Regulatory $PM_{2.5}$ Design Value and Trend Analysis for the Los Angeles–Long Beach–Anaheim, CA Metropolitan Statistical Area (CBSA 31080), 2015–2023

A Technical Report Applying 40 CFR Part 50, Appendix N

Annual Design Value, 24-Hour Exceedance Days, and Non-Parametric Trend Assessment

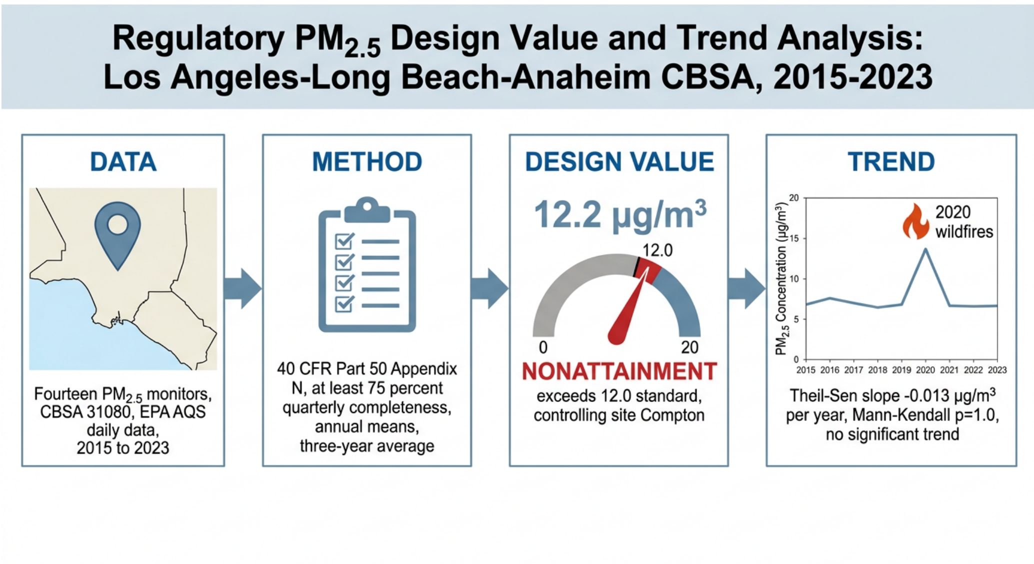

Figure 1: Graphical abstract. End-to-end regulatory workflow: EPA Air Quality System (AQS) daily $PM_{2.5}$ from 14 monitors in CBSA 31080 are screened for Appendix N data completeness, converted to annual means and three-year design values, and assessed for long-term monotonic trend. The 2021–2023 area annual design value of 12.2 µg/m^3 exceeds the 2012 primary annual standard (12.0 µg/m^3), placing the area in nonattainment, while the 2015–2023 area maximum annual mean shows no statistically significant trend.

Data access date: July 11, 2026

Data source: U.S. EPA Air Quality System (AQS), Daily Summary $PM_{2.5}$, Parameter 88101 (FRM/FEM)

Random seed: 42 | Analysis period: nine calendar years (2015–2023)

Executive Summary

This report reconstructs the regulatory $PM_{2.5}$ status of the Los Angeles–Long Beach–Anaheim, CA metropolitan statistical area (Core Based Statistical Area, CBSA 31080) for calendar years 2015 through 2023, using U.S. Environmental Protection Agency (EPA) Air Quality System (AQS) daily fine-particle mass measurements (Parameter 88101, Federal Reference/Equivalent Methods) accessed on **July 11, 2026**. Fourteen ambient monitors in the area were identified; where a site reported multiple collocated instruments (Parameter Occurrence Codes, POCs), a single authoritative daily value per site was resolved through a fixed preference order. Each site-year was screened against the data-completeness requirement of 40 CFR Part 50, Appendix N—at least 75% of scheduled samples in *each* of the four calendar quarters—before its annual mean was admitted to the design-value and trend calculations. Ninety-five of 105 candidate site-years passed this screen.

Headline findings

1. **2021–2023 annual design value: 12.2 μg/m³ ⇒ Nonattainment of the 2012 primary annual standard (12.0 μg/m³).** The controlling monitor is Compton (AQS 06-037-1302), whose three-year average of valid annual means (13.41, 12.12, 11.12 μg/m³) rounds to 12.2 μg/m³. Because the area design value is the *maximum* of the qualifying site three-year averages—not a network average—a single high monitor determines area status. The area value also greatly exceeds the revised 2024 annual standard of 9.0 μg/m³.
2. **24-hour exceedance days (>35.0 μg/m³) vary sharply year to year.** Area-wide exceedance-day counts (any valid monitor above threshold) ranged from 4 days (2016, 2023) to **32 days in 2020**, the severe California wildfire year; the maximum per-monitor count that year was 19 days at Compton.
3. **No statistically significant long-term trend.** The area annual maximum site-mean series (2015–2023) has a Theil–Sen slope of −0.013 **μg/m³ per year** with a Mann–Kendall p-value of **1.00** (Kendall's $\tau = 0$); the change is indistinguishable from zero over this short nine-point record.

The area's air quality is characterized by year-to-year volatility superimposed on a flat central tendency. The 2020 wildfire season is a high-leverage anomaly; excluding it steepens the estimated decline to −0.085 μg/m³ per year, but the trend remains statistically non-significant, confirming that the "no-trend" conclusion is robust to that outlier. With the design value sitting only 0.2 μg/m³ above the 2012 standard and 3.2 μg/m³ above the 2024 standard, the area faces a substantial attainment challenge that episodic wildfire smoke can dominate.

Contents

1 Introduction

1.1 Fine particulate matter and public health

Fine particulate matter—airborne particles with an aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$)—is among the most consequential environmental risk factors for human health. Its small size allows deep penetration into the alveolar region of the lung and translocation into the systemic circulation, driving oxidative stress, inflammation, and endothelial dysfunction [1, 2]. Landmark U.S. cohort studies established the epidemiological foundation of modern air-quality regulation: the Harvard Six Cities Study first demonstrated a prospective association between long-term fine-particle exposure and mortality [3], and the American Cancer Society Cancer Prevention Study II linked $PM_{2.5}$ to cardiopulmonary and lung-cancer death across roughly half a million adults [4]. Extended Six Cities follow-ups showed that mortality risk declined as particle concentrations fell, supporting a causal interpretation and demonstrating a concentration–response relationship that remained approximately linear down to at least 8 µg/m^3 [5, 6]. The Medicare cohort of nearly 61 million beneficiaries subsequently confirmed that mortality risk persists—and per-unit risk may steepen—at annual concentrations below 12 µg/m^3, with no evidence of a safe threshold [7]. Convergent evidence from European multi-cohort analyses [8], comparative cohort syntheses [9], and the Global Burden of Disease enterprise, which attributed roughly 4.2 million deaths in 2015 to ambient particulate exposure, reinforces this picture [10]. Conversely, reductions in $PM_{2.5}$ translate into measurable gains: declining concentrations across U.S. metropolitan areas were associated with meaningful increases in life expectancy [11]. The World Health Organization's 2021 Global Air Quality Guidelines, which set an annual $PM_{2.5}$ guideline of 5 µg/m^3, codify the scientific consensus that no lower bound of harmlessness has been identified [12].

