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Emerging pattern of anthropogenic NO_X emission over Indian subcontinent during 1990s and 2000s

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ABSTRACT

The fossil fuel and bio–fuel burning in a developing country like India can have a significant impact on global climate. In the current work, we have set–up a more realistic, accurate and spatially distributed, all India, NO_X emissions from different fuel combustion and industrial activities at 1°×1° grid resolution by incorporating the most recently available micro–level activity data as well as country specific emission factors (EFs) at high resolution. The emission scenarios and their trends are studied in a comprehensive way for approximately 593 districts (sub–region) in India. We have developed three scenarios to construct the possible range of past and present NO_X emissions using Geographical Information System (GIS) based methodology. The total NO_X emissions are estimated to be 2 952 Giga gram (Gg)/yr, 4 487 Gg/yr and 7 583 Gg/yr for three different base years, i.e., 1991, 2001 and 2011. NO_X emission trends in India during 1990s and 2000s due to different major anthropogenic activities are estimated and their growth is discussed. A strong growth of NO_X is found during 2000s as compared to 1990s. All major cities remain as top emitters of NO_X. The present work depicts that the contribution of fossil fuel will gradually increase in coming years and will be around 91% by 2011. The present new gridded emission inventory will be very useful as an input to Chemical Transport Modeling study over Indian geography.

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1. Introduction

Oxides of nitrogen (NO_X) play important role in production of greenhouse gases (GHGs) like tropospheric ozone in local, regional and global scales (Dignon, 1992) as well as recycling of the hydroxyl radical (Pozzer et al., 2009) which acts as a cleaner and plays an crucial role in the chemistry of several trace gases and determines the lifetime of reactive GHGs (Houghton et al., 1990; Piccot et al., 1992). Chemical pollutants in chemical transport models as well as climate model simulations need the accurate surface emission data (Pozzer et al., 2009) which is not well developed (inaccurate) over Indian geography. For Asian emission inventory (EI), this inaccuracy could be high because country specific EFs along with high resolution activity data are often not available resulting in application of EF from European and American studies (Van Aardenne et al., 1999). Among the rest of the world excluding North America and Europe, particular concern should be paid to the emissions in India and China (emerging economy in Asia) (Akimoto and Narita, 1994) as only these three Asian countries (China, India, and Japan) account for more than 75% of the total Asian energy consumption in 1990 (Green et al., 1995; Van Aardenne et al., 1999). EI is a major tool for identifying the source of pollution and quantitative expression of pollution load in a defined area. Developing an accurate and detailed picture of NO_X emissions in India serves for multiple purposes like scientific application as well as policymaking.

To understand the tropospheric ozone and its precursors, Chemical modeling studies require an accurate spatial distribution and temporal change of emissions of ozone precursors such as oxides of nitrogen (NO_X) in developing countries like India which is not available. A few global NO_X inventories are available (EDGAR, 2000; GEIA, 1995; TRACE–P, 2000; Ohara et.al., 2007) where the Indian gross NO_X estimations are carried out at national level data, meaning that different developments between urban and rural areas were not distinguished, leading to misinterpretation of Indian emission scenarios (Gurjar et al., 2004). Moreover, this kind of inventory may not be suitable for regional modeling study over Indian subcontinents. It is also found that global inventory like TRACE–P, EDGAR and INTEX–B shows extremely rapid growth in Asia since 2001, which need to be validated by a bottom up approach for emissions estimation for India. At national levels, some work was carried out to develop the NO_X inventory in India (Kato and Akimoto, 1992; Akimoto and Narita, 1994; Garg et al., 2001b; Gadi et al., 2003; Garg et al., 2006). However, these emission inventories are also prepared in a broader scale (state–level) by using the gross values without involving recently available district–level activity data only in some studies, the old district level data is used. In the previous study, district level EI was prepared by using old census data available at that time (Garg et al., 2001a). Previous research also reported the national level gross values of NO_X but only for the years 1995, 2000 and 2005 (Garg et al., 2006). In light of this situation, the development of Indian multi–year (1991–2001–2011) NO_X EI for is very important for the understanding emission trends and its application in Chemical Transport Model (CTM) over Indian cities as well as on Indian geography. To our knowledge, no NO_X emission inventories for Indian region have been published which incorporates the present latest district boundaries along with recent activity data and technological EFs for above base years with a bottom up emissions estimation. In the present work, NO_X EI at district level (593) as well as 1°×1° resolution is constructed by incorporating the latest district boundaries and corresponding micro–level activity data along with country specific EFs for the base years 1991, 2001 and 2011. In the absence of activity data for 2011, most recent available activity data along with projected data from government reports having business as usual scenario were used where the accesses to these data is only recently available.

2. Emission Factors and Activity Data

2.1. Emission factor

EFs is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with a particular activity associated with the release of that pollutant. Typically, EFs of a fuel depends on the chemical composition of fuel, combustion type, temperature and efficiency of any emission control device. Thus, the EFs vary from geographical region to region based on its practice level. Unfortunately, there are very limited numbers of EFs developed for Indian geographical regions. Incorporating a country specific appropriate EF is very sensitive part in development of EI. Hence, in the development of EI, selection of appropriate EF for a fuel type, for specific country is extremely meticulous work. Most of technological EFs used in the present work are developed for Indian conditions and few are collected from different studies which seem to suit Indian conditions. Vehicular pollution sources are not homogenous, as there is a complete range of technological mix of the following; fuel type used like gasoline, diesel or natural gas; use of engine type and technology i.e. 2–stroke or 4–stroke or Bharat Statge (BS–I), BS–II or BS–III etc. According to the age of vehicles, present engine technology, type of the fuel used, corresponding EF of two wheelers, three wheelers and four wheelers are developed for Indian cities under Air Quality Monitoring Project– Indian Clean Air Programme (ICAP) (ARAI, 2007; CPCB, 2010) . Age–wise technological EFs for transport sector are used for the first time in this study and developed indigenously for Indian conditions. The scientific justification for the chosen EFs can also be found and is discussed in the respected individual reports (ARAI, 2007; CPCB, 2010; TERI, New Delhi, 2007). All the EFs are defined in g/kg or g/km. The EFs used in the present work has been tabulated in Tables 1 and 2. Although the EFs vary from region to region but the present given EFs are the average values of various vehicle types as well as for other sectors. We are not discussing the measurement technique behind the development of present EFs because measurement technique itself is a large area of focus. However, we believe that the presently used EFs for different sectors are more appropriate for development of NO_X emission inventory over India.

