Project Summary

Breathe Easy Dallas: Analysis of the Performance and Calibration of Low-Cost Air Quality Monitors Report

Overview

The need for low-cost air quality monitors arose in response to the fixed mobility, high-calibration requirements, and maintenance costs of traditional air pollution monitors, as well as the high variability of air quality in urban environments.

The Texas A&M Transportation Institute (TTI's) Center for Advancing Research in Transportation Emissions, Energy and Health (CARTEEH) and The Nature Conservancy of Texas (TNC) recently completed Breathe Easy Dallas: Analysis of the Performance and Calibration of Low-Cost Air Quality Monitors, a study assessing the performance and calibration of low-cost air quality monitors continuously measuring four criteria air pollutants in Dallas, Texas. The report documents a sub-study in the bigger Breathe Easy Dallas project and aims to advance scientific understanding and application of local air monitoring for improved public health outcomes among high-risk populations.

Traditionally, regulatory devices monitor air pollution at fixed sites owned by a public agency or environmental organization. These monitors typically measure multiple pollutants with a high degree of accuracy. However, fixed mobility, high calibration, and maintenance costs limit the ability to understand and map air quality, which varies significantly in urban areas. For example, the concentrations of black carbon, nitrogen oxide, and nitrogen dioxide can vary by 5 times within a single city block. These limitations led to the recent emergence and deployment of low-cost air quality monitors.

Characterized by their mobility, small size, low cost and relative ease of use, these monitors can measure air pollution in distributed networks and personal sensing, which has garnered interest among researchers and community members hoping to better understand local air quality through broader geographical deployment. However, few studies have examined their overall performance over an extended period. This study aimed to address this research gap through a comprehensive literature review and empirical analysis of the performance and calibration of these monitors in phase one of the Breathe Easy Dallas project.

Literature Review

The literature review compiled 26 studies conducted in the past seven years and was divided into four main categories for analysis:

- Evaluation of sensor performance in field and/or laboratory conditions;
- Evaluation of sensor performance in field and/or laboratory conditions with additional calibration methods;
- Specific-use case studies of sensors without calibration; and
- Specific-use case studies of sensors with applied or examined calibration and modeling applications.

The review's findings indicate that sensor performance varies widely depending on sensor types, pollutants examined, concentration levels, field locations, meteorological conditions, and calibration methods. Most of the studies surveyed identify the promise of low-cost sensing technology, despite some performance inconsistencies and deficiencies — including overestimation and underestimation of pollutant levels, and biases, which sometimes depend on ambient environmental and meteorological conditions.

Empirical Analysis

The empirical analysis assessed the performance and calibration of 12 low-cost air quality sensors co-located at a reference site in Dallas where a high-cost federal air quality monitoring station was operating continuously for 18 months between Feb. 11, 2019, and Aug. 31, 2020 (see Figure 1). The site's sensors measured the concentrations of four criteria pollutants: Ozone (O_3), Nitrogen Dioxide (NO_2), Particulate Matter with 10 micrometers or less in diameter (PM_{10}) and Particulate Matter with 2.5 micrometers or less in diameter ($PM_{2.5}$). Pollutants like NO_2, PM_{10} and $PM_{2.5}$ result from traffic activity and pose significant threats to human health resulting in premature mortality and a wide range of diseases. Areas with increased levels of exposure to these pollutants are at a higher risk of developing lung cancer, respiratory infections, asthma, ischemic heart disease, and chronic obstructive pulmonary disease.

Figure 1: 12 Aeroqual AQY Version 1 (AQY1) low-cost air quality monitors co-located at the Hinton site in Dallas.

The empirical analysis represents one of the longest follow-ups in the literature and aimed to answer four questions:

- How well do the raw and calibrated Micro Air Quality Monitoring System (AQY1) monitor readings match readings from the reference air quality monitoring station?
- How well do the AQY1 readings from the 12 different AQY1 monitors match each other?
- Do meteorological factors (temperature, relative humidity, wind speed, wind direction) impact the AQY1 monitor's performance and how?
- Does the performance of the AQY1 monitors decline as the time since a calibration was completed increases?

