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Greenhouse Gas Inventory Estimates from Agriculture Sector in Jammu and Kashmir State of India

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ABSTRACT

Aims Greenhouse gas (GHG) emission estimates were made from agriculture sector in Jammu and Kashmir to assess the 2015 situation and future trends in emission which would help in formulating a policy for mitigation.
Materials & Methods The Intergovernmental Panel on Climate Change (IPCC) tier-II methodology (IPCC, 1997) has been adopted for estimating methane (CH4) emissions from enteric fermentation in livestock and Tier-I methodology for other sectors of agriculture for GHG emission.
Findings Agriculture in J and K accounted for a total GHG emission of 5.411 Tg of carbon dioxide (CO2)e in the year 2015. Source-wise, enteric fermentation was responsible for emittance of 160.233 Gg of CH4 and 1.399 Gg of nitrous oxide (N2O), manure management for 8.25 Gg of CH4 and 0.276 Gg of N2O, rice cultivation for 28.75 Gg of CH4, cultivated soils for 1.988 Gg of N2O, and residue burning for 0.405 Gg of CH4, 0.029 Gg of N2O, and 118.01 Gg of CO2.
Conclusion Higher GHG emission from enteric fermentation was mainly due to higher population of livestock in the state. The most effective methods for reducing GHG emissions in the state would be to adjust the part of animal feed to decrease digestion time, using feed additives to reduce metabolic activity of rumen bacteria that produce CH4, and increase nitrogen-use efficiency by applying nitrogenous fertilizer or manure to crops as per crop needs and time of need.

Keywords Agriculture Sector; Greenhouse gases; Jammu and Kashmir; Inventory

CITATION LINKS

[1] Greenhouse gas emissions from India ... [2] Greenhouse gas inventory ... [3] Agricultural soils as a sink to mitigate CO_2 ... [4] Soil carbon sequestration to mitigate ... [5] Climate change 2007 the physical ... [6] Decoding urban India's carbon footprint: Spatial-numerical mapping of thermal ... [7] Assessment of climate change impacts ... [8] Carbon budgets for climate ... [9] Atmospheric gas concentrations over the ... [10] Modeling greenhouse gas emissions from rice-based ... [11] Simulating trends in soil organic carbon in ... [12] Uncertainty should be powerful motivator ... [13] Fertilizer management practices ... [14] A review of global potentially available ... [15] Changes in cropping pattern in Jammu ... [16] Nitrous oxide, climate change and ... [17] High performance computing of data for a new sensitivity analysis ... [18] Direct emission of nitrous oxide from ... [19] Assessment of greenhouse gas emissions ... [20] Impact of resource-conserving technologies ... [21] Emission factors for open and domestic biomass ... [22] 2004 methane and nitrous oxide emissions ... [23] Exchange of trace gases between terrestrial ecosystem ... [24] Revised 1996 IPCC guidelines for national greenhouse ... [25] N_2O and CH_4 emissions from soils under ... [26] Annual report ... [27] Novel climates, no-analog communities ... [28] Management implications of global ... [29] Historical warnings of future food insecurity ... [30] Elevated ozone reduces methane emissions ... [31] Ecological physiology of diet and digestive ... [32] In vitro total gas, CH_4, H_2, volatile ... [33] Modeling methane emissions from ... [34] Greenhouse gas emissions from Indian ... [35] Inventory of methane and nitrous ... [36] The impact of nitrogen fertilizer use on greenhouse ... [37] Nitrous oxide emissions from fertilized ... [38] Increased soil emissions of potent greenhouse gases under increased atmospheric ... [39] Agroecosystems, nitrogen-use efficiency, and nitrogen ... [40] Global metaanalysis of the nonlinear response of soil nitrous oxide (N2O) emissions to fertilizer ... [41] Agriculture crop residue burning in the indo-gangetic plains: A study using IRS-P6 AWiFS satellite...

