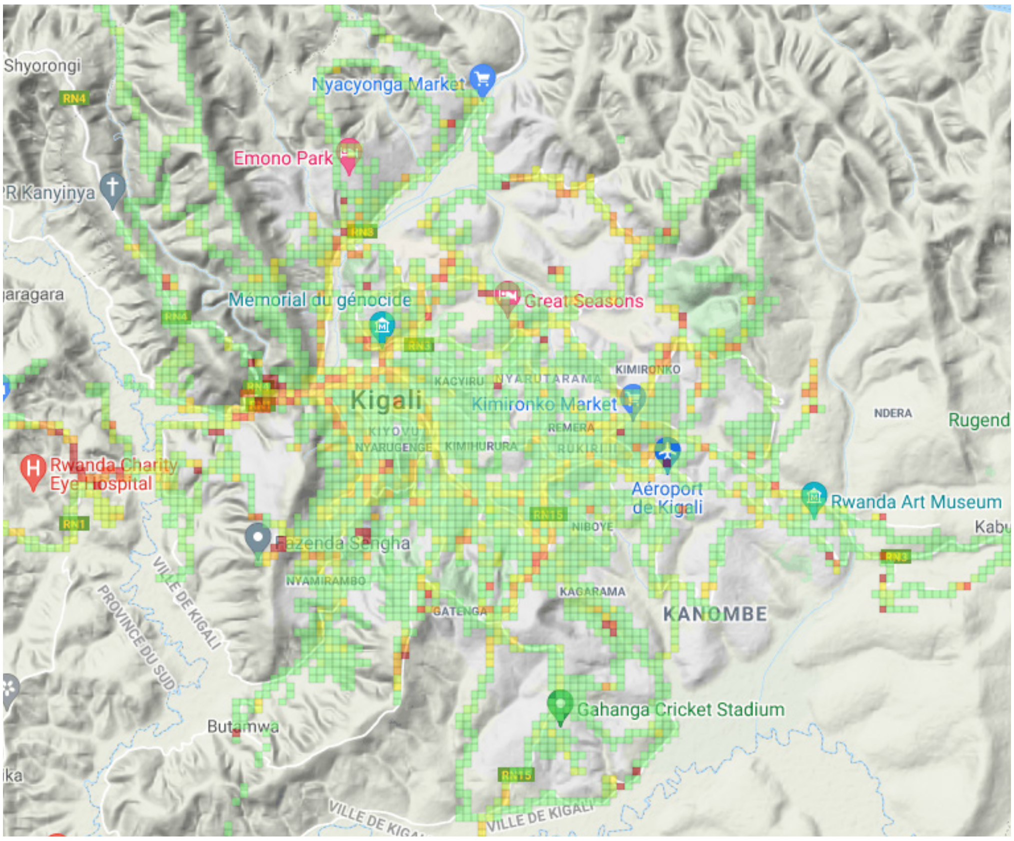
Figure 6. Histogram of average PM pollution during the four-week monitoring period.
The baseline of the city is depicted as a dashed line at 31.0 μg/m³.



Identification of hotspots

After processing the data and removing the "pollution baseline" of the city (i.e. the PM2.5 background calculated as the 15-minute moving-median value of all PM2.5 readings across the city), open-seneca was able to identify various air pollution hotspots across the city (figure 6). In this map, the colour scale is set so that areas that have average pollution levels are shown in green, and areas that consistently exceed the city background will be highlighted in yellow, orange or red (see methodology explanation in section 2.2.A). For instance, if a spot on the map displays a value of 15μg (yellow), it means the hotspot was 15μg above the median value of PM2.5 data within the last minutes in the city. This map is available online on the open-seneca platform:
http://app.open-seneca.org/RegionMap.php?dp=Kigali_fixed_dec2021&df=pm25_baseline_removed_dlat002_-1_0_30_30&tiled=1&cmin=0&cmax=50

