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# Urban air quality citizen science

# Project overview report

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# 1 Introduction

## 1.1 Background

In early 2013, SEPA issued a call for proposals with the overall aim of designing a local air quality programme which would engage the public through the use of Citizen Science. Citizen Science involves the participation of the wider community (particularly non- scientists) in scientific projects. The benefits of Citizen Science include the facility for extensive data collection and the interaction between scientists and the community. In addition citizen scientists get a chance to inform scientists, and in the process, learn more about their environment. Information gained through Citizen Science projects can change public perceptions of the natural world, promote interaction with nature, and engage the community in the management of natural resources.

The overall aim of the work was to help build further capabilities in the area of Citizen Science, as a follow-on to existing work in this area, building on existing projects and networks including Scotland’s Environment Web, CAMERAS and Scotland Counts.

To carry out the work, SEPA commissioned a consortium of scientific organisations led by the Institute of Occupational Medicine (IOM) in collaboration with the NERC Centre for Ecology & Hydrology (CEH), The Conservation Volunteers (TCV) and the Respiratory Group within the University of Aberdeen (RGA).

## 1.2 Study aims and objectives

The objectives of this study were to:

- Identify the scientific and policy questions that could be answered using a Citizen Science approach for learning about urban air quality.

- Explore possible methodologies and tools that could be used for an outdoor air quality Citizen Science approach and scope out a set of options that include data collection, data use and volunteer engagement.

- Based on the preferred option/s, design a programme of work with different projects.

- Build a partnership that was willing and able to deliver the project including identifying the aims of the programme, target participants and funding and resources for delivery and implementation.

## 1.3 Study methods

The overall aim of the study was to produce a programme of work, comprising a number of projects, to advance the use of Citizen Science in the area of local air quality.

The programme of work was developed in three phases:

*Phase 1: the review phase*

This first project phase focused on review of existing information on methodologies of Citizen Science activities within the UK and beyond. This review phase included the compilation, collation and evaluation of literature, reports and other information sources. It also included a review of current technology (sensors), of relevant research projects and a preliminary description of the tools available for Citizen Science projects provided on Scotland's Environment website (SEWeb).

In preparation for the second phase of the study, within Phase 1 a consultation was carried out with an Advisory Group, including a range of stakeholders. This consultation provided input into the subsequent development of a suggested programme of Citizen Science air quality projects, and is described under the Phase 2 results in the following sections.

*Phase 2: development of a programme of projects*

Based on the findings of Phase 1 and on the discussions with the Advisory Group, a suggested programme of projects was developed. This included information on:

- Aims and objectives
- Basic methodology
- Intended participants
- Benefits and drawbacks
- Costs and timescale
- Potential funding sources

*Phase 3: pilot studies*

In Phase 3, small pilot studies of two of the suggested projects were undertaken. These pilot studies included identifying suitable study participants, instructing them on the purpose of the pilot studies and the technology to be used, gathering and processing measurement data and some feedback to the study participants.

In addition, a brief evaluation process was carried out whereby participants in the pilot studies were asked to complete an evaluation questionnaire about their experiences during the pilot work. Finally, a more detailed assessment of the Citizen Science toolkit available on SEWeb was carried out, informed by the experience of and feedback from the pilot studies.

# 2 Results

## 2.1 Phase 1: Review of methods and projects

Findings of Phase 1 of the study are summarised here and reported in detail in the Phase 1 report "Review of methods and projects" (Reis *et al*, 2013)[1]. The report maps the technologies and approaches currently available for air quality monitoring and provides an overview on how they could be applied in a Citizen Science context. In addition, an overview of existing Citizen Science activities with relevance to air pollution is included.

Two approaches to monitoring air quality were assessed – those that directly monitor air quality and passive methods, including bio-monitoring, which provide a more indirect measure of air quality and its effects. While direct reading, personal monitoring solutions have the advantage of providing direct feedback to users, these technologies are in a relatively early stage of development. Passive samplers and bio-monitoring methods have been widely applied and could therefore offer a robust near-term opportunity, but are not available for all air pollutants, and do not offer immediate feedback and time-resolved results.

*Sensor technologies*

A range of sensors were assessed according to their scientific/technical quality, applicability and usability, as well as cost and form factor (e.g. size, weight, portability). The most appropriate sensors for Citizen Science use would be small, lightweight, portable sensors that can be worn or carried by individuals, can provide a good measure of personal exposure and at the same time generate a spatially and temporally resolved picture of urban air quality. Other key criteria include the data quality required and methods of data generation and management - even a small network of air quality sensors will quickly generate a large amount of data points (for example, monitoring air quality and location once a minute over a week easily generates several tens of thousands of data points for one person only), which will need to be managed and evaluated.

