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Community-based Air Quality Monitoring Using Low-Cost Sensors

By Chris Long, Sc.D., DABT

While low-cost sensors for community-based air quality monitoring have potential, there remains a general need to improve their precision, accuracy, and reliability.

Just like the latest bestselling novels, toilet paper, and running shoes, you can now hop on the Internet to buy handheld sensors capable of making real-time measurements of common air pollutants, including particulate matter (*e.g.*, $PM_{2.5}$ and PM_{10}), ozone (O_3), nitrogen dioxide (NO_2), and volatile organic chemicals (VOCs) such as benzene. There are sensors for every budget, including ones costing less than $100 that claim to measure $PM_{2.5}$ and PM_{10} down to levels of 1 μg/m^3. There are also a number of apps and websites that process data, provide graphical visualizations, and conduct data interpretation. It is a common mantra among scientists that "the more data, the better," and this article will address this question for the specific case of community-based air monitoring data from low-cost sensors.

...best practice recommendations are now available to assist citizen scientists in selecting, calibrating, and deploying sensors...

In the U.S., air monitoring data has traditionally been collected at fixed-site monitoring locations using equipment costing tens of thousands of dollars that is operated by trained professionals. Although these fixed-site air monitoring data

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I N S I D E

Letter from the Editors

September 2018

Dear Colleague,

In this issue of *Trends*, we discuss citizen science – public participation in scientific data collection and analysis – including how recent tools are increasing the amount and accessibility of citizen data, and also the potential shortfalls of data generated outside the confines of trained scientists.

The first *Trends* article discusses key strengths and limitations of low-cost air monitoring sensors relative to traditional fixed-site monitors, and their promise for improving air quality awareness and supplementing data from fixed-site networks. The second article discusses the rigor of collecting data using established quality assurance practices, and how samples collected in a casual or reactionary method are unlikely to meet the high bar for decision-making and litigation. The third article discusses the interface between community-based participatory public health research and environmental justice.

Gradient contributors to this issue include Dr. Chris Long, DABT, Dr. A. Dallas Wait, and Julie Lemay, M.P.H. Joining us with a guest editorial are attorneys Steven Burns and Katlyn Caldwell from the law firm of Balch & Bingham LLP, providing legal perspective on citizen suits under the Coal Ash Rule.

We hope that this issue of *Trends* gives you insight into citizen science.

Yours truly,

Chris Long, Sc.D., DABT and Kurt Herman, M.Eng., P.G.
clong@gradientcorp.com kherman@gradientcorp.com

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Community-based Air Quality Monitoring Using Low-Cost Sensors

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are typically collected for regulatory compliance purposes, they have also gained common usage for characterizing community exposures and conducting human health risk assessments and epidemiological studies. Given their low cost, small size, and minimal power requirements, today's low-cost sensors offer unique advantages compared to fixed-site air monitoring equipment, including increased spatial coverage, the ability to characterize real-time personal exposures and inform individual decision-making regarding air pollution exposures, and mobile sampling capability. Low-cost sensors can provide neighborhood-level data specific to local air emission sources of concern, such as in environmental justice communities (see related article).

While recognizing some of their novel advantages, today's low-cost sensors should not be confused with the rigorously tested and well-validated U.S. EPA Federal Reference Methods (FRM) and Federal Equivalent Methods (FEM) that are used to collect regulatory compliance air pollutant data in the U.S. Many sensors that are currently on the market have not been extensively validated by comparing their performance against that of gold standard methods, and some that have been evaluated in validation studies have been shown to have unacceptable precision and/or accuracy (see sensor evaluation reports available on the California's South Coast Air Quality Management District (SCAQMD) AQ-SPEC website). Other problems that have been commonly identified for low-cost sensors include highly variable results that depend on meteorological conditions and atmospheric composition, susceptibility to chemical interference, poor agreement between co-located, identical instruments, slow response times, instrument drift requiring re-calibration, and deteriorated performance with sensor aging. Together with these technological limitations, data collection by untrained users can result in major data quality challenges (see related article).

It is well recognized that more robust evaluations of sensor performance are needed from instrument manufacturers, but several organizations have attempted to fill this void by performing independent sensor evaluations. Together with some academic researchers, organizations such as California's SCAQMD, the U.S. EPA Office of Research and Development (ORD), and the European Commission Joint Research Center (JRC) have conducted both field and controlled laboratory performance tests of commercially available low-cost sensors. Castell *et al.* (2017) recently reported strong sensor performance in the laboratory but significantly reduced performance in the field for varying environmental conditions, supporting the importance of both laboratory and real-world field testing.

