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Exploration of 'hot-spots' of methane and nitrous oxide emission from the agriculture fields of Assam, India

Satyendra Nath Mishra[1†], Sudip Mitra[2*†], Latha Rangan[3], Subashisha Dutta[3] and Pooja Singh[2]

Abstract

Background: Agricultural soils contribute towards the emission of CH_4 (mainly from paddy fields) and N_2O (from N-fertilizer application), the two important greenhouse gases causing global warming. Most studies had developed the inventories of CH_4 and N_2O emission at the country level (larger scale) for India, but not many studies are available at the local scale (e.g. district level) on these greenhouse gases (GHGs). Assam is an important state in the North Eastern region of India. In addition to being the regional economic hub for the entire region, agriculture is the major contributor to the state's gross domestic product. In Assam about three-fourths of the area is under paddy cultivation and rice is the staple food. With this background, a district wise inventory of CH_4 and N_2O emission in the North Eastern state of Assam, India was carried out using different emission factors, viz., IPCC, Indian factors and others, to highlight the discrepancies that arose in the emission estimation of these important GHGs while used at the smaller scale i.e. district level. This study emphasizes the need for better methodologies at the local level for GHGs inventories. This study also reiterates the fact that no emission factor is universally applicable across all regions. The GHGs like CH_4 and N_2O are highly site and crop specific and the factors required for their inventory are driven by cultural practices, agronomic management, soil resources and socio-economic drivers.

Material and methods: In this study, Intergovernmental Panel on Climate Change (IPCC) methodology was used for the estimation of CH_4 and N_2O emission. In case of N_2O emission, both direct and indirect emission from agricultural soil was estimated for the various districts of Assam.

Results: The CH_4 (base year 2000–2001) and N_2O (base year 2001–2002) emission was estimated to be 121 Gg and 1.36 Gg from rice paddy and agricultural fields of Assam state respectively.

Conclusions: This study is the first report on the estimation of the GHG emission at the district level from the entire state of Assam, agriculturally one very important state of North Eastern India. This state is also considered as remote due to its geographical location. The study clearly elucidates that there is large variation in the emission inventory of CH_4 and N_2O at the district level (local scale) when different emission factors are used. This calls for detailed and comprehensive data collection and mapping at the micro level for accurate inventory of greenhouse gases in future from agriculture fields.

Keywords: Agriculture, Paddy fields, Methane, Nitrous oxide, Assam, India

* Correspondence: sudipmitra@yahoo.com
[†]Equal contributors
[2]School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India
Full list of author information is available at the end of the article

Background

Increasing industrialisation and developmental activities across the globe have led to stress on the Earth's resources. One of the major damaging impacts of this increasing developmental activity (especially industrial and agricultural) is increasing concentration of the greenhouse gases (GHGs), namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbon (CFCs), etcetera, which are potential causes of global warming due to the enhanced greenhouse effect. CO_2, CH_4 and N_2O are key GHGs that contribute toward global warming at 60%, 15% and 5% respectively [1,2]. Concentrations of these gases in the atmosphere are increasing at 0.4%, 0.3% and 0.22% per year respectively [1,3]. On average, the agricultural sector emits about 47% and 58% of total global anthropogenic emissions of CH_4 and N_2O respectively. Although CH_4 and N_2O emission constitutes only about 20% of the total GHG emissions, they play a significant role in global warming due to their higher values of global warming potential (GWP) of 21 and 310 respectively. It has been estimated that about 74% of the agricultural GHG emissions are from non-annex[1] countries [4]. The amount of CH_4 emission from paddy fields (about 50 to100 Tg yr^{-1}) accounts for about 10% to 20% of total CH_4 emission around the world. Huang *et al.* [5] projected that the CH_4 emission from rice fields may increase to 145 Tg yr^{-1} by 2025. Industrial nitrogen fixation for use in agriculture had increased from less than 10 Tg yr^{-1} in the 1950s to over 80 Tg yr^{-1} by the year 2000. Nitrogen applied in agricultural systems is emitted in different forms like dinitrogen, ammonium, dissolved organic nitrogen or NO_x. Of all these N_2O, which is increasing in the atmosphere at the rate 0.2% to 0.3% per year, is of particular concern [6].

The anthropogenic emission of CO_2, CH_4 and N_2O in India was about 1,398,700 Gg, 20,560 Gg and 240 Gg respectively in the year 2007 [7]. In 2007, the agriculture sector was the largest source of CH_4 emission, accounting for about 65% of the total. Of this, livestock, paddy cultivation and onsite burning of crop residues represented shares of 48%, 16% and 1% respectively. In view of this, Indian scientists have placed special emphasis in recent times on the exploration of CH_4 emission from paddy fields [8-12]. In 2007, the agricultural sector accounted for about 65% of total N_2O emission in India. The main source of direct and indirect N_2O emission in agriculture was the application of nitrogen fertilizer[2] [7]. In 2008, the Government of India (GoI) came up with the National Action Plan on Climate Change. Of the eight national missions mentioned in this plan, one deals with a national mission for sustainable agriculture [13]. After the energy sector, being a dominant and dynamic source of GHG emission, the agricultural sector got special attention for studies and management to abate GHG emissions [14]. It has been easy to change the technology to reduce GHG emission from the energy sector either by using regulatory norms or good backstop technology. However, this is not the case with the agricultural sector, as agriculture directly deals with the cultural, socio-economic matrix of society and farmers, and local setup. So, it is not easy to assess the emissions, due to the random distribution of variables on which emissions depend, or to develop a proper mitigation plan at field level. Few studies have been taken at experimental level to estimate GHG emissions at the local level [15,16].

National level data provides lots of information and inputs for national and international level planning and negotiation. However, data and information at district level would be imperative and very important in the near future for local level decision-making, and for upcoming district and regional planning activities initiated at local and regional level in the age of the decentralised planning approach. It is unanimously accepted across the scientific and policy-making bodies that while climate change and global warming is a global phenomenon, its solution lies at the level of local planning and adaptation. Considering this background, a local level study was carried out by estimating district-wise emission of CH_4 and N_2O from rice paddy and agricultural fields respectively for the state of Assam, India, as per the Intergovernmental Panel on Climate Change (IPCC) guidelines and using other available emission factors[3]. Assam is the gateway to the north-eastern part of India, situated between 90° to 96° longitude east and 24° to 28° latitude north. Assam is bordered in the north and east by the Kingdom of Bhutan and Arunachal Pradesh state. The states, namely, Nagaland, Manipur and Mizoram are situated in the South of Assam, and West Bengal state and Bangladesh to the west. Meghalaya state lies to the south-west of Assam.

