EPA's Report on the Environment

Technical Documentation

Identification

1. Indicator Title

Ambient Concentrations of Particulate Matter

2. ROE Question(s) This Indicator Helps to Answer

What are the trends in outdoor air quality and their effects on human health and the environment?

3. Indicator Abstract

This indicator presents nationwide trends in ambient air concentrations of particulate matter (PM) from 1990 to 2021. Particulate matter pollution, such as PM_{10} and $PM_{2.5}$, consists of solid particles and liquid droplets suspended in air, which can cause respiratory and cardiovascular illnesses among exposed populations and impair visibility.

4. Revision History

07/2023

Data Sources

5. Data Sources

This indicator is based on 1990-2021 ambient air quality data retrieved in 2022 from EPA's National Air Quality: Status and Trends of Key Air Pollutants website (https://www.epa.gov/air-trends). The trends data are based on PM ambient air monitoring data in EPA's Air Quality System (AQS). AQS data are direct measurements of pollutant concentrations at monitoring stations operated by tribes and state and local governments throughout the nation. EPA and other federal agencies also operate some air quality monitoring sites on a temporary basis as a part of air pollution research studies. For more information about the AQS, see https://www.epa.gov/aqs.

6. Data Availability

The complete set of PM monitoring data used to prepare this indicator can be queried from the publicly available National Air Quality: Status and Trends of Key Air Pollutants website (https://www.epa.gov/air-trends). Underlying data are available at https://www.epa.gov/outdoor-air-quality-data. Information about AirData and AQS can be found at https://www.epa.gov/outdoor-air-quality-data/air-data-basic-information and https://www.epa.gov/aqs, respectively.

Methodology

7. Data Collection

Study Design

Thousands of monitoring sites measure ambient air concentrations of one or more of the six criteria pollutants. The sites consist of State and Local Air Monitoring Stations (SLAMS), and other special-purpose monitors. The SLAMS network is designed to meet three basic monitoring objectives.

1. Support compliance with ambient air quality standards and emissions strategy development. Data from Federal Reference Methods (FRM), Federal Equivalent Methods (FEM), and Approved Regional Methods (ARM) monitors for National Ambient Air Quality Standard (NAAQS) pollutants will be used for comparing an area's air pollution levels against the NAAQS. Data from monitors of various types can be used in the development of attainment and maintenance plans. SLAMS will be used to evaluate the regional air quality models used in developing emission strategies, and to track trends in air pollution abatement control measures' impact on improving air quality. In monitoring locations near major air pollution sources, source-oriented monitoring data can provide insight into how well industrial sources are controlling their pollutant emissions.
2. Provide air pollution data to the general public in a timely manner. Data can be presented to the public in a number of attractive ways including through air quality maps, newspapers, Internet sites, and as part of weather forecasts and public advisories.
3. Support for air pollution research studies. Air pollution data from the NCore network can be used to supplement data collected by researchers working on health effects assessments and atmospheric processes, or for monitoring methods development work.

Pollutant-specific guidance for establishing SLAMS networks is provided in 40 CFR 58, Appendix D. Routine PM_{10} monitoring began in 1988, and for this indicator, the period of record is 1990-2021. In all, 90 PM_{10} monitoring sites met the criteria for inclusion. Extensive monitoring for $PM_{2.5}$ began in 1999; for this indicator, the period of record is 2000-2021 and 375 annual average $PM_{2.5}$ monitoring sites met the criteria for this analysis. (For reference, in 2021, there were a total

of 615 sites monitoring PM_{10} concentrations, 833 sites with valid annual average $PM_{2.5}$ concentrations, and 850 sites with valid annual 98th percentile 24-hour $PM_{2.5}$ concentrations.) Temporally, the PM_{10} data (1990-2021) and $PM_{2.5}$ data (2000-2021) provide a good indication of general trends over time. Spatially, these monitors are distributed across the U.S., and the sampling is adequate to provide information on an EPA Regional scale.

