Assessment and Quantification of Methane Emission from Indian Livestock and Manure Management

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ABSTRACT

Methane (CH_4) is one of the most abundant organic trace gases in the atmosphere having a strong global warming potential of 28 in 100 years, is a significant GHGs, and has a vital role in atmospheric chemistry and climate change. India is home to the largest number of livestock in the world and is responsible for higher methane emissions from enteric fermentation and manure management. In the present study, the methane emissions from Indian livestock, i.e., enteric fermentation, is estimated to be 11.63 Tg yr^{-1} in 2019 using IPCC methodology and recent census livestock activity data from the Department of Animal Husbandry and Dairying, Govt. of India, and corresponding country-specific revised emission factors. The CH_4 emissions from livestock manure management system was found to be 1.11 Tg yr^{-1}, resulting in 12.74 Tg yr^{-1} of CH_4 emission from the Indian livestock sector. The district-level spatial CH_4 emission pattern was developed to identify the potential emission hotspots across the country. Initial findings suggest that changing livestock population patterns plays an important role in governing methane emissions in rural India. The information generated could be important tools for policymakers to control methane emissions across the country.

Keywords: Methane Emission, Livestock, Manure, Emission hotspots, Greenhouse Gases

1. Introduction:

Methane (CH_4), one of the potential greenhouse gases (GHGs), is also naturally available in the atmosphere as a trace gas. Due to both anthropogenic and natural activities in the last couple of decades, its concentration rose from 722 parts per billion (ppb) in pre-industrial times to 1907 ppb recently (Global Monitoring Laboratory, ESRL, NOAA, 2021). The global warming potential (GWP) of CH_4 is 28 times more effective in 100 years in modulating climate change by absorbing electromagnetic radiation ranging between 3.5 - 8 µm (US EPA, 2017; IPCC, 2022). CH_4 has a residence time of 11.8 years in the atmosphere and has direct effects on the earth's radiation balance (IPCC 6th Assessment report, 2022). Methane is a precursor of tropospheric ozone, as it directly contributes to global warming by releasing a significant quantity of CO_2 and H_2O (Manhan, 2017; Francoeur et al., 2021). Globally the total methane emissions are estimated to be 566 Tg yr^{-1} (Teragram/Year) in 2019 as per the Emissions Database for Global Atmospheric Research (EDGAR) dataset (Wang et al., 2019). As per the Confederation of All India Traders (CAIT, 2020), India is the third largest producer of GHGs globally after the USA and China. According to the recent EDGAR emission inventory, India stands in 2nd position in methane emission due to various anthropogenic activities and natural sources. The most dominating methane emitting sectors include sectors like wetland, livestock, paddy cultivation, agricultural residues, and biomass combustion, followed by coal mining, oil exploration, landfilling sites, solid waste burning sites from industries, waste-water disposal and biogas for energy etc. (Garg et al., 2011). Traditionally in India in South Asia, the most dominating sectors that emit methane are livestock, paddy fields, and solid waste (Jha et al., 2011; Garg et al., 2011). As per Garber et al. (2013), livestock has emerged as a prominent sector that contributes nearly 14.5% to global total methane emission due to anthropogenic activities, where Asian countries contribute significantly. Similarly, manure management is another vital source of methane

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with a global emission load of 9.3 Tg yr^{-1} (Scheehle and Kruger, 2006).. It is observed cattle are the main contributors to the global methane emission with a relative contribution of approximately 62% (IPCC, 2022). There are comparatively low emissions from other livestock like pigs, poultry, buffaloes, and small ruminants, which accounts for between 7-11% of methane's total emissions (Global Livestock Environmental Assessment Model (GLEAM, 2018).

The livestock sector plays an important role in the rural economy of a country like India. India is ranked a noticeable position in livestock population among Asian countries (first among cattle, buffalo and goat population and fifth in sheep population), so bovines and ruminants are major contributors to methane emission from the entire world (Swamy and Bhattacharya, 2006). At the same time, livestock like cows, buffaloes, goats, sheep, pigs, horses and ponies are mainly responsible for methane emission through manure where the dependable factors are population, body weight, size, level of production and manure generated (Knapp, 2014). About 44 % of methane emitted from livestock is attributed to enteric fermentation by ruminants with four compartmental-based digestive systems as part of their normal digestive processes (GLEAM 2.0, 2018). This release of nearly ~95 % of methane is released through the buccal cavity followed by another 5% through anal canal (5%). The resultant methane gas is released from the metabolic byproducts of the methanogenic bacteria produced from anaerobic digestion of cellulose and other macromolecules present in the fodder by utilizing H_2 and expelling it through eructation from buccal and nasal cavity. However, the enormity and type of carbohydrates fermented followed by the production ratio of propionic to acetic acid determines the amount of methane produced by livestock (Lassy, 2007; Jha et al., 2011; Shresta et al., 2013).