Material and methods

Extensive data collection and investigation was carried out to make the inventory of CH_4 and N_2O emissions at the district[4] level (smaller administrative unit) in one of the major paddy-growing states of India, namely, Assam in the north-eastern part of India. Assam was chosen for this study as paddy is the major crop in this state, is grown three times a year, and is major source of agricultural gross domestic product (GDP)[5]. Emission of CH_4 from paddy fields and N_2O from agricultural fields (as per the Indian emission factor and IPCC standard) were represented geographically on the map of Assam using Geomatica GIS software.

Data collection

The CH_4 emission inventory from the paddy fields of all the districts of Assam was calculated by taking into consideration that the paddy area was under the high yielding variety(HYV). Information about paddy fields under different water management systems was obtained from the *Statistical Handbook of Assam 2003* [17]. District-wise irrigation potential utilized in Assam during the Kharif, Rabi, and pre-Kharif seasons in 2000 to 2001 was taken as the paddy field area under a continuous irrigation system. Paddy is the major crop in Assam, is grown in all three seasons of the year, and demands a huge amount of water. It was assumed that all the irrigation potentials were used only for the paddy cultivation. Information about the district-wise area under a rain-fed ecosystem was obtained by subtracting the area under HYV of paddy for the year 2000 to 2001, with that of the area under continuous irrigation. Emission factors for these water management practices were followed as per the IPCC report.

Estimation of N_2O emission from agricultural fields was done using the district-wise data of N-fertilizer use in the year 2001 to 2002 [17]. N_2O emission due to animal manure was calculated using livestock data from the 1997 livestock census [17]. During calculation, two factors that affect direct N_2O emission are not taken into consideration due to non-availability of data, namely, N_2O emission due to the N- fixed by the crops biologically and the amount of emission contributed by the burning of N-fixing and non-N fixing crop residue in the State (Tables 1 and 2). The choice of different base years for CH_4 and N_2O was made on the basis of data availability at that point of time when the study was conducted. Multiple years of data may provide better accuracy in the inventory. Considering the fact that this study is the first attempt towards a district-level inventory of the Assam state, even one year of data provides a reasonable idea about the GHG emission potentials at the district level and the importance of developing site-specific emission factors.

Methodology for the emission inventory

Methane

The district-wise inventory of CH_4 emission from Assam was calculated on the basis of the IPCC formula that was issued in the revised guideline in 1996 [19]. Also three different emission factors were used to estimate the CH_4 emission from the districts of Assam. This was to highlight the differences in the CH_4 emission and the need for a proper local-level emission inventory database for better planning and mitigation strategies in the future. The details of the four different factors that were used are as follows.

Emission factor as reported by Gupta et al

The seasonal integrated flux of 46 g m^{-2} was used for the calculation of CH_4 emission in this case. This emission flux was from the Jorhat experimental farms in which the HYV *Mahsuri* cultivar of paddy was grown in the year 1991. The seasonal integrated flux was much higher than the other experimental stations in India due to the irrigated water regime, addition of organic amendment in the experimental field [32], and higher content of organic carbon in the soil of North Eastern states (about 5%) of India (about 1%) [8].

IPCC emission factor based on Bhatia et al

The IPCC emission factor for the base year 1994 to 1995 was calculated by dividing the methane emission of Assam as calculated in the study reported by Bhatia *et al.* using the IPCC emission factor. The emission factor was calculated as follows:

Emission factor in g m^{-2} = total emission from paddy field of Assam [8]/total area under paddy cultivation [17] = the factor comes out to be 12.81 g m^{-2}.

Indian emission factor based on Bhatia et al

The Indian emission factor for base year 1994 to 1995 was calculated by dividing the methane emission of Assam as calculated by Bhatia *et al.* using the Indian emission factor.

Emission factor in g m^{-2} = total emission from paddy field of Assam [8]/total area under paddy cultivation [17] = the factor comes out to be 6.92 g m^{-2}.

Emission factor used for this study as per the IPCC standard equation

The emission factor and details used in this study for calculation of district-wise CH_4 emission for Assam was as per the IPCC formula. The assumptions made in the calculation of CH_4 emission were as follows: 1) paddy field irrigated under continuous flooding was taken based on the district-wise irrigation potential for the Kharif, Rabi, and pre-Kharif seasons in the year 2000 to 2001 [17]. Paddy is the major crop and is cultivated three times a year, so it was assumed that most of the irrigation was used for it; 2) paddy field under a rain-fed, flood-prone condition was obtained by subtracting the area under continuous flooding from the total area under paddy cultivation (HYV variety) for each district [17]. The formula used for the calculation of CH_4 emission as per the IPCC guideline [19] is as follows:

$$Emission\left(Tgyr^{-1}\right) = \Sigma_i \Sigma_j EF_{ij} * 10^{-12} \quad (1)$$

where i = irrigation under continuous flooding system, j = rain-fed flood-prone, EF_j (seasonally integrated emission factor for rain-fed flood-prone) = 8 g m^{-2}, and EF_i (seasonally integrated emission factor for irrigation under continuous flooding) = 10 g m^{-2} [8].