Introduction

Rapid increase in carbon dioxide (CO_2) concentration in the atmosphere along with other greenhouse gases (GHGs), such as nitrous oxide (N_2O) and methane (CH_4), is a major concern due to its impact on climate change.[1, 2] Therefore, there is an urgent need to adopt effective measures for mitigating the threat of global climate change. Land use change such as deforestation and land degradation also contributes to anthropogenic CO_2 emission.[3, 4] Carbon sequestration by terrestrial vegetation has been identified by the Intergovernmental Panel on Climate Change (IPCC), as one of the most effective alternatives for reducing the GHG emission.[5-7] India and many other developing countries will obtain even this limited amount of carbon space only if the developed countries reduce their emissions sharply.[8] Globally, the concentrations of CO_2, CH_4, and N_2O in the atmosphere are increasing at 0.4%, 3.0%, and 0.22% per year, respectively.[9] Apart from causing global warming, N_2O is also responsible for the destruction of the stratospheric ozone.[10] Quantification of GHG emissions from soil is needed for global modeling studies in the context of ecosystem modification and climate change.[11] Due to climate change, the people of the world are moving into an uncertain and changing climate regimen, with consequences that are likely to differ regionally in severity.[12]

CH_4 is a simple hydrocarbon compound that is most familiar as the main constituent of natural gas. In emission from agriculture sector, a significant amount of GHGs is emitted from livestock production with animals directly contributing to emissions through enteric fermentation and manure management. Linquista *et al*.[13] reported that flooded rice systems emit both CH_4 and N_2O. Agricultural soils under appropriate management can contain substantial amounts of soil C in the form of soil organic matter (SOM). Eitelberg *et al.*[14] mentioned that non-utilized and non-forested land, containing sufficient carbon, is available for agriculture.

Near about 75% of the Jammu and Kashmir's population is dependent on agriculture in one way or the other. Increasing GHG emissions from agriculture sector becomes a cause for concern in the context of climate change. Climate change with the emission of GHG s and climate extremes will have direct and indirect effects on the crops, soils, livestock, and pests. The purpose of this study was to assess GHG emissions from agriculture sector from the state of Jammu and Kashmir (J and K) and see a trend of emissions over time to understand its future implications.

Materials and Methods

Study area

The state of J and K, having an area of 222, 236 km^2, is strategically located in the Northwest corner of India. It shares its borders with China in the east, Pakistan in the west, Afghanistan and Russia in the north, and plains of Punjab and Himachal in the south and southeast. The state lies between 32°17' to 37°05' North latitudes and 72°31' to 80°20' East longitudes. The state has the diverse climate, extreme variations in temperature and rainfall where different types of crops can be grown and livestock reared. Jammu, Kashmir, and Ladakh regions have different climates and cultural identities. Rice is the major crop in Kashmir zone, followed by maize, barley, and wheat, whereas maize and wheat are predominant in Jammu region, while barley is major crop in Ladakh region.[15] With the change in climate of the state, the cropping patterns are likely to vary. Hence, it is important to study the present status of GHG emission and measures to mitigate.

Methodology

The IPCC tier-II methodology[16] has been adopted for estimating CH_4 emissions from enteric fermentation in livestock and Tier-I methodology for animal manure management. The methodology for enteric fermentation takes into account age distribution and hence the weight of the animals. For ruminants, Tier-II method was adopted for CH_4 emission; however, default IPCC emission factors were used for other animals.[5] CH_4 conversion factor and CH_4 emission factor values for the present estimation broadly conform to the National Dairy Research Institute emission values. The age groups of livestock adopted in the present estimation are the same as those adopted by Swamy and Bhattacharya.[17] N_2O emission from soils was determined with the equation as suggested by Bouwman.[18] Emissions of N_2O and CH_4 from poultry enteric fermentation were investigated using the values as suggested by Wang and Huang.[19] The GHG emission from rice production was calculated as per the method suggested by Pathak *et al.*[20] The GHG from residue burning was determined as per the method suggested by Jain *et al.*[21] The CO2e was calculated by multiplying the values by multiplying factor 21 for CH_4 and 310 for N_2O. The CH_4 has 21 times and N_2O 310 times more warming potential than CO_2.

Findings

Area under different crops in J and K

The area under different crops has been shown in Table 1. Among the cereal crops, maize leads with an area of 310.9 thousand ha, followed by wheat and rice. Total area under cultivation was 1119 thousand ha during 2012–2013 (J and K Governmnet 2012–2013). Between 2005–2006 and 2012–2013, the area under maize is showing a declining trend with annual compound growth rate (ACGR) of −0.45%, while the area under wheat and rice has increased with ACGR of 2.07% and 0.81%, respectively, during the above period (Figure 1).