The complete findings indicate that monitor performance and the coefficient of determination (R^2) between the AQY1 versus the reference air quality monitor's data varies significantly by device and pollutant (see Table 1).

Table 1: Assessment of AQY1 vs. Reference Monitor's Air Pollution Readings.

	Adjusted R^2 Range Between the Calibrated AQY1 vs. Reference Monitor Data (mean and median value)	Reference Monitor Mean vs. Calibrated AQY1 Mean Difference in % (actual value)
O_3	0.56 to 0.97 (mean = 0.84, median = 0.90)	-19% (5.2 ppb)
NO_2	0.00 to 0.58 (mean = 0.35, median = 0.37)	+23% (1.7 ppb)
$PM_{2.5}$	0.20 to 0.39 (mean = 0.32, median = 0.33)	-24% (2.2 ug/m^3)
PM_{10}	0.36 to 0.54 (mean = 0.47, median = 0.49)	-11% (2.3 ug/m^3)

ppb: Parts per billion
ug/m^3: Micrograms per Cubic Meter of Air

Overall, time series pattern readings of pollutant concentrations followed similar trends in the AQY1 monitors and traditional reference monitor (see Figure 2 for selected comparisons).

The effects of meteorological data on performance were not uniform, and results varied across different monitors.

"Proper calibration and monitoring of the low-cost sensors once installed are key to ensure consistent operation", says TTI Research Specialist Jeremy Johnson. "Sensors that may not be operating properly may be indicative of faulty devices or site issues, and proper oversight by operators can help detect low-performing monitors, which can then be replaced", he added.

