

Monthly ambient benzo[a]pyrene concentrations and emergency department service use among children and adults in two Polish cities, 2018–2025: an ecological time-series study

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Abstract

BACKGROUND

Benzo[a]pyrene (BaP) is a carcinogenic, particle-bound polycyclic aromatic hydrocarbon generated by incomplete combustion. Poland experiences high and strongly seasonal ambient BaP concentrations, but evidence for a specific short-term association with emergency department (ED) service use, particularly among children, remains limited. We evaluated this association in Bydgoszcz and Częstochowa, Poland; adult ED services were a secondary comparison.

METHODS

This two-city ecological time-series study covered January 2018–December 2025. Monthly BaP concentrations in PM₁₀ were linked with aggregated pediatric and adult ED service counts and annual city populations. City-specific negative binomial models used a population offset and adjusted for calendar month, linear time trend, the COVID-19 pandemic period, and the post-pandemic period. Heteroskedasticity- and autocorrelation-consistent standard errors were estimated using 12 lags. Associations are reported as incidence rate ratios (IRRs) per 1 ng/m³ increase in BaP.

RESULTS

The dataset comprised 192 city-months; BaP was available for 96 months in Bydgoszcz and 87 in Częstochowa. Median monthly BaP concentrations were 1.74 and 1.91 ng/m³, respectively (paired $p = 0.195$), and the exposure trajectories were highly concordant (Spearman $\rho = 0.952$). Adjusted pediatric IRRs were 0.999 (95% CI: 0.986, 1.012) in Bydgoszcz and 0.975 (95% CI: 0.931, 1.021) in Częstochowa. Adult IRRs were 1.007 (95% CI: 0.998, 1.017) and 0.991 (95% CI: 0.974, 1.009), respectively. None of the four primary associations was statistically significant after false discovery rate control.

CONCLUSIONS

Strong BaP seasonality and between-city concordance did not translate into detectable independent associations with monthly all-cause ED service use after population and temporal adjustment. These null short-term findings do not establish that ambient BaP exposure is safe; daily, diagnosis-specific, multipollutant analyses are needed.

Background

Benzo[a]pyrene (BaP) is a five-ring polycyclic aromatic hydrocarbon formed during incomplete combustion of carbon-containing fuels and materials. In ambient air, it is carried predominantly on particulate matter and is widely used as an indicator of a carcinogenic polycyclic aromatic hydrocarbon

mixture [1, 2]. Metabolic activation can produce DNA adducts and alter methylation, linking exposure to mutagenic and carcinogenic pathways [3, 4]. Experimental evidence also supports airway epithelial injury through Wnt5a-mediated noncanonical Wnt–YAP/TAZ signaling [5], and human biomonitoring studies have linked particle-bound BaP and 1-nitropyrene exposure with oxidative stress [6]. Chronic toxicity is therefore well documented, whereas evidence for a BaP-specific, short-term effect on emergency healthcare use remains limited.

Children warrant particular attention because their lungs and immune systems are still developing, their ventilation per unit body mass is higher, and activity patterns may increase inhaled dose [7, 8]. The literature identifies polycyclic aromatic hydrocarbons as plausible contributors to nonmalignant respiratory disease [9], divergent asthma pheno-endotypes [10], airway inflammation, respiratory symptoms, and impaired lung function in children with asthma [11, 12]. Studies using daily or individual-level data have associated ambient pollutants with nonviral asthma exacerbations [13] and asthma-related ED visits, including analyses of PM_{2.5}-bound polycyclic aromatic hydrocarbons and other fine-particle constituents [14, 15]. Results from ecological studies of pediatric ED use have nevertheless been inconsistent [16].

Poland remains a European hotspot for ambient BaP [17]. The European Union annual target value is 1 ng/m³ [18], and residential combustion of solid fuels is an important national source, especially during the heating season [17, 19]. Annual polycyclic aromatic hydrocarbon exposure has also been associated with asthma exacerbation frequency among adults [20]. These observations support biological plausibility but do not establish whether month-to-month changes in a city-level BaP indicator correspond to changes in broad ED service use.

We compared Bydgoszcz in north-central Poland with Częstochowa in the more industrialized Silesian region. The primary objective was to estimate the city-specific association between monthly ambient BaP concentration and pediatric ED service use. Adult ED services were examined as a secondary comparison. We hypothesized greater exposure and a stronger association in Częstochowa, while allowing monitoring data to test the exposure contrast itself.

Methods

Study design and setting

We conducted a two-city ecological time-series study spanning 96 consecutive months from January 2018 through December 2025. The analytic dataset contained monthly aggregate counts and no individual-level records or patient identifiers. Pediatric and adult strata followed the source-data labels: pediatric services were those for patients aged < 18 years, and adult services were those for patients aged ≥ 18 years. Bydgoszcz and Częstochowa were analyzed separately and then compared.