Source: Digest of Statistics, Directorate of Economics and Statistics, J and K (2012–2013)

GHG Emissions in J and K

Livestock population

In Jammu and Kashmir, the population of cattle, buffaloes, sheep, and goats registered an ACGR of 1.646, 2.385, 2.431, and 2.807% between 1951 and 2003, respectively. However, between 2003 and 2012, a decline in ACGR of −1.075, −3.714, −0.068, and −0.201 has been observed in above categories of livestock, respectively (Figure 2). The livestock population in J and K in 2012 was about 9.2 million, with cattle, buffaloes, sheep, and goats constituting 30.4%, 8.0%, 36.9%, and 21.9%, of the total population, respectively (Table 2).

The poultry population was 8.24 million during the year 2012. The number of livestock per thousand persons in J and K is 792.2, compared to a national statistic of 409.6 in India. The more number of livestock in the state is expected to have larger share in GHG emission as against other sources of emission in agriculture sector.

Source: 19th Livestock Census, Ministry of Agriculture, India, 2012

Emission by livestock

CH_4 and CO_2 emission in Jammu and Kashmir from livestock sector is given in Table 3.

Emission of CH_4 by cattle, buffaloes, sheep, goats, pigs, horses/ponies, mules/donkeys and camels in J and K was estimated at 93.015, 34.893, 18.876, 9.735, 0.003, 2.914, 0.742, and 0.051 Gg, respectively (Table 3).

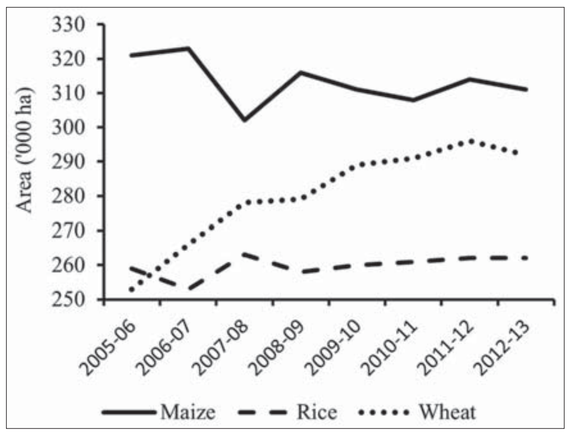

Figure 1: Trends of area under major cereal crops in Jammu and Kashmir

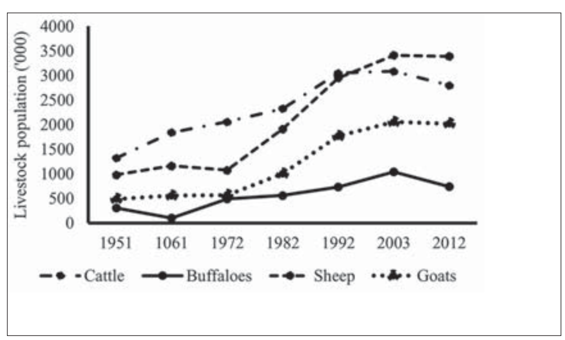

Figure 2: Growth trend of livestock population in Jammu and Kashmir

Table 1: Area under different major crops in Jammu and Kashmir ('000 ha) (2012–2013)

Crop	Area	Crop	Area
Rice	274.0	Oilseeds	35.5
Wheat	292.4	Fruits/vegetables	100.7
Maize	310.9	Spices/condiments	2.4
Coarse cereal	30.0	Fodder crops	46.3
Pulses	26.8	Total	1119.0

Table 2: Livestock population in Jammu and Kashmir ('000)

Livestock	Number	Livestock	Number
Cattle	2798	Mules	36
Buffaloes	739	Donkeys	17
Sheep	3390	Camels	1
Goats	2018	Yaks	54
Pigs	2	Total	9199
Horses, ponies	144	Poultry	8240

Total emission of CH_4 is estimated to be 160.233 Gg, which is equivalent to 3.365 Tg of CO_2e warming potential. The crossbred cattle accounted for 1041.9 Gg of CO_2e and indigenous cattle 911.3 Gg of CO_2e emissions in the state.

