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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.

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

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 EFs, the emissions from transport sector have been calculated using the Equation (2).

Table 1. *NO_X EFs for various fuel types used in the current work*

Sector	Unit	Fuel type						
		CNG/NG	LPG	Wood	Diesel	Coal/Coke	Kerosene	FO
Industries	kg/KL	0.0028 [a]	1.45		2.75	7.5 [b]		7.5
Residential	g/kg	1.80	14.00			3.99	2.5 [c]	
Power	kg/Mg					1.44		

[a] kg/m^3, [b] kg/Mt , [c] g/lit, Mg (Mega–gram)

Table 2. *Technology specific NO_X EFs used in the current work for the calculation of transport emissions*

Vehicle category		2W	3W (2S)	3W (4S)	PV	PV	PV	LCV	HCV	Bus
Fuel used		**Petrol**	**CNG**	**CNG**	**Petrol**	**Diesel**	**CNG**	**Petrol**	**Diesel**	**CNG**
Emission Factor (g/km)	5 yrs	0.25	0.19	0.53	0.09	0.28	0.53	2.12	9.30	6.21
	10 yrs	0.27	0.19	0.53	0.21	0.49	0.53	2.12	9.3	6.21
	15 yrs	0.27	0.19	0.53	0.645	0.49	0.01	2.48	13.84	6.21

2W: Two Wheeler, 3W (2S): Two Stroke Three wheelers, 3W (4S): Four Stroke Three wheelers, PV: Passenger Vehicle, HCV: Heavy Commercial Vehicles, LCV: Light Commercial Vehicles.

Table 3. *Energy Consumption in India during 1991 to 2011*

Fuel Type Unit in Million Tons (Mt)	1991	2001	2011
Coal (Power Sector)	136	230.36	465
Lignite	20	22.6	35
Coking Coal (Steel)	21	30.7	68
Coal (Cement)	7.8	15.32	37
Domestic Coal	44	42.21	85
Coal (Total)	228.8	341.2	690
Gasoline	3.54	6.7	12
Diesel	21.13	38.57	65
Kerosene	8.42	11.30	9
LPG	2.41	7.01	18
Fuel Wood	256.2	281	281
Dung	74.4	62	62
Crop–Residue	56	36	36

$$E_t = \sum(Veh_l \times D_l) \times EF_{l,km} \quad (2)$$

where E_t is the total emission of compound, Veh_l is the number of vehicle per type, D_l is the distance traveled in a year per different vehicle type, and $EF_{l,km}$ is the emission of compound, vehicle type per driven kilometer.

For this purpose, the vehicle kilometer traveled (VKT) per vehicle category have been taken from (CPCB, 2001b) for six vehicle categories like (i) two wheelers (2W), (ii) auto rickshaws (3W), (iii) cars and jeeps including passenger cars and multi utility vehicles (PC), (v) buses (Bus), (v) heavy commercial vehicles (HCV), and (vi) light commercial vehicles (LCV). For better understanding and a clear picture of EI development, the schematic methodology for the development of Indian emissions estimation is depicted in the Figure 1a. The GIS based statistical methodology, digital data generation, spatial allocation and grid extraction techniques are similar to our earlier work (Sahu et al., 2008; Sahu et al., 2011) where more detail could be found.

3.1. Digital data generation and spatial distribution and grid extraction

A geographical information system based approach organizes the emission data from different sources like point, area and line. Emissions of atmospheric pollutants are not a spatially uniform problem. The GIS based technique involves two major steps, spatial distribution using statistical or relationship parameters using GIS methodology, followed by application of GIS to grid the values to required one degree resolution. Prior to the incorporation of calculated emissions into the GIS environment, some pre–processing tasks like geo–referencing, digitization of district boundaries as well grid layer and building of attribute database are required. Indian geographical region consist of 593 districts (the smallest possible sub–region). Geographically it is covered by 407 grid cells, each having 1°x1° (~110 km) resolution. Spatial allocation (gridding) of emissions can be done by overlaying the facility location layer with the grid cell layer and aggregating the facility points in each cell. It is a process to transform large and irregularly shaped emission data to uniform data using GIS tools. For the grid data extraction, developed geo–referenced grid cells of 1 degree resolution covering India using GIS environment were superimposed over the spatially distributed emissions from different sectors (area sources) as well as from LPSs. The emission values for the gridded cells based on the corresponding contribution from different sources lying inside the grid cells were calculated by aggregating the facility in each cell. The emission values from different sources were also organized as a set of thematic layers so that they could be analyzed separately.

