Original Article

Effect of Particulate Matter Air Pollution on High-sensitivity C-reactive Protein: A Cross-sectional Observational Study with Ambispective Data Collection in Tiruchirappalli District, Tamil Nadu

P. Rajkumar, Nakkeeran Mathivanan[1], Sharon Reginald

Department of Pathology, Dhanalakshmi Srinivasan Medical College and Hospitals, Perambalur, [1]Department of Biochemistry, Swamy Vivekananda Medical College Hospital and Research Institute, Namakkal, Tamil Nadu, India

Abstract

Background: Ambient particulate matter (PM) exposure has been linked with systemic inflammation, and high-sensitivity C-reactive protein (hs-CRP) is a well-established subclinical biomarker of inflammatory activity. This study examined the relationship between ambient PM concentrations and serum hs-CRP levels in apparently healthy adults. **Methodology:** This observational study used ambispective data collection within a cross-sectional analytical framework. Healthy adult residents were prospectively enrolled during 2026 following ethics approval and written informed consent. For each participant, serum hs-CRP results generated during January–February 2025 were retrieved retrospectively from the independent NABL-accredited Diagnostic Laboratory in Dhanalakshmi Srinivasan Medical College and Hospitals. Ambient PM2.5, PM10, and Air Quality Index data for the same period were obtained from the Central Pollution Control Board archive, ensuring temporal alignment of exposure and outcome. Participants were classified into low-exposure (Group A; $n = 30$) and high-exposure (Group B; $n = 30$) groups using residential, occupational, and ambient air quality criteria. **Results:** The mean hs-CRP was significantly higher in Group B than in Group A (5.03 ± 1.64 versus 1.55 ± 0.40 mg/L; Welch's $t = 11.27$, $P < 0.000001$). The difference was confirmed by the Mann–Whitney U-test ($U = 899.0$, $P < 0.000001$), with a very large effect size (Cohen's $d = 2.91$) and a mean difference of 3.48 mg/L (95% confidence interval: 2.88–4.09). In Group B, 96.7% of participants were in the high-risk hs-CRP band (>3 mg/L), whereas all Group A participants were within the moderate-risk band (1–3 mg/L). **Conclusion:** Higher ambient PM exposure was strongly associated with higher serum hs-CRP concentrations. Given the cross-sectional design, these findings indicate the association rather than causation.

Key words: Air pollution, C-reactive protein, high-sensitivity C-reactive protein, India, particulate matter, particulate matter 10, particulate matter 2.5, systemic inflammation, Tamil Nadu, Tiruchirappalli

Address for correspondence: Dr. P. Rajkumar, Department of Pathology, Dhanalakshmi Srinivasan Medical College and Hospitals, Siruvachur, Perambalur - 621 113, Tamil Nadu, India.
E-Mail: suzell@outlook.com

Introduction

Ambient particulate matter (PM) is a well-recognized environmental hazard capable of inducing a systemic inflammatory response through oxidative stress-mediated pathways. Fine particles ≤2.5 μm in aerodynamic diameter (PM2.5) and coarser

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particles (PM10, ≤10 μm in aerodynamic diameter) are inhaled into the respiratory tract, with the finer fraction able to penetrate the systemic circulation and trigger downstream release of proinflammatory mediators, including activation of the nuclear factor-kappa B cascade.[1,2]

C-reactive protein (CRP), synthesized by hepatocytes under stimulation from interleukin-6 and tumor necrosis factor-alpha, is an established acute-phase reactant widely used to detect subclinical inflammatory states and to stratify cardiovascular risk.[1] India carries a disproportionately heavy burden of ambient air pollution; nevertheless, population-level evidence linking PM exposure to inflammatory markers remains sparse among communities in the southern regions of the country.[3,4]

Tiruchirappalli is a rapidly expanding secondary urban center in central Tamil Nadu. It is characterized by dense population concentrations, developing transport networks, small-to-medium industrial enterprises, thermal power generation facilities, and periodic biomass combustion associated with agricultural cycles. These emission sources collectively sustain elevated ambient particulate loads, making the district an informative setting for examining pollution-linked inflammatory outcomes. The present investigation was designed to evaluate how ambient concentrations of PM2.5, PM10, and the Air Quality Index (AQI) relate to circulating high-sensitivity C-reactive protein (hs-CRP) levels among healthy long-term residents of this district.

Methodology

Ethics approval and consent to participate

The research protocol was reviewed and approved by the Institutional Ethics Committee before commencement of any study activity (Approval Reference: IECHS/IRCHS/1061/2026). The investigation was carried out in full accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from every participant after explaining the purpose, procedures, potential risks, and benefits of the study. Participation was voluntary, and participants could withdraw at any time without penalty or loss of benefit.

