Low Cost Air Pollution Sensors

A Users Guide

Clean Air for Bristol

BRISTOL CITY COUNCIL

Contents

Introduction

In recent years there has been an increased interest and awareness in air pollution from the public and the media. At the same time there has been a rapid increase in the range of low-cost sensors being sold to monitor air pollution. Citizens are starting to use these sensors to collect their own data, and more extensive air pollution monitoring projects are being developed by a wide range of organisations.

To get the most out of the investment of time and money that air pollution monitoring requires, it is important for those using low-cost sensors to understand what they can and can't do and to understand the factors that need to be considered when planning to monitor air pollution. This can improve the chances of the data collected fulfilling the aims of a project or providing useful and understandable data to an individual.

This guide has been written to assist individuals and organisations who are considering using low-cost air pollution sensors. After reading it you should be able to develop projects and collect data that meets your requirements, whilst avoiding some common problems associated with using low-cost air pollution sensors.

What is a Low Cost Air Pollution Sensor?

Low-cost sensors range from simple single pollutant sensors that are sold for a few tens of pounds to relatively sophisticated multi-pollutant devices, that include communication and meteorological capabilities, and may cost several thousand pounds. Low-cost sensors differ from the more expensive and officially approved reference/equivalence methods because of their compactness, mobility, lower power consumption and less rigorous data quality requirements.

What Can Low-Cost Sensors be Used For?

Low-cost sensors can be used for a number of different applications and the best outcomes are achieved if the projects are well planned, and the low-cost sensor technology options, their relative strengths, weaknesses and their limitations are understood by the user/project coordinators at the outset. Some examples are:

- **Citizen Sensing Projects** – to engage citizens and raise awareness of air pollution.
- **Research** – Discovering new information about air quality.
- **Personal Exposure Monitoring** – Monitoring exposure to pollution of an individual during normal activities.
- **Supplement Existing Monitoring** – Placing sensors within an existing regulatory monitoring network to fill in coverage.
- **Source Identification and Characterisation** – Establishing possible emission sources by monitoring next to a suspected emission source.
- **Education Settings** – For use in maths, and science classes for example.
- **Information/Awareness** – Using sensors for informal air quality awareness raising.

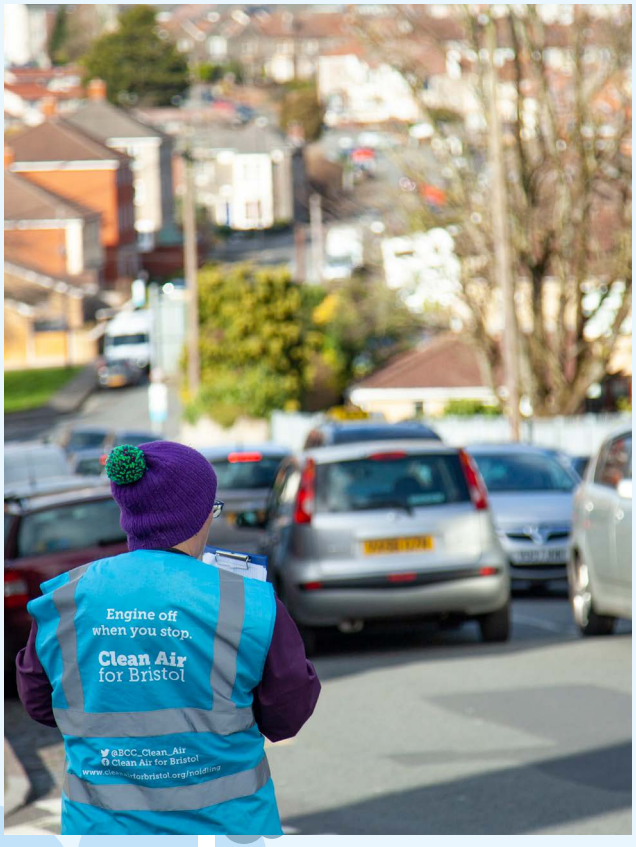
Demonstration of Exceedance/Compliance with UK Air Pollution Objectives

Low-cost sensors CANNOT be used to demonstrate compliance against EU limit values and UK objectives. There is a rigorous testing framework for sensors to be approved for this purpose. Those sensors that have met these requirements are known as reference or equivalence standard air quality monitors[1]. The testing and performance requirements have been set in EU directives which have been adopted and are managed by the Environment Agency in the UK. There are also stringent quality assurance and quality control procedures that need to be followed to regularly test the performance of these sensors during operation. Data produced also needs to be carefully checked (ratified) if the data is to be used to determine whether compliance is being achieved with air quality objectives. Currently no low-cost gaseous or particulate analysers have achieved reference type or equivalence approval for regulatory reporting purposes.