Figure 2: AQY Data vs. Reference Monitor Data of Pollutants

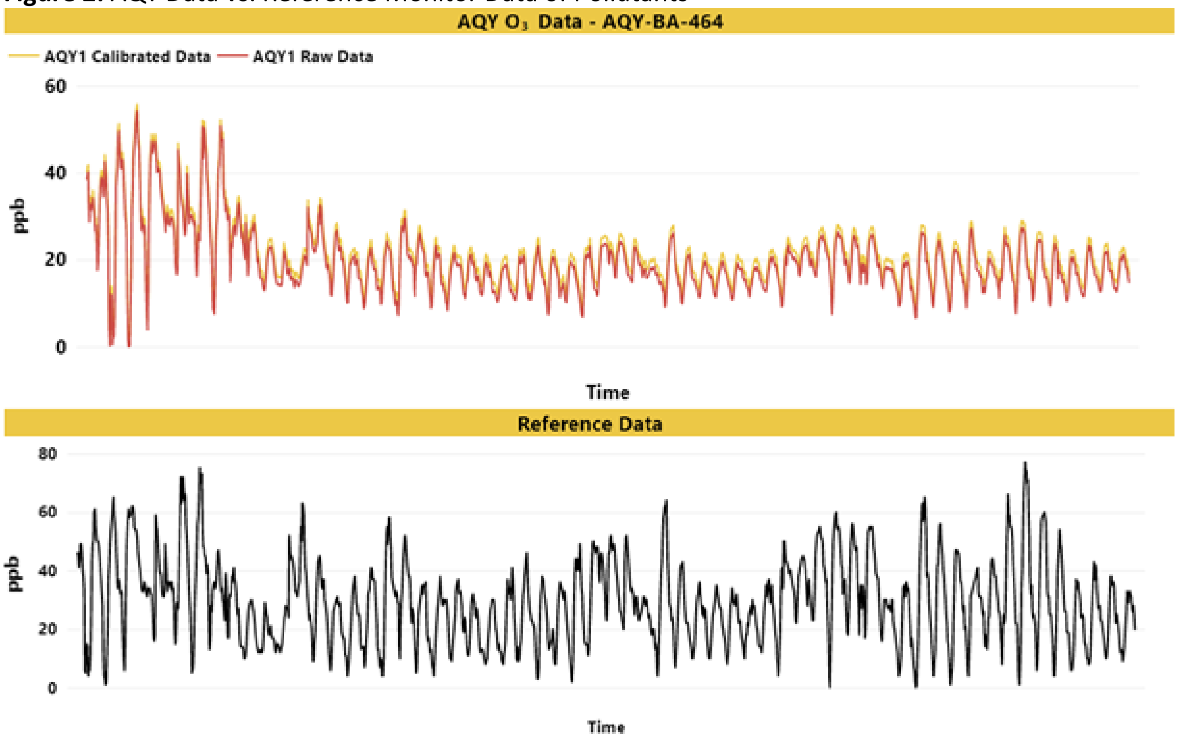

Figure 2A: O_3 data from AQY Monitor AQY-BA-464 (top panel) vs. Reference Monitor (lower panel) Jun. 10, 2019–Aug. 11, 2019.

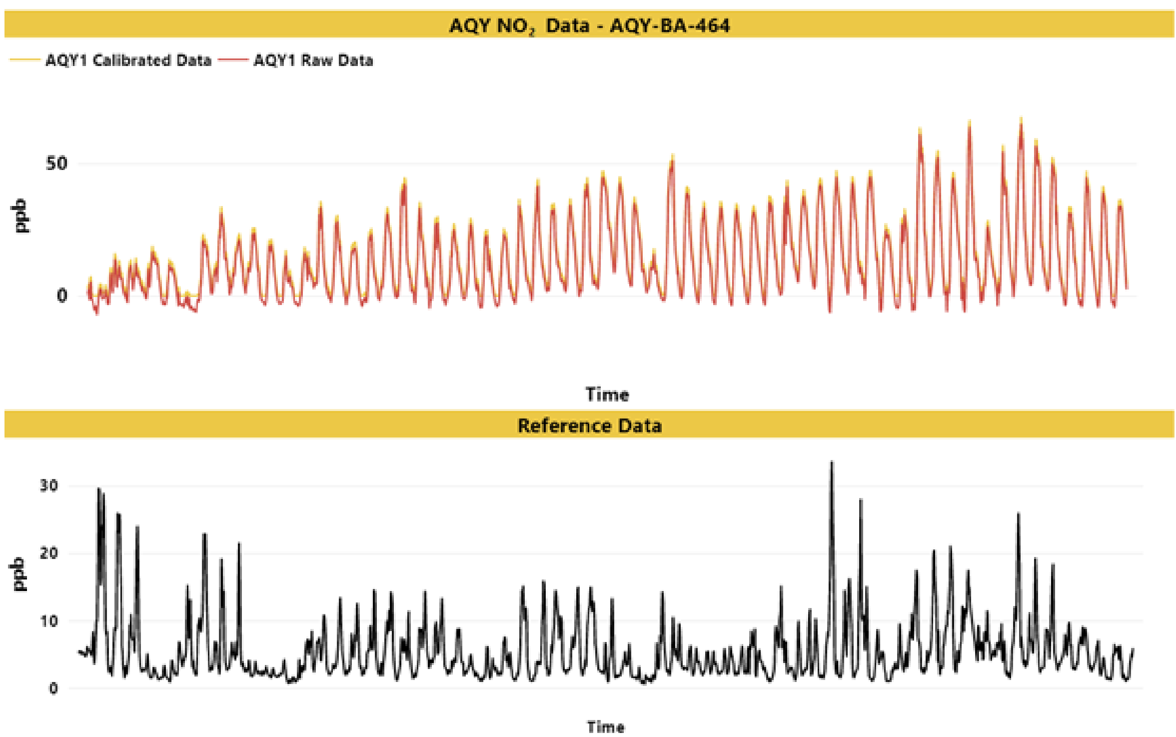

Figure 2B: NO_2 data from AQY Monitor AQY-BA-464 (top panel) vs. Reference Monitor (lower panel) Jun. 10, 2019–Aug. 11, 2019.