1.1. Previous Works:

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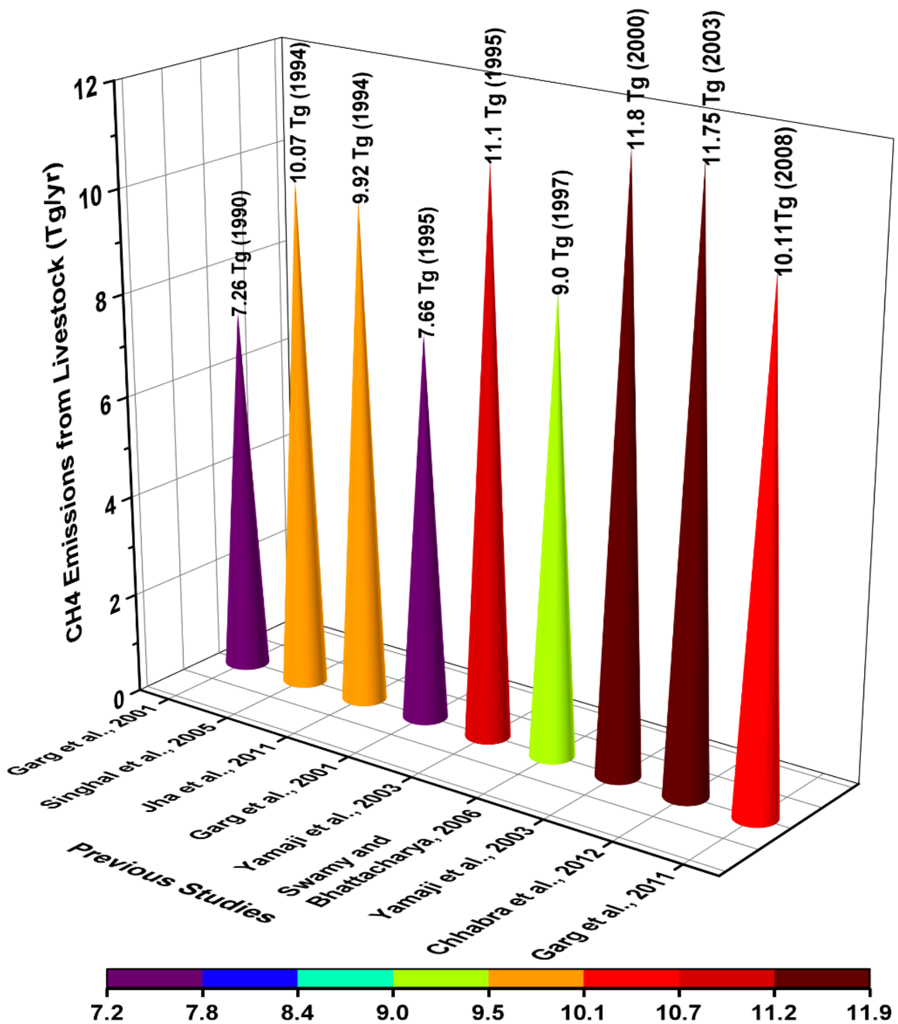

Figure 1: Intercomparison of previous studies on CH_4 emissions from Indian livestock

A couple of earlier studies pursued in developing methane inventories for Indian livestock i.e., enteric fermentation and manure are very limited in terms of activity data used and emission factors adopted, presented in **Fig. 1**. Moreover, most of the estimations have been carried out at very coarse resolution (State level), which may not be suitable for regional atmospheric chemistry and climate study. Garg et al., (2001) estimated CH_4 emission from Indian livestock to be ~7.66 Tg yr^{-1} for 1995 and the revised estimation is found to be 10.11 Tg for base year 2008. This emission difference is because of the changes in ruminant population though the number of species that have been taken into

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account has remained the same. Similarly, another study by Singhal et al., (2005) estimated 10.07 Tg yr^{-1} of methane for the year 1994. Jha et al., (2011) estimated the total methane emission as ~9.92 Tg yr^{-1} for base year 1994, where 9 types of livestock species were taken into account. Yamaji et al. (2003) estimated methane emission from Indian livestock as 11.1 Tg yr^{-1} for 1995 (10 species) as compared to 11.8 Tg yr^{-1} in 2000. Considering 1997 as base year of study, Swamy and Bhattacharya (2006) estimated the methane emission from livestock as ~9 Tg yr^{-1}. A similar estimation by Chhabra et al. (2012) recorded 11.75 Tg yr^{-1} for the base year 2003.

