AQEG (Air Quality Expert Group) review of low-cost sensors

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For more information see:

https://uk-air.defra.gov.uk/library/aqeg/pollution-sensors.php
The request from Defra.

- To provide some advice on lower cost sensors, to aid Defra in responding to increasing numbers of queries from other bodies, Local Authorities and the public.
- Item was placed on AQEG work plan towards end of 2016, during a period ‘peak sensor’ media coverage.
- *Not a systematic review, not a product endorsement, reflects mid-2017.*
Complex and rapidly changing landscape

- Air Quality Tester function
  (Excellent / Good / Moderate / Bad)
  by collecting indoor air quality levels
Where are we now?

Hype Cycle and Technology Adoption Lifecycle

- **Technology Trigger**
  - Peak of Inflated Expectation
  - Trough of Disillusionment
- **Slope of Enlightenment**
- **Plateau of Productivity**

- **Innovators**
- **Early Adopters**
- **Early Majority**
- **Late Majority**
- **Laggards**

**Time**

**Adoption Rate**

- Media stories & product launches
- "Unpublished studies"
- Pilot data vs reference
- Academic evaluations
- International reviews
- Technical group recommendations
- Established best practice
- Large user base

**Enthusiasm**

**Review**

**Best practice**

"Hype Cycle" model used by Gartner since 1995 and the "Technology Adoption Lifecycle" model popularized by Rogers and Moore.
The challenge of component and system diversity

- AQEG was conscious that the rate of change of sub-components can be rapid
- Past studies don’t necessarily represent current capability
- Peer reviewed literature is the primary evidence source that AQEG must work with.
- The data quality from one sensor may differ from a network of sensors
- *There is far more to ‘cost’ than just buying the equipment*

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**Sensors have many other positive attributes beyond cost**

- **Metal oxide**
  - ~ £5
  - ~ since 1960s

- **Electrochemical / voltammetric**
  - ~ £50
  - ~ since 1980’s

- **Photochemical**
  - ~ £200
  - ~ since 1990’s

- **Micro-optical**
  - > £100
  - ~ since 2000’s
Some of the issues to consider

- Sensitivity to meteorology and environment
- Sensitivity to other air pollutants (interferences)
- Sensor to sensor variability
- Long-term performance and change

• Data strategies are proposed to potentially correct for all of these factors in some way
• No talk on sensors is complete without the words “Machine Learning”.
Applications and data requirements

- Not an exclusive list of applications, but these are some that have been proposed to Defra
- General requirements in terms of sensor performance differ by application

Temporal variability

- e.g. ‘Pollution is highest in the morning’

Minimum requirements:
1. Sensors are stable over the period of interest
2. Sensors respond broadly to the pollution parameter

Spatial variability

- e.g. ‘location x has higher pollution than location y and z’

Minimum requirements:
1. Stable over the period of interest
2. Responds broadly to pollution parameter
3. Sensors are internally reproducible

Concentration dependence

- e.g. ‘location x exceeds the AQ guidelines but y and z do not’

Minimum requirements:
1. Stable over the period of interest
2. Sensors are compound specific
3. Sensors are externally reproducible

Long-term trends

- e.g. ‘species at location x is increasing at 3% yr’

Minimum requirements:
1. Stable over the period of interest
2. Sensors are compound specific
3. Sensors are globally intercomparable
2014-2018 – substantial increase in “evaluation” publications

- Many positive examples of correlations next to reference monitors.
- Increasing use of training data and machine learning against reference

- Inter-sensor variability is less well defined – heavy tuning the ‘best sensor’
- Very few annual or longer studies or performance
AQEG assessment

- AQEG is using the uk-air website as the route for dissemination rather than the traditional AQEG formal report.
- This allows for greater flexibility to update the advice over time
- Plans to revisit the topic and related advice in the light of new evidence in 2019 and update as necessary.
- Google ‘AQEG’ and ‘sensors’ and this is the top hit.

This isn’t the only source of information see examples at:

- [www.epa.gov/air-sensor-toolbox](http://www.epa.gov/air-sensor-toolbox)
- Many academic journal reviews appearing
- Longer WMO report being published in June 2018.
- CEN TC 264 WG42 working on new guidelines for testing and evaluation
When could I use a low-cost sensor?

This is a common question that is now being asked about low cost sensors, but unfortunately there is no simple answer. The appropriateness of using a particular device depends critically on what the data is to be used for.

- Is it for awareness raising or educational purposes? To inform personal decision-making? As part of research studies or integrated into urban pollution control systems?
- Will the data from one sensor be used in isolation, or is the intention to use a whole network of data from many sensors which may provide some cross-reference validation?

QUESTION: Can low-cost sensors help a user find out whether over several years a particular pollutant is increasing or declining at a fixed location in a city?

ANSWER: There is no evidence at present to show that current sensors are stable in their responses if left uncalibrated over very long periods of time. Unless the change in concentrations was very substantial they would not likely be suitable to quantify inter-annual trends.
Conclusions

• AQEG provides advice based solely on peer-reviewed literature (not manufacturers claims, unpublished studies; it does not conduct original research
• AQEG appreciates that pace of publication may be slower than rate of technological change, but ‘rules of evidence’ cannot be by-passed.
• Growing body of evidence on a variety of sensor performance since 2015, with a general upward trajectory in performance
• Value of networks over individual measurements remains poorly quantified, but may well be significant.
• Evaluation against reference monitors in the real world remains the key test.
• Matching an application to appropriate capability is, as ever, vitally important
• Statistical methods and training datasets offer considerable promise for minimizing other environmental interferences – not clear the effect on outliers.
• Gaps remain in the evidence for performance over periods of months to years.
• AQEG is very positive about the potential for sensors to provide complementary information.
• Expect to re-evaluate advice reasonably regularly as capability advances.