Manure management

Management of livestock manure is one of the main sources of GHG emissions, producing mainly CH_4 and N_2O. These emissions are dependent on how manure is stored, as liquid-stored manure mainly produces CH_4 while dry manure enhances production of N_2O.[22] By and large, dry manure is used in J and K. Emission of CH_4 and N_2O from the manure management was estimated to be 8253 Gg and 0.276 Gg, respectively, during 2015 with a global warming potential equivalent to 258.87 Gg of CO_2 (Table 4).

Rice production and GHG emission

In J and K, total area under rice is about 274000 ha, of which 113568 ha is irrigated and 156832 ha is rainfed, while about 4000 ha is upland rice (Table 5). Total CH_4 emissions have been estimated as 18.398 Gg from irrigated rice fields and 10.351 Gg from rainfed rice. This amounts equivalent to a warming potential of 603.729 Gg of CO_2 emissions from rice fields.

Emission from cultivated soils

Primarily, biogenic production of N_2O in the soil results from two processes, namely, bacterial oxidation of mineral nitrogen (N) to nitrate under aerobic condition known as nitrification and during the reduction of nitrate to molecular nitrogen under anaerobic condition called de-nitrification.[23]

AtmosphereAtmosphere

Soil organic matter, $\uparrow N_2O$ $\uparrow N_2O$

Fertilizer, manure $\rightarrow NO_3$ $\rightarrow N_{2\uparrow}$
$\rightarrow$ NH4

Nitrification Denitrification

(1)

Emissions of N_2O occur in the soil through the processes of nitrification and denitrification.[24] Nitrites and nitrates are converted to N_2O and N_2 during the aerobic processes of nitrification as illustrated below: [24, 25]

Nitrification

N_2O (Atmosphere)

$$NH_4^+ + O_2 \rightarrow H^+ + H_2O + NO_2^- \uparrow$$
$$NO_2^- + O_2 \rightarrow NO_3^- \quad (2)$$

Denitrification

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (3)$$

Emission of N_2O from area cultivated for various crops is given in Table 6. In J and K, total N_2O emission was 1.9881 Gg (616.3 Gg CO_2e) from cultivated soils during 2015. We included the soils where agricultural (cereals, oilseed, pulses, etc.) and horticultural (fruits and vegetable) crops are grown. The annual N_2O emission from cultivated soils under rice, wheat, maize, coarse cereals, pulses, oilseeds, fruits and vegetables, spices and condiments, and fodder crops is given in Table 6. The emission of N_2O from soils cultivated with cereals was 82.6% compared to 17.4% from soils cultivated with other crops.

Residue burning

When there is open burning of crop residue, a number of GHGs are emitted from combustion. The average annual amount

Table 3: Livestock methane emission in Jammu and Kashmir

Livestock	CH_4 (Mg)	CO_2e (Gg)	Livestock	CH_4 (Mg)	CO_2e (Gg)
Cattle crossbred			>1 year	4281.76	89.91
<1.5 years	7995.12	167.89	Total	18876.36	396.40
1.5–2.5 years	6997.46	146.94	Goats		
>2.5 years	34626.96	727.16	<1 year	2043.91	42.92
Indigenous			>1 year	7691.92	161.53
<1.5 years	3976.08	83.49	Total	9735.83	204.45
1.5–3.5 years	6219.81	130.62	Pigs		
>2.5 years	33199.90	697.20	Exotic	1.58	0.033
Total	93015.33	1953.30	Indigenous	1.81	0.038
Buffaloes			Total	3.39	0.071
<1 year	1196.84	25.13	Horses/ponies		
1–3 years	5132.72	107.79	<3 years	536.51	11.27
>3 years	28564.19	599.85	>3 years	2378.18	49.94
Total	34893.75	732.77	Total	2914.69	61.21
Sheep			Mules/donkey	742.04	15.58
Exotic			Camels		
<1 year	2954.29	62.04	<4 years	6.55	0.14
>1 year	10310.79	216.53	>4 years	45.26	0.95
Indigenous			Total	51.81	1.09
<1 year	1329.52	27.92	Grand total	160233.20	3364.87

CH4: Methane, CO2: Carbon dioxide

Table 4: GHG emission from manure management (Gg)