The large variation in total methane estimation is due to varying activity data used and base year followed by methodology adopted and diverse emission factors (EFs) used. Moreover, most of the previous studies have taken into account the livestock data from 14th and 16th livestock census data published in 2003. Keeping the limitation of data being used in various previous estimations that includes the 18th livestock census (2007), and 19th livestock census (2012). The detail of livestock-based activity data is vital in improving the estimation because the composition of species keeps on changing with time and government policy. The changing composition of species as per changing breed type and its age and weight with time in Indian livestock census is extremely sensitive to understand methane emission. Therefore, the activity data needs to be updated with time for a better understanding of the composition of livestock, and it has to be updated consecutively to understand the present scenarios of methane emission from livestock. Apart from this the IPCC Tier-I and Tier-II approach that considers the dry matter intake as a key factor is also equally important along with the species/breed-specific emission factor that fits the Indian climatic condition. This will improve the Indian CH_4 emission scenario, which will be an important initiative to discover the policy gaps and implement long-term strategies to reduce methane emissions (Kumari et al., 2016). The present attempt

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is an attempt to estimate district-level methane emission by adopting IPCC Tier-I and II based statistical bottom-up methodology using recently available 20th livestock census activity data and revised emission coefficient suitable to Indian conditions in 2019. The generated methane surface database will be crucial in many aspects in terms of the climate change point of view as well as the regional atmospheric chemistry understanding. This will be an important tool for policymakers to mitigate methane emissions in the country.

2. Activity Data:

After Brazil, India stands 2nd in the world with 1.47 billion livestock accounting for nearly 13% of the total livestock population in the world. Traditionally, livestock has been an integral part of rural India and plays a significant role in agricultural sector, they contribute nearly 8% to the country's gross domestic product (GDP) and employs nearly 8% of the national labor force (RNCOS, 2006).. Half of the country's unorganized agricultural operation and rural transporting system depends on livestock directly or indirectly. Hence, the census of livestock population in India is carried out every decade by the Department of Animal Husbandry and Dairying under the Ministry of Agriculture (MOA), Government of India, and it has been carried out for the last seven decades. The livestock census data provides information about the indigenous and cross-breed/exotic population viz. cattle, buffalo, sheep, goat, camel etc. along with other information like age groups, sex, and composition at various district/state levels. It is observed that India possessed ~536 million of livestock as of 2019, which is 4.6% higher than earlier estimation of 512 million in 2012 (livestock census data, GOI, 2012). There has been just moderate growth of 15% in the last 3 decades. It is observed that India is home to 28 well-defined categories of cattle and 8 major categories of buffalo. Contrary to the large population, the productivity of Indian livestock is low as compared to many developing countries (Jha et al. 2011).

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The productivity of livestock depends on the major feed type being consumed. Moreover, it is seen that cattle are often fed on crops grown residues and grasses from grazing lands. The use of concentrated feed is low and limited to productive animals only (Kumar et al. 2008). However, bulk of the cattle (~90%) is non-descript, low-producing, indigenous breed, even in the case of buffaloes, high-producing animals are less (10–20%) (Swamy and Bhattacharya, 2006). It observed that there are nearly 30 species of cattle and 10 species of buffalo widespread all over the country. Ruminant livestock like exotic and indigenous cattle, buffalo, sheep, goats, pigs, horses, and ponies have been considered for emission estimates. Diverse data sources like previously published papers, statistical sites like Indiastat and Statista are consulted and cross-verifications have been made as much as possible. The livestock population data are taken from census data of the Department of Animal Husbandry and Dairying, Government of India. In the case of unavailability of year-specific data, growth trends of the previous years have been applied. Mainly the emission factors are taken from the average of India's Initial National Communication (NATCOM) emission coefficient and IPCC default emission factors for livestock.

For the present national-level livestock-related activity data, the census data as per government sources for the base year 1992 – 2019 was accounted to understand the trend of various species. The category-wise livestock population (1992 – 2019) is presented in **Fig. 2,** where the trend of data shows that there has been a variable trend of ruminant animals since last two and half decades (Department of Animal Husbandry and Dairying, MOA, Govt of India, 2019). The historical livestock data reveals that the Indigenous cow population contributes one-fourth of the total ruminants in India. The ruminants' population increased from nearly 468 million (1992) to 535 million (2019) with an annual growth rate ranging between nearly 2% to 3%. Among bovines, the crossbred/Exotic cow population

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increased from approximately 15 million (1992) to 51 million (2019) which is in line to support the milk demand across the country. During the same time, there was a significant decrease in indigenous cow number (~33%) i.e., ~189 million (1992) to ~142 million (2019), whereas the buffalo number was increased from 84 million to 109 million during same time. However, It is observed that there was no such significant change in bovine population between 1992 and 2019 (i.e., ~299 million to 303 million). However, under non-bovines category, concurrently there was a significant increase in goat population by 28%. The sheep population has a very waving pattern in last two decades whereas the pig population increased marginally from 12 million in 1991 to 13 million in 2003. It is seen that there is a continuous decrease trend in horses and ponies population during 1992 to 2019. We can summarize that the overall livestock population increased in last two and half decades may have an impact on methane emissions. Indian livestock plays an important role in methane emission due to its large spatial and temporal changes, which is being taken into account in the present study to understand methane load. The body weight, feed capacity, and milk production rate used for calculation are taken from the National Dairy Development Board report (2017 – 2018) and adopted the process by Jha et al. (2011).