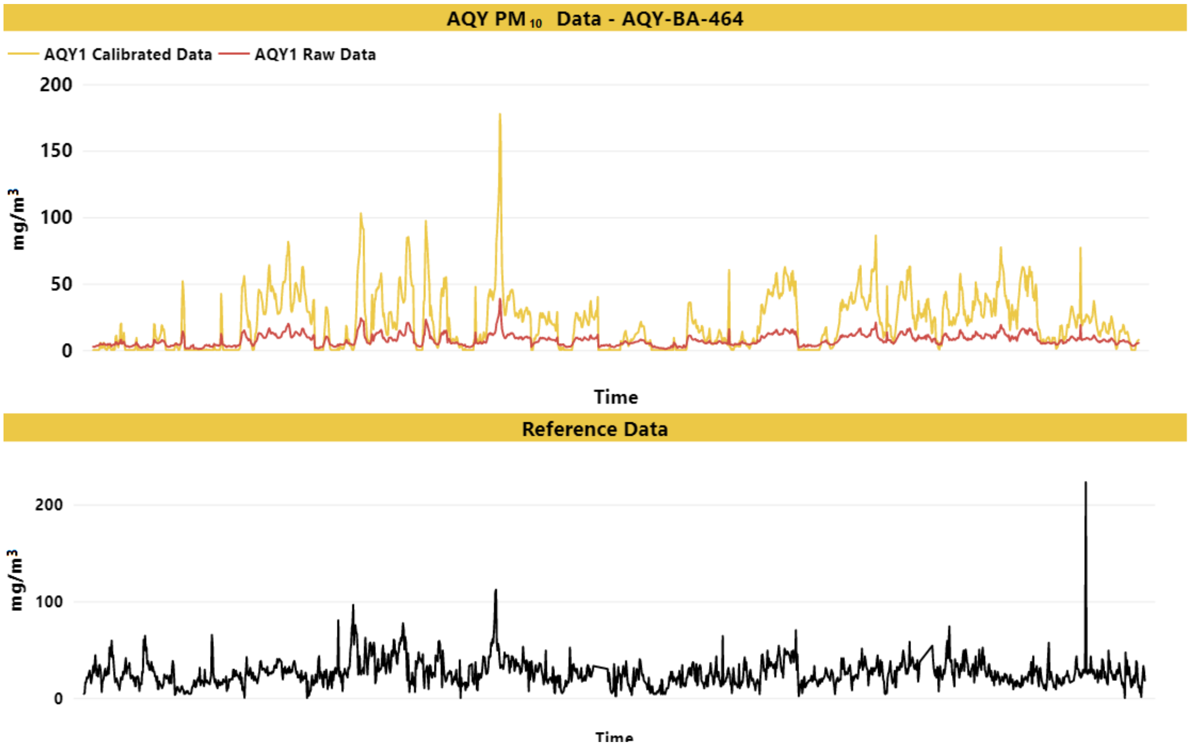

Figure 2C: PM_{10} data from AQY Monitor AQY-BA-WilburSpare09 (top panel) vs. Reference Monitor (lower panel) Jun. 10, 2019–Aug. 11, 2019.