Sampling Procedures

This indicator is based on measurements of ambient concentrations of two types of particulate matter (PM): PM_{10} (particles with aerodynamic diameter less than or equal to 10 microns [μm]) and $PM_{2.5}$ ("fine" particles with aerodynamic diameter less than or equal to 2.5 μm). Ambient concentrations of PM_{10} and $PM_{2.5}$ are measured using a set of standard methods (e.g., gravimetric filtration), which are officially documented in (1) 40 CFR 50—National ambient air quality standards (NAAQS) and reference methods for determining criteria air pollutant concentrations in the atmosphere; and (2) 40 CFR 53—Process for determining reference or equivalent methods for determining criteria air pollutant concentrations in the atmosphere. For access to these documents and other information about ambient air monitoring, see https://www.epa.gov/amtic. For a list of methods, see the "Designated EPA Reference and Equivalent Methods," which are updated periodically and available online at at https://www.epa.gov/amtic/air-monitoring-methods-criteria-pollutants.

The monitoring objectives for the SLAMS network are found in (1) 40 CFR 58, Appendix D; (2) 40 CFR 58.2(c); and (3) EPA 454/R-98-004, Part I, Section 3.2. These documents are available through https://www.epa.gov/amtic. This monitoring network conforms to uniform criteria for monitor siting, instrumentation, and quality assurance. In particular, see 40 CFR 58—Ambient air quality surveillance (monitoring) requirements. As described in "Indicator Derivation," this indicator reflects only those sites that met specific criteria for data completeness over the period of record.

Documentation

Standard documentation is available to support these data. The AMTIC (https://www.epa.gov/amtic) provides links to numerous resources that contain information on ambient air quality monitoring programs, details on monitoring methods, relevant documents and articles, and federal regulations related to ambient air quality monitoring.

Physical methods for sampling/monitoring are specifically described in EPA's 2019 Integrated Science Assessment for PM (https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534#tab-3) and in EPA's most recent list of approved reference and equivalent methods for criteria pollutant monitoring, which are posted and periodically updated on the AMTIC website (https://www.epa.gov/amtic/air-monitoring-methods-criteria-pollutants).

The SLAMS monitoring network and other aspects of survey design are documented in the following:

1. Federal regulations, including 40 CFR 58, Appendix D; 40 CFR 58.2(c); and EPA 454/R-98-004, Part I, Section 3.2. These documents are available through https://www.epa.gov/amtic.
2. EPA's Air Quality System (AQS, https://www.epa.gov/aqs) has links to data download functions.
3. EPA's National Air Monitoring Strategy documents; see https://www.epa.gov/amtic/ambient-air-monitoring-strategy-state-local-and-tribal-air-agencies.

Numerical methods used to process data for this indicator, including data quality criteria and averaging, are described in "Indicator Derivation." Additional information about sampling and

analytical methods can be found in many reports available from EPA's Office of Air and Radiation (e.g., U.S. EPA, 2008).

8. Indicator Derivation

The conceptual model used to derive this indicator has been used and thoroughly reviewed as part of the Agency's national report on air quality trends. For this indicator, PM_{10} monitoring sites were included in the trend analysis if they had at least 75 percent valid years of data during the trend period, and were not missing more than 2 consecutive years of data. A "valid" year was a year in which at least 30 valid 24-hour average PM_{10} measurements were recorded. Sites for $PM_{2.5}$ were included if they had at least 75 percent valid years of data during the trend period, and were not missing more than 2 consecutive years of data. For annual average $PM_{2.5}$, a "valid" year was one in which at least 11 valid 24-hour average measurements were recorded in each calendar quarter.

For this indicator, daily $PM_{2.5}$ measurements were combined into seasonally weighted annual averages. This indicator reports the weighted annual averages for $PM_{2.5}$ and compares them with the annual NAAQS (see below for more information about the NAAQS). As described in EPA's 2019 Integrated Science Assessment for PM (https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534), this is a standard averaging method, which was determined to be appropriate based on a variety of factors (e.g., toxicological knowledge). This indicator also reports the second highest 24-hour average PM_{10} concentration and the 98^{th} percentile of the 24-hour concentrations for $PM_{2.5}$. These values are compared to the corresponding NAAQS for PM_{10} and $PM_{2.5}$, respectively (see https://www.epa.gov/naaqs for more information about the NAAQS). No information is presented on annual PM_{10} concentrations, because EPA revoked the NAAQS for annual PM_{10} concentrations in December 2006.