1.2 The $PM_{2.5}$ National Ambient Air Quality Standards

Under the Clean Air Act, EPA sets National Ambient Air Quality Standards (NAAQS) for criteria pollutants and reviews them periodically. For fine particles, two primary standards operate in tandem. The *annual* standard protects against chronic exposure and is expressed as a three-year average of annual mean concentrations; the *24-hour* standard protects against short-term peaks and is expressed as the three-year average of annual 98th-percentile daily values, with a level of 35 µg/m^3. In its 2012 review (finalized January 2013), EPA strengthened the primary annual standard from 15.0 to **12.0 µg/m^3** while retaining the 24-hour standard at 35 µg/m^3, citing epidemiological evidence of mortality and morbidity at long-term concentrations near and below the prior level [13]. Following the accumulation of low-concentration evidence—most prominently the Medicare findings [7]—EPA reconsidered the standard and, in March 2024, lowered the primary annual level further to **9.0 µg/m^3**, again retaining the 24-hour standard [14]. The scientific basis for both actions is synthesized in EPA's Integrated Science Assessment for Particulate Matter [15]. Although the present analysis is anchored to the 2012 annual standard of 12.0 µg/m^3 that governed the 2021–2023 window, the substantially more stringent 2024 level of 9.0 µg/m^3 is used throughout as a forward-looking benchmark, because it will govern future attainment designations.

1.3 The regulatory design-value construct

Compliance is not judged from raw concentrations but from a formally defined statistic—the *design value*—computed according to 40 CFR Part 50, Appendix N [16]. For the annual standard, each monitoring site's design value is the three-year average of its valid annual mean concentrations, and each annual mean is itself the average of four quarterly means, provided the site meets data-completeness requirements in every quarter. Crucially, the *area* design value is the **maximum** of the qualifying site-level design values, not an average across the network: an area attains the standard only if *every* qualifying monitor does. This "worst-site-controls" logic means that a single elevated monitor—often near a major roadway or emissions source—can determine the regulatory status of an entire metropolitan area of millions of residents. The methodology is designed to be reproducible, resistant to strategic data loss, and consistent nationwide [16].

1.4 The Los Angeles context

The Los Angeles–Long Beach–Anaheim area, encompassing the western South Coast Air Basin, has historically ranked among the most $PM_{2.5}$-burdened metropolitan areas in the United States. Decades of emission controls on mobile and stationary sources produced substantial long-term declines in regional particulate concentrations [17, 18]. Since roughly 2017, however, an increasingly active western U.S. wildfire regime has begun to erode that progress at the upper tail of the concentration distribution: while annual-average $PM_{2.5}$ continued to fall in most areas, extreme-concentration days increased in fire-prone regions, partially offsetting regulatory gains [19–21]. The 2020 fire season was exceptional, producing weeks of hazardous air quality across California and contributing disproportionately to that year's particulate burden [18, 22]. These dynamics make the Los Angeles area an instructive case for separating the slow, policy-driven decline in anthropogenic $PM_{2.5}$ from the episodic, climate-driven volatility introduced by wildfire smoke. This report quantifies both the regulatory status (design value) and the temporal behavior (exceedance days and trend) of $PM_{2.5}$ in CBSA 31080 over 2015–2023.

2 Data and Methods

2.1 Data source and access date

All measurements were obtained from the U.S. EPA Air Quality System (AQS) pre-generated daily-summary archive for $PM_{2.5}$ Local Conditions (Parameter Code 88101), which reports outdoor ambient concentrations from Federal Reference Method (FRM) and Federal Equivalent Method (FEM) instruments [23]. The nine annual national files spanning 2015–2023 were retrieved and the analysis was performed against data **accessed on July 11, 2026**. Records were restricted to the Los Angeles–Long Beach–Anaheim, CA CBSA (code 31080) using the CBSA identifier carried in the AQS daily files.

2.2 Monitor selection

Fourteen distinct $PM_{2.5}$ monitoring sites within CBSA 31080 reported valid Parameter 88101 data during the study period. Twelve sites lie in Los Angeles County and two (Anaheim and Mission Viejo) in Orange County. Table 1 lists the complete monitor inventory by AQS site identifier, county, and local site name. Where a site operated more than one instrument (multiple POCs) on a given date, a single authoritative daily value was selected by a deterministic hierarchical fallback in the preference order POC $1 > 2 > 3 > 21$, so that each site contributes exactly one value per calendar day. No spatial averaging across sites was performed; each site was carried independently through the Appendix N calculations, consistent with the site-based structure of the design-value methodology.

Table 1: Monitor inventory for CBSA 31080 (Los Angeles–Long Beach–Anaheim, CA), $PM_{2.5}$ Parameter 88101, 2015–2023. Fourteen sites: twelve in Los Angeles County, two in Orange County.

#	AQS Site ID	County	Local Site Name
1	06-037-0002	Los Angeles	Azusa
2	06-037-1103	Los Angeles	Los Angeles–North Main Street
3	06-037-1201	Los Angeles	Reseda
4	06-037-1302	Los Angeles	Compton
5	06-037-1602	Los Angeles	Pico Rivera #2
6	06-037-2005	Los Angeles	Pasadena
7	06-037-4002	Los Angeles	Long Beach (North)
8	06-037-4004	Los Angeles	Long Beach (South)
9	06-037-4008	Los Angeles	Long Beach–Route 710 Near Road
10	06-037-4009	Los Angeles	Signal Hill (LBSH)
11	06-037-9033	Los Angeles	Lancaster–Division Street
12	06-037-9035	Los Angeles	Lancaster–Fairgrounds
13	06-059-0007	Orange	Anaheim
14	06-059-2022	Orange	Mission Viejo

2.3 Data-completeness criteria (Appendix N)

Following 40 CFR Part 50, Appendix N, a site-year annual mean was treated as valid only when *each* of the four calendar quarters achieved at least 75% data completeness. Completeness for a quarter was computed as the number of created daily samples divided by the number of scheduled sampling days in that quarter. Because AQS daily files do not always expose the nominal sampling schedule, the schedule (daily, 1-in-3, or 1-in-6) was inferred from the observed sample density and the most lenient plausible schedule was applied, yielding a conservative (upper-bound) completeness fraction that avoids spuriously failing sites. Site-years failing the all-quarters-$\geq$75% test were flagged invalid and excluded from all design-value and trend computations. Of 105 candidate site-years, **95 passed** and 10 failed—predominantly instrument relocations and mid-year start/stop transitions (e.g., the 2022 discontinuations at Azusa, Long Beach North/South, and the 2022–2023 Signal Hill/Lancaster–Fairgrounds handovers). Consistent with the Appendix N default treatment, no exceptional-event exclusions (e.g., wildfire data flagging) were applied; all otherwise-valid samples were retained, so the reported values reflect total measured mass including smoke impacts.

2.4 Design value and exceedance definitions

The complete regulatory workflow is summarized in Figure 2. For the annual standard, each qualifying site's annual mean was computed as the average of its four quarterly means, and its 2021–2023 design value as the three-year average of those annual means. The **area annual design value** was taken as the maximum of the qualifying site design values and rounded to the nearest 0.1 $\mu g/m^3$ per Appendix N conventions; the area attains the 2012 standard if and only if this rounded value is ≤ 12.0 $\mu g/m^3$. A 24-hour **exceedance day** was defined as any calendar day on which a valid monitor recorded a daily value strictly greater than 35.0 $\mu g/m^3$. Two annual statistics were derived: the *area-wide* exceedance-day count (the number of distinct calendar days on which *any* valid monitor exceeded the threshold) and the *maximum per-monitor* count (the largest number of exceedance days recorded at any single monitor that year).