Study design and setting

This was an observational study employing ambispective data collection within a cross-sectional analytical framework. The design combined a prospective enrolment component with retrospective ascertainment of the outcome. Participant identification, informed consent, demographic assessment, anthropometric measurement, and exposure classification were performed prospectively during 2026 following ethics approval. Serum hs-CRP laboratory records corresponding to January–February 2025 were then retrieved retrospectively from hospital investigational archives. Because hs-CRP measurements were compared against ambient air quality data from the same time window, Central Pollution Control Board (CPCB) PM2.5, PM10, and AQI data for January–February 2025 were obtained to ensure temporal alignment of exposure and outcome.

Clarification of design terminology and rationale for consent

Although the hs-CRP outcome data were obtained retrospectively from existing laboratory records, participants were identified and enrolled prospectively in 2026. Written informed consent was, therefore, both necessary and obtained for the prospective study procedures (structured questionnaire, anthropometric measurement, and exposure classification) and for authorized access to and use of participants' retrospective laboratory records. The study is accordingly not purely retrospective: consent pertains to the prospective components and to the authorized access to existing laboratory records. The combination of prospective enrolment with retrospective outcome ascertainment is best described as ambispective data collection, while the analytical comparison of two exposure-defined groups at a single conceptual time point is cross-sectional in nature.

The study was conducted in Tiruchirappalli District, Tamil Nadu, South India. Hourly ambient air quality data for PM2.5, PM10, AQI, temperature, and relative humidity were obtained from the operational monitoring stations of the CPCB within the district (St. Joseph College, Trichy).[5] Daily mean values were calculated from hourly readings during the study period. AQI ranged from moderate to poor (35–106), with a mean PM10 of 76.4 ± 18.1 μg/m^3 and a mean PM2.5 of 59.5 ± 14.2 μg/m^3. PM2.5 values frequently approached or exceeded the 24-h National Ambient Air Quality Standard (NAAQS) threshold of 60 μg/m^3, while PM10 levels occasionally neared or exceeded the NAAQS limit of 100 μg/m^3.

Participants

Inclusion criteria

Healthy permanent residents of Tiruchirappalli District aged 18–75 years who had lived continuously in the same locality for a minimum of 5 years, were willing to provide written informed consent, and were free from clinically apparent acute or chronic inflammatory conditions at enrolment, as verified through self-report and brief clinical examination.

Exclusion criteria

Documented cardiovascular disease, chronic obstructive pulmonary disease, bronchial asthma, diabetes mellitus, or other chronic inflammatory or metabolic disorders; current treatment with anti-inflammatory agents, statins, or any medication known to influence CRP concentrations; acute illness, infection, or surgical intervention within the preceding four weeks; pregnancy or lactation; occupational contact with recognized inflammatory hazards unrelated to general ambient air pollution (for example, chemical manufacturing or mining); and incomplete demographic or laboratory records.

Participants were recruited from community settings across Tiruchirappalli District through purposive sampling facilitated by community health centers, residential welfare associations, and personal referrals. After informed consent, participants were screened for eligibility, data were collected using a structured questionnaire, and anthropometric parameters were

assessed. Only participants with hs-CRP laboratory records generated during January–February 2025 at NABL-accredited laboratories were included. Recruitment continued until the target sample of 60 participants was attained. Participant flow is summarized in Figure 1.

Exposure classification and assessment

Participants were classified into two exposure groups at recruitment on the basis of residential location and employment pattern. Group A (low exposure, $n = 30$) comprised individuals living in relatively low-pollution areas, mostly rural or village settings, primarily employed in indoor occupations with minimal routine exposure to traffic emissions or industrial discharge. Group B (high exposure, $n = 30$) comprised individuals living within 1 km of major traffic corridors, industrial sites or known high-pollution areas, and/or working in predominantly outdoor occupations with frequent exposure to traffic or industrial emissions.

The classification framework incorporated residential proximity to major pollution sources, occupational exposure characteristics, and CPCB monitoring station data. The low-exposure classification required residence in predominantly rural or low-traffic settings located more than 5 km from major traffic corridors or industrial zones, together with predominantly indoor employment and average PM2.5 concentrations below 40 μg/m^3. The high-exposure classification required residence within 1 km of major traffic corridors or industrial areas and/or predominantly outdoor employment, with corresponding CPCB monitoring station PM2.5 concentrations exceeding 60 μg/m^3 during the study period. Exposure classification, therefore, reflected both residential and occupational determinants of ambient PM exposure.

Variables

Outcome variable

The primary outcome was serum hs-CRP concentration (mg/L), treated as a continuous variable for between-group comparison and additionally classified into recognized cardiovascular risk strata: low risk (<1.0 mg/L), moderate risk (1.0–3.0 mg/L), and high risk (>3.0 mg/L).

