Environment Conservation Journal 27 (3): 1005-1010, 2026

Journal homepage:https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)



Spatial and source-sensitive assessment of urban particulate matter using $PM_{2.5}/PM_{10}$ ratios and statistical analysis

Rishabh Bhardwaj

Department of Zoology and Environmental Science, Gurukula Kangri (Deemed to be University), Haridwar, Uttarakhand, India

Rakesh Bhutiani ✉

Department of Zoology and Environmental Science, Gurukula Kangri (Deemed to be University), Haridwar Uttarakhand, India

ARTICLE INFO

Received : 05 January 2026
Revised : 25 June 2026
Accepted : 20 July 2026

Available online: 08 August 2026

Key Words:
Air pollution
Hotspot
$PM_{2.5}$
PM_{10}
Source screening
Spatial heterogeneity

ABSTRACT

The present study proposes a compact source-screening framework integrating $PM_{2.5}/PM_{10}$ ratios and statistical analysis to characterise urban particulate matter. The data provided are for 16 samples for 4 zones. $PM_{2.5}$ ranged from 12 to 165 µg m^{-3} while PM_{10} ranged from 28 to 260 µg m^{-3}, and the means were 59.19 and 96.75 µg m^{-3}, respectively. The mean of grid-level $PM_{2.5}/PM_{10}$ ratios was 0.578 (0.429–0.709), while the ratio of the means was 0.612. $PM_{2.5}$ and PM_{10} were strongly correlated, both statistically significant (Pearson r = 0.998; Spearman ρ = 0.991; p < 0.001) and regression explained 99.6% of the variance ($PM_{2.5}$ = 0.640 PM_{10} − 2.747; 95% CI for slope: 0.616–0.664). Zone B had the highest mean concentrations (141.25 µg m^{-3} $PM_{2.5}$ and 227.50 µg m^{-3} PM_{10}), whereas Zone C had the lowest. Kruskal–Wallis tests highlighted that $PM_{2.5}$ and PM_{10} had significant differences among the zones (H = 13.10, p = 0.004 for $PM_{2.5}$; H = 12.77, p = 0.005 for PM_{10}). The results indicated significant differences along with a clear relative burden of fine versus coarse particles. Within the higher concentration zones, the higher $PM_{2.5}/PM_{10}$ ratios are more indicative of a fine PM dominant burden, while the lower $PM_{2.5}/PM_{10}$ ratios would be more indicative of a coarse PM burden. Due to the inability of concentration ratios to definitively allocate sources, the present study interprets these findings as source screening rather than source allocation. This source screening provides the potential to influence targeted air pollution studies as well as the incorporation of meteorology, chemical speciation and modelling.

Introduction

The health and environmental impact of PM depends on particle size, composition and exposure time. Fine $PM_{2.5}$ can cause adverse cardiopulmonary effects. PM_{10} has a large coarse fraction, which comes from the resuspension of soil, road dust, and other sources (Pope & Dockery, 2006) (Organization, 2021). PM from urban air pollution is the result of complex, interdependent co-primary and co-secondary processes like traffic, combustion, industry, construction, and dust resuspension (Guttikunda & Goel, 2013) (Guttikunda *et al*., 2014) (Zhang *et al*., 2015). Spatial heterogeneity is particularly important along heavily trafficked urban corridors because concentration gradients can change over relatively short distances in response to emission intensity, background conditions and meteorology (Zhou & Levy, 2007). Consequently, corridor-scale measurements can reveal localised concentration contrasts that are obscured by broad spatial averages (Board, 2020).

The $PM_{2.5}/PM_{10}$ ratio is a useful size-fraction metric for evaluating the relative contribution of fine and coarse particles. Studies across Indian urban environments show that the ratio varies spatially and temporally, providing contextual evidence about fine - versus coarse-particle dominance (Seinfeld & Pandis, 2016) (Spandana *et al*., 2021) (Fatima *et al*., 2022). However, a concentration ratio should not be interpreted as quantitative source apportionment. Robust source attribution generally requires chemically resolved measurements, along with receptor- or source-oriented modelling (Pant & Harrison, 2012) (Kumar *et al*., 2022) (Yadav *et al*., 2022).