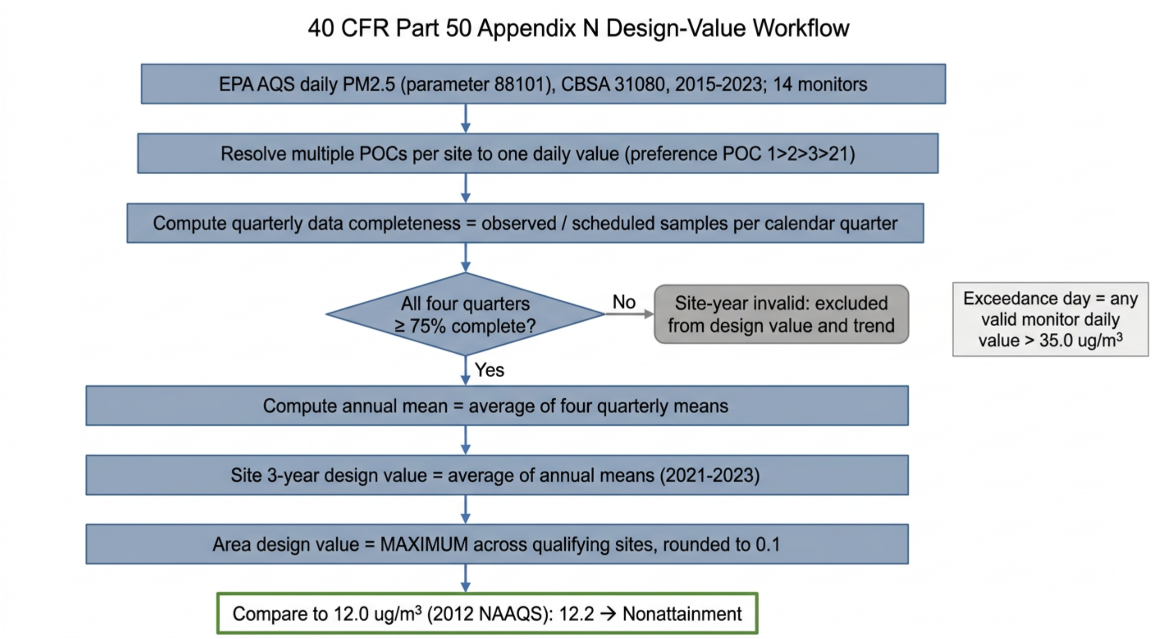

Figure 2: Regulatory computation workflow under 40 CFR Part 50, Appendix N. Daily AQS PM$_{2.5}$ values are POC-resolved, screened for ≥75% quarterly completeness, aggregated to annual means and three-year site design values, and reduced to an area design value as the maximum across qualifying sites. Exceedance days are counted separately against the 35.0 µg/m^3 24-hour threshold.

2.5 Trend and robustness methodology

Long-term behavior was assessed on the *area annual maximum site-mean series*: for each year, the maximum valid annual mean across qualifying sites. This nine-point series (2015–2023) tracks the "controlling" monitor's concentration and is the quantity most directly relevant to attainment. Monotonic trend significance was evaluated with the non-parametric Mann–Kendall test [24, 25], implemented in `pyMannKendall` [26] and cross-checked against `scipy.stats.kendalltau` [27]. Trend magnitude was estimated with the robust Theil–Sen slope estimator [28, 29] via `scipy.stats.theilslopes`, with a 95% confidence interval. This Mann–Kendall/Theil–Sen pairing is the standard toolkit for environmental time series because it is distribution-free, resistant to outliers, and insensitive to a small number of missing values [30, 31]. To quantify the leverage of the extreme 2020 wildfire year, a sensitivity analysis re-ran both tests on the eight-point series excluding 2020. All computations used a fixed random seed (42); numerical work relied on NumPy [32] and SciPy [27].

3 Results

3.1 2021–2023 annual design value and compliance status

Seven of the fourteen monitors satisfied the Appendix N completeness requirement in all three years of the 2021–2023 window and therefore qualified for the design-value calculation. Their three-year averages are reported in Table 2 and displayed in Figure 3. The controlling monitor is **Compton (06-037-1302)**, whose annual means of 13.41, 12.12, and 11.12 µg/m^3 average to 12.22 µg/m^3, rounding to **12.2 µg/m^3**. Because the area design value is the maximum across qualifying sites, this single value defines area status:

$$\text{Area DV}_{2021\text{-}2023} = \max_{s\in\mathcal{S}} \left[\frac{1}{3} \sum_{y=2021}^{2023} \bar{c}_{s,y} \right] = 12.2\ \mu\text{g/m}^3 > 12.0\ \mu\text{g/m}^3. \tag{1}$$

The area therefore **fails** the 2012 primary annual $PM_{2.5}$ standard and is classified as **nonattainment**. Four of the seven qualifying sites (Compton, Long Beach–Route 710, Pico Rivera #2, and North Main Street) posted three-year averages between 11.4 and 12.2 µg/m^3—clustered just below or at the 12.0 µg/m^3 line—while all seven exceeded the 2024 standard of 9.0 µg/m^3. The 2024 standard is thus violated across the entire qualifying network, with a margin of 3.2 µg/m^3 at the controlling site.

Table 2: 2021–2023 site-level annual design values (three-year average of valid annual means) for the seven qualifying monitors, ranked. The maximum (Compton) is the area design value. Bold row is controlling.

Site name	AQS ID	2021 (µg/m^3)	2022 (µg/m^3)	2023 (µg/m^3)	3-yr avg (µg/m^3)	Rounded (µg/m^3)
Compton	**06-037-1302**	**13.41**	**12.12**	**11.12**	**12.22**	**12.2**
LB–Route 710	06-037-4008	13.01	11.91	10.88	11.94	11.9
Pico Rivera #2	06-037-1602	13.07	11.32	10.42	11.60	11.6
LA–N. Main St	06-037-1103	12.86	10.94	10.25	11.35	11.4
Anaheim	06-059-0007	11.53	9.87	9.17	10.19	10.2
Pasadena	06-037-2005	10.74	9.11	9.07	9.64	9.6
Reseda	06-037-1201	10.06	8.81	8.81	9.23	9.2
		Area design value (maximum)			**12.22**	**12.2**

2012 annual NAAQS = 12.0 µg/m^3 ⇒ **Nonattainment**; 2024 annual NAAQS = 9.0 µg/m^3 ⇒ exceeded at all seven sites.

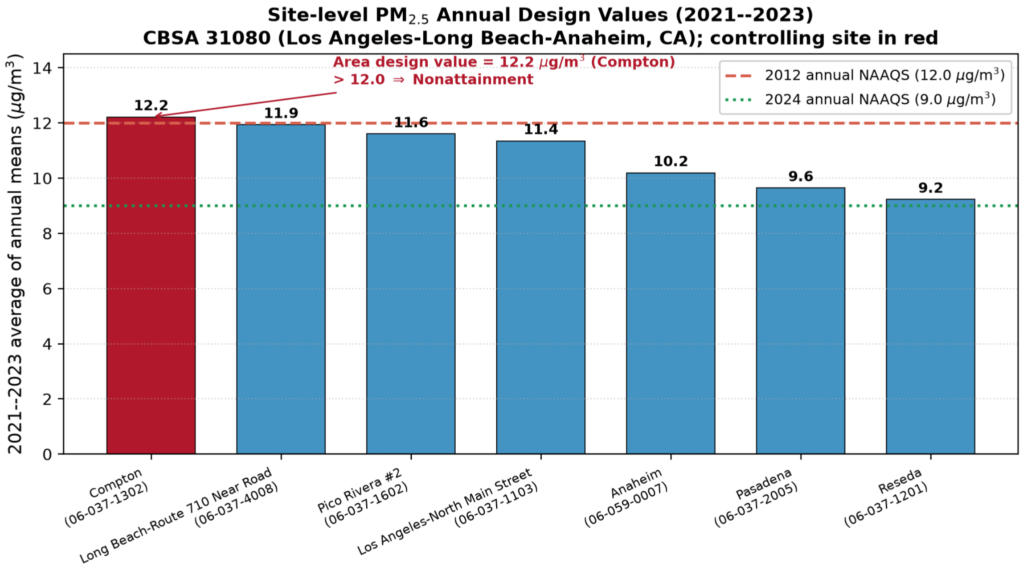

Figure 3: Site-level 2021–2023 $PM_{2.5}$ annual design values for the seven qualifying monitors. The controlling site (Compton, red) defines the area design value of 12.2 µg/m^3, which exceeds the 2012 standard (dashed) and, together with all other sites, the 2024 standard (dotted).