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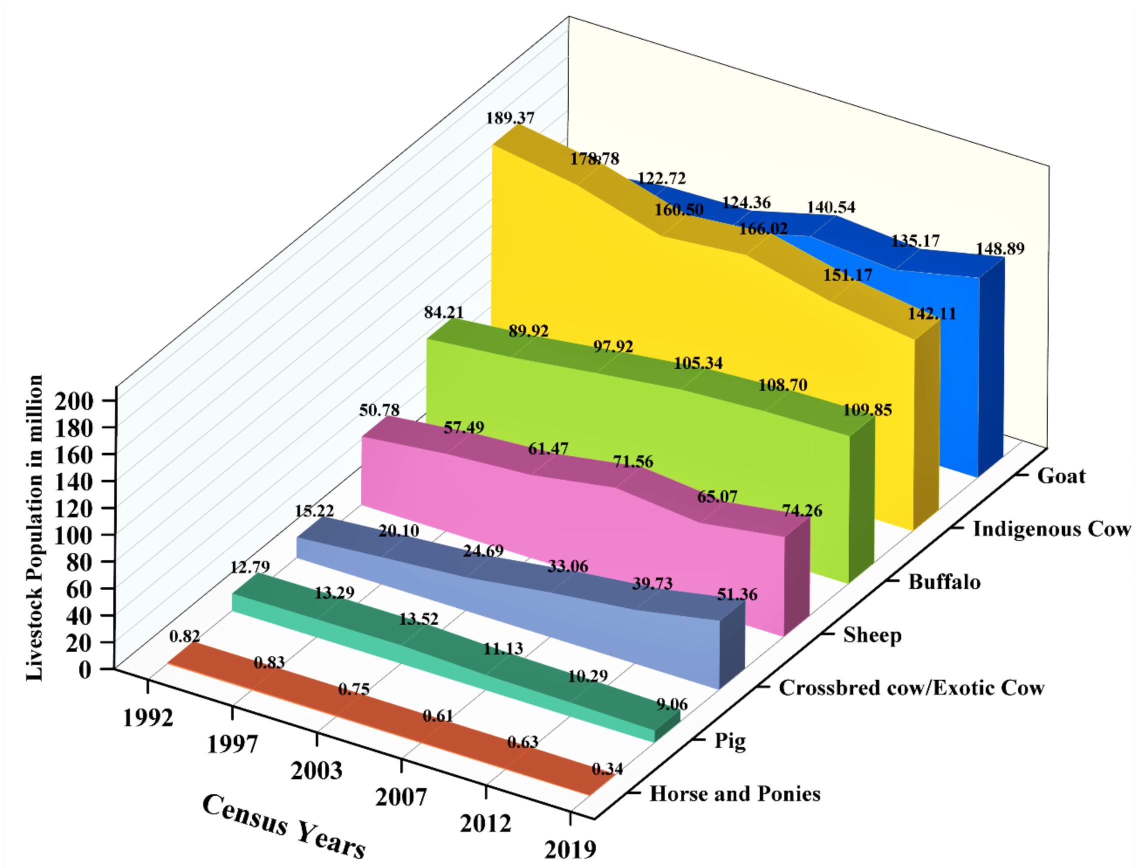

Figure 2. The growth pattern of various categories of livestock (1992-2019).

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2.1. Emission Factor &Methodology used:

As mentioned earlier, the present study has adopted the most commonly used emission factor-based traditional approach implemented by Sahu et al., (2015, 2017, 2021, 2023a, 2023b) and Kumar et al., (2018) based on IPCC Tier-II methodology, an emission factor-based bottom-up approach, which will not only improve the estimation with country-specific livestock specific emission factors but also optimize the spatial pattern due to high-resolution district-level activity data that includes detailed statistics about major livestock like cattle, buffalo, goat, sheep, and pigs. To improve the estimation, the country-specific emission coefficients are adopted by comparing the earlier works from NATCOM, India's report published by the Ministry of Environment and Forests (MOEF), (2004) and

