What are the current methodologies and effectiveness of air quality monitoring systems in urban areas of Poland?

Urban areas in Poland monitor air quality through professional reference-grade systems, low-cost sensor networks, and mobile systems, with stationary systems providing the highest accuracy for multi-pollutant measurements.

Abstract

Air quality monitoring in Poland's urban areas relies on a range of methodologies that address the challenge of measuring complex, variable emissions. Studies in Kraków, Poznań, Łódź, and other cities report that professional stationary or reference-grade systems (used in 5 of 10 studies) deliver high accuracy and multi-pollutant data, particularly for particulate matter (PM10 in 9 studies and PM2.5 in 6). Low-cost sensor networks (2 studies) deliver high temporal resolution and spatial detail, though calibration issues persist, while mobile systems and automatic networks supplement fixed grids and aid hotspot detection. Studies note that manual verification can outperform automated measurements for PM2.5, and that network designs integrating meteorological data enable finer analysis of seasonal and diurnal trends—winter and evening periods reliably show higher pollutant concentrations. Dense population, mixed emission sources, and meteorological variability present challenges that these varied approaches seek to overcome.

Paper search

Using your research question "What are the current methodologies and effectiveness of air quality monitoring systems in urban areas of Poland?", we searched across over 126 million academic papers from the Semantic Scholar corpus. We retrieved the 50 papers most relevant to the query.

Screening

We screened in papers that met these criteria:

- **Geographic Setting**: Was the study conducted in an urban area of Poland?
- **Monitoring System Focus**: Does the study examine air quality monitoring systems or methodologies (including fixed stations, mobile sensors, or sensor networks)?
- **Data Reporting**: Does the study report quantitative or qualitative data on monitoring system effectiveness, including performance metrics?
- **Study Type**: Is the study either a primary research study, systematic review, or meta-analysis containing empirical data?
- **Quality Assurance**: Does the study include analysis of data validation and quality assurance procedures?
- **Implementation Status**: Does the study include actual implementation and monitoring data (rather than solely theoretical models)?
- **Monitoring Environment**: Does the study include outdoor/ambient air quality monitoring (not exclusively indoor monitoring)?

We considered all screening questions together and made a holistic judgement about whether to screen in each paper.

Data extraction

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column.

- **Study Design Type**:

  Identify the primary type of study design used:

- Observational study (cross-sectional, cohort, case-control)
- Monitoring study
- Comparative analysis
- Measurement-based assessment

Look in the methods or introduction section. If multiple design elements are present, list all that apply. If the design is not explicitly stated, infer from the study's methodology and data collection approach.

- **Air Quality Monitoring Methodology**:

  Describe the specific air quality monitoring methods:

- Type of monitoring stations (e.g., background, urban, rural)
- Measurement devices used (professional stationary, low-cost monitors)
- Pollutants measured (list specific pollutants)
- Number and location of monitoring stations

Extract this information from the methods section. If multiple methods are used, list all. Include specific details about equipment, measurement techniques, and spatial coverage.

- **Geographic Coverage**:

  Specify:

- Cities/regions studied
- Province or administrative area
- Urban/rural classification of monitoring sites

Look in the methods or introduction sections. Provide precise location details, including population size of areas studied if mentioned. If multiple locations are studied, list all.

- **Time Frame of Study**:

  Record:

- Exact years of data collection
- Seasonal variations noted (e.g., winter vs. summer periods)
- Frequency of measurements (hourly, daily, etc.)

Extract from methods section or data description. If multiple time periods are covered, list all. Note any specific time-related observations about air quality patterns.

- **Pollutant Concentration Findings**:

  Extract:

- Specific pollutant concentration levels

- Comparisons between different locations/station types
- Exceedance of acceptable pollution levels
- Identified pollution sources

Look in results and discussion sections. Include numerical data if available. Note any statistically significant findings or notable trends in pollution levels.

- **Implications and Recommendations**:

  Identify:

- Key conclusions about air quality
- Recommendations for air quality management
- Potential health implications
- Suggestions for future monitoring

Extract from discussion or conclusion sections. Focus on practical insights derived from the study's findings. If multiple recommendations are present, list all in order of importance.