Data collection and mapping platforms, which include the U.S. EPA's Real Time Geospatial Data Viewer (RETIGO) and the AirCasting platform, offer citizen scientists the opportunity to process and share air monitoring data collected using low-cost sensors. Some example output are provided in the figure for the U.S. EPA's RETIGO, which was specifically developed to serve as a "plug and play" web-based tool for uploading large, complex data sets, overlaying them on maps, and graphing them to identify trends. AirCasting is an open source project that shares data *via* a CrowdMap application. With these and other apps and websites, there is clearly the potential for the public to be

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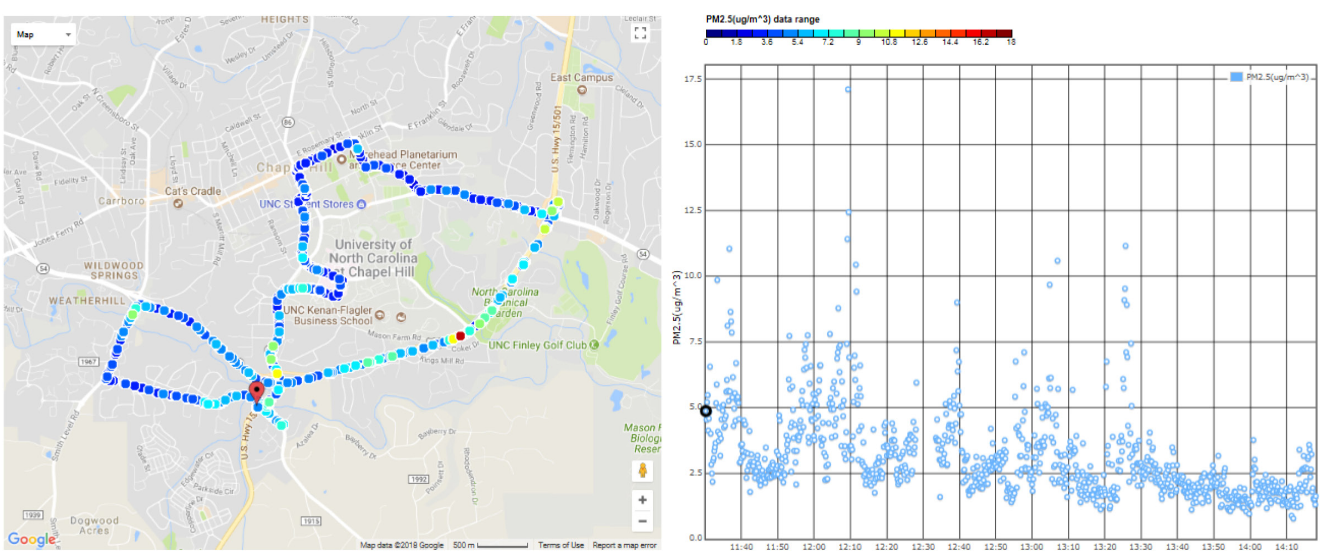
Example Output from the U.S. EPA's Real-Time Geospatial Data Viewer (RETIGO) Tool for Visualizing and Analyzing Air Monitoring Data



Data Quality Challenges Posed by Citizen Science

By A. Dallas Wait, Ph.D.

Citizen scientists must follow quality assurance practices to ensure the collection of reliable data that can be used in decision-making.

Can citizens produce reliable scientific data? Yes. However, the bar is high and often citizens fail to reach that bar. That doesn't mean a citizen's interest in obtaining reliable data isn't admirable and necessary, but frequently data are collected in a reactionary and urgent manner without the proper expertise, planning, and training that will result in reliable measurements that can withstand scrutiny from other parties.

For decades, the U.S. EPA has operated on the principal that reliable data are needed to answer questions concerning environmental quality, pollution abatement, and control measures. These data should be procured through rigorous adherence to established quality assurance practices, such that the measurements are valid, defensible, and of known precision and accuracy.

Running out into the field to take a few grab samples is often inappropriate, resulting in biased and misleading data.