The present study, therefore, addresses a narrower and more defensible question: can spatial contrasts in $PM_{2.5}$ and PM_{10} along Garh Road be characterised using grid-resolved concentrations, the $PM_{2.5}/PM_{10}$ ratio, association and regression statistics, and zone-level non-parametric testing? The goal is to design a source screening framework that clearly indicates where higher-intensity monitoring should be performed, without making claims of source apportionment.

Objectives

Determine the variability of $PM_{2.5}$ and PM_{10} across the supplied sections of the Garh Road grid. Compute and compare $PM_{2.5}/PM_{10}$ ratios at the grid level and in the aggregate.

Analyse the $PM_{2.5}$-to-PM_{10} association by using

Corresponding author E-mail: rbhutiani@gmail.com
Doi:https://doi.org/10.36953/ECJ.45172026
This work is licensed under Attribution-Non Commercial 4.0 International (CC BY-NC 4.0)
© ASEA

Pearson and Spearman statistics and assess the regression relationship.

Assess whether particulate concentrations differ among the four regions, identify the most concentrated regions (relative to all other regions), and estimate the approximate particle size and emissions source range.

Establish control and monitoring priorities, as well as the measurements necessary for future source apportionment studies.

Materials and Methods

Study area and study design

The study focuses on Garh Road, Meerut, as described in the accompanying manuscript, as a busy urban corridor with mixed land use, commercial activities, and roadside dust generation. The analytical dataset contains 16 paired observations, arranged in four zones (A-D), with four observations in each zone. The accompanying material has none of the elements stated here: geographic coordinates, date of sampling, average sampling period, type of monitoring instrument, sampling duration, calibration of the instrument or quality assurance/quality control; these elements should be given by the authors if they exist.

Dataset and variables

The dataset comprises $PM_{2.5}$ and PM_{10} paired concentrations for each monitoring grid. The general formula for the grid level ratio was

$$R_i = PM_{2.5,i} / PM_{10,\ i}$$

Two aggregate summaries were presented. The first was the arithmetic mean of the 16 grid level ratios, where each grid was given equal importance. The second was the ratio of the mean $PM_{2.5}$ to the mean PM_{10}, with emphasis on observations with greater PM_{10} concentrations. These are two entirely different cases and therefore will be presented separately. Pearson correlation and Spearman rank correlation were used to evaluate the nature of the relationship between the variables, where Spearman rank correlation was used in the absence of a defined linear relationship. PM_{10} was used as the predictor variable, and $PM_{2.5}$ was used as the response variable for fitting an ordinary least-squares regression model. The model performance was assessed and summarised in terms of R^2, root mean square error (RMSE), mean absolute error (MAE), and the 95% confidence interval for the slope.

Because only four observations were available for each zone, zone differences were assessed via the non -parametric Kruskal–Wallis test. The two-sided hypothesis tests were used to assess statistical significance at $\alpha = 0.05$. Although the dataset lacked georeferenced coordinates, geostatistical and spatial hotspot analyses were not conducted because the researchers did not have those coordinates.

Source-sensitive interpretation

A higher $PM_{2.5}/PM_{10}$ ratio indicates a relatively greater fine-particle fraction, whereas a lower ratio indicates a relatively greater coarse-particle fraction. In an urban setting, higher fine fractions may be consistent with combustion- and traffic-associated particles, while coarse fractions may be consistent with resuspended road or surface dust. These are screening-level interpretations only. The ratio cannot uniquely separate vehicle exhaust, industrial combustion, biomass burning, secondary aerosol or dust sources without chemical and/or receptor-model evidence (Pant & Harrison, 2012) (Spandana *et al*., 2021) (Yadav *et al*., 2022).