Ambient exposure

The exposure was the monthly BaP concentration in PM₁₀ reported by the Polish State Environmental Monitoring program and obtained from the Chief Inspectorate of Environmental Protection Measurement Data Bank [21]. BaP monitoring in Poland is based on laboratory analysis of selected PM₁₀ filters, with manual measurements published after laboratory processing. Missing BaP values were not imputed. Annual arithmetic means were calculated descriptively from available months; annual estimates based on incomplete monthly data were not treated as formal compliance determinations. The heating season was defined as October through March.

Emergency department outcomes

Regional branches of the Polish National Health Fund provided monthly numbers of pediatric and adult ED services. The data represented services or encounters, not necessarily hospital admissions. They did not include diagnoses, residential addresses, hospital disposition, or individual characteristics. Outcome counts were complete for both cities.

Population denominators

City population values for 2018 and 2025 were obtained from the Statistics Poland Local Data Bank [22], and values for 2019–2024 were linearly interpolated. The natural logarithm of population divided by 1,000 was used as the model offset. The total administrative population was used for both age strata; therefore, the resulting rates describe ED service use per 1,000 total residents and are not age-specific incidence rates. Because patient residence and hospital catchment areas were unavailable, the denominators may not represent the populations actually served by the EDs.

Statistical analysis

Monthly BaP concentrations and ED service rates from matched months were compared between cities with two-sided Wilcoxon signed-rank tests. Spearman correlation quantified agreement between the two exposure series. Levene's test compared exposure variability. Crude Spearman correlations between BaP and ED service rates were descriptive because both series were strongly seasonal and healthcare use was disrupted during the COVID-19 pandemic.

For each city and age stratum, we fit a negative binomial model with a log link, an offset equal to the logarithm of population divided by 1,000, 11 indicator variables for calendar month, a linear monthly time trend, an indicator for March 2020–December 2021, and an indicator for January 2022 onward. Heteroskedasticity- and autocorrelation-consistent standard errors were estimated using the Newey–West estimator with 12 lags. We report IRRs per 1 ng/m³ increase in BaP. Between-city heterogeneity was evaluated with a Wald test. A sensitivity analysis used BaP lagged by one month. Benjamini–Hochberg q values controlled the false discovery rate across the four primary models. Tests were two-sided. For unadjusted analyses, $p < 0.05$ was considered statistically significant; for the four primary

models, $q < 0.05$ defined statistical significance after false discovery rate control. Analyses were conducted in Python using SciPy and statsmodels.

Language and editorial assistance

AI-assisted language tools were used solely to support translation from Polish, English-language editing, and adaptation to the journal's formatting requirements. They were not used to generate or analyze the study data. All assisted content and references were critically reviewed and verified by the authors, who retain full responsibility for the final manuscript.

Results

The dataset comprised 192 city-month observations. ED service counts were complete in both cities. BaP was available for all 96 months in Bydgoszcz and for 87 months in Częstochowa. Missing Częstochowa values occurred in July 2018; April, May, and October 2022; December 2023; September–November 2024; and November 2025, leaving 183 city-months with exposure data.

Median monthly BaP was 1.74 ng/m^3 in Bydgoszcz and 1.91 ng/m^3 in Częstochowa; the paired median difference was 0.13 ng/m^3 ($p = 0.195$), providing no evidence of a higher exposure distribution in Częstochowa (Table 1). Exposure variability also did not differ (Levene $p = 0.318$). The city trajectories were highly concordant ($\rho = 0.952$; $p < 0.001$; Fig. 2A). Every calculated annual mean exceeded 1 ng/m^3 . The calculated annual means were lower in 2025 than in 2018, changing from 4.44 to 1.62 ng/m^3 in Bydgoszcz and from 3.15 to 1.52 ng/m^3 in Częstochowa. Five Częstochowa annual means used 9–11 months and should not be interpreted as formal compliance assessments. Median heating-season BaP was 25 times the non-heating-season median in Bydgoszcz and 11 times the corresponding median in Częstochowa (both $p < 0.001$; Fig. 2B).

Table 1

Ambient exposure, population, and emergency department service use, 2018–2025. *Five annual means for Częstochowa were calculated from 9–11 available months. Paired p values are descriptive Wilcoxon signed-rank tests. Person-year rates were calculated using the sum of annual population denominators for 2018–2025. Rates may not represent resident risk if ED catchment areas extend beyond city boundaries. IQR, interquartile range; BaP, benzo[a]pyrene; ED, emergency department.