The environmental measurement process consists of three phases, also known as the project life cycle: planning, implementation, and assessment. These types of information should be detailed in a Quality Assurance Project Plan (QAPP) prior to the start of any environmental study. Without this type of planning and documentation, studies often fall short of being reliable and meeting the data quality objectives of the investigation. To support a citizen's need for reliable data, the U.S. EPA (1996) has provided guidance on how to prepare a QAPP, as well as a guidance checklist for citizen scientists (U.S. EPA, 2013). More detail about QAPP preparation is available in the U.S. EPA's (2002) Quality Systems manual.

One critical objective of a QAPP is to discern and document the data quality objectives (DQOs) of the investigation before the study begins. DQOs include statements about the level of uncertainty that a decision-maker is willing to accept. For example, "after cleanup, the average concentration of PFAS [Per- and Polyfluoroalkyl Substances] in soil for an entire hazardous waste site will be 1 mg/kg (ppm) with a 90 percent level of confidence."

A QAPP will provide citizens structure and direction for the entire series of measurement activities. These activities include, in part, sample collection, chain of custody, sample storage and shipment, sample preparation, sample analysis, data reduction, data validation, and data interpretation. A QAPP should also detail quality assurance and quality control measures such that the measurement process can be shown to be "in control," and critical quality control measures such as precision, accuracy, and representativeness (spatial and temporal) can be demonstrated.

Without proper planning, citizens' studies are often prone to various shortcomings and errors which may make their data unusable for decision-making. For instance, in citizen science air monitoring studies, instruments such as particulate matter (PM) monitors are sometimes inadequately calibrated or "factory calibrations" for non-representative PM mixtures are improperly relied upon. Without proper instrument calibrations, the accuracy of air measurements is in doubt. Another common problem, which often occurs due to a lack of citizen expertise or finances, is a dearth of quality control samples (such as blanks and replicates) that provide valuable bias and precision information. Without an adequate field and laboratory blank program in place, how would a citizen evaluate whether the detection and quantification of an alleged analyte is the result of a sampling and/or laboratory contaminant?

Representativeness is a key data quality indicator that is often ignored by inexperienced citizens. A sampling program needs to consider the exposure routes of the populations of interest. Spatial, temporal, and sample size issues should all be rigorously considered as part of the DQO process, and documented in a QAPP. Running out into the field to take a few grab samples is often inappropriate, resulting in biased and misleading data. The ultimate quality of a measurement is a function of each and every step of a complex data collection process, with the failure of any step in the process potentially jeopardizing the reliability and usability of the resultant data.

The author can be reached at dwait@gradientcorp.com.

References:

U.S. EPA. 1996. The Volunteer Monitor's Guide to Quality Assurance Project Plans. EPA 841-B-96-003. September.

U.S. EPA. 2002. Guidance for Quality Assurance Project Plans. EPA/240/R-02/009. December.

U.S. EPA. 2013. Citizen Science QAPP Guidance. April.

Using Community-based Participatory Research to Address Environmental Justice

By Julie Lemay, M.P.H.

Community-based participatory research can influence public health policy, improve transparency, and engage and empower environmental justice communities.

Many people participate in citizen science each day through use of crowdsource traffic data like Waze or GPS-enabled bike share programs. Similarly, "community-based participatory research" is being used by public, private, and community partners in the field of public health to generate data. This article explores the emergence of several forms of community-based participatory research to address public health concerns in economically disadvantaged communities.

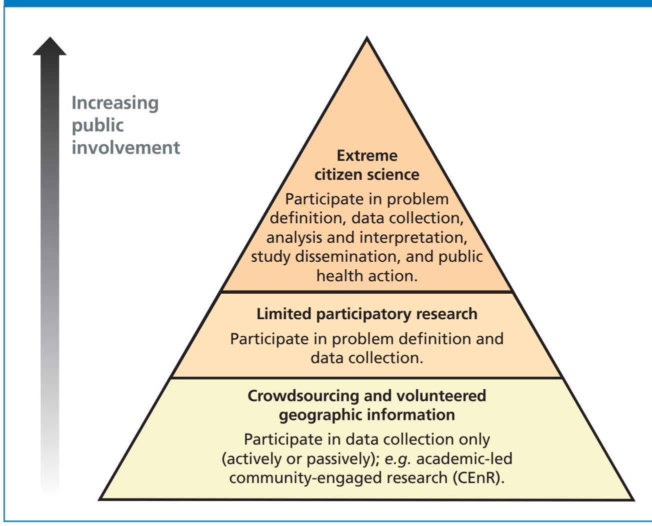
> ***Participatory research is…a valuable tool… for disadvantaged communities that might otherwise be left out of the traditional scientific process.***