4. Results

Figure 2a shows the estimated NO_X emissions for Indian geographical region in 1991. The total NO_X emission from all sectors for 1991 is estimated to be 2 952 Gg/yr. The NO_X emissions from coal, petrol/diesel, LPG/Kerosene and bio–fuel are estimated to be around 1 190 Gg/yr, 931 Gg/yr, 231 Gg/yr and 600 Gg/yr, respectively. Contribution of coal combustion related NO_X emission is found to be around 40% during 1991 followed by transport sector (31.5%)**.** Commuter vehicle is the major source of NO_X emissions in the urban area. From Figure 2a, it is observed that the major part of central India and northwestern region show low NO_X emissions. The IGP (Indo–Gangatic–Plan) region marked in Figure

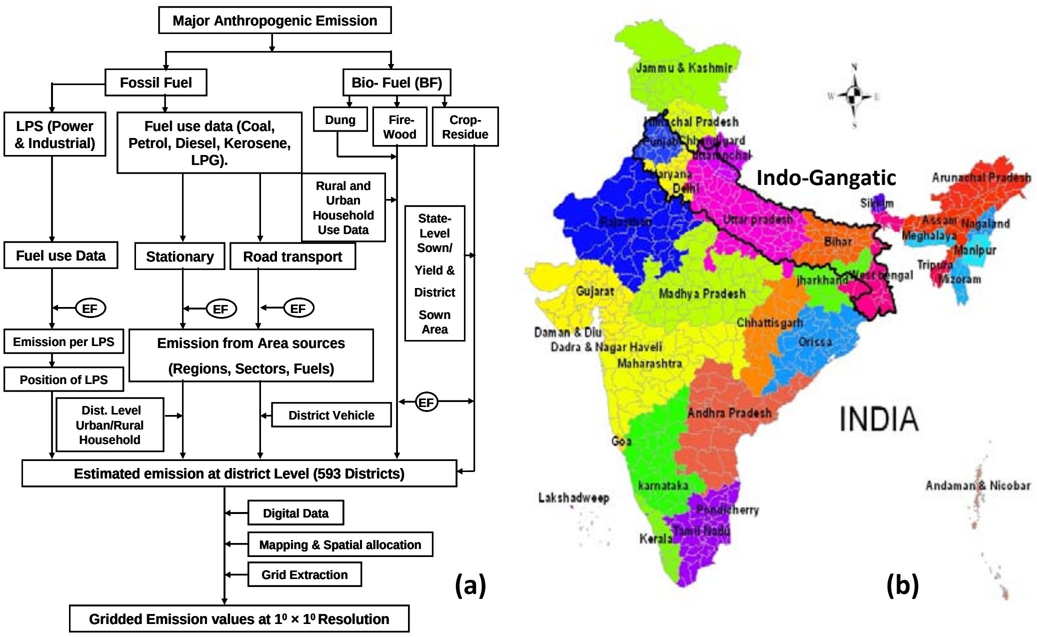

***Figure 1. (a)** Schematic methodology for the development of Indian Emission estimation, **(b)** digital vector map for Indian state boundaries.*

2a shows the highly fertile land which is made up of alluvial soil, deposited by the Ganges and Brahmaputra rivers that are highly densely populated regions in India. The NO_X loading over the IGP region is due to the combined effect of bio–fuel related emissions, vehicular emissions and coal is used in domestic sector as well as in thermal power plants. IGP region accounts only 15% of the total Indian geographical region but contributes around 24.7% (around 730 Gg/yr) to the total NO_X emissions in India during 1991 and contribute nearly 31% of the total bio–fuel related NO_X emissions in India during 1991. In IGP, the vehicular source is dominating by contributing 270 Gg/yr (37%), followed by coal at 228 Gg/yr (31%) and bio–fuel at 184 Gg/yr (25%).