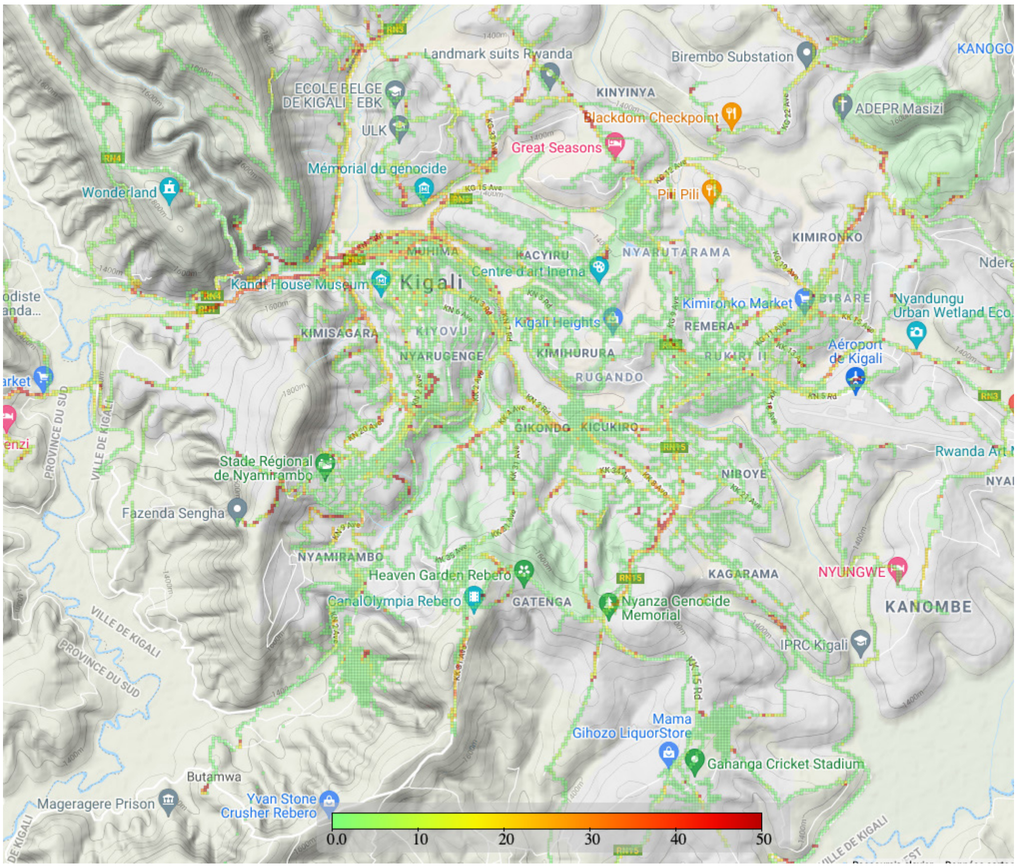
Figure 7. Hotspot (baseline removed) air pollution map of Kigali. The map highlights hotspots of air pollution in the city and shows the processed pollution data collected over four weeks.



In the map above in Figure 7, one square, or tile, represents a geographical area of 225 x 225 m. The map provides an excellent overview of areas with higher levels of ambient air pollution, i.e. hotspots.

Following the realisation of this first hotspot map, the project team expressed its intention to refine the identification of hotspots at a smaller scale, leading open-seneca to decrease the size of the tiles to 55x55m. This resulted in the second hotspot map shown in Figure 8, also available on the open-seneca platform:
http://app.open-seneca.org/RegionMap.php?dp=Kigali_fixed_dec2021&df=pm25_baseline_removed_dlat0005_-1_0_30_30&tiled=1&cmin=0&cmax=50

Figure 8. Hotspot (baseline removed) air pollution map of Kigali, with smaller tile size.