[1] EU Standard Methods for monitoring and UK Approach - Defra, UK

Planning the Air Pollution Monitoring

The first step should be to establish a clear concept of what you intend to accomplish through the collection of air pollution data. This will help identify the pollutant/s of interest, type of sampling location/s, the duration of data collection, type of measurements (short-term mobile/ long term stationary for example) and the quality of data needed to fulfil the aims. When developing a plan to monitor pollution, it might be useful to do some research or speak to someone with specialist knowledge on air pollution. If a more extensive monitoring project is being developed, then this research is likely to be even more important.



Companies selling or making sensors are not necessarily experienced in air pollution monitoring. It is very easy to end up monitoring pollution using a technology or approach which doesn't provide the kind of data expected or required, due to its quality, the type of data or location in which the data has been collected etc. A good starting point is to find out what air pollution data is already being collected in the area of interest by the local authority, other organisations, or citizens. Monitoring data collected by Bristol City Council is published on an Open Data Portal.

Engagement with citizens on air pollution issues could be the main aim of projects utilising low-cost sensors. Involving citizens in the early stages of a project could help define what questions/concerns they have, and this can then inform the monitoring and data dissemination strategy. The next part of this guide provides a list of steps and things that need to be considered to get the most out of the monitoring, and to help avoid mistakes that can result in the data being unsuitable for the intended use.

The Steps Required to Develop a Low Cost Sensor Monitoring Project

1. Answer the Following questions

- What are the aims of the project/monitoring?
- Is it intended to use data to engage citizen and raise awareness of air pollution sources?
- Is it intended to understand pollution levels at a specific location?
- Is it intended to understand the impact from a particular pollution source?
- Is it intended to collect data to help develop policy?
- What questions are intended to be answered with the sensors?
- What data is needed to achieve the aims?
- What would a successful project/monitoring exercise achieve?

2. Design the Monitoring/Project Plan

- The next stage is to plan the monitoring exercise. This should be partly informed by the answers to the previous questions. Having a good background understanding of air pollution, the nature, and sources of different pollutants and how concentrations behave over time and space, is likely to be needed to do this effectively. The UK's Clean Air Strategy (2019) is a good place to start for a comprehensive overview of air pollution in the UK.
- Specific questions and tasks relating to the monitoring that need to be addressed at this stage could include:
- Considering WHO – will monitor the pollution, WHAT – pollutant/s need to be monitored, WHERE, WHEN and for HOW LONG pollution measurements need to be taken.
- Determining the number of sensors and the quality of data needed. Sensor performance requirements will differ according to the desired aims and outcomes of the monitoring. For example, the quality of data required for a citizen sensing project aimed at public engagement might be lower than a project that aims to provide data intended to assist policy development.

- Identify the total financial and time resources needed. There are often hidden and unexpected costs to running sensors for more than a few months. It is important to understand the requirements relating to the sensor maintenance, data quality control and data analysis at this stage.
- Identifying how data will be collected and stored.
- Identifying how it will be ensured the data will be of the quality required for the purpose identified. Consideration will need to be given to what data quality assurance and control is needed during data collection and if routine data adjustment is needed. For some sensors, this can require considerable time input and have an associated financial cost.
- Identifying if additional data such as temperature, humidity etc. will be needed to adjust sensor readings.
- Identifying how the data that is collected can be used to answer the questions identified or fulfil the aims of monitoring.
- Preparing how to answer questions other parties may ask about the data or project.

3. Considering Sensor Location

Static Sensors

Pollution can vary greatly over very short distances. For some pollutants and sources, even a one metre change in distance from the pollution source can make a significant difference to pollution levels. Different pollutants display different dispersion characteristics. Factors influencing pollution concentrations include the source of the pollutant, the pollutant characteristics, weather/climatic conditions, and physical structures, for example. As a result, consideration of the sensor location/s can be equally as important as sensor type, in meeting the aims of the monitoring project.

Whilst low-cost sensors are usually quicker and easier to deploy than more expensive reference air pollution monitors, it is important to consider sensor mounting, power and communication requirements carefully. This should be considered at an early stage to ensure there are no unexpected delays. As an example, within Bristol there is a requirement for approval to be sought to deploy sensors on lampposts, which can take up to 1-2 months to complete and has a cost associated with the application.

Mobile Sensors

Mobile low-cost sensors can be used to monitor a person's exposure to pollution throughout their everyday activities, or to map pollution levels over an area using one sensor. Care must be taken as to where a sensor is placed when being carried. For example, a sensor located inside a bag will not be taking a representative sample of outside (ambient) air. Another thing to consider is that it is likely that mobile sensors may provide less reliable data due to the unsettled conditions of use in terms of sudden movements and potentially sudden changes in temperatures and humidity.