Livestock	CH_4	N_2O	CO_2e
Cattle	5.001	0.149	151.21
Buffaloes	2.217	0.046	60.82
Sheep	0.306	0.042	19.45
Goat	0.177	0.027	12.08
Horses/mules/donkeys	0.548	0.009	14.30
Others	0.004	0.003	1.01
Total	8.253	0.276	258.87

CH_4: Methane, CO_2: Carbon dioxide, GHG: Greenhouse gas

Table 5: Methane emission from rice cultivation in Jammu and Kashmir

Area (ha)	CH_4 emission (Gg)	CO_2e (Gg)
113568 (irrigated)	18.398	386.358
156832 (rainfed)	10.351	217.371
270400 (total)	28.749	603.729

CH_4: Methane, CO_2: Carbon dioxide

of crop residue generated in J and K is 1.59 Mt and the surplus quantity is 0.28 Mt;[26] however, the quantity burnt varied from study to study. The quantities shown for crop residue burning in J and K state appear to be exaggerated. We have found that a very limited quantity of 0.11 Mt crop residue (mostly rice straw) is burnt in the state as there is no system of residue burning in the fields. The sources of crop residue generation in the state are limited, that is, mostly from cereal and pulse crops. By and large, full quantity of wheat and maize straw and limited rice straw are used as animal feed during winters when there is a scarcity of fodder and the livestock is mostly stall-fed. Total emission of CO_2, CH_4, and N_2O by crop residue burning in J and K during 2015 was

108.015, 0.405, and 0.029 Gg, respectively, having 135.10 Gg of CO_2e warming potential (Table 7).

Annual GHG emission from different sources

The estimate shows that annual emission of CO_2e from agriculture sector in the state of J and K is 3.798, 0.259, 0.603, 0.616, and 0.135 Tg from enteric fermentation, manure management, rice cultivation, cultivated soils, and residue burning, respectively (Figure 3). The total annual emission in 2015 is estimated at 5.411 Tg of CO_2e. The carbon sequestered through land use, land-use change, and forestry (LULUCF) by cropland was 1.526 Tg during the period. Hence, the net emission from agriculture sector in that state was 3.885 Tg of CO_2e. Per capita annual gross emission of GHG from agriculture sector in the state is 416 kg and net emission 299 kg of CO_2e. N_2O emission has been of the order of 1.988 Gg from soils, 0.029 Gg from residue burning, and 0.276 Gg from manure management. Percentage contribution of different sectors to GHG emission is shown in Figure 4. Enteric fermentation accounted for 70.1% GHG emission in J and K, followed by cultivated soils (11.4%), rice cultivation (11.2%), manure management (4.8%), and crop residue burning (2.5%) (Figure 4). A large quantity of GHG emission due to enteric fermentation in the state is due to very high population of livestock.

Table 6: N_2O emission from cultivated soils

Crop	N_2O (Gg)	CO_2e (Gg)
Rice	0.5176	160.456
Wheat	0.5196	161.076
Maize	0.5583	173.073
Other coarse cereal	0.0453	14.043
Pulses	0.0356	11.036
Oilseeds	0.0538	16.678
Fruits and vegetables	0.1882	58.342
Spices and condiments	0.0038	1.178
Fodder crops	0.0659	20.429
Total	1.9881	616.311

CO_2: Carbon dioxide

Table 7: GHG emitted from crop residue burning in Jammu and Kashmir

GHG	Emittance (Gg)	CO_2e (Gg)
CO_2	118.015	118.015
CH_4	0.405	8.505
N_2O	0.029	8.990
Total		135.510

CH_4: Methane, CO_2: Carbon dioxide, GHG: Greenhouse gas

Trend in GHG emission over time

The annual GHG emissions in J and K state in terms of Tg of CO_2e emitted between 1980 and 2015 are given in Figure 5. According to our estimates, the annual emission of GHG from agriculture sector in the state during 2015 was 5.411 Tg of CO_2e while LULUCF was −1.526 Tg (Figure 5). Maximum annual CH_4 emission in the state is from livestock (3.798 Tg) which accounted for 70.1% of the total emissions from agriculture sector. The annual rate of emission of CO2e of GHG has been found to be 0.1052, 0.0884, and 0.1905 Tg, during 1980–1990, 1990–2000, and 2000–2015, respectively. A sharp rise in GHG emission was observed between 2000 and 2015, which was largely due to enteric fermentation, increase in the use of synthetic fertilizers (2), and slight increase in area under rice cultivation.