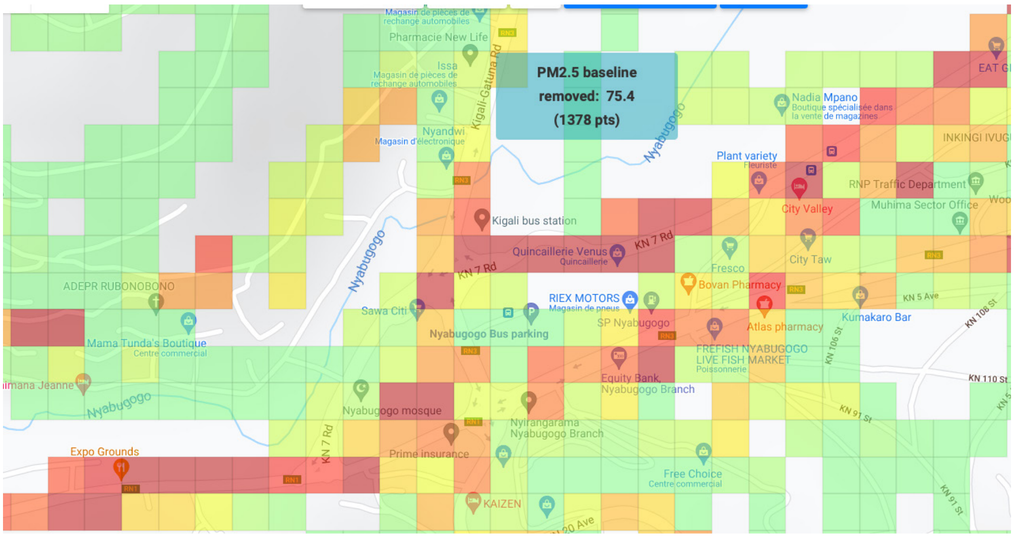


This smaller scale enables a more precise identification of the air pollution levels within previously identified hotspots. For instance, in the hotspot located in the south of Kicukiro, the first map showed a maximum level of PM2.5 of 40.9 µg/m3 to the north of Mount Kenya University/Kicukiro Campus. Decreasing the size of sizes shows variations around this average of 40.9 µg/m3. It enables the identification of two further sub-hotspots within this area: one sub-hotspot to the West of KK527 St, and one at the intersection of KK15 Rd, KK26 Ave, KK25 Ave, and KK540 St, where a maximum of 73.4 µg/m3 is found.

Focus on some hotspots

The area around the segment of the RN1 in Kigali's Northwest, between Nyabugogo and Nyamabuye, was exposed as the most broadly polluted space in the city during this study. A particularly warning hotspot was found around the highly frequented Nyabugogo bus station area, on the intersection of RN1 and KN7 Rd. In the areas surrounding the bus station, the fine particulate matter concentration was determined to be on average 70.9 µg/m³, which was exceeding the newest WHO guidelines for annual exposure to PM2.5 by 14x and for daily exposure by more than 4x. This was particularly the case on RN1 to the western side of the bus station, and KN7 Rd and KN12 Ave to the easter side.