Exposure variables

The principal exposure indicators were ambient PM2.5 (μg/m^3), PM10 (μg/m^3), and the composite AQI, available at CPCB monitoring station level and linked to participant groups through residential proximity. PM2.5 and PM10 were treated as continuous variables for descriptive purposes, and AQI was treated categorically (moderate versus poor).

Predictor variable

The main predictor was group assignment (Group A versus Group B), representing differential levels of ambient PM exposure.

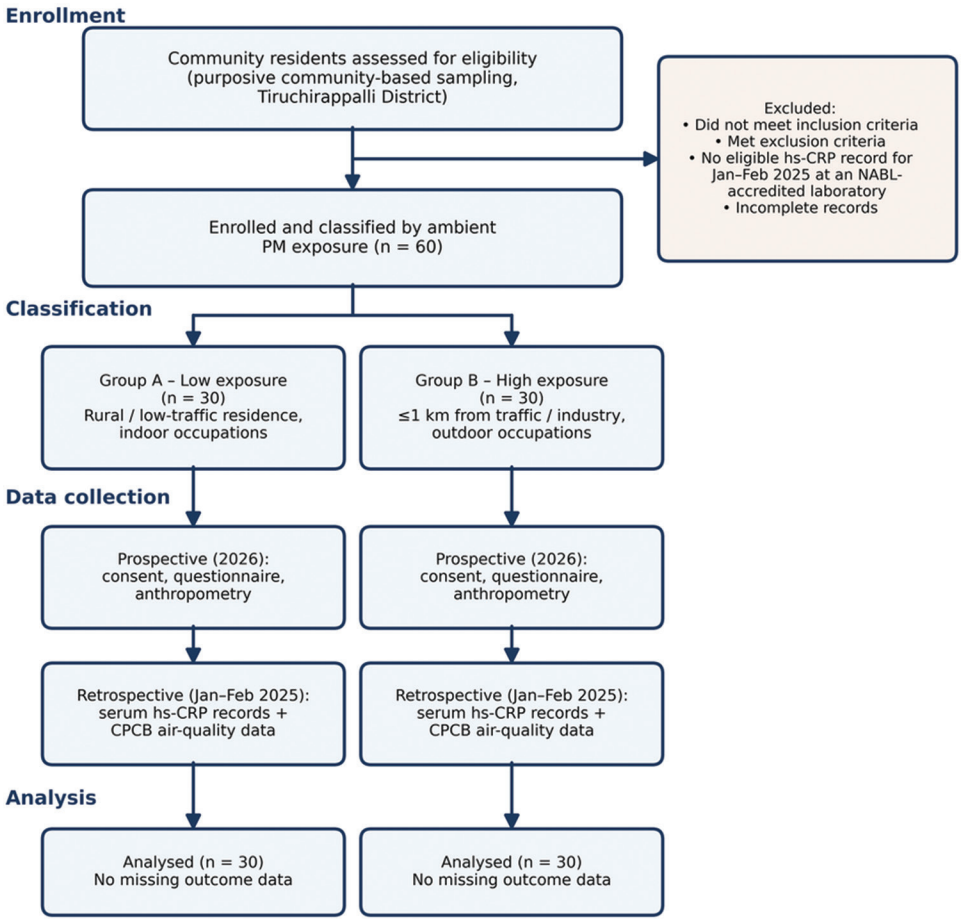

Figure 1: STROBE participant flow diagram showing eligibility assessment, exposure group classification, ambispective data collection, and analysis.

Potential confounders

Confounders selected from the literature and biological reasoning included age (years, continuous), sex, body mass index (BMI) (kg/m^2, continuous), and smoking status (current, former, never). Prespecified effect modifiers comprised sex and BMI category; however, formal effect-modification analysis was not undertaken given the restricted sample size.

Laboratory methods

Serum hs-CRP values were gathered retrospectively from existing medical records held at the participating diagnostic center. These records contained hs-CRP measurements performed as part of participants' prior clinical evaluations or health-screening visits to the NABL-accredited Laboratory in Dhanalakshmi Srinivasan Medical College and Hospitals.

All hs-CRP assays had been performed by automated immunoturbidimetric and nephelometric methods with a minimum analytical sensitivity of 0.3 mg/L. Venous blood samples (5 mL) had been collected under standardized aseptic conditions by qualified phlebotomists, with serum separated by centrifugation within 2 h of collection and stored at 2°C–8°C until analysis. Only records meeting the following criteria were included: (i) blood collection date within the study window of January–February 2025 and (ii) no history of acute illness, infection, or anti-inflammatory medication use at the time of the original blood draw, as verified through accompanying clinical notes. Records lacking hs-CRP results or complete documentation were excluded. Data were extracted using a structured data collection form, with double-entry verification by two independent investigators.

