



TRIP - CENTRE BULLETIN

TRANSPORTATION RESEARCH & INJURY PREVENTION
CENTRE
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ABOUT THE TRIP CENTRE

The Transportation Research and Injury Prevention Programme has been operational for two decades. On May 21st 2021 it was established as the TRIP Centre. It is based at the Indian Institute of Technology (Delhi) and is an interdisciplinary academic unit focusing on the reduction of adverse health effects of road transportation.

Researchers at the TRIP Centre seek to integrate all issues concerned with transportation to promote safety, active mobility, cleaner air, and energy conservation. They are involved in planning safer urban and inter-city transportation systems and developing designs for vehicles and safety equipment. Activities include applied research projects, special courses, the workshops, and the supervision of students at the postgraduate and undergraduate levels.

The Centre promotes collaboration with the construction (highway) industry and public transport agencies. The TRIP Centre organises short-term courses and workshops on road safety and transport issues.

Academic Program

PhD

The TRIP Centre has been running Ph.D. programmes since May 2004. Research scholars work on transport planning, traffic safety, vehicular pollution, pedestrian dynamics and safety, highway safety audits, construction zone safety, public transport planning, automotive safety and impact biomechanics in collaboration with other Departments and Centres at IIT Delhi. At present there are six Institute Fellowships that are available for Ph.D. students at the TRIP Centre. Additional fellowships are available through research projects and industry partnerships.

M.S.(Research)

The 2-year Masters level program will be offered to researchers and practitioners with a focus on vehicle, infrastructure and traffic safety aspects. Applicants from diverse disciplines will learn the fundamental principles of road safety, policy implementation and applications to safe infrastructure and vehicles. The course will prepare students for advanced learning and provide hands-on field experience.

Annual Lecture

The TRIPP Annual Lecture will now be held as the Dinesh Mohan Memorial Lecture annually.

International Workshops

The TRIP Centre holds an Annual International Workshop on Transportation Planning and Safety every December. This was started in 1991 and the 30th edition was held in December 2020. Now the workshop attracts over sixty participants; more than half

of them come from low and middle income countries of Asia and Africa. The faculty includes the TRIP Centre academic partners from the US, Canada, Sweden, Austria and France. The course is sponsored by The Indian Automotive Industry, The Ministry of Roads and Highways, The Indian Roads Congress and The World Health Organization.

Faculty

Geetam Tiwari (University of Illinois, USA)
Professor and Head

Expertise in transportation planning and travel behaviour analysis, traffic safety and safety of vulnerable road users, public transport planning, pedestrian and bicycle infrastructure planning, highway safety and road safety audits.

Joint Faculty

Anoop Chawla, (IIT Kanpur)
Professor, Mechanical Engineering Department. Expertise in CAD/CAM and mathematical modeling, biomechanics.

Kumar Neeraj Jha, (IIT Delhi)
Professor, Civil Engineering Department
Expertise in construction technology and management

Puneet Mahajan (Montana)
Professor, Applied Mechanics Department
Expertise in dynamics and vibrations.

Kalaga Ramachandra Rao (IIT Kharagpur)
Professor, Civil Engineering Department
Expertise in transportation engineering

Sanjeev Sanghi (CUNY, New York)
Professor, Applied Mechanics Department,
Expertise in fluid dynamics

Sudipto Mukherjee (Ohio State),
Professor, Mechanical Engineering Department, Expertise in dynamics, vehicle crash modeling, biomechanics.

Associated Faculty

Civil Engineering Department
Prof. Aravind K Swamy

Prof. Gazala Habib

Prof. Manoj M

Prof. Nezamuddin

Humanities & Social Sciences Department
Prof. Ankush Agarwal

Prof. Ravinder Kaur

Prof. Reetika Khara

Prof. Sourabh B Paul

Computer Sciences & Engineering Department
Prof. Rijurekha Sen

Prof. Subashis Banerjee

Mechanical Engineering Department
Prof. Kaushik Mukherjee

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Prof. Sagnik Dey

Department of Management
Prof. Ravi Shankar

Mathematics Department
Prof. Niladri Chatterjee

Visiting Faculty

Dr. Rahul Goel
Expertise in: Transportation planning, public transport, road safety, Travel behaviour and health inspection of transport

Adjunct Faculty

Dr. Mathew Varghese,
St. Stephens Hospital, New Delhi

Prof. Shrikant Bangdiwala,
McMaster University, Hamilton, Canada

Prof. Girish Agrawal,
Jindal Global University

Dr. Sarath Guttikunda,
Urban Emissions.info

Memorandum of Understanding

Recently we have signed a Memorandum of Understanding with Transport Department of the Government of NCT Delhi. The purpose of this MoU is to enter into relationships between TD-GNCTD and FITT with regard to cooperation in different activities. The following activities are being considered for mutual collaboration at present. However, the scope will be expanded with mutual consent to include any other challenges arising in future.

- Collaborative Projects
- Training/ Knowledge transfer
- Research / Consultancy Projects
- Executive Development program for TD-GNCTD executives
- Sharing laboratories of IITD and TD-GNCTD for research
- Nomination of expert lecturers of TD-GNCTD for knowledge sharing with IITD
- Any other project of Mutual interest

The above activities shall be conducted in the following research areas:

- Road Safety
- Vehicle Safety
- Public Transport
- Road Design
- Road Safety Policies
- Electric Vehicle

These activities will be executed at Transportation Research and Injury Prevention Centre (TRIP Centre), IIT Delhi.