The assessment of sensor technologies currently available for Citizen Science approaches is summarised in Table 2.1. Overall, there is an obvious trade-off between the commercial availability of sensors, their unit cost and the degree of system integration. The Sensaris concept, for instance, with small, lightweight sensors using Bluetooth connections with existing smartphones to broadcast personal monitoring data to a central web server is promising, however the technical quality of the existing sensors makes them unsuitable for application at this stage. In contrast, the SidePak AM510 is a mature commercial product for air pollution monitoring, but designed for industrial/workplace applications and (subjectively) too loud for application in day-to-day activities. In addition, the price tag of the AM510 (~£2,500) does not make it readily accessible in larger numbers for a Citizen Science project. The CairClip approach with a very small form factor looks promising; however there is no information on the sensing quality and operational handling of the sensors. The Dylos 1700 in connection with a GPS receiver fulfils the usability requirements in general, albeit data retrieval and analysis requires a certain degree of computer literacy and manual intervention.

[1] Available at: http://www.environment.scotland.gov.uk/about-us/lifeplus-project/lifeplus-project-news-and-updates

**Table 2.1.** Overview of existing sensors mapped with evaluation criteria *(the ranking is based on expert assessment, with ++ = fully suited/applicable, + = partly suited/applicable, o = not fully suited/applicable, - = not suited/applicable, ? = not possible to assess with available information)*

| | Scientific/technical quality | | | Applicability/usability | | | | | Costs/Form Factor | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Is a sensor fit for purpose?, i.e. can it measure ambient air pollutant concentrations across an adequate range, with sufficient sensitivity | Are cross-sensitivities and other factors influencing the measured concentration levels known? Are sensors calibrated? | Can information from the sensors be readily downloaded to a web portal for mapping? | Are sensors commercially available or is there a production mechanism to allow use in sufficient numbers | Are sensors and sensor-packages easy to operate for a lay person? | Does operating the sensors or extracting/reporting data require specialist skills? | Are sensor-packages cumbersome with the potential to interfere with people's daily activities? | How well can sensors be integrated with contextual information gathered (e.g. time stamps, other synchronisation aspects)? | Are sensors sufficiently cheap to allow for a wide-spread use within an appropriate budget? | Are sensor packages robust and small enough to be easily carried or deployed? Are data communications set up in a way as to incur no additional costs to users? |
| Personal sensors | | | | | | | | | | |
| Dylos 1700 | ++ | ++ | + | + | o | o | + | + | ++ | + |
| Sensaris Senspods | - | - | ++ | o | + | + | ++ | + | + | + |
| Panstamp RESPIRA[4] | (++)[1] | ? | ? | ? | ? | ? | ? | ? | ? | ? |
| CairPol CairClip[5] | ? | ? | + | + | + | ? | ++ | ? | ? | ++ |
| MicroPEMS | ++ | ++ | + | + | + | + | ++ | + | o | + |
| iDust | (++)[2] | ++ | ? | o | + | + | N/A[3] | N/A[3] | ++ | + |
| TSI SidePak AM510 | ++ | ++ | + | ++ | + | + | - | + | - | + |

**Notes:**

1) no information on commercial availability
2) prototype development ongoing
3) designated for stationary use indoors
4) no sufficient information on development status available
5) sensors not tested yet, limited information available

*Passive samplers*

Passive samplers include bio-monitoring and bio-indicators and technical solutions for passive sampling such as diffusion tubes for gaseous pollutants, glass slides and other gravitational samplers for dust/aerosols.

In their article on biomonitoring, Holt & Miller[2] set out general criteria for the selection of suitable bio-indicators (see Table 2.2).

**Table 2.2.** Regardless of the geographic region, type of disturbance, environment, or organism, good bio-indicators often share several characteristics. Source: Holt & Miller (2011)[1]

| | |
|---|---|
| Good indicator ability | Provide measurable response (sensitive to the disturbance or stress but does not experience mortality or accumulate pollutants directly from their environment) |
| | Response reflects the whole population/community/ecosystem response |
| | Respond in proportion to the degree of contamination or degradation |
| Abundant and common | Adequate local population density (rare species are not optimal) |
| | Common, including distribution within area of question |
| | Relatively stable despite moderate climatic and environmental variability |
| Well-studied | Ecology and life history well understood |
| | Taxonomically well documented and stable |
| | Easy and cheap to survey |
| Economically/commercially important | Species already being harvested for other purposes |
| | Public interest in or awareness of the species |

The advantages for the use of bio-indicators identified in this article are, as follows:

- bio-indicators add a temporal component corresponding to the life span or residence time of an organism in a particular system, allowing the integration of current, past, or future environmental conditions;
- bio-indicators have the ability to indicate indirect biotic effects of pollutants when many physical or chemical measurements cannot.