Table 1 Details of factors used for the assessment of direct nitrous oxide (N_2O) emission

Primary factor	Break-up of primary factor	Details	Coefficient or value		Remark
			IPCC emission factor	Indian emission factor	
F_{SN} (annual amount of synthetic N-fertilizer applied to soil adjusted for the amount that volatilizes as NH_3 and NO_x)	N_{FERT}	The total amount of synthetic fertilizer consumed annually [18]	–	–	–
	$F_{racGASF}$	Fraction of fertilizer volatilize as NH_3 and NO_X	10.0% [19]	15.0% [8,20]	The difference in the emission factor was due to soil management practices, soil type, pH, climatic condition and also the methodology used for emission assessment [19]. Details of differences in the emission factor due to different methodology used for assessment have been discussed in the Sarkar study [20].
F_{AM} (annual amount of animal manure nitrogen applied to soils adjusted to account for volatilization of NH_3 and NO_x)	T	Each defined livestock	–	–	For this study four categories were taken, namely, cattle, buffalo, sheep and goat, based on the details available in the *Assam statistical handbook* [17].
	$N_{(T)}$	Number of animals in each category [17]	–	–	–
	$N_{ex\ (T)}$	Annual average nitrogen excretion rate per head for each livestock	Recommended to use country specific factors [19]	Indian emission factor for each livestock category [21]	$N_{ex\ (T)}$ in g yr^{-1} = (wet dung excreted by livestock in g day^{-1})*(dry matter of livestock)*(nitrogen constant of livestock)*365
	$Frac_{GASM}$	Fraction of N that volatilizes in NH_3 and NOx	20.0% [19]	15.0% [8]	–
	$Frac_{FUEL}$	Animal manure burnt for fuel	52.5% [22]	52.5% [22]	IPCC manual suggested to national study or official statistics of country or region [19]
	$Frac_{PRP}$	Fraction of animal manure deposited on soil by grazing livestock	Not used in this study	Not used in this study	No data were available
	$F_{racCOLLEC}$	Loss during the collection of dung	30.0% [23]	30.0% [23]	–
	$F_{racFEED}$	Fraction of animal manure used as feed	0.0%	0.0%	Taken as zero, as animal manure is hardly used as feed in India [8]
	$F_{racCONST}$	Fraction of animal manure used in construction	2.0% [22]	2.0% [22]	–
F_{BN} (amount of nitrogen fixed annually by nitrogen fixing crops)	$Crop_{BF}$	Seed yield of nitrogen fixing crops	Not used in this study	Not used in this study	If seen in terms of area under nitrogen fixing crop in Assam (about 1.23 lakh hectare was under pulses in 2000 to 2001, against gross cropped area of 38.43 lakh hectares) then F_{BN} contribution to total N_2O emission may be negligible [17]. However, it is imperative that to have comprehensive source and sink of GHG emission from agriculture sector, which would help in developing better mitigation strategy and policy in the future. This study could not estimate the emission of F_{BN}, due to non-availability of data at district level.
	$Frac_{NCRB}$	Nitrogen content of grain and straw of legumes	Not used in this study	Not used in this study	

Table 1 Details of factors used for the assessment of direct nitrous oxide (N_2O) emission *(Continued)*

F_{CR} (amount of nitrogen in crop residues returned to soil annually)	$Crop_{ST}$	Amount of straw of non-nitrogen fixing crops incorporated to the soil as residue	Not used in this study	Not used in this study	
	$Frac_{NCRST}$	Nitrogen content of residue of non-nitrogen fixing crops	Not used in this study	Not used in this study	
	$Crop_{SBF}$	Amount of straw of nitrogen fixing crops incorporated to the soil as residue	Not used in this study	Not used in this study	The gross cropped area in Assam - other than paddy and pulses -under spices, horticulture, vegetable, wheat etcetera, was about 12.74 lakh hectares in 2000 to 2001 [24]. Since crop residue in India is mostly used as fodder or as burning fuel, it is likely that the contribution to N_2O emission would not be substantial. However, it is always warranted that if data are made available, the emission inventory would have to be developed in the future.
	$Frac_{NCRSBF}$	Nitrogen content of residue of nitrogen fixing crops	Not used in this study	Not used in this study	
EF_1 (kg N_2O-N kg^{-1} N input)	–	The emission factor for N_2O-N emitted from various nitrogen additions in soil	0.0125 [19]	0.007 [8, 25, 26]	The N_2O emission through nitrification and denitrification in the field, applied with nitrogen fertilizer are strongly influenced by soil temperature, moisture, pH, and soluble organic matter availability [27]. It is to be noted that the IPCC emission factor is taken from the studies of Klemedtsson*et al*. [28] and Clayton *et al*. [27], as referenced in the IPCC manual [19]. These studies were done in Europe's peatland and clay loam grassland soil respectively. The Indian factor is based on the studies of Kumar*et al*. [25], Majumdar *et al*. [29] and Pathak *et al*. [26] which were done in India. It is to be noted that in European and Indian conditions the above-mentioned factors that influence the N_2O emission from soil differ markedly, which led to the differing values of emission factors.
F_{OS}	–	Area of organic soil harvested	Not used in this study	Not used in this study	Not an application for Indian conditions, as the organic content in Indian soil varies only from 1% to 5%, while organic soils are those having 12% to 18% organic carbon [8].
EF_2	–	Percent of N_2O emissions from organic soil	Not used in this study	Not used in this study	–

IPCC, Intergovernmental Panel on Climate Change; GHG, greenhouse gas.

Table 2 Details of coefficients used for the assessment of indirect nitrous oxide (N_2O) emission

Primary factor	Break-up of primary factor	Details	Coefficient or value		Remark
			IPCC emission factor	Indian emission factor	
$N_2O_{(G)}$ (N_2O emission from volatilization of applied nitrogen fertilizer and animal manure and its subsequent atmospheric deposition as NO_x and NH_4)	N_{FERT}	The total amount of synthetic fertilizer consumed annually [17]	–	–	–
	The value of $Frac_{GASF}$, T, $N_{(T)}$, $Nex_{(T)}$, and $Frac_{GASM}$weresame as in Table 1.	–	–	–	–
	EF_4 [kg N_2O-N kg^{-1} NH_4-N and NO_x-N deposited]	Emission factor for N_2O emission from atmospheric NH_3 and NOx	0.01 [19]	0.005 [8]	–
$N_2O_{(L)}$ (N_2O produced from leaching and runoff of applied nitrogen fertilizer and animal manure)	N_{FERT}	The total amount of synthetic fertilizer consumed annually [17]	–	–	–
	The value of T, $N_{(T)}$, and $Nex_{(T)}$, are same as in table 1.	–	–	–	–
	$Frac_{FUEL-AM}$	Animal manure burnt for fuel	52.5% [22]	52.5% [22]	IPCC manual suggests using official statistics of the nation or expert survey [19].
	$Frac_{PRP-AM}$	Fraction of animal manure that is deposited on to the soil by grazing animal	Not used in this study	Not used in this study	No data available.
	$Frac_{COLLEC}$	Loss during the collection of dung	30.0% [23]	30.0% [23]	–
	$Frac_{FEED-AM}$	Fraction of animal manure used as feed	0.0%	0.0%	Taken as zero, as animal manure is hardly used as feed in India [8].
	$Frac_{CONST-AM}$	Fraction of animal manure used in construction	2.0% [22]	2.0% [22]	IPCC manual suggestsuse of official statistics of the nation or expert survey [19].
	$Frac_{LEACH}$	Fraction of nitrogen lost through leaching	30.0% [19]	10.0% [8]	IPCC manual uses default value of 30%for $Frac_{LEACH}$. This default value was largely based on mass balance studies comparing agricultural N inputs to N recovered in rivers. The IPCC manualsuggests the N that is deposited away from agricultural land, a lower value of $Frac_{LEACH}$ may be more appropriate based on regional or national studies [19]. Bhatia *et al.* [8] used an Indian emission factor of 10% based on the studies by Singh *et al.* [30] and Patel *et al.* [31].
	EF_5 [kg N_2O-N kg^{-1}leached and run off]	The emission factor for depositing N from leaching and run-off.	0.025 [19]	0.005 [8]	–

