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Impact of air pollutants from surface transport sources on human health: A modeling and epidemiological approach

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ABSTRACT

This study adopted an integrated 'source-to-receptor' assessment paradigm in order to determine the effects of emissions from passenger transport on urban air quality and human health in the megacity, Delhi. The emission modeling was carried out for the base year 2007 and three alternate (ALT) policy scenarios along with a business as usual (BAU) scenario for the year 2021. An *A*ctivity-*S*tructure-Emission *F*actor (ASF) framework was adapted for emission modeling, followed by a grid-wise air quality assessment using AERMOD and a health impact assessment using an epidemiological approach. It was observed that a 2021-ALT-III scenario resulted in a maximum concentration reduction of ~24%, ~42% and ~58% for carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter (PM), respectively, compared to a 2021-BAU scenario. Further, it results in significant reductions in respiratory and cardiovascular mortality, morbidity and Disability Adjusted Life Years (DALY) by 41% and 58% on exposure to $PM_{2.5}$ and NO_2 concentrations when compared to the 2021-BAU scenario, respectively. In other words, a mix of proposed policy interventions namely the full-phased introduction of the Integrated Mass Transit System, fixed bus speed, stringent vehicle emission norms and a hike in parking fees for private vehicles would help in strengthening the capability of passenger transport to cater to a growing transport demand with a minimum health burden in the Delhi region. Further, the study estimated that the transport of goods would be responsiblex for ~5.5% additional VKT in the 2021-BAU scenario; however, it will contribute ~49% and ~55% additional NO_2 and $PM_{2.5}$ concentrations, respectively, in the Delhi region. Implementation of diesel particulate filters for goods vehicles in the 2021-ALT-IV-O scenario would help in the reduction of ~87% of $PM_{2.5}$ concentration, compared to the 2021-BAU scenario; translating into a gain of 1267 and 505 DALY per million people from exposure to $PM_{2.5}$ and NO_2 concentrations, respectively. These findings suggest that significant health benefits are possible if goods transport is also included while designing strategies and polices in order to improve the overall urban air quality and minimize health impacts in city areas.

1. Introduction

Air pollution is recognized as an important health problem affecting millions of lives around the globe. It also adversely affects local ecological systems, regional atmospheric chemistry as well as global climate (Vlachokostas et al., 2010; Watson and Chow, 2007; Dockery and Pope, 2006). The World Health Organization (WHO) identified ambient air pollution as one of the 10 major risk factors contributing to the global health burden (Lim et al., 2012); causing ~16% of premature deaths in 2009 (WHO, 2009) and ~3.7 million deaths in 2012. The Organisation for Economic Cooperation and Development (OECD) in its report on 'Environmental Outlook to 2050' estimated that ambient air pollution would become the top cause of environmental mortality; resulting in an additional ~3.6 million premature deaths by the year 2050 (OECD, 2012). However, the situation is anticipated to deteriorate in densely populated urban areas and megacities of developing regions, especially India and China (Lim et al., 2012).

The major source of air pollution in urban areas is road transport, in addition to thermal power plants, industries and diffused biomass burning (Kumar et al., 2013; CPCB, 2010; Jain and Khare, 2010, 2008; WHO, 2005). The Auto Fuel Policy of India (MPNG, 2003) revealed that the condition was worse in the metropolitan cities of India as compared to many developed regions of the world. For instance, Delhi is considered as the most motorized city of India with ~299 two-wheelers and ~162 cars for every 1000 people (MoRTH, 2011; Sahai and Bishop, 2009); witnessing serious traffic congestion and delays (Lebel et al., 2007). It is one of the most polluted megacities around the globe, where the average concentration of μg/m^3 respirable suspended particulate matter (RSPM) is noted to increase from 161 μg/m^3 in the year 2007 to 281 μg/m^3 in the year 2011 (Kumar et al., 2013). This exceeds the global and national ambient air quality standards; therefore, it is responsible for a notable amount of excess deaths and hospital admissions (CPCB,

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2012; Kumar et al., 2011). Further, Sindhwani and Goyal (2014) have estimated the air pollution concentration from various sectors in the Delhi region. They have reported that the transport sector contributes around 8 μg/m^3 PM_{10} concentrations for the year 2007 in the ambient environment. Several initiatives have been taken to address the issues of traffic and air pollution in the Delhi region; for e.g., introduction of unleaded petrol in 1995, and introduction of vehicle emission standards i.e., Bharat Standard (BS) III in 2005 and BS IV in the year 2010 (Jain et al., 2014). However, these initiatives were not able to achieve the acceptable level of reduction in ambient air pollution (Yagi and Nagayama, 2010), as reflected in deteriorating human health due to poor air quality conditions (Gurjar et al., 2010). These findings strongly suggest an urgent need to 'integrate' the assessment of environmental and social benefits of proposed transport policy interventions, prior to their implementation as a part of development strategy (World Bank, 2013; Aunan, 1995).

