IMPACT OF URBAN-RURAL INTERFACE AIR POLLUTION ON AMBIENT AIR QUALITY: A CASE STUDY IN THE DISTRICT OF SAHARANPUR

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by
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CERTIFICATE

This is to certify that the thesis entitled **"Impact of Urban-Rural Interface Air Pollution on Ambient Air Quality: A Case Study in The District of Saharanpur"**, being submitted by **Mr. Gaurav Tomar** to the Indian Institute of Technology Delhi for the award of **"Doctor of Philosophy"** is a record of bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis. To the best of our knowledge, the results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Ambient air pollution levels in Indian regions have been breaching alarming levels regularly. These high air pollution levels lead to substantial human health impacts, which can further translate into loss of livelihood in the available workforce. Addressing the information gap on contribution of various infrastructure sectors to air pollution in smaller Indian cities and rural area, the current work carried out in an Indian district, Saharanpur, estimates high resolution $PM_{2.5}$ emission. The observations suggests that in urban areas of the region; transport, open waste burning, HH cooking fuel, and industries annually contribute 97 tonnes (5%), 368 tonnes (18%), 499 tonnes (24%), and 1121 tonnes (53%) to the total $PM_{2.5}$ emissions, respectively. In rural areas; transport, open waste burning, industries, agriculture residue burning and HH cooking fuel annually contributes 236 tonnes (2%), 1201 tonnes (11%), 1824 tonnes (16%), 3732 tonnes (33%), and 4349 tonnes (38%) to total $PM_{2.5}$ emissions, respectively. These contribution patterns and their high-resolution analysis is critical to finding sources of importance and planning microlevel activities based on individual sector's hotspots to mitigate air pollution and its impact. The results point towards priority for sectors like HH cooking fuel burning, industries, and agriculture residue burning in the region. However, some areas would also require stricter implementation in transportation and solid waste burning sectors, as they can prove to be a critical factor in deciding the air quality of a local hotspot.

Finally, with the help of dispersion modelling and health impact assessment using concentration response function, high resolution health impacts in the study domain are estimated. Estimation of health and livelihood impact on a finer scale is achieved to analyze the varying contribution to and exposure from air pollution in varying demographic and socioeconomic groups. Health and livelihood impact from ambient air pollution among populations in developing countries are disproportional. These disparities are often overlooked due to lack of information on micro-level emission data, especially in smaller cities and rural areas. Therefore, the current work also analyses the health impacts estimated based on the surface $PM_{2.5}$ concentration and suggest that the rate of premature deaths is 158 (95% CI: 122-163) and 143 (95% CI: 65-151) deaths per 1,00,000 people in urban and rural areas, respectively. 68% of the 6372 (95% CI: 3321-6987) annual premature deaths occurs in rural areas. Depicting higher contribution-exposure disparities among socioeconomic groups, the study observed that compared to their contribution to air pollution, low Socioeconomic Status (SES) groups in the region experience 6, 7, 7, 26, and 7% more premature deaths from $PM_{2.5}$ exposure for industries, household cooking fuel burning, open waste burning, and

transportation, respectively. Majority of Daily adjusted Life Years (DALYs) in the study domain are observed in economically weaker worker categories. Reduced income due to loss of these life years will significantly impact these groups due to their dependence on daily wages for basic life necessities.

Micro-level pollution mitigation policies with focus on these inequalities are critical for promoting environmental equity and justice. However, implementation of these micro-level policies would require information on impact of various local and regional sources at a finer scale and studies on improving accuracy of this information would prove critical in the race to achieving clean air for all.

