Gaseous Emissions from Agricultural Activities and Wetlands in National Capital Territory of Delhi

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Abstract

This work aims to develop an emission inventory of methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3), nitrogen oxides (NO, NO_2) and CO_2 from various agricultural activities and wetlands in Delhi area using an emission factor and activity based approach between the years 2001 and 2011. Among all agricultural activities, livestock enteric fermentation (LEF) was found to be the main source, contributing up to 90% of total CH_4. This is followed by livestock manure management (LMM) (6-7%), paddy field (3-5%) and burning of crop residue (0.6-0.9%). It was also found that LMM practices alone contributed ~99.8% of total N_2O emissions and ~106-141 Gg of NH_3 during 2001-2011. Crop residue burning was responsible for ~41 Gg of annual average emissions of NO_x over the period 2001-2011. Annual CH_4 emissions from rice cultivation practices were found to be in the 560-634 Gg range during same period. N_2O emission from crop residue burning and fertilizer were insignificant when compared with LMM practices. About 54 Gg, 1.5 Gg and 14 Mg of CO_2, CH_4 and N_2O, respectively, were released by natural and manmade wetlands in Delhi during 2009 while manmade wetlands were found to be responsible for 48-49% of total GHG(CO_2,CH_4,N_2O) emissions.

Keywords: Greenhouse gas emissions; Enteric fermentation; Manure management; Agriculture activities; Megacity Delhi; India

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1. Introduction

Agricultural sector is one of the potential sources of greenhouse gas (GHG) emissions in many parts of the world (IPCC, 2007). WRI (2006) and IPCC (2007) reports state that agricultural sector was responsible for 14% of the total global GHG emissions in 2000. With respect to agriculture sector worldwide, India is among the largest contributors of GHG emissions such as methane (CH_4), nitrous oxide (N_2O), and other gaseous air pollutants such as ammonia (NH_3), nitrogen oxide (NOx), nitric oxide (NO) and nitrogen dioxide (NO_2) (Bhattacharya and Mitra, 1998; Garg et al., 2004). In 2000, India's total contribution towards the world's total CH_4 and N_2O emissions was ~4.7% and ~2.8%, respectively; of which as much as ~3.2% and ~2.7% were contributed by the Indian agriculture sector alone (ALGAS, 1998; Bhatia et al., 2004). Similar to agriculture sector natural and manmade wetlands are also responsible for significant amount of GHG emissions (Mander ,2013, 2014, Turetsky, et al.,2014, Barbera,2014).

Principal agriculture activities leading to emissions of CH_4, N_2O, NH_3 and NO_x (= NO+NO_2) include livestock enteric fermentation (LEF), livestock manure management (LMM), rice cultivation, field burning of agricultural crop residue and use of various types of fertilizers (Sass and Fisher 1998; NATCOM, 2004; Singhal et al., 2005). Most of these gaseous emissions are interrelated and measures to curtail emissions of one of these gases can affect the emissions of others. Therefore, all the GHGs are important for regulatory policies (Brink et al., 2005).

Increasing industrial and vehicle population over the past decades in Nation Capital Territory (NCT) Delhi have put it among one the of most polluted cities in the world (Nagpure et al., 2010, 2011, 2013; Kumar et al., 2011, 2013; Jain et al., 2014). Over the last decade, most of the research in India has focused on emissions from vehicles and industries as major source of air pollutants (Kumar et al, 2008, 2013; Nagpure and Gurjar 2012; Shukla et al, 2013; Babaee et al, 2014). Key source such as agriculture sector has received a very little attention by previous studies (Gurjar et al., 2004, 2010; Sharma et al., 2002). The NCT of Delhi includes an area of 1,484 km^2; of which 369.35 and 1113.6 km^2 is designated as rural and urban areas, respectively, and therefore making it the largest city in terms of area in the country (DSA, 2010; DSH, 2011). Currently, comprehensive emission inventory for various greenhouse gases from the agriculture activities for the NCT Delhi is non-existent. Existing inventories (e.g. Gurjar et al., 2004; CPCB, 2010) focus on a few agriculture activities (e.g., LEF, LMM) or for a particular pollutant such as CH_4. Furthermore, there is no specific study available for the estimates of wetland emissions in Delhi. This

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article presents a first comprehensive emission inventory of key greenhouse gases (CH_4, N_2O, NO_x, NH_3,CO_2) originating from agriculture activities such as LEF, LMM, rice cultivation, use of fertilizers and crop residue burning and wetlands in the administrative boundaries of NCT Delhi. The boundaries of NCT considered are those defined by the report of Economic Survey of Delhi (ESD, 2013).