However, some challenges of bio-indicators need to be highlighted as well:

- populations of indicator species may be influenced by factors other than the disturbance or stress (e.g., disease, parasitism, competition, predation), complicating our picture of the causal mechanisms of change;

[2] Holt, E. A. & Miller, S. W. (2011) Bioindicators: Using Organisms to Measure Environmental Impacts. Nature Education Knowledge 3(10):8

- bio-indicator species invariably have differing habitat requirements than other species in their ecosystem, e.g. responses of selected bio-indicators may not allow inferring effects on human health or other species.

*Existing Citizen Science projects*

The Phase 1 report provides a table describing in detail the methods used by eleven existing Citizen Science projects. The main themes are summarised below.

A wide variety of methods and tools are being used. Methods of data collection can be very simple, requiring little previous knowledge or requiring a degree of expertise and training. Tools range in cost and complexity from cost-free bio-indicators and inexpensive diffusion tubes to complex and costly networked technologies. There is no correlation between simplicity of method and tool, with some simple tools requiring some expertise in participants and some complex tools requiring very little expertise or training.

The data infrastructure requirements for citizen science projects are non-trivial and require careful attention already in the design stage. Work on the development of methodologies and infrastructure for Citizen Science projects is being funded e.g. by the European Commission (FP7), and recent work carried out by the University of Aberdeen on measuring second-hand smoke (SHS) concentrations has encouraged study participants to use these measuring devices while completing a simple paper-based activity diary to record smoking and other particle generating actions.

Across the projects researched, participants fall into three distinct groups which can be defined as follows:

<u>Group A - ‘Already interested’</u>: These participants are keen to take control of measuring their local air quality and are easy to engage to participate.

<u>Group B - ‘Out there anyway’</u> : These participants are already involved in activities which air quality monitoring either dovetails with (e.g. people engaging in outdoor activities) or complements (e.g. school pupils).

<u>Group C - ‘Wider public’</u>: These participants might be members of a particular community or citizens in the widest sense.

Engagement, training, support and feedback varies widely between projects and includes awareness raising events, community engagement workshops, training in data collection and submission, on-site support to collect and submit data and follow-up events to share data and identify actions.

*Phase 1 conclusions*

Within Phase 1 a review of sensors, passive sampling methods and existing Citizen Science projects was undertaken. Sensor technology has the advantage of providing direct feedback to users; however technologies are in a relatively early stage of development. For Citizen Science purposes, a sensor should be small, lightweight and portable and able to measure air pollutants such as particulate matter, $NO_x$ and CO. Based on our evaluation, there are several packages and sensors available or in development which fulfil some of the requirements set out in the evaluation criteria, but none currently commercially available that could be regarded as mature enough for a full scale Citizen Science application at this stage. For Phases 2 and 3 of this study, the use of the Dylos 1700 was recommended on the basis of affordability, ease of use and portability. However, this sensor has no built-in GPS so that a separate

GPS unit should be used, and the measurement data requires downloading and processing before being reported back to the users.

Bio-monitoring and other passive sampling methods have been widely applied and extensively tested, but are not available for all air pollutants. While passive sampling methods have a range of advantages, their lack of time resolution and inability to detect episodes due to averaging over time, as well as not providing direct feedback may be seen as disadvantages for a Citizen Science application.

## 2.2 Phase 2: Suggested programme of projects

Findings of Phase 2 of the study are summarised here and reported in detail in the Phase 2 report "Suggested programme of research projects" (Cowie *et al*, 2014)[3]. The report contains a short description of the elements of a suggested programme of projects for Citizen Science in the area of urban air quality. Summaries of each suggested project include background, aims, target participants, example methodology, stakeholders and outcomes, benefits and challenges and timescale and estimated costs. The report also includes some general principles for carrying out Citizen Science and the identification of potential funding bodies for Citizen Science work.