IPCC, Intergovernmental Panel on Climate Change.

Nitrous oxide

The district-wise emission inventory of N_2O from Assam was based on the formula given by the 1996 revised IPCC guideline [19]. It includes N_2O emitted as a result of the anthropogenic N-fertilizer input through the direct pathway of nitrification and denitrification from soil and also through indirect pathways, that include volatilisation losses, leaching and runoff from applied N-fertilizer, animal manure etcetera. Thus, the emission of N_2O was calculated in two steps, namely, direct N_2O emission from agricultural soil (net sown area) and indirect N_2O emission from agricultural soil (net sown area) as follows:

$$N_2O_{Total} = N_2O_{direct} - N + N_2O_{Indirect} - N \quad (2)$$

Direct N_2O emission

The following equation (2.1) was used to estimate the direct emission of N_2O from the agricultural field (for details about IPCC and Indian factors used in this study see Table 1).

$$N_2O_{direct} - N = \{(F_{SN} + F_{AM} + F_{BN} + F_{CR}) * EF_1\} + (F_{OS} * EF_2) \quad (2.1)$$

where EF_1 is percentage N_2O emission from the applied fertilizer, F_{OS} is the area of organic soil harvested, and EF_2 is percentage N_2O emitted from the organic soil.

F_{SN} denotes the annual amount of synthetic N- fertilizer applied to soil, adjusted to account for the amount that volatilizes as NH_3 and NO_x:

$$F_{SN} = N_{FERT} * (1 - Frac_{GASF}) \quad (2.1.1)$$

where N_{FERT} denotes the total amount of synthetic fertilizer consumed annually and $Frac_{GASF}$ is the fraction of fertilizer that volatilizes as NH_3 and NO_x.

F_{AM} denotes the annual amount of animal manure N applied to soils, adjusted to account for the volatilization as NH_3 and NO_x:

$$F_{AM} = \Sigma_T\left(N_T * N_{ex(T)}\right) * (1 - Frac_{GASM}) * [1 - (Frac_{FUEL} + Frac_{PRP} + Frac_{COLLEC} + Frac_{FEED} + Frac_{CONST})] \quad (2.1.2)$$

where T stands for each defined livestock category/species (in this study, four categories of livestock, namely, cattle, buffalo, sheep and goat have been taken), N_T is the number of animals in each category, $N_{ex\ (T)}$ is the annual average nitrogen excretion rate per head for each livestock category, $Frac_{GASM}$ is the fraction of N that volatilizes as NH_3 and NO_x, $Frac_{FUEL}$ denotes animal manure that is burnt for fuel, $Frac_{PRP}$ is the fraction of animal manure deposited on soil by grazing livestock, $Frac_{CONST}$ is the fraction of animal manure used as construction, $Frac_{FEED}$ is the fraction of animal manure used as feed, $Frac\text{-}_{COLLEC}$ is the loss during collection of dung.

F_{BN} is the amount of N- fixed annually by N- fixing crop as:

$$F_{BN} = Crop_{BF} * Frac_{NCRBF} \quad (2.1.3)$$

where $Crop_{BF}$ is the seed yield of N-fixing crops. Four crops, that is, gram, arhar, groundnut and soybean were taken into account for the calculation, and $Frac_{NCRBF}$ is the N content of grain and straw of legumes.

F_{CR} is the amount of N in crop residue returned to soil annually:

$$F_{CR} = (Crop_{ST} * Frac_{NCRST} + Crop_{SBF} * Frac_{NCRSBF}) \quad (2.1.4)$$

Where, $Crop_{ST}$ is the amount of straw of non-N fixing crops incorporated into soil as residue, $Frac_{NCRST}$ is the N content of residue of non-N fixing crops, $Crop_{SBF}$is the amount of straw of N-fixing crops incorporated to the soil as residue and $Frac_{NCRSBF}$ is the N content of residue of N-fixing crop.

Due to non-availability of data, F_{BN} and F_{CR} are not included in the calculation of $N_2O\text{-}N_{\ Direct}$ emission (see Table 1 for details and a note on its potential contribution to the emission inventory for N_2O).

Indirect N_2O emission

The following equation (2.2) was used for the calculation of indirect emission of N_2O ($N_2O_{indirect}$) from the agricultural fields as per the IPCC guideline (for details about IPCC and Indian factors used, see Table 2):

$$N_2O_{Indirect} = N_2O_{(G)} + N_2O_{(L)} \quad (2.2)$$

where $N_2O_{\ (G)}$ is the N_2O produced from volatilization of applied N-fertilizer and animal manure and its subsequent atmospheric deposition as NO_x and NH_4. This is calculated by the formula (2.2.1) as below:

$$N_2O_{(G)} = \left[(N_{FERT} * Frac_{GASF}) + \left(\Sigma_T\left(N_{(T)} * N_{ex(T)} * Frac_{GASM}\right)\right] * EF_4 \quad (2.2.1)$$

where, N_{FERT} is the amount of fertilizer consumed annually, $Frac_{GASF}$ is the fraction of fertilizer that volatilizes as NH_3 and NO_x, $\sum_T$ ($N_{(T)}$ * $N_{ex\ (T)}$ is the amount of N in animal manure excreted annually, T is each defined livestock category, N_T is the number of animals in each category, $N_{ex\ (T)}$ is the annual N excretion rate per head for each livestock category and EF_4 is the emission factor for N_2O emission from atmospheric NH_3 and NO_x.