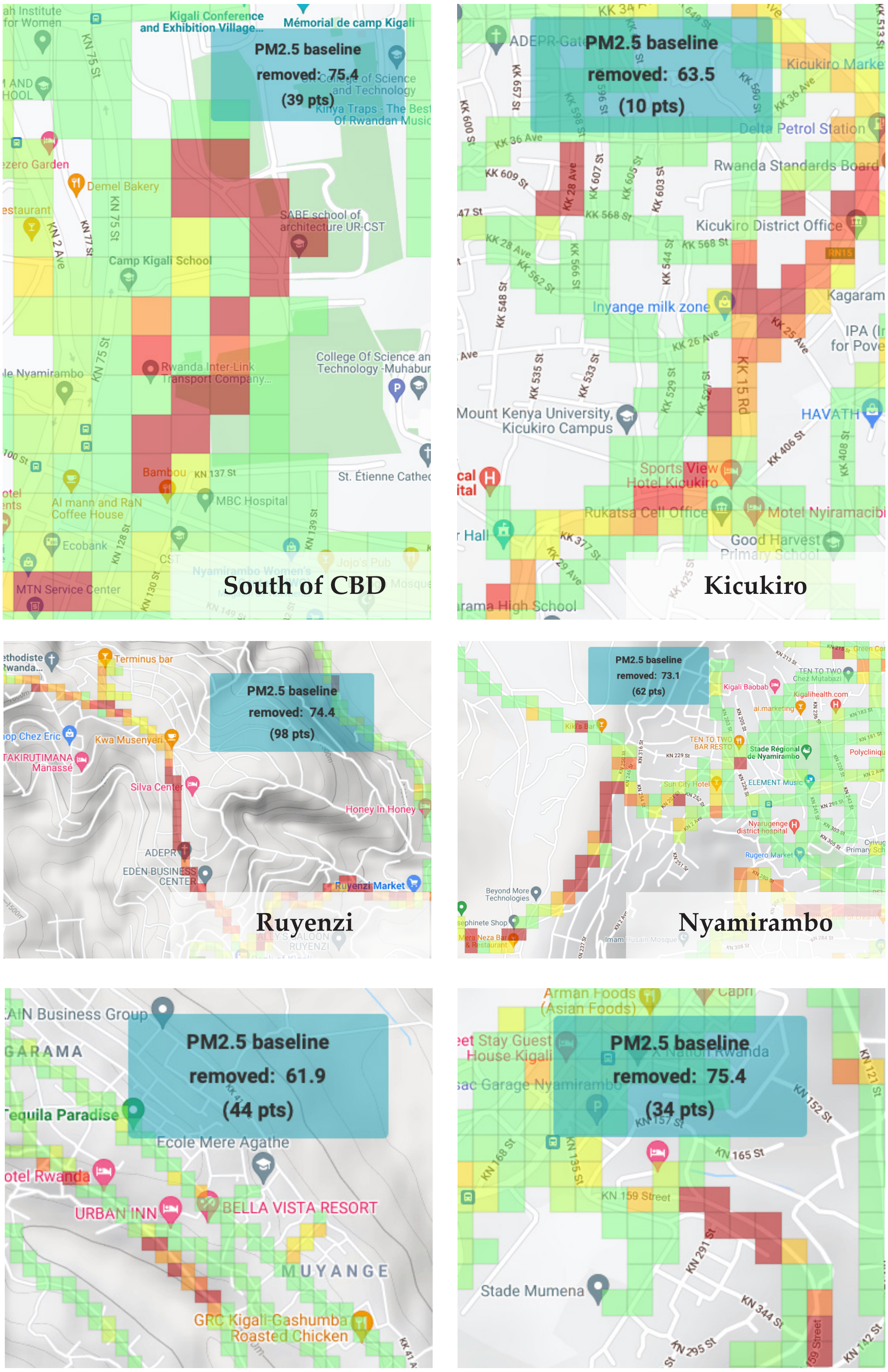
Figure 9. Left: Hotspot analysis in downtown Kigali conducted by open-seneca. The scale is referenced to the PM2.5 baseline of the city, which was found to be 31.0 µg/m³. After data processing and baseline removal, A PM pollution hotspot was exposed at the Nyabugogo bus station, with values exceeding the WHO guidelines on annual PM2.5 exposure by 14x. Right: Photograph of Nyabugogo bus station, highlighting the highly frequented nature of one of Kigali's main transport and trading hubs. Picture Credit: Franciscu Anzola, WikiCommons.



Other hotspots can be identified in the map. These include in particular:

- Ruyenzi, located eastern of Kigali City, on RN1,
- Kicukiro around KK 15 Rd,
- South of Nyarugenge, eastern side to KN75 St (Camp Kigali School, Rwanda Interlink Transport Company, SABE school of architecture),
- Mumena around KN159 St,
- Nyamirambo around KN250 St,
- Western part of Muyange, on KK 23 Ave.