An excerpt from: TRANSPORT AND HEALTH IN A GLOBAL SOUTH MEGACITY - A CASE STUDY OF NEW DELHI

Rahul Goel, Sarath Guttikunda, Geetam Tiwari

With increasing income levels and urbanisation in many low-and-middle income countries (LMICs), populations are moving towards sedentary lifestyles. Growth in the use of private motorised modes has reduced travel-related physical activity and is projected to reduce further over the next decade of 2020-30 (Ng and Popkin, 2012). In Latin America and South Asia, prevalence of insufficient physical activity is significantly higher than the global average (Guthold et al., 2018). Unmanaged growth in transport sector and rapidly changing travel patterns have resulted in road death rates in LMIC that are three times higher than high-income countries and contribute 93% of the global road deaths (WHO, 2018). Emissions are increasing rapidly in many LMICs compared to Europe or the United States where emissions are stabilised or decreasing (Crippa et al., 2018). As expected, fine particulate matter (PM_{2.5}) levels in East Asia, South Asia, and parts of Sub-Saharan Africa have increased markedly over the past decades and are currently the highest in the world (Apte et al., 2018; Burnett and Cohen, 2020).

These levels of pollution combined with large population size result in disproportionate share of premature mortality due to cardiovascular and respiratory diseases in LMICs (Burnett and Cohen, 2020). New evidence on the impact of PM_{2.5} pollution on infant mortality (Heft-Neal et al., 2018) and diabetes (Bowe et al., 2018), now included in the Global Burden of Disease (GBD) estimates (Stanaway et al., 2018), have added to the health burden of PM_{2.5}.

Thus, transportation sector, through the pathways of physical activity, traffic injuries and air pollution, is likely a major contributor of rapidly increasing health burden in many LMICs. However, our understanding of this relationship is limited in the context of LMICs. A recent systematic review of studies that evaluated health impact of transport interventions reported a scarcity of such studies in LMICs (Stankov et al., 2020). A review of health impact assessment studies in LMICs found that most studies included air pollution as the only pathway, and only few studies included other pathways such as injuries and physical activity (Thondoo et al., 2021). In the past few years, there have been a growing interest in LMICs for health impact modelling that account for multiple exposure pathways, such as in Sao Paulo, Brazil (Sá et al., 2017), Accra, Ghana (Garcia et al., 2021), and Port Louis, Mauritius (Thondoo et al., 2020). (Woodcock et al., 2009) was one of the earliest such modelling study for London, UK and Delhi, India.

In this paper, we aim to fill this gap in the literature. We present a health impact model of transport for the megacity Delhi. We present baseline health burden due to

transport through the three exposure pathways of physical activity, traffic injuries, and PM_{2.5} pollution, for population 15 years or older. We also present physical activity and injury impacts resulting from future scenarios of travel patterns. The work presented in this paper was done as a part of doctoral thesis at Transportation Research and Injury Prevention Programme, Indian Institute of Technology Delhi (Goel, 2017).

In 2011, Delhi had a population of 16.7 million and along with its contiguous cities, forms an agglomeration of 22.5 million, and has a population density of 240 person per hectare (Goel and Guttikunda, 2015). In 2014, annual average PM_{2.5} concentrations was 146 ug/m³ (median: 111 ug/m³ and interquartile range: 66-374 ug/m³; (Goel, Gani, et al., 2015)) contributed by multiple sectors (Guttikunda and Calori, 2013). With these concentration levels, Delhi is one of the most polluted cities in the world. In 2011, about 21% of the households owned at least one car, 38% reported owning at least one motorised two-wheeler (2W) and 30% owned at least one cycle. The ownership of vehicles has been rapidly growing. In the past decade (2009-2018), half a million cars and 2W have been registered every year. Public transportation includes intermediate public transportation (cycle rickshaws, three-wheeled motorised rickshaws (auto rickshaws), mini vans), buses, and a metro rail system (Goel & Tiwari, 2016). We present health impact analysis for 2014 as the baseline year with projected population of 18.3 million and for individuals 15 years or older.

We conducted a household travel diary survey in Delhi in 2013 using a face-to-face interview approach. To sample households, we used a stratified (area-level income × distance from centre × four quadrants of the city), two-stage random sampling approach using a gridded (1 km × 1 km) population sampling frame (see Supplementary Information (SI) for details). We used random walk approach for final sample of households in the sampled grids. The average response rate was 65%, with significant variation across the sampled grids.

We recorded previous-day trip diary of all the members of the households and used proxy responses for young children and those not present in the household at the time of interview. Post cleaning, we retrieved travel diaries from ~1700 households (6844 individuals). Table 1 presents mode share of trips for population of age 15 years or greater, considering only main modes, and the gender distribution of trips within each mode. Up to half of all the trips are by walking and a quarter of all trips have been made using various public transport modes— bus, metro, shared auto, auto rickshaw, and train. There are

significant differences across the modes in terms of gender representation. Females are most underrepresented in cycling and motorised two-wheelers.

