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CONTENTS

Reactive Nitrogen Emissions from Crop and Livestock Farming in India

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ABSTRACT

Recent studies suggest that human activities have accelerated the production and emissions of reactive nitrogen on a global scale. Increased nitrogen emissions may lead to environmental impacts including photochemical air pollution, reduced visibility, changes in biodiversity, and stratospheric ozone depletion. Emissions from agricultural activities, both crop and animal, are known to contain reactive nitrogen compounds.

Emissions of reactive nitrogen for India (for the base year 2003 as a case study) from animal and crop farming are analyzed. These emissions are compared and contrasted with global, US, and European reactive nitrogen emissions. Ammonia and nitrous oxide from animal farming in India were estimated at about 1392 Gg NH_3-N and 136 Gg N_2O-N from livestock; and 2221 Gg NH_3-N and 126 Gg N_2O-N from fertilizer application. The activity data for all livestock in all the districts were collected from the website of the Department of Animal Husbandry, Dairying and Fisheries; and for fertilizers consumption, the activity data were collected from the Ministry of Chemicals and Fertilizers, Govt. of India. Emission factor suitable for region specific for all sources were utilized. Overall, the Indo-Gangetic basin in the North India had considerably high emissions of all reactive nitrogen components.

1. INTRODUCTION

With its triple covalent bond, nitrogen gas (N_2) is very unreactive, accounting for nearly all of the nitrogen present in Earth's atmosphere. Other N species are present only in trace concentrations; however, these trace N species play a vital role for life on Earth. Biologically-active, photochemically-reactive, and radiatively-active nitrogen compounds in the atmosphere, hydrosphere, and biosphere are collectively referred to as reactive nitrogen (Nr) (Galloway *et al.*, 2003). The Nr includes inorganic chemically reduced forms of nitrogen (NHx) [e.g., ammonia (NH_3) and ammonium ion (NH_4^+)], inorganic chemically oxidized forms of N [e.g., nitrogen oxides (NO_x), nitric acid (HNO_3), nitrous oxide (N_2O), nitrogen pentaoxide (N_2O_5),nitrous acid (HONO), peroxy acetyl compounds such as peroxyacytyl nitrate (PAN), and nitrate ion (NO_3^-)as well as organic compounds

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(e.g., urea, amines, amino acids, and proteins). Over the past few decades, human activities leading to the production of reactive nitrogen from diatomic nitrogen (N_2) have exceeded the natural rate of nitrogen fixation on land at the global scale (Galloway *et al*., 2004). Although nitrogen (N) is a major nutrient that governs growth and reproduction of organisms, accumulations of reactive nitrogen from various sources have a profound effect on air and water quality (Aneja *et al*., 2006a; Aneja *et al*., 2006b; Aneja *et al*., 2008a; Erisman *et al*., 2008; Aneja *et al*., 2009).

Each year, increasing human requirements for energy to sustain economic development result in higher emissions of nitrogen oxides to the atmosphere from fossil fuel combustion. Greater food requirements to meet nutritional requirements of a growing population result in agricultural emissions of ammonia, oxides of nitrogen, and nitrous oxide, as well as losses of nitrate to water bodies due to leaching and runoff. Once released to the atmosphere by either man-made (anthropogenic) or natural processes, these Nr compounds undergo transformation in atmospheric reactions e.g. gas-to-particle conversion (Baek and Aneja, 2004a; Baek *et al*., 2004b; and Baek *et al*., 2006), transport associated with wind, and finally wet and dry deposition (Fig. 1). Reactive nitrogen lost from agricultural |systems can enter groundwater, streams, lakes, estuaries, and coastal waters where the Nr can undergo further transformation in a wide range of biotic and abiotic processes (Schlesinger, 2009). Unusual accumulations of reactive N can perturb the environment with a host of beneficial and detrimental effects, for example increased crop yields from nitrogen fertilizer or decreased human health by the respiration of nitrogen-derived aerosols.

Over the last few decades, the number of domestic animals in the world has increased faster than the human population. Between 1960 and 2000, while the human population roughly doubled, the number of domestic animals roughly tripled (Oenema, 2006). Increases in livestock population are particularly large in developing countries such as India and China (Gerber *et al*., 2005; Galloway, 2008).

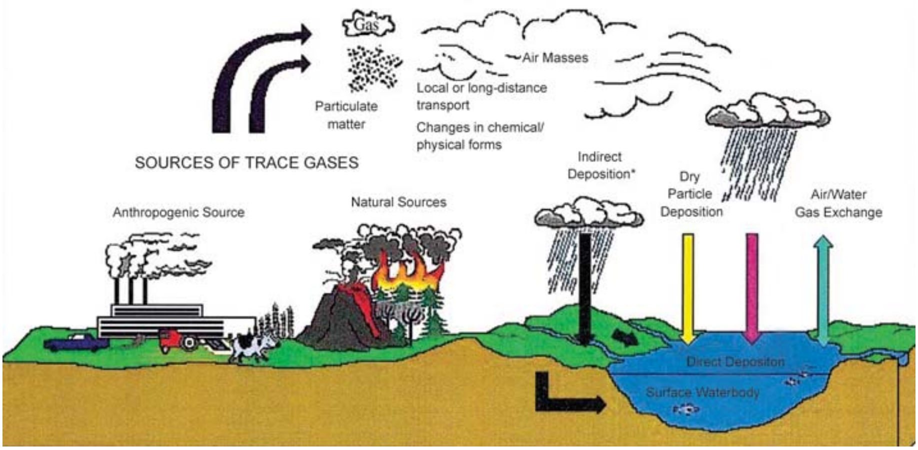


Fig. 1: Atmospheric emissions, transport, transformation and deposition of reactive nitrogen
Source: Aneja *et al*., 2008a.
*Indirect deposition is directed to land followed by runoff or seepage through groundwater to a surface water-body.