The estimated total NO_X emission for Indian region was 4 487 Gg/yr in 2001 as shown in Figure 2b. The estimated NO_X emissions from coal, petrol/diesel, LPG/Kerosene and bio–fuel sources are around 1 871 Gg/yr, 1 669 Gg/yr, 319 Gg/yr and 628 Gg/yr respectively for the year 2001 with a corresponding decadal growth of 57%, 79%, 38% and 5% during 1990s. High NO_X emissions of the order of 30–150 Gg/yr is found over the upper and lower IGP and some parts of the Western, Southern and Eastern–Central India. The presences of high captive thermal power stations along with transport load have contributed to high emissions over these regions. Among the high NO_X emitting regions, IGP contributes more than 26% (around 1 172 Gg/yr) to total Indian NO_X emissions during 2001 where the vehicular source is contributing 526 Gg/yr (45%) followed by coal at 387 Gg/yr (33%) and bio–fuel at 259 Gg/yr (22%) to total NO_X emissions over IGP. Apart from the IGP region, large numbers of industrial activities are also found over the states like Maharashtra, Gujarat, Andhra Pradesh and Tamil Nadu which drive the emissions to an order of 40–150 Gg/yr. Some part of North–West, Northeast regions and Central India show low emissions of NOx (~ 2–8 Gg/yr) due to low population density and dense forest cover. The district level range analysis shows a diverse spatial distribution where the most emitting 59 districts (10%) contribute around 2.29 Tg/yr (65%) to NO_X to total Indian emissions in 2001. All the major cities show higher values of NO_X due to increase in vehicle numbers with rising population density. Loading of NO_X per square kilometer is found to be very high in all the major cities in India. We can say that the urban areas are dominated by petrol and diesel related NO_X emissions from transport sector along with thermal power stations and industrial activities. It is found that the spatial pattern of bio–fuel use is very scattered over India.

The Figure 2c shows the growth of 52% NO_X emissions during 1990s (1991–2001) which is due to maximum growth and contribution from vehicular related emissions followed by coal and bio–fuel combustion. During 1990s, the vehicle numbers in transport sector had grown by more than two folds but the fuel efficiency and technology had reduced the NO_X emissions which are clearly marked by the growth number (only 79%). The locations of the major thermal power stations with their capacities are shown in Figure 2d which indicate further intensification of the NO_X emissions in that region. It is seen that the decadal growth of NO_X is high over some other regions of India like the eastern parts of central India and Southern India and some parts of Western India. The growth of NO_X emissions from bio–fuel activity was very low, may be due to increase in the LPG consumers by many folds [1.7×10^7 (1991) to 6.85×10^7 (2001)] along with the consumption of LPG which increased from 2 415 TMT (1991) to 10 845 TMT (2007) (Indiastat.com).

Figure 2e and Figure 2f show that NO_X emissions estimation for the projected year 2011 and its growth during 2000s respectively. Around 7 583 Gg/yr of NO_X was emitted by all sources during 2011 which is 69% more than the 2001 estimation. During 1990s, the transport sector had grown by nearly two folds but same sector will be replaced by the coal related NO_X emissions activity by 2011 which will be increased by more than two folds during 2000s. The demand of the thermal power capacities will be increased from 62 000 MW in 2001 to 106 000 MW by 2011 (www.Indiastat.com; Individual Plants website; Planning Commission, Govt. of India). Currently, India lies third in world in terms of coal production and consumption. The trend of high emission will persist over the IGP for the projected year 2011 too but the contribution to total value will be decreased to 25% as compared to 26% in 2001. By 2011, Sonbhadra, district of Uttar Pradesh (240 Gg/yr) will be the top NO_X emitting district followed by Korba of Chattisgarh (181 Gg/yr), Delhi (156 Gg/yr) and Bokaro district of Jharkhand (154 Gg/yr). All the above districts were among the top 10 NO_X emitting districts during 1990s too. The bio–fuel related NO_X emissions growth remained stagnant during 2000s as well due to rapid growth of LPG. The spatial pattern of NO_X emissions from bio–fuel in 2001 is shown in Figure 3. As the growth of NO_X from bio–fuel is stagnant due to multi–fold increase in LPG used in residential sector in last 2 decades, the spatial pattern of hot spots are more and less similar. So, emissions from bio–fuel sector for one single year (2001) is provided only. Strong emissions of the order of 10–55 Gg/yr is found over the IGP, some part of western India as well as few regions over southern India where agricultural practice is found to be high. High rural population density drives high bio–fuel emissions. Low emissions of the order 1–4 Gg/yr is found over North–east region, North–west, central and Northern Indian regions where population density as well as forest cover is large.