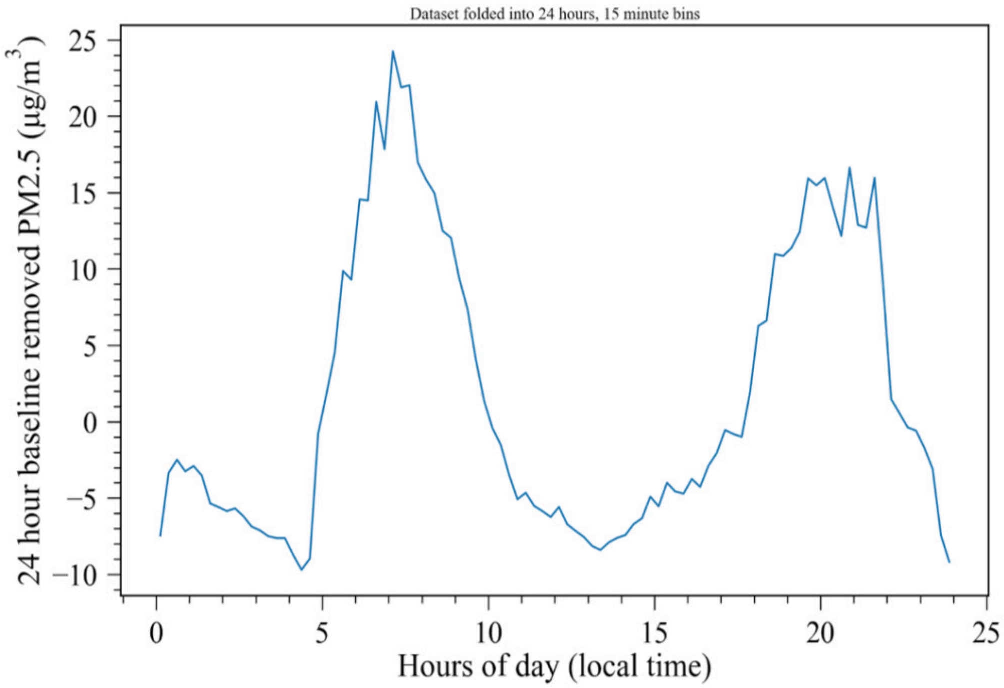
Figure 10. Examples of hotspot of smaller size, showing some of the PM2.5 values found (open-seneca, 2021).



Variation per hour of the day

The very significant volume of data collected enabled open-seneca to deepen the analysis, by looking at the evolution of levels of PM2.5 (baseline removed) per hour. Peaks of air pollution can be clearly identified in the morning between 7 and 9 am, hinting toward a link with traffic rush hours, as well as in the evening between 7 and 10 pm, possibly linked with rush hours or with meteorological phenomena.

Figure 11. Baseline-removed average PM2.5 pollution profile over the course of a day, showing peaks of air pollution during the morning and evening rush hours.



B. Drivers' feedback

A user survey was designed and shared with the motorcycle taxi drivers for them to provide feedback on using the device. This survey also aimed to know whether they learned about air pollution and their opinion on sources of air pollution in Kigali. From 16 motorcycle drivers, 15 participated in the survey. All participants reported that they have enjoyed the experience of using the sensor but indicated that they still did not know details about air pollution and particulate matters after the end of project, highlighting that informational material or an introductory lecture on air pollution is key to familiarise the users with the parameters they were collecting in order to assure a learning experience and initiate behavioural change.

Similar experiences were shared by the cycling volunteers, who indicated that they had enjoyed using the sensor, but suggested that additional information highlighting the basic operational features of the device would be of support.

The motorcycle-taxi drivers reported that they observed the sensor showing high PM values when they were in traffic jams, areas with high traffic volumes or next to old vehicles. In addition, four of the participants reported high PM values when they were driving on unpaved or dusty roads. In similar fashion, three of the four cycling volunteers indicated that in their experience old ICE-type vehicles are the main source of air pollution in the Rwandan capital, in addition to coal burning. Despite these reports being subject to each volunteer's own commuting route and individual experience in the city, they are clearly in line with reports on sources of air pollution in Kigali in the scientific literature.