2. Methodology

Emissions from agricultural activities for Delhi are estimated using an emission factor (EF) and activity based approach. Emissions of CH_4 and N_2O are estimated from all agricultural activities, whereas estimates of NH_3 and NO_x are made from LMM and burning of crop residue, respectively. Emissions of CH_4, CO_2 and N_2O have estimated for both the natural and manmade wetlands in Delhi

2.1 Compilation of activity data

Livestock population, total rice cultivated area, rice and wheat production data have been obtained from Delhi Statistical Handbook 2011 (DSH, 2011); see Table S1. Due to unavailability of rice cultivation area with water management practices, total rice cultivated area (**Table S2**) was scaled with the ratio of national rice cultivation whereas water management practices were adopted as given by Parashar et al. (2003). Since the total burnt crop residue (wheat and paddy) data for Delhi was not available, this was scaled with the ratio of wheat production and its residual burning (27%) given by Sahai et al. (2007), as presented in **Table S3**. Data for natural and manmade area have been obtained from National Wetland Atlas of India (SAC, ISRO, 2009).

2.2. Emission estimations

Emission of CH_4 from LEF, LMM, rice cultivation and burning of crop residue have been calculated by using Eq. (1)

$$E_i = \sum(i_n \times EF_n) \qquad (1)$$

Here E_i denote the emissions of CH_4, N_2O, NO_x and CO_2 from *i* activities such as LEF, LMM, rice cultivation, fertilizer, burning of crop residue and wetlands area; *n* represent the factor responsible for the emissions from *i* activities (i.e. animal population for LEF and LMM, rice cultivation area with its management practices, quantity of fertilizer use, quantity of residue burn and wetland area). Emission factors adopted for LEF, LMM, and rice cultivation have been given in Table **S4, S5, S6 and S9.** Delhi lies in Indo-Gangetic plain and normally the farmers of this region apply 240 kg N per hectare in the form of fertilizer (i.e. urea) for rice or wheat crops in the agriculture field. In the Indo-Gangetic region including Delhi, the

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rice-wheat crops occupy about 13 million hectares of land and these crops consume most of the N fertilizer in this region that makes them a major source of N_2O emission (Pathak et al., 2002). Because wetland area data is only available for the year 2009 so we only estimated GHG emissions from wetlands for this particular year.

N_2O and NH_3 are other important products of LMM practices Eq. (2) has been used for calculating N_2O and NH_3emissions from LMM system:

$$E_i = \sum(i_n \times Nex \times EF_n \times C) \qquad (2)$$

where i_n = Population of different types of animal; Nex = total nitrogen excreted annually per animal (kg/yr/head); EF_m = emission factor for the animal group (kg/animal/yr), as presented in **Table S6 and S8;** C= conversion factor of N_2O-N (44/28 for N_2O and 28/17 for NH_3)

To determine the uncertainty associated with calculated emissions Monte Carlo simulations have used. The details of methodology deployed for the uncertainty analysis are available ted in supplementary material Section S2.

3. Results and Discussion

The LEF contributed highest amount of agricultural CH_4 emissions, in the range of 88-90%, between 2001 and 2011. After LEF, LMM practices are the second largest contributor of CH_4 in Delhi, contributing about 6% of total CH_4 emissions during 2001 to 2011 (Figure 1a). As shown in Figure 1b and 1c, CH_4 emission from LEF have increased by about 43% in 2011 from the 13 Gg levels in 2001. The similar increase for the LMM was only 20%. Among all livestock population, buffaloes were the largest contributor of total CH_4 from LEF and LMM, followed by cattle crossbreed, cattle indigenous and other livestock such as goat, pigs, sheep, horse and camel. Larger share (59-69%) and increasing population makes buffaloes as the highest contributor of CH_4 emissions in Delhi.