Data collection

Demographic and clinical information were gathered through a structured, interviewer-administered questionnaire together with standardized anthropometric assessment. Age was self-reported and verified against government-issued identification, and sex was self-reported. Standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and body weight to the nearest 0.1 kg using a calibrated digital scale, with participants in light clothing and without footwear. BMI was computed as weight (kg) divided by height (m) squared. Smoking status was categorized as current smoker (any tobacco use within the past 30 days), former smoker (regular past use with abstinence exceeding 30 days), or never smoker.

Bias mitigation measures

Selection bias

Participants were recruited using purposive community-based sampling according to the predefined eligibility criteria.

Exposure misclassification

Clear spatial criteria anchored to verified distances from pollution sources and to independently confirmed CPCB station readings were used to define exposure groups, with dual-investigator review of all assignments. As personal air monitoring was not available, the potential for residual exposure misclassification is addressed explicitly in the discussion and limitations.

Measurement bias

All hs-CRP measurements were performed using standardized assay platforms under established internal and external quality control procedures at the NABL-accredited Laboratory (Central Lab), minimizing analytical variability.

Confounding

Key demographic and lifestyle factors, namely age, sex, BMI, and smoking status, were systematically recorded and compared between groups. Although no statistically significant baseline differences were observed, residual confounding from measured and unmeasured variables cannot be excluded.

Recall bias

Recall bias was inherently limited because the primary exposure (ambient PM) was measured objectively through regulatory monitoring stations and the outcome (hs-CRP) through standardized biochemical assay.

Statistical analysis

Sample size justification

As an exploratory pilot investigation, a target of 30 participants per exposure group was adopted. This exceeds the minimum of 12 participants per group recommended for pilot studies to yield stable variance estimates for subsequent definitive studies.[6] For orientation, applying the framework for comparison of two independent means described by Charan and Biswas,[7] detection of a conservatively assumed large standardized effect (Cohen's $d \approx 0.8$) with two-sided $\alpha = 0.05$ and 80% power requires approximately 26 participants per group; 30 per group was, therefore, selected to allow for incomplete records. No formal adjustment for multiple comparisons or multivariable modeling was planned, and the study was not powered for subgroup analyses.

Continuous variables were summarized as mean ± standard deviation and median (interquartile range [IQR]); categorical variables were summarized as frequencies and percentages. Normality of hs-CRP distributions was evaluated with the Shapiro–Wilk test and visual inspection of histograms. For descriptive and contingency analyses, hs-CRP was categorized into low- (<1.0 mg/L), moderate- (1.0–3.0 mg/L), and high-risk (>3.0 mg/L) bands. Baseline characteristics were compared using Welch's independent *t*-test for continuous measures (age and BMI) and the Chi-square test for categorical variables (sex, smoking status, and BMI category); homogeneity of variance was assessed with Levene's test.

The principal comparison of hs-CRP between exposure groups used Welch's independent *t*-test, which does not assume equal variances, together with the Mann–Whitney *U*-test as a nonparametric alternative; both were appropriate given the observed nonnormal distribution and heterogeneous variance. Effect magnitude was quantified using Cohen's *d* (thresholds 0.2: small, 0.5: medium, 0.8: large, and >0.8: very large), and

the mean difference with its 95% confidence interval (CI) was calculated. Risk-category distributions were compared using Fisher's exact test. Given the modest sample size and exploratory nature of the study, primary analyses focused on unadjusted comparisons; multivariable adjustment was not undertaken, so residual confounding cannot be excluded. The complete absence of high-risk individuals in Group A precluded reliable odds ratio estimation. All tests were two-tailed with significance at $P < 0.05$. Analyses were conducted in IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, New York, USA) Statistics and independently verified with Python version 3.11 (SciPy, NumPy, and Pandas; Python Software Foundation, Wilmington, Delaware, USA).

Results

Baseline characteristics

Sixty healthy individuals (30 per exposure group) were enrolled; participant flow is shown in Figure 1. Baseline demographic and clinical characteristics are presented in Table 1. No statistically significant between-group differences were detected for age, sex distribution, smoking status, or BMI (all $P > 0.05$), indicating broadly comparable baseline characteristics across the two exposure groups. A summary of ambient air quality during the study period is given in Table 2, and the exposure-classification criteria are detailed in Table 3.