Discussion

Climate change and agriculture

Agriculture has always experienced a variable climate, but the changes presently underway driven by human-caused increases in GHG emissions are proceeding at a rate that will rapidly propel agriculture into new environmental circumstances.[27] Morgan *et al*.[28] reported that these changes are already causing species shifts in agro-ecosystems such as rangelands and forests and affecting water and nutrient cycling. Crops such as wheat, corn, and cotton are already being genetically adapted to grow under a wide variety of environments. Crop yields are significantly affected by consistently high temperatures during the

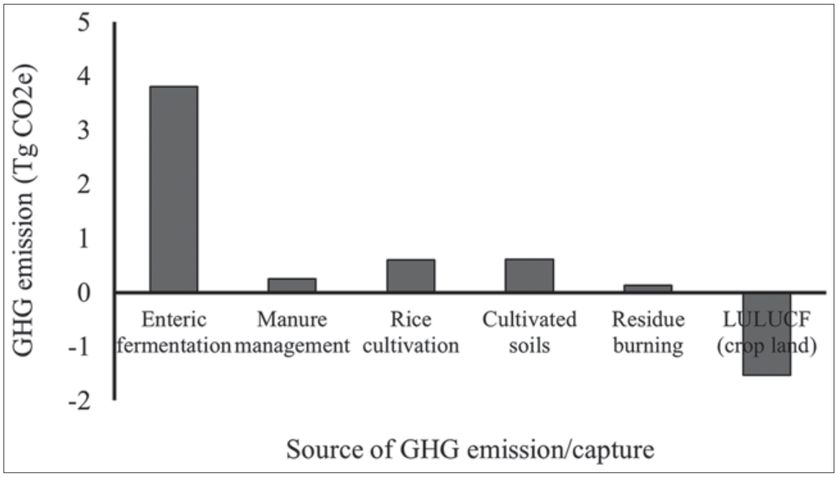

Figure 3: Greenhouse gas emission from different sources and land use, land-use change, and forestry in Jammu and Kashmir

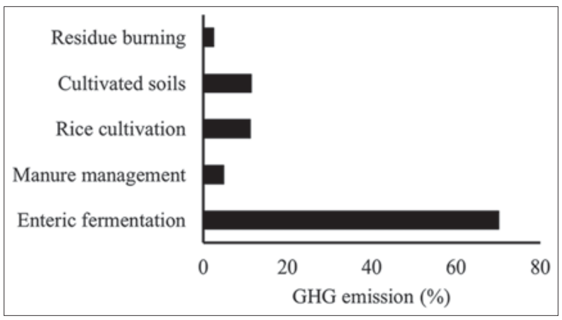

Figure 4: Percentage emission of greenhouse gas from different sources in Jammu and Kashmir

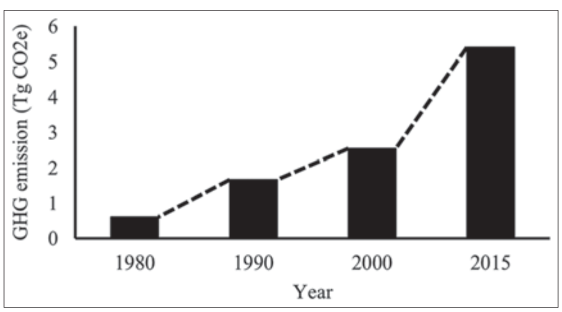

Figure 5: Trend in Greenhouse gas emission from 1980 to 2015

crop growth period.[29] On the other hand, a warming environment with a longer growing season is likely to enhance productivity in regions where cold temperatures currently limit growth, such as high-altitude or high-latitude regions. Toet *et al.*[30] reported that many environmental factors influence the production and consumption of CH_4 and N_2O.

Emissions from livestock

Like the other trace gases, CH_4 is present naturally in the atmosphere in small amounts and is derived from a variety of natural and human-induced sources. CH_4 is produced during the normal digestive processes of animals. Particularly, ruminant is the major contributors due to the type of digestive process by which carbohydrates are broken down by microorganisms and CH_4 is released as a by-product of enteric fermentation.[31] Relatively, small amounts of CH_4 are produced by non-ruminants.[32]

There are many factors such as treatment, storage, and transportation of livestock manure which are responsible for producing CH_4 and N_2O emissions. CH_4 is produced by the anaerobic decomposition of manure. N_2O emissions are produced through both direct and indirect pathways. Denitrification of the organic N from livestock excretions and N cycle during nitrification encourages direct emission of N_2O. The temperature, moisture, and manure storage or residency time affect the amount of CH_4 produced because they influence the growth of the bacteria responsible for CH_4 formation.

