

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

MAY 2023

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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A handwritten signature in blue ink, reading "Shubham", with a horizontal line underneath it.

(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 µg/m³) and lower in the HICs (annual mean exposure (2011–2017) of 20.02 µg/m³). 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, 2020, the concentrations of PM₁₀, PM_{2.5}, CO, NO₂, ozone, and SO₂ in 22 cities throughout diverse areas of India were analyzed. The levels of PM_{2.5}, PM₁₀, CO, and NO₂ in India dropped by about 43%, 31%, 10%, and 18%, respectively, during the lockdown period, as compared to the levels in prior years. O₃ 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 (एआईसी) में किए गए थे, भले ही PM2.5 सांद्रता एलएमआईसी (48.42 $\mu\text{g}/\text{m}^3$ का वार्षिक औसत जोखिम (2011-2017)) में अधिक है और एआईसी में कम (20.02 $\mu\text{g}/\text{m}^3$ का वार्षिक औसत एक्सपोजर (2011-2017))। इसलिए, PM2.5 से जुड़े मृत्यु दर अनुमानों के लिए जोखिम प्रतिक्रिया कार्य और एआईसी 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) PM_{2.5} 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 PM_{2.5} 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, PM_{2.5}, CO, NO₂, O₃ और SO₂ की सांद्रता का विश्लेषण किया गया। भारत में PM_{2.5}, 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, हालांकि 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 PM_{2.5} प्रतिकूल मौसम विज्ञान में केवल 33% तक बढ़ सकता है। यह विश्लेषण नीति निर्माताओं को आश्चस्त 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 PM_{2.5} 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 PM_{2.5} और इसके घटकों और दैनिक भर्ती रोगी के बीच संबंधों की तुलना करते समय, हमने पाया कि PM_{2.5} और ओआईएन का सीए की तुलना में कमजोर संबंध था। सेकेंडरी ऑर्गेनिक एयरोसोल (एसओए) में हर 10 µg/m³ वृद्धि से ब्रोंकियल अस्थमा (बीए), कोरोनरी आर्टरी डिजीज (सीएडी), क्रॉनिक ऑब्स्ट्रक्टिव 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 PM_{2.5} 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, PM_{2.5}, कोविड-19, भारत, वायु गुणवत्ता सूचकांक, AERMOD, कार्बोनेसियस एरोसोल, WRF-Chem, बायोमास बर्निंग, स्वास्थ्य प्रभाव

Graphical Abstract

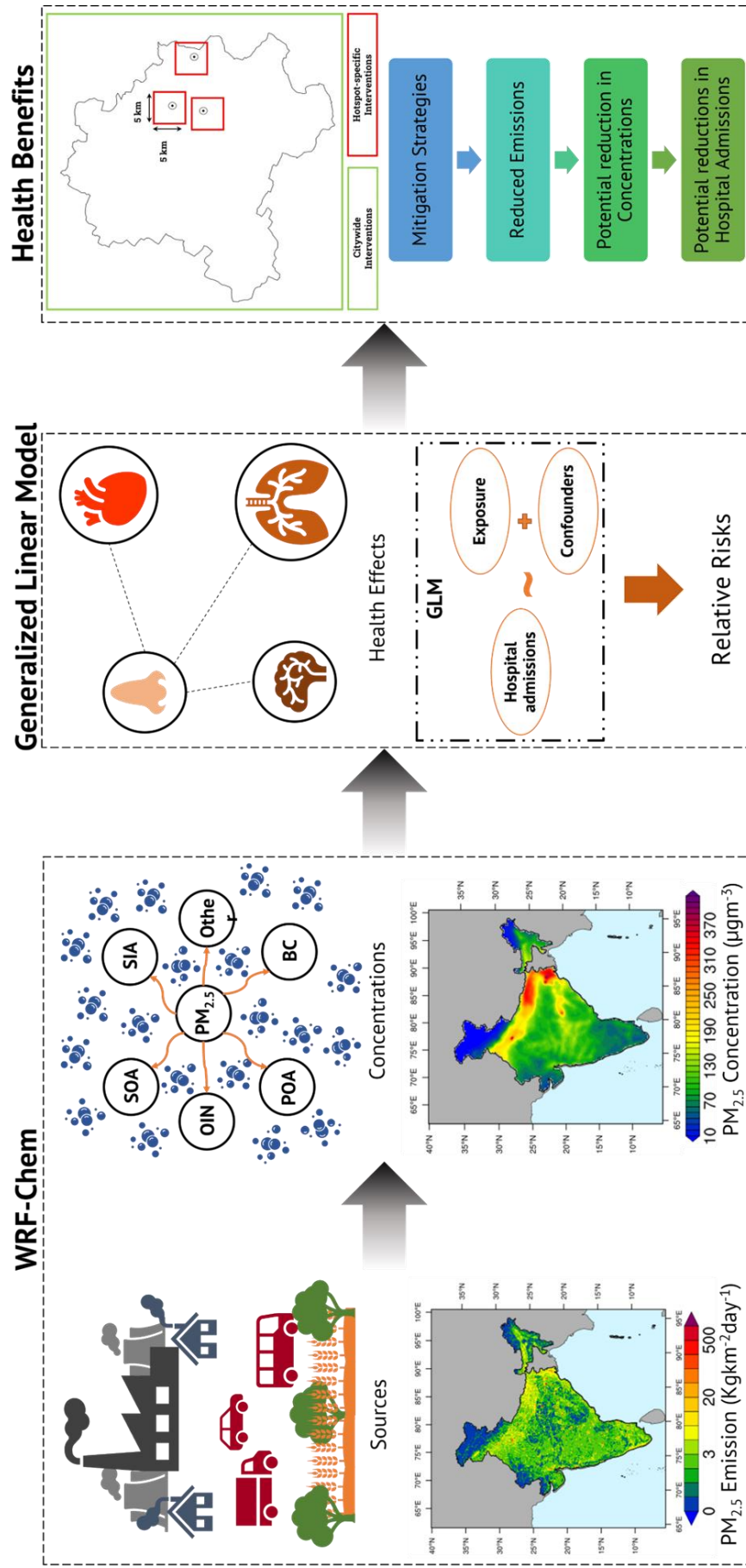


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LIST OF ABBREVIATIONS AND ACRONYMS

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	Carbonaceous 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	Generalized 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

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