Results and Discussion

Grid-resolved particulate concentrations

The 16 observations show pronounced spatial heterogeneity in both particle-size fractions (Figure 1

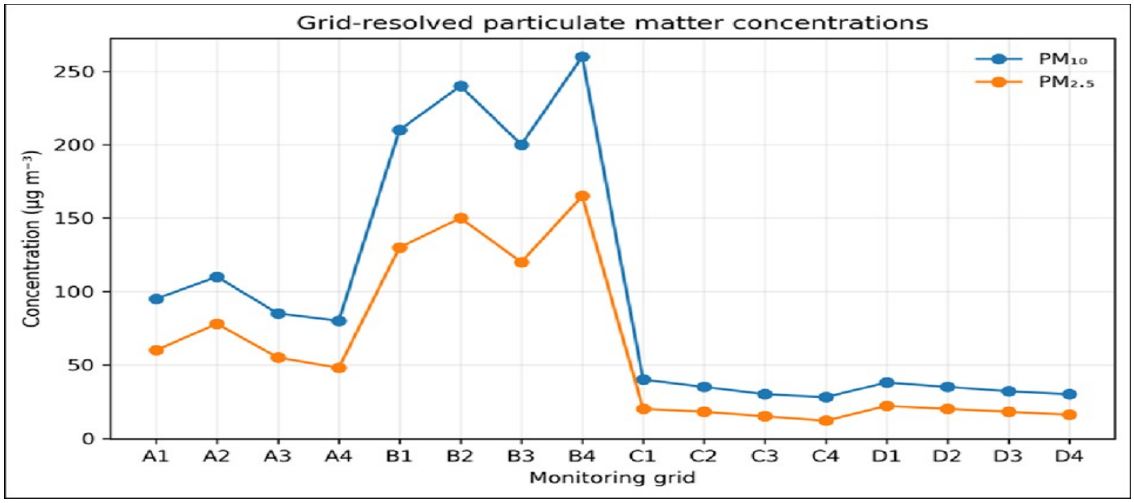


Figure 1. Grid-resolved $PM_{2.5}$ and PM_{10} concentrations in the supplied dataset

Table 1. Grid-resolved particulate concentrations and $PM_{2.5}/PM_{10}$ ratios

Grid	$PM_{2.5}$ (μg m^{-3})	PM_{10} (μg m^{-3})	$PM_{2.5}/PM_{10}$ ratio
A1	60	95	0.632
A2	78	110	0.709
A3	55	85	0.647
A4	48	80	0.600
B1	130	210	0.619
B2	150	240	0.625
B3	120	200	0.600
B4	165	260	0.635
C1	20	40	0.500
C2	18	35	0.514
C3	15	30	0.500
C4	12	28	0.429
D1	22	38	0.579
D2	20	35	0.571
D3	18	32	0.562
D4	16	30	0.533

and Table 1) $PM_{2.5}$ ranged from 12 to 165 μg m^{-3} and PM_{10} from 28 to 260 μg m^{-3}. The overall means were 59.19 ± 53.26 μg m^{-3} for $PM_{2.5}$ and 96.75 ± 83.02 μg m^{-3} for PM_{10}, corresponding to coefficients of variation of 90.0% and 85.8%, respectively.

Zone B contained the highest four grid concentrations, with $PM_{2.5}$ values of 120–165 μg m^{-3} and PM_{10} values of 200–260 μg m^{-3}. Zone A showed intermediate concentrations, while Zones C and D contained substantially lower values. This pattern establishes a clear concentration contrast among the supplied zones. The data support a relative hotspot interpretation, but concentration measurements alone cannot establish that traffic, fuel combustion or any other individual source caused the observed maxima.

$PM_{2.5}/PM_{10}$ ratio and fine/coarse contrast

The grid-level $PM_{2.5}/PM_{10}$ ratio ranged from 0.429 at C4 to 0.709 at A2, with an arithmetic mean of 0.578. Zone A had the highest mean ratio (0.647), followed by Zone B (0.620), Zone D (0.562) and Zone C (0.486) (Table 2 and Figure 2). The ratio of the overall means was 0.612. The difference between the grid-level mean ratio and the ratio of the overall means is expected because the former weights each grid equally, whereas the latter is influenced more strongly by observations with larger PM_{10} concentrations.

The relatively higher ratios in Zones A and B indicate a greater fine-particle fraction than in Zone C, while the lowest ratio at C4 indicates a comparatively larger coarse fraction. This pattern is consistent with the use of the $PM_{2.5}/PM_{10}$ ratio as a screening indicator, as reported in Indian urban studies (Spandana *et al*., 2021) (Fatima *et al*., 2022). It should not, however, be converted into quantitative source percentages.