We express intensity of travel physical activity as Metabolic Equivalent of Task (MET) and the volume of activity as MET-h which is the product of duration of activity and its corresponding MET value. For walking, we used MET values of 3.5 and 3.7 for females and males, respectively, and for cycling, a value of 6.8 METs for both sexes (Ainsworth et al., 2000; Woodcock, Givoni and Morgan, 2013). We estimated average weekly active travel time (walking and cycling) as 107 minutes and 156 minutes per capita for males and females, respectively. Most of this time is contributed by walking alone—99% for females and 84% for males. For females, 27% of their walking time is contributed by public transport access trips, and for males, this share is 37 percent. The difference between travel physical activity between two groups is widened more when expressed in volumes— 6.3 MET-h for females and 10.9 MET-h per capita per week for males. We used weekly non-travel physical activity of 25.3 and 26.4 MET-h for males and females, respectively (Anjana et al., 2014).

We used case-level traffic fatality data reported by Delhi Traffic Police for years 2010 through 2012 (Goel et al., 2018). We do not use police-reported traffic injury data due to high levels of underreporting of injury cases in Indian cities (Mohan, Tiwari and Bhalla, 2017). Instead, we use GBD-reported data (see below) to estimate DALYs corresponding to road deaths. During the 3-year period, there were 5972 fatalities, equivalent to 11.9 deaths per 100,000 persons. Pedestrians, cyclists, and 2W contribute 87% of all the fatalities. In total, 38% of the fatalities occur with freight vehicles (trucks) as other vehicle involved.

37% with 2W and cars, and 17% with buses and other public transport modes. For 2014, total number of deaths were estimated as 2154 using 2010-2012 death rate and projected population. Among the victims, 81% are males and 94% are 15 years or older. See SI for more details on traffic deaths and the road users involved.

We estimated transport emissions using a bottom-up approach. We developed a dynamic time-trend annual emissions model that accounts for changes in vehicle technology, fuel use and emission standards (Goel and Guttikunda, 2015). To parameterise this model, we used data reported in literature, analysed secondary datasets, and conducted primary surveys (Goel, Guttikunda, et al., 2015). In 2014, 2W, cars, three-wheeled auto rickshaws and buses contributed 12%, 18%, 1% and 5% of



transport PM2.5 emissions, respectively, and light- and heavy-duty freight vehicles contributed 64% of emissions. We updated Atmospheric Transport Modelling System (ATMoS) dispersion model for Greater Delhi region (Guttikunda and Calori, 2013) with spatially- and temporally-resolved transport emissions.

Using the model, we obtained modelled annual-average PM2.5 concentrations and source contributions at 1 km × 1 km resolution. To account for elevated exposure levels during on-road travel, we conducted a study to measure PM2.5 exposure in 11 transport microenvironments in Delhi that include all modes of transport, and surface and underground public transportation stops (Goel, Gani, et al., 2015). We used a portable optical-sensor PM2.5 monitor to measure exposure in different modes of transport. To estimate, population-weighted PM2.5 exposure, we integrated spatio-temporal movement of population (using the travel survey) with spatio-temporal variation in modelled PM2.5 concentrations and accounted for on-road elevated exposure in corresponding transport microenvironments. The annual-average population-weighted concentrations is 118 ug/m3 accounting for 30% contribution from regional pollution observed in Indo-Gangetic plains (Guttikunda, Nishadh and Jawahar, 2019) and population-weighted contribution of transport to PM2.5 concentration is 21 percent. Health impact model

We developed a health impact model that used sex- and age-stratified aggregate population exposure of PM2.5 concentrations and sex-stratified exposure of travel physical activity. For traffic injuries, we developed a model to predict injury outcomes resulting from changes in travel patterns. The model uses road death counts classified into pairs of victim road user type and the other road user involved (e.g. for a pedestrian killed in a crash with car, pedestrian is victim and car is other road user). This data can be expressed as a two-way matrix (see SI). The model uses non-linear relationship between travel exposure and injury risk and have been used in ITHIM modelling framework.

We used the latest meta-analysis for parameterising non-linearity of the model (Elvik and Goel, 2020). We used integrated-exposure response functions (Burnett et al., 2018) for the six GBD-reported causes of deaths attributed to ambient PM2.5 points that are Ischemic heart disease (IHD), and Ischemic stroke, Lower respiratory infections (LRI), Lung cancer, Chronic obstructive pulmonary disease (COPD) and Diabetes (Stanaway et al., 2018). Out of these six, dose-response functions are age specific (5-year band) for IHD and Stroke, and common across the age for the other four. We modelled non-accidental deaths i.e. non-communicable diseases and Lower Respiratory Infections (NCDs and LRI) using Global Exposure Mortality Model (GEMM; Burnett et al., 2018) for sensitivity analysis. For physical activity, following the approach by (Götschi et al., 2015), we modelled eight disease end-points that include Breast and Colon cancers in addition to the six diseases for PM2.5.

We used GBD India Compare online portal (Indian Council of Medical Research, Public Health Foundation of India and Evaluation, 2017)

to access Delhi's baseline year cause-specific deaths and DALYs stratified by sex and 5-year age groups

Traffic injuries result in about three times higher health burden than PM2.5. The combined health burden due to two risk factors is equivalent to 6.9% of total NCD plus injury burden in Delhi. Note that traffic-related PM2.5 health burden is 21% of the total PM2.5 burden. We can further classify traffic-related PM2.5 health burden into different vehicle types. Within transport, 2W and cars contribute 30%. This implies that 6% (30% of 21%) of total PM2.5 can be attributed to personal motorised transport. Baseline level of active travel prevents equivalent to 40% of the combined health burden due to PM2.5 and injuries.