During 2001-2011, CH_4 emissions from rice cultivation or paddy fields account for about 3-5% of the total CH_4 emissions produced by all agriculture activities (Figure 1a). About 13% of increase (560 Mg in 2001 to 634 Mg in 2011) in CH_4 emissions was found due to rice cultivation (Figure 1d). As expected, continuously flooded rice cultivated area accounted highest amount (31%) of CH_4 emission during 2001-2011. This could be because of the generation of anaerobic conditions in flooded areas, which are ideal for CH_4 production

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(Dore et al., 2008). A modest percentage (0.6-0.9%) of CH_4 emissions was contributed by crop residue burning as compared to other agricultural activities such as LEF, LMM and rice

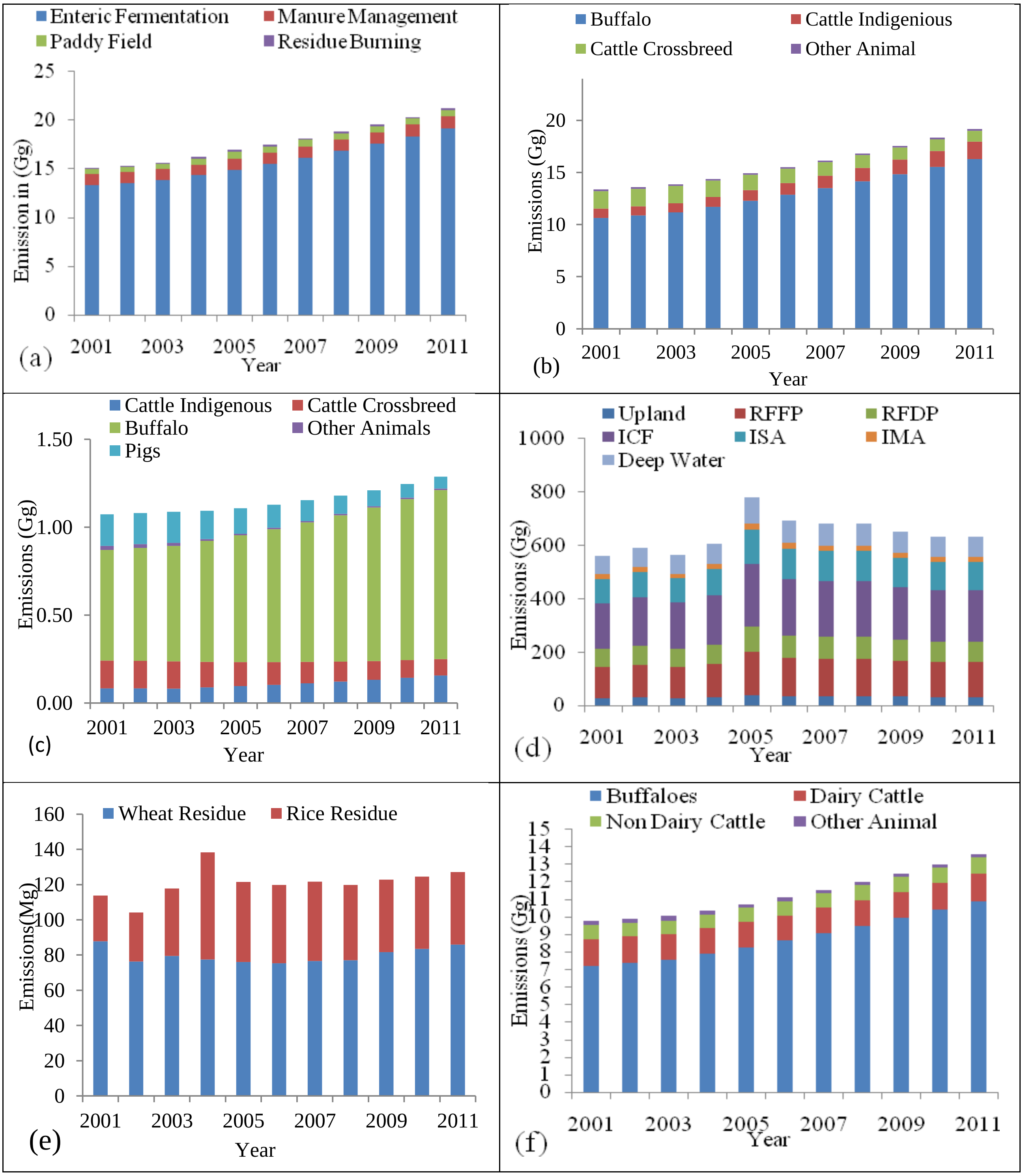

Figure 1. *Emissions of* CH_4 *from: (a) different agricultural activities, (b) Livestock Enteric Fermentation, (c) LMM of different livestock, (d) different rice cultivation practices, (e) burning of crop residues, and (f) Emission trend of* N_2O *(Gg) from LMM in megacity Delhi during 2001-2011.*