Governmental agencies including the National Institutes of Health (NIH) and the Environmental Protection Agency (EPA) are actively promoting the use of community-based participatory research. As illustrated by the figure below from English *et al.* (2018), this research can take several forms that differ in terms of the level of public involvement. For example, community-engaged research (CEnR) is driven by academics who design the research question and reach out to community members for assistance in collecting data (both active and passive). Extreme citizen science, on the other hand, is driven by community stakeholders who design the research questions (sometimes in collaboration with academics or the public sector) to address their local public health concerns and then have involvement in all steps of the process.

While recognizing the important role of community participation in public health research, there are several challenges that can affect the usefulness of participatory research. As discussed in the previous articles, community-led citizen science environmental sampling efforts have the potential for generating biased, inaccurate, and/or unreliable data. Biased community health data can also arise from improperly administered surveys and questionnaires when community members have limited or no knowledge of epidemiological study design or how to conduct an unbiased survey.

Despite its limitations, participatory research can increase the relevance of public health research to community stakeholders, impact public health policy, engage the community, and improve public transparency. Participatory research is viewed as a valuable tool to provide neighborhood-level data for disadvantaged communities that might otherwise be left out of the traditional scientific process. This is the case for what are known as environmental justice (EJ) communities, which are generally defined by several socioeconomic criteria (including economic, ethnic, and/or racial isolation) and may be disproportionately burdened by pollution or lack of environmental enforcement (FEMA Executive Order No. 12,898, 1994). An important component of community-based participatory research in EJ communities is ensuring that they have "equal access to the decision-making process" (U.S. EPA, 2018). It has been demonstrated that participatory research can empower community members to take ownership of an environmental issue and use community-based knowledge to help solve the problem in a way that is beneficial and relevant for the community (English *et al.*, 2018).

TIERS OF PARTICIPATORY RESEARCH



Source: English, P.B., M. J. Richardson, C. Garzon-Galvis. 2018. From Crowdsourcing to Extreme Citizen Science: Participatory Research for Environmental Health. *Annual Review of Public Health.* 39:335-350. DOI:10.1146/annurev-publhealth-040617-013702.

One example of the impact of participatory research involves the EJ community of New Bedford, Massachusetts. In response to concerns regarding a potential elevation in cancer incidence in their community, New Bedford community members worked with academic and public sector partners to select air sampling locations for airborne PCB measurements

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What's New at Gradient

Awards and Announcements

Teresa Bowers has been elected as a Fellow of the Geological Society of America.

Kurt Herman has been appointed to the Editorial Advisory Board of Remediation Journal.

Kurt Herman is now a licensed Professional Geologist in Washington state.

Heather Lynch has been appointed to the Massachusetts Toxic Use Reduction Science Advisory Board.

Matt Mayo was elected Chairman of the Zoning Board of Appeals in Lancaster, MA.

Lorenz Rhomberg participated in the UN Environmental Program-SETAC Pellston Workshop "Global Guidance for Lifecycle Impact Assessment Indicators and Methods" in Valencia, Spain in June 2018.

Publications

Beyer, L.A., M.L. Hixon. 2018. Review of animal studies on the cardiovascular effects of caffeine. *Food Chem. Toxicol.* 118:566-571. DOI:10.1016/j.fct.2018.06.002.

Goodman, J.E., K. Zu, C.T. Loftus, **H.N. Lynch, R.L. Prueitt, I. Mohar, S.P. Shubin,** S.N. Sax. 2018. Short-term ozone exposure and asthma severity: Weight-of-evidence analysis. *Environ. Res.* 160:391-397. DOI:10.1016/j.envres.2017.10.018.

Lynch, H.N., R.L. Prueitt, J.E. Goodman. 2018. Critique of the ACGIH 2016 derivation of toluene diisocyanate threshold limit values. *Regul. Toxicol. Pharmacol.* DOI:10.1016/j.yrtph.2018.06.017.

Rice, J.W., T.A. Lewandowski. 2018. Potential health risks of cannabis concentrate products. *ABA Products Liability Newsletter.*

Zu, K., L. Shu, R.L. Prueitt, X. Liu, J.E. Goodman. 2018. Critical review of long-term ozone exposure and asthma development. *Inhal. Toxicol.* 30(3):99-113. DOI:10.1080/08958378.2018.1455772.