Figure 12. Driver moto (right), Deployment Ampersand (left)

2.4. Recommendations

a. Initial recommendations based on Kigali's hotspots

Based on the air quality dataset collected and the drivers' feedback, some initial recommendations were identified. It is essential to note that it is only the start of the process and these findings will be further assessed and discussed with researchers, citizens and decision-makers.
Some recommendations include:

- **Hotspots identified in the study confirm previous findings,** such as, in the first place, the highest levels of air pollution found around Nyabugogo's bus terminal (RN1, KN7 Rd)

- **Other air pollution hotspots are identified,** such as Kicukiro, south of Nyarugenge, Mumena, south of Nyamirambo, western part of Muyange. In addition, areas with "intermediate" levels of air pollution above the baseline (yellow to orange) are also identified. These areas should be further identified and discussed via a collaborative process. We suggest organising this collective identification during an upcoming Car-free day, together with researchers, the University of Rwanda, and with close involvement of the Rwanda Environment Management Authority (REMA), the Ministry of Infrastructure (MININFRA) and the City of Kigali. This process should target a refined identification of the boundaries of hotspots, characteristics, and consequences on the environment.

- **Air quality management areas.** The high levels of outdoor air pollution in these hotspots, reaching sometimes 70 $\mu g/m^3$ PM2.5 on average and above, have a daunting impact on human health. They significantly exceed the thresholds set by the World Health Organisation. We recommend concentrating policy measures on these hotspots. As shown by the hourly variation, the dataset hints towards a strong association of air pollution with vehicular traffic. We therefore **recommend targeted interventions in these areas** to reduce conventional motorised transportation, support public transport, and promote active mobility namely walking and cycling. This data could usefully support the work led by transport and infrastructure authorities to identify further car free zones and areas where private vehicles are discouraged, as highlighted in the National Transport Policy and Strategy for Rwanda.

For instance, a hotspot is identified in the south of Nyarugenge and Central Business District, eastern side to KN75 St (Camp Kigali School, Rwanda Interlink Transport Company, SABE- School of Architecture and Built Environment of the University of Rwanda), with PM2.5 levels reaching 75.4 $\mu g/m^3$. **Extending existing cycle lanes** currently present in the Central Business District to a network of cycle lanes extending to KN 75 St and KN7 Ave, as proposed by ITDP Africa and the SolutionsPlus project, would therefore have strong meaning to decrease motorised transportation and reduce air pollution.

- **Regarding causes,** the project looked at data of paved and unpaved roads provided by the City of Kigali, in order to identify whether hotspots were more frequently found in areas with unpaved roads. Dust can indeed contribute to air pollution, and some motorcycle-taxi drivers reported to have observed high PM values when driving on unpaved or dusty roads. The analysis was however not conclusive since some hotspots are found in paved road areas, while some areas with unpaved roads have average air quality levels. It seems therefore difficult to isolate at this stage the criteria of pavement from other sources of pollution, such as the number of vehicles found in an area or the type of vehicles used in that area, for instance trucks. We recommend further studies disaggregating factors of air pollution, to better understand causes.
- It is key to understand better the consequences of these air pollution hotspots. We recommend further analysis of the data to concentrate on the **presence of schools and hospitals** in these areas. An initial screening shows the identification of such establishments in polluted areas, such as the UR-CST's SABE- School of Architecture & Built Environment (75.4 $\mu g/m^3$) or Kagarama High School (43.9 $\mu g/m^3$). This should be done through a collaborative process. Possible recommendations could include quick interventions on conventional vehicles idling outside of these establishments during drop-off or pick-up, the support of collective transportation via cleaner vehicles, e.g. electric school buses or vehicles respecting higher emission standards, and the deployment of infrastructure facilitating cycling and walking around them.

- Beyond the question of the hotspots, the PM2.5 baseline level of 31 31.0 $\mu g/m^3$, six times higher than the WHO annual threshold, shows the need to **address air pollution at the City level** as well. The policy measures identified by the City of Kigali and the Ministry of infrastructure to support sustainable, active and electric mobility go in the right direction. The ambitious support towards electrification is commendable and must be sustained.

- Maps show that trips realised by motorcycle-taxi drivers extend beyond the boundaries of the City of Kigali, showing air pollution in those areas. An important air pollution hotspot is found in Ruyenzi, located at the west of the city of Kigali. This shows a need to **intervene in other secondary or satellite cities** around Kigali. Within Kigali, some suburban areas also show important levels of air pollution, such as Kicukiro, some parts in Nyamirambo, or to the north of Kimironko. Understanding patterns of commute and motorised transport from these areas is a further recommendable step.