Table 3 Details of livestock categories and characteristic [21] used to calculate the nitrogen excretion rate per head ($N_{ex\ (T)}$)

Livestock characteristics	Livestock category			
	Cattle	Buffalo	Sheep	Goat
Wet dung excreted by cattle (kg per day)	8.335	10.380	1.430	0.625
Body weight (kg)	350	350	50 to 60	40
Urine (litres per day)	12.960	6.810	0.950	0.498
Dry matter content(%)	18	18	32	32
Nitrogen content (oven-dry,%)	1	1	1.87	1.87

N_2O $_{(L)}$ is N_2O produced from leaching and the runoff of the applied fertilizer and animal manure and calculated through the following formula (2.2.2):

$$N_2O_{(L)} = [N_{FERT} + \{\Sigma_T(N_{(T)} * N_{ex(T)} *[1 - Frac_{FUEL-AM} + Frac_{PRP-AM} + Frac_{COLLEC} + Frac_{FEED-AM} + Frac_{CONST-M})]\}] * Frac_{LEACH} * EF_5 \quad (2.2.2)$$

where $Frac_{FUEL\text{-}AM}$ denotes animal manure that is burnt for fuel, $Frac_{PRP\text{-}AM}$ is the fraction of animal manure that is deposited onto the soil by grazing livestock, $Frac_{COLLEC}$ is the loss of dung during collection, $Frac_{FEED\text{-}AM}$ is the fraction of animal manure that is being fed, $Frac_{CONST\text{-}AM}$ is the fraction of animal manure that is used as construction, $Frac_{LEACH}$ is the fraction of N-lost through leaching and EF_5 is the emission factor for deposited N from leaching and runoff.

The IPCC and Indian standard emission factor values were used to calculate the emission of $N_2O\text{-}N_{Total}$ for Assam (see Table 1 and 2 for details). For the calculation of $N_{ext(T)}$ (in the F_{AM}), the annual average nitrogen excretion rate per head for each livestock category was calculated. The livestock categories used were cattle, buffalo, sheep and goat (see Table 3 for details). The values of annual average nitrogen excretion rate per head ($N_{ext(T)}$) for each livestock category was the same

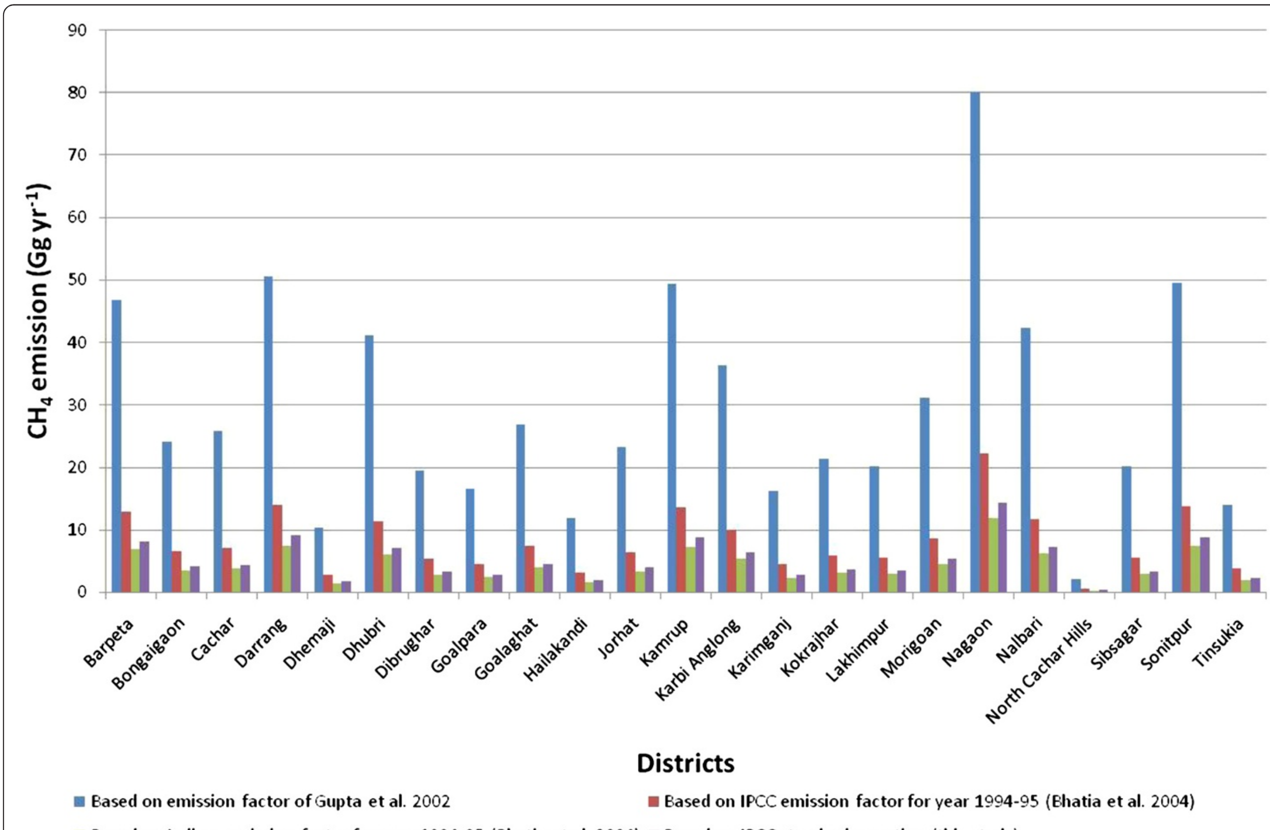

Figure 1 Assam district-wise emission inventory of CH_4(in Gg yr^{-1}) using different emission factors for the base year 2000 to 2001.

when calculating the N_2O emission as per IPCC and the Indian standard, since the IPCC guideline suggests using national or expert studies as the reference [19].