The world's population has grown from about 1.5 billion at the beginning of the 20th century to 6.8 billion today. This population increase has been accompanied by the advent and growth of "intensive" agriculture, with associated impacts on the environment (Aneja *et al*., 2001; Erisman *et al*., 2008; Aneja *et al*., 2008a; Aneja *et al*., 2009). Increased agricultural output is also the result of mechanization combined with the abandonment of traditional practices, better pesticides, cultivation of marginal land, readily available hybrid- and genetically-modified crop varieties, and improvements in production efficiency (Aneja *et al*., 2009). Substantial evidence points to perturbation of the global nitrogen cycle, but the exact quantification of the magnitude and spatial distribution of this perturbation is presently unknown. Research projects such as the NitroEurope is working towards deriving more precise nitrogen balances from local to regional scales (Sutton *et al*., 2007; http://www.nitroeurope.eu); and the US Environmental Protection Agency, Science Advisory Board's Integrated Nitrogen Committee report on reactive nitrogen

http://yosemite.epa.gov/sab/sabproduct.nsf/ea5d9a9b55cc319 285256cbd005a472e/67d7889dcca38b2e852577320003e5b1/$FILE/INC%20Draft%20Report%205_28_10.pdf

While developed nations are concerned with reducing emissions of Nr to the environment, developing nations are far away from such initiatives. This paper has been designed to estimate NH_3 and N_2O emissions from farming (both crop and livestock) in India using emission factors with regional specificities, livestock species' characteristics, and regional inventories of the types of fertilizers applied. Emissions to the atmosphere via waste management systems for livestock (non-dairy cattle, dairy cattle, buffaloes, sheep, goats, pigs, horses, asses and mules, camels, and poultry) and fertilizer usage are estimated. This paper provides state-wide estimates for the sources of NH_3 and N_2O from animal farming and fertilizer application on land used for agriculture in India for the base year 2003. We compare and contrast the values obtained with the previous studies in other regional areas of the world.

2. GLOBAL REACTIVE NITROGEN EMISSIONS

Table 1 presents current global estimates for sources and sinks of NO_x, N_2O and NH_3. These reactive nitrogen trace gases in the atmosphere play important roles in local, regional, and global environments. NO_x is a major precursor of atmospheric photo-oxidants and has important contributions to acid deposition and tropospheric ozone (Crutzen 1970; Crutzen 1979). Ozone is phytotoxic, so it may reduce terrestrial sequestration of CO_2 (Holland *et al*., 2005). Ozone also contributes to a number of human respiratory ailments and increased morbidity in urban areas (NRC, 1991). N_2O is one of the important greenhouse gases in Earth's atmosphere, where it has approximately 320 times the global warming potential of carbon dioxide. It is now the major species contributing to the depletion of stratospheric ozone (Ravishankara *et al*., 2009). Ammonia is the most abundant alkaline constituent in the atmosphere (Aneja *et al*., 2008a; Aneja *et al*., 2008b; Aneja *et al*., 2008c), where it regulates atmospheric acidity (Brasseur *et al*., 1999). In addition, NH_3 is also an important source of atmospheric aerosols (PM_{fine})

Table 1: Global atmospheric budgets of NO_X and NH_3 (Aneja *et al*., 2001)

Source or sink	NO_x[a]	N_2O[b]	NH_3[c]
	(Tg Nyr^{-1})[d]		
Fossil fuel combustion	21	0.5	2.0
Biomass burning	8.0	0.4	5.0
Sea surface	< 1.0	5.7	13
Domestic animal waste	–[e]	1.6	32
Human excrement	–	–	4
Lightning	8	–	–
NH_3 oxidation by OH	1	0.6	–
Stratospheric input	0.5	–	–
Soil emissions	20.2	10.7	19
Other[f]		6.3	
Total sources[g]	59	26	75
Wet deposition	12–42	–	46
Dry deposition	12–22	–	10
Stratospheric sink	–	19.3	–
NH_3 oxidation by OH	–	–	1
Atmospheric accumulation	–	3.5	–
Total sinks	59	19.3	57

[a] *Source:* Levine (1991).
[b] *Source:* Bouwman *et al*. (1995); stratospheric sink from Houghton *et al*. (1995).
[c] *Source:* Schlesinger and Hartley (1992)
[d] 1 Tg = 10^{12} g
[e] (–) Indicates insignificant or unavailable terms
[f] Includes adipic and nitric acid production, nitrogen fertilizer, land use change and other small sources.
[g] It is accepted that the apparent difference between total NH_3 sources and sinks represents uncertainties in identified budget terms, not atmospheric accumulation.

because it facilitates gas-to-particle conversion (Baek and Aneja, 2004a; Baek *et al*., 2004b). Its deposition contributes to soil acidification through oxidation of the deposited ammonia to acidic compounds (Roelofs *et al*., 1987).

3. STUDY AREA AND METHODOLOGY

India hosts land in six major climatic subtypes, ranging from the desert in the west, to alpine tundra and glaciers in the north, to humid tropical regions supporting rainforests in the southwest and on the island territories in the south. Many regions have starkly different microclimates. With a total land area of 3,287,263 km^2, India measures 3,214 km from north to south and 2,993 km from east to west. It has a land frontier of 15,200 km and a coastline of 7,517 km. India's unique geography and geology strongly influence its climate; this is particularly true for the Himalayas in the north and the Thar Desert in the northwest.