Measure	Bydgoszcz	Częstochowa	Paired p
Months with ED data, n	96	96	—
Months with BaP data, n	96	87	—
BaP, ng/m ³ ; median [IQR]	1.74 [0.15–3.77]	1.91 [0.36–3.86]	0.195
Calculated annual mean > 1 ng/m ³	8/8 years	8/8 years*	—
Population, June 30, 2018	351,254	223,322	—
Population, June 30, 2025	322,464 (– 8.2%)	202,415 (– 9.4%)	—
Children: services/1,000 residents/month; median [IQR]	2.59 [2.17–3.08]	6.18 [5.32–6.84]	< 0.001
Children: total services, n	82,844	120,151	—
Children: services/1,000 person-years	30.84	70.83	—
Adults: services/1,000 residents/month; median [IQR]	21.54 [19.30–24.00]	22.73 [20.72–25.16]	0.002
Adults: total services, n	688,846	467,892	—
Adults: services/1,000 person-years	256.42	275.84	—

Population declined from 2018 through 2025 by 8.2% in Bydgoszcz and 9.4% in Częstochowa. Median monthly pediatric service rates were 2.59 and 6.18 per 1,000 total residents, respectively; the median Częstochowa-to-Bydgoszcz ratio was 2.27 (paired $p < 0.001$). Adult service rates were closer: 21.54 and 22.73 per 1,000 total residents (paired $p = 0.002$). Both cities showed a marked decline in ED service use during the pandemic period, followed by recovery, especially among children (Fig. 1).

Crude correlations between BaP and ED service rates were negative in Bydgoszcz for children ($\rho = -0.372$; $p < 0.001$) and adults ($\rho = -0.454$; $p < 0.001$). Corresponding correlations in Częstochowa were -0.173 ($p = 0.109$) and -0.243 ($p = 0.023$). After adjustment for population and temporal variables, none of the four BaP coefficients was statistically significant (Table 2; Fig. 3).

Among children, the adjusted IRR per 1 ng/m³ increase in BaP was 0.999 (95% CI: 0.986, 1.012) in Bydgoszcz and 0.975 (95% CI: 0.931, 1.021) in Częstochowa; between-city heterogeneity was not detected ($p = 0.316$). Adult IRRs were 1.007 (95% CI: 0.998, 1.017) and 0.991 (95% CI: 0.974, 1.009), respectively, with heterogeneity $p = 0.113$. Benjamini–Hochberg q values ranged from 0.427 to 0.886. In

the one-month-lag sensitivity analysis, pediatric estimates remained null (IRRs 0.994 and 0.988 in Bydgoszcz and Częstochowa, respectively).

Table 2

Crude and adjusted associations between monthly benzo[a]pyrene and emergency department service use. Adjusted IRRs are from negative binomial models with a log-population offset, calendar-month indicators, linear trend, pandemic and post-pandemic indicators, and heteroskedasticity- and autocorrelation-consistent standard errors using 12 lags. Between-city heterogeneity p values were 0.316 for children and 0.113 for adults. BH, Benjamini–Hochberg; CI, confidence interval; IRR, incidence rate ratio.

Group	City	n	Spearman ρ (p)	Adjusted IRR (95% CI)	p	BH q
Children	Bydgoszcz	96	-0.372 (< 0.001)	0.999 (0.986, 1.012)	0.886	0.886
Children	Częstochowa	87	-0.173 (0.109)	0.975 (0.931, 1.021)	0.279	0.427
Adults	Bydgoszcz	96	-0.454 (< 0.001)	1.007 (0.998, 1.017)	0.139	0.427
Adults	Częstochowa	87	-0.243 (0.023)	0.991 (0.974, 1.009)	0.320	0.427

Discussion

In this eight-year, two-city ecological time-series study, monthly BaP concentration was not independently associated with the frequency of all-cause pediatric ED services after adjustment for population, seasonality, secular trend, and pandemic-related structural changes. Adult results were also null, and there was no evidence of between-city heterogeneity. Negative crude correlations disappeared after temporal adjustment, illustrating the risk of interpreting strongly seasonal exposure and outcome series without adequate control for time.

The monitoring data did not support the contextual assumption that Częstochowa had a higher BaP distribution than Bydgoszcz. The two series were strikingly synchronized despite the approximately 300-km separation and different regional industrial profiles. This pattern, together with 25-fold and 11-fold heating-season contrasts, is consistent with a common seasonal driver and the importance of dispersed residential solid-fuel combustion in Poland [17, 19]. Industrial context and topography should therefore not substitute for measured exposure within each city.