*Design of programme of projects*

Following the completion of Phase 1 of the current study, the next stage was to put together a programme of suggested projects in the area of urban air quality. A stakeholder's Advisory Group was set up and a meeting held in August 2013. This was attended by nine stakeholders along with members of the project team and representatives of SEPA. The stakeholders represented organisations including Scottish Government, Transport Scotland, NHS Scotland, Friends of the Earth, Health Protection Scotland and Scottish Natural Heritage. During the meeting, stakeholders were given an introduction to the study, a summary of the findings of Phase 1 and the aims of Phase 2. There followed a general discussion on the types of projects that would fulfil the aims of developing a programme of Citizen Science in urban air quality.

Following the meeting, and based on the Phase 1 review and Advisory Group discussion, a draft programme of projects was produced. It had been hoped to hold a second meeting of the Advisory Group to discuss this draft but it did not prove possible to find a mutually convenient date for a meeting. Instead, the draft report was e-mailed to the Advisory Group members and comments invited by email or by phone. Replies were received from three members and were incorporated into the final version of the report.

*Proposed programme of projects*

The programme of work focused on two main areas – transport and schools. These areas are not exhaustive, other areas were also identified which could be taken forward through a similar programme.

Within the areas of schools and transport, five specific projects were identified.

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[3] Available at: http://www.environment.scotland.gov.uk/about-us/lifeplus-project/lifeplus-project-news-and-updates

Schools:

- Schools near busy roads: Many schools in cities are situated near busy roads, and in particular, many playgrounds are roadside. Children in playgrounds will often be active (e.g. playing football, running) resulting in higher breathing rates and potentially higher exposure to pollutants in outdoor air. The aims of this project included development of a method for children to measure the air quality of their playground, collection of data from children and staff on perceptions of air quality and provision of simple visualisation of the data with easy access for children and staff.

  The benefits of this project may include an increased knowledge of outdoor air quality among staff and children, more information about status of outdoor air quality at the schools involved, potential to deliver outcomes and experiences in the Curriculum for Excellence and links to other initiatives such as school travel planning and eco-schools. Challenges may include the level of engagement and support time required, control of the setting up of the equipment, data collection and interpretation and the need to calibrate the sampling equipment at regular intervals.

- Cars idling outside schools: Studies have shown that cars and school buses parked outside schools with their engines running can have a significant adverse effect on air quality, and idling engines can produce more emissions than engines in motion so that children waiting to be collected from the school may be exposed to poor air quality on a daily basis. The aims of this project include monitoring of outdoor air quality outside schools to compare levels at pick-up/drop-off times with other times of day, provision of simple visualisation of the data with easy access for children and staff, and development of simple tools and materials to help the school to reduce the practice of leaving car and bus engines idling outside the school e.g. by improving travel plans, behavioural change and active travel for school children.

  The benefits of this project may include reduction in the idling of car and bus engines outside the school, an increase in active travel to school, increased knowledge of outdoor air quality among staff and children, links to other initiatives such as school travel planning and contribution towards outcomes and experiences in the Curriculum for Excellence. Challenges are the same as for the previous project - the level of engagement and support time required, control of the setting up of the equipment, data collection and interpretation and the need to calibrate the sampling equipment at regular intervals.

Transport:

- Pollution ‘hotspots’: Concerns can be expressed by media and local residents about air quality related to particular locations or through particular building works, or obvious sources of pollution (e.g. diesel trains or rush-hour congestion) can result in perception of poor air quality and expression of acute and chronic health problems among those in the area. The aims of this project include the development of ways for interested parties to deploy and use a small portable tool to measure air quality in a given location over short periods of time, communication of air pollutant concentrations through simple graphical outputs and provision of context on how the levels relate to those found in other locations and how they compare to health-based guidance/limit values.

The benefits of this project may include increased knowledge of air quality among those involved, with particular focus on their local study location, and availability of new information on temporal variability in air pollution and how to avoid the highest concentrations. Challenges may include problems with gaining access to some locations, control of the setting up of the equipment, data collection and interpretation, the need to calibrate the sampling equipment at regular intervals, and communicating differences in permitted exposure limits in outdoor and semi-outdoor spaces.

- Transport corridors: Exposure to air pollution during commuting often accounts for a substantial part of total daily intake while transport corridors and the vehicles (cycles, buses, taxis) that use them offer the opportunity to gather large quantities of data on air pollutants across a city in real-time, and covering a wide area. In addition public transport vehicles are often tracked in real-time so geo-location data is already collected. The aims of this project include provision to a cyclist or transport provider of a number of air pollutant measuring devices to attach to cycles or vehicles within their fleet, development of methods to access collected data in real-time with minimal need for the cyclists or on-vehicle staff to interface with the instrumentation, and examination of web-based methods to provide the air quality information collected to those with an interest in air pollution within the city being studied.