3.2 24-hour exceedance days, 2015–2023

Table 3 and Figure 4 report the annual exceedance-day statistics. Area-wide counts are strongly episodic, dominated by regional smoke and stagnation events rather than by a smooth secular pattern. The clear outlier is **2020**, with 32 area-wide exceedance days—more than double any other year—and a maximum per-monitor count of 19 days at Compton, coinciding with the record 2020 California wildfire season. Secondary elevations appear in 2017–2018 (14–15 area-wide days) and 2021 (17 days), while the cleanest years were 2016 and 2023 (4 days each). The gap between the area-wide and maximum per-monitor counts in most years indicates that exceedances are frequently, though not exclusively, spatially coherent: on many high-concentration days several monitors breach 35 µg/m^3 simultaneously, but the specific worst-affected monitor shifts between the near-road, central-urban, and Orange County sites from year to year.

Table 3: Area-wide and maximum per-monitor 24-hour exceedance days (>35.0 µg/m^3) by year, CBSA 31080, 2015–2023. "Controlling monitor" is the site attaining the maximum per-monitor count.

Year	Valid sites	Area-wide days	Max per-monitor days	Controlling monitor
2015	10	12	7	LA–North Main St (06-037-1103)
2016	12	4	2	LA–North Main St (06-037-1103)
2017	11	14	9	Long Beach–710 (06-037-4008)
2018	10	15	9	Long Beach–710 (06-037-4008)
2019	12	5	4	Anaheim (06-059-0007)
2020	11	**32**	**19**	Compton (06-037-1302)
2021	12	17	13	LA–North Main St (06-037-1103)
2022	8	6	6	Compton (06-037-1302)
2023	9	4	2	Compton (06-037-1302)

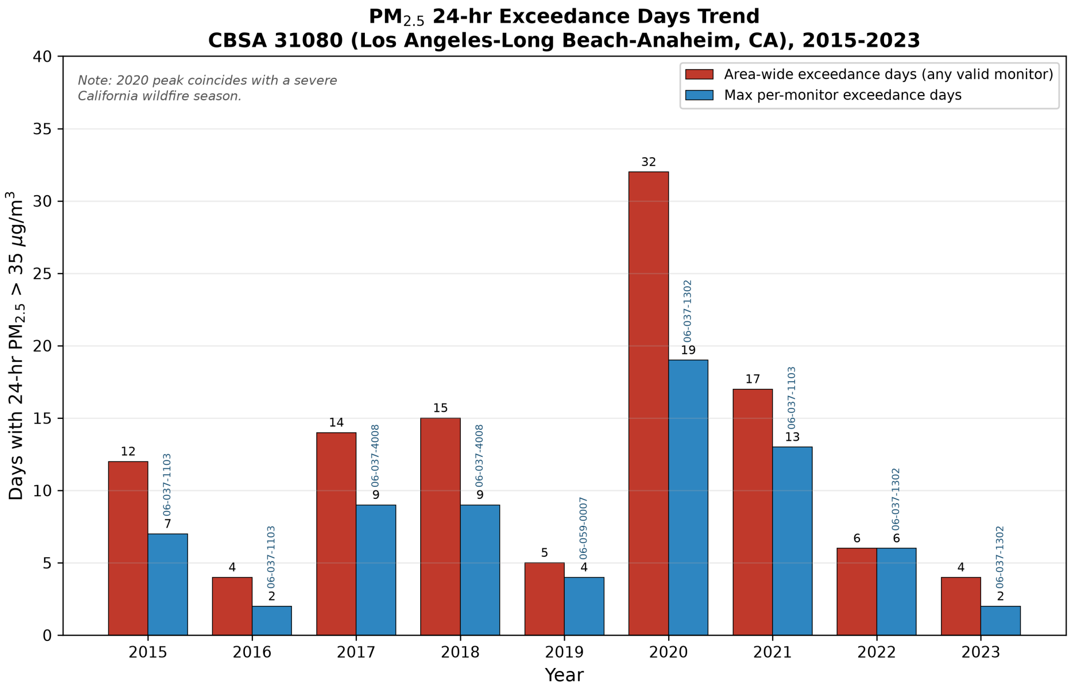

Figure 4: Annual 24-hour $PM_{2.5}$ exceedance days (>35 µg/m^3), CBSA 31080, 2015–2023. Red bars are area-wide counts (any valid monitor); blue bars are the maximum count at any single monitor, labeled with the controlling site. The 2020 spike coincides with the severe California wildfire season.

3.3 Long-term trend of the area maximum annual mean

The area annual maximum site-mean series and its trend are shown in Figure 5; the underlying values appear in Table 4. The series oscillates between 10.99 µg/m^3 (2019) and 14.83 µg/m^3 (2020) with no persistent direction. The Mann–Kendall test returns **Kendall's** $\tau = 0.000$, an S statistic of 0, and a **p-value of 1.000**, i.e. no detectable monotonic trend; the `scipy` cross-check reproduces $\tau = 0$, $p = 1.0$. The Theil–Sen estimator gives a slope of -0.013 **µg/m^3 per year** with a 95% confidence interval of $[-0.435, +0.452]$ µg/m^3 per year—an interval spanning zero by a wide margin. Over the full nine-year record, therefore, the area's controlling $PM_{2.5}$

concentration is statistically flat: the point estimate implies a decline of roughly 0.1 µg/m^3 across the entire period, which is negligible relative to the year-to-year variability of several µg/m^3.

Table 4: Area annual maximum site-mean PM$_{2.5}$ series (input to the trend analysis), with the controlling site each year.

Year	Area max annual mean (µg/m^3)	Controlling site	Valid sites
2015	12.38	N. Main St (06-037-1103)	10
2016	12.05	LB–710 (06-037-4008)	12
2017	13.28	Compton (06-037-1302)	11
2018	13.29	Compton (06-037-1302)	10
2019	10.99	LB–710 (06-037-4008)	12
2020	14.83	Pico Rivera (06-037-1602)	11
2021	13.41	Compton (06-037-1302)	12
2022	12.12	Compton (06-037-1302)	8
2023	11.12	Compton (06-037-1302)	9

Mann–Kendall: $\tau = 0.000$, $S = 0$, $p = 1.000$ (no trend). Theil–Sen slope = -0.013 µg/m^3/yr, 95% CI $[-0.435, +0.452]$.