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Other animals include goat, pigs, horse, sheep, camel and poultry. Note: RFFP = Rain Fed Flood Prone; RFDF = Rain Fed Drought Prone; ICF = Irrigated Continuously Flooded; ISA = Irrigated Single Aeration; IMA = Irrigated Multiple Aeration.

cultivation. Wheat and rice are two major crops cultivated in Delhi and these produce a significant amount of residues that are burnt in the agriculture fields. CH_4 emission trend from this source showed about 12% growth between 2011 and 2012 i.e.114 Mg in 2001 compared to 127 Mg in 2011 (Figure 1e). Emission produced through wheat residue burning decreased by 2% in 2011 from 2001 values. Conversely, burning of rice residue in 2011 resulted in 58% more than that in 2001 (i.e. 26 Mg in 2001 and 41 Mg in 2011). Primary reasons for these changes were increase in the rate of rice production and an opposite trend for wheat production rate. Note that the variation in emission trends, as shown in Figure 1e, can directly be attributed to the varied areas used for wheat and rice production in Delhi (e.g., lowest in 2002 and highest in 2004). Contribution of wheat residues burning towards CH_4 emissions in 2011 decreased while this increased for rice residue.

About 10-14 Gg of annual N_2O emissions during 2001-2011came from the following agriculture activities: LMM, fertilizer and burning of crop residue. Nearly 99% of these emissions were contributed by the LMM practice alone, indicating minimal contribution from other sources such as use of fertilizers and burning of crop residue. Estimated emissions of N_2O from the LMM were 10 Gg in 2001, with a growth rate of 39%, taking it to 14 Gg in 2011 (Figure 1f). Figure 2a shows that fertilizer uses in agriculture fields contribute negligible N_2O emissions in Delhi. However, the trend of N_2O emissions is highly varying over the years. This could be presumably due to the periodic crop alteration practice prevalent in Delhi area. Figure 2b shows yearly trend of N_2O emissions from burning of crop residue with an increase of 5% from 21 Mg in 2001 to 22 Mg in 2011. This contribution from wheat residues was substantially higher (83-89%) compared with rice (11-17%).

From 2001 to 2011, about an average 106-141 Gg/year of NH_3 was emitted from LMM practices in megacity Delhi (Fig 2c). Figure 2d shows that there is no much yearly variation in NO_x emissions and has a slight decrease of 2% from 42 Gg in 2001 to 41 Gg in 2011. Thus, burning of crop residue in Delhi is a potential source of NO_x emissions and control on this source can substantially contribute to cut down NO_x emissions. However, this contribution is negligible as compared to transport sector emissions (87 Gg/year) in Delhi (Nagpure, 2011).

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Because of very small areas of wetland, the emission from manmade and natural wetland in Delhi is very less as compare to agricultural activities. Wetlands are responsible for about 55 Gg, 1.5 Gg and 14 Mg of CO_2, CH_4 and N_2O emission respectively in Delhi during year 2009. Out of total wetland in Delhi, manmade wetland is responsible for about 49% of CO_2, CH_4 and N_2O emissions.