Figure 13. Quality public transport (ITDP, 2021), car-free zone (Martin, 2021), electric mobility (Martin, 2021))

b. Recommendations for air quality monitoring projects

- *Mobile* air quality sensors help address the gap of data and challenges of the costs of monitoring stations, which cannot cover the whole territory of the city. While reference-grade monitoring stations are needed, mobile sensors can complement them. The use of good quality low-cost sensors in a mobile setting (i.e., the sensors are mounted on vehicles and move around the city, mapping air pollution street-by-street) is a very powerful tool. Open-seneca sensors show excellent inter-sensor comparability (measurements within ±0.6 $\mu g/m^3$ when placed in the same location), which enables a comparison of PM2.5 readings between sensors that are moving around the city. Within a month of data collection, air quality city maps covering most of the city area were obtained that help understand spatial variations of PM2.5 with a resolution unachievable by stationary sensors.

- Calibration of the low-cost sensors with a reference-grade monitoring station is necessary to provide accurate absolute PM2.5 values and should be undertaken in future use of the open-seneca sensors staying in Kigali. Previous open-seneca calibration studies with reference stations show that open-seneca low-cost sensors follow the same trend as the reference station, but with a slight offset (underreports PM2.5 absolute concentrations). Yet, uncalibrated measurements can still be used to provide evidence for decision-making by doing relative comparisons. Hotspot maps highlight areas in the city that are more polluted than others, independently of the actual PM2.5 value. Once a hotspot is identified, understanding what is causing that relative increase in PM2.5 compared to other parts of the city is key to inform good and bad practices in urban planning, as well as identifying priority areas for intervention activities.

- The identification of "local champions" that lead local implementation was key for the success of the project. Local champions understand the local context and needs, help to establish partnerships with relevant local stakeholders and lead the activities on the ground.

- Adaptation to local needs and conditions was paramount to ensure support from local stakeholders. Ensuring that data could be collected offline, catering for the lack of data plans, as well as the financial support of Ampersand to the project, compensating the drivers for the participation in the data collection, ensured a strong adherence of the drivers with the project, and smooth communication to organise data download. Alongside the motorcycle-taxi drivers, the support from cyclists shows the opportunity to mobilise a community of sustainability mobility champions, who can help disseminate the results.

- Collecting air quality data and producing city maps is only the first step. Local expertise about the city dynamics is essential to bring meaning to the data and turn the maps into actionable tools. Hotspot maps highlight areas that have higher PM2.5 pollution than others and local knowledge helps identify sources of pollution in those hotspots. When sources are identified, the right solutions and interventions can be applied. The interpretation of the air quality city maps need to be crowdsourced to the general public for much more granular input, in an open data perspective.

- In order to trigger behaviour change in citizens towards reducing their personal exposure and emissions, a strong focus on community education is important to ensure that they understand the impact of high PM2.5 concentrations on their health. Citizen engagement is a powerful complementary tool to facilitate the adoption and transition to cleaner mobility. Motorcycle-taxi drivers and cyclists expressed the wish to obtain additional information about air pollution and particulate matters. As this was limitedly possible during the COVID-19-pandemic, further occasions to mobilise the public should be identified. In the case of the motorcycle-taxi drivers, this could be done in cooperation with the national federation Ferwacotamo. It could be tied to current initiatives to transition to electric motorcycles, suppressing tailpipe emissions.

3. Conclusion

The deployment of 20 mobile air quality monitoring devices in Kigali during four weeks on electric motorcycle-taxis and private bicycles, enabled the collection of an unprecedented dataset with high spatial and temporal resolution. The large dataset informs about the situation of air quality in Kigali with a median baseline of 31.0 $\mu g/m^3$ overall, which is about 6 times higher than the annual average of 5µg/m3 recommended by the WHO. Since the mobile sensors were used throughout the city, the project is able to reveal areas facing particularly high levels of outdoor pollutants in Kigali. A series of initial recommendations is done to curb air pollution in these areas, via targeted local measures and City-level policies supporting public and active mobility, as well as electrification. Urban Pathways and its sister project SolutionsPlus will continue to support the City of Kigali and institutions of the Government of Rwanda in taking action towards improved air quality and sustainable urban mobility.