Results

Characteristics of Included Studies

Study	Study Type	Monitoring Method	Location	Parameters Measured	Full text retrieved
Ciepiela and Sobczyk, 2021	Measurement-based assessment, Monitoring, Comparative analysis	Professional stationary (WP6130 dust meter), manual verification	Kraków (urban, 3 districts)	Particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5), formaldehyde, volatile organic compounds (VOCs)	Yes

Study	Study Type	Monitoring Method	Location	Parameters Measured	Full text retrieved
Nieckarz and Zoladz, 2020	Monitoring study	Low-cost monitors (SEN0177, BME280)	Kraków Metropolitan Area (urban, rural, town)	Particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5), particulate matter less than 1 micrometer in diameter (PM1), temperature, humidity, pressure	Yes
Sówka et al., 2023	Monitoring, Measurement-based assessment	Urban background stations (MetOne BAM-1020, MP101M, DERENDA PNS 16T-3.1)	Poznań (urban, 4 sites)	Particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5), arsenic (As), cadmium (Cd), nickel (Ni)	No
Maslouski et al., 2023	Monitoring, Measurement-based assessment, Comparative analysis	Mobile car system (DustTrak II 8530)	Rural communities around Kraków	Particulate matter less than 10 micrometers in diameter (PM10)	Yes

Study	Study Type	Monitoring Method	Location	Parameters Measured	Full text retrieved
Oleniacz and Gorzelnik, 2021	Monitoring, Comparative analysis, Measurement-based assessment	Traffic, urban background, industrial stations	Kraków (urban)	Particulate matter less than 10 micrometers in diameter (PM10), nitrogen dioxide (NO2), benzene (C6H6), sulfur dioxide (SO2)	No
Rogulski, 2018	Observational (monitoring), Comparative analysis, Measurement-based assessment	Low-cost PM10 monitors, professional VIEP stations	Nowy Sącz (urban)	Particulate matter less than 10 micrometers in diameter (PM10)	Yes
Orlowski et al., 2017	Monitoring, Comparative analysis, Measurement-based assessment	8 monitoring stations (type not specified)	Gdańsk Metropolitan Area	7 parameters (no mention found)	No
Chambers and Podstawczyńska, 2019	Monitoring, Measurement-based assessment	No mention found	Łódź (urban)	Particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5)	No

Study	Study Type	Monitoring Method	Location	Parameters Measured	Full text retrieved
Kobza et al., 2018	Measurement-based assessment, Monitoring	Urban background stations (TECORA, ATMOSERVICE)	Katowice, Żory (urban, Silesia)	Particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5)	Yes
Cichowicz and Stelęgowski, 2019	Monitoring, Measurement-based assessment, Observational	Automatic stations (city, town, rural background)	5 cities, 5 towns, 5 villages (5 provinces)	Nitrogen dioxide (NO2), nitrogen oxides (NOx), ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), particulate matter less than 10 micrometers in diameter (PM10), particulate matter less than 2.5 micrometers in diameter (PM2.5), benzene	Yes

Across the 10 studies, the following patterns were identified:

- Monitoring Method:
  - 5 studies used professional stationary or reference-grade monitoring stations.
  - 2 studies used low-cost monitors.
  - 1 study used a mobile car-based monitoring system.
  - 1 study used automatic stations covering city, town, and rural backgrounds.
  - We didn't find mention of the monitoring method in 2 studies.

- Parameters Measured:
  - Particulate matter less than 10 micrometers in diameter (PM10) was measured in 9 studies.
  - Particulate matter less than 2.5 micrometers in diameter (PM2.5) was measured in 6 studies.
  - Particulate matter less than 1 micrometer in diameter (PM1) was measured in 1 study.
  - Gaseous pollutants (nitrogen dioxide, nitrogen oxides, ozone, sulfur dioxide, carbon monoxide, benzene, benzene (C6H6)) were measured in 2 studies.
  - Heavy metals (arsenic, cadmium, nickel) were measured in 1 study.
  - Volatile organic compounds and formaldehyde were measured in 1 study.
  - Meteorological parameters (temperature, humidity, pressure) were measured in 1 study.
  - We didn't find mention of the parameters measured in 1 study.
- Location:
  - 7 studies were conducted in urban areas.
  - 1 study was conducted in rural areas.
  - 2 studies included multiple area types (urban, rural, and/or town).
  - We didn't find mention of studies conducted only in towns or with location not specified.

Thematic Analysis

Monitoring System Technologies

Study	Technology Type	Coverage Area	Measurement Frequency	Key Capabilities
Ciepiela and Sobczyk, 2021	Professional stationary, manual verification	3 urban districts in Kraków	Daily	High accuracy, manual cross-checking, multi-pollutant
Nieckarz and Zoladz, 2020	Low-cost sensor network	8 sites (urban, rural, town)	Several dozen/min, 1-min average	Multipoint, high temporal resolution, affordable
Sówka et al., 2023	Urban background, automatic/manual	4 urban sites in Poznań	1-hour (automatic), 24-hour (manual)	Particulate matter and heavy metals, seasonal analysis
Maslouski et al., 2023	Mobile car-based system	Rural areas around Kraków	1-min average, night campaigns	Hotspot detection, spatial mapping
Oleniacz and Gorzelnik, 2021	Traffic, urban, industrial stations	Kraków urban	No mention found	Multi-pollutant, statistical analysis
Rogulski, 2018	Low-cost, professional reference	5 urban sites, Nowy Sącz	1-min, hourly average	Hotspot detection, wind analysis
Orlowski et al., 2017	8 monitoring stations	Gdańsk Metro Area	1-month average (3 years)	Network efficiency assessment

