Assessment of Low–Cost Smoke Sensors in comparison to Mid- and High-Cost Optical Particle Instruments in Queensland's Air Quality Monitoring Network

Erdem Mustafa[1]

[1] Queensland Department of Environment, Science and Innovation, 41 Boggo Rd, Dutton Park Queensland, 4102, Australia

Keywords: bushfires, air quality network, Queensland, smoke sensors, data quality, particle monitoring, optical particle instruments, comparability, multi-sensor approach, air pollution event, limitations, quality assurance, public health advice.

1. Introduction

Following the extensive 2019-20 summer bushfires, the Royal Commission into National Natural Disaster Arrangements recommendations, coupled with feedback from the Queensland public, highlighted the need to expand the coverage of the Queensland air quality network.

In response, the Department of Environment, Science and Innovation (DESI) has increased the coverage of particle monitoring over the past three years. While mid- and high-cost optical particle instruments (Dr Födisch FDS-17 fine dust sensor[1] and Teledyne API T640x PM mass monitor respectively[2]) were deployed in more remote or major population centres, the network expansion was primarily achieved through the deployment of in-house solar-powered low-cost smoke sensors (STARS). This self-contained, small-footprint and easily deployable solution has made it possible to provide indicative particle level information covering all Queensland communities with a population of more than 3,000.

However, the use of such a multi-sensor approach raises questions. For example, how does each of these instruments perform amongst each other, especially during an air pollution event? In addition, what are the limitations of each instrument that may affect the data produced? To answer these questions, DESI has undertaken a preliminary study at its Cannon Hill monitoring station in Brisbane where all three instruments are co-located. The understanding of instrument performance and limitations will feed into more informed quality assurance decisions to ensure data is fit for purpose when used as the basis for public health advice during poor air quality episodes.

2. Methodology

The STARS and FDS-17 $PM_{2.5}$ 1-hour average particle concentration data obtained during a bushfire smoke event on 15-16 December 2023 were each compared against the T640x 1-hour data using orthogonal regression (i.e. determination of the linear relationship where both variables contain measurement error). The T640x monitor has US EPA $PM_{2.5}$ Federal Equivalence Method designation EQPM-0516-238[3]. The T640x 1-hour data was firstly corrected based on the relationship between the T640x 24-hour average concentrations and those from a co-located Partisol 2025 reference $PM_{2.5}$ sampler data (multiplier of 0.8751, offset of +0.49). This smoke event was chosen due to the spread of particle concentration values captured.

3. Results

Orthogonal regression analysis on the 1-hour $PM_{2.5}$ particle concentrations produced from the STARS, FDS-17 and T640x instruments yielded the following results.

The STARS versus T640x $PM_{2.5}$ 1-hour data are presented in the scatterplot in Figure 1.

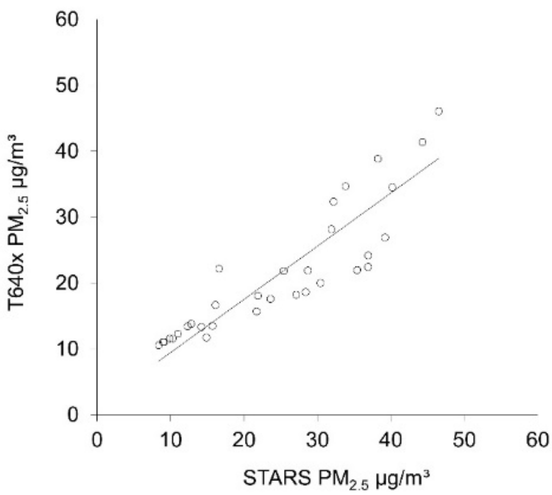

Figure 1. Scatterplot of 1-hour $PM_{2.5}$ concentrations showing orthogonal regression fitted line – STARS versus T640x.

The correlation coefficient for this data was 0.8912. The standard deviation results were high for both the T640x at 11.8 and the STARS at 9.7. The STARS versus T640x data analysis is summarised in Table 1.

Table 1. Data analysis summary of $PM_{2.5}$ 1-hour concentrations for STARS against T640x (reference method).