Several nonexclusive explanations may account for the null findings. First, biologically relevant short-term effects may unfold over days, whereas monthly aggregation smooths peaks and precludes detailed distributed-lag analysis. Second, BaP is not an isolated environmental exposure but a component of a correlated combustion mixture. Co-occurrence with particulate matter, shared sources, and meteorological influences make a single-pollutant coefficient difficult to interpret as a BaP-specific toxic effect [14, 15, 23, 24]. Third, monthly all-cause ED service use is an outcome with low specificity. A signal restricted to asthma, respiratory infection, or another susceptible subgroup may be diluted by injuries and conditions unrelated to ambient pollution; injuries constitute a substantial component of pediatric

emergency care [25]. Finally, well-established genotoxic and carcinogenic pathways develop over longer time scales and are not expected to be captured by an analysis of short-term service use [1, 3, 4].

The broader literature supports biological plausibility but remains heterogeneous. Designs using daily data, diagnosis-specific outcomes, or individual exposure estimates are more sensitive to acute respiratory effects than monthly all-cause counts [10–16]. The pandemic also altered access to and use of emergency care in Poland, independently of environmental exposure; an ecological study from the authors' team documented marked changes in ED visit volume before, during, and after the pandemic [26]. The explicit pandemic and post-pandemic terms in our models reduced, but cannot eliminate, this source of structural confounding.

The more than twofold crude pediatric service-rate difference between cities should not be attributed to BaP: exposure distributions were similar, and the adjusted models showed no association. A likely explanation is misalignment between city administrative populations and hospital catchment populations, together with differences in the organization of pediatric care. The much smaller adult rate difference reinforces the need to define catchment areas before interpreting intercity service-use contrasts.

Strengths include an eight-year observation period, complete outcome series, independent evaluation in two cities, population offsets, explicit control for calendar month and pandemic-related periods, autocorrelation-robust standard errors, multiple-testing control, and a prespecified lag sensitivity analysis. We also separated descriptive annual means from formal regulatory compliance judgments when exposure months were missing.

The study also has important limitations. Its ecological design cannot link an individual patient's exposure with an ED encounter. City-level monitoring may misclassify spatially heterogeneous exposure, and nine BaP months were missing in Częstochowa. Monthly aggregation limits power and masks acute peaks. Outcome data lacked diagnoses, residence, disposition, repeat-visit identifiers, and the actual hospital catchment population. The denominator was the total city population rather than age-specific populations. Models did not include temperature, humidity, pollen, respiratory-virus activity, school calendars, healthcare access, other pollutants, or socioeconomic factors. BaP may therefore act as a marker of a combustion mixture, and residual confounding and exposure measurement error remain plausible. With only 96 or 87 exposed months per city, wide confidence intervals—especially for pediatric services in Częstochowa—also limit the precision of null conclusions.

Conclusions

At monthly ecological resolution, ambient BaP concentration was not independently associated with all-cause pediatric or adult ED service use in Bydgoszcz or Częstochowa during 2018–2025. This absence of a detectable acute association does not demonstrate safety, particularly because every calculated annual mean exceeded the European Union target value. Future work should use daily data, diagnosis-

specific outcomes, age-specific denominators, measured catchment populations, multipollutant and meteorological adjustment, and distributed-lag models.

Abbreviations

BaP	
benzo[a]pyrene	
BH	
Benjamini–Hochberg	
CI	
confidence interval	
COVID-19	
coronavirus disease 2019	
ED	
emergency department	
EU	
European Union	
HAC	
heteroskedasticity- and autocorrelation-consistent	
IQR	
interquartile range	
IRR	
incidence rate ratio	
PM10	
particulate matter with an aerodynamic diameter $\leq 10 \mu\text{m}$	
PM2.5	
particulate matter with an aerodynamic diameter $\leq 2.5 \mu\text{m}$.	

Declarations

Ethics approval and consent to participate

The study protocol was reviewed and approved by the Research Ethics Committee of the Faculty of Medicine, Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń (Komisja Etyki Badań Naukowych Wydziału Lekarskiego; decision no. KEWL 12/2025; 30 July 2025). All methods were carried out in accordance with relevant guidelines and regulations and with the conditions specified in the Committee's decision. The study used exclusively pre-existing monthly aggregated and anonymized administrative data on pediatric and adult emergency department services, together with ambient air-quality and population data. No individual-level patient records or direct or indirect personal identifiers were accessed. The Committee approved analysis without individual informed consent on the condition that only anonymized data devoid of personal information were used when consent had not been

obtained. Because this condition was met, the requirement for individual informed consent was waived by the Committee for the anonymized aggregate dataset analyzed in this study. No participants were recruited or contacted, and no interventions were performed.

Consent for publication

Not applicable. The manuscript contains no individual person's data.

Competing interests

The authors declare that they have no competing interests.

Clinical trial number

Not applicable.

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Author Contribution

M.S., S.J., W.T., and T.M.-B. contributed equally to the conception and design of the study, methodology, data acquisition and curation, formal analysis, interpretation of the results, and preparation and critical revision of the manuscript. M.S. coordinated the manuscript preparation and submission and serves as the corresponding author. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Not applicable.