Zone-level concentration hotspot structure

Zone B was the dominant relative concentration hotspot, with mean $PM_{2.5}$ of 141.25 μg m^{-3} and mean PM_{10} of 227.50 μg m^{-3} (;). These means were 2.39-fold and 2.35-fold higher than the corresponding study-wide means. B4 had the highest individual concentrations (165 μg m^{-3} $PM_{2.5}$ and 260 μg m^{-3} PM_{10}), whereas C4 had the lowest concentrations (12 and 28 μg m^{-3}, respectively) (Table 2 and Figure 3).

The strong contrast between zones suggests that local spatial structure is important for this corridor. The most defensible interpretation is that the higher -burden grids warrant targeted investigation of traffic, combustion, dust and other local activities. The available dataset does not contain sufficient information to identify which source dominates at any individual grid.

Association and regression between $PM_{2.5}$ and PM_{10}

$PM_{2.5}$ and PM_{10} showed an exceptionally strong positive association (Pearson $r = 0.998$, $p < 0.001$; Spearman $\rho = 0.991$, $p < 0.001$). The ordinary least-squares model was $PM_{2.5} = 0.640 \times PM_{10} - 2.747$, with $R^2 = 0.996$ (;). The 95% confidence interval for the slope was 0.616–0.664. RMSE and MAE were 3.34 and 2.24 μg m^{-3}, respectively (Table 3 and Figure 4).

The very high correlation indicates that the two particle-size fractions varied closely together across the 16 grids. This finding is consistent with shared spatial drivers; however, the result does not imply a common emission source. A challenge for urban PM is distinguishing primary and secondary constituents that can transform during atmospheric processing and meteorology (Sharma & Dikshit, 2016) (Zhang *et al*., 2015).

Importance of zone variation

The Kruskal–Wallis tests demonstrated significant

Table 2. Zone-level particulate burden and $PM_{2.5}/PM_{10}$ ratio

Zone	Mean $PM_{2.5}$	Mean PM_{10}	Mean ratio	Maximum $PM_{2.5}$	Maximum PM_{10}
A	60.25	92.50	0.647	78	110
B	141.25	227.50	0.620	165	260
C	16.25	33.25	0.486	20	40
D	19.00	33.75	0.562	22	38

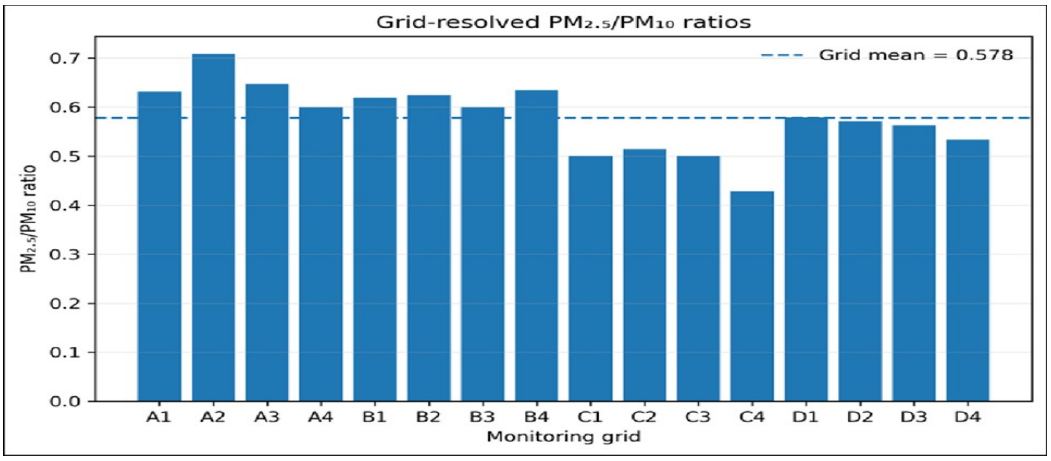


Figure 2. Grid-resolved $PM_{2.5}/PM_{10}$ ratios; dashed line indicates the arithmetic mean of the 16 grid-level ratios

