# ASSOCIATION OF $PM_{2.5}$ WITH INPATIENT ADMISSION FOR SELECTED DISORDERS IN A TERTIARY CARE INSTITUTE IN DELHI

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# ASSOCIATION OF $PM_{2.5}$ WITH INPATIENT ADMISSION FOR SELECTED DISORDERS IN A TERTIARY CARE INSTITUTE IN DELHI

by

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**Submitted**

In the fulfilment of the requirements of the degree of Doctor of Philosophy

**to the**

**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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Dedicated to

my parents

# CERTIFICATE

This is to certify that the thesis entitled "**Association of $PM_{2.5}$ with Inpatient Admission for Selected Disorders in a Tertiary Care Institute in Delhi**", being submitted by **Mr. Shubham Sharma**, to the **Indian Institute of Technology Delhi** for the award of the degree of '**Doctor of Philosophy**' in Department of Civil Engineering is a record of the bonafide research work carried out by her under my supervision and guidance. She has fulfilled the requirements for the submission of this thesis, which to the best of my knowledge has reached the requisite standard.

The material contained in the thesis has not been submitted in part or full to any other University or Institute for the award of any other degree or diploma.


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**(Shubham Sharma)**

# ABSTRACT

Air pollution is a global problem with $PM_{2.5}$ being one of the major pollutants causing many diseases. The concentrations of $PM_{2.5}$ are found to exceed the World Health Organization (WHO) standards especially in lower middle-income countries (LMICs) that house around 40% of the global population. India's air quality is in a dismal state, with many studies ascribing it to $PM_{2.5}$. Systematic review of 247 studies revealed that $PM_{2.5}$ and other air pollutants have been found to be associated with increased mortality and morbidity due to respiratory, cardiovascular, cerebrovascular disorders and diabetes. However, most of the total studies (~ 69%) were carried out in the high-income countries (HICs) even though $PM_{2.5}$ concentrations are higher in the LMICs (annual mean exposure (2011–2017) of 48.42 $\mu g/m^3$) and lower in the HICs (annual mean exposure (2011–2017) of 20.02 $\mu g/m^3$). Therefore, the exposure response functions for mortality estimates associated with $PM_{2.5}$ and developed using the exposure data from the HICs will not have predictive value in the LMICs. Furthermore, very few studies relate chemical components and source apportionment of $PM_{2.5}$ to the associated toxicity.

However, as investigations on the effect of long-term meteorological or emission changes on $PM_{2.5}$ and its components, and their associated health effects are rare, in this study, WRF-Chem simulations for three seasons over four years (2016-2019) were carried out to cogitate the spatial and temporal changes in $PM_{2.5}$ and its components in India. Model predicted $PM_{2.5}$ concentrations were in good agreement with the ground-based observations for 25 cities. $PM_{2.5}$ was highest in winter and lowest in pre-monsoon. $PM_{2.5}$ reduced by ~8% in Indo-Gangetic Plain (IGP) but increased by ~38% and ~130% in south and northeast India, respectively, from 2016-2019. IGP witnessed three times higher average $PM_{2.5}$ concentrations than south India. No significant interannual change in CA contributions was observed, however, it peaked in the winter season. Other inorganics (OIN) were the major component of $PM_{2.5}$, contributing more

than 40%. Primary organic aerosol (POA) fractions were higher in north India, while secondary inorganic aerosol (SIA) dominated south India. Transport and residential sectors were the chief contributors to CA across India. Biomass burning contributed up to ~23% of $PM_{2.5}$ in regions of IGP during post-monsoon, with CA fractions up to 50%.

Additionally, the COVID-19 pandemic was studied to demonstrate the efficacy of emission controls. From March 16th to April 14th, 2017, to 2020, the concentrations of $PM_{10}$, $PM_{2.5}$, CO, $NO_2$, ozone, and $SO_2$ in 22 cities throughout diverse areas of India were analyzed. The levels of $PM_{2.5}$, $PM_{10}$, CO, and $NO_2$ in India dropped by about 43%, 31%, 10%, and 18%, respectively, during the lockdown period, as compared to the levels in prior years. $O_3$ increased by 17 percent, although changes in SO2 were hardly noticeable. In the northern, southern, eastern, central, and western regions of India, the air quality index (AQI) improved by 44, 33, 29, 15, and 32 percent, respectively. Compared to prior years, city-to-city correlations in the north and east improved in 2020, suggesting more regional transportation. The WRF-AERMOD model system was also applied in Delhi-NCR with actual meteorology during the lockdown period and an unfavourable event in early November of 2019 in order to eliminate the effects of potential favourable meteorology. The results show that predicted $PM_{2.5}$ could increase by only 33% in unfavourable meteorology. This analysis assures policymakers that, despite unfavourable weather conditions, air quality may be improved significantly by the stringent use of air quality control measures.