Results and discussion

Methane

The district wise emission of CH_4 from the rice paddy fields of Assam (as per the IPCC standard formula) was estimated to be 121 Gg for the base year 2000 to 2001. Nagaon district emitted the highest amount of CH_4 (14 Gg), followed by Darrang (9 Gg) and Sonitpur (8 Gg). The lowest amount of CH_4 emission was from the North-Cachar Hills district (0.47), which had lowest area under paddy cultivation. The CH_4 emission inventory of Assam State estimated from this study was compared with emission values obtained using three other emission factors (see Figure 1). CH_4 emission was highest (682 Gg) based on the 46 g m^{-2}emission factor of Gupta *et al*. [33], followed by an emission of 190 Gg based on the 12.81 g m^{-2}emission factor of Bhatia *et al.* [8], based on IPCC coefficients. The CH_4 emission of 102 Gg was lowest when the 6.92 g m^{-2}emission factor of Bhatia *et al*. [8] was used, which was based on the Indian emission factors. The CH_4 emission estimate based on our study comes out about 121 Gg for the base year 2000 to 2001.

It is interesting to note that while most of central plain districts of Assam along the banks of Brahmaputra had CH_4 emission in the range of 5 to 15 Gg, Nagaon district produced a much higher amount of CH_4 (see Figure 2). Nagaon district had a greaterarea under rice and also produced more rice in comparison to other central plain districts and thus the higher CH_4 emission estimation is very much in line with the anticipated results. It is a matter of concern for scientists, policy makers and planners when there is great difference between the highest (682 Gg) and lowest (102 Gg) values of CH_4 emission for a state. Discrepancies of such nature call for an immediate inventory of GHGs at local level for better mitigation planning in future. This variability calls for further strengthening of methodologies in the emission inventory of CH_4 from paddy fields at the micro level, to obtain better estimates.

Correlation analysis was carried out between N-fertilizer application and CH_4 emission values obtained using the Indian emission factor for the base year

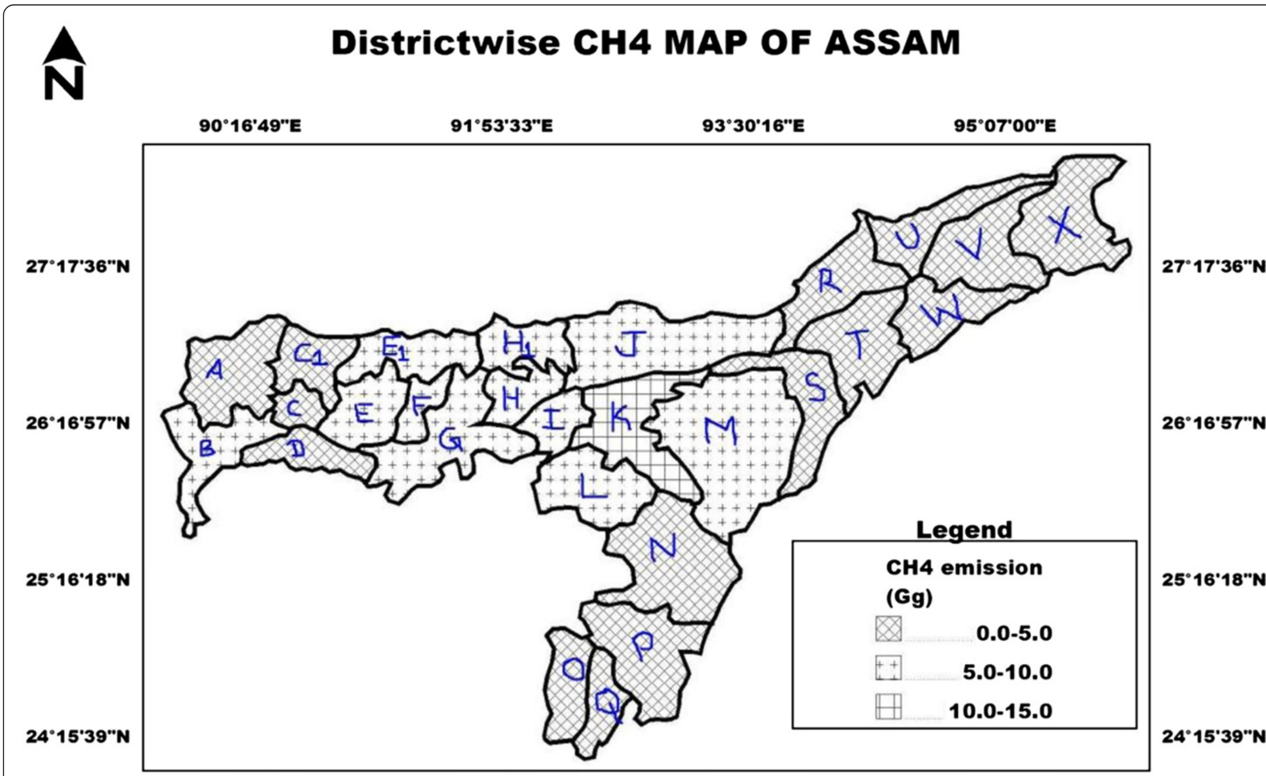

Figure 2 CH_4emission from the paddy fields of Assam for the base year 2000 to 2001 (in Gg). A, Kokaraghar; B, Dhubari; C, Bongaigaon; C_1, Chirand (carved out of the Bongaigaon district); D, Goalpara; E, Barpeta; E_1, Baksa (carved out of the Nalbari, Barpeta and Kamrup districts); F, Nalbari; G, Kamrup; H, Darrang; H_1, Udalguri; I, Morigaon; J, Sonitpur; K, Nagaon; L and M, KarbiAnglong; N, North Cachar Hills (now called DimaHasao); O, Karimganj; P, Cacher; Q, Hailakandi; R, Lakhimpur; S, Golaghat; T, Jorhat; U, Dhemaji; V, Dibrughar; W, Sibsagar; X, Tinsukia.

2000 to 2001. A significant relationship ($r = 0.84$) was observed with 95% confidence. However, this correlation needs to be field-tested in Indian conditions, as there are contradicting claims about nitrogen fertilizer application and its impact on increasing [34] or decreasing [35] the CH_4 emission from paddy fields.