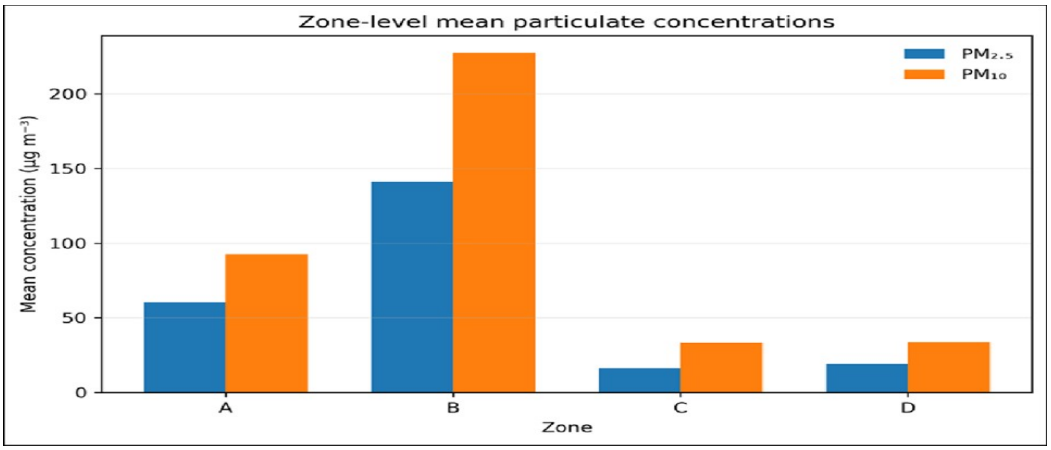


Figure 3. Zone-level mean $PM_{2.5}$ and PM_{10} concentrations

Table 3. Association and regression diagnostics for $PM_{2.5}$ versus PM_{10}.

Statistic	Estimate	Interpretation / uncertainty
Pearson r	0.998	p = 4.85e-18
Spearman ρ	0.991	p = 1.11e-13
Regression slope	0.640	95% CI 0.616–0.664
Intercept	-2.747	µg m^{-3}
R^2	0.996	
RMSE	3.34	µg m^{-3}
MAE	2.24	µg m^{-3}

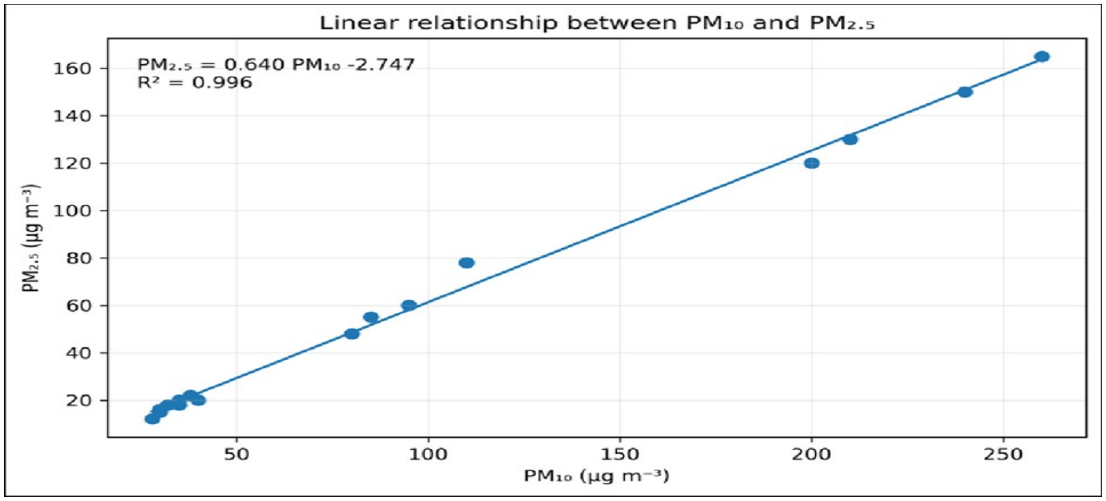


Figure 4. Linear relationship between PM_{10} and $PM_{2.5}$ across the 16 grid observations; fitted line represents ordinary least-squares regression

differences between zones for $PM_{2.5}$ ($H = 13.10$, $p = 0.004$) and PM_{10} ($H = 12.77$, $p = 0.005$). This shows that the zone pattern cannot be explained by isolated maximum values. Because of the limited observations per zone, nevertheless, the results show strong evidence for notable differences in the dataset for the entire region. They should not be considered a complete description of the whole region.