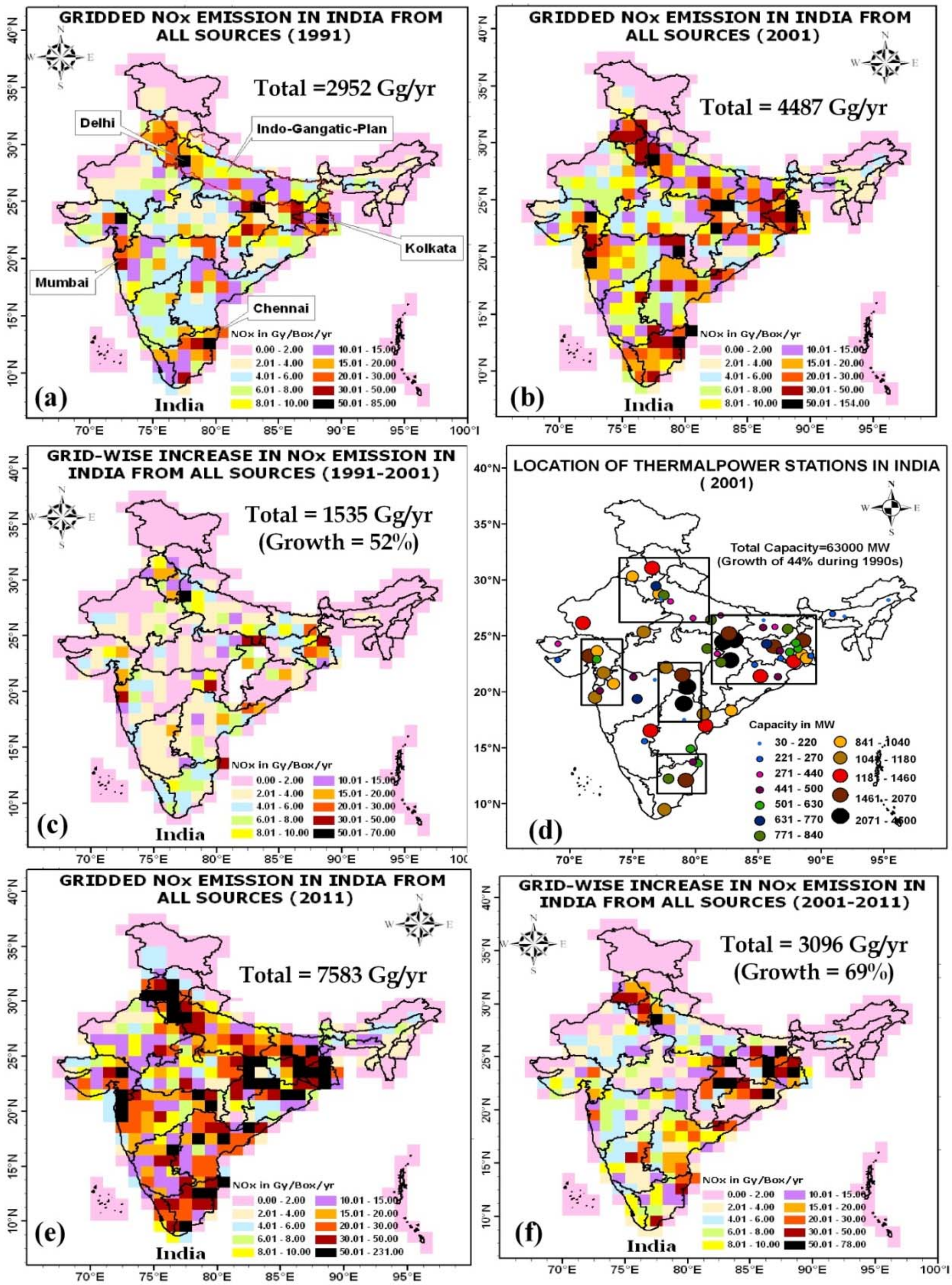

Figure 2. *Gridded NO_X emission in India from all sources **(a)** 1991, **(b)** 2001, **(c)** growth during 1991–2001, **(d)** locations of thermal power stations in India (2001), **(e)** 2011, **(f)** growth during 2001–2011.*