  The benefits of this project may include a much greater spatial network of air pollutant sensors across a city, increased resident awareness of the measurement of air pollution and reduction of the perception that monitoring only takes place in the city centre, and local residents able to identify in near real-time where pollution is highest and modify their travel plans accordingly. Challenges may include the technicality of the project that relies on a high degree of Wi-Fi/GPRS/server communication, and the large quantities of data that will be generated in a short space of time with associated computer/server, data analysis and data feedback implications.

- Parks and greenspaces: There is increasing scientific evidence that access and ‘exposure’ to greenspace is beneficial to physical and mental health but there is often considerable pressure to build on existing greenspace or for local authorities to make cuts in maintenance of local greenspace areas particularly where these are under-utilised. The measurement of air quality in outdoor greenspaces is likely to illustrate that pollutant concentrations here are lower than indoors at home. The aims of this project include provision to users of a simple tool to measure personal exposure to air pollutant levels while spending time in local greenspace areas and/or have them look for specific species of lichen on the trees to detect the general quality of the air, development of a simple questionnaire and observational tools to quantify the effect of spending time in greenspaces on their personal health and communication of air pollutant levels through simple real-time numerical feedback.

  The benefits of this project may include increased knowledge of air quality within greenspace among those involved and of how spending time in greenspace impacts on their health and wellbeing, personalised, objective measures of air quality within greenspace and the opportunity to engage and communicate with other stakeholders/greenspace users. Challenges may include possible raising of concern among participants when comparing to measurements of air quality made within homes or raising of anxiety or stress among those with existing health conditions and problems of co-location of greenspace and play areas near busy roads.

*Potential funding sources*

There are many potential funding sources available for Citizen Science in the area of urban air quality. These are described in more detail, with web links, in the detailed Phase 2 report.

For larger studies, funding sources include:

- European Commission Horizon 2020 framework programme
- UK government departments and research councils (e.g. DEFRA, Department of Health, Medical Research Council, National Environment Research Council)
- Scottish Government (e.g. RESAS, Chief Scientist's Office)
- Future Cities (launched by the UK's Technology Strategy Board)

For smaller studies, funding sources include:

- Local authorities
- Heritage Lottery Fund
- Big Lottery Fund
- Scottish Environment Protection Agency (SEPA)
- Scottish Collaboration for Public Health Research and Policy

*Phase 2 conclusions*

Phase 2 has built on the findings of Phase 1, set up and held productive discussions with an Advisory Group of stakeholders and produced a programme of five suggested Citizen Science projects – two based in schools, and three based around transport. The projects cover a range of air quality topics and involve school pupils and staff, cyclists, public transport companies and individuals who use greenspace within cities. Aims, methods, target participants and stakeholders, estimated costs and timescales and benefits and challenges of each project have been described. In addition, potential funding sources for large and small Citizen Science projects have been identified.

## 2.3 Phase 3: Pilot studies

Findings of Phase 3 of the study are summarised here and reported in detail in the Phase 3 report "Findings of the pilot studies" (Reis *et al*, 2014)[4]. The report contains a description of the two small pilot studies carried out based on the projects identified in Phase 2 of the work. Details of the study methods, participants and findings are included along with a brief evaluation of the pilot studies. The report also

[4] Available at: http://www.environment.scotland.gov.uk/about-us/lifeplus-project/lifeplus-project-news-and-updates

includes a more detailed review of the software toolkit available on SEWeb, informed by the findings of the pilot studies.

Two different pilot study approaches were selected to test both a stationary air quality monitoring setup in the context of a secondary school, including the viability of using devices and monitoring methods in regular teaching activities, and using a mobile setup (with small backpacks including the air quality monitor as well as a GPS for geo-referencing). For the latter, the focus was on cyclists and volunteers were approached through existing contacts within the bike charity SPOKES (www.spokes.org.uk) and – through Transport Scotland – the Glasgow Bike Station. The main effort was not on providing air quality measurements, but on testing the approaches, methods, devices and engagement with citizen scientists.