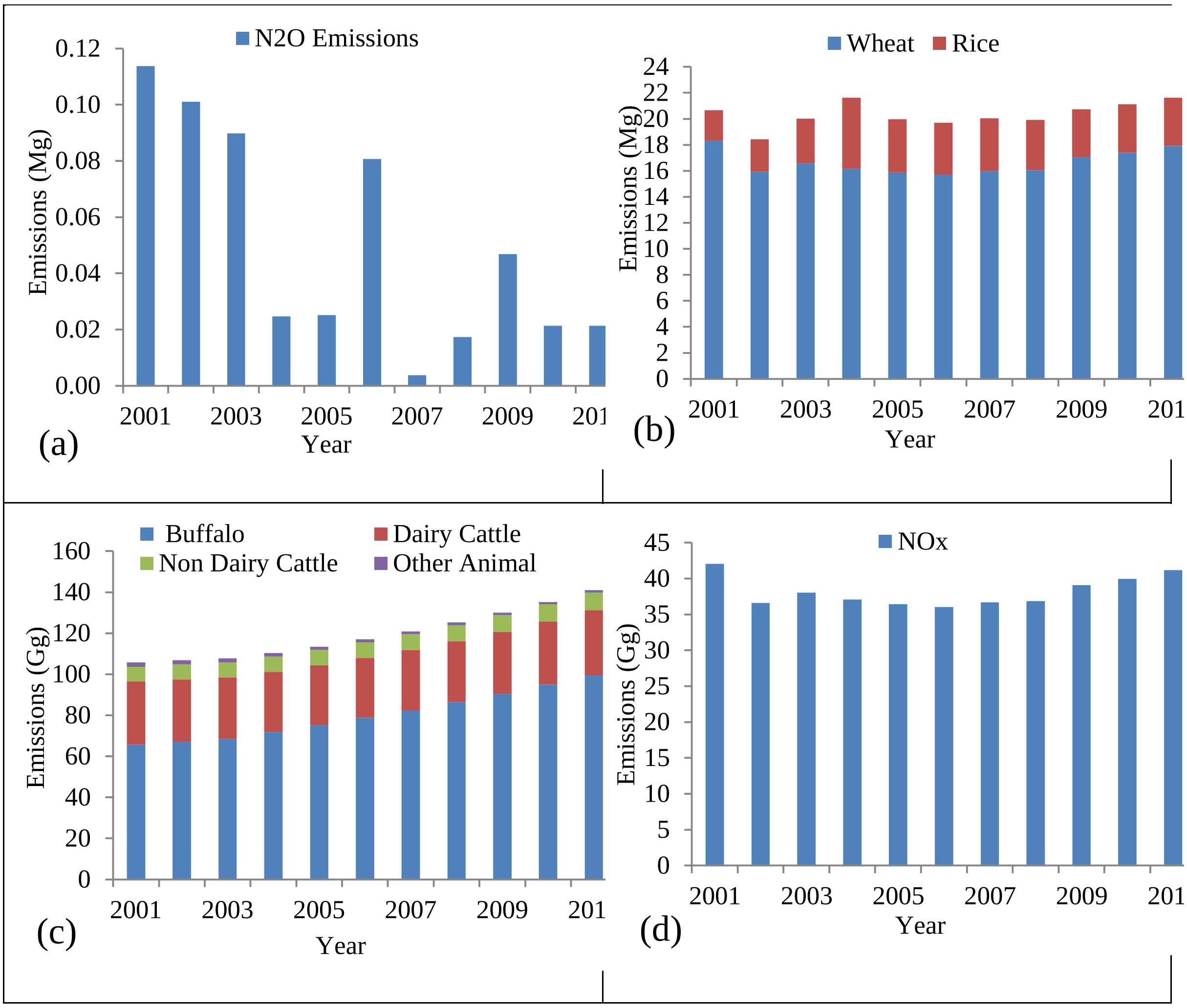

Figure 2. *Emission trend of N_2O from: (a) fertilizer use, (b) burning of crop residue, (c) Emission trend of NH_3 from LMM system, and* ***(d)*** *Emission trend of NO_x, from agriculture activities in megacity Delhi during 2001-2011. Note: LMM = Livestock Manure Management; LRF = Livestock Enteric Fermentation; PF = Paddy Field; BCR = Burning of Crop Residue.*

Emissions of CH_4, N_2O and NH_3 were dominated by buffalo population among all the livestock activities (e.g., LMM, LEF) during the study period. The most significant cause of this has been increasing buffalo numbers in Delhi for meeting increasing demand of food supplements (e.g., milk) due to continuous growth in population (Kumar et al., 2014). According to Animal Husbandry Statistics (DSH, 2011), the milk production in Delhi during 2001 was 294 Gg that increased to 480 Gg in 2011. Buffalos are preferred over other livestock because of their high yield of milk and less maintenance cost. As a result, buffalo population for milk production increased from 71% in 2001 to 77% in 2011 compared with population of other cattle in Delhi (DSH, 2011). Further detailed discussion on the impact of animal husbandry and crop patterns on emissions and abatement measures are available in supplementary Section S3.

4. Resulting uncertainties

CH_4 and NO_x emissions from burning of crop residue are the most uncertain among all other agricultural activities (10-60%). Emissions from all agricultural activities are positively skewed (i.e. the uncertainties in the upper bound are larger than in the lower bound). Buffalo population emerged as an important key source for CH_4 emissions from LEF and LMM. Whereas EF of burning of wheat residues came out as an important key source among other input variables to estimate CH_4 and N_2O emissions from burning of crop residues. The details of uncertainty associated with different activities are given in **Table S10**.