GHG from rice production

The CH_4-producing bacteria (methanogens) produce CH_4 to the atmosphere from the soils cultivated with flooded rice during the processes involved in CH_4 emission, as well as, CH_4 oxidation within oxic zones of the soil and flood water by CH_4-oxidizing bacteria. Rice fields are an important source of atmospheric CH_4, the second most important GHG as a result of anaerobic conditions. Cao *et al.*[33] reported that period between flooding of the soil and initiation of methanogenesis can be different in different soils. Different application rates of N fertilizer to rice significantly influenced the simulated yield, N uptake, and emissions of GHG from soil.[34] Due to increased root growth in rice with N application, higher amounts of root exudates and debris are generated, supplying C for the heterotrophic microbes, which enhance CO_2 and CH_4 emission considerably.

Emission from cultivated soils

In the present study, the emission of N_2O from cultivated soils mainly depended on the nature of the crop, nitrogen status of the soil, and N applied to the crop. It is supported by the earlier reports.[35, 36] Agricultural soils under appropriate management contain substantial amounts of soil C in the form of SOM. Proper management of agricultural soils cannot only sequester carbon but in turn enhance the quality of soils. Chemical fertilizers have been a major focus in the production or flux of N_2O from agricultural soils.[37] High doses of N application can result in significant release of CO_2, especially in the presence of soil moisture and increased labile pool of carbon.[38] Emission of N_2O by the application of N to the soil occurs directly from the soils to which the N is added and through volatilization and leaching of N. The uptake of fertilizer N by crops during the growing season, generally, varies from 30% to 60%. Nitrogen applied in excess of crop needs is particularly susceptible to loss.[39] Increased N use efficiency through management practices reduces N_2O emissions because higher amount of N is assimilated by the crop. Nitrogen availability is the single best predictor of N_2O fluxes in cropped ecosystems.[40] The N_2O emissions are high when N fertilizer is applied at rates greater than crop need.

Emission from residue burning

In the state of Jammu and Kashmir, the crop residue is burnt on very limited quantities because a significant part of the crop straw is used for feeding livestock. Badarinath[41] estimated the GHG emissions from rice and wheat straw burning in Punjab during May–October 2005 and suggested that emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields.

Conclusion

Majority of scientists are of the view that climate change is underway and is largely induced by human activities. CO_2, CH_4, and N_2O are the major GHGs that are directly affected by human agricultural activities and a matter of concern for global warming. Although these causes of GHG emissions cannot be completely eliminated, they can be lowered through (i) modified land use and management, (ii) agricultural activities can mitigate emissions by increasing sequestration of C in SOM and plant biomass, (iii) the rate at which GHG emissions in Jammu and Kashmir are increasing is a matter of concern. The great potential of C sequestration in cropland will provide a promising approach to reduce the atmospheric concentration for mitigating climate change, (iv) increasing nitrogen use efficiency by applying N fertilizers and manure as per crop needs, (v) reducing emissions from ruminant livestock and animal waste by adjusting the part of animal feed to decrease digestion time, using feed additives to reduce metabolic activity of rumen bacteria that produce CH_4, and (vi) growing rice cultivars that inhibit CH_4 production. The most effective method for reducing GHG emissions would be to increase nitrogen-use efficiency by applying nitrogenous fertilizer or manure to crops as per crop needs and time of need, reducing emissions from ruminant livestock, animal waste, and rice cultivation by adjusting the part of animal feed to decrease digestion time, using feed additives to reduce metabolic activity of rumen bacteria that produce CH_4, capturing CH_4 emissions from livestock manure, introducing more efficient water and fertilizer management, and growing rice cultivars that inhibit CH_4 production.

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Ethical Permissions
Not reported.

Conflicts of Interest
The authors declared that they have no conflicts of interest.

Authors' Contributions
Both the authors contributed to the development of the paper.

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