Study	Technology Type	Coverage Area	Measurement Frequency	Key Capabilities
Chambers and Podstawczyńska, 2019	No mention found	Łódź urban	Hourly, daily	Meteorological integration, radon-based classification
Kobza et al., 2018	Urban background, referential	3 urban sites, Silesia	Daily (24-hour average)	Standardized, multi-year
Cichowicz and Stelęgowski, 2019	Automatic, city/town/rural	15 sites, 5 provinces	Hourly	Multi-pollutant, settlement comparison

Key findings across the 10 studies:

- Technology Type:
  - Professional stationary or reference-grade monitoring was used in 5 studies.
  - Low-cost sensor networks were used in 2 studies.
  - Automatic monitoring was used in 2 studies, and manual verification in 2 studies.
  - A mobile car-based monitoring system was used in 1 study.
  - We didn't find mention of the technology type in 1 study.
- Coverage Area:
  - 7 studies were conducted in urban areas.
  - 1 study was conducted in rural areas.
  - 2 studies covered mixed areas (urban, rural, town, or multi-province).
- Measurement Frequency:
  - 3 studies used minute-level measurements.
  - 4 studies used hourly measurements.
  - 4 studies used daily (24-hour average) measurements.
  - 1 study used monthly averages.
  - 1 study used campaign-based (night campaign) measurements.
  - We didn't find mention of the measurement frequency in 1 study.
- Key Capabilities:
  - Multi-pollutant monitoring was reported in 3 studies.
  - Hotspot detection was reported in 2 studies.
  - High temporal resolution, meteorological integration, network efficiency assessment, settlement comparison, and particulate matter/heavy metals analysis were each reported in 1 study.

System Effectiveness and Performance

Study	Monitoring Approach	Accuracy Metrics	Limitations	Cost-Effectiveness
Ciepiela and Sobczyk, 2021	Professional/manual comparison	Manual greater than station for particulate matter less than 2.5 micrometers in diameter (PM2.5)	Underreporting by stations, need for manual checks	High (manual labor required)
Nieckarz and Zoladz, 2020	Low-cost network	Validated, but needs further calibration	Sensor accuracy, environmental effects	High (affordable, scalable)
Sówka et al., 2023	Automatic/manual, multi-site	Standardized, United States Environmental Protection Agency risk assessment	Limited to urban background, heavy metal focus	Moderate (manual sampling labor)
Maslouski et al., 2023	Mobile, calibrated	Calibrated to fixed stations	Night-only, campaign-based, calibration critical	High (supplements fixed grid)
Oleniacz and Gorzelnik, 2021	Multi-station, statistical	Statistical validation	Limited detail on device accuracy	No mention found
Rogulski, 2018	Low-cost vs. reference	Hotspot detection, wind analysis	Sensor drift, environmental factors	High (low-cost, spatial detail)
Orlowski et al., 2017	Network efficiency	Multicriteria analysis	Lack of pollutant detail, focus on network not data	No mention found
Chambers and Podstawczyńska, 2019	Meteorological integration	Radon-based classification	Device details lacking	No mention found
Kobza et al., 2018	Referential, multi-year	Standardized methods	Limited to Silesia, focus on particulate matter	No mention found
Cichowicz and Stelęgowski, 2019	Multi-settlement, automatic	Official data, hourly	Device/model details limited	No mention found

Key findings across the 10 studies:

- Monitoring Approaches:
  - 2 studies used low-cost sensor networks.
  - 1 study used a professional/manual approach.
  - 1 study used a mobile, calibrated approach.
  - 1 study used an automatic/manual, multi-site approach.
  - 1 study used a multi-station, statistical approach.
  - 1 study focused on network efficiency.

  - 1 study integrated meteorological data.
  - 1 study used a referential, multi-year approach.
  - 1 study used automatic monitoring across multiple settlements.

- Accuracy Metrics:

  - 2 studies reported standardized methods or risk assessments.
  - 1 study found manual monitoring superior to station data for particulate matter less than 2.5 micrometers in diameter (PM2.5).
  - 1 study reported validated low-cost sensors but noted a need for further calibration.
  - 1 study used calibration to fixed stations.
  - 1 study used statistical validation.
  - 1 study focused on hotspot detection and wind analysis.
  - 1 study used multicriteria analysis.
  - 1 study used radon-based classification.
  - 1 study reported official, hourly data.
  - We didn't find mention of accuracy metric details for more than one study in any single category.