Use of motorised transport increased and travel physical activity reduced in all scenarios, resulting in additional health burden due to the two risk factors. Injuries of pedestrians and motorcyclists contribute the most to injuries in LDN and NYC scenarios, while in AMD scenarios, cycle injuries are also prominent. Within each scenario, burden from injuries is much greater than the burden from reduced physical activity. Since the burden of traffic injuries is almost the same across the three scenarios, the difference across scenarios is dominated by changes in physical activity.

We estimated health burden of transport in Delhi from the three pathways of traffic injuries, physical activity and PM2.5 pollution. For future scenarios of travel patterns, we estimated health impacts due to changes in injuries and physical activity. We found that despite extremely high levels of pollution in Delhi, health burden due to traffic-related PM2.5 is about a third of the burden due to traffic injuries. This is partly because transport is only a part of the overall air pollution problem, contributing one-fifth of all PM2.5 pollution in Delhi. Also, traffic injury incidents are more common among younger population while diseases that are caused by PM2.5 have greater prevalence among older population. Deaths and disability of young people due to injuries result in greater number of life years lost and years lived in disability. Besides the age patterns, per capita traffic death rate in Delhi is also high. It is about five times as high as the median death rate in European cities, and the latter are among the safest in the world (ITF, 2019).

We found that prevented health burden due to baseline levels of active travel is greater than the health loss due to traffic-related PM2.5 and about half as large as health loss due to traffic injuries. The preventive effect of physical activity underscores the potential loss in health that may result from a future mode shift away from active travel or public transport. In scenarios based on mode shares of London and New York City, increase in health burden due to reduced physical activity (16800 and 15500 DALYs, respectively) is almost the same as the total contribution of cars plus 2W to PM2.5 health burden in the baseline (30% of 63600=19080 DALYs).

In other words, even if a part of active travel is replaced by motorised modes in the future, it can easily negate benefits achieved from cleaner transport, for example, through electric vehicles. Since pollution levels can be measured and

injuries can be observed, they get disproportionate attention in transport decision making. Our results indicate that mode shift towards motorised transportation should be recognised for its unobserved, and potentially far greater, effect on population health through reduced physical activity.

Our study adds to the growing literature on health impact modelling in LMICs. Our findings are in line with similar work done in other LMIC cities. For example, for Accra, Ghana, (Garcia et al., 2021) reported that traffic injuries may negate benefits from greater physical activity in scenarios with greater use of active travel. This is similar to the dominance of injury burden that we found in future scenarios for Delhi. The health impact modelling study by (Woodcock et al., 2009) for London and Delhi reported greater health benefits from a shift to active travel than from cleaner motor vehicles, which is again similar to our findings above.

We found that walking to public transport is a significant contributor to overall physical activity, and more so among females that have greater dependence on public transport than males. Thus, use of public transport can improve health by providing an opportunity to engage in active travel for trips that are too long for walking or cycling. This finding has also been reported in multiple international settings. Thus, public transport is an important intervention that should be included within the broad framework of active travel policies in the cities.

We found that females represent a minority of road users among most travel modes except in walking and intermediate public transport modes. Due to lower out-of-home mobility of females and lack of opportunity to engage in active travel, their population average travel physical activity is much lower than males. This finding is confirmed by previous research. For example, also found gender gap in travel physical activity (women lower than men) to be the highest in India compared to other LMICs. For a peri-urban area in southern India, (Sanchez et al., 2017) reported that men make three times as many trips as women. According to the Census data of India, women constituted only 17 per cent of all workers in urban areas who reported travelling to work outside home (Census-India, 2016), which results from one of the lowest levels of work participation rate of Indian women in the world.

For LMICs to tackle growing burden of NCDs and injuries, there is a need to move towards health centric transport policies and greater involvement of public health experts in designing cities. The experience in many high-income countries (e.g. the United States, Australia) shows that safer roads and cleaner vehicles can co-exist with very low levels of active travel. Therefore, it is important that the policies to improve road safety or to reduce pollution are centred on policies to improve active travel. As argued, a unilateral focus on reducing vehicular emissions in Indian cities could be detrimental to sustainable transport policies. recommended for a need to adopt a Health-in-All-Policies approach to transportation engineering and planning. Such an approach will result in "transportation systems that prioritize active travel through widespread and safe walking, cycling, and public transit infrastructure"



NEWS

Lancet launches its third series on Physical activity

Ahead of the 2020 Tokyo Olympics and Paralympics, The Lancet launches its third Series on physical activity, which extends our knowledge base from previous Series' (2012 and 2016) on the importance of regular physical activity and sport to our health and wellbeing. In the past decade, not enough progress has been made to improve physical activity worldwide, with adolescents and people living with disabilities (PLWD) among the least likely populations to have the support needed to meet WHO's physical activity guidelines.

Physical inactivity is linked to an increased risk of non-communicable diseases (NCDs) such as heart disease, diabetes, and some cancers. But the health benefits also include improvements in mental health, dementia and cognitive function, sleep, preventing falls, and fall-related injuries. Increasingly recognised are the co-benefits of physical activity promotion such as improved air quality and climate mitigation.

