Atmospheric Environment 98 (2014) 1–7

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Short communication

Estimation of vehicular emissions using dynamic emission factors: A case study of Delhi, India

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HIGHLIGHTS

- Review of the used methodology for development of the dynamic emission factors.
- Application of the dynamic emission factors to estimate the emissions from the vehicular sources over Delhi urban area.
- Discussion of the uncertainties to estimate the emissions from vehicles after CNG implementation.

ARTICLE INFO

Article history:
Received 22 March 2014
Received in revised form
18 August 2014
Accepted 19 August 2014
Available online 20 August 2014

Keywords:
Criteria pollutants
Dynamic emission factors
IVE model
Vehicle emission
Delhi

ABSTRACT

The estimation of vehicular emissions depends mainly on the values of emission factors, which are used for the development of a comprehensive emission inventory of vehicles. In this study the variations of emission factors as well as the emission rates have been studied in Delhi. The implementation of compressed natural gas (CNG), in the diesel and petrol, public vehicles in the year 2001 has changed the complete air quality scenario of Delhi. The dynamic emission factors of criteria pollutants viz. carbon monoxide (CO), nitrogen oxide (NO_x) and particulate matter (PM_{10}) for all types of vehicles have been developed after, which are based on the several factors such as regulated emission limits, number of vehicle deterioration, vehicle increment, vehicle age etc. These emission factors are found to be decreased continuously throughout the study years 2003–2012. The International Vehicle Emissions (IVE) model is used to estimate the emissions of criteria pollutants by utilizing a dataset available from field observations at different traffic intersections in Delhi. Thus the vehicular emissions, based on dynamic emission factors have been estimated for the years 2003–2012, which are found to be comparable with the monitored concentrations at different locations in Delhi. It is noticed that the total emissions of CO, NO_x, and PM_{10} are increased by 45.63%, 68.88% and 17.92%, respectively up to the year 2012 and the emissions of NO_x and PM_{10} are grown continuously with an annual average growth rate of 5.4% and 1.7% respectively.

1. Introduction

Air quality management system in a country requires two essential building blocks for compiling an emission inventory. The first is an emission factor and the second one is the activity data. Emission factor is the relationship between the amounts of air pollutants produced by the amount of raw material processed. These are usually expressed as the weight of pollutant divided by a unit weight, distance, volume or duration of the activity emitting the pollutant (e.g., grams of air pollutants emitted per gram of coal burned). The first Indian emission regulations were idle emission limits, which became effective in 1989. These idle emission regulations were soon replaced by mass emission limits for both gasoline (1991) and diesel (1992) vehicles. India started adopting European emission and fuel regulations for vehicles from the year 2000. Central Pollution Control Board (CPCB) under the Ministry of Environment & Forests, Government of India, sets the standards and the timeline for implementation. Bharat stage emission standards are norms instituted by Government of India to regulate the output of air pollutants from vehicular engine combustion etc. (Table 1). In the year 2000, the emission norms for passenger cars and commercial vehicles was equivalent to Euro I and known as India 2000 norms. Euro II equivalent to Bharat Stage (BS) II norms were enforced from 2001 in four metros of India i.e. Delhi, Mumbai, Chennai and Kolkata only. CNG (Methane stored at high pressure)

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http://dx.doi.org/10.1016/j.atmosenv.2014.08.047
1352-2310/

Table 1
Regular year of Bharat Stage of vehicles emission implementing.

Vehicle type	Fuel type	India 2000	Bharat Stage II	Bharat Stage III	Bharat Stage IV
2W	Petrol	2000	Apr-05	Apr-10	
3W[a]	Petrol	2000	Apr-05	Apr-10	
	Diesel	2000	Apr-05	Apr-10	
PC[a]	Petrol	2000	2001	Apr-05	Apr-10
	Diesel	2000	2001	Apr-05	Apr-10
Bus[a]	Diesel	2000	2001	Apr-05	Apr-10
LCV	Petrol	2000	2001	Apr-05	Apr-10
	Diesel	2000	2001	Apr-05	Apr-10
HCV	Diesel	2000	2001	Apr-05	Apr-10

[a] CNG was implemented from 2001.
Source: CPCB.

was started to use as a fuel in place of gasoline (petrol) and diesel from the year 2001. Since from 2010, Bharat stage III norms for 2W have been enforced across the country while Bharat stage IV emission norms have been in place since April 2010 except 2W only in 13 major cities in India including Delhi. Currently, Bharat Stage norms are running behind to European emission norms by a few years. These fuel policies, i.e. Bharat Stages II, III and IV norms and CNG had reduced the air pollution considerably but not effectively. Further, to improve air quality, the government should force automobile companies to use readily available technology as well as need to be invested in this research area for implementation of the next Bharat Stage V. However, the government is planning to introduce intermediate emission norms e.g., Bharat Stage IV(+) till 2017 for vehicular sources before moving on to Bharat Stage V. This is due to avoid the huge amount of investments (i.e. approximately 800 billions currency). Vehicular emissions under BS-IV(+) norms will have a sulfur content of 40 ppm compared with 50 ppm under BS-IV norms (Sharma, 2014).