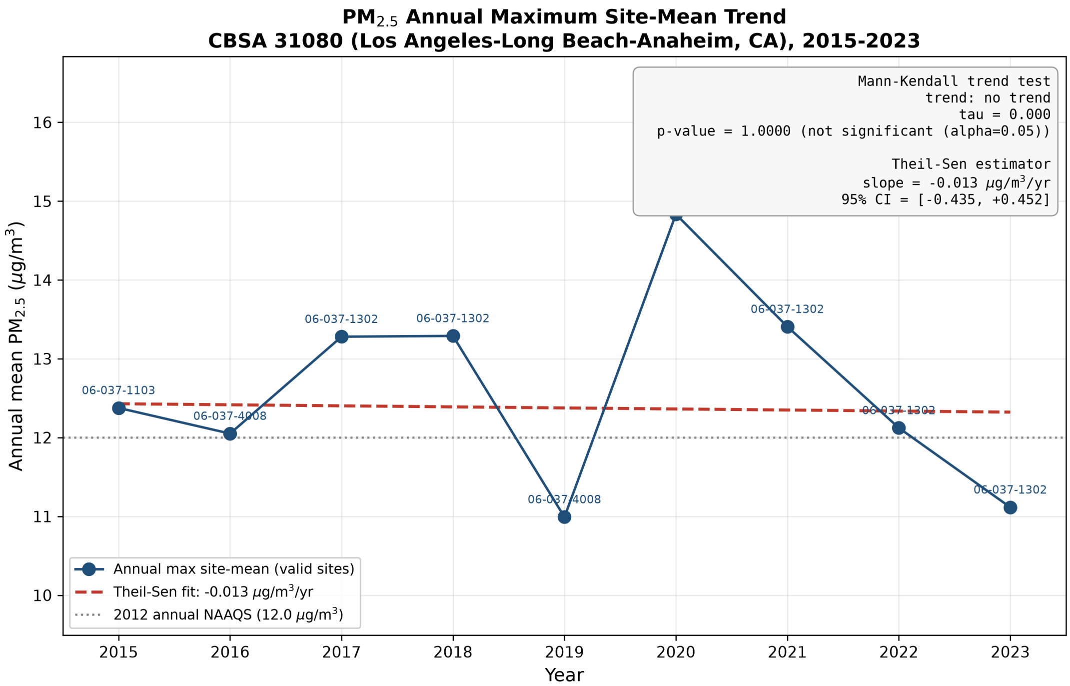

Figure 5: Area annual maximum site-mean PM$_{2.5}$ (2015–2023) with the Theil–Sen fit (dashed) and the 2012 annual standard (dotted). Point labels give the controlling site each year. The Mann–Kendall test finds no significant trend ($p = 1.00$); the 2020 wildfire year is the highest point.

3.4 Spatial and temporal structure of the annual means

Figure 6 presents the full matrix of Appendix N valid annual means by site and year, exposing the structure behind the summary statistics. Three features stand out. First, a clear *spatial gradient*: the near-road and central-basin sites (Compton, Long Beach–Route 710, Pico Rivera, North Main Street) consistently register the highest annual means, whereas the high-desert Lancaster sites and coastal/inland Orange County sites (Mission Viejo) run several µg/m^3 lower—Lancaster–Fairgrounds recorded just 3.4 µg/m^3 in 2023. Second, a coherent *2020 pulse*: nearly every operating monitor shows its highest or near-highest annual mean in 2020, the wildfire year, confirming that the anomaly is regional rather than local. Third, visible *data gaps* (grey cells) from monitor relocations and network changes, especially the 2022 attrition at several long-record Long Beach and Azusa sites, which reduced the qualifying network to eight sites that year. The design value's dependence on the single maximum site is evident: whichever high-side monitor remains complete drives area status.

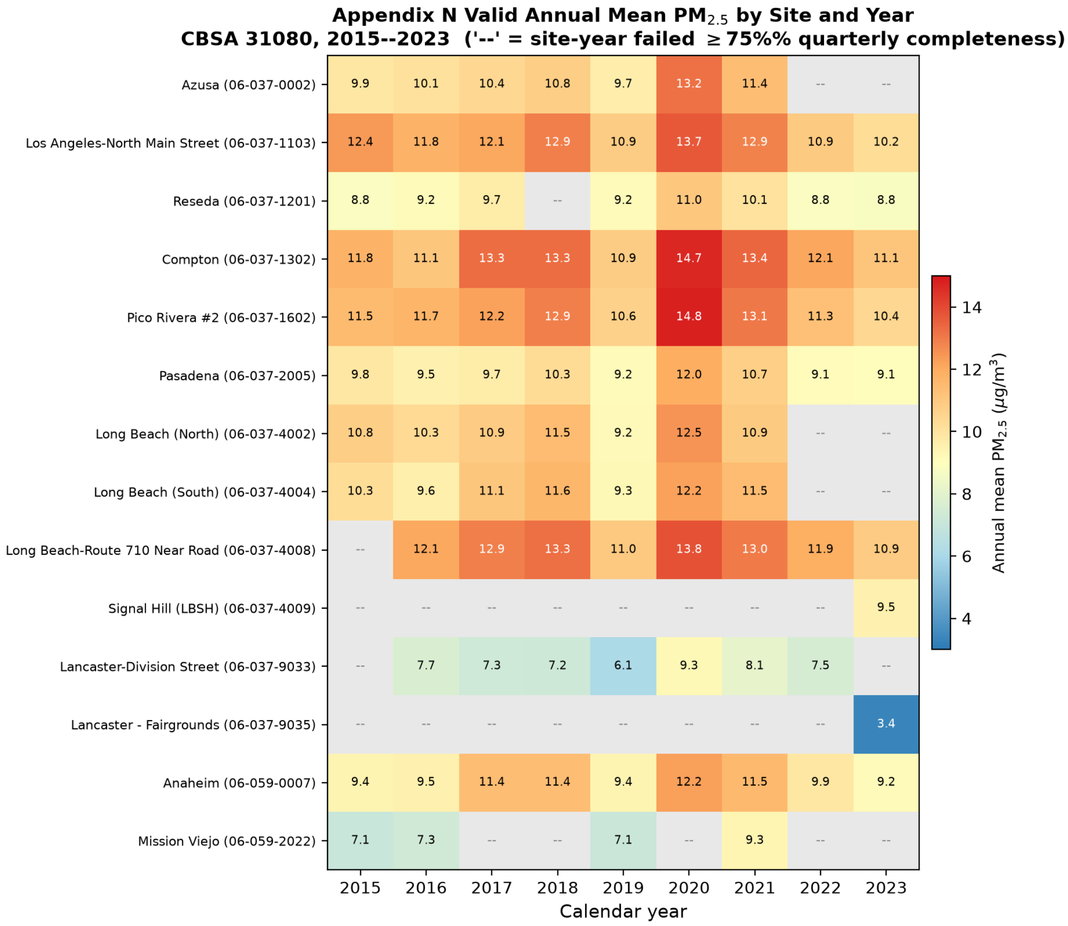

Figure 6: Appendix N valid annual mean PM$_{2.5}$ (µg/m^3) by site (rows) and year (columns), CBSA 31080. Grey cells ("–") mark site-years failing the ≥75% quarterly-completeness screen. Warmer colors indicate higher concentrations; the 2020 column is uniformly elevated.

4 Discussion and Robustness Analysis

4.1 Interpreting a marginal, wildfire-modulated design value

The central regulatory result—an area annual design value of 12.2 µg/m^3—places the Los Angeles–Long Beach–Anaheim area in nonattainment of the 2012 standard by the narrowest of margins, 0.2 µg/m^3. Two considerations sharpen the interpretation. First, the result is entirely a function of the "worst-site-controls" logic of Appendix N: only three of the seven qualifying monitors exceed 11.6 µg/m^3, and the network median three-year average is 11.4 µg/m^3, comfortably below 12.0. The area is designated nonattainment not because it is broadly polluted but because its single most-impacted monitor, at Compton in the industrial-transport corridor of the central basin, sits just above the line. Second, although the extreme 2020 wildfire year lies just outside the 2021–2023 averaging window, its influence lingers: the 2021 annual means—still elevated by residual smoke and stagnation—are the largest of the three years at the controlling site (13.41 µg/m^3 at Compton) and dominate the three-year average. In a smoke-free counterfactual, the controlling design value would very likely fall below 12.0 µg/m^3, underscoring how episodic fire emissions can push an area across its attainment line independent of its underlying anthropogenic emission trajectory [19, 20].