The COVID-19 pandemic has a reciprocal relationship with physical activity. Lockdowns and

restrictions are likely to have decreased physical activity levels, whilst people who are physically active are less likely to experience severe symptoms and hospitalisations from COVID-19. The authors call for urgent efforts to improve physical activity levels in key populations, and recognise the potential to incorporate population health initiatives into future mass sporting events such as the Olympics.

Executive Summary: Editorial

<https://www.thelancet.com/series/physical-activity-2021>

Availability of population-level data sources for tracking the incidence of deaths and injuries from road traffic crashes in low-income and middle-income countries

Introduction Tracking progress towards Sustainable Development Goal (SDG) 3.6 of reducing traffic deaths and serious injuries poses a measurement challenge in most low-income and middle-income countries (LMICs) due to large discrepancies between reported official statistics and estimates from global health measurement studies. We assess the extent to which national population censuses and health surveys can fill the information gaps.

Methods We reviewed questionnaires for nationally representative surveys and censuses conducted since 2000 in LMICs. We identified sources that provide estimates of household ownership of vehicles, incidence of traffic deaths

and non-fatal injuries, and prevalence of disability. **Results** We identified 802 data sources from 132 LMICs. Sub-Saharan African countries accounted for 43% of all measurements. The number of measurements since 2000 was high, with 97% of the current global LMIC population having at least one measurement for vehicle ownership, 77% for deaths, 90% for non-fatal injuries and 50% for disability due to traffic injuries. Recent data (since 2010) on traffic injuries were available from far fewer countries (deaths: 21 countries; non-fatal injuries: 62 and disability: 12). However, there were many more countries with recent data on less-specific questions about unintentional or all injuries (deaths: 41 countries, non-fatal: 87, disability: 32).

Conclusion Traffic injuries are substantially underreported in official statistics of most LMICs. National surveys and censuses provide a viable alternative information source, but despite a large increase in their use to monitor SDGs, traffic injury measurements have not increased. We show that relatively small modifications and additions to questions in forthcoming surveys can provide countries with a way to benchmark their existing surveillance systems and result in a substantial increase in data for tracking road traffic injuries globally.

Sudeshna Mitra et al.

<https://gh.bmj.com/content/6/11/e007296.abstract>

Active Travel, Transit Added To Official COP26 Declaration After Last-Minute Appeal By EU Official

Today's main agenda item on the COP26 Transport Day focussed primarily on electric vehicles. Cycling, walking, trains, and buses were all excluded from the high-level discussions. However, following a plea from the EU's Matthew Baldwin at the transport plenary session, a sentence on active travel was added to the so-called Glasgow Declaration on Accelerating the Transition to 100% Zero Emission Cars and Vans.

Thanks to Baldwin's intervention—and intensive on-the-ground lobbying from cycling, walking and transit organization executives at the save-the-world summit—the final declaration included the following sentence at the base of the document:

"We recognise that alongside the shift to zero emission vehicles, a sustainable future for road transport will require wider system transformation, including support for active travel, public and shared transport."

It's possible this sentence was inserted when it was confirmed that Baldwin—the EU's top official on sustainable urban mobility—would speak in the plenary session.

Thirty countries—and some of the world's leading automotive companies, including Ford, General Motors and Volvo Cars—signed the Declaration at COP26. The main aim is to phase out gasoline and diesel-powered motor vehicles

by 2040 and replace them with electric cars and trucks. Sign-ups to the promise include Canada, New Zealand, and the Netherlands.

The U.K.—which had already pledged to phase out new gasoline and diesel vehicles by the more ambitious target of 2030—also signed the agreement.

Notably, the U.S., China and Germany did not sign the Declaration.

Carlton Reid

<https://www.forbes.com/sites/carltonreid/2021/11/10/electric-cars-wont-save-the-planet-say-transport-experts-at-cop26/?sh=158271067978>

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Endowments for perpetual Chairs

CONFER, India: TRIPP Chair for Transportation Planning
Ford Motor Co., USA: Ford Chair for Biomechanics and Transportation Safety
Ministry of Urban Development India: MoUD Chair for Urban Transport & Traffic Planning
MoUD Chair for Urban Transport and Environment
MoUD Chair for Urban Traffic Safety
VREF: Volvo Chair for Transportation Planning for Control of Accident and Pollution

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An excerpt from: **IMPACT OF ACUTE EXPOSURE TO AMBIENT PM_{2.5} ON NON-TRAUMA ALL-CAUSE MORTALITY IN THE MEGACITY DELHI**

Pallavi Joshi, Santu Ghosh, Sagnik Dey, Kuldeep Dixit, Rohit Kumar Choudhary, Harshal Ramesh Salve, Kalpana Balakrishnan

Exposure to ambient fine particulate matter (PM_{2.5}) has been identified as the largest environmental health risk globally (Cohen et al., 2017; Pope et al., 2020). Regionally, the South Asian region carries the highest burden of PM_{2.5}, with only 6 out of 355 cities meeting the World Health Organization (WHO) annual ambient air quality guideline (AQG) for PM_{2.5} of 10 µg/m³ (World Air Quality Report, 2019). Amongst the top 30 most polluted cities in the world in 2019, 21 were located in India, where ambient PM_{2.5} exposure has been identified as one of the leading health risk factors (Dandona et al., 2017). Nearly three-fourths of the population was exposed to PM_{2.5} level exceeding the national ambient air quality standard (NAAQS) of 40 µg/m³ in 2017, with the highest exposure observed in megacity Delhi (Balakrishnan et al., 2019).