IPCC -2006 reported emission factors as tabulated in **Table 1**. The emission estimation for present work is calculated by taking the modified emission factor, which is the average of IPCC and NATCOM emission coefficients for different age groups of livestock. For better representation and understanding, cattle are divided into exotic/crossbred and indigenous types. Further subtypes are divided as dairy and non-dairy where both non-dairy indigenous and non-dairy crossbred are sub-categorized according to age as given in **Table 1**. Similarly, all other livestock varieties are sub-categorized according to age. The emission factor for manure management considered for present study is also adopted from NATCOM report, where the similar age-specific categorization of livestock is taken into account and tabulated in **Table 1**. No categorization of other animals viz. for sheep, goat, pigs, horses and ponies due to non-availability of data. A comparison of emission factor of IPCC, NATCOM and the present study is given in **Table 1**. The regional emission factors of the methane emission for livestock like dairy cattle (Indigenous), Non-dairy cattle (0-1 yr), Non-dairy cattle crossbred (0-1 yr & 1-3 yr) have large discrimination and their population size is huge. It plays a significant role in modulating the entire emission pattern if any particular kind of emission type is issued for estimation. In order to avoid the large discrimination, we have adopted average emission factors, which will reduce bias and error (Paliwal et al., 2016; Aardenne et al., 1999; Shami et al., 2022). The average emission factors will standardize emission Inventory and reduce the uncertainty lies in both emission factors and total emission estimation.

Table 1: Emission factor of IPCC, NATCOM and Present study for livestock categories (Kg head^{-1} year^{-1}).

Category	**Subcategory**	**Enteric fermentation**	**Manure management**

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		NATCOM	IPCC	Present Study	NATCOM	IPCC	Present Study
Dairy cattle	Indigenous	28±5	46	37	3.5±0.2	5	4
	Crossbred	43±5	46	45	3.8±0.8	5	4
Non-dairy cattle (Indigenous)	0-1 year	9±3	17	24	1.2	2	2.4
	1-3 year	23±8	25		2.8	2	
	Adult	32±6	25	29	2.9±1.4	2	2.4
Non-dairy cattle (Crossbred)	0-1 year	11±3	17	14	1.1	2	1.5
	1-2 ½ year	26±5	25	26	2.3	2	2.3
	Adult	33±4	25	29	2.5±0.9	2	2.5
Dairy buffalo		50±17	55	53	4.4±0.6	5	4.7
Non-dairy Buffalos	0-1 year	8±3	23	39	1.8	5	4.2
	1-3 year	22±6	55		3.4	5	
	Adult	44±11	55	50	4	5	4.5
Sheep		4±1	5	4	0.3	0.3	0.3
Goat		4±2	5	4		0.2	0.2
Horses & Ponies		IPCC Default Tier I	18	18	IPCC Default Tier I	1.6	1.6
Donkeys			10			0.9	
Camels			46			1.6	
Pigs			1	1		4	4

The factor to which feed energy (FE) is converted to methane and depends on several interacting feed and animal characteristics is called Methane Conversion Factor (MCF). These values for the present estimation are based on country-specific feed and animal characteristics. So, it reflects the country's actual scenario of livestock feed consumption pattern. MEF is calculated according to the methane produced per animal per year. Derivation of emission factors is due to the average of dry

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matter intake, energy balance equation and feeding standards based on total digestible nutrients. Methane Emission Estimation (MEE) from livestock (both from enteric and manure activities) is the sum of the product of category-wise livestock population (P_i) to respective emission factors (Kg head^{-1} year^{-1}). The sum of both enteric and manure methane emissions gives Total Methane Emission (TME) per livestock. Later the emission is converted to Tera-gram year^{-1} (Tg yr^{-1}).

$$TME = \Sigma P_i \times (EF_{EME} + EF_{MME}) \text{ (kg yr}^{-1}\text{)}$$

Where EME= Enteric Methane Emission, MME= Manure Methane Emission

The methane emission was calculated at 721 districts using livestock population and corresponding age/category-wise EFs, which are again spatially allocated to village level based on population data and availability of grazing land and farmland. The methane emissions from the livestock are then quantified for both enteric fermentation and manure management sectors and plotted in a GIS-based statistical tool. Since village level is the most refined and finest resolution where the rural population play a key role. Access to such a geographical database is limited and is being used for the first time to allocate district-level calculated methane. Since the rural population is closely associated with agricultural activity and closely driven by the livestock in particular region.