Nitrous oxide

Emission of N_2O-N using the IPCC standard was estimated at 1.36 Gg for the base year 2001 to 2002, while the emission estimated using the Indian standard was 0.43 Gg (Figure 3). This difference of about 216% between the lowest and highest values of the N_2O emission inventory was due to the different emission factors of the IPCC and the Indian standards used for the calculation of direct and indirect N_2O emission (see Table 1 and 2 for details). This variation in N_2O emission emphasises the need for micro-level planning for future data gathering and inventory management to have an accurate and dependable database of GHG emissions from agricultural fields. This may lead to better agriculture management and mitigation planning in future. For N_2O also, the central plain districts of Assam emissions were much higher than for rest of the state (0.04 Gg to 0.18 Gg; see Figure 4). Unlike CH_4, in the case of N_2O, the different ranges of emission are widely spread over the state.

Correlation analysis was performed to find out the relationships between the N_2O emissions and application of N-fertilizer. Correlation analysis was carried out for the emission values obtained from the IPCC and Indian standard for the year 2001 to 2002. It was found that there is a significant correlation ($r = 0.98$ at 95% confidence level) between N_2O emission (Indian standard) with that of N-fertilizer used in that year. Similar strong correlation ($r = 0.98$ at 95% confidence level) was found between N_2O emission (using an IPCC emission factor) and N-fertilizer used in that base year. These significant correlations reinstate the earlier findings that N-fertilizers are the major sources of N_2O emitted from agricultural soils.

Conclusions

District-wise emission of CH_4 (for the base year 2000 to 2001) from the paddy fields of Assam is estimated to be 121 Gg based on this study. However, there is a large difference in the highest (682 Gg) and lowest (102 Gg) value of CH_4 emission when different emission factors were used. The district-wise N_2O emission (for the base year 2001 to 2002) for Assam State was estimated to be 1.36 Gg and 0.43 Gg using the IPCC and Indian factors respectively.

The study clearly shows that there is large variation in the emission inventory of CH_4 and N_2O at the district level when different emission factors are used. This

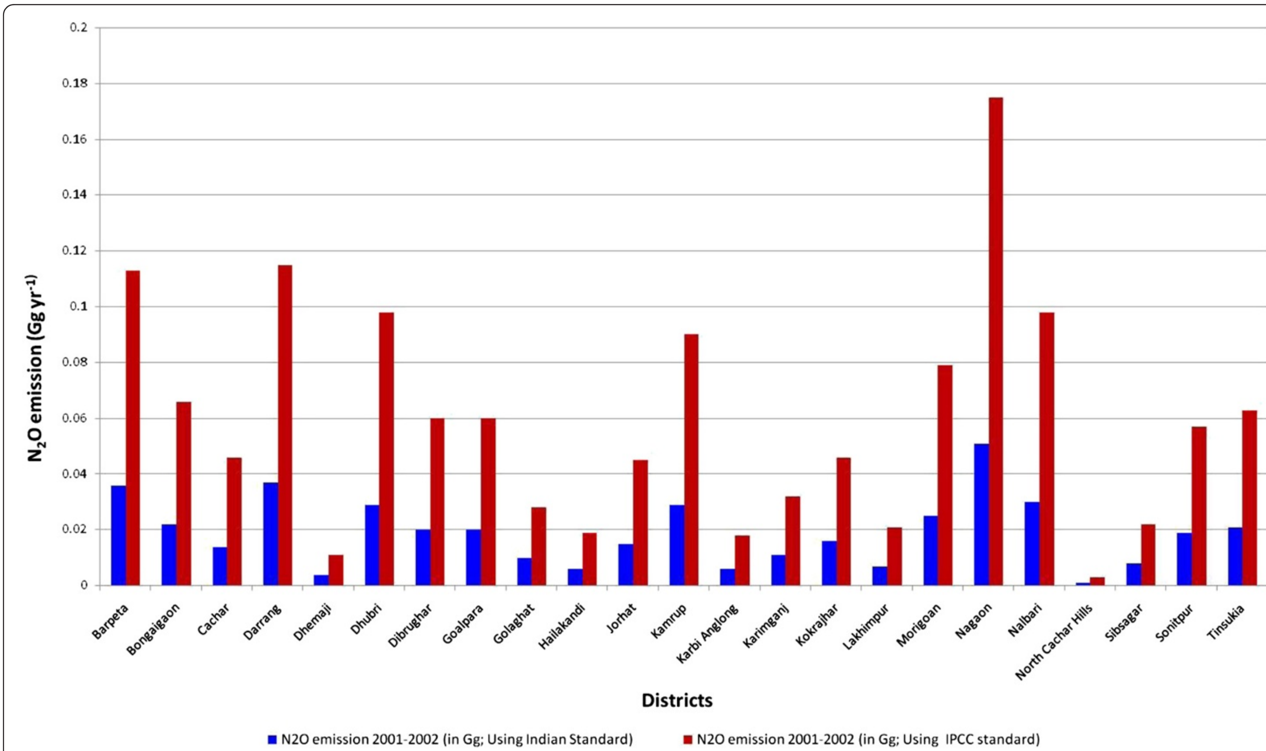

Figure 3 Assam district-wise emission of nitrous oxide (N_2O)in Gg yr^{-1} using different emission factors for the base year 2001 to 2002.