India ranks second worldwide in farm output today. Agriculture and allied sectors, such as forestry and logging, accounted for 16.6% of the gross domestic product (GDP) in 2007, and employed 52% of the total workforce. India is the world's largest producer of milk, cashew nuts, coconuts, tea, ginger, turmeric and black pepper. It also has the world's largest cattle population (281 million). It is the second largest producer of wheat, rice, sugar, groundnut and inland fish. It is the third largest producer of tobacco and accounts for 10% of the world fruit production, with first rank in the production of banana and sapota.

The district-wise data for livestock numbers was obtained from the 17th Indian livestock census in 2003 (States in India are further divided into districts, equivalent to counties in the U.S.) from the website of The Department of Animal Husbandry, Dairying and Fisheries (http://dms.nic.in/ami/home.htm). The data-base was prepared for various types of livestock (e.g. cattle, buffalo, sheep, goats, horses, asses and mules, camels, pigs and poultry) for each state and district of the country. District-wise consumption of various fertilizers (urea, diammonium phosphate, ammonium sulphate, NPK fertilizers) was obtained from the Ministry of Chemicals and Fertilizers India for the year of 2003.

Gaseous emissions from livestock in each district, E_{ij} (kg yr^{-1}) were estimated as Eq (1):

$$E_{ij} = EF_{ij} \times LP_i \qquad \text{... (1)}$$

Where, subscripts *i* and *j* signify the kind of livestock and atmospheric components, respectively; EF_{ij} is the emission factor in 'kg $head^{-1}$ yr^{-1}'; LP_i is the population of each livestock type in a district. A similar approach was followed for calculation of these gas emissions from fertilizer application on the field, by multiplying the fertilizer consumption in kg by the emission factor for each fertilizer.

Earlier studies have estimated NH_3 emissions from livestock in Europe and the US (Battye *et al*. (2003), Buowman *et al*. (1997), Misselbrook *et al*. (2000), and Van Der Hoek (1998). Battye *et al*. (2003) used the emission factors, where possible, from the U.S. studies; and also by European researchers considering the farming conditions of the USA. Some research groups have presented NH_3 inventories for Asia (Zhao and Wang, 1994; Lee and Park, 2002). But these studies have relied on emission factors based on animal farming conditions in European countries (Klaassen, 1991; Asman, 1992; European Environment Agency (EEA), 1999) because they did not have enough information on Asian-specific emission factors. The latest study done by Yamaji *et al*. (2004) has estimated the NH_3 emission from the livestock farming for Asian countries. They estimated NH_3 emissions by taking into account the N-excretion values from the livestock combined with coefficients for NH_3 volatilization in different breeding periods.

We used Yamaji *et al*. (2004) for emission factors of NH_3 for livestock in India. The livestock considered for this study are cattle, buffalo, sheep, goat, camel, pigs, horse, mules and asses, and poultry.

The IPCC guidelines show N_2O emission from animal waste management systems in each region of the world, using values for N-excretion per head of six different types of livestock; cattle, poultry, sheep and pigs (Houghton *et al*., 1997). In addition to these recommended values, N_2O emission factors were estimated from the N excretion values of the other four types of livestock; buffaloes, camels, horses, and goats, obtained from Van der Hoek (1994). Table 2 provides the emission factors used in this study to estimate the emission of NH_3 and N_2O from various livestock farming in India.

Several research groups in the past have estimated NH_3 emission from synthetic fertilizer applied on agricultural land in the world (e.g. Bouwman *et al*., 1997;

Table 2: Emission Factors of NH_3 and N_2O from various livestock

Livestock	kg NH_3–N head^{-1} yr^{-1}	kg N_2O–N head^{-1} yr^{-1}
Cattle	4.3	0.32
Buffalo	3.4	0.39
Sheep	1.4	0.21
Goat	1.1	0.17
Camel	7.0	1.06
Pigs	1.5	0.18
Horses	7.0	0.87
Mules & assess	7.0	0.87
Poultry	0.1	0.01

Misselbrook *et al*., 2000; Lee and Park, 2000). The emission factors vary as a function of the chemical composition of the fertilizer, soil properties (pH, calcium content, water content, buffering capacity, porosity, etc.), meteorological conditions (temperature, wind speed, precipitation), mode of application, and soil and water management (Bouwman *et al*., 1997). However, due to lack of data, the NH_3 emission from fertilizers cannot be presented as a function of all the above factors. Therefore, we relied on the emission factors of Bouwman *et al*. (1997), as they have been compiled for different regions of the world. In India the most common synthetic nitrogen fertilizers applied on the agricultural land are urea, diammonium phosphate, ammonium sulphate and NPK fertilizers.

The IPCC assumed an N_2O emission factor of 1.25±1.0% of fertilizer N applied. No allowance was made for different fertilizer types, for different soil management and cropping systems, and for variations in rainfall, which are important variables. Substantial reductions in emissions from grasslands can be achieved by matching fertilizer type to environmental conditions, and in arable systems by using controlled release fertilizers and nitrification inhibitors. We have adopted the emission factors from the study by Smith *et al*. (1997). Table 3 presents the emission factors for NH_3 and N_2O from fertilizer application for this study.

4. RESULTS AND DISCUSSION

4.1 Scenarios of the Sources in India

The livestock population of India is large, and animals play an important role in the agricultural economy even though they often receive inadequate nourishment. In 2001 there were an estimated 219.6 million heads of cattle, more than in any other country and representing about 15% of the world's total. For each subcategory, India's livestock population as a proportion of the world's total is: cattle 13.5%, buffaloes 55.1%, sheep 5.7%, goats 16.1%, pigs 1.8% and horses 1.4% for the year 2003 (http://dms.nic.in/ami/home.htm).