Relation to WHO guidelines

The 2021 WHO global air quality guidelines set 24-hour guidelines as 15 µg/m³ for $PM_{2.5}$ and 45 µg/m³ for PM_{10} and annual guidelines as 5 and 15 µg/m³, respectively (Organization, 2021). The averaging period of the present observations is not documented. Therefore, a formal compliance assessment is not possible.

If the supplied observations represent 24-hour mean concentrations, the study-wide means of 59.19 µg m^{-3} $PM_{2.5}$ and 96.75 µg m^{-3} PM_{10} would be approximately 3.9-fold and 2.1-fold the WHO 24-hour guideline levels. This conditional comparison indicates potential environmental significance but should not be interpreted as an exposure or epidemiological risk estimate (Tiwari *et al*., 2014) (United States Environmental Protection Agency (USEPA, 2018).

Implications for environmental management

The concentration contrast identified in Zone B supports spatially targeted monitoring and management rather than relying solely on corridor-wide averages. High-concentration grids should be prioritised for direct observation of traffic intensity, idling, commercial combustion, construction activity and road-dust loading. Where relatively low $PM_{2.5}$/PM_{10} ratios coincide with elevated PM_{10}, road-surface dust, unpaved shoulders, material handling and resuspension should be investigated. Such source-screening priorities are consistent with the multi-source character of particulate pollution documented for Indian cities (Gupta & Christopher, 2009) (Hopke, 2016).

The present framework is particularly useful as a screening stage. A subsequent campaign should add repeated seasonal observations, meteorological measurements, chemical speciation, and receptor modelling so that the observed spatial patterns can be translated into quantitative source contributions.

Limitations and required next-phase measurements

The analytical dataset contains only 16 observations, with four observations per zone, which limits statistical power and prevents robust characterisation of temporal variability. Sampling dates, averaging time, instrument model, detection limits, calibration procedures, field blanks and quality-assurance/quality-control information were not supplied and should be added before submission if available. Meteorological variables such as wind speed and direction, temperature, relative humidity, boundary-layer conditions and precipitation were not supplied. No chemical speciation data were available; consequently, source labels are presented only as source-sensitive interpretations and not as quantitative source apportionment.

Geographic coordinates were not supplied. The revised manuscript therefore does not retain the original IDW/contour panels, because interpolation based on grid indices should not be presented as georeferenced GIS mapping. The study does not estimate individual exposure or health risk. The WHO comparison is conditional on the unknown averaging period. Future work should combine repeated seasonal sampling with elemental/organic carbon, water-soluble ions, trace elements and receptor modelling such as positive matrix factorisation or chemical mass balance.

Conclusion

The supplied 16-grid dataset demonstrates strong spatial heterogeneity in urban particulate matter, with $PM_{2.5}$ ranging from 12 to 165 µg m^{-3} and PM_{10} from 28 to 260 µg m^{-3}. The two fractions were tightly coupled ($r = 0.998$; $R^2 = 0.996$), indicating that their spatial variability was strongly linked across the sampled grids. The grid-level $PM_{2.5}/PM_{10}$ ratio averaged 0.578 and ranged from 0.429 to 0.709, demonstrating meaningful variation in the relative fine/coarse burden.

Zone B was the principal relative concentration hotspot, with mean $PM_{2.5}$ of 141.25 µg m^{-3} and PM_{10} of 227.50 µg m^{-3}, while Zone C had the lowest mean concentrations and the lowest mean ratio. The statistically significant zone differences demonstrate that corridor-scale spatial structure is substantial within the supplied observations.

The principal contribution of the study is a transparent source-screening framework rather than a definitive source-apportionment model. The results can guide targeted field investigation of traffic, combustion and road-dust processes, while the identified data gaps define the next phase of monitoring required for quantitative source attribution.

Acknowledgments

Authors are thankful to the Department of Zoology and Environmental Science, Gurukula Kangri (Deemed to be a University), for providing necessary facilities.

Funding

This research received no external funding.

Ethical Statement

The study does not require any ethical approval.

Use of Artificial Intelligence (AI) Tools

The authors confirm that they did not use any artificial intelligence (AI) tools in the preparation, analysis, or writing of this manuscript.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Board, Central Pollution Control (2020). National air quality index report.

Fatima, S., Ahlawat, A., Mishra, S.K., Maheshwari, M., & Soni, V.K. (2022). Variations and source apportionment of PM2.5 and PM10 before and during covid-19 lockdown phases in delhi, india. *Mapan*, 37(4), 937-955. https://doi.org/10.1007/s12647-021-00506-5

Gupta, P. & Christopher, S.A. (2009). Particulate matter air quality assessment using integrated surface, satellite, and meteorological products. *Atmospheric Environment*, 43(2), 294-303.

Guttikunda, S.K. & Goel, R. (2013). Health impacts of particulate pollution in a megacity—Delhi, India. *Environmental Development*, 6, 8-20. https://doi.org/10.1016/j.envdev.2012.12.002

Guttikunda, S.K., Goel, R., & Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. *Atmospheric Environment*, 95, 501-510. https://doi.org/10.1016/j.atmosenv.2014.07.006

Hopke, P.K. (2016). Review of receptor modelling methods for source apportionment. *Journal Of The Air & Waste Management Association*, 66(3), 237-259.

Kumar, V., Yadav, M., & Behera, S.N. (2022). Characterisation of PM 2.5-bound trace elements, source apportionment, and assessment of associated human health risks during summer and winter in Greater Noida, the national capital region of India. *Frontiers In Environmental Science*, 10, 949913. https://doi.org/10.3389/fenvs.2022.949913

Pant, P. & Harrison, R.M. (2012). Critical review of receptor modelling for particulate matter: a case study in India. *Atmospheric Environment*, 49, 1-12. https://doi.org/10.1016/j.atmosenv.2011.11.060

Pope, C.A. & Dockery, D.W. (2006). Health effects of fine particulate air pollution: lines that connect. *Journal Of The Air & Waste Management Association*, 56(6), 709-742. https://doi.org/10.1080/10473289.2006.10464485

Seinfeld, J.H. & Pandis, S.N. (2016). Atmospheric chemistry and physics: from air pollution to climate change.

Sharma, M. & Dikshit, O. (2016). Comprehensive study on air pollution and greenhouse gases in Delhi.

Spandana, B., Srinivasa Rao, S., Upadhya, A.R., Kulkarni, P., & Sreekanth, V. (2021). PM2.5/PM10 ratio characteristics over urban sites of India. *Advances In Space Research*, 67(10), 3134-3146. https://doi.org/10.1016/j.asr.2021.02.008

Tiwari, S., Chate, D.M., Srivastava, M.K., Bisht, D.S., Padmanabhamurty, B., & Sharma, M. (2014). Statistical evaluation of PM2.5 and PM10 concentrations in Delhi. *Environmental Monitoring And Assessment*, 186, 123-135.

United States Environmental Protection Agency (USEPA). (2018).

Organization, World Health (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide. https://doi.org/10.2471/9789240034228

Yadav, S., Tripathi, S.N., & Rupakheti, M. (2022). Current status of source apportionment of ambient aerosols in India. *Atmospheric Environment*, 274, 118987. https://doi.org/10.1016/j.atmosenv.2022.118987

Zhang, R., Wang, G., Guo, S., Zamora, M.L., Ying, Q., Lin, Y., Wang, W., Hu, M., & Wang, Y. (2015). Formation of urban fine particulate matter. *Chemical Reviews*, 115(10), 3803-3855. https://doi.org/10.1021/acs.chemrev.5b00067

Zhou, Y. & Levy, J.I. (2007). Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. *BMC Public Health*, 7, 89. https://doi.org/10.1186/1471-2458-7-89

Publisher's Note: The ASEA remains neutral with regard to jurisdictional claims in published maps and figures