Standard procedures exist for handling missing data. Monitoring sites with a substantial amount of missing data were excluded from the analysis (see "Data Collection"). For those sites meeting the data quality criteria, missing annual summary statistics were filled by linear interpolation. The resulting data sets are statistically balanced, allowing simple statistical procedures and graphics to be easily applied. Other statistical procedures are all relatively simple, standard ways to generalize ambient concentration data—i.e., generating annual averages that are weighted to provide equal coverage throughout the year, and then finding the mean, median, and 10^{th} and 90^{th} percentile values from the distribution of results for each year. All sites were weighted equally in calculating the composite average trend statistics. No attempt was made to portray data beyond the temporal bounds of the data set. The statistical procedures used for this indicator comply with the recommendations of the Intra-Agency Task Force on Air Quality Indicators (U.S. EPA, 1981).

9. Quality Assurance and Quality Control

The quality assurance/quality control (QA/QC) of the national air monitoring program has several major components: (1) the data quality objective (DQO) process; (2) reference and equivalent methods program; (3) EPA's National Performance Audit Program (NPAP); (4) system audits; (5) and network reviews (https://www.epa.gov/amtic/state-and-local-ambient-air-monitoring-network-assessments). To ensure quality data, the SLAMS are also required to meet the following QA/QC criteria: (1) each site must meet network design and site criteria; (2) each site must provide adequate QA assessment, control, and corrective action functions according to minimum program requirements; (3) all sampling methods and equipment must meet EPA reference or equivalent requirements; (4) acceptable data validation and record keeping procedures must be followed; and (5) data from SLAMS must be reported annually to EPA. Finally, there are system audits that regularly review the overall air quality data collection activity for any needed changes or corrections.

Further information on QA/QC procedures is available on the Internet (https://www.epa.gov/amtic/ambient-air-monitoring-quality-assurance) and through EPA's Quality Assurance Handbook (EPA-454/R-98-004, Section 15). There is a QAPP from each state or local agency operating a SLAMS monitor meeting the EPA Requirements for Quality Assurance Project Plans, EPA QA/R-5. The QA plans for specific sites are publicly available by request to the reporting agency or the corresponding EPA Regional Office; some of these may also be accessed online (see: https://www.epa.gov/amtic/state-and-local-ambient-air-monitoring-network-assessments). The plans are audited at least once every 3 years as required in 40 CFR 58, Appendix A, Section 2.5.

Analysis

10. Reference Points

The Clean Air Act (CAA) requires EPA to set NAAQS for widespread pollutants from numerous and diverse sources considered harmful to public health and the environment (general information about NAAQS can be found at https://www.epa.gov/naaqs). The NAAQS standard for PM_{10} is 150 micrograms per cubic meter ($\mu g/m^3$) for a 24-hour period (not to be exceeded more than once per year). The NAAQS standards for $PM_{2.5}$ are 12.0 $\mu g/m^3$ for an annual arithmetic mean (averaged over 3 years) and 35 $\mu g/m^3$ for an annual 98^{th} percentile of 24-hour average concentrations (averaged over 3 years).

These are all "primary" standards, meaning they are designed to protect public health including the health of "sensitive" populations (e.g., asthmatics, children, elderly persons). Some of the primary standards cited above for PM also serve as "secondary" standards, which are established to protect public welfare including protection against visibility impairment, and damage to animals, crops, vegetation, and buildings.

The scientific basis for these particular standards is described in EPA's 2019 Integrated Science Assessment for PM (https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=347534). The CAA requires periodic review of the science upon which the standards are based and the standards themselves. This indicator compares the trends in PM monitoring data to the different NAAQS listed above.

Refer to https://www3.epa.gov/ttn/naaqs/standards/pm/s_pm_history.html for more information on the history of the PM_{10} and $PM_{2.5}$ NAAQS.

11. Comparability Over Time and Space

The data presented in this indicator are viewed as highly comparable over both time and space because all data summarized in this indicator were collected using federal reference or equivalent methods, monitoring locations were selected according to strict and consistent siting criteria, and extensive quality assurance protocols must be followed.