Annex I – Partners involved in the project

International Implementing Partners

UN-Habitat. UN-Habitat is the United Nations programme working towards a better urban future. The Urban Basic Services Branch of UN-Habitat will work with international partners and highly motivated cities in Asia, Africa and Latin America on the implementation of the New Urban Agenda focusing on urban energy, mobility and resources systems. This will build directly on a broad range of activities by UN-Habitat in the respective sectors and on the dedication to sector integration.

Urban Electric Mobility Initiative (UEMI). UEMI is the coordinator of the SolutionsPlus project promoting integrated and innovative urban electric mobility across the world, financed by the European Union via the Horizon 2020 programme. UEMI coordinated the implementation of the Urban Pathways air quality project, since most of the sensors were deployed on electric vehicles supported by SolutionsPlus.

The Centre for Global Equality (CGE), open-seneca initiative. The Centre for Global Equality (CGE) is a Cambridge-based charity, which facilitates collaboration between business, academia, and civil society to address the problems that undermine the wellbeing of the poorer half of the world's population. CGE cultivates innovative solutions to global challenges through their Global Goals Innovation Cultivator (GGIC). One of CGIC's members is the 'open-seneca' initiative, led by six PhD students at the University of Cambridge.

Open-seneca deploys low-cost, mobile air quality sensor networks driven by citizen science. The aim of the initiative is to build local capacity for deployment of large-scale air quality monitoring networks, with two main objectives: (1) provide actionable, high-resolution air quality city maps to policy makers to inform a data-driven transition towards cleaner transport systems, and (2) empower citizens with data about their personal exposure to pollution and drive behavioural change about the use of cleaner transport means.

Combining the use of low-cost sensors with a citizen science approach makes them even more powerful by enabling the monitoring of personal exposure and the identification of hotspots of air pollution. Engaging citizens allows raising their awareness about the importance of taking action to reduce air pollution and to empower them as active stakeholders in the search for solutions. A society that is aware can have a huge impact in reducing air pollution: by reducing their own individual emissions, by minimising their personal exposure, and by complying to measures to reduce emissions implemented in cities by local governments.

University of Helsinki. The University of Helsinki is Finland is Finland's largest and oldest academic institution. Since 1640, it has contributed to the establishment of a fair and equal society that is considered the best in the world according to a number of indicators. The University of Helsinki, Department of Atmospheric Sciences has a long tradition in air pollution research and working alongside local government institutions and businesses, such as the Helsinki metropolitan Air Quality Testbed (HAQT) in Nanjing, China and many other international urban environments. The University of Helsinki, Department of Computer Science is a contributor to the Urban Lab of Europe. It is a leading partner in the EU UIA HOPE - Healthy Outdoor Premises for Everyone. Led by the City of Helsinki, the Department of Computer Science provides an end-to-end high-resolution air quality service for public authorities, businesses, and citizens. This includes downloadable HOPE APP, portable low-cost air quality sensors, cloud-based MegaSense platform, and Real-time analytics.
The University of Helsinki collaborated with the Finnish Meteorological Institute (FMI) and Matatavu.

Local Partners

Our warmest thanks go to our very committed local partners:

Dr. Egide Kalisa. Postdoctoral Researcher, Expert in Air Pollution and Environmental Science and Health, University of Toronto; College of Science and Technology, University of Rwanda

Dr. Alphonse Nkurunziza, Lecturer at College of Science and Technology, University of Rwanda, and a senior Transport Planning and Engineering Expert

Moise Bitangaza, Assistant Lecturer, College of Science and Technology, University of Rwanda ; UEMI research fellow

Ampersand Rwanda Ltd, c/o Clive Irambona, manufacturer of affordable electric motorbikes and charging systems

Francois Zirikana, E-mobility specialist, City of Kigali

Cyclists: Ammar Kawash; Patrick Ntwari; Bernard Binagwaho; and Jimmy Dushimimana

Urban Pathways

www.urban-pathways.org

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