Fig. 2 provides the livestock numbers for India for the year 2003. From these data, it can be observed that India has the largest proportion of the world's population of poultry (34.1%) followed by cattle (24.7%), goats (17.1%) and buffalo (13.4%). Each of these percentages is based on the total population (i.e. sum of cattle, buffalo, sheep, goat, pigs, horses, mules and asses). The overall highest livestock population is in the state of Andhra Pradesh followed by Tamil Nadu,

Table 3: Emission Factors of NH_3 and N_2O from various fertilizer application

Fertilizer	N content (%)	NH_3 losses as % of N applied	N_2O losses as % of N applied
Urea	46	25	1.4
Diammonium phosphate	21	5	0.25
Ammonium sulphate	21	8	0.35
NPK fertilizer	17	4	0.2

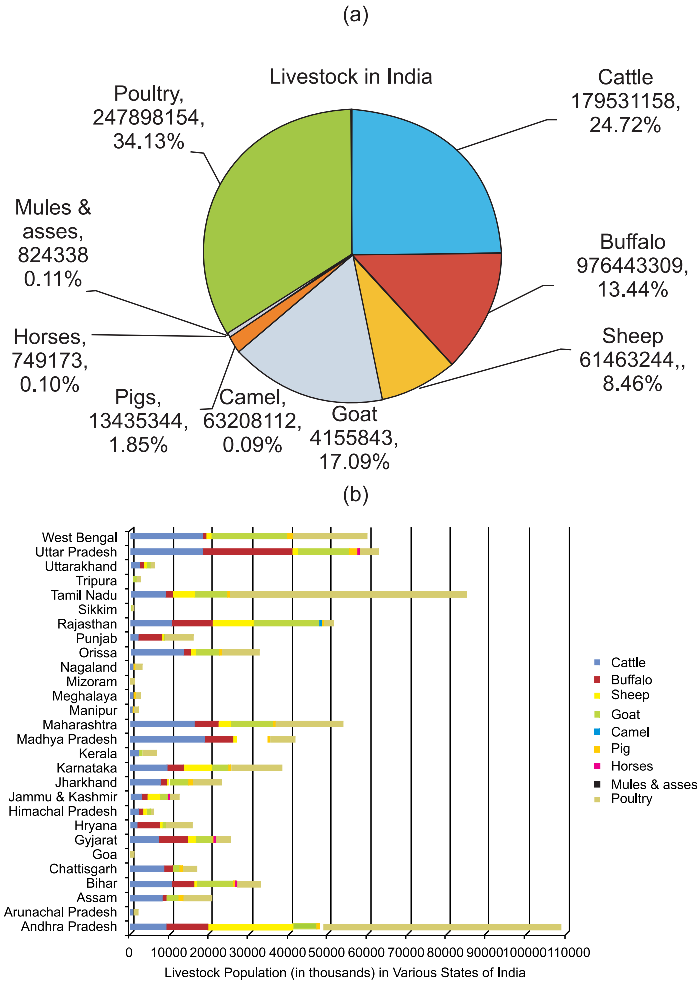
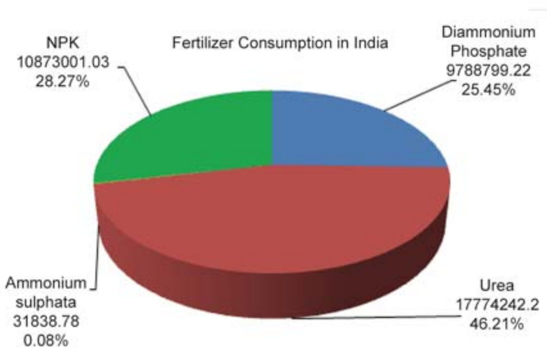


Fig. 2: Livestock in India 2003: (a) overall population, and (b) with state-wise distribution

Uttar Pradesh and West Bengal. The greatest individual population of livestock is found for cattle in Madhya Pradesh (18.58 million), buffalo in Uttar Pradesh (22.91 million), sheep in Andhra Pradesh (21.37 million), goats in West Bengal (18.77 million), camel in Rajasthan (0.49 million), pigs in Uttar Pradesh (2.28 million), horses in Jammu and Kashmir (0.17 million), mules and asses in Uttar Pradesh (0.23 million) and poultry in Andhra Pradesh (60.70 million).

(a)



(b)

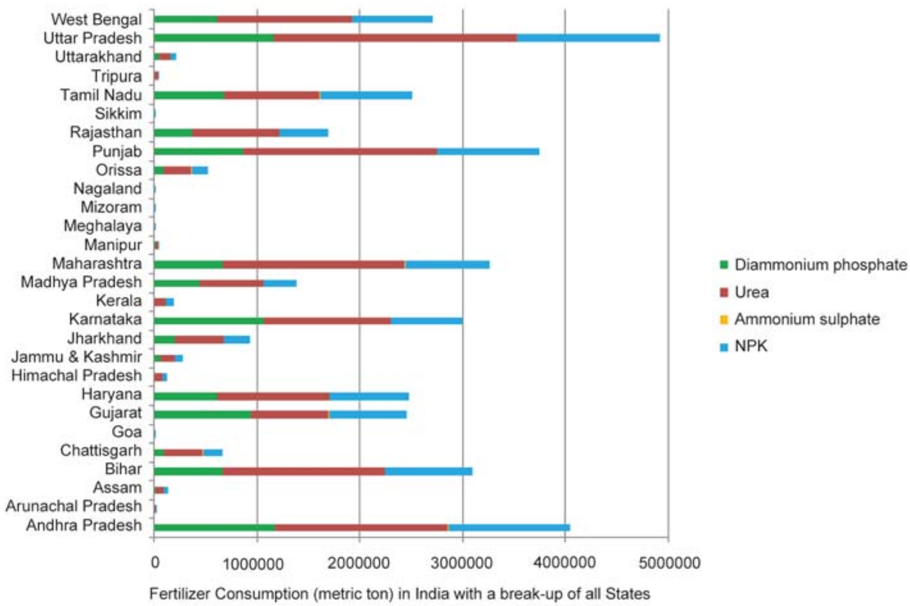


Fig. 3: Fertilizer Consumption in India 2003: (a) Overall consumption, and (b) with state-wise distribution