Data Availability

Ambient benzo[a]pyrene-in-PM10 measurement data are publicly available from the Measurement Data Bank of the Chief Inspectorate of Environmental Protection (GIOŚ) at <https://powietrze.gios.gov.pl/pjp/archives>. Population data are publicly available from the Local Data Bank of Statistics Poland at <https://bdl.stat.gov.pl/bdl/>. Aggregated monthly pediatric and adult emergency department data were obtained from regional branches of the Polish National Health Fund

and are not publicly available because they are subject to the permissions governing these administrative data. The analytic dataset and code may be made available by the corresponding author upon reasonable request and subject to permission from the relevant data providers.

References

1. Bukowska, B., Mokra, K. & Michałowicz, J. Benzo[a]pyrene—environmental occurrence, human exposure, and mechanisms of toxicity. *Int. J. Mol. Sci.* **23** (11), 6348. <https://doi.org/10.3390/ijms23116348> (2022).
2. Vu, J., Nadeau, K. & Kasowski, M. Molecular mechanisms of air pollution-induced carcinogenesis and the emerging role of microplastics. *Hum. Genomics.* **20**, 6. <https://doi.org/10.1186/s40246-025-00880-0> (2026).
3. Gerhards, M., Böhme, A., Schubert, K., Kodritsch, B. & Ulrich, N. DNA adducts as link between in vitro and in vivo carcinogenicity—a case study with benzo[a]pyrene. *Curr. Res. Toxicol.* **4**, 100097. <https://doi.org/10.1016/j.crttox.2022.100097> (2023).
4. Zhao, C. et al. The dual effects of benzo(a)pyrene/benzo(a)pyrene-7,8-dihydrodiol-9,10-epoxide on DNA methylation. *Sci. Total Environ.* **950**, 175042. <https://doi.org/10.1016/j.scitotenv.2024.175042> (2024).
5. Fan, L. et al. Benzo(a)pyrene induces airway epithelial injury through Wnt5a-mediated non-canonical Wnt-YAP/TAZ signaling. *Sci. Total Environ.* **815**, 151965. <https://doi.org/10.1016/j.scitotenv.2021.151965> (2022).
6. Choi, S. H., Ochirpurev, B., Toriba, A., Won, J. U. & Kim, H. Exposure to benzo[a]pyrene and 1-nitropyrene in particulate matter increases oxidative stress in the human body. *Toxics* **11** (9), 797. <https://doi.org/10.3390/toxics11090797> (2023).
7. Brumberg, H. L., Karr, C. J. & Council on Environmental Health. Ambient air pollution: health hazards to children. *Pediatrics* **147** (6), e2021051484. <https://doi.org/10.1542/peds.2021-051484> (2021).
8. Matthews-Kozanecka, M., Sadowska-Krawczenko, I., Łysiak-Majchrzak, M. & Surdacki, M. Impact of air pollution and environmental tobacco smoke (ETS) on the health of children and women of reproductive age. *J. Health Inequal.* **12** (1), 34–41. <https://doi.org/10.5114/jhi.2026.162318> (2026).
9. Låg, M., Øvrevik, J., Refsnes, M. & Holme, J. A. Potential role of polycyclic aromatic hydrocarbons in air pollution-induced non-malignant respiratory diseases. *Respir Res.* **21**, 299. <https://doi.org/10.1186/s12931-020-01563-1> (2020).
10. Choi, H., Dostal, M., Pastorkova, A., Rossner, P. Jr & Sram, R. J. Airborne benzo[a]pyrene may contribute to divergent pheno-endotypes in children. *Environ. Health.* **20**, 40. <https://doi.org/10.1186/s12940-021-00711-4> (2021).
11. Kuang, H. et al. Co-exposure to polycyclic aromatic hydrocarbons, benzene and toluene may impair lung function by increasing oxidative damage and airway inflammation in asthmatic children. *Environ. Pollut.* **266**, 115220. <https://doi.org/10.1016/j.envpol.2020.115220> (2020).