5. Limitations and further scope of the study

There are several limitations of this study due to unavailability of accurate annual livestock population data, burnt crop residue and country specific EFs for some of the livestock. The livestock population data were available only for year 1997, 2003 and 2007 (DSA, 2010). Therefore, the data were extrapolated for rest of the years until 2011. For estimating N_2O emission from the LMM, there was a lack of country–specific EFs for livestock. N_2O emission factors for India were only available for solid storage of livestock manure (Gupta et al., 2007) and we had to adopt EF from LMM given by Yamiji et al. (2004) given for China; this may create uncertainties in N_2O emissions for Delhi. Similar was the case with estimation of NH_3 from LMM, leaving us to adopt EFs available for Asian region (Yamiji et al., 2004). No data were available for crop residue burning in Delhi which was scaled from the ratio given by Sahai et al. (2007) for the Indian crop production and residue burnt. Also, area of rice cultivation and water management practice with rice cultivated area was unavailable for Delhi that was scaled down according to practices applied nationally for rice cultivation. Due to the nonexistence of agriculture site specific air pollution data for CH_4, N_2O and NH_3, we could not compare our estimates against the measured data. Despite these boundaries, the importance of current study is, however, highly significant because the study consolidates all agricultural activities and their emissions together for the first time. Therefore, the outputs would be very helpful for the policy making purpose. Furthermore, a methodology to make such estimates is established, which could be adopted by other similar studies elsewhere. Identification of the key limitations of this work and overcoming these will provide opportunity for the future research to build more precise inventory of pollutant emissions from agricultural activities.

6. Conclusions

The LEF was found to be the dominant source of CH_4 (88-90%), whereas N_2O and NH_3 emissions were dominated by the LMM practices alone. Crop residue burning and LMM practices were responsible for major portion of NO_x and N_2O emissions, respectively. With respect to GWP, the LMM practices contributed highest (89%) of CO_2 equivalent emissions. However, greenhouse gas emissions from wetlands are only ~2% compared with the all agriculture activities. It was found that among all livestock categories, buffaloes were the highest (80-85%) contributor of CH_4 emissions from the LEF, followed by the LMM (59-64%). Buffalos also dominated (74-80%) the N_2O emissions that were originated from the LMM practices. The trends of agricultural emission in Delhi showed a strong inter annual variability which depends on the livestock population, agriculture production and fertilizer use. To date, no strict control measures have been effectively taken by the government or by other agencies to reduce GHG emission in Delhi from agriculture sector.

This emission inventory is among the first available that includes a number of agriculture activities and time span of ten years (2001-2011) for any Indian megacity. Substantial uncertainty in the present emission inventory may be expected depending on the quality of EF values (as Delhi or India specific data are not available for some activity) and because of the limitations of the methodology which we have explained in Section 5.

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Table 1. *Rice cultivated area (hectare) within the NCR region of Delhi between years 2001 and 2011 (DSA, 2010; Parashar et al., 2003).*

Types of rice cultivation areas	2001	2002	2003	2004	2005	2006	2007	2009	2010	2011
Upland	912	965	919	987	1271	1131	1112	1112	1061	1033
Rain fed Flood Prone	608	643	612	658	847	754	741	741	707	688
Rain fed, Drought Prone	973	1029	980	1052	1355	1206	1186	1186	1131	1101
Irrigated, Continuously Flooded	973	1029	980	1052	1355	1206	1186	1186	1131	1101
Irrigated, Single Aeration	1398	1479	1408	1513	1947	1734	1705	1705	1626	1583
Irrigated Multiple Aeration	825	873	831	892	1149	1023	1006	1006	959	934
Deep Water	365	386	368	395	508	453	445	445	424	413
Total Area	6053	6405	6096	6549	8431	7506	7381	7381	7039	6853

Table 2. *Estimated crop residue burned (Mt) in Delhi NCR during 2001-2011.*

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Types of straw	2001	2002	2003	2004	2005	2006	2007	2009	2010	2011
Wheat	24746	21522	22381	21816	21439	21204	21593	21696	23004	23509
Rice	4886	5227	7202	11427	8542	8370	8461	8049	7734	7734

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Table 3. *Available EF (kg/head/yr) of CH_4 for LMM practices in India.*