In the last two decades, several policy measures were implemented in Delhi to curb air pollution. The conversion of the city's public transport from diesel to compressed natural gas (CNG) in 2002-2003 initially improved the air quality (Narain and Krupnik, 2007). However, the benefit could not be sustained due to various factors, including a rapid rise in non-CNG vehicles and emissions from other sources. Later, a graded response action plan (GRAP) was implemented in 2018 to control the high pollution episodes in Delhi. The most recent and vital policy attempt has been in the form of the National Clean Air Program (NCAP) in 2019, which has set a target to reduce PM_{2.5} and PM₁₀ concentrations by 20-30% by 2024 relative to 2017. With one year of NCAP, significant progress is seen in terms of an increase in the number of air quality monitoring stations in the region.

Since the year 2000, the ground-based monitoring sites developed and maintained by the Central Pollution Control Board (CPCB) measured only PM₁₀ (particulate matter smaller than 10 µm). Using these data, Cropper et al. (1997) reported a 0.23% increase in mortality with a 10 µg/m³ increase in short-term PM₁₀ concentration. In the PAPA study, a 0.15% increase in all-cause non-accidental mortality was found for a 10 µg/m³ increase in short-term PM₁₀ exposure in Delhi (Rajaratnam et al., 2011). A similar study was conducted by Maji et al. (2017) to examine all-cause mortality associated with a suite of pollutants (PM₁₀, NO₂, SO₂, and O₃). A short-term increase in PM₁₀ was associated with a higher risk of respiratory and cardiovascular morbidity (Jayaraman and Nidhi, 2008; Maji et al., 2018) in Delhi. Exposure to air pollution in Delhi was also found to contribute to excess cases of respiratory, cardiovascular, total mortality, and chronic obstructive pulmonary disease-related hospital admissions (Kumar and Mishra, 2018; Nagpure et al., 2014) and asthma attacks (Guttikunda and Goel, 2013). The previous three developed their own risk functions whereas, the latter two estimated air pollution attributed health effects based on previously used standardized concentration-response functions.

These studies undoubtedly demonstrated the health impacts of air pollution exposure in Delhi. However, all these studies were restricted to the association between PM₁₀ and gaseous pollutants with daily mortality counts, and only one study so far has examined the impact of PM_{2.5} (Singh et al., 2021).

The primary reason for this gap could be attributed to the sparse ground-based data on PM_{2.5} (Martin et al., 2019). The CPCB monitoring network started measuring PM_{2.5} in Delhi in 2009, but the network expanded only after 2016, limiting the use of a handful of ground-based monitoring sites for a time-series study. Previous studies (e.g., Rajaratnam et al., 2011; Singh et al., 2021) had to rely on a limited number of ground-based observations for assigning exposure, thereby posing a greater uncertainty in exposure misclassification because exposure to PM_{2.5} varies widely within the city (Jain et al., 2017). Balakrishnan et al. (2013) highlighted the role of spatial disaggregation in minimizing exposure misclassification for time-series studies in Indian cities.

To fill this knowledge gap, a need for a longer record of the PM_{2.5} database was recognized, for which satellite-based PM_{2.5} data was generated at 50-km resolution (Dey et al., 2012). Subsequent advancements in satellite algorithm allowed developing PM_{2.5} database at a 1-km resolution at a city scale (Chowdhury et al., 2019), and the data was used to map the PM_{2.5} build-up in Delhi during 2001-2015. The analysis discerned the two major pollution peaks in Delhi – the first during mid-Oct-early Nov and the second during late Dec-early Jan. The first peak was associated with meteorological changes and transport of pollution from upwind states affected by crop residue burning, and the latter affected by meteorology and local emissions. However, no attempt was ever made in utilizing such satellite data for time series analysis on the health effects of PM_{2.5} in Delhi or anywhere else in India. This study addressed this issue by examining the impact of short-term PM_{2.5} exposure on daily non-trauma all-cause mortality in the megacity Delhi between 2013-2017.

The daily mortality data were collected from the Municipal Corporation Headquarters, Civic Centre, New Delhi. The Municipal Corporation of Delhi (MCD) records and compiles zone-wise births and deaths within the jurisdictional boundaries of its three administrative subdivisions, North, East, and South. The area under municipal corporation constitutes approximately 94.2% of the geographical location and accounts for about 75.53 % of the total registered deaths in Delhi. (Government of NCT of Delhi, 2020).

The mortality data were received as zone-wise daily individually registered deaths with the deceased's demographic and residential details. Each registered death datum carried details of age, sex, and the latest residential address of the

deceased, along with the date and place of death. The deceased's details were exclusively used for research purposes, maintaining strict confidentiality about personal information. Each deceased's residential address was used to extract an identifier zip code for ambient PM_{2.5} exposure assignment at varying spatial scales. The reason to use the residential address and not death address for exposure assignment, unlike past studies (Balakrishnan et al., 2013), was because it was the most consistent information in the death records.

In the raw data received from the MCD, the death events carried the cause of death information, but this was not medically classified according to the international classification system. However, the exclusive cases of accident and suicide were exclusively identifiable. Hence we decided not to use the cause-specific mortality and restrict the analysis to all-cause non-trauma mortality. The raw data was cleaned to exclude deaths attributed to trauma such as accidents, injuries, and suicide. The data of the deceased with residential addresses lying exclusively inside the geographical boundaries of NCT Delhi were used in the analysis. Hereafter, 'all-cause mortality' implies non-trauma all-cause mortality in our results and interpretation.