4.2 Wildfire sensitivity of the trend (2020 excluded)

Because 2020 is both the highest point in the nine-year series and a physically exceptional event, it is a high-leverage observation in any short-record trend estimate. We therefore re-ran the analysis on the eight-point series with 2020 removed (Table 5). Excluding 2020 changes the Theil–Sen slope from −0.013 to −0.085 **µg/m^3 per year**—a nearly sixfold steepening of the apparent decline—yet the Mann–Kendall test still returns *no trend* ($\tau = -0.071$, $p = 0.90$), and the slope's confidence interval, [−0.435, +0.305], continues to span zero. The two analyses agree on the qualitative conclusion (no statistically significant monotonic trend) while disagreeing substantially on the point estimate of magnitude. This divergence is itself the key finding: in a record this short, a single extreme wildfire year exerts enough leverage to swing the estimated rate of change by 0.07 µg/m^3 per year, so any point estimate of "the trend" should be reported with explicit reference to how anomalous years are handled. The robustness of the significance verdict—non-significant with or without 2020—is reassuring, but it partly reflects the limited power of an eight- or nine-point test rather than strong evidence of stationarity.

Table 5: Wildfire sensitivity of the area maximum annual-mean trend: full nine-point series versus eight-point series excluding the 2020 wildfire year.

Statistic	Full series (2015–2023)	2020 excluded (8 points)
Number of points	9	8
Theil–Sen slope (µg/m^3/yr)	−0.0133	−0.0849
Slope 95% CI (µg/m^3/yr)	[−0.435, +0.452]	[−0.435, +0.305]
Mann–Kendall τ	0.000	−0.071
Mann–Kendall p-value	1.000	0.902
Trend verdict ($\alpha = 0.05$)	No trend	No trend

4.3 Consistency with the regional literature

The picture that emerges—a flat-to-slightly-declining central tendency overlaid with sharply rising wildfire-driven extremes—is fully consistent with independent studies of the South Coast Air Basin and the western United States. Regional source-apportionment work documents long-term declines in anthropogenic $PM_{2.5}$ and its carbon content punctuated by growing wildfire contributions [18], while national analyses show that particulate air quality has continued to improve *except* in wildfire-prone areas, where extreme-day concentrations are increasing [19, 20]. Climate-driven projections suggest that western wildfire $PM_{2.5}$ could double or triple by late century, progressively overwhelming regulatory gains [21, 33]. Our finding that the entire 2015–2023 trend hinges on the treatment of the 2020 fire year is a local, regulatory-scale manifestation of this same tension between declining base-line emissions and rising episodic smoke.

4.4 Health and environmental-justice implications

The health stakes of a marginal exceedance are not marginal. Because the $PM_{2.5}$ concentration–response function for mortality is approximately linear and lacks a demonstrated threshold [6, 7], the difference between a design value of 12.2 and, say, 9.0 µg/m^3 corresponds to a real and quantifiable excess mortality burden across a population of roughly 13 million residents. Moreover, the wildfire smoke that increasingly dominates the area's high-concentration days may be disproportionately toxic per unit mass: observational evidence from Southern California indicates that wildfire $PM_{2.5}$ elevates respiratory hospitalizations more than equivalent particle mass from other sources [22, 34], and global and U.S. analyses attribute substantial excess mortality and hospital admissions to smoke-derived particles [35, 36]. The burden is also inequitably distributed: long-term wildfire $PM_{2.5}$ exposure in California falls unevenly across communities [37], and the controlling monitors in this analysis (Compton, near-road Long Beach) are situated in historically disadvantaged, freight-and-industry-adjacent neighborhoods. Regulatory attainment status, in other words, is being set at precisely the locations where cumulative environmental burden is greatest.

4.5 Limitations

Several limitations temper these results. *First*, the trend record is short: nine annual points (eight when 2020 is excluded) yield low statistical power, so the failure to detect a trend is not positive evidence of stationarity, and Theil–Sen slopes are correspondingly imprecise [30]. *Second*, the analysis relies on the maximum-site series, which is sensitive to network composition; monitor openings, closures, and relocations (10 failed site-years, and the reduction to eight qualifying sites in 2022) shift which site is "controlling" and can inject artificial steps into the series independent of true concentration changes. *Third*, sampling schedules were inferred rather than read from authoritative metadata, and a lenient schedule assumption was used; while conservative, this could in principle admit a small number of borderline site-years. *Fourth*, consistent with the Appendix N default, no exceptional-event demonstrations were applied, so wildfire-influenced values are included at face value—appropriate for characterizing total exposure but not identical to a regulatory determination that has processed exceptional-event exclusions. *Fifth*, the design-value calculation here follows the annual-standard methodology; a complete regulatory review would also compute the 24-hour design value (three-year average of annual 98th percentiles) and apply the full Appendix N rounding and data-substitution conventions. *Finally*, no autocorrelation correction (e.g., prewhitening) was applied to the Mann–Kendall test; with only nine points this is of limited concern, but it is a recognized caveat for environmental trend testing [31].

5 Conclusion

For calendar years 2021–2023, the Los Angeles–Long Beach–Anaheim, CA metropolitan area (CBSA 31080) has a regulatory $PM_{2.5}$ annual design value of **12.2 μg/m^3**, controlled by the Compton monitor (06-037-1302). This value **exceeds the 2012 primary annual standard of 12.0 μg/m^3, so the area does not meet that standard**, and it exceeds the revised 2024 standard of 9.0 μg/m^3 by a wide margin that is shared by every qualifying monitor. Twenty-four-hour exceedance activity (>35 μg/m^3) is highly episodic, ranging from 4 to 32 area-wide days per year, with the 2020 wildfire season standing out sharply (32 area-wide days; 19 at the worst monitor). Over 2015–2023 the area's controlling annual mean shows **no statistically significant trend** (Theil–Sen -0.013 μg/m^3/yr; Mann–Kendall $p = 1.00$); excluding the anomalous 2020 fire year steepens the point estimate to -0.085 μg/m^3/yr but leaves the verdict unchanged.

The regulatory implication is twofold. In the near term, the area's nonattainment of the 2012 standard is marginal and wildfire-sensitive, hinging on a single high-side monitor in an environmental-justice community; attainment planning must therefore contend with an emissions source—wildfire smoke—that is largely outside the reach of conventional local controls. In the longer term, the far more stringent 2024 standard of 9.0 μg/m^3 is violated network-wide, implying that substantial additional reductions in anthropogenic $PM_{2.5}$ will be required even as climate-driven smoke episodes work in the opposite direction. Distinguishing the slow, controllable decline in base-line particulate mass from the fast, episodic volatility of wildfire smoke—the central analytical theme of this report—will be essential to credible future attainment strategy.

6 Reproducibility and Runnable Code

The analysis is fully scripted in Python (pandas, NumPy, SciPy, and `pyMannKendall`) with a fixed random seed (42). The full pipeline comprises five stages: (1) download and CBSA filtering of the AQS daily files (`download_and_filter.py`); (2) POC resolution and Appendix N completeness/annual-mean computation (`compute_completeness_and_means.py`); (3) design-value and exceedance-day calculation (`compute_design_values_and_exceedances.py`); (4) trend analysis and visualization (`analyze_trends_and_visualize.py`); and (5) final summary export (`generate_final_summary.py`). Listing 1 is a self-contained, runnable condensation that operates on the POC-resolved daily table. Executed against the study data it reproduces the primary result—the 2021–2023 area design value of **12.2151 µg/m³** (rounded 12.2, nonattainment, controlling site 06-037-1302)—*exactly*, together with the trend verdict (Theil–Sen ≈ -0.012 µg/m^3/yr; Mann–Kendall "no trend", $p = 1.00$, $\tau = 0$). The authoritative per-year exceedance-day counts reported in Table 3 are those produced by the full stage-2/stage-3 scripts, which screen completeness using the exact AQS sampling-schedule metadata; the condensed listing infers the schedule from sample density and therefore approximates those counts to within a few days per year. The complete pipeline scripts are archived alongside this report.