Upcoming Presentations

Washington, D.C. September 24-26, 2018. The 11th International Occupational Hygiene Association (IOHA) International Scientific Conference.

- **"A Toxicological Perspective on Indoor Air Standards for VOCs."** L. Beyer.

Chicago, IL. September 26-28, 2018. 2018 National Forum for Environmental and Toxic Tort Issues (FETTI).

- **"Coming Soon to a Drinking Water Source Near You: EPA Regulation of Perchlorate."** D. Dodge.

Washington, D.C. September 27-29, 2018. Product Stewardship 2018.

- **"Characterizing UVCB Substances: Unique Challenges for Product Stewardship and Compliance."** J. Kneeland, A. Lewis.
- **"Dealing with Data Gaps: Emerging Tools in Predictive Toxicology."** J. Zhang, J. Rice.

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Using Community-based Participatory Research to Address Environmental Justice

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and conduct a study to determine blood serum polychlorinated biphenyl (PCB) levels in community members living near areas of historical contamination. Working together with academics and regulators, community members gained an in-depth understanding of the issues and used data to determine that community members did not have higher levels of PCBs in their bodies than the U.S. population (MA DPH, 2013).

Overall, while an evolving process that is not without recognized challenges and potential limitations, community-based participatory research is helping to reshape the way public health problems are investigated.

The author can be reached at jlemay@gradientcorp.com.

References:

English, P.B., M.J. Richardson, C. Garzon-Galvis. 2018. From Crowdsourcing to Extreme Citizen Science: Participatory Research for Environmental Health. *Annual Review of Public Health.* 39:335-350. DOI:10.1146/annurev-publhealth-040617-013702.

FEMA. Executive Order 12,898, Environmental Justice for Low Income & Minority Populations. 1994.

MA DPH. 2013. Health Consultation: Evaluation of Indoor Environmental Conditions and Potential Health Impacts.

U.S. EPA. 2018. Environmental Justice.

Guest Editorial: Ash Pond Citizen Suits and Scientific Issues

By Steven Burns and Katlyn Caldwell

A highly credentialed and professional expert witness is indispensable in resolving the complex scientific and technical issues raised in ash pond citizen suits.

The Clean Water Act (CWA) and Resource Conservation Recovery Act (RCRA) authorize private "citizen suits," and a number of utilities have already faced lawsuits relating to ash pond operations and closure plans. Plaintiffs have relied heavily on a theory that groundwater issues are subject to the CWA – which only regulates surface waters like rivers and wetlands – if the groundwater could convey pollutants to jurisdictional waters. RCRA cases may focus on potential impacts to groundwater, or they may allege an imminent and substantial endangerment to the environment or human health.

Citizen groups have access to groundwater monitoring data for ash ponds developed and published by the utilities themselves.

Utilities in a citizen suit will argue to the contrary: there is no groundwater connection to surface water, or the connection (*i.e.*, "nexus") does not result in measurable pollution; or the presence of a given pollutant does not pose an appreciable risk; or the facility and its closure plans are designed and built to perform well and ensure environmental protection.

On both sides, these arguments rest on scientific data. Citizen groups have access to groundwater monitoring data for ash ponds developed and published by the utilities themselves. Through discovery, the plaintiffs will obtain documentation on issues such as regulatory compliance, environmental impact, technical support for closure plans, and construction processes. Any relevant information could be subject to a discovery request. Citizen groups also may develop information on their own.

So how does a judge – possibly relying on a jury as the trier of fact – sort through all the technical issues? Both the plaintiffs and the defendants provide experts to explain the meaning of the groundwater monitoring data, the engineering and environmental studies, the construction plans, and any other relevant information. Under the federal rules of evidence, expert witnesses must be "qualified" to offer scientific testimony, and opposing counsel can move to disqualify and exclude experts based on their knowledge, skill, experience, training, or education. Even if an expert is deemed to be qualified, an opposing attorney can attempt to discount his or her testimony as biased based on considerations such as compensation for one's work or general patterns established through past publications or expert testimony in other cases.

A federal courtroom is an imperfect forum to resolve disputed technical and scientific issues. In this context, experts are critical. Ultimately, the ideal expert witness can exert maximal influence on trial proceedings based on a few important factors. She or he will have impeccable credentials; communicate on complex issues in a simple, easy-to-access way; show a principled basis for one's conclusions; convey an even-handed, non-defensive approach; and display a confident and sympathetic disposition.