Table 1: Baseline demographic and clinical characteristics of study participants ($n=30$)

Parameter	Group A	Group B	Statistical test	*P*
Age (years)	43.5±15.4	41.1±17.0	Welch's *t*-test	0.569
Sex				
Male	17 (56.7)	13 (43.3)	χ^2	0.439
Female	13 (43.3)	17 (56.7)	χ^2	0.439
Smoking	3 (10.0)	8 (26.7)	χ^2	0.182
BMI (kg/m^2)	23.93±2.76	25.12±3.12	Welch's *t*-test	0.121
Normal BMI	20 (66.7)	14 (46.7)	χ^2	0.155
Overweight BMI	10 (33.3)	14 (46.7)	χ^2	0.155
Obese BMI	0	2 (6.7)	χ^2	0.155
hs-CRP (mg/L)	1.55±0.40	5.03±1.64	Welch's *t*-test	<0.001
Mean difference	-	+3.48 mg/L	Cohen's *d*	2.91 (very large)

Data are mean±SD or *n* (%). $P<0.001$ denotes a highly significant difference. hs-CRP: High-sensitivity C-reactive protein, SD: Standard deviation, BMI: Body mass index

Table 2: Ambient air quality summary (January-February 2025)

Parameter	Mean±SD	Median	Range	Indian NAAQS
PM2.5 (μg/m^3)	59.5±14.2	62	28–84	60
PM10 (μg/m^3)	76.4±18.1	80	35–106	100
AQI	76.4±18.1	80	35–106	-
Temperature (°C)	25±3	25	20–31	-
Relative humidity (%)	67±7	68	52–84	-

PM10 was the predominant pollutant contributing to AQI values during the study period; therefore AQI statistics closely mirrored PM10 concentrations. PM2.5 and PM10 frequently approached or exceeded the Indian NAAQS. NAAQS: National Ambient Air Quality Standards, SD: Standard deviation, PM: Particulate matter, AQI: Air Quality Index

Comparison of high-sensitivity C-reactive protein levels between groups

Serum hs-CRP concentrations were markedly higher in Group B (high exposure) than in Group A (low exposure). Group B recorded a mean hs-CRP of 5.03 ± 1.64 mg/L (median: 4.67 mg/L; IQR: 4.25–5.35 mg/L; range: 2.31–11.91 mg/L), whereas Group A showed a mean of 1.55 ± 0.40 mg/L (median: 1.42 mg/L; IQR: 1.32–1.81 mg/L; range: 1.00–3.00 mg/L). Across the whole sample (n = 60), hs-CRP averaged 3.29 ± 2.15 mg/L (median: 3.18 mg/L; IQR: 1.42–5.03 mg/L; range: 1.00–11.91 mg/L). Both group distributions were right-skewed (skewness: 1.49 for Group A and 2.52 for Group B; overall skewness: 1.51).

Welch's independent t-test yielded $t = 11.27$, $P < 0.000001$, with a very large effect size (Cohen's $d = 2.91$), and the Mann–Whitney U-test confirmed the finding ($U = 899.0$, $P < 0.000001$). The estimated mean difference between groups was 3.48 mg/L (95% CI: 2.88–4.09). Normality testing revealed significant departures from normality in both groups (Shapiro–Wilk: Group A – $W = 0.863$, $P = 0.001$; Group B – $W = 0.736$, $P < 0.001$), and Levene's test confirmed heterogeneous variances ($F = 5.87$, $P = 0.019$), supporting the use of robust, variance-adjusted and nonparametric methods.

Risk stratification analysis

Risk-category analysis demonstrated a pronounced divergence between the two exposure groups [Table 4]. All 30 (100%) participants in Group A fell within the moderate-risk band (1.0–3.0 mg/L). In Group B, 29 (96.7%) of 30 participants were classified as high risk (>3.0 mg/L), including one individual with a markedly elevated hs-CRP of 11.91 mg/L. No Group A participants exceeded 3.0 mg/L, and no Group B participants registered below 2.31 mg/L. Fisher's exact test revealed a highly significant difference in the distribution of risk categories between groups ($P < 0.001$). Because Group A contained no high-risk individuals, the odds ratio could not be reliably estimated owing to complete separation between the groups.

Discussion

This investigation revealed a pronounced positive association between higher ambient PM exposure and systemic inflammatory burden, reflected by elevated serum hs-CRP

Table 3: Exposure-classification characteristics

Variable	Group A (low exposure)	Group B (high exposure)
Residential setting	Predominantly rural/low-traffic	Predominantly urban/high-traffic
Distance from major pollution sources	>5 km	≤1 km
Occupational profile	Mainly indoor occupations	Mainly outdoor occupations
Mean PM2.5 category	<40 μg/m³	>60 μg/m³
Exposure classification basis	Residential+occupational+CPCB data	Residential+occupational+CPCB data

CPCB: Central pollution control board, PM: Particulate matter

Table 4: Risk stratification of high-sensitivity C-reactive protein across exposure groups (n=30)