Ever since urbanization, overall population growth and development have led to the rapid growth of Delhi. According to Census reports, the urban population has increased from 10 percent in 1901 to 28 percent in 2001. And ever increasing, the urban growth rate is running at 31.8 percent – almost three times higher than rural areas in 2011 (Census, 2011). The increase in population invariably translates into increased vehicle populations and traffic jams in Delhi. There has been a sharp increase in vehicle's population in the national capital. In March 2001, Delhi had 3.2 million vehicles for a population of about 13.4 million, which has now increased to approximately 7 millions in March 2013 (DSH, 2012). The capital has more number of personal cars as compared to other three megacity Mumbai, Chennai and Kolkata (CPCB, 2010). Moreover, the total road length has merely increased from 28,508 km in 2001 to 31,373 km in 2009. But increment in vehicles has always been doubled, thereby creating the problem of congestion and parking in the city remains redundant. However, more than 90 percent of the 1200 vehicles sold every day in Delhi are personal vehicles on its roads (Perappadan, 2012). This is almost double what was added in the city in pre-CNG days.

In 2002, there were 79.2 million vehicle km were traveled on city roads, the figures increased by almost double to 150.6 million vehicle km in 2009 and 10, eventually leading to alarming levels of emissions from vehicles during peak rush hours on all busy Delhi corridors (Pandey, 2012). So the estimations of emissions directly through Bharat Stages may lead to deficiency in the results because there will be a steep decrease in the emissions during changes of Bharat Stages. While, it is highly unlikely that such a change occurred in the road fleet since turnover takes time. The rate of increase of yearly emissions can't be estimated due to the unavailability of yearly emission factors. Therefore, the dynamic emission factor raises serious questions regarding the accuracy of the emission calculation methodology. Hence, the present study aims to develop the yearly emission factors i.e. dynamic emission factors for vehicles, which, along with activity data can be used to estimate the emissions from different types of vehicles in Delhi.

2. Materials and methods

The estimation of dynamic emission factors is the primary step for the development of a dynamic emission inventory, which are different from conventional emission factors e.g., Bharat Stages II, III and IV. The dynamic emission factor for any particular year takes into account the total number of phased out vehicles, the vehicular growth per year, vehicle age etc. Therefore, the dynamic emission factors are capturing the transition in vehicular technology by taking into account as the fraction of vehicles that are being added to the total vehicle fleet and the percentage of vehicles operating on various Bharat Stage standards in that particular year. Thus, the dynamic emission factors show a non-linear relationship with the values of Bharat Stage over a period of time.

The methodology of development of dynamic emission factors from 2003 to 2012 is described in sufficient detail. The input parameters are described first, followed by the calculation of dynamic vehicle emission factors. In the present study, the year 2003 is chosen as the base year. The required data for the base year 2003 has been collected from Goyal, 2007. The vehicle fleet mostly comprises of 2-wheelers (2W), personal cars (PC), 3-wheelers (3W), light commercial vehicles (LCV), heavy commercial vehicles (HCV) and buses. Emission factors of criteria pollutants as CO, NO_x and PM_{10} of vehicle fleets are calculated for each type of vehicles and fuels independently. Under this, the basic emission factors of CO, NO_x and PM_{10} from petrol, diesel and CNG vehicles under Bharat Stages II, III and IV are revised with actual monitored data. To estimate the vehicular emissions, IVE model, developed by U.S. Environmental Protection Agency (USEPA), which has been validated in many developing countries, with dynamic emission factors have been used at various places over the study area of Delhi.

2.1. Delhi study area

Delhi is located in northern India, shares its border with the states of Uttar Pradesh and Haryana. It has an area of 1483 km^2 with its maximum length is 51.90 km and the greatest width as 48.48 km. The growth of the city over the years has been in a ring and radial pattern, with road based transport. Delhi's current vehicle population is more than 6.9 million. Which stood approximately 3.5 million in 2001 registering a growth rate of 7.40% for private vehicles and 9.15% for commercial vehicles causing severe transportation and environmental problems (Goyal et al., 2013a). The phased out process of old age vehicle population was in the years 2001 and 2002 and the exact distribution of vehicles was not known during those years. Therefore, the years 2003–2012 has been chosen as a study period in this study. The year wise vehicles growth is shown in Fig. 1.

2.2. Development of dynamic emission factors

Emission inventory is an integral part of air pollution management. All relevant information and data on emissions have been collected through different sources for the years 2003–2012. In this study, the data of different types of engines and fuels have been obtained from many previous studies such as Iyer and Badami, 2007 for 2W, CPCB, 2009 for 3W (CNG), Ravindra et al., 2006 for buses, EPCA, 2007 for cars (petrol/diesel/CNG) and LCV/HCV from