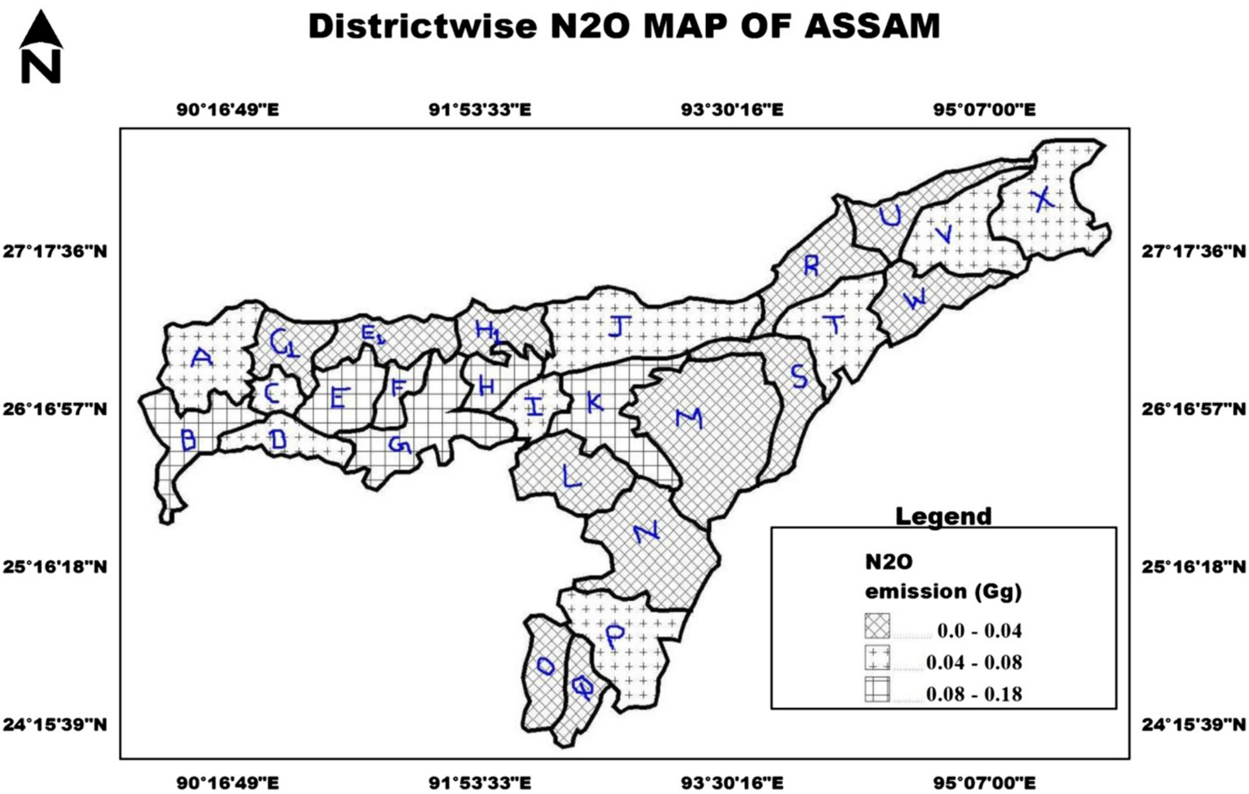

Figure 4 Nitrous oxide (N_2O)emission from the agricultural fields of Assam for the base year 2001 to 2002 (in Gg). A, Kokaraghar; B, Dhubari; C, Bongaigaon; C_1, Chirand (carved out of the Bongaigaon district); D, Goalpara; E, Barpeta; E_1, Baksa (carved out of the Nalbari, Barpeta and Kamrup districts); F, Nalbari; G, Kamrup; H, Darrang; H_1, Udalguri; I, Morigaon; J, Sonitpur; K, Nagaon; L and M, KarbiAnglong; N, North Cachar Hills (now called DimaHasao); O, Karimganj; P, Cacher; Q, Hailakandi; R, Lakhimpur; S, Golaghat; T, Jorhat; U, Dhemaji; V, Dibrughar; W, Sibsagar; X, Tinsukia.

indicates that for an accurate inventory of CH_4 and N_2O, universal or regional emission factors cannot be applied at the smaller scale (for example,at district level). The emission of CH_4 and N_2O from the agricultural sector is a function of specific crop and site, and is influenced by factors such as cultural practice, agronomic management, soil type and socio-economic drivers. This calls for detailed and comprehensive mapping and data collection at the micro-level for accurate inventory of CH_4 and N_2O in the future. This is pertinent in the present context when more emphasis is being given to the localisation of issues to avert the negative effect of climate change, and the bottom-up approach to planning. In the Indian context, this is even more important as power and planning are being devolved more at the bottom-most level of governance, namely, the Panchayats and District Planning Committee as per the Indian Constitution (article 243ZD[3-a]) on the issue of environmental planning and conservation [36]. So, it is important to have strong and able local-level planning to mitigate the CH_4 and N_2O emission in the future, on the basis of sound estimates of these gases. This requires little extra effort from various stakeholders to raise the level of awareness among researchers, policy makers and farmers by providing them adequate training and sensitisation to local issues.

Endnotes

[a]Non-annex countries are a group of 152 countries classified by the IPCC, belonging to the low-income group, with very few classified as a middle-income group. For detail see <http://unfccc.int/parties_and_observers/parties/non_annex_i/items/2833.php>.

[b]Since 1950, the area under cultivation in India had increased by only 27.43 times (96.6 million hectares in 1951 to 1952 to 123.1 million hectares in 1999 to 2000), while the application of N-fertilizer (55, 000 tonnes in 1950 to 1951 to 11,592,500 tonnes in 1999 to 2000) increased by about 20,977 times [18,37,38]. This increasing use of N-fertilizer on the limited land is not only posing a threat in term of N_2O emission causing global warming but also reducing N-use efficiency of the plant.

[c]The emission of CH_4 and N_2O was calculated for different base years, namely, 2000 to 2001 and 2001 to 2002 respectively. This was due to the availability of relevant data for the calculations.

[d]When the study was carried out in 2004, the data were available only for 23 districts of Assam state. In 2012, Assam has total of 27 districts. For this study we have done the calculation for 23 districts. While representing the emission on the GIS map we mentioned the name of the new districts and also the name of the parent district from which the new district was carved out.

[e]In the year 2000 to 2001, of the total gross cropped area of 38.43 lakh hectares in Assam, about 26.46 lakh hectares was under paddy (autumn, winter and summer paddy cultivation) cultivation [24,39].

Abbreviations

CFCs: Chlorofluorocarbon; CH_4: Methane; CO_2: Carbon dioxide; GDP: Gross domestic product; Gg: Gigagram; GHG: Greenhouse gas; GIS: Geographic information systems; GoI: Government of India; GWP: Global warming potential; HYV: High yielding variety; IPCC: Intergovernmental Panel on Climate Change; N_2O: Nitrous oxide; Tg: Terragram.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SNM and SM conceived the idea of study and participated in its initial design, data collection, data analysis, and initial drafting of the research work. LR, SD and PS participated in further data analysis and drafting the final manuscript. All authors read and approved the final manuscript.

Author details

[1]Institute of Rural Management, Post Box No. 60, Anand 388001Gujarat, India. [2]School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India. [3]Indian Institute of Technology-Guwahati, Assam 781039, India.

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