*Pilot study – air quality outside schools*

Potential participants in this pilot study were identified via the Scotland Counts Schools Working Group and Preston Lodge High School in Prestonpans, East Lothian agreed to take part. Initial engagement with the school took place through telephone conversations and then researchers visited the school and demonstrated the Dylos 1700 particle counter. Initial interest in the school was from the Chemistry department, but ultimately it was deemed to be more relevant to the Geography curriculum.

The sampling device was supplied to the school in early February 2014 with monitoring starting in mid-February. The device was used for both stationary monitoring at the school grounds and a short motorbike trip inside Edinburgh city centre by one of the teachers to explore different use options. Monitoring activities took place and were documented with notes on location, activity and meteorological conditions. The equipment was picked up at the school grounds on 25th of March.

Data evaluation commenced immediately after pick-up and feedback received from the teacher using the device was that he had been unable to directly access and retrieve data from the Dylos monitor. Data retrieval using both the legacy Dylos software, and alternative terminal software was only able to download logs for two dates, 27$^{th}$ and 28$^{th}$ of February, without any further data having been logged. There was no obvious explanation for this data loss. Analysis of the available data showed some interesting patterns over time, however due to the problems with data loss in this pilot study, the main lessons learned from this pilot study are on the engagement process, while the actual measurement results are of limited value.

*Pilot study – transport corridors (cyclists)*

The second pilot study was designed to use volunteer cyclists to track pollution as they cycle round their city. First contact was made through existing contacts of the study team at SPOKES in Edinburgh. An additional contact was established through a recent engagement with Transport Scotland, who had been working with the Glasgow Bike Station during a staff day out using a monitoring pack. Both groups were highly motivated to take part in the pilot study which made preliminary engagement straightforward. The volunteers were issued with monitoring packs, instructions for operation of the devices and time-activity diaries.

Monitoring in Glasgow took place over 5 days for short trips across Glasgow city centre, including commuting to and from work by bike, as well as other activities. After data processing, another face-to-face meeting was held on 20th of March, presenting the monitoring results and further discussing the experience of using the pack, including barriers and potential improvements. Figure 2.1 shows an example of the mapping of the measurements collected.

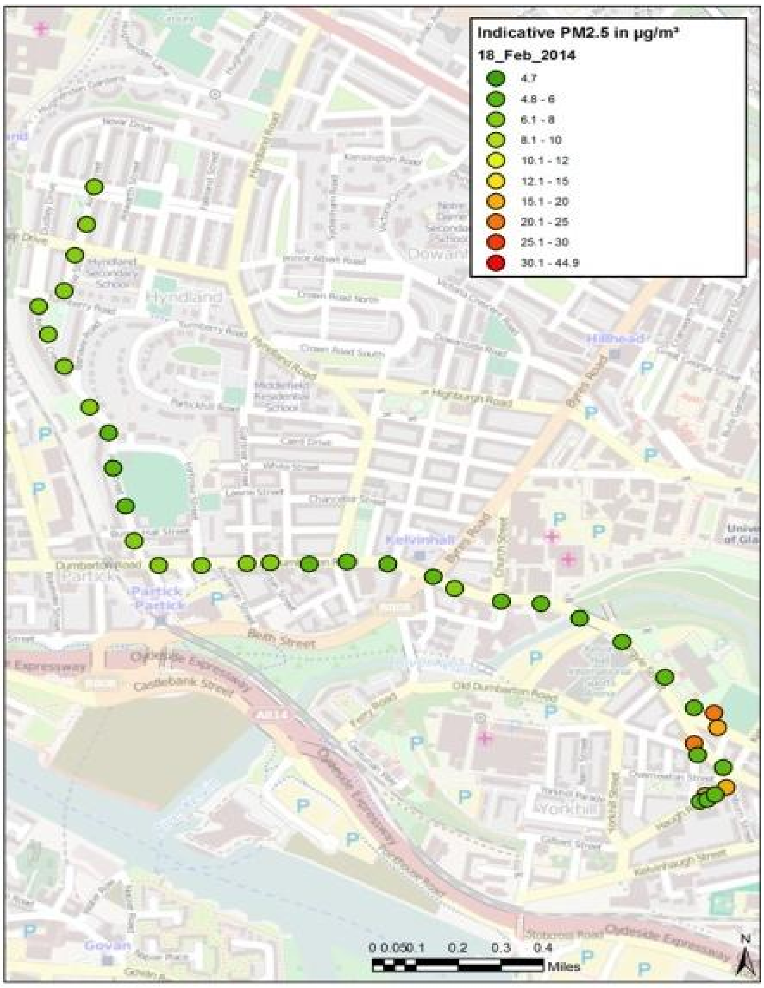


**Figure 2.1 – Example of mapping of findings of cycling pilot study**

The pilot study in Edinburgh followed the same protocol as in Glasgow. Here the two volunteers were both working in a cycling context as bike couriers and delivery drivers, spending a substantial amount of time cycling across the Edinburgh city area.