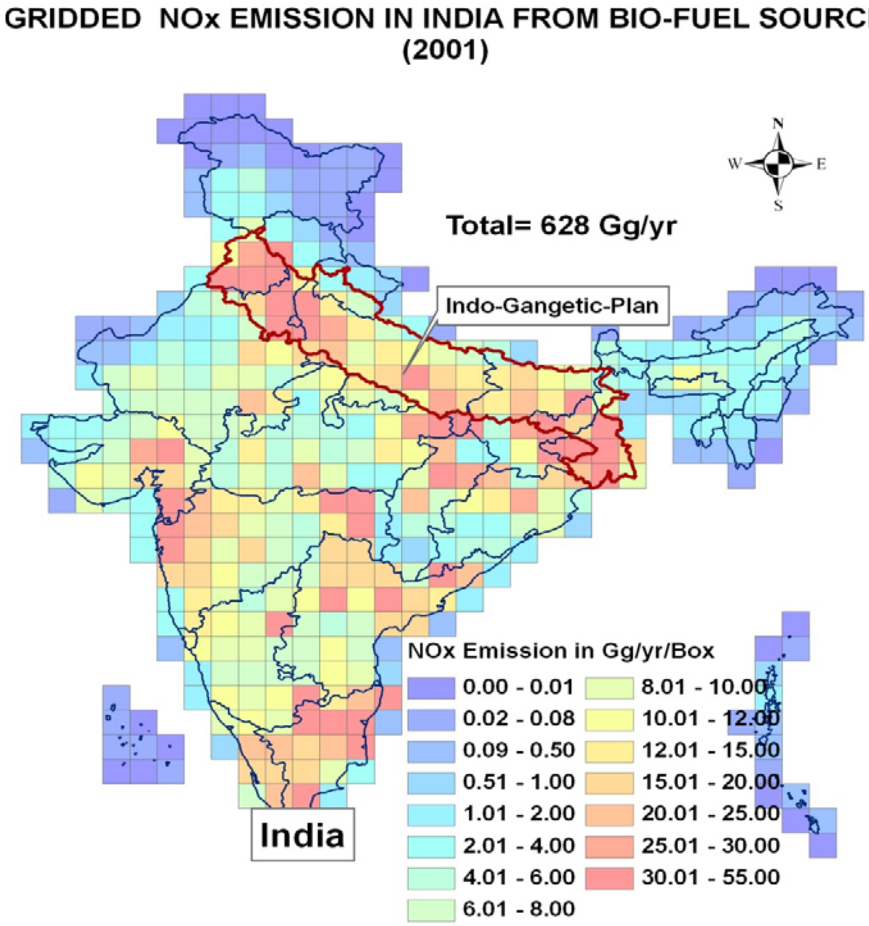

Figure 3. *Gridded NO_X emissions in India from bio–fuel combustion in 2001.*

The district level analysis show a diverse spatial distribution with the top 10% emitting districts contributing more than 52% of total NO_X emissions in 1991 and 53% in 2001 which will be more than 57% by 2011.The present work show that the contribution of fossil fuels will gradually increase in coming years which was nearly 79% in 1991 and 86% in 2001 and will be around 91% by 2011. From 1991 to 2011, Indian NO_X emissions are estimated to increase three fold with the largest increase in coal consumption in power sector and other industrial activities. In grid level analysis, out of 407 grid boxes, only 100 grid boxes contribute around 70% of the total NO_X emissions. Most of these grid boxes lie over the region having thermal power stations and major cities. It is also found that major cities along with mega cities, Delhi remain the top emitter of NO_X in last two decades and there is a strong growth as well. Transport sector play an important role in total emissions followed by Industrial practices. In the past, a few researchers reported the NO_X emissions over India using different approaches without involving the details of micro–level activity data which was not available to them (Kato and Akimoto, 1992; Akimoto and Narita, 1994; Van Aardenne et al., 1999; Gadi et al., 2003; Streets et al., 2003; Garg et al., 2006). These estimates made by various global researchers are tabulated in Table 4. The differences in estimations by these authors are due to the different sources of activity data as well as different sets of EFs used (i.e. for developed countries and developing countries). Our newly estimated NO_X value of 4 487 Gg/yr for 2001 is more or less similar to the estimation by Ohara et al. (2007) where gross estimation of all sectors including aviation and shipping is taken in to account for 2000. Present estimation is comparatively large than the estimation made by Zhange et al. (2009) for the base year 2006. They estimated a gross value for India using activity data provided by International Energy Agency (IEA) and more focus on China region. Moreover, the activity data used in above studies are gross level and are taken from IEA. Emission estimation by Garg et al. (2006) for base year 2005 seems to be very low as compared to our estimation for 2011. The reason could be the difference in EFs (i.e. global emission factor). However, the estimation by Streets et al. (2003) for the base year 2000 is very close to our present estimation for 2001. Estimation by Gadi et al. (2003) is quite low due to inclusion of only bio–fuel section. However, the estimation by Van Aardenne et al. (1999) is quite far from our present estimation where the activity data as well as EFs both seem to be very old. The present technological EFs are the best available ones over Indian geography. Present estimation is also quite low as compared to widely used EDGAR estimated value in 2000 and close to TRACE–P estimation for 2001 and INTEX–B for 2006.