4. Data Collection

Data collection requirements need to be considered in the process of choosing the sensor/s to be used. Some sensors require data to be downloaded physically, many offer remote download through either a GSM network or link to a Wi-Fi network. These requirements can limit the range of suitable locations in which a sensor can be placed.

5. Buy a Sensor/s

There is a relatively new and emerging competitive market for low-cost air pollution sensors. It is important for any organisation or individual to take control of the process of choosing the right sensor, rather than being led by the company selling sensors.

Recent experience has shown that it is not uncommon for companies selling low-cost sensors to make unrealistic claims about the capabilities and suitability of sensor technology to provide data for a specified purpose. This can lead to sensors being used that are unable to collect data of a sufficient quality to fulfil the aims of the monitoring. These issues can potentially be addressed by doing careful research and gaining an understanding of the available low-cost sensors, their real-world capabilities, and limitations. As an example, there are cases where sensors have been sold to monitor outdoor ambient air when their limits of detection are not suitable for outdoor measurements.

Currently there is no regulation of low-cost air quality sensor technology performance, so companies do not have to prove that their product performs in the real world, as described in data sheets, before going to market. Claimed sensor performance data is often taken from laboratory tests where temperature and humidity are carefully controlled, and sensors are exposed to one pollutant at a time. In the real world, environmental conditions change rapidly, and multiple pollutants are present in the air. As a result, real-world sensor performance can differ significantly from these laboratory tests. Understanding the strengths and limitations of an air pollution sensor is essential in ensuring that the data collected is appropriate for the defined monitoring aims and outcomes.

6. Monitoring

If the monitoring project requires relatively high-quality data, it may be advisable to test the sensors performance against a reference method monitor before collecting data. Depending on the sensor and the length of time over which monitoring will take place, it may also be advisable to do this at periodic intervals to check how well the sensor is performing. Within Bristol there are reference/equivalence method monitors measuring nitrogen dioxide (NO_2) particulate matter ($PM_{2.5}$ and PM_{10}) and ozone (O_3). The Bristol City Council Sustainable City Team can advise whether it is possible for the sensor/s to be 'co-located' next to a reference quality sensor for this purpose. Other cities and towns may have similar reference monitors at which this can be done.

Regular action may be needed to keep sensors working within a defined measurement standard. This could range from simple maintenance or calibration activities to regular sensor replacement. It is important to factor in these time and costs demands at the start of the project as they can be significant. It may be necessary to review the data collected at regular intervals to ensure the sensor is working as expected. This can involve screening data for issues like interference and unusual readings, step changes in data and data drift over time.

7. Analyse, Interpret and Communicate your Results

The way data is communicated can be crucial to successfully achieving the goals set at the start of your project. You should be able to demonstrate that the following have been considered in the process of collecting data.

- **Quality Assurance** – adequate planning to ensure sensor design and use meet data performance requirements.
- **Quality Control** – If data quality requirements or the type of sensor requires it, that calibration, maintenance and data checks have been carried out to the relevant standards.

The way air pollution data is understood or communicated can be crucial to successfully achieving the goals set at the start of the monitoring activities.

Interpretation of air pollution data can be complicated and not as straightforward as expected. The EU and UK regulations set health-based limits for pollutants. Many pollutants have both a long-term and short-term limit, which cover annual, 24-hour, 1-hour or 15-minute time periods. For example, nitrogen dioxide has both a long-term annual and short-term hourly health-based limit. The annual average long-term value is set at 40µg/m^3 whilst the average hourly concentration limit is set at 200µg/m^3. An hourly measured NO_2 concentration of 120µg/m^3, could cause alarm for a participant in a citizen sensing project if they compare it to the annual objective value of 40µg/m^3, however, the level it should be compared to is the short-term hourly objective of 200µg/m^3. How data is collected, displayed, interpreted, and relayed to the public needs to be considered at the outset, which in turn may help inform the type of sensor to use.

Additional Reference Sources

Bristol City Council runs an extensive air pollution monitoring network across the city. Full details of the network and air pollution policy and interventions can be found at the Clean Air for Bristol Website. Real time and historic monitoring data for Bristol can be found on the Air Quality Dashboard of the Open Data Portal. Involvement of air pollution specialists in the early stages of a project in some cases can be useful. For projects being carried out in Bristol the Bristol City Council Air Quality Officers in the Sustainable City Team Service can be consulted on project ideas and development. The UK's Air Quality Expert Group (AQEG) have provided interim advice on the use of low-cost pollution sensors. The European Environment Agency Published a 2019 report through the Eionet Portal on low-cost sensor systems for air quality assessment. This covers some of the points raised in this guide in more detail. The United States Environmental Protection Agency have developed an extensive Air Sensor Guidebook which offers advice on how to use low-cost sensors.