Fig. 3 provides the fertilizers consumptions, applied on land for agriculture purposes in India for the year 2003. It can be observed that the maximum consumption of fertilizers in India were urea (46.21%) followed by NPK (28.27%), diammonium phosphate (25.45%) and ammonium sulphate (0.08%). The percentage of each fertilizer used was based on its consumption upon the total consumptions (i.e., sum of diammonium phosphate, urea, ammonium sulphate and NPK fertilizers). The highest fertilizer consumption was in the state of Uttar Pradesh followed by Andhra Pradesh, Punjab, Maharashtra and West Bengal. Highest individual category of fertilizer consumption were: diammonium phosphate in Andhra Pradesh (1.18 million metric tons), urea in Uttar Pradesh (2.36 million metric tons), ammonium sulphate in Andhra Pradesh (6339 metric tons) and NPK in Uttar Pradesh (1.39 million metric tons).

4.2 Emission Inventory for India

The NH_3 and N_2O from livestock waste for each type of livestock, except for emissions after application as fertilizers was estimated at state and district levels by multiplying the specific emission factor taking into account the N-excretion value from each livestock by the livestock population. Table 4a presents the emissions of NH_3 and N_2O from livestock excretion (from waste management process excluding the application of these wastes on land). For NH_3, among the livestock, cattle contributed highest emission as 55.5% of the total emission from the livestock; followed by the buffalo (28.1%). Though the population of poultry was highest, but their contributions towards the NH_3 pollution were low owing to their low emission factors. For N_2O, cattle also contributed the highest (42.3%) followed by buffalo (28.1%) and goat (15.5%) towards the total pollution from the livestock sector. Uttar Pradesh is the highest contributor for NH_3 emission from livestock (178 Gg/yr) followed Madhya Pradesh (117 Gg/yr) and Maharashtra (109 Gg/yr). Similarly the higher contributor for N_2O emission from livestock are Uttar Pradesh (18 Gg/yr) followed by Madhya Pradesh (11 Gg/yr) and Maharashtra (10 Gg/yr).

Similarly NH_3 and N_2O from fertilizer application on agricultural land for each type of fertilizer was estimated at state and district levels by multiplying the specific emission factor taking into account the N-loss value from each fertilizer by multiplying fertilizer consumption. Table 4b presents the emissions of NH_3 and N_2O from fertilizer application from various fertilizers. It can be observed that for NH_3, it was the urea contributed highest emission (92.0%) among fertilizers and for N_2O, it was also urea, which contributed highest emission (90.8%) among the fertilizers. Uttar Pradesh is the highest contributor for NH_3 emission from fertilizer (293 Gg/yr) followed Punjab (232 Gg/yr) and Maharashtra (216 Gg/yr). Similarly the higher contributor for N_2O emission from fertlizer are Uttar Pradesh (16 Gg/yr) followed by Punjab (13 Gg/yr) and Maharashtra (12 Gg/yr).

4.3 Comparison of Emission Estimates with Previous Studies

The total amount of NH_3 and N_2O emissions from livestock were estimated at 1392

Table 4a: Emissions of NH_3 and N_2O from different Livestock

	Emission of NH_3		Emission of N_2O	
Category	Gg/yr	%	Gg/yr	%
Cattle	771.9	55.5	57.4	42.3
Buffalo	331.9	23.8	38.1	28.1
Sheep	86.1	6.2	12.9	9.5
Goat	136.6	9.8	21.1	15.5
Camel	4.4	0.3	0.7	0.5
Pigs	20.2	1.5	2.4	1.8
Horses	5.2	0.4	0.7	0.5
Mules and asses	5.8	0.4	0.7	0.5
Poultry	29.8	2.1	1.7	1.3

Table 4b: Emissions of NH_3 and N_2O from Fertilizer Application

Category	Emission of NH_3		Emission of N_2O	
	Gg/yr	%	Gg/yr	%
Diammonium phosphate	102.8	4.6	7.9	6.3
Urea	2044.1	92.0	114.5	90.8
Ammonium sulphate	0.5	0.02	0.02	0.02
NPK	73.9	3.3	3.7	2.9

Table 5a: Comparison of NH_3 and N_2O from livestock waste emission (Gg/yr) with previous studies in Indian perspectives

Pollutant	Category	This Study 2003	Yamaji *et al.* (2004) 2000	Oliver *et al.* (1998)[c] 1990	Zhao and Wang (1994)[c] 1990	EDGAR[c] 1995
NH_3	Livestock waste	1392	1300	3756	4100	–
	Application[a]	1700[a]	–			
N_2O	Livestock waste	136	143	185	–	200
	Application[b]	83[b]	–			

[a] Ammonia emissions from application of wastes to agricultural lands (Yan *et al.*, 2003)
[b] Nitrous oxide emissions from application of wastes to agricultural lands (Yan *et al.*, 2003)
[c] Emissions from all stage of animal wastes treatment. These values are equal to the sum of waste and application (http://www.rivm.nl/bibliotheek/rapporten/773301001.pdf).
IPCC emissions estimates for agricultural sources in India in 2000
Ammonia: 3,450 Gg NH_3/yr (or 2,840 Gg NH_3-N/yr)
Nitrous oxide: 465 Gg N_2O/yr (or 296 Gg N_2O-N/yr)
Based on IPCC, 2009, RCP Database, version 2.0.5. http://www.iiasa.ac.at/web-apps/tnt/RcpD