3. **Results and discussion:**

The varying composition of live-stock population which keeps changing with time plays a vital factor in changing methane emission trends. Apart from this, body weight, age and food intake also have an effect on emissions. As presented in **Fig. 3**, among livestock categories, bovines (exotic/crossbred cattle, Indigenous cattle, and buffalo) share ~92% emissions than other smaller ruminants (goat, sheep, pig, horses and ponies). However, dairy buffalo contributes about 70% of

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emissions in buffalo population and non-dairy indigenous cattle share near about 60% of emissions among the cattle population. The ruminant exotic cattle below 2.5 yrs. share a minimal emission in cattle category because their ruminants may not have fully developed. From non-bovine category, the goat population shows a dominant position in methane emission followed by sheep, pig, and horses and ponies (Goat > sheep > pig > horses and ponies). The emission factor chosen for this study is a newly derived one which is the average of IPCC and NATCOM emission factor. The estimated gridded CH_4 emission is found to be 12.74 Tg from livestock for the base year 2019 and the grided pattern of it is depicted in **Fig. 4**.

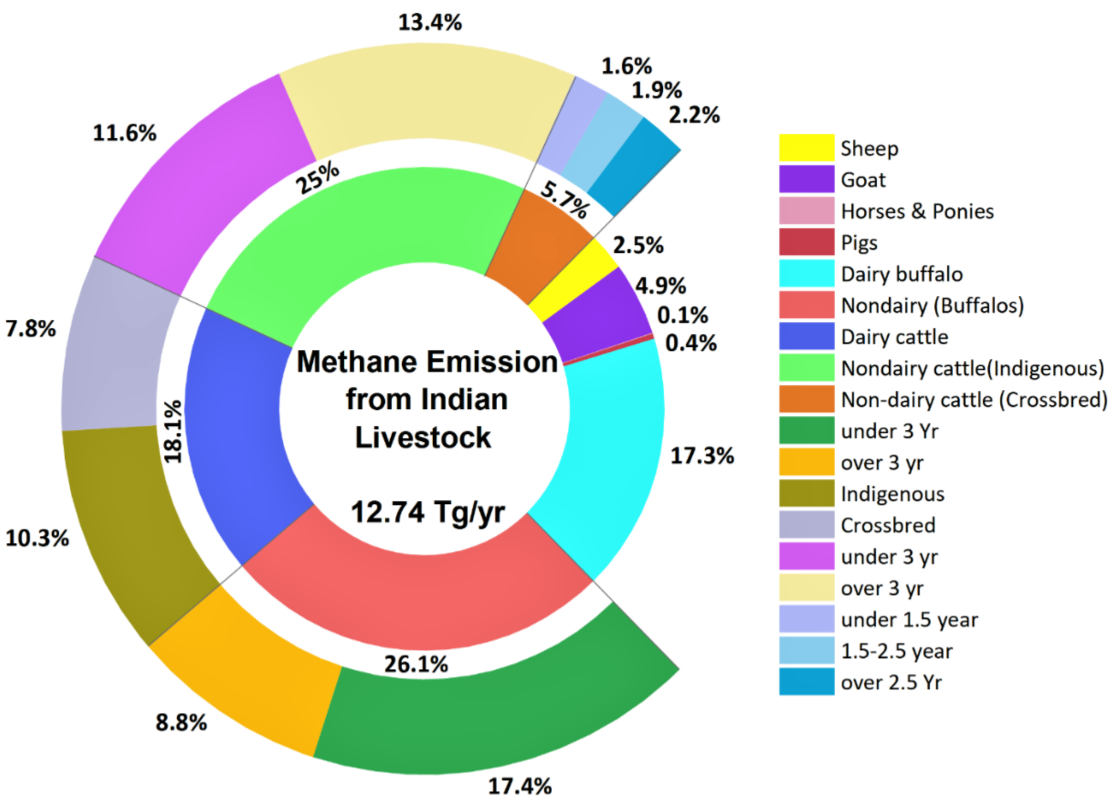

Figure 3: Livestock category-wise Methane emission from the country (2019).