	T640x	STARS
Valid data points	32	32
Minimum value	8.4	10.6
Maximum value	46.5	46.1
Standard Deviation	11.8	9.7
Mean value	24.5	21.2
Median value	24.5	18.5
Orthogonal Regression		
$y = 0.8076\ x + 1.39$		
$r = 0.8912$		
$r^2 = 0.7942$		

The FDS-17 versus the T640x $PM_{2.5}$ 1-hour data are presented in the scatterplot in Figure 2.

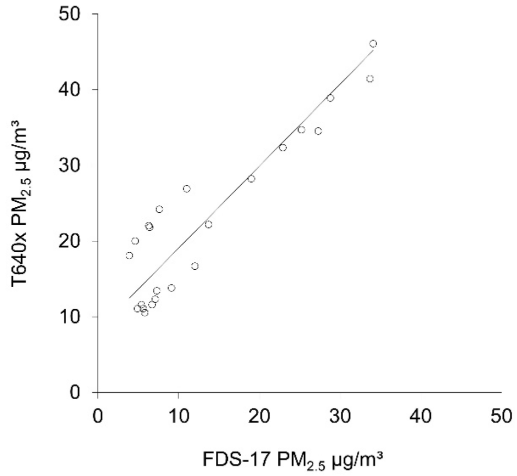

Figure 2. Scatterplot of 1-hour $PM_{2.5}$ concentrations showing orthogonal regression fitted line – FDS-17 versus T640x.

The correlation coefficient for this data was 0.9206. The standard deviation results were high for both the T640x at 9.9 and the FDS-17 at 10.9. The FDS-17 and T640x data analysis is summarised in Table 2.

Table 2. Data analysis summary of $PM_{2.5}$ 1-hour concentrations for FDS-17 against T640x (reference method).

	T640x	FDS-17
Valid data points	23	23
Minimum value	3.9	10.6
Maximum value	34.1	46.1
Standard Deviation	9.9	10.9
Mean value	13.4	22.8
Median value	7.6	21.8
Orthogonal Regression		
$y = 1.0836\ x + 8.24$		
$r = 0.9206$		
$r^2 = 0.8474$		

4. Discussion

The STARS sensor was found to be overestimating $PM_{2.5}$ particle concentrations compared to the FDS-17 instrument. This may be due to the sensor using low-cost components (Plantower PMS-5003 sensors) and, to conserve battery power, operates on an intermittent basis (single instantaneous reading on the 35th second of every 1 minute). This limitation could affect the representativeness of the data being captured therefore, the resulted low correlation coefficient. For this reason, the STARS measurements are considered indicative only.

The lowest concentration levels that can be recorded by the FDS-17 is 2 µg/m^3 consequently, limiting capture of a true range of particle variability. Since these 2 µg/m^3 values cannot be truly determined as they could be less than the recorded value, the data pairs from the FDS-17 and T640x were removed from analysis. This may have impacted the correlation coefficient and explain why it was slightly low when compared to the T640x. In addition, due to an instrument fault, only 23 1-hour FDS-17 data values were available compared to 32 1-hour values for the STARS sensor, which may have influenced the analysis results.

Readings from all instruments had a high standard deviation, indicating that the data has a spread that was not precise. However, this could have been caused by the limited datasets, in this case the smoke event from 00:00 15 December to 07:00 16 December 2023 for the STARS comparison and 00:00 to 23:00 15 December 2023 for the FDS-17 comparison.

5. Recommendations

This exercise has identified that a larger dataset for all three instruments is required to obtain a robust indication of how these instruments perform and correlate against each other. Ideally, one to two years of data capture covering a range of variability in particle concentrations would give a better understanding of data validity and how it can be used as the basis for health advice in a residential setting such as Cannon Hill.

Acknowledgments

Acknowledgment is made of assistance with equipment, data processing and analysis provided by the following DESI Air Quality Monitoring staff: Steven Torr, Chris Collins, Ryan Stuart and Donald Neale.

References

1. Dr Födisch Umweltmesstechnik AG, 2020, “Operation Manual – Fine Dust Sensor FDS 17”, Markranstädt, Germany, vol. 1.2, pp. 5-13.

2. Teledyne API, 2023, “User Manual – Model T640 PM Mass Monitor”, San Diego, California, pp. 12-13.

3. U.S. Environmental Protection Agency (EPA), 2016. Teledyne advanced pollution instrumentation model T640 PM mass monitor. Automatic equivalent method: EQPM-0516-238.Federal Register: vol. 81, pp. 45285.