2.2. Activity data

Indian geography consists of approximately 590 districts (http://www.censusindia.gov.in/, http://www.censusindia.gov.in/2011–prov–results/census2011_PPT_paper1.html) which are defined by smallest political boundaries. The population density is unevenly distributed over a large area. The number of inhabitants increased from 846 Million (1991) to 1 208 Million (2011) (http://www.censusindia.gov.in/PopulationFinder/PopulationFinder.aspx). Energy is consumed in various forms in India i.e., the commercial energy (coal, petrol, and diesel) which is quite dominated in the urban area and the non–commercial energy such as bio–fuel (fuel wood, crop–residue and animal waste) which is dominating mostly in the rural areas. The emission sources are of two categories, namely large point source (LPS) and area sources. In large point source categories, we have considered emissions from thermal power plants, steel plants and cement plants for this inventory with their location information. In the present work, we have incorporated around 170 LPSs (71 thermal power plants, 12 steel plants and 87 cement plants), 185 LPSs (84 thermal power plants, 12 steel plants and 87 cement plants) for the years 1991 and 2001, respectively. The number will be increasing to around 204 LPSs (101 thermal power plants, 16 steel plants and 87 cement plants) by 2011. Emissions are also projected for the year 2011 under a no–further–control scenario where the activities data for the base year 2009 have been linearly increased based on the projected information. The information of individual power plants and other few plants have been procured from the websites like www.indiastat.com, www.cea.nic.in, www.ntpc.co.in etc. Similarly, the sources like bio–fuels, LPG/kerosene used for cooking as well as transport sectors are consider as area sources.

India is one of the largest producer and consumer of coal in the world. The major consumers of coal in India are the thermal power stations, followed by the steel plants and cement plants. The different fuels used in various sectors for different base year are tabulated in Table 3 (Indiastat.com; ILO, 1991; NCAER, 2006; PIB, 2001; Planning commission, Govt. of India, 2010; Puncher et al., 2005; UNCTAD, 2006; ISSV, 2011–12). Nearly 70% of electrical energy demand is met by the thermal power stations in India. Here, district level registered technological vehicles data is used (Indiastat.com). Data reveals that there were nearly 55 millions of registered vehicles in India for the year 2001 which is more than the double of that 1991's figure (21 millions). According to the growth statistics for vehicles by National council of applied economic research (NCAER), there will be another 80 million vehicles that would be added during the current decade (2001–2011) including 9.4 millions of diesel vehicles. In India, it is normally seen that vehicle population is directly proportional to urban population (Pucher et al., 2005). Under bio–fuel sector, there are three major categories i.e., wood burning, cattle manure and agricultural residue burning which are widely used for cooking and heating purposes in rural areas. About 90% of the fuel wood and a large fraction of crop residues are combusted in household stoves in developing countries (Smith et al., 2000). There is no systematic information on production and consumption of bio–fuel on an annual basis. The national total amount of fuel wood, dung and agriculture residue consumption data was 281 Tg/yr, 62 Tg/yr and 36 Tg/yr respectively in 1995 as compared to 220 Tg/yr, 93 Tg/yr and 86 Tg/yr in 1985 (Venkataraman et al., 2005). The activity data related to consumption of fossil fuels and bio–fuels at national level used in present calculations have nearly negligible uncertainties.

3. Basic Methodology and Mathematical Formulation

The methodology used to estimate the total NO_X emissions for Indian geographical region is similar to the commonly used IPCC (Intergovernmental Panel on Climate Change) methodology as well as our previous work (Sahu et al., 2011). Development of EI is a complex process due to numerous, diverse and widely dispersed emission sources in a developing country like India. We have adopted a "bottom up" approach to improve the accuracy, reliability and uncertainty of inventory with more refined district level activity data. The present emissions were estimated on the basis of activity data, LPSs and area sources at each district level and further refined to grid level. The quality of grid emissions is improved as the number of grid cells are less than the number of district level activity data. Emissions of a particular pollutant from a particular source category are estimated as a product of activity data, EF, application of combustion technology and removal efficiency of emission control. To calculate the total emissions of that pollutant from all the sources are summed over all source categories. This calculation is similar to that described by Klimont et al. (2002) and Bond et al. (2004). Hence the total emissions can be expressed by Equation (1) for all the pollutants unless specified otherwise.

$$TE = \sum_a \sum_b FU_{a,b}\left[\sum_c EF_{a,b,c}U_{a,b,c}\right] \qquad (1)$$

where *a*, *b*, *c* are the sector, fuel type, and technology, *TE* is the total emission, *FU* is the sector and fuel specific amount, *EF* is the technology specific EFs, *U* is the fraction of fuel for a sector with particular technology ($\sum U = 1$ for each fuel and sector).

But, in case of presence of technology and age specific vehicular *EF*s, the emissions from transport sector have been calculated using the Equation (2).