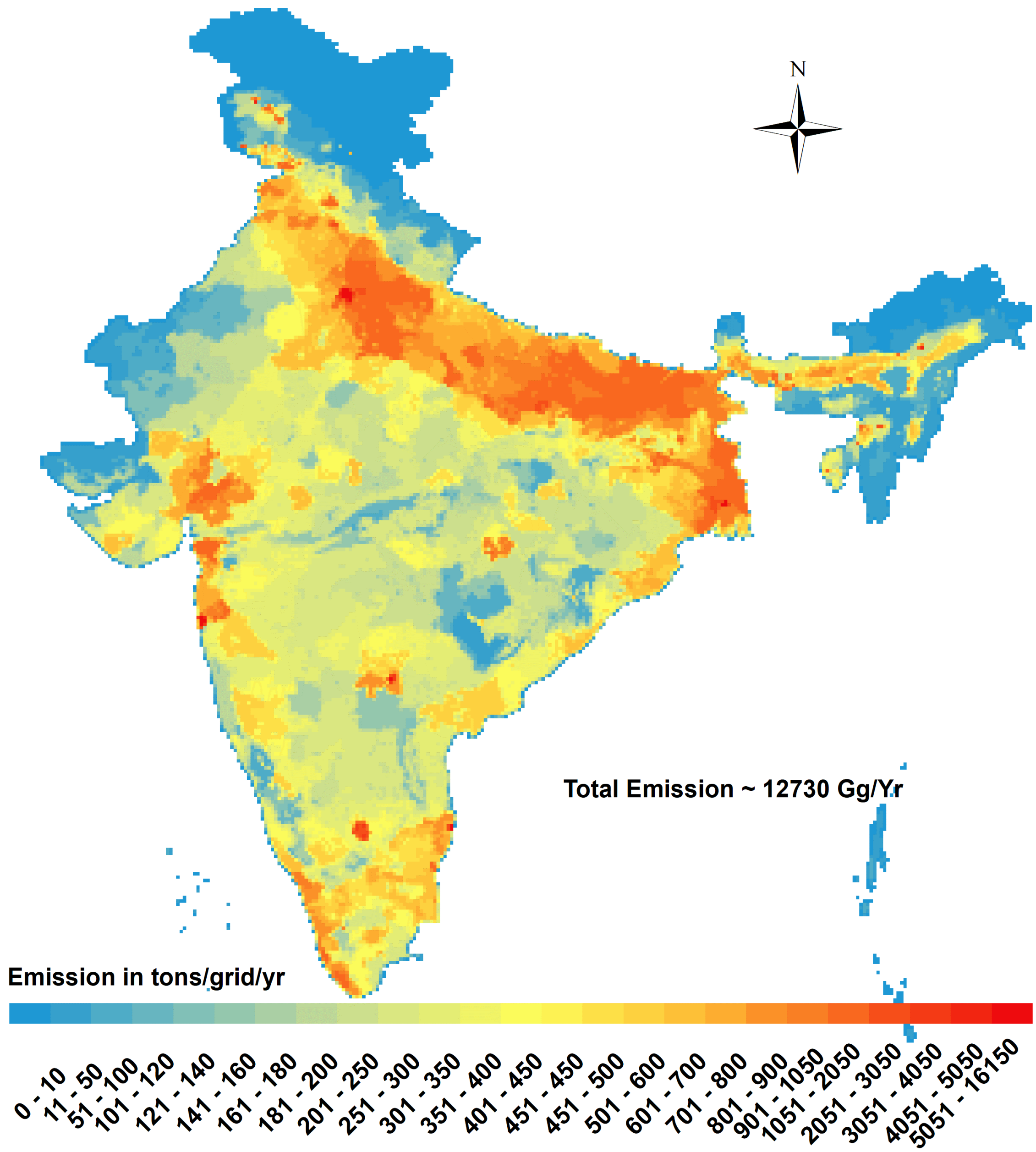

Figure 4: Gridded Methane Emission from Livestock in India in 2019

In district-level analysis, the 100 most methane-producing districts contribute ~4.8 Tg yr^{-1}, which accounts for nearly 40% of national total emissions. Indian subcontinent is subdivided into 36 states and Union territories, where the top five highest emitting states due to both enteric and manure activities are Utter Pradesh (2550.92 Gg yr^{-1}) followed by Rajasthan (1342.44 Gg yr^{-1}), Madhya

Pradesh (1187.84 Gg yr^{-1}), Bihar (998.63 Gg yr^{-1}), Maharashtra (861.38 Gg yr^{-1}), Gujarat 797.42 (Gg yr^{-1})and West Bengal (707.25 Gg yr^{-1})(**Fig. 5**). Northeastern states like Mizoram (3.45 Gg yr^{-1}) are among the least emitting state followed by Goa (4.01 Gg yr^{-1}) in Western India (**Fig. 5**). The emission of methane from Enteric fermentation and manure management is population based. Thus, the emission pattern of manure management is quite similar to enteric fermentation. As India is populous to bovines, states having more cattle and buffalo show greater emission tendencies. Moreover, states of high altitude like Jammu and Kashmir, Himachal Pradesh and Uttarakhand show significant amounts of non-bovine emission of 22.47 Gg yr^{-1}, 8.24 Gg yr^{-1} and 7.26 Gg yr^{-1} (**Fig. 5**).. Districts like Kathua, Anantnag (of Jammu & Kashmir), Palakkad, Ernakulum (of Kerala), Gurdaspur, Firozpur (of Punjab), Karnal, Sirsa (of Haryana) adopt different Government schemes such as MAITRI, Rashtriya Gokul Mission, Pashu Sanjivini to increase hybrid cattle population for better milk production and improve their livelihood status. With Contradicting emission pattern of above districts; Allahabad, Kheri, Sonbhadra, PaschimMedinpur, Bankura, Udaipur, Todhpur of Uttar Pradesh, West Bengal and Rajasthan respectively emit 2-3 times more methane emission due to greater number of Indigenous cattle than Exotic cattle. The buffalo population also plays a challenging role in increasing methane emissions. Districts like Banaskantha, Udaipur of Gujarat, Jaipur, Alwar of Rajasthan, Ahmadnagar of Maharashtra, Budaun, Agra, Allahbad of Uttar Pradesh, Belgaum of Karnataka, Paschim Medinipur of West Bengal emits highest methane emission due to a greater number of buffalo population than cattle. A list of top ten districts showing the highest methane emission irrespective of state is given in **Fig. 6**.