1.1. Measures to mitigate vehicle emissions

Estimation of emissions from vehicular sources is the first step to assess the impact of vehicular use on ambient air quality and human health. Many past studies have quantified vehicle emissions in the Delhi region; for instance, Gurjar et al. (2004) prepared an emission inventory for the years 1990–2000 and concluded that in the year 2001, the transport sector contributed to ~82% of nitrogen dioxide (NO_2), ~17% of total suspended particulate matter (TSP) and ~86% of carbon monoxide (CO) emissions, in comparison to other sources. This is attributable to old vehicle technology, diesel-based busses and secondary emission factors collated from different sources. Recently, two studies reported the contribution of the transport sector in overall pollutant concentration using satellite-based emission estimation methodology in the Delhi region. Guttikunda and Calori (2013) estimated that the transport sector contributes to ~17% of particulate matter less than or equal to 2.5 μm ($PM_{2.5}$), ~13% of PM less than or equal to 10 μm (PM_{10}), ~53% of nitrogen oxides (NOx) and 18% of CO in the study region; while Sahu et al. (2011) estimated that it contributes ~29% and ~45% of PM_{10} and $PM_{2.5}$ emissions, respectively. It was observed that there is a tremendous change in technology and fuel-mix since 2001, making it difficult to compare the results of Gurjar et al. (2004) with the latter two studies. On the other hand, Guttikunda and Calori (2013) and Sahu et al. (2011) reported the percentage (%) contribution of transport for different boundary locations i.e., the National Capital Territory of Delhi (NCTD) along with satellite towns around NCTD in a former study and the Delhi National Capital Region (Delhi NCR) in a later study, which resulted in ~0.15 million tons and 0.3 million tons of $PM_{2.5}$ emission, respectively. Further, these studies have used registered vehicle data for computing vehicle emissions, which may result in uncertainties during emission modeling. Further, none of these studies have projected future transport demand (in vehicle kilometers traveled, VKT or passenger kilometers, PKM).

On the other hand, it was observed that the majority of air quality projection studies employed a deterministic modeling approach in the Indian region. Sharma and Khare (2001) have reported that the deterministic models are best suited to predict air pollution levels in the Delhi region owing to its capability of handling temporal and spatial variations appropriately. Further, Gokhale and Khare (2004) observed that the causal nature as well as its ability to integrate emission inventory and meteorological parameters during air quality modeling, makes the Gaussian plume model a significant tool for traffic emission analyses. Similarly, Goyal and Kumar (2011) observed that the Gaussian plume models such as CALINE-4, DFLSM and ISCST-3, have found maximum application for quantifying the dispersion of air pollutants from point, area and volume sources in the Delhi region. Recently, Mohan et al. (2011) estimated the air quality impact of residential, industrial and transport use in Delhi using an ISC-AERMOD model and observed that it gives a more satisfactory result when compared to the ISCST-3 model. However, no notable studies have used AERMOD to estimate the impact of '*on-road vehicle sources*' on urban air quality in the Delhi region.

In case of health impact assessment, there are notable studies which have established an association between ambient air quality and human health in various locales (HEI, 2004). Dockery (2001) observed that epidemiologic studies provided the strongest evidence for establishing a cause and effect relationship. These studies support the causal relationship of PM and other air pollutants with increased asthma cases (Auerbach and Hernandez, 2012); and exacerbate chronic obstructive pulmonary disease (COPD) (Eisner et al., 2010) and cardiovascular damage (Brook et al., 2010). In the Indian context, Simon et al. (1997) for the first time established a causal relationship of ambient air pollution and an increase in mortality in Delhi using time-series data for the year 1991–1994. Further, Pande et al. (2002) have correlated cardio-respiratory hospital admissions with ambient air pollutants, showing an increase of ~25% emergency room visits as the ambient air pollution level increases. A similar analysis of daily hospital admissions was conducted by Nidhi and Jayaraman (2007) where they reported very high risk (relative risk, RR) on exposure to ambient air pollution (1.07–2.82 for a 10 μg/m^3 increase in pollutant concentration). However, it can be observed that inclusion of admitted patients from Delhi and other states might have introduced structural bias during the computation of these results.

Recently, Lahiri and Ray (2012) collected health prevalence data for the Delhi region and correlated it with ambient air pollution to establish an impact on morbidity, lung functions, cytology and hematology. However, the development of RR functions from Delhi and West Bengal (outside Delhi) based prevalence rates would introduce undesirable error and uncertainty, owing to differences in weather and air pollution conditions prevalent in both the regions. On the other hand, very few Delhi based studies, for instance Guttikunda (2008), Gurjar et al. (2010) and Guttikunda and Goel (2013), have adopted global concentration response functions (RR) developed by the World Health Organization (WHO, 2006) in order to quantify health effects of growing air pollution. It is very well accepted that the use of global RR function can aid in preliminary research and decision making, when local response functions for a particular region are unavailable. However, these estimates may not be accurate — as global RR functions are designed to capture the impact of exposure to global average air pollutant concentrations rather than the impact of 'proximity and high exposure to roadside emissions', as in case of Delhi region (Lu et al., 2015; HEI, 2010; Suresh et al., 2000; Lipfert et al., 2006a, b). Hence, it is inevitable for the megacities with higher traffic density to study the health effects of vehicle pollution by developing local RR functions after considering ambient environment and health conditions (Zou et al., 2009). Therefore, the current study estimates the impact of 'identified' policy interventions targeting road transport on urban air quality and human health, with the case of Delhi region.

To summarize, the current study estimates 'source-to-receptor' impact of transport sources in the Delhi region on ambient air quality and public health, by adopting scenario analysis. It intends to inventorize and characterize on-road vehicle activity in the NCTD region in order to determine energy-emissions from passenger transport for current and future years. Further, impact on ambient air quality would be estimated by using dispersion modeling, extending it up to the local level. Subsequently, the human health impacts of these air pollutants would be captured by adopting health survey and statistical regression analyses, for the proposed alternate scenarios.

2. Material and methods

The primary objective of the study is to estimate the impact of vehicular emissions on urban air quality and human health in the Delhi region. It can be noted that the prime focus is to study the impacts of on-road passenger vehicle-based emissions using an integrated impact assessment framework, as presented in Fig. 1. The study has considered