The precise prediction of $PM_{2.5}$ concentrations at high resolutions relies heavily on chemistry and long-range transport, as shown by a comparison of the chemical transport model WRF-Chem with AERMOD, an urban scale Gaussian dispersion model. The performance of AERMOD was rated satisfactory, giving regulators confidence in its usage for rapid decision

making, given high resolution inventories and adequate background concentration adjustments utilizing a one-way coupled modelling system.

When comparing the relationships between $PM_{2.5}$ and its components and daily inpatient admissions at a tertiary care centre in Delhi, we found that $PM_{2.5}$ and OIN had weaker associations than CA. Every 10 $\mu g/m^3$ rise in secondary organic aerosol (SOA) increased the risk of bronchial asthma (BA), coronary artery disease (CAD), chronic obstructive pulmonary disease (COPD), diabetic mellitus (DM), hypertension (HTN), and tuberculosis (TB) by 28%, 74%, 37%, 26%, 18%, 19%, and 10%, respectively. SIA and POA concentrations at lag day 15 enhanced the risk of BA hospitalization by 28 and 9%, respectively. It has been shown that persons over 60 and women are generally at increased risk of being hospitalized. Highest RR for BA, CAD, and DM were found on lag day 15, but the highest relative risk for COPD were identified on lag day 1. This highlights the need for further actions in India to reduce health concerns related with CA rather than $PM_{2.5}$.

Keywords: Relative risks, Lower middle-income countries, Mortality, Morbidity, $PM_{2.5}$, COVID-19, India, AQI, AERMOD, Carbonaceous aerosols, WRF-Chem, Biomass burning, Health effects

# सार

वायु प्रदूषण एक वैश्विक समस्या है, जिसमें PM2.5 प्रमुख प्रदूषकों में से एक है जो कई बीमारियों का कारण बनता है। PM2.5 की सांद्रता विशेष रूप से निम्न मध्यम आय वाले देशों (एलएमआईसी) में विश्व स्वास्थ्य संगठन के मानकों से अधिक पाई गई है, जो वैश्विक आबादी का लगभग 40% है। कई अध्ययन भारत की निराशाजनक वायु गुणवत्ता को PM2.5 से जोड़ते हैं। 247 अध्ययनों की व्यवस्थित समीक्षा से पता चला कि PM2.5 और अन्य वायु प्रदूषक श्वसन, हृदय, मस्तिष्कवाहिकीय विकारों और मधुमेह के कारण मृत्यु दर और रुग्णता में वृद्धि से जुड़े पाए गए हैं। हालाँकि, कुल अध्ययनों में से अधिकांश (~69%) उच्च आय वाले देशों (एचआईसी) में किए गए थे, भले ही PM2.5 सांद्रता एलएमआईसी (48.42 μg/m3 का वार्षिक औसत जोखिम (2011-2017)) में अधिक है और एचआईसी में कम (20.02 μg/m3 का वार्षिक औसत एक्सपोजर (2011-2017))। इसलिए, PM2.5 से जुड़े मृत्यु दर अनुमानों के लिए जोखिम प्रतिक्रिया कार्य और एचआईसी से जोखिम डेटा का उपयोग करके विकसित एलएमआईसी में भविष्य कहनेवाला मूल्य नहीं होगा। इसके अलावा, बहुत कम अध्ययन रासायनिक घटकों और PM2.5 के स्रोत विभाजन को संबंधित विषाक्तता से संबंधित करते हैं।

हालाँकि, PM2.5 और इसके घटकों पर दीर्घकालिक मौसम संबंधी या उत्सर्जन परिवर्तनों के प्रभाव और उनके संबंधित स्वास्थ्य प्रभावों की जांच दुर्लभ है, इस अध्ययन में, चार वर्षों (2016-2019) में तीन मौसमों के लिए WRF-Chem सिमुलेशन, भारत में PM2.5 और इसके घटकों में स्थानिक और लौकिक परिवर्तनों पर विचार करने के लिए किए गए थे। अनुमानित PM2.5 सघनता वाले मॉडल 25 शहरों के लिए जमीन आधारित प्रेक्षणों के अनुरूप थे। PM2.5 सर्दियों में सबसे ज्यादा और पूर्व-मानसून में सबसे कम था। 2016-2019 से भारत-गंगा के मैदान (आईजीपी) में PM2.5 ~8% कम हुआ, लेकिन दक्षिण और पूर्वोत्तर भारत में क्रमशः ~38% और ~130% बढ़ा। आईजीपी ने दक्षिण भारत की तुलना में तीन गुना अधिक औसत PM2.5 सांद्रता देखी। सीए योगदान में कोई महत्वपूर्ण अंतर-वार्षिक परिवर्तन नहीं देखा गया,