12. Sources of Uncertainty

Sources of uncertainty in this indicator's air quality trends include measurement uncertainty associated with the air sampling equipment and uncertainties associated with characterizing regional air quality trends using data from a limited number of monitoring sites. Measurement uncertainty is believed to be limited because the indicator is derived entirely from Federal Reference Method or equivalent method monitoring devices—methods that have been shown to be capable of measuring

criteria pollutant air concentrations to a high degree of precision and accuracy. Further, the monitoring sites considered are required to meet strict quality assurance and quality control criteria to ensure the comparability of data from monitor to monitor. This is necessary because a primary objective for most of these monitors is to measure against the same air quality standards. A greater source of uncertainty arises from the spatial coverage of monitors. The statistics in this indicator are a composite of monitoring data collected from a discrete number of fixed monitoring sites, mostly found in higher populated areas as required by federal monitoring regulations. The depicted trends reflect air quality across those locations, and might not reflect conditions at unmonitored locations outside these more populated areas.

13. Sources of Variability

Year-to-year variability may be influenced by meteorological factors and changes in emission sources. However, this indicator has a relatively long period of record, which makes it a useful indicator of long-term, general trends in ambient PM concentrations across the U.S. Trends in the annual average concentrations (for $PM_{2.5}$) most likely are not overly influenced by shorter term fluctuations in meteorological conditions or emission events; and the statistic used to present the 24-hour PM_{10} and $PM_{2.5}$ trends helps ensure that these trends are also not heavily biased by infrequent events.

14. Statistical/Trend Analysis

The indicator presents time series of concentrations averaged across PM_{10} and $PM_{2.5}$ monitoring stations that met the site selection criteria. This indicator uses ordinary least-squares linear regressions to calculate the slopes of the observed concentration trends in Exhibits 1, 4, and 7. A t-test was used to determine significance of the slopes at the 95 percent confidence level. The p-values for the slopes of the linear regressions for Exhibits 1, 4, and 7 are <0.05, indicating that the downward concentration trends in the exhibits are statistically significant.

Limitations

15. Data Limitations

Limitations to this indicator include the following:

1. Because there are far more PM_{10} and $PM_{2.5}$ monitors in urban areas than in rural areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.
2. PM_{10} and $PM_{2.5}$ measurement data are based on monitoring methods that are consistent with those used to establish EPA's National Ambient Air Quality Standards. These "indicator" measurements provide mass concentrations that may be different than the concentrations of particulate matter (PM_{10} and $PM_{2.5}$) in the ambient air. These potential differences are due to losses from volatilization of nitrates and other semi-volatile materials and retention of particle-bound water associated with hygroscopic species. A study of six locations in the Eastern U.S. showed that the net difference was less than 10 percent (Frank, 2006).
3. Due to the relatively small number of monitoring sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa. In addition, the trend sites in this indicator are not dispersed uniformly across all states in the EPA Regions. For instance, the 90 PM_{10} trend sites are located in 25 states. In the remaining 25 states, there currently are insufficient long-term data from the existing PM_{10} monitoring sites to include in this indicator. In contrast, the 375 annual average $PM_{2.5}$ trend sites are

located in 47 states, the District of Columbia, and Puerto Rico. The remaining three states did not have sufficient long-term data from the existing $PM_{2.5}$ sites to include in this indicator.

4. To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of PM monitoring sites with sufficient data to assess trends over the time frames covered by this indicator. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported PM concentrations above the level of the PM standard during the years covered by this indicator. In 2021, for example, 74 monitoring sites nationwide recorded 24-hour PM_{10} concentrations above the level of the NAAQS: this includes the three sites shown in Exhibit 2, and 71 sites that did not have sufficient long-term data to be included in this indicator.

References

Frank, N.H. 2006. Retained nitrate, hydrated sulfates, and carbonaceous mass in federal reference method fine particulate matter for six eastern U.S. cities. Journal of the Air and Waste Management Association 56:500-11.

U.S. EPA (United States Environmental Protection Agency). 2008. National air quality: Status and trends through 2007. EPA-454/R-08-006. https://nepis.epa.gov/Exe/ZyPDF.cgi/P10028WQ.PDF?Dockey=P10028WQ.pdf (PDF) (48 pp, 5.0MB).

U.S. EPA. 1981. Intra-Agency Task Force report on air quality indicators. EPA/450/4-81-015. https://nepis.epa.gov/Exe/ZyPDF.cgi/2000MZKO.PDF?Dockey=2000MZKO.pdf (PDF) (113 pp, 3.7 MB).