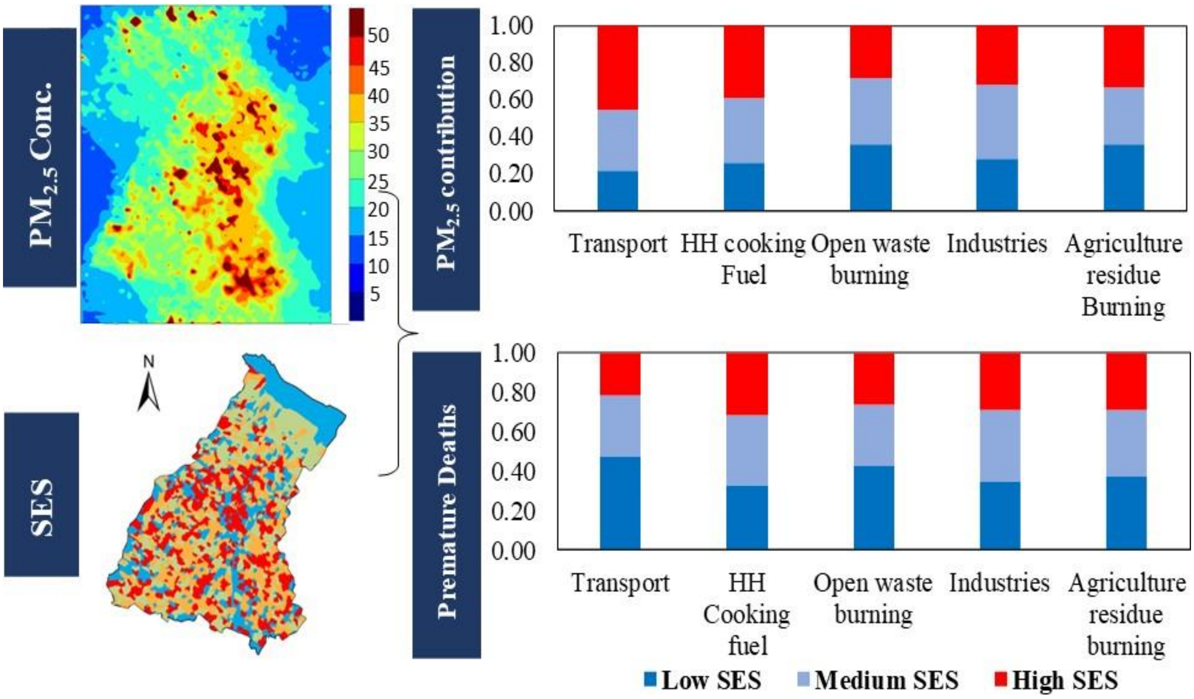
सार

भारतीय क्षेत्रों में परिवेशीय वायु प्रदूषण का स्तर नियमित रूप से खतरनाक स्तर को पार कर रहा है। इन उच्च वायु प्रदूषण स्तरों से मानव स्वास्थ्य पर काफी प्रभाव पड़ता है, जो उपलब्ध कार्यबल की आजीविका को नुकसान पहुंचा सकता है। वर्तमान अध्ययन में छोटे भारतीय शहरों और ग्रामीण क्षेत्रों में होने वाले वायु प्रदूषण में विभिन्न बुनियादी ढांचा क्षेत्रों के योगदान पर सूचना की कमी को संबोधित करते हुए, भारतीय जिले, सहारनपुर में उच्च रिज़ॉल्यूशन पर $PM_{2.5}$ उत्सर्जन का अनुमान लगाया गया है। अवलोकनों से पता चलता है कि शहरी क्षेत्रों में; परिवहन, खुले में कचरा जलाना, घरेलू खाना पकाने का ईंधन, और उद्योग सालाना $PM_{2.5}$ उत्सर्जन में 97 टन (5%), 368 टन (18%), 499 टन (24%) और 1121 टन (53%) का योगदान करते हैं। ग्रामीण क्षेत्रों में; परिवहन, खुले में कचरा जलाना, उद्योग, कृषि अवशेष जलाना और घरेलू खाना पकाने का ईंधन सालाना क्रमशः 236 टन (2%), 1201 टन (11%), 1824 टन (16%), 3732 टन (33%), और 4349 टन (38%) का योगदान देता है। ये योगदान पैटर्न और उनका उच्च-रिज़ॉल्यूशन विश्लेषण वायु प्रदूषण और इसके प्रभाव को कम करने के लिए व्यक्तिगत क्षेत्र के हॉटस्पॉट के आधार पर स्रोतों को खोजने और माइक्रोलेवल गतिविधियों की योजना बनाने के लिए महत्वपूर्ण है। क्षेत्र में घरेलू खाना पकाने का ईंधन जलाने, उद्योगों और कृषि अवशेष जलाने जैसे क्षेत्रों के लिए प्राथमिकता की ओर इशारा करते हैं। हालाँकि, कुछ क्षेत्रों में परिवहन और ठोस अपशिष्ट जलाने वाले क्षेत्रों में भी सख्त कार्यान्वयन की आवश्यकता होगी, क्योंकि ये स्थानीय हॉटस्पॉट की वायु गुणवत्ता तय करने में एक महत्वपूर्ण कारक साबित हो सकते हैं।

अंत में, डिस्पर्जन मॉडलिंग और कंसंट्रेशन रिस्पांस फंक्शन का उपयोग करके स्वास्थ्य प्रभाव मूल्यांकन की सहायता से, अध्ययन क्षेत्र में उच्च रिज़ॉल्यूशन स्वास्थ्य प्रभावों का अनुमान लगाया गया है। विभिन्न जनसांख्यिकीय और सामाजिक-आर्थिक समूहों में वायु प्रदूषण में अलग-अलग योगदान और जोखिम का विश्लेषण करके स्वास्थ्य और आजीविका के प्रभाव का बेहतर पैमाने पर अनुमान लगाया गया है। विकासशील देशों में आबादी के बीच परिवेशी वायु प्रदूषण से स्वास्थ्य और आजीविका पर असंगत प्रभाव होता है। विशेष रूप से छोटे शहरों और ग्रामीण क्षेत्रों में सूक्ष्म-स्तरीय उत्सर्जन डेटा पर जानकारी की कमी के कारण इन असमानताओं को अक्सर नजरअंदाज कर दिया जाता है। इसलिए, वर्तमान कार्य सतह पर $PM_{2.5}$ सांद्रता के आधार पर अनुमानित स्वास्थ्य प्रभावों का भी विश्लेषण करता है और सुझाव देता है कि शहरी और ग्रामीण क्षेत्रों में प्रति 1,00,000 लोगों पर समय से पहले होने वाली मौतों की दर क्रमशः 158 (95% CI: 122-163) और 143 (95% CI: 65-151) हैं। कुल हुई 6372 वार्षिक असामयिक मौत में से 68% (95% CI: 3321-6987) असामयिक मौतें ग्रामीण क्षेत्रों में होती हैं। सामाजिक-आर्थिक समूहों के बीच उच्च योगदान-जोखिम असमानताओं को दर्शाते हुए, अध्ययन में पाया गया कि वायु प्रदूषण में उनके योगदान की तुलना में, क्षेत्र में कमजोर सामाजिक-आर्थिक स्थिति समूहों में उद्योगों, घरेलू खाना पकाने के

