Low-cost smart sensors for PM monitoring in ambient air: analysis and comparisons

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Abstract Air pollution remains a major global concern, causing around 400,000 premature deaths annually in the EU. Particulate matter (PM), especially PM_{10} and $PM_{2.5}$, is one of the most harmful pollutants due to its association with cardiovascular and respiratory diseases; it is classified as a Group 1 carcinogen by the IARC. In Europe, PM concentrations are officially measured via gravimetric analysis (EN 12341:2023), which ensures high accuracy but lacks real-time data and requires significant resources. This study evaluates the performance of two low-cost sensors (SEN55 and SDS011) and one optical reader (MPC1), compared to the reference method over a 30-day campaign in multiple environmental conditions. Results are analyzed using R^2, bias, and RMSE to assess inter-sensor variability and agreement with standard methods, aiming to support the integration of low-cost technologies in air quality monitoring networks.

Keywords: *particulate matter, monitoring, air quality, sensors*

1. Introduction

Air pollution represents one of the most critical global challenges, contributing to approximately 400,000 premature deaths annually in the EU (EEA, Among all atmospheric pollutants, particulate matter (PM) is notably harmful due to its links to respiratory and cardiovascular diseases and it is classified as a Group 1 carcinogen by the IARC. European and international regulations require the monitoring of PM10 and PM2,5 fractions, which refer to particles with aerodynamic diameters less than or equal to 10 µm and 2.5 µm, respectively. The reference method to measure PM_{10} and $PM_{2.5}$ concentrations in ambient air is gravimetric analysis, according to EN 12341:2023, which ensures high accuracy but lacks real-time capability and requires substantial resources. To overcome these limitations, low-cost smart sensors (LcSS) have gained popularity due to their affordability, portability, and ability to provide continuous data. . In this study, two low-cost sensors and one optical reader were compared with the gravimetric method during a field campaign, and the collected data were subsequently processed through statistical analyses to assess inter-sensor variability and agreement with the reference.

2. Material and methods

An experimental activity was carried out for 30 days, during which PM10 and PM2,5 concentrations were measured in continuous using one low-cost sensor (Sensirion model SEN55 and Nova Fitness model SDS011) and two optical readers (Contec model MPC1, FAI model OPC Tracer). These devices were compared against the TCR Tecora Charlie automatic sequential sampler, which performs gravimetric analysis in compliance with EN 12341:2023. Meteorological data (temperature, relative humidity, wind speed and direction, solar radiation, and precipitation) were recorded using a KME weather station (LSI Lastem). All instruments were installed on board the SEED AIR a mobile laboratory (Sanitary Environmental Engineering Division, Department of Civil Engineering, University of Salerno, Campania, Italy) located in a parking area in the University Campus. Performance evaluation included the following metrics:

- **Linearity**, assessed through linear regression using the slope and the coefficient of determination (R^2);
- **Accuracy**, calculated as the percentage proximity of the sensor value to the gravimetric value;

3. Results

Figure 1 shows the daily concentrations of PM10 and PM2,5 measured by the gravimetric method, low-cost sensors (SEN55), and optical reader (MPC1) over a 30-day period.

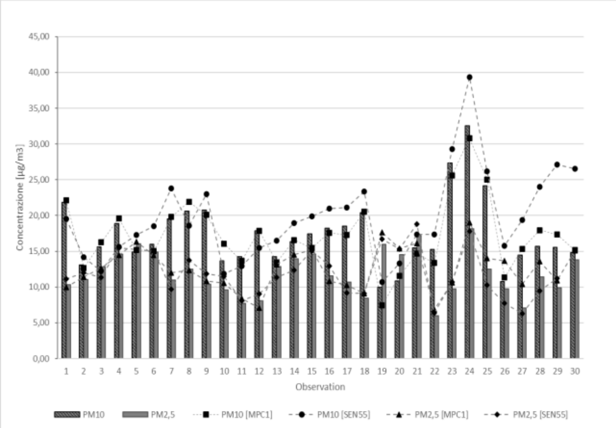

Figure 1. Daily concentration of PM10 and PM2,5 measured with gravimetric analysis

During the monitoring period, the average PM10 concentration measured with the gravimetric method was 17.88 µg/m³, while the average PM2,5 concentration was 12.09 µg/m³.

Table 1 summarizes the coefficient of determination (R^2) and the percentage accuracy of each instrument in comparison to the gravimetric method.

Table 1. Evaluation of LCSs performances compared to gravimetric analysis

	PM fraction	Linearity (R^2)	Accuracy (%)
SEN55	PM10	0,62	82,4
	PM2,5	0,86	90,90
MPC1	PM10	0,93	84,1
	PM2,5	0,84	91,3

The results indicate that the optical reader shows the highest linearity for PM10 ($R^2 = 0.93$) and maintains good accuracy for both size fractions. The SEN55 sensor performs better for PM2,5 ($R^2 = 0.86$), while its correlation for PM10 is moderate ($R^2 = 0.62$), suggesting a greater suitability for fine particulate monitoring in this specific environmental context.

4. Conclusion

This study assessed the performance of two low-cost smart sensors and one optical reader (MPC1) for the measurement of PM10 and PM2,5 concentrations in ambient air, using gravimetric analysis as the reference method. The results showed that, among the tested instruments, the MPC1 optical reader exhibited the highest correlation with the gravimetric data for PM10($R^2 = 0.93$), suggesting its suitability for coarse particle monitoring. On the other hand, the SEN55 sensor demonstrated better agreement for PM2,5 measurements ($R^2 = 0.86$), indicating a greater reliability in detecting fine particulate matter. The findings confirm that low-cost sensors can serve as valuable tools for indicative air quality monitoring, especially when real-time data and wide spatial coverage are required. However, careful calibration, environmental validation, and consideration of sensor-specific limitations are essential to ensure the reliability of the collected data.

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