Gg NH_3–N/yr and 136 Gg N_2O–N/yr, respectively, for the base year 2003 (Table 5a). Our estimate of NH_3 emissions cannot be compared directly with previous studies (Olivier *et al.*, 1998; Zhao and Wang, 1994) since their values included NH_3 emissions after application as fertilizers. But it can be compared with Yamaji *et al.* (2004), where they calculated 1392 NH_3-N Gg/yr—matching exactly with our estimate. Table 5a also presents the NH_3 emissions from animal excreta used as manure which were estimated by Yan *et al.* (2003). Considering the year's gap, our results for NH_3 emission (from waste generation and application) is 8% more than by Olivier *et al.* (1998) and is well matched with Zhao and Wang (1994) for India. Similarly for N_2O, our results matched well with Yamaji *et al.* (2004). The higher value N_2O from animal waste of Yamaji *et al.* (2004) might be due to the emission factor selection and lack of accuracy in the activity data.

Table 5b presents the NH_3 and N_2O emissions from the fertilizer application in comparison with the earlier studies (e.g. Oliver *et al.*, 1998; Parashar *et al.*, 1998). Our values for NH_3 are higher than the values by Oliver *et al.* (1998), perhaps due to more consumption of fertilizer for different years. We believe that our work is more appropriate in the sense that we had the activity level data at district level and chose the emission factors suitable for Asian context.

4.4 Reactive Nitrogen Emissions in India Compared to Global, US and European Emissions

Table 6 presents NH_3 and N_2O emission for India, China, European Union countries and the USA. The emission for India is from this study (after adding the values

Table 5b: Comparison of NH_3 and N_2O from fertilizer application emission (Gg/yr) with previous studies in Indian perspectives

Pollutant	This Study 2003	Oliver *et al*. (1998) 1990	Parashar *et al*. (1998) 1993
NH_3	2221	1992	1174
N_2O	126	123	199

Table 6: Comparison of NH_3 and N_2O Emission (Gg/yr) India with other regions of the world

Pollutant	This study	Oliver *et al*. (1998)			EDGARv4 (2005)		
	India[a]	China	USA	EU[b]	China	USA	EU[c]
NH_3*	5313	6881	1946	3228	7587	2248	3915
N_2O*	345	387	192	287	495	322	302

* Values indicate the emissions from livestock waste, its application and fertilizer application, [a]Values are after adding livestock application, [b]European Union excluding former Soviet Union, [c]European Union except Malta and Cyprus.
Other U.S. agricultural emissions estimates for 2005:
For ammonia: 2,980 Gg NH_3/yr (or 2,450 Gg NH_3-N/yr) Based on USEPA, 2008, 2005 National Emissions Inventory. http://www.epa.gov/ttn/chief/net/2005inventory.html
For nitrous oxide: 752 Gg N_2O/yr (or 458 Gg N_2O-N/yr) Based on USEPA, April 2010, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008, U.S. EPA # 430-R-10-006. http://epa.gov/climatechange/emissions/usinventoryreport.html

for the livestock manure application). The emission values for all regions are from sources including livestock manure and its application, and fertilizer application. In comparison to data for other regions, India stands second after China for emission of both NH_3 and N_2O from the agricultural sector.

4.5 Effects of Reactive Nitrogen

Circulation of anthropogenic Nr in Earth's atmosphere, hydrosphere, and biosphere has a wide variety of consequences, which are magnified with time as Nr enters biogeochemical cycles. The same atom of Nr can cause multiple effects in the atmosphere, in terrestrial ecosystems, in fresh water and marine systems, and on human health. The sequence of effects is called as the nitrogen cascade (Fig. 4) (Galloway *et al*., 2003). As the cascade progresses, the origin of Nr becomes unimportant. There are two important sectors from which the cascade effects propagates. First sector is the energy production by fossil fuel combustion, which results in the conversion of atmospheric N_2 (or fossil Nr) into NO_x. A potential sequence of reactions in the first sector might include: (i) mobilization of an atom of N to NOx in the atmosphere which in turn increases ozone concentrations, (ii) higher NOx and O_3 concentrations lead to the formation of fine particles, decrease visibility of the atmosphere, and increase precipitation acidity, (iii) Nr deposition on terrestrial ecosystem can increase soil acidity, (iv) decrease biodiversity, and (v) discharge to aquatic ecosystems, where the N atom can increase the acidity of surface waters and lead to coastal eutrophication. The N_2O produced in the cascade can increase greenhouse warming and decrease stratospheric ozone.

A similar cascade of effects of Nr stem from the second sector that is from food production including livestock farming and fertilizer application. The pollutants