Burns and Caldwell are attorneys at Balch & Bingham LLP in Birmingham, Alabama. They represent electric utilities and others on waste management and other environmental issues. Burns is the lead contributor of @CCR_Source, a resource for coal combustion residuals and coal ash news. They can be reached at sburns@balch.com (205-226-8736) and kcaldwell@balch.com (205-226-3447).

References:

33 U.S.C. §§ 1319(g)(6)(A), 1365(a)(1) (CWA citizen suit provisions).
42 U.S.C. § 6972(a)(1) (RCRA citizen suit provision).
Disposal of Coal Combustion Residuals from Electric Utilities, 80 Fed. Reg. 21,302, 21,309 (Apr. 17, 2015) (codified at 40 C.F.R. Part 257, Subpart D).
Fed. R. Evid. 702.

By The Way...

National Audubon Society's Christmas Bird Count is the longest-running citizen science bird project in the U.S., informing conservation efforts for bird species and their habitats.

Source: https://www.audubon.org/conservation/history-christmas-bird-count.

What's New at Gradient

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- **"The Big Reveal: Preparing for Increased Ingredient Transparency."** A. Lewis, R. LaMotte.

Atlanta, GA. October 1-3, 2018. Polyurethanes Technical Conference.

- **"Evaluation of Thresholds for Respiratory Effects of Toluene Diisocyanate."** J. Goodman, H. Lynch, R. Prueitt.

Amherst, MA. October 17, 2018. 34th Annual International Conference on Soils, Sediments, Water and Energy.

- **"Natural Gas Condensate Forensics: A Case Study."** P. Tcauciuc, J. Kneeland.

Pittsburgh, PA. October 23-25, 2018. Shale Insight 2018.

- **"Ambient Air Monitoring for Shale Gas Operations: What You Need to Know and How to Manage Risks."** L. Bailey, panelist.
- **"Healthy Shale: Is Natural Gas Development Affecting Public Health?"** C. Long, panelist.

Sacramento, CA. November 4-8, 2018. Society of Environmental Toxicology and Chemistry North America 39th Annual Meeting.

- **"Environmental Assessment of New Human Drugs in the U.S. & EU – Lessons Learned."** T. Lunsman, T. Verslycke.
- **"The Pros and Cons of Performance-Based Site Remediation."** G. Greenberg, T. Verslycke.

West Palm Beach, FL. November 4-11, 2018. American College of Toxicology 39th Annual Meeting.

- **"Assessing the Predictive Ability of an *in silico* Tool for Developmental Toxicity."** S. Pacheco Shubin, T. Lewandowski.
- **"Considerations for Qualifying VCN in Cell-based Therapies."** I. Mohar, T. Lewandowski.
- **"Derivation of a PEL for Antibody Conjugated Iron Dextran Nanoparticles."** J. Cohen, I. Mohar, T. Lewandowski.

Community-based Air Quality Monitoring Using Low-Cost Sensors

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overwhelmed by large amounts of potentially questionable data.

There remain many questions and outstanding issues involving low-cost sensors, and they are unlikely to ever replace FRM and FEM data for regulatory compliance purposes. However, some low-cost sensors have been demonstrated to correlate reasonably well (r^2>0.7) with FRM/FEM measurements (Clements *et al.*, 2017), and best practice recommendations are now available to assist citizen scientists in selecting, calibrating, and deploying sensors for collection of community-based air monitoring data (*e.g.*, the EPA's Air Sensor Toolbox website).

Like any source of air quality data, it is necessary to carefully assess their accuracy and reliability. However, low-cost sensors hold significant promise for improving air quality awareness and supplementing the data from fixed-site air monitoring networks.

The author can be reached at clong@gradientcorp.com.

References:

Castell, N., F.R. Dauge, P. Schneider, M. Vogt, U. Lerner, B. Fishbain, D. Broday, A. Bartonova. 2017. Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates? *Environ. Int.* 99:293-302.

Clements, A.L., W.G. Griswold, A. Rs, J.E. Johnston, M.M. Herting, J. Thorson, A. Collier-Oxandale, M. Hannigan. 2017. Low-cost air quality monitoring tools: From research to practice (a workshop summary). *Sensors.* 17(11):2478.

Gradient
Cambridge, MA
Seattle, WA
Charlottesville, VA
trends@gradientcorp.com
www.gradientcorp.com

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