The study used the satellite-based PM_{2.5} exposure that was calibrated against the ground-based measurements in this study. Surface PM_{2.5} concentrations were estimated by converting aerosol optical depth (AOD) from Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS has various algorithms to retrieve AOD at 10-km, 3-km, and 1-km spatial resolutions. In this work, we analyzed the AOD product retrieved using Multiangle Implementation of Atmospheric Correction (MAIAC) algorithm at 1-km resolution (Lyapustin et al., 2018) and converted it to PM_{2.5} using spatially and temporally varying scaling factors (i.e., the ratio of PM_{2.5}/AOD) from Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2) data (Buchard et al., 2017). The MERRA-2 derived scaling factors were calibrated against that from the ground-based measurements of CPCB sites following Bali et al. (2021). The satellite-derived instantaneous PM_{2.5} (representative of the satellite overpass time 10:00 AM to 2:00 PM) was converted to 24-hr average PM_{2.5} using a diurnal scaling factor (i.e., the ratio of 24-hr PM_{2.5}/PM_{2.5} during the satellite overpass) from MERRA-2.

The final retrieved 24-hr PM_{2.5} concentration showed a high correlation (R=0.89) and low (26.4 µg/m³) root mean square error (RMSE) against the data from the CPCB network in Delhi (Figure 1). The strong correlation and low RMSE for satellite-derived PM_{2.5} over NCT Delhi, our study location, propelled us to use the data further. During our study period, the population-weighted PM_{2.5} exposure ranged from 17 to 583 µg/m³. More details about the retrieval of PM_{2.5} from satellite data, calibration, and validation are



Continued from overleaf

available in Dey et al. (2020). The satellite-derived PM_{2.5} product is accessible from our data portal (www.saans.co.in).

The satellite data was used to carry out exposure assignment to death events at three spatial scales – (1) aggregated over NCT Delhi, (2) disaggregated at the district level in NCT Delhi, and (3) at the zip-codes in NCT Delhi. We used total daily deaths and average daily concentrations of PM_{2.5} over Delhi NCT for the aggregated analysis. In the spatially disaggregated analysis, each death event was identified at two sub-spatial scales, i.e., district and zip-code, using the deceased's residential address and further used for exposure assignment at that particular scale.

For assigning the PM_{2.5} exposure to a particular death event at the zip-code level, we estimated the geographical coordinate of each death event from their respective zip-code using Google Map's API. We then extracted the surface level PM_{2.5} at all grids within 2-km by 2-km area centering the geographical coordinate and assigned its average as a proxy representative of the PM_{2.5} exposure to the respective death event. This process was repeated for all the death events at a 24-hr scale. Similarly, we spatially extracted the PM_{2.5} data for all grid points within the districts of NCT Delhi and assigned that exposure to daily death events in various districts.

In this study, we examined the acute impact of PM_{2.5} exposure on all-cause non-trauma mortality in NCT Delhi. To the best of our knowledge, this was the first such attempt in estimating the effect of acute exposure to PM_{2.5} on daily mortality in India using satellite-based exposure data. We note that stratified analysis was almost impossible because of lower death counts at the district level. Though we reported both results at an aggregated level, we emphasize that it is 2-fold higher than the city level model. Only the core model was used to assess the effect modification and examine the sensitivity of other specifications of the model. Though an alternative individual-level logistic model could have been opted, controlling exposure misclassification at an individual level could have been a bigger challenge from satellite data.

The previous attempt to study acute PM_{2.5} exposure impact on all-cause mortality in Varanasi (1.06%, 0.45–1.66%) was estimated using ground-based data (Singh et al., 2021), assuming that the exposure level (103.6 µg/m³, 25th-75th percentile ranges: 37.1-145.3 µg/m³) across the city was uniform and therefore can be represented by a single monitoring site. Our core model estimate in Delhi (0.52%, 0.42-0.62%) was lower than the estimate reported in Varanasi, but district-level disaggregated model estimates almost similar effect of PM_{2.5} exposure on mortality (1.10%, 0.84-1.35%). Earlier, the satellite-based analysis revealed large spatial variability in PM_{2.5} within the city of Varanasi (Jain et al., 2017). This suggests that spatially aggregated analysis over-estimates the impact, most probably due to exposure misclassification, and therefore, a disaggregated analysis is desirable.

Our results with effect estimates for PM_{2.5} exposure came out three-times higher than the previous effect estimates for PM₁₀ exposure in Delhi - 0.15% (0.07-0.23%, Rajaratnam et al.

2011), 0.14% (0.02%- 0.26%, Maji et al. 2017) and 0.23% (Cropper et al. 1997). The higher effect estimate from PM_{2.5} exposure affirmed greater biological repercussions of finer sub-components of particulate matter pollution in the same population and geographical location. However, we want to mention that we could not control our estimates for other pollutants such as NO₂ and SO₂ due to the unavailability of spatially disaggregated data, and this could enhance our effect estimates.