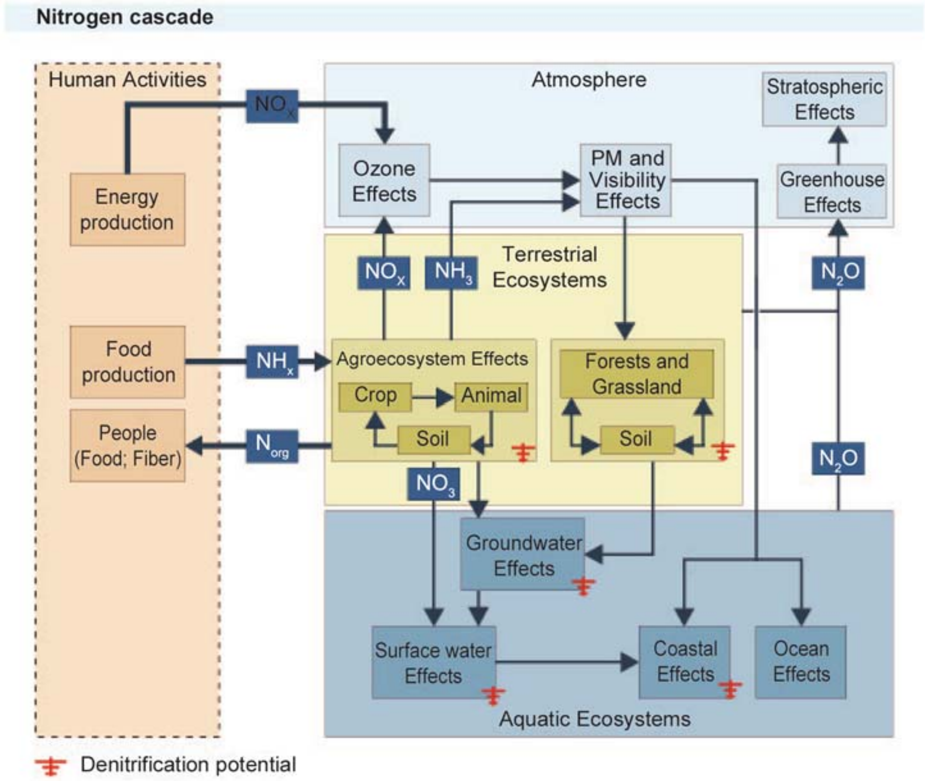


Fig. 4: Effects of Reactive Nitrogen
Source: Galloway *et al*., 2003.

emitted from this sector are NH_3, NO, N_2O, or N_2, and NO_3^- which is lost to aquatic ecosystems. Once transferred to these downstream or downwind systems, the forms of Nr become part of the cascade. Depending on its chemical form, Nr will enter the cascade at different places. An important characteristic of the cascade is that once it starts, the source of the Nr (i.e., fossil fuel combustion or animal waste management or fertilizer production) becomes irrelevant. The Nr species can be rapidly inter-converted from one form to another. The only way to eliminate Nr accumulation and stop the cascade is to convert Nr back to non-reactive N_2.

4.5.1 Indirect Effects on Human Health

Increases in N availability lead to a cascade of ecological impacts at multiple levels. Such responses, in turn, are likely to cause varied and complex changes in the epidemiology of human diseases that depend on the life histories of disease-causing organisms. Some evidence suggests that the abundance and distribution of several important vectors, including the mosquito hosts of malaria and West Nile virus, may be affected by changes in N availability. For example, several studies have shown a positive correlation between concentrations of inorganic N in surface water and larval abundance for malarial *Anopheles* sp. mosquitoes, as well as for *Culex* sp. and *Aedes* sp., carriers of La Crosse encephalitis, Japanese encephalitis, and West Nile virus (Rejmankova *et al.*, 1991; Teng *et al.*, 1998; Walker *et al.*, 1991). One clear and widespread effect of an accelerated N cycle is the eutrophication of coastal and marine eco-systems, an ecological change which may also affect human health. For example, the worldwide increase in harmful algal blooms (HABs) has been linked to anthropogenic nutrient loading (Burkholder, 1998; NRC, 2000). The HABs can include neurological, amnesic, paralytic, and/or diarrheic shellfish poisoning, as well as toxins produced by various cyanobacteria, and by the estuarine dinoflagellates *Pfiesteria piscicida* and *P. shumwayii* (Burkholder, 1998). The HABs can also indirectly affect humans by disrupting freshwater and marine ecosystems and sources of nutrition derived from them. Increased N can also increase the availability of other key nutrients, changes that can, in turn, facilitate blooms of many species of harmful algae (NRC, 2000). Finally, the bacterium *Vibrio cholerae* is associated with a wide range of marine life, and cholera outbreaks have long been associated with coastal algal blooms (Colwell and Huq, 2001; Cottingham *et al.*, 2003).

4.5.2 Nitrate Contamination of Drinking Water

The Nr from agroecosystems leaches into the ground water and in sequence the fates of Nr in ground water are: accumulation, conversion to N_2 and distribution to other systems through hydrologic pathways (e.g., as NO_3^-) or atmospheric pathways (e.g., N_2O or NO) (Puckett *et al.*, 1999, Refsgaard *et al.*, 1999). Although the accumulation of Nr in groundwater is not a regionally or globally important sink relative to the amount of Nr created (Schlesinger, 2009), the effects of elevated Nr in groundwater pose a significant human health risk, because drinking water can become contaminated. In the human body, NO_3^- is converted to nitrite, which can cause methemoglobinemia by interfering with the ability of hemoglobin to take up O_2. The nitrate pollution of ground water caused by fertilizer application and livestock farming may affect the human health in many ways. High nitrate concentration in drinking water (>10 ppm) may responsible for reproductive problems, methemoglobinemia, and cancer (Kramer *et al.*, 1996; Nolan, 1999).

Many headwater streams and lakes are highly disturbed in landscapes and thus have high NO_3^- concentrations, which can lead to eutrophication problems locally or farther downstream. In addition, for headwater streams and lakes draining poorly buffered soils, increased NO_3^- concentrations can result in stream acidification, with resultant impacts on biota (Peterson *et al.*, 2001).