12. Cilluffo, G. et al. Effects of polycyclic aromatic hydrocarbons on lung function in children with asthma: a mediation analysis. *Int. J. Environ. Res. Public. Health*. **19** (3), 1826. <https://doi.org/10.3390/ijerph19031826> (2022).
13. Altman, M. C. et al. Associations between outdoor air pollutants and non-viral asthma exacerbations and airway inflammatory responses in children and adolescents living in urban areas in the USA. *Lancet Planet. Health*. **7** (1), e33–e44. [https://doi.org/10.1016/S2542-5196\(22\)00302-3](https://doi.org/10.1016/S2542-5196(22)00302-3) (2023).
14. Hsu, S. C. et al. Differential time-lag effects of ambient PM_{2.5} and PM_{2.5}-bound PAHs on asthma emergency department visits. *Environ. Sci. Pollut Res. Int.* **27**, 43117–43124. <https://doi.org/10.1007/s11356-020-10243-y> (2020).
15. Ho, Y. N. et al. Fine particulate matter constituents associated with emergency room visits for pediatric asthma: a time-stratified case-crossover study in an urban area. *BMC Public. Health*. **21**, 1593. <https://doi.org/10.1186/s12889-021-11636-5> (2021).
16. Söğütlü, Y. et al. Evaluation of the relationship between air pollutants and emergency department admissions with childhood asthma. *Diagnostics* **14** (24), 2778. <https://doi.org/10.3390/diagnostics14242778> (2024).
17. European Environment Agency. Benzo(a)pyrene—BaP. Air quality status report 2025. Published 2025. Accessed August 7. (2026). <https://www.eea.europa.eu/en/analysis/publications/air-quality-status-report-2025/benzoapyrene-bap>
18. European Parliament and Council of the European Union. Directive (EU) 2024/2881 of 23 October 2024 on ambient air quality and cleaner air for Europe (recast). Off J Eur Union. Published November 20. Accessed August 7, 2026. (2024). <https://eur-lex.europa.eu/eli/dir/2024/2881/oj/eng>
19. Chief Inspectorate of Environmental Protection. *The State of the Environment in Poland: Report 2022* (Chief Inspectorate of Environmental Protection, 2022).
20. Lee, S. W. et al. Impact of annual exposure to polycyclic aromatic hydrocarbons on acute exacerbation frequency in asthmatic patients. *J. Asthma Allergy*. **14**, 81–90. <https://doi.org/10.2147/JAA.S288052> (2021).
21. Chief Inspectorate of Environmental Protection. Measurement Data Bank. Warsaw, Poland. Accessed August 7. (2026). <https://powietrze.gios.gov.pl/pjp/archives>
22. Statistics Poland. Local Data Bank: subgroup P2914, variable 199203; units 040410661011 and 012414664011; years 2018–2025. Warsaw, Poland. Accessed August 7. (2026). <https://bdl.stat.gov.pl/bdl/dane/podgrup/wymiary/3/7/2914>
23. Amarandei, C., Negru, A. G., Iancu, C., Olariu, R. I. & Arsene, C. Seasonality, sources apportionment, human health risks assessments, and potential implications on the atmospheric chemistry of polycyclic aromatic hydrocarbons in size-segregated aerosols from a Romanian metropolitan area. *Chemosphere* **368**, 143738. <https://doi.org/10.1016/j.chemosphere.2024.143738> (2024).
24. Clauzel, A., Persoons, R., Maître, A., Balducci, F. & Petit, P. Review of environmental airborne pyrene/benzo[a]pyrene levels from industrial emissions for the improvement of 1-hydroxypyrene

- biomonitoring interpretation. *J. Toxicol. Environ. Health B Crit. Rev.* **27** (5–6), 212–232. <https://doi.org/10.1080/10937404.2024.2362632> (2024).
25. Whitfill, T. et al. Emergency care for children in the United States: epidemiology and trends over time. *J. Emerg. Med.* **55** (3), 423–434. <https://doi.org/10.1016/j.jemermed.2018.04.019> (2018).
26. Surdacki, M., Nijakowski, K. & Matthews-Brzozowska, T. Changes in emergency department visit volume before, during and after the COVID-19 pandemic, with an exploratory assessment of air pollution: a preliminary ecological study from Poznań, Poland. *Pol. J. Public. Health.* **136**, 55–59. <https://doi.org/10.12923/2083-4829/2026-0010> (2026).