In the present study, although secondary sources of activity data are collected from authentic government sites and various previously published papers which might remain uncertain up to a few

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extents. Therefore, we have adopted both the linear error propagation method and the Monte Carlo simulation methodology for the uncertainty estimation as recommended by IPCC. In the Monte Carlo Simulation method, the source-specific activity data and the emission factors data are plotted and fitted to the five probability distribution functions viz. Normal distribution, Log-Normal Distribution, Student's t-distribution, Triangular distribution and Uniform distribution. The output of the sector-specific uncertainties is calculated using the known function of each distribution. Every sectoral uncertainty output is iterated 100000 times and finally the mean, Standard deviation and 95% confidence interval are calculated. All the necessary statistical calculations are done in the IBM SPSS 24.0 (Paliwal et al., 2016). The uncertainty in methane emission from livestock is largely in EFs. It is found to be an uncertainty level around ± 39 %, which is within acceptable range. Most of the previously published papers have not reported the uncertainty in their estimation and in the rest, the uncertainty is in between 50% – 80% We believe the emission estimation has improved significantly in term of spatial allocation and specie types confined in India.

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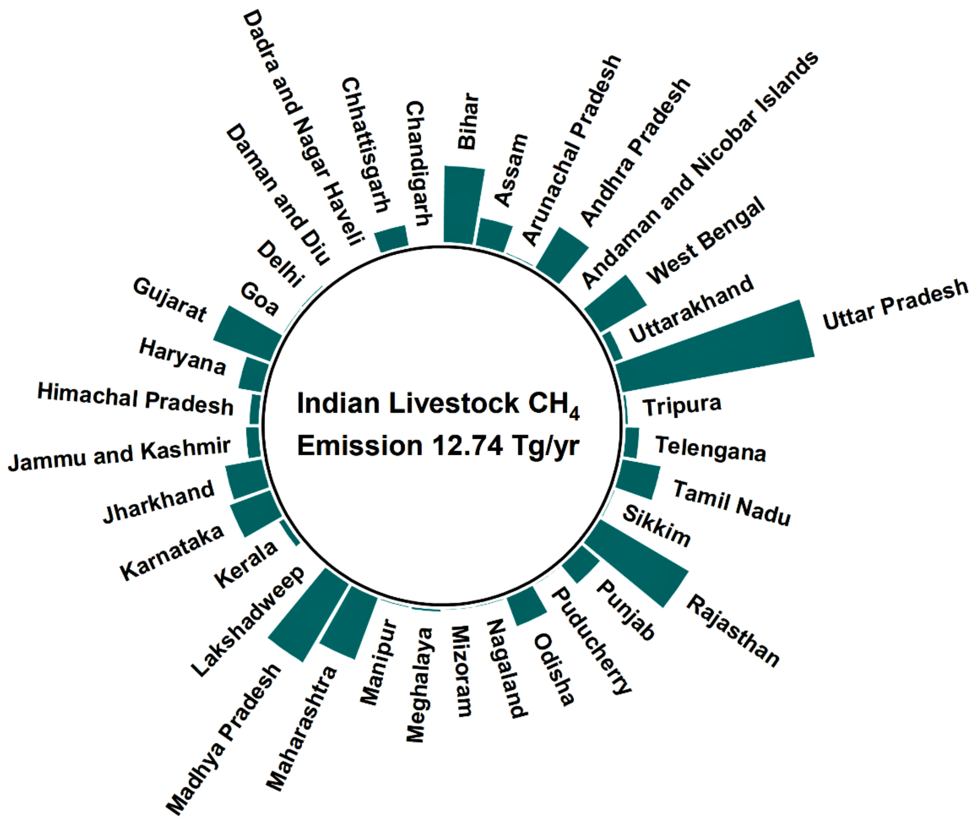

Figure 5: State wise Methane emission (Gg yr^{-1}) from livestock (both enteric fermentation and manure management) in 2019.

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