Our results of 0.52% (0.42-0.62%) increase in all-cause mortality due to a 10 µg/m³ increase in PM_{2.5} exposure were found to be close with the effect estimates in city-specific time-series studies based in Guangzhou, China (0.55%, 0.24-0.86%), where the average daily PM_{2.5} exposure was 40.5 µg/m³ (Wu et al., 2018). The estimates in Seoul, South Korea (0.76%, 0.40-1.12%) where the daily exposure varied between 4.2 to 219 µg/m³ (Bae, 2014), in Beijing, China (0.65%, 0.29-0.80%) where the mean ± 1S.D. exposure was 75±54 µg/m³ (Li et al. 2013) and in a meta-analysis with exposure data (varying between 5 to >100 µg/m³) from 499 cities (0.68%, 0.59-0.77%; Liu et al. 2019) were slightly higher than our estimates for Delhi. However, our study on Delhi gave a higher effect estimate compared to the multicity meta-analysis on mainland China, including Hong Kong and Taiwan (0.36%, 0.26-0.46%), where PM_{2.5} exposure varied in the range 39-177 µg/m³ (Lu et al. 2015) and East Asia (0.38%, 0.21-0.55%) where PM_{2.5} exposure varied in the range <25 to >60 µg/m³ (Lee et al., 2015). A similar study in Beijing, China using satellite-based exposure ranging in 9-109 µg/m³ (Liang et al., 2018), found a linear dose-response curve and a larger effect on lag days smaller than what we found for Delhi. One plausible explanation for these differences could be different exposure ranges and perhaps variation in PM_{2.5} composition across the cities, which needs to be examined in detail.

The effect estimates from exposure to PM₁₀ (previous studies) and PM_{2.5} (this study) in the megacity Delhi were smaller than the effect estimates in the developed countries. A recent multicity time-series study in the USA estimated 1.18% (0.93, 1.44%) increase in all-cause mortality with a 10 µg/m³ increase in 2-day averaged PM_{2.5} concentration with seasonal effect (Dai et al. 2014). Another multi-community study in the USA, accounting for 1.3 million deaths, estimated 0.74 % (0.41-1.07%) increase in all-cause mortality with 10 µg/m³ increase in the previous day's PM_{2.5} (Franklin et al. 2007). In European studies, the effect estimates from PM_{2.5} exposure ranged from 0.8% (0.3–1.2%) in the Netherlands (Janssen et al. 2013) and 0.7% (0.1-1.6%) in a multicity analysis in France.

Smaller effect estimates for Delhi where PM_{2.5} exposure is manifold higher than in the developed countries (Apte et al., 2015) are consistent with previous studies demonstrating a stronger association between acute exposure to PM_{2.5} and mortality in locations with lower annual PM_{2.5} concentrations (Liu et al. 2019). One plausible explanation for this could be the differential toxicity in PM_{2.5} (Basagaña et al., 2015, Ostro et al., 2006). In Delhi, a large fraction of PM_{2.5} is resuspended dust (Maji et al. 2017) and organic

carbon, which may be of lower toxicity than the particles generated by fossil-fuel burning. Another possible hypothesis could be the variability of effect size over the gradient of exposure. The average daily exposure in Delhi is much higher than in those cities of developed countries. This plausible phenomenon could be explained with supporting evidence from time-series studies with uniform protocol in two cities, Delhi and Chennai in India (Rajaratnam et al. 2011 and Balakrishnan et al. 2011), with two extreme gradients of PM₁₀ exposure. The Chennai estimate was almost 2-fold higher than Delhi estimate, with a relatively much lower PM₁₀ exposure gradient across the city. This hypothesis needs to be tested with a multicity study in India that the Ministry of Environment, Forest, and Climate Change is currently planning to undertake.

More recently, measurements in Delhi and comparison with similar measurements from the developed countries by Puthussery et al. (2020) showed that particle mass and oxidative potential (a measure of toxicity) are not equivalent. Our results highlight the importance of exploring the impact of PM_{2.5} components on mortality in the future, particularly in developing countries. We plan to address this issue as a follow-up to the present study.

The differential quality of civil registration data between developed and developing countries could also be a factor. The Indian mortality data, in terms of its completeness and representativeness, would not be at par with the robust registration systems of the developed countries. There may be a gender bias in death reporting too. This has, however, not been previously discussed in any other time-series study, and it is difficult to draw any conclusion at this point. The registered deaths under Municipal Corporation jurisdiction included both domiciliary and institutional deaths, and hence not compulsorily medically certified for the cause of death. This rendered the specific causes of death unreliable for any use in our analysis, and we had to restrict our analysis to all-cause mortality. The daily death records also had gaps in the information, such as place of death (institutional vs. non-institutional death), which did not allow us to include it as a proxy indicator of socio-economic condition as an effect modifier in our analysis. Since we focused here on the disaggregated analysis, we could not use a multi-pollutant mix model for our sensitivity analysis due to the lack of spatial data of other pollutants.

Finally, PM_{2.5} exposure increased by more than 200 µg/m³ in the dry season relative to the monsoon season in a short period of time (Chowdhury et al., 2019). Our results suggest that interventions during this peak season can result in a substantial health benefit. As various mitigation measures are being implemented across the country under the NCAP, our results can be useful for the policymakers to estimate the potential health benefits in a short-term reduction in PM_{2.5} exposure in Delhi. The study can be replicated in other non-attainment cities and rural regions in India from where health data are made increasingly available, and exposure data are already generated (Dey et al., 2020).