Figures

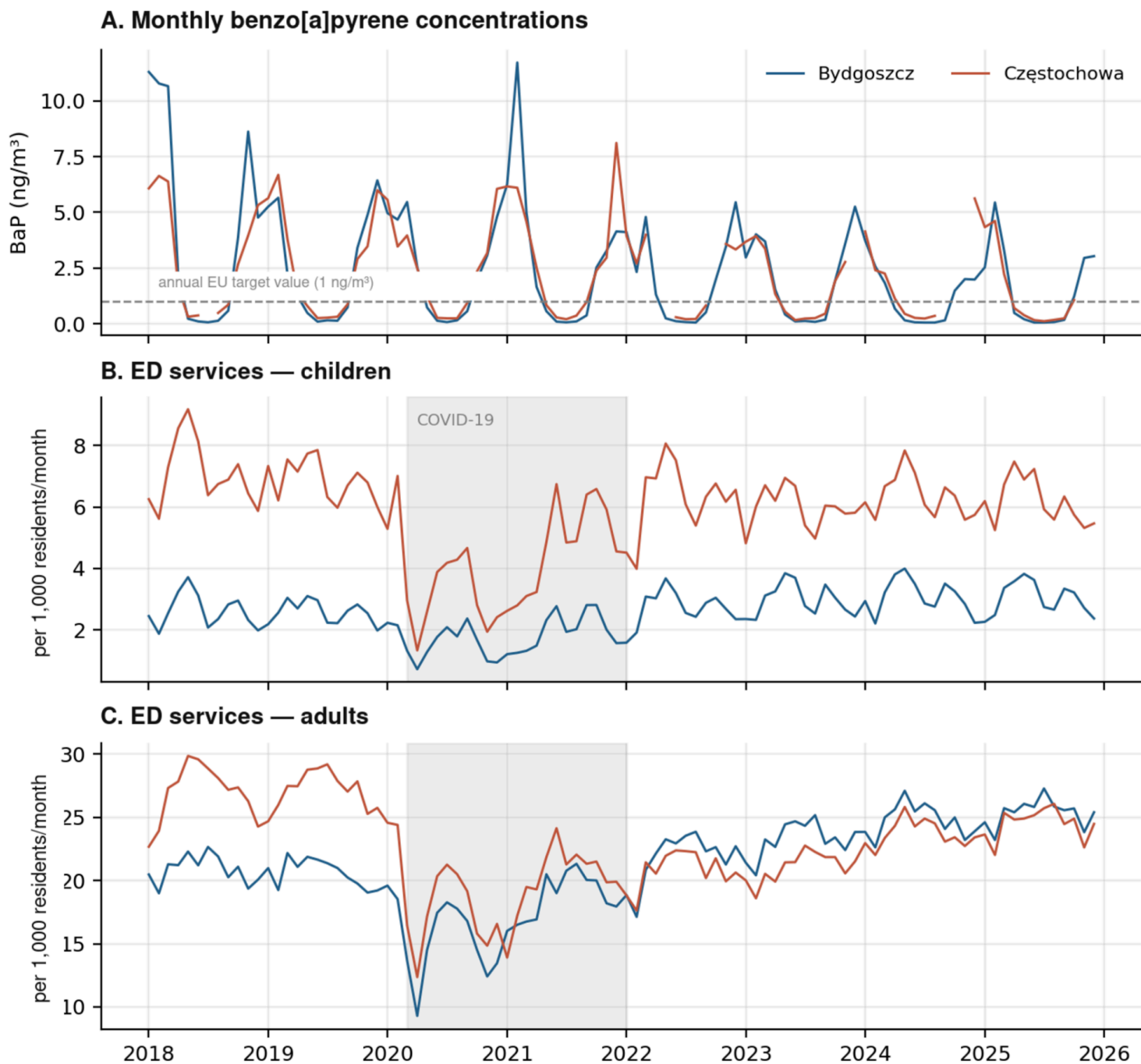


Figure 1

Monthly ambient BaP concentrations (A) and population-standardized ED services among children (B) and adults (C), 2018–2025. The dashed line in panel A shows the annual European Union target value and does not apply to individual months. Shading denotes March 2020–December 2021. BaP, benzo[a]pyrene; ED, emergency department.