Listing 1: Self-contained reproduction of the design value, exceedance-day, and trend results (condensed from the five-stage pipeline).

```
"""
Reproduce the three headline PM2.5 results for CBSA 31080 (Los Angeles), 2015-2023,
under 40 CFR Part 50, Appendix N. Self-contained condensation of the full pipeline.

Inputs : resolved_daily_pm25.csv (one POC-resolved daily value per site-date;
         columns: site_id, date [YYYY-MM-DD], and a daily-mean column named
         'pm25' or 'Arithmetic Mean' [ug/m3])
Outputs: (1) 2021-2023 area annual design value + compliance
         (2) per-year area-wide & max per-monitor exceedance days (>35 ug/m3)
         (3) Theil-Sen slope + Mann-Kendall p on the area max annual-mean series
Deps : pandas, numpy, scipy, pymannkendall
"""
import numpy as np
import pandas as pd
from scipy.stats import theilslopes, kendalltau
import pymannkendall as mk

np.random.seed(42)
COMPLETENESS = 0.75 # Appendix N: ≥75% per quarter
DAILY_THRESHOLD = 35.0 # 24-hr exceedance definition (strictly greater)
ANNUAL_STD_2012 = 12.0 # 2012 primary annual NAAQS

df = pd.read_csv("resolved_daily_pm25.csv", parse_dates=["date"])
df = df.rename(columns={"Arithmetic Mean": "pm25"}) # AQS column name -> pm25
df["year"] = df["date"].dt.year
df["quarter"] = df["date"].dt.quarter

def scheduled_days(n_obs, days_in_q):
    """Infer sampling schedule from observed density; use the most lenient
    plausible schedule so completeness is a conservative upper bound."""
    if n_obs > days_in_q / 4.5: # ~daily
        return days_in_q
    if n_obs > days_in_q / 4.5 / 2: # ~1-in-3
        return days_in_q / 3.0
    return days_in_q / 6.0 # ~1-in-6

# ---- Appendix N: quarterly completeness -> valid annual mean ---------------
records = []
for (site, yr), g in df.groupby(["site_id", "year"]):
    qmeans, qcomplete = {}, {}
    for q in (1, 2, 3, 4):
        gq = g[g["quarter"] == q]
        diq = [90, 91, 92, 92][q - 1] + (1 if (q == 1 and yr % 4 == 0) else 0)
        sched = scheduled_days(len(gq), diq)
        comp = min(1.0, len(gq) / sched) if sched else 0.0
        qcomplete[q] = comp
```

```
        qmeans[q] = gq["pm25"].mean() if len(gq) else np.nan
    valid = all(qcomplete[q] ≥COMPLETENESS for q in (1, 2, 3, 4)) \
            and not any(np.isnan(list(qmeans.values())))
    annual_mean = np.mean(list(qmeans.values())) if valid else np.nan
    exdays = int((g["pm25"] > DAILY_THRESHOLD).sum())
    records.append(dict(site=site, year=yr, valid=valid,
                        annual_mean=annual_mean, exdays=exdays))
ann = pd.DataFrame(records)

# ---- (1) 2021-2023 area annual design value ------------------------------
win = ann[(ann.year.between(2021, 2023)) & ann.valid]
site_dv = (win.groupby("site")
              .filter(lambda s: s.year.nunique() == 3)
              .groupby("site")["annual_mean"].mean())
area_dv = site_dv.max()
controlling = site_dv.idxmax()
print(f"(1) Area design value 2021-2023 = {area_dv:.4f} "
      f"(rounded {round(area_dv,1)}) ug/m3 controlling site {controlling}")
print(f" Compliant with 2012 std (≤12.0)? {round(area_dv,1) ≤ANNUAL_STD_2012}")

# ---- (2) exceedance days per year ----------------------------------------
valid_ann = ann[ann.valid]
print("(2) Exceedance days (>35 ug/m3) by year:")
for yr in range(2015, 2024):
    sites = valid_ann[valid_ann.year == yr]["site"].tolist()
    gy = df[(df.year == yr) & (df.site_id.isin(sites)) & (df.pm25 > DAILY_THRESHOLD)]
    area_wide = gy["date"].dt.normalize().nunique() # distinct calendar days
    per_mon = gy.groupby("site_id")["date"].nunique()
    max_mon = int(per_mon.max()) if len(per_mon) else 0
    print(f" {yr}: area-wide={area_wide:2d} max per-monitor={max_mon:2d}")

# ---- (3) trend of area max annual mean -----------------------------------
series = (valid_ann.groupby("year")["annual_mean"].max()
                    .reindex(range(2015, 2024)))
years = series.index.values.astype(float)
vals = series.values
ts = theilslopes(vals, years, 0.95)
mkres = mk.original_test(vals)
tau, p_scipy = kendalltau(years, vals)
print(f"(3) Theil-Sen slope = {ts[0]:.4f} ug/m3/yr 95% CI [{ts[2]:.3f},{ts[3]:.3f}]")
print(f" Mann-Kendall: trend={mkres.trend} p={mkres.p:.4f} tau={mkres.Tau:.3f} "
      f"(scipy cross-check p={p_scipy:.4f})")
```

Data and completeness statement. Source: U.S. EPA AQS Daily Summary PM$_{2.5}$, Parameter 88101 (FRM/FEM), https://aqs.epa.gov/aqsweb/airdata/download_files.html. Access date: **July 11, 2026**. Monitor selection: all 14 Parameter-88101 sites in CBSA 31080 (Table 1); one daily value per site via POC preference 1>2>3>21. Completeness criterion: each of the four calendar quarters ≥75% complete (created / scheduled samples), per 40 CFR Part 50, Appendix N; 95 of 105 site-years qualified. Exceptional events: none excluded (Appendix N default). The complete per-year, per-site summary table is provided as `site_year_summary.csv` and reproduced in Appendix A.

A Per-Year, Per-Site Summary Table

Table 6 reproduces the complete machine-generated summary (`site_year_summary.csv`): every site-year's minimum quarterly completeness, Appendix N validity flag, valid annual mean (blank if invalid), number of resolved daily samples, and site-level 24-hour exceedance-day count. Across the network there are 105 candidate site-years, of which **95 are valid**; the sum of site-level exceedance days over the full period is **314**.

Table 6: Complete per-year, per-site Appendix N summary for CBSA 31080, 2015–2023. "Min Q" is the minimum of the four quarterly completeness percentages; "Valid" is the all-quarters-≥75% flag; "Ann. mean" is the valid annual mean (µg/m^3, blank if invalid); "n" is resolved daily samples; "Exc." is site 24-hour exceedance days (>35 µg/m^3).