Animal Category	Gupta et. al (2007)	NATCOM, (2004)	Gurjar et.al* (2004)	Yamaji, et. al., (2003)
Dairy Cattle				
Crossbreed	3.3	3.5	27	6
Indigenous	2.7	3.8	27	6
Crossbreed Non Dairy Cattle				
0-1 year	0.8	1.2	2	6
1-25 year	1.7	2.8	27	6
Adult	2.3	2.9	27	6
Indigenous Non Dairy Cattle				
0-1 year	0.8	1.1	2	6
1-25 year	2	2.3	27	6
Adult	2.8	2.5	27	6
Dairy Buffalo	3.3	4.4	3	5
Non Dairy buffalo				
0-1 year	1.2	1.8	3	5
1-25 year	2.3	3.4	3	5
Adult	2.7	4	3	5
Sheep	-	-	0.21	0.21
Goat	-	-	0.22	0.22
Horses	-	-	2.2	2.2
Pigs	-	-	7	6
Camels	-	-	2.6	2.6
Poultry	-	-	0.023	0.023
Other	-	-	-	1.2

Where symbols '–' denotes 'not available' and '*' refer to EFs taken from IPCC/OECD/IEA (1997).

Table 4. *CH_4 emission factor (g/m^2) from rice field in India for different cultivation and water management practices.*

Rice Cultivation practices	IPCC(1996)[a] g/ m	NATCOM [b] g /m
Upland	-	3.085[c]
Rain fed flood prone	19	19
Rain fed Drought Prone	6	7
Irrigated continuously flooded	25.1	17.5
Irrigated single aeration	6	6.6
Irrigated multiple aeration	1.36	2
Deep water	19	19

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Sources: [a]Parashar et al. (2003) ; [b]Gupta et al. (2004); [c]Ghosh et al. (2003)

Table 5. EF of N_2O from LMM practices.

	Yamiji et al. (2004) kg N2O–N /head/yr	IPCC[a] (kg N_2O–N/ head/yr	N- excretion kg/head
Dairy Cattle			
Crossbred	0.29	0.29	60
Indigenous	0.29	0.29	60
Non Dairy Cattle (Crossbreed)			
0-1 year	0.34	0.34	40
1-2.5 year	0.34	0.34	40
Adult	0.34	0.34	40
Non Dairy Cattle (Indigenous)			
0-1 year	0.34	0.34	40
1-3 year	0.34	0.34	40
Adult	0.34	0.34	40
Dairy Buffalo	0.39	0.34	53
Non Dairy buffalo			
0-1 year	0.39	0.34	53
1-3 year	0.39	0.34	53
Adult	0.39	0.34	53
Goats	0.17	0.77	9
Sheep	0.21	0.21	10
Horses	0.87	0.77	45
Pigs	0.18	0.18	11
Camels	1.06	0.77	55
Poultry	0.0069	0.0068	0.5

[a]Obtained from Appendix B from the IPCC guidelines (Houghton et al., 1997); [b]Gurjar et al. (2004)

Table 6. *Emission Factors (g/kg) various emission species from the wheat and paddy straw burning.*

Types of pollutants	Wheat (g/kg)	Paddy, (g/kg)
CH_4	3.55	5.32
N_2O	0.74	0.48
NO_x	1.7	–

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Sources: Sahai et al. (2007); symbol '–' means not available.

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Table 7: NH_3 emission factors for LMM.

Livestock Category	Kiaasson (1991)[a] (kg/head/yr)	Yamiji et al. (2004) (kg NH3-N /head/yr)
Dairy Cattle	28.3	5.6
Non Dairy Cattle	12.8	3
Buffalo	–	3.4
Sheep	2.2	1.4
Goats	2.2	1.1
Horses	12.5	7
Pigs	5.03	1.5
Camels	12.5	7
Poultry	0.32	0.12

Note: symbol '–' means not available.

Table 8. Available uncertainties in the emission of various agriculture activities in Delhi.

Activity and Emission	Uncertainty (%)	
CH_4		
Burning of Crop Residue	60.63	-58.06
Enteric Fermentation	26.62	-23.66
Rice Cultivation	15.33	-14.52
Manure Management	10.26	-10.08
N_2O		
Manure Management	64.22	-49.32
NH_3		
Manure Management	58.35	-45.82
NO_x		
Burning of Crop Residue	105.76	-98.02

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