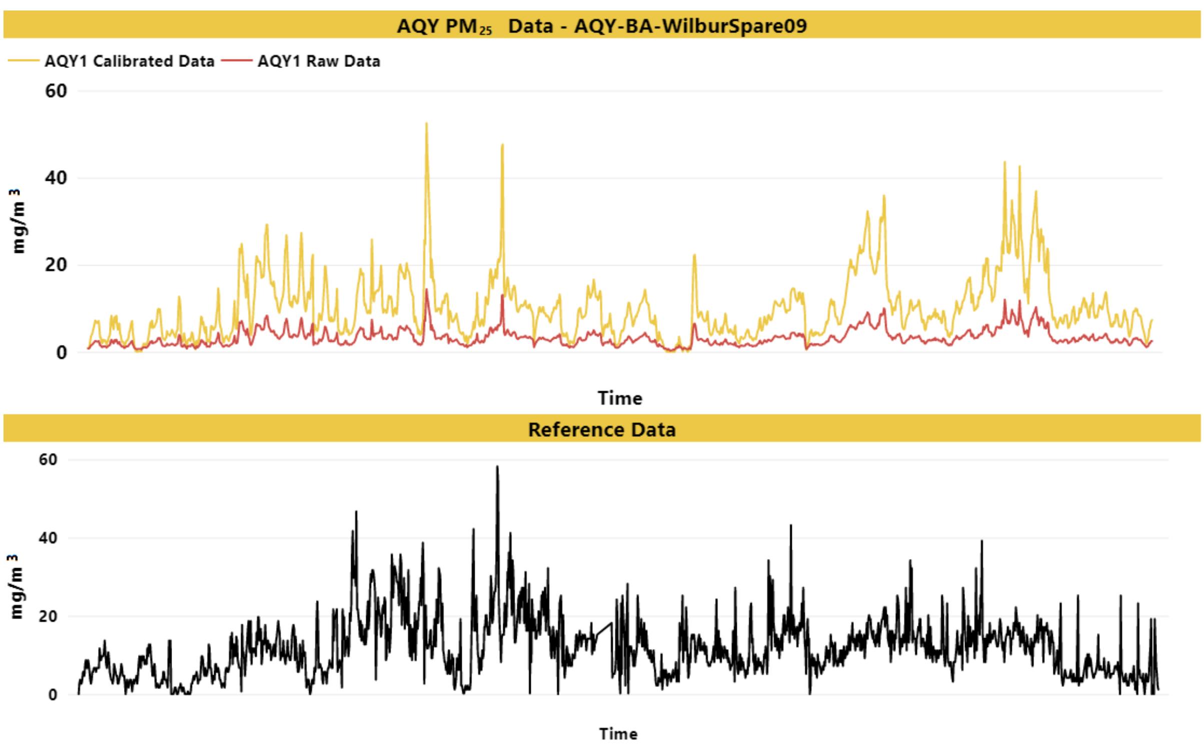

Figure 2D: $PM_{2.5}$ Data from the AQY Monitor AQY-BA-WilburSpare09 (top panel) vs. the Reference Monitor (lower panel) Jun. 10, 2019–Aug. 11, 2019.

“While the traditional reference monitors present more accurate measurements of pollution, low-cost air quality monitors are able to demonstrate trends in air quality and provide insight on parameters used for public and stakeholder engagement, such as the health-related Air Quality Index levels [AQI] used by the U.S. Environmental Protection Agency [USEPA] to communicate the state of air quality,” says TTI Associate Research Scientist Haneen Khreis. “We found that the performance of AQY monitors varies significantly by device and by pollutant, making an overall statement about their performance challenging. The monitors seem to perform best for O_3, followed by PM_{10}, $PM_{2.5}$ and NO_2. It’s also worth noting that the trends over time seemed to be captured relatively well for all pollutants.”

The study notes that although the absolute air pollution readings from low-cost air quality sensors deviated from the traditional reference monitors’ readings, the low-cost sensors’ readings tracked the reference monitors’ air-quality trends relatively well. The low-cost air quality sensors were also able to present a more accurate picture when the air quality was categorized using the USEPA AQI, rather than presenting the results as absolute measurements of air pollution concentrations.

The AQI is a calculated index value used by USEPA to relay air quality readings and their impacts on human health to the public. The data collected in this report shows value in broad deployment of low-cost monitors to track air quality trends and compare air pollution levels over time. The low-cost monitors can also track health-related parameters over wider geographical areas than the more expensive reference monitors. These capabilities may help shed light on why public health outcomes vary within cities.

This study, led by Khreis and her research team in collaboration with TNC, represents the first phase of a two-phase project addressing air quality concerns in Dallas. Phase two is currently under way and includes Dallas installing nine air quality monitors to measure air pollution levels across the city (see Figure 3).

Figure 3: AQY1 Installed in Dallas.

“Given the recent emergence of low-cost air-quality monitors and their increasing popularity, our findings are timely and relevant to the general public; public health and environmental scientists; and policymakers wanting to better understand and mitigate urban air pollution and its many adverse—and often inequitable—health impacts,” Khreis noted.