5. Conclusions

The major objective to provide the multi–year NO_X emission estimation and its decadal growth for the Indian region has been achieved in this work. The total emissions are estimated to be 2 952 Gg/yr, 4 487 Gg/yr and 7 583 Gg/yr for three different base years, 1991, 2001 and 2011 respectively along with a decadal growth of 52% during 1990s and 69% during 2000s. Present emission data could be very useful for regional CTM study over India as well as for identification of "Hot Spots", relative contribution of various sources and sectors that can be targeted for mitigation. It also explains the fact that decadal growth of NO_X emissions in India are increasing rapidly and will persist the same trend over the decade to come. The relative contribution of fossil fuel had an increasing trend whereas the bio–fuel was stagnant in last two decades. Therefore it is informative to look more closely at these projections for mitigation plans in the future. Another important feature is the rapid rate of urbanization in India that is

Table 4. *NO_x estimation for Indian region as reported by different researchers*

Reference	Estimated NO_X in Gg (Year)			Sources
Present Study	2 952 (1991)	4 487 (2001)	7 583 (2011)	FF + BF
Zhange et al. (2009)			4 861 (2006)	FF + BF
Ohara et al. (2007)	4 377 (1995)	4 730 (2000)		FF + BF
Garg et al. (2006)	2 640 (1990)	4 310 (2000)	5 020 (2005)	FF + BF
Gadi et al. (2003)	1 010±410 (1990)			From Bio–fuel only
Garg et al. (2001b)	3 460 (1995)			FF + BF
Streets et al. (2001)	4 500 (1995)			FF + BF
Streets et al. (2003)		4 590 (2000)		Anthropogenic and Bio–mass
Van Aardenne et al. (1999)	3 480 (1990)	5 610 (2000)	10 840 (2010)	Anthropogenic activity (Fossil)
Akimoto and Narita (1994)	778 (1987)			Excluding Dung in Bio–fuel
Kato and Akimoto (1992)	2 310 (1985)	2 400 (1986)	2 560 (1987)	Anthropogenic activity (Fossil)
EDAGR 3.2 (2000)	5 347 (1995)	6 285 (2000)		FF + BF
TRACE–P (2000)		4 047 (2000)		FF + BF
IIASA (2001)	3 470 (1995)	4 563 (2000)		FF + BF

FF: Fossil fuel; BF: Bio–fuel

taking place in all the mega cities and adding to the main hotspot regions. Coal is going to replace the transport related emissions in coming years. Increase in spatial resolution as well as inventory of other major pollutants over India will be possible future work which requires further refined activity data. Application of present inventory in CTM model and its validation with available observations could be the next focus work to be carried out in future. NO_X estimation from all possible natural sources could be another area to be focused in future. Therefore, this inventory will not only improve the understanding on emissions scenarios in the country and their possible impacts but also can be used in national interest for the future emission strategies and CTM studies.

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