Risk category (hs-CRP)	Group A	Group B	Fisher's exact test
Low risk (<1.0 mg/L)	0	0	-
Moderate risk (1.0–3.0 mg/L)	30 (100)	1 (3.3)	P<0.000001
High risk (>3.0 mg/L)	0	29 (96.7)	P<0.000001

OR could not be reliably estimated owing to complete separation between groups (no high-risk individuals in Group A). OR: Odds ratio, hs-CRP: High-sensitivity C-reactive protein

concentrations, among a healthy population in Tiruchirappalli District, Tamil Nadu. Individuals classified under high-exposure conditions displayed substantially greater hs-CRP levels than their low-exposure counterparts. Notably, the mean hs-CRP of 5.03 mg/L in the high-exposure group lies well above the 3.0 mg/L threshold defining high cardiovascular risk, pointing to clinically meaningful low-grade systemic inflammation even in the absence of overt disease.

Biological plausibility

The positive relationship between PM exposure and hs-CRP elevation rests on well-characterized biological mechanisms.[1,2] Inhalation of fine PM, particularly PM2.5, promotes oxidative stress within pulmonary tissue and triggers inflammatory signaling cascades, prominently involving activation of the nuclear factor-kappa B pathway.[1] This transcriptional response drives release of proinflammatory cytokines, notably interleukin-6 and tumor necrosis factor-alpha, which stimulate hepatic production of CRP.[1,2] The small aerodynamic diameter of PM2.5 particles (≤2.5 μm) permits deep alveolar penetration and potential translocation into the systemic circulation, endowing this fraction with greater biological potency than coarser particles.[8]

Comparison with existing literature: National context

Evidence from India specifically remains limited, underscoring the value of the present data. Mitra *et al*.[3] reported associations between indoor PM, serum CRP, and cardiopulmonary health among biomass-using rural Indian women, consistent with the inflammatory gradient observed here. Beyond India, work from other low- and middle-income settings similarly supports the relationship: Ihim *et al*.[9] documented elevated hs-CRP and interleukin-4 among occupationally exposed cooks, reinforcing the relevance of combustion-derived particulate exposure in developing-country contexts. Our findings extend this sparse national and regional evidence base to an apparently healthy South Indian community exposed to ambient, predominantly traffic- and industry-related PM.

Comparison with existing literature: International context

The present study's results align with a substantial international literature. In East Asian populations, Kim *et al*.[10] reported a positive association between long-term PM and gaseous pollutant exposure and hs-CRP among Korean adults, while Baek *et al*.[11] provided nationwide South Korean evidence of a relationship between ambient PM and elevated hs-CRP. Zeng *et al*.[12] demonstrated that the PM2.5–hs-CRP association was modified by habitual physical activity among Asian adults, and Cho *et al*.[13] observed that low-grade chronic inflammation modified associations between particulate exposure and neuroimaging measures. Chinese cohort studies further corroborate systemic effects: Han *et al*.[14] found that systemic inflammation accentuated the metabolic effects of air pollution in the CHARLS cohort, Huang *et al*.[15] linked pollution to cognitive decline independent of hs-CRP, Yang *et al*.[16] reported effects on peripheral leucocytes and inflammatory biomarkers among rural residents, and Lin *et al*.[17] described airway inflammation and stress responses in young adults.

Evidence from European and North American populations is concordant. Vogli *et al*.[18] reported inflammatory responses to long-term air pollution exposure in the German KORA study, and Azzouz *et al*.[19] observed associations between air pollution and cardiovascular and inflammatory biomarkers in the Swedish Malmö Diet and Cancer cohort. In the United States, Sangaramoorthy *et al*.[20] and Tang *et al*.[21] reported rises in circulating CRP and related plasma proteins with increasing PM exposure. Gogna *et al*.[22] found that multipollutant exposure during pregnancy was associated with higher CRP, and Busenkell *et al*.[23] and Guo *et al*.[24] described modification of PM–inflammation associations by clinical status and reviewed the broader cardiometabolic consequences of air pollution, respectively. Taken together, these national and international studies support the cross-population generalizability of the PM–hs-CRP association observed in the present cohort.

The magnitude of effect detected here (Cohen's d = 2.91) represents a very large effect size and indicates considerable separation between the exposure groups. This substantial divergence likely reflects both the steep exposure gradient characterizing the study groups and the inherently high ambient PM concentrations typical of the study region. The near-complete partitioning of risk categories (100% moderate

risk in the low-exposure group versus 96.7% high risk in the high-exposure group) further underscores the potential clinical relevance of these findings.