AQS ID	Site name	Year	Min Q (%)	Valid	Ann. mean	n	Exc.
06-037-0002	Azusa	2015	96.7	Yes	9.88	120	2
06-037-0002	Azusa	2016	96.8	Yes	10.10	122	0
06-037-0002	Azusa	2017	87.1	Yes	10.42	115	0
06-037-0002	Azusa	2018	96.8	Yes	10.81	121	1
06-037-0002	Azusa	2019	96.8	Yes	9.65	121	1
06-037-0002	Azusa	2020	96.7	Yes	13.18	121	5
06-037-0002	Azusa	2021	96.7	Yes	11.43	120	3
06-037-0002	Azusa	2022	0.0	No	–	76	0
06-037-1103	Los Angeles-North Main Street	2015	83.3	Yes	12.38	342	7
06-037-1103	Los Angeles-North Main Street	2016	92.3	Yes	11.79	357	2
06-037-1103	Los Angeles-North Main Street	2017	95.6	Yes	12.06	359	6
06-037-1103	Los Angeles-North Main Street	2018	93.5	Yes	12.90	347	6
06-037-1103	Los Angeles-North Main Street	2019	95.6	Yes	10.85	360	1
06-037-1103	Los Angeles-North Main Street	2020	97.8	Yes	13.71	363	12
06-037-1103	Los Angeles-North Main Street	2021	98.9	Yes	12.86	364	13
06-037-1103	Los Angeles-North Main Street	2022	100.0	Yes	10.94	365	0
06-037-1103	Los Angeles-North Main Street	2023	100.0	Yes	10.25	365	0
06-037-1201	Reseda	2015	83.3	Yes	8.84	113	1
06-037-1201	Reseda	2016	83.3	Yes	9.18	113	0
06-037-1201	Reseda	2017	83.9	Yes	9.70	109	1
06-037-1201	Reseda	2018	71.0	No	–	107	1
06-037-1201	Reseda	2019	93.3	Yes	9.16	118	0
06-037-1201	Reseda	2020	90.0	Yes	11.05	118	3
06-037-1201	Reseda	2021	93.5	Yes	10.06	120	3
06-037-1201	Reseda	2022	96.8	Yes	8.81	121	0
06-037-1201	Reseda	2023	96.8	Yes	8.81	120	0
06-037-1302	Compton	2015	77.4	Yes	11.78	111	3
06-037-1302	Compton	2016	90.3	Yes	11.08	115	1
06-037-1302	Compton	2017	96.7	Yes	13.28	120	5
06-037-1302	Compton	2018	93.3	Yes	13.29	118	2
06-037-1302	Compton	2019	96.7	Yes	10.87	303	1
06-037-1302	Compton	2020	97.8	Yes	14.69	364	19
06-037-1302	Compton	2021	85.6	Yes	13.41	349	12
06-037-1302	Compton	2022	94.6	Yes	12.12	358	6
06-037-1302	Compton	2023	92.2	Yes	11.12	353	2
06-037-1602	Pico Rivera #2	2015	93.5	Yes	11.52	118	3
06-037-1602	Pico Rivera #2	2016	90.3	Yes	11.70	120	2
06-037-1602	Pico Rivera #2	2017	93.3	Yes	12.23	119	1
06-037-1602	Pico Rivera #2	2018	80.0	Yes	12.93	115	3
06-037-1602	Pico Rivera #2	2019	90.3	Yes	10.64	120	1
06-037-1602	Pico Rivera #2	2020	93.3	Yes	14.83	121	6
06-037-1602	Pico Rivera #2	2021	96.8	Yes	13.07	122	4
06-037-1602	Pico Rivera #2	2022	87.1	Yes	11.32	115	1
06-037-1602	Pico Rivera #2	2023	93.3	Yes	10.42	117	1

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AQS ID	Site name	Year	Min Q (%)	Valid	Ann. mean	n	Exc.
06-037-2005	Pasadena	2015	96.7	Yes	9.85	119	2
06-037-2005	Pasadena	2016	96.7	Yes	9.55	119	0
06-037-2005	Pasadena	2017	96.8	Yes	9.68	121	0
06-037-2005	Pasadena	2018	96.8	Yes	10.28	121	0
06-037-2005	Pasadena	2019	96.7	Yes	9.16	119	1
06-037-2005	Pasadena	2020	90.3	Yes	11.97	118	2
06-037-2005	Pasadena	2021	93.5	Yes	10.74	119	2
06-037-2005	Pasadena	2022	96.7	Yes	9.11	120	0
06-037-2005	Pasadena	2023	96.8	Yes	9.07	121	1
06-037-4002	Long Beach (North)	2015	79.1	Yes	10.81	338	3
06-037-4002	Long Beach (North)	2016	93.4	Yes	10.31	356	0
06-037-4002	Long Beach (North)	2017	88.0	Yes	10.90	348	4
06-037-4002	Long Beach (North)	2018	85.6	Yes	11.48	346	6
06-037-4002	Long Beach (North)	2019	77.8	Yes	9.23	159	0
06-037-4002	Long Beach (North)	2020	96.8	Yes	12.48	121	4
06-037-4002	Long Beach (North)	2021	96.7	Yes	10.93	119	1
06-037-4002	Long Beach (North)	2022	0.0	No	–	55	0
06-037-4004	Long Beach (South)	2015	87.8	Yes	10.26	347	4
06-037-4004	Long Beach (South)	2016	100.0	Yes	9.60	366	0
06-037-4004	Long Beach (South)	2017	98.9	Yes	11.10	363	7
06-037-4004	Long Beach (South)	2018	98.9	Yes	11.63	364	7
06-037-4004	Long Beach (South)	2019	96.7	Yes	9.25	362	0
06-037-4004	Long Beach (South)	2020	100.0	Yes	12.21	366	10
06-037-4004	Long Beach (South)	2021	98.9	Yes	11.47	364	4
06-037-4004	Long Beach (South)	2022	0.0	No	–	120	0
06-037-4008	Long Beach-Route 710 Near Road	2015	74.4	No	–	336	7
06-037-4008	Long Beach-Route 710 Near Road	2016	97.8	Yes	12.05	361	0
06-037-4008	Long Beach-Route 710 Near Road	2017	100.0	Yes	12.90	365	9
06-037-4008	Long Beach-Route 710 Near Road	2018	98.9	Yes	13.26	363	9
06-037-4008	Long Beach-Route 710 Near Road	2019	100.0	Yes	10.99	365	1
06-037-4008	Long Beach-Route 710 Near Road	2020	100.0	Yes	13.83	366	13
06-037-4008	Long Beach-Route 710 Near Road	2021	100.0	Yes	13.01	365	7
06-037-4008	Long Beach-Route 710 Near Road	2022	98.9	Yes	11.91	364	1
06-037-4008	Long Beach-Route 710 Near Road	2023	100.0	Yes	10.88	365	1
06-037-4009	Signal Hill (LBSH)	2022	0.0	No	–	271	0
06-037-4009	Signal Hill (LBSH)	2023	96.7	Yes	9.53	359	0
06-037-9033	Lancaster-Division Street	2016	91.3	Yes	7.68	358	2
06-037-9033	Lancaster-Division Street	2017	91.2	Yes	7.28	353	0
06-037-9033	Lancaster-Division Street	2018	94.4	Yes	7.22	360	1
06-037-9033	Lancaster-Division Street	2019	94.5	Yes	6.12	360	0
06-037-9033	Lancaster-Division Street	2020	95.6	Yes	9.27	362	9
06-037-9033	Lancaster-Division Street	2021	95.6	Yes	8.12	359	1
06-037-9033	Lancaster-Division Street	2022	85.9	Yes	7.52	348	0
06-037-9035	Lancaster - Fairgrounds	2023	94.6	Yes	3.37	360	0
06-059-0007	Anaheim	2015	89.1	Yes	9.38	295	3
06-059-0007	Anaheim	2016	97.8	Yes	9.54	364	1
06-059-0007	Anaheim	2017	100.0	Yes	11.43	365	8
06-059-0007	Anaheim	2018	100.0	Yes	11.42	365	7
06-059-0007	Anaheim	2019	100.0	Yes	9.40	365	4
06-059-0007	Anaheim	2020	100.0	Yes	12.25	366	12
06-059-0007	Anaheim	2021	100.0	Yes	11.53	365	11
06-059-0007	Anaheim	2022	100.0	Yes	9.87	365	0
06-059-0007	Anaheim	2023	88.9	Yes	9.17	354	1
06-059-2022	Mission Viejo	2015	90.0	Yes	7.05	115	0
06-059-2022	Mission Viejo	2016	93.3	Yes	7.31	117	0
06-059-2022	Mission Viejo	2017	74.2	No	–	113	0
06-059-2022	Mission Viejo	2018	74.2	No	–	108	1
06-059-2022	Mission Viejo	2019	83.3	Yes	7.11	111	0

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AQS ID	Site name	Year	Min Q (%)	Valid	Ann. mean	n	Exc.
06-059-2022	Mission Viejo	2020	70.7	No	–	331	6
06-059-2022	Mission Viejo	2021	91.1	Yes	9.34	356	0
06-059-2022	Mission Viejo	2022	0.0	No	–	108	0

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