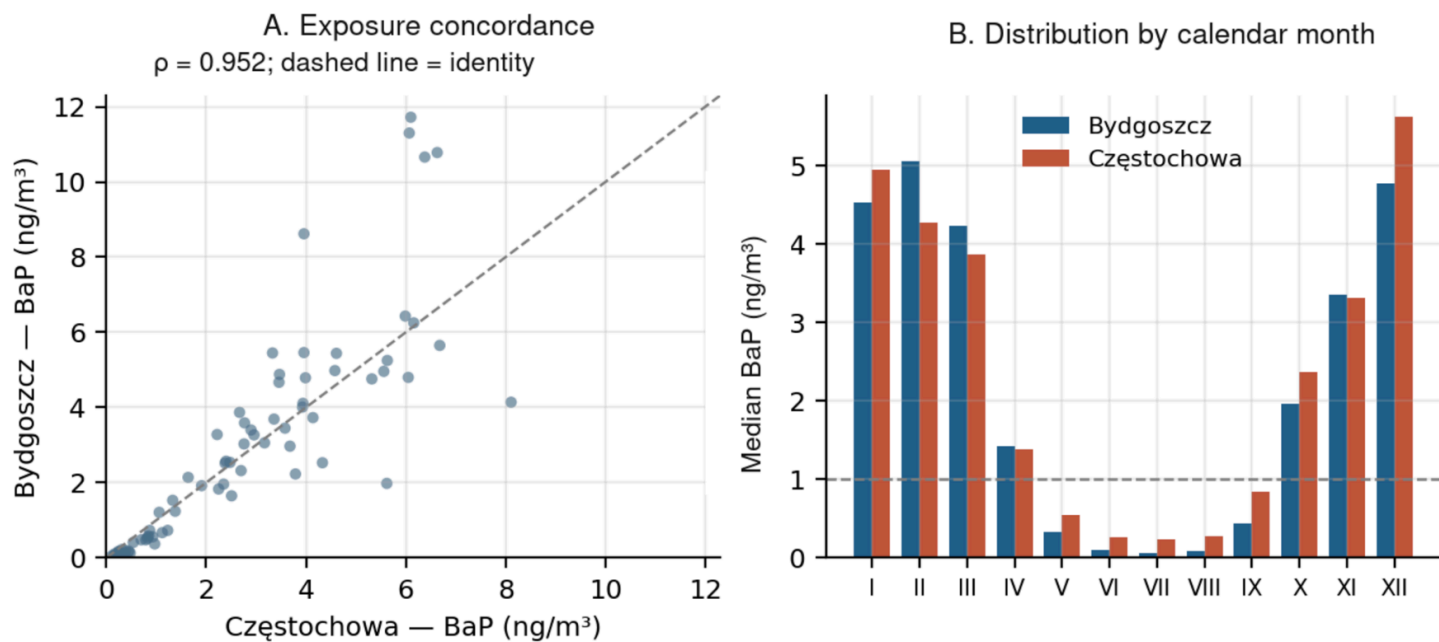


Figure 2

Exposure concordance between cities (A) and monthly BaP medians across the calendar year (B). The dashed line in panel A is the identity line; the dashed line in panel B marks 1 ng/m³. BaP, benzo[a]pyrene.

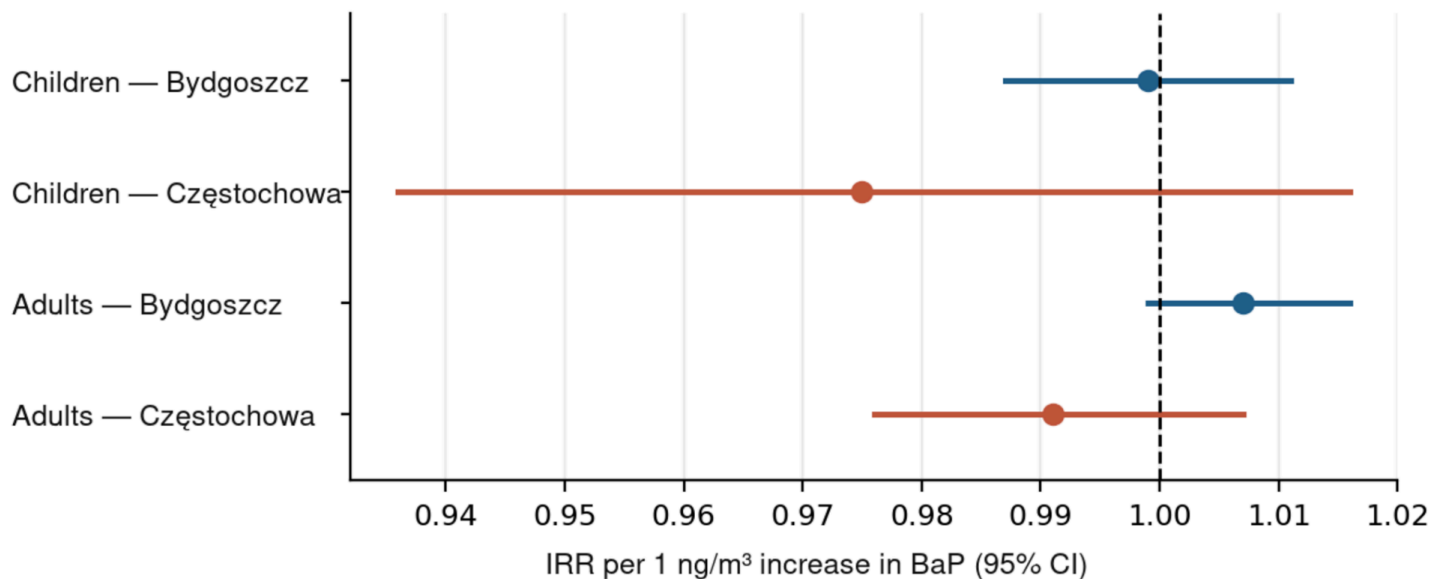


Figure 3

Adjusted associations between monthly BaP concentration and ED service use. Points are IRRs per 1 ng/m³ increase in BaP; bars are 95% CIs; the dashed vertical line is the null. BaP, benzo[a]pyrene; CI, confidence interval; ED, emergency department; IRR, incidence rate ratio.