Causality and directionality

The strength and consistency of the observed association, together with its biological plausibility, are compatible with a contributory role of ambient PM in systemic inflammation. However, the cross-sectional analytical design does not permit inference of causality or temporal sequence. Exposure status was defined at the group level rather than through individual longitudinal tracking, and unmeasured or residual confounding may contribute to the observed differences. The findings should therefore be interpreted as demonstrating a strong association rather than a proven causal relationship; confirmation of causality would require longitudinal designs with individual-level exposure ascertainment and repeated outcome measurement.

Public health implications

The mean PM2.5 concentration recorded during the study period (59.5 μg/m^3) approached, and frequently exceeds, the Indian NAAQS 24-h limit of 60 μg/m^3 and was frequently exceeded on individual days (range 28–84 μg/m^3); the mean also substantially surpassed the World Health Organization 24-h air quality guideline of 15 μg/m^3. AQI values in the moderate-to-poor range (35–106) suggest that even these ostensibly moderate pollution levels are associated with measurable systemic inflammatory responses among apparently healthy individuals. These observations are relevant to air quality surveillance in rapidly urbanizing secondary cities such as Tiruchirappalli, where monitoring and regulatory infrastructure may be less developed than in major metropolitan areas.

Strengths and limitations

Strengths

The study benefited from a stable permanent resident population with consistent environmental exposure patterns and a clear exposure stratification enabling meaningful between-group comparison. hs-CRP was measured at NABL-accredited laboratories using standardized procedures, and the statistical evidence was robust, as indicated by the large effect size and highly significant *P* values obtained by both parametric and nonparametric methods.

Limitations

Several limitations warrant emphasis. First, and most importantly, the cross-sectional design precludes any inference of causality or temporal ordering between exposure and outcome. Second, individual-level personal air pollution monitoring was unavailable; exposure classification relied on ecological linkage using residential and occupational information together with CPCB monitoring data. This absence of individual exposure measurement may have introduced nondifferential or differential exposure misclassification and is a key constraint on the interpretation of the findings. Third, despite baseline comparability, residual confounding from smoking, diet, physical activity, occupational intensity, socioeconomic status, and other lifestyle factors cannot be excluded, and the higher proportion of smokers in the high-exposure group may have contributed partially to the elevated hs-CRP levels. Fourth, the modest sample size limited statistical power for subgroup analyses and multivariable adjustment. Finally, BMI and smoking status were assessed at enrolment in 2026 rather than at the time of the original hs-CRP measurement in 2025, introducing the possibility of limited temporal misclassification.

Future investigations should incorporate larger samples, longitudinal follow-up, personal exposure monitoring using wearable sensors, and adjustment for additional covariates, including dietary pattern, physical activity, and genetic determinants of inflammatory response. Longitudinal designs would more effectively characterize the temporal dynamics of PM-associated inflammatory change and address the causal questions that the present design cannot resolve.

Conclusion

In this cross-sectional study of healthy residents of Tiruchirappalli District, higher ambient PM exposure was associated with significantly higher serum hs-CRP concentrations, with a very large effect size and near-complete separation of cardiovascular risk categories between the low- and high-exposure groups. Because of the cross-sectional design and the absence of individual-level exposure monitoring, these results should be interpreted as a strong association rather than evidence of causation. Confirmation and quantification of any causal contribution will require adequately powered longitudinal studies with individual exposure assessment.

Authors contribution

RP and NM: Concept and design, definition of intellectual content, literature search, participant recruitment and statistical analysis. NM, RP and SR: Data acquisition, data analysis, interpretation of data, manuscript preparation, manuscript editing, and substantial revision of the manuscript. RP is the guarantor of this article.

Data availability statement

The data that support the findings of this study are accessible from the corresponding author upon reasonable request (suzell@outlook.com).

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Conflicts of interest

There are no conflicts of interest.