For all data collected by volunteers, substantial day-to-day variability can be observed, both represented in the monitoring data from the mobile monitors and the preliminary comparison data from fixed monitoring sites. In addition, however, the observations from the volunteers illustrate how location and time of day have a measurable effect. Both average and maximum concentrations can be substantially above urban background or kerbside values at local hotspots or during rush hour conditions. The pilot study also identified, respectively confirmed, caveats of the approach taken, for instance highlighting that GPS tracking coverage is generally incomplete due to signal loss indoors and in street canyons/near high buildings. Across all profiles recorded, GPS data was patchy, resulting in incomplete mapping information. In addition, one particle counter developed a fault during the final stage of monitoring with Glasgow Bike Station, resulting in total data loss (recording zero particle numbers) for over 24 hours.

*Pilot study evaluation*

Two evaluation questionnaires were received from the school pilot study and four questionnaires from the cyclists. The cyclists also provided verbal feedback.

Within the schools, the training was thought to be adequate and the use of the equipment and diary completion ‘quite easy’. However they found it ‘a little difficult’ to submit the data. They enjoyed participating in the project but would have liked more time to carry out data collection. As noted above, there were issues in retrieving data from the sensor and so feedback has been limited and it has not been possible to fully evaluate the pilot as a learning experience. Nonetheless, it was felt that the study had resulted in greater participation in fieldwork, increased awareness of sampling and contextualisation of the topics studied.

One member of staff noted that they were, and always are, pushed for time and that full participation in work of this kind would have to be factored into their year early on to get the most out of it. This may have been a particular issue with the age group of pupils involved in the pilot study, where there would have been a strong focus on preparation for the Scottish Qualification Authority spring examinations. Involvement of younger pupils, including those at primary schools, may mitigate this concern.

For future development of this kind of activity, it was suggested that set experiments involving data collection could be produced that would be made available for schools to use. The current method/format of data presentation is a little daunting for pupils with limited science knowledge and different presentation methods could be considered.

The verbal feedback from the cyclists was overwhelmingly positive on the overall ability to use a personal device to monitor personal exposure to air pollution. Specific feedback on the handling of the monitoring pack highlighted the encumbrance-factor as one of the key aspects. Bike couriers and cyclists transporting goods often carry backpacks or delivery bags, making it difficult if not impossible to handle another backpack. The size, weight and lack of weatherproof design (it could not be used when raining) were also seen as drawbacks. All volunteers said that they would like to view their results en route and/or online to be able to react to high values or inform decisions on routing etc.

From the evaluation questionnaire, cyclists thought the training was adequate and the equipment ‘quite easy’ to use. All participants enjoyed participating in the project. Making the equipment less heavy, bulky and awkward to carry alongside other bags was seen as an important factor in improving the experience for cyclists. Participants felt that they learned through participating in the project, one mentioned ‘some interesting facts and statistical data about small particles of pollutants and what causes them’. They also felt that there had been changes in their lives as a result of participating including greater awareness of air pollutants; ‘I am thinking more about the routes that I choose, I don’t beat myself up for choosing an off road route sometimes to avoid a particularly busy junction; before I just thought about getting from a to b as fast as possible!’

*Data feedback and visualisation*

The evaluation of the pilot studies shows that participants are keen to have real-time feedback on the data they are collecting. To do this, sensors have to have built-in communication to a means of displaying data. This can be through connection to a smartphone app, by using Wi-Fi to communicate with the web or using a sim card within the sensor to communicate with a hub that can then transmit the data to a smartphone or web page. There are also many websites available or in development which allow either the project team or the study participants to design simple questionnaires to record contextual or observational data. Links to these questionnaires can be via QR codes, web widgets and/or Facebook apps.

Scotland's Environment provides a comprehensive website (SEWeb) that provides in one place the most current assessment of the state of the environment in Scotland. The website also encourages the general public to become involved in Scotland's environment through environmental projects and through provision of a toolkit that pulls together several freely available resources for use in Citizen Science projects. The tools within the SEWeb toolkit are divided into three subcategories – Identification Tools Collation Tools, and Infrastructure Tools.