4.6 Reactive Nitrogen in Indian Context

Over half of the world's population is centered in Asia (primarily China and India) and thus agricultural drivers of change are also centered here. While other regions of the world have led the global economy in the 20th century, causing global-scale changes (e.g. in rising CO_2 in the atmosphere), their dominance will soon diminish – Asia is projected over the next few decades to be the dominant force in the alteration of the global environment (Galloway *et al.*, 2008). Assessments of the nitrogen cycle of Asia over the past decade have revealed that: (i) human activities are the major source of new Nr in Asia, (ii) Asia is the largest consumer of fertilizer N on a global basis, (iii) there are major ecosystem and human health impacts due to increased Nr in the Asian environment, (iv) Asia is predicted to become an even larger creator of Nr over the next few decades as both population and per-capita resource use continue to grow (Galloway *et al*., 2008; Galloway *et al*., 2004; Galloway, 2000).

While the developed countries of the world and China seem to be conscious about the need to reduce of Nr; India seems to be lacking in unified study of Nr on either a regional or national scale. Hence it is imperative to study the Nr with respect to monitoring, emission inventory by means of spatial and temporal distribution, control options to be implemented and policies to be legislated in India. The need for an integrative approach to research and policy regarding Nr in Indian agriculture, industry and environment was realized in 2004, when the Society for Conservation of Nature (SCON), a voluntary body of scientists, brought together some concerned Indian experts from diverse backgrounds to discuss the issue. This was followed by a series of nationwide consultations in association with the National Academy of Agricultural Sciences (NAAS) in 2005 and with the Union Government's Department of Biotechnology and Indian National Science Academy (INSA) in 2006, with active support from other agencies such as the Ministry of Environment and Forests (MOEF) and Council of Scientific and Industrial Research. The discussions at NAAS (2005) on Nr and N use efficiency in Indian agriculture led to the adoption of a policy paper (NASS, 2005). A network of nitrogen researchers and experts called 'Indian Nitrogen Group' (ING) has also been formalized as an outcome of the INSA workshop in 2006.

India is currently the third largest producer and consumer of fertilizers (after China and USA), and fertilizer usage is bound to increase with further intensification of agriculture. We need a precise understanding of the scale of nitrogen use/misuse/release through various agricultural, industrial, vehicular and other activities and their contribution to the pollution of waters and air, with special reference to various point and non-point sources and the biogeochemical N cycle. In this respect, one of the major challenges before the scientific community is to provide policy makers with reliable estimates of Nr transfers to different ecosystems and to describe balanced, cost-effective and feasible strategies and policies to reduce the amount of reactive nitrogen where it is not wanted. In this regard, this paper is meant to address the issues related to Nr emission (specifically NH_3 and N_2O) from agricultural sector in India.

5. SUMMARY AND CONCLUSIONS

This study estimates the emissions of atmospheric reactive nitrogen NH_3 and N_2O, which were produced from animal farming and fertilizer application for agricultural purpose in India. It suggests for NH_3 that among the livestock, cattle contributed highest emission as 55.5% of the total emission stems from the livestock, followed by buffalo (28.1%). For N_2O, cattle also contributed highest proportion (42.3%), followed by buffalo (28.1%) and goats (15.5%), relative to the total pollution from the livestock sector. It can be observed that for NH_3, urea contributed the highest proportion of emission (92.0%) among fertilizers and for N_2O, urea also contributed highest emission (90.8%) among the fertilizers. The amount of total NH_3 and N_2O emission from livestock was estimated at 1392 Gg NH_3–N/yr and 136 Gg N_2O–N/yr, respectively for the base year 2003. The emission loads from fertilizer application were as, 2221Gg NH_3-N and 126 N_2O. Overall, the Ganga basin in the North India had relatively high emissions of all components.

Production agriculture has adopted modern technologies and science to maximize productivity, but it has not as yet been subjected to the same environmental regulations that other modern industries must obey. Regulations and policies should require that Concentrated Animal Feeding Operations (CAFOs) and crop production systems use all of practical methods to reduce ammonia and other air emissions. The potential health and environmental risks of intensified modern agriculture demand that we develop emission abatement policies based on best available science (Aneja *et al*., 2008a; Aneja *et al*., 2008b; Aneja *et al*., 2008c; Aneja *et al*., 2009).

In Western European countries and the US (to some extent), health and environmental concerns about agriculturally emitted air pollutants have prompted regulators and policymakers to implement mitigation strategies. In the Netherlands, for example, livestock production must meet stringent ammonia emission based on deposition reduction targets. Since the introduction of a mineral bookkeeping system in the Netherlands, leading to a decrease in fertilizers, along with regulations to incorporate manure into the soil, modifications to animal housing systems and introducing end of pipe scrubbers, the ammonia emissions have decreased by more than 40%, since 1995 and particulate emissions decreased also.

Emission reduction policy should not be hindered by technology limitations; effective techniques are already available, e.g., ammonia emissions from swine manure are reduced as it passes through a treatment plant with solid–liquid separation (Aneja *et al*., 2008b) and as emission-free housing systems, nutrient management systems, including precision fertilization, are adopted. Policy incentives that could be used to encourage increased on-farm nutrient efficiencies include: tax incentives or financial grants, setting targets for nitrogen losses, carbon credits, and cap and trade of GHG emissions.

Although gaps remain in the scientific understanding of agricultural emissions, the potential health and environmental risks require that we develop emission abatement policies based on the best available science—and that we do so without further delay: extending regulations in Europe, introducing them in the US and stimulating the consideration in Asia.

We need a precise understanding of the scale of the reactive nitrogen use/misuse/release through various agricultural activities and their contribution to the pollution of waters and air, with special reference to various point and non-point sources and the biogeochemical N cycle. In this respect, one of the major challenges before the scientific community is to provide policy makers with reliable estimates of Nr transfers to different ecosystems and to describe balanced, cost-effective and feasible strategies and policies to reduce the amount of reactive nitrogen where it is not wanted.

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