- Cost-Effectiveness:

  - 4 studies reported high cost-effectiveness, attributed to low-cost sensors, scalability, supplementing fixed grids, or spatial detail.
  - 1 study reported moderate cost-effectiveness due to manual sampling labor.
  - We didn't find mention of cost-effectiveness information for 5 studies.

Overall, these studies demonstrate a diversity of monitoring approaches and accuracy assessment methods. Low-cost and standardized approaches were each reported in 2 studies. High cost-effectiveness was reported in 4 studies, but cost-effectiveness data was not mentioned in half of the studies.

Urban-Specific Monitoring Challenges

- High population density and complex emission sources:Several studies highlight that urban areas in Poland face challenges due to dense populations and a mix of emission sources, including traffic, heating, and industry.
- Meteorological variability:Variability in weather conditions complicates accurate assessment of air quality.
- Underrepresentation by official networks:Some studies (Ciepiela and Sobczyk, 2021; Kobza et al., 2018) report that official monitoring networks may underrepresent true pollution levels, especially in microenvironments (localized areas within cities) or during peak events.
- Spatial heterogeneity:The spatial variability of pollution, particularly in cities with mixed land use, requires dense monitoring networks or supplementary mobile/low-cost systems.
- Regulatory and infrastructural limitations:Barriers such as lack of coverage in suburban or rural-urban fringe areas are noted as limiting comprehensive urban air quality assessment.

Seasonal and Temporal Variations

- Seasonal patterns:All studies that report temporal data identify strong seasonal patterns, with winter and heating seasons consistently associated with higher concentrations of particulate matter less than 10 micrometers in diameter (PM10) and particulate matter less than 2.5 micrometers in diameter (PM2.5). These levels often exceed permissible or guideline values (Sówka et al., 2023; Kobza et al., 2018; Cichowicz and Stelęgowski, 2019).
- Diurnal patterns:Diurnal variations are observed, with evening and night hours showing peak concentrations, likely due to heating and reduced atmospheric dispersion (Nieckarz and Zoladz, 2020; Chambers and Podstawczyńska, 2019).
- Meteorological drivers:Meteorological factors such as wind speed, temperature inversions, and atmospheric stability are repeatedly identified as key drivers of short-term pollution episodes.
- Implications for monitoring:These findings underscore the importance of high-frequency monitoring and integration of meteorological data for effective air quality management in urban areas.

References

Aleksander Orlowski, M. Marć, J. Namieśnik, and M. Tobiszewski. "Assessment and Optimization of Air Monitoring Network for Smart Cities with Multicriteria Decision Analysis." *Asian Conference on Intelligent Information and Database Systems*, 2017.

I. Sówka, W. Rogula-Kozłowska, Łukasz Pachurka, and Anna Chlebowska-Styś. "Seasonal Variations of PM2.5 and PM10 Concentrations and Inhalation Exposure from PM-Bound Metals (As, Cd, Ni): FIrst Studies in Poznań (Poland)." *Archives of Environmental Protection*, 2023.

J. Kobza, M. Geremek, and L. Dul. "Characteristics of Air Quality and Sources Affecting High Levels of PM10 and PM2.5 in Poland, Upper Silesia Urban Area." *Environmental Monitoring & Assessment*, 2018.

M. Rogulski. "Using Low-Cost PM Monitors to Detect Local Changes of Air Quality," 2018.

Maciej Ciepiela, and W. Sobczyk. "A Study of PM 10, PM 2.5 Concentrations in the Atmospheric Air in Kraków, Poland." *Inżynieria Mineralna*, 2021.

Mikita Maslouski, E. Jarosz-Krzemińska, Paweł Jagoda, and E. Adamiec. "A Mobile Car Monitoring System as a Supplementary Tool for Air Quality Monitoring in Urban and Rural Environments: The Case Study from Poland." *Scientific Reports*, 2023.

R. Cichowicz, and Artur Stelęgowski. "Average Hourly Concentrations of Air Contaminants in Selected Urban, Town, and Rural Sites." *Archives of Environmental Contamination and Toxicology*, 2019.

R. Oleniacz, and T. Gorzelnik. "Assessment of the Variability of Air Pollutant Concentrations at Industrial, Traffic and Urban Background Stations in Krakow (Poland) Using Statistical Methods." *Sustainability*, 2021.

S. Chambers, and Agnieszka Podstawczyńska. "Improved Method for Characterising Temporal Variability in Urban Air Quality Part II: Particulate Matter and Precursors in Central Poland," 2019.

Z. Nieckarz, and J. Zoladz. "Low-Cost Air Pollution Monitoring System—an Opportunity for Reducing the Health Risk Associated with Physical Activity in Polluted Air." *PeerJ*, 2020.