These tools provide useful functionality for the collection and processing of air quality Citizen Science data. Particularly relevant to these projects are the identification tool iSpot and collation tools iRecord for recording natural observations relevant to air quality (e.g. lichens), and ODK and EpiCollect for the collection and display of contextual data. The most relevant infrastructure tool is Open Air for the analysis of air quality measurement, but use of this tool requires some IT expertise and, ideally, knowledge of the 'R' software package. However, none of these tools provide the real-time data processing and feedback that many citizen science participants would prefer and to do this would require the use of more sophisticated (and expensive) sensors with built-in communication facilities.

*Phase 3 conclusions*

Two pilot studies, one in a school and one involving cyclists have been successfully carried out. The studies have confirmed the key challenges and potential caveats related to the non-availability of integrated sensors at this point in time, both in the form factor and operational aspects of the devices used in the mobile pilot deployment, and the potential for operator errors or device malfunctions which are not picked up as there is no direct feedback to the user.

As expected, user engagement was a key aspect. It is of note that the cyclists participated in the project because they saw clearly how it related to their interests and fitted simply into their existing daily activities. Though there are clear links between air quality monitoring and the Curriculum for Excellence, the effective engagement of schools, particularly at secondary level, requires a long term engagement process and sustained support throughout the project period.

Tied in with the development of more accessible and robust devices, the training needs for citizen scientists, as well as the reduction of manual, one-off data processing would need to receive a high priority.

The visualisation of results in both accessible, simple graphs and in a geospatial and temporal context, using maps and animations would likely further add value for lay people to interpret their own results.

# 3 Conclusions

This programme of work has produced three main outcomes:

- A review of existing technology for active and passive measurement of air quality data and a review of existing Citizen Science projects in this area;
- A programme of suggested Citizen Science projects based on the findings of the review and on discussions with an Advisory Group of interested stakeholders;

- A pilot study of two of these suggested projects, one in schools and one with cyclists, including an evaluation by the participants and a review of the SEWeb toolkit.

The conduct of the study has also strengthened links among those interested in air quality and Citizen Science in Scotland, with a broad range of stakeholders involved in the Advisory Group and in other aspects of the work. Links have been developed between scientists and voluntary and government departments and, during the course of the study, the researchers have helped individuals and groups to carry out *ad hoc* sampling exercises, in addition to the pilot studies, using the Dylos 1700 sampler. Analysis and feedback of the data has also been carried out by the NERC Centre for Ecology & Hydrology.

Despite early attempts by the project team and by SEPA to involve representatives from Local Authorities in the Advisory Group, this proved ultimately unsuccessful and it would be beneficial to include them in the Group if it continues to meet. In addition, it would be beneficial to make further contact with existing initiatives in the Citizen Science area, for example work being carried out with schools in West Lothian on pollution from cars idling at the start and end of the school day, and the ongoing European Citi-Sense project which will look at outdoor air quality in Edinburgh using specially-designed personal and static sensors.

The use of Citizen Science approaches is likely to increase in the near future. This work has identified the need to closely match the methods and technology to the specific group involved. A 'one-size fits all' concept is unlikely to succeed and it is of primary importance to discuss at the planning stage the expectations, skills and resources of those taking part. Sustaining interest can also be difficult and methods of continual engagement and feedback are likely to be necessary to ensure that Citizen Scientists collect information in ways that provide meaningful data. Finally, the resource required to interpret and analyse the substantial quantities of data that can be generated should not be under-estimated.

*Next steps*

It is hoped that the Advisory Group will continue to meet after the completion of this work. It is recommended that this group might scope further air quality Citizen Science projects based on both the outputs of the current work, and the recently published guide 'Choosing and using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment'[5]. For example, a key finding of the pilot study was that cyclists would appreciate the development of facilities to feedback data in real-time - this could also be used to promote action by other road users and feedback information about spatial and temporal pollution hotspots and could be a good place to start with developing a future monitoring/action project.

Education Scotland, with support from SEWeb, is funding the creation of a Citizen Science Development Officer post for a period of one year, with the main purpose of promoting the incorporation of Citizen Science activities within the school curriculum. The Advisory Group could consider the possibilities of working with the post-holder to get further work on air quality worked into the school curriculum.

[5] Pocock MJO, Chapman DS, Sheppard LJ, Roy HE (2014). Choosing and using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment. Centre for Ecology & Hydrology. http://www.ceh.ac.uk/products/publications/understanding-citizen-science.html