हालांकि, यह सर्दियों के मौसम में चरम पर था। अन्य अकार्बनिक (ओआईएन) PM2.5 के प्रमुख घटक थे, जिनका योगदान 40% से अधिक था। प्राथमिक कार्बनिक एरोसोल (पीओए) अंश उत्तर भारत में अधिक थे, जबकि द्वितीयक अकार्बनिक एरोसोल (एसआईए) दक्षिण भारत में हावी थे। पूरे भारत में सीए में परिवहन और आवासीय क्षेत्रों का प्रमुख योगदान था। मॉनसून के बाद आईजीपी के क्षेत्रों में बायोमास बर्निंग ने PM2.5 द्रव्यमान का ~23% तक योगदान दिया, जिसमें सीए अंश 50% तक था।

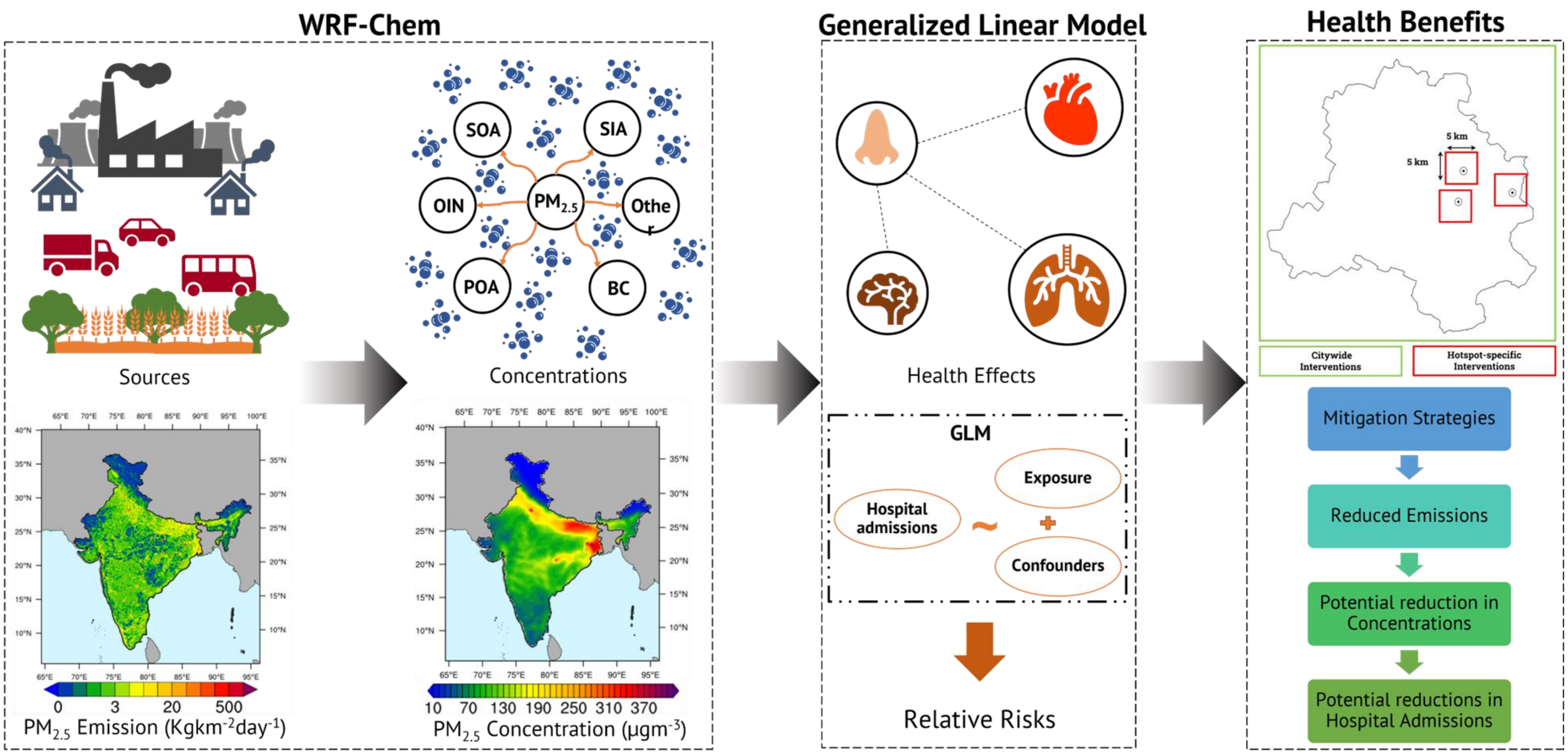
इसके अतिरिक्त, उत्सर्जन नियंत्रण की प्रभावकारिता प्रदर्शित करने के लिए कोविड-19 महामारी का अध्ययन किया गया। 16 मार्च से 14 अप्रैल, 2017 से 2020 तक, भारत के विभिन्न क्षेत्रों के 22 शहरों में PM10, PM2.5, CO, NO2, O3 और SO2 की सांद्रता का विश्लेषण किया गया। भारत में PM2.5, PM10, CO और NO2 के स्तर में पिछले वर्षों के स्तर की तुलना में लॉकडाउन अवधि के दौरान क्रमशः लगभग 43%, 31%, 10% और 18% की गिरावट आई है। O3 में 17 प्रतिशत की वृद्धि हुई, हालाँकि SO2 में परिवर्तन शायद ही ध्यान देने योग्य थे। भारत के उत्तरी, दक्षिणी, पूर्वी, मध्य और पश्चिमी क्षेत्रों में वायु गुणवत्ता सूचकांक (ए.क्यू.आई) में क्रमशः 44, 33, 29, 15 और 32 प्रतिशत का सुधार हुआ है। पिछले वर्षों की तुलना में, 2020 में उत्तर और पूर्व में शहर-दर-शहर सहसंबंध में सुधार हुआ है, जो अधिक क्षेत्रीय परिवहन का सुझाव देता है। WRF-AERMOD मॉडल प्रणाली का उपयोग दिल्ली-एनसीआर में वास्तविक मौसम विज्ञान के साथ लॉकडाउन अवधि के दौरान और संभावित अनुकूल मौसम विज्ञान के प्रभावों को खत्म करने के लिए नवंबर 2019 की शुरुआत में एक प्रतिकूल घटना के साथ भी किया गया था। परिणाम बताते हैं कि पूर्वानुमानित PM2.5 प्रतिकूल मौसम विज्ञान में केवल 33% तक बढ़ सकता है। यह विश्लेषण नीति निर्माताओं को आश्वस्त करता है कि प्रतिकूल मौसम की स्थिति के बावजूद, वायु गुणवत्ता नियंत्रण उपायों के कड़े उपयोग से वायु की गुणवत्ता में काफी सुधार हो सकता है। उच्च रिजॉल्यूशन पर PM2.5 की सघनता का सटीक पूर्वानुमान रसायन और लंबी दूरी के परिवहन पर बहुत अधिक निर्भर करता है, जैसा कि रासायनिक परिवहन मॉडल WRF-Chem की AERMOD के साथ

तुलना करके दिखाया गया है, जो एक शहरी पैमाने का गॉसियन फैलाव मॉडल है। AERMOD के प्रदर्शन को संतोषजनक माना गया था, जिससे नियामकों को तेजी से निर्णय लेने के लिए इसके उपयोग में विश्वास हो गया, उच्च रिज़ॉल्यूशन इन्वेंट्री और पर्याप्त पृष्ठभूमि एकाग्रता समायोजन एक तरफ़ा युग्मित मॉडलिंग प्रणाली का उपयोग कर रहे थे।

दिल्ली में एक तृतीयक देखभाल केंद्र में PM2.5 और इसके घटकों और दैनिक भर्ती रोगी के बीच संबंधों की तुलना करते समय, हमने पाया कि PM2.5 और ओआईएन का सीए की तुलना में कमजोर संबंध था। सेकेंडरी ऑर्गेनिक एयरोसोल (एसओए) में हर 10 μg/m3 वृद्धि से ब्रोन्कियल अस्थमा (बीए), कोरोनरी आर्टरी डिजीज (सीएडी), क्रॉनिक ऑब्सट्रक्टिव पल्मोनरी डिजीज (सीओपीडी), डायबिटिक मेलिटस (डीएम), हाइपरटेंशन (एचटीएन), और तपेदिक (टीबी) क्रमशः 28%, 74%, 37%, 26%, 18%, 19% और 10% का खतरा बढ़ जाता है। एसआईए और पीओए सांद्रता ने अंतराल दिवस 15 पर क्रमशः बीए के अस्पताल में भर्ती होने के जोखिम को 28 और 9% तक बढ़ा दिया। यह दिखाया गया है कि 60 से अधिक व्यक्तियों और महिलाओं को आम तौर पर अस्पताल में भर्ती होने का खतरा बढ़ जाता है। बीए, सीएडी और डीएम के लिए उच्चतम आरआर 15 के अंतराल के दिन पाए गए, लेकिन सीओपीडी के लिए उच्चतम सापेक्ष जोखिम की पहचान पहले दिन हुई। यह PM2.5 के बजाय सीए से संबंधित स्वास्थ्य संबंधी चिंताओं को कम करने के लिए भारत में आगे की कार्रवाई की आवश्यकता पर प्रकाश डालता है।

कीवर्ड: सापेक्ष जोखिम, निम्न मध्य-आय वाले देश, मृत्यु दर, रुग्णता, PM2.5, कोविड-19, भारत, वायु गुणवत्ता सूचकांक, AERMOD, कार्बोनेसियस एरोसोल, WRF-Chem, बायोमास बर्निंग, स्वास्थ्य प्रभाव

# Graphical Abstract



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| | |
|---|---|
| ABVIMS | Atal Bihari Vajpayee Institute of Medical Sciences |
| AIC | Akaike Information Criterion |
| ALS | Amyotrophic lateral sclerosis |
| AOD | Aerosol optical depth |
| AQI | Air Quality Index |
| BB | Biomass burning |
| BC | Black Carbon |
| CA | Carboncaeous aerosol |
| CAAQMS | Continuous ambient air quality monitoring stations |
| CAD | Coronary artery disease |
| CEVD | Cerebrovascular disease |
| CI | Confidence Interval |
| CMAQ | Community Multiscale Air Quality |
| COPD | Chronic obstructive pulmonary disease |
| CPCB | Central Pollution Control Board |
| CVD | Cardio vascular disease |
| DEM | Dementia |
| DM | Diabetes Mellitus |
| DOW | Day of the week |
| DPCC | Delhi Pollution Control Committee |
| ED | Emergency department |
| EDGAR | Emissions Database for Global Atmospheric Research |
| ENE | Energy sector |
| ERR | Excess Relative Risk |
| GBD | Global Burden of Disease |
| GIS | Geographical Information System |
| GLM | Gnerlaized linear model |
| GNI | Gross National Income |
| HIC | High income countries |
| HR | Hazard Ratio |
| HTN | Hypertension |

| | |
|---|---|
| ICD | International Statistical Classification of Diseases and Related Health Problems |
| IER | Integrated Exposure-Response |
| IGP | Indo Gnagetic Plain |
| IHD | Ischemic heart disease |
| IMD | India Meteorological Department |
| IND | Industry sector |
| IQR | Inter quartile range |
| LC | Lung cancer |
| LIC | Low income countries |
| LMIC | Lower middle income countries |
| MEGAN | Model of Emissions of Gases and Aerosols from Nature |
| MFB | Mean fractional bias |
| MFE | Mean fractional error |
| MG | Geometric mean bias |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| NAAQS | National Ambient Air Quality Standards |
| NCAP | National Clean Air Programme |
| NCAR | National Centre for Atmospheric Research |
| NCR | National Capital Region |
| NMB | Normalised mean bias |
| NMSE | Normalized mean square error |
| OIN | Other inorganics |
| OTH | Others sector |
| POA | Primary organic aerosols |
| RD | Respiratory diseases |
| RES | Residential sector |
| RH | Relative humidity |
| RMSE | Root mean square error |
| RR | Relative risks |
| SAFAR | System of Air Quality and Weather Forecasting And Research |
| SIA | Secondary inorganic aerosol |
| SJV | San Joaquin Valley |

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|---|---|
| SOA | Secondary organic aerosol |
| SPM | Suspended particulate matter |
| TB | Tuberculosis |
| TRA | Transport sector |
| UI | Uncertainty Interval |
| UMIC | Upper middle income countries |
| USEPA | United States Environmental Protection Agency |
| VC | Ventilation coefficient |
| VG | Geometric variance |
| WHO | World Health Organization |
| WRF | Weather Research and Forecasting |
| YLD | Life lived with Disability |
| YLL | Years of Life Lost |
| DALY | Disability Adjusted Life Years |
| AECOPD | Accute exacerbation chronic obstructive pulmonary disease |