References

1. Pryor JT, Cowley LO, Simonds SE. The physiological effects of air pollution: Particulate matter, physiology and disease. Front Public Health 2022;10:882569.
2. Zhang L, Fang B, Wang H, Zeng H, Wang N, Wang M, *et al*. The role of systemic inflammation and oxidative stress in the association of particulate air pollution metal content and early cardiovascular damage: A panel study in healthy college students. Environ Pollut 2023;323:121345.
3. Mitra P, Pradhan S, Chakraborty D, Mukherjee B, Dan U, Mondal N. Assessment of indoor air quality through particulate matter, serum CRP levels and cardiopulmonary health of biomass-using rural women. Atmos Environ 2025;362:121552.
4. Xu R, Li Z, Zhu X, Guo C, Su Q, Peng J, *et al*. Acute effects of exposure to fine particulate matter and ozone on lung function, inflammation and oxidative stress in healthy adults. Ecotoxicol Environ Saf 2022;243:114013.
5. Central Pollution Control Board. National Air Quality Index. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India; 2025. Available from: https://airquality.cpcb.gov.in/AQI_India/. [Last accessed on 2025 Feb 28].
6. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. Pharm Stat 2005;4:287-91.
7. Charan J, Biswas T. How to calculate sample size for different study designs in medical research? Indian J Psychol Med 2013;35:121-6.
8. Hamanaka RB, Mutlu GM. Particulate matter air pollution: Effects on the respiratory system. J Clin Invest 2025;135:e194312.
9. Ihim AC, Iloka JC, Onah CE, Okonkwo CC, Nwosu MC, Udeh EE, *et al*. Evaluation of interleukin-4, high-sensitivity C-reactive protein and activity of alanine transaminase among cooks in Nnewi. J Drug Deliv Ther 2024;14:54-9.
10. Kim JH, Woo HD, Choi S, Song DS, Lee JH, Lee K. Long-term effects of ambient particulate and gaseous pollutants on serum high-sensitivity c-reactive protein levels: A cross-sectional study using KoGES-HEXA data. Int J Environ Res Public Health 2022;19:11585.
11. Baek SU, Won JU, Lee YM, Yoon JH. Association between exposure to ambient particulate matter and high-sensitivity C-reactive protein: A nationwide study in South Korea, 2015–2018. Atmos Environ 2024;339:120856.
12. Zeng YQ, Chan SH, Guo C, Chang LY, Bo Y, Lin C, *et al*. Habitual exercise, chronic exposure to fine particulate matter and high-sensitivity C reactive protein in Asian adults. Occup Environ Med 2022;79:557-65.
13. Cho J, Jang H, Noh Y, Lee SK, Koh SB, Kim SY, *et al.* Associations of particulate matter exposures with brain gray matter thickness and white matter hyperintensities: Effect modification by low-grade chronic inflammation. J Korean Med Sci 2023;38:e159.
14. Han S, Zhang F, Yu H, Wei J, Xue L, Duan Z, *et al.* Systemic inflammation accelerates the adverse effects of air pollution on metabolic syndrome: Findings from the China health and retirement longitudinal study (CHARLS). Environ Res 2022;215:114340.
15. Huang L, Hu X, Liu J, Wang J, Zhou Y, Li G, *et al*. Air pollution is linked to cognitive decline independent of hypersensitive C-reactive protein: Insights from middle-aged and older Chinese. Environ Health 2024;23:111.
16. Yang Y, Wu H, Zeng Y, Xu F, Zhao S, Zhang L, *et al*. Short-term exposure to air pollution on peripheral white blood cells and inflammation biomarkers: A cross-sectional study on rural residents. BMC Public Health 2024;24:1702.
17. Lin Z, Chen P, Yuan Z, Yang L, Miao L, Wang H, *et al*. Fine particulate matter, airway inflammation, stress response, non-specific immune function and buccal microbial diversity in young adults. Environ Pollut 2022;308:119692.
18. Vogli M, Peters A, Wolf K, Thorand B, Herder C, Koenig W, *et al*. Long-term exposure to ambient air pollution and inflammatory response in the KORA study. Sci Total Environ 2024;912:169416.
19. Azzouz M, Xu Y, Barregard L, Fagerberg B, Zöller B, Molnár P, *et al.* Air pollution and biomarkers of cardiovascular disease and inflammation in the Malmö Diet and Cancer cohort. Environ Health 2022;21:39.
20. Sangaramoorthy M, Yang J, Tseng C, Wu J, Ritz B, Larson TV, *et al*. Particulate matter, traffic-related air pollutants, and circulating C-reactive protein levels: The multiethnic cohort study. Environ Pollut 2023;332:121962.
21. Tang Z, Wang Y, Sarnat JA, Diver WR, Everson TM, Deubler E, *et al*. The associations of air pollution mixture exposure with plasma proteins in an elderly U.S. Panel. Environ Sci Technol 2025;59:15692-704.
22. Gogna P, Borghese MM, Villeneuve PJ, Kumarathasan P, Johnson M, Shutt RH, *et al*. A cohort study of the multipollutant effects of PM(2.5), NO(2), and O(3) on C-reactive protein levels during pregnancy. Environ Epidemiol 2024;8:e308.
23. Busenkell E, Collins CM, Moy ML, Hart JE, Grady ST, Coull BA, *et al*. Modification of associations between indoor particulate matter and systemic inflammation in individuals with COPD. Environ Res 2022;209:112802.
24. Guo LH, Zeeshan M, Huang GF, Chen DH, Xie M, Liu J, *et al*. Influence of air pollution exposures on cardiometabolic risk factors: A review. Curr Environ Health Rep 2023;10:501-7.