ईंधन जलाने, खुले में कचरा जलाने और परिवहन में $PM_{2.5}$ से क्रमशः 6, 7, 7, 26 और 7% अधिक असामयिक मौतें होती हैं। अध्ययन क्षेत्र में अधिकांश दैनिक समायोजित जीवन वर्ष (DALYs) आर्थिक रूप से कमजोर श्रमिक श्रेणियों में देखे गए हैं। जीवन के इन वर्षों के नुकसान के कारण आय में कमी से बुनियादी जीवन आवश्यकताओं के लिए दैनिक मजदूरी पर निर्भर इन समूहों पर काफी प्रभाव पड़ेगा। इन असमानताओं पर ध्यान देने वाली सूक्ष्म-स्तरीय प्रदूषण शमन नीतियां पर्यावरणीय समानता और न्याय को बढ़ावा देने के लिए महत्वपूर्ण हैं। हालाँकि, इन सूक्ष्म-स्तरीय नीतियों के कार्यान्वयन के लिए विभिन्न स्थानीय और क्षेत्रीय स्रोतों के प्रभाव पर बेहतर पैमाने पर जानकारी की आवश्यकता होगी और इस जानकारी की सटीकता में सुधार पर अध्ययन सभी के लिए स्वच्छ हवा प्राप्त करने की दौड़ में महत्वपूर्ण साबित होगा।

GRAPHICAL ABSTRACT



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GDP: Gross Domestic Product

NCAP: National Clean Air Programme

PM: Particulate Matter

MoEFCC: Ministry of Environment, Forest and Climate Change

MoHUA: Ministry of Housing and Urban Affairs

NCR: National Capital Region

CPCB: Central Pollution Control Board

SES: Socioeconomic Status

CAAQMS: Continuous Ambient Air Monitoring Stations

ECI: Economic Census of India

SECC: Socio-economic and Caste Census

NSSO: National Sample Survey Office

DALYs: Daily Adjusted Life Years

MSW: Municipal Solid Waste

HH: Household

NO_X: Nitrogen Oxides

CO: Carbon Monoxide

VOCs: Volatile Organic Compounds

SO_2: Sulphur Dioxide

CO_2: Carbon Dioxide

CH_4: Methane

N_2O: Nitrous Oxide

NMHC: Non-Methanic Hydrocarbon

GHG: Greenhouse Gases

ARAI: Automotive Research Association of India

ASI: Annual Survey of Industries

GIS: Geographic Information System

GPS: Global Positioning System

IGP: Indo-Gangetic Plains

VKT: Vehicle Kilometer Travel

2W: Two Wheelers

3W: Three Wheelers

4W: Four Wheelers

LCV: Light Commercial Vehicle

HCV: Heavy Commercial Vehicle

EF: Emission Factor

SD: Standard Deviation

IST: Indian Standard Time

USEPA: United States Environmental Protection Agency

IARI: Indian Agricultural Research Institute

CSE: Centre for Science and Environment

COPD: Chronic Obstructive Pulmonary Disease

IHD: Ischemic Heart Disease

LC: Lung Cancer

CRF: Concentration Response Function

IER: Integrated-exposure Response Functions

LPG: Liquified Petroleum Gas

WHO: World Health Organization

MPCE: Monthly Per Capita Expenditure

NDSAP: National Data Sharing and Data Accessibility Policy

LPS: Large point sourcesFO: Fuel Oil

HSD: High Speed Diesel

NG: Natural Gas

FCC: Fluid Catalytic Cracking

GBD: Global Burden of Disease

WRF: Weather Research & Forecasting

NCEP: National Centers for Environmental Prediction

FNL: Final Analysis

NCAR/ACOM: National Centre for Atmospheric Research/Atmospheric Chemistry Observation & Modeling

EDGAR: Emission Database for Global Atmospheric Research

MOZART: Model of Ozone and Related Tracer Chemicals

GCMs: General Circulation Models

CRF: Concentrations Response Function

RR: Relative Risk

PAF: Population Attributable Function

YLL: Years of Life Lost

YLD: Years Lived with Disability

CI: Confidence Interval

NAAQS: National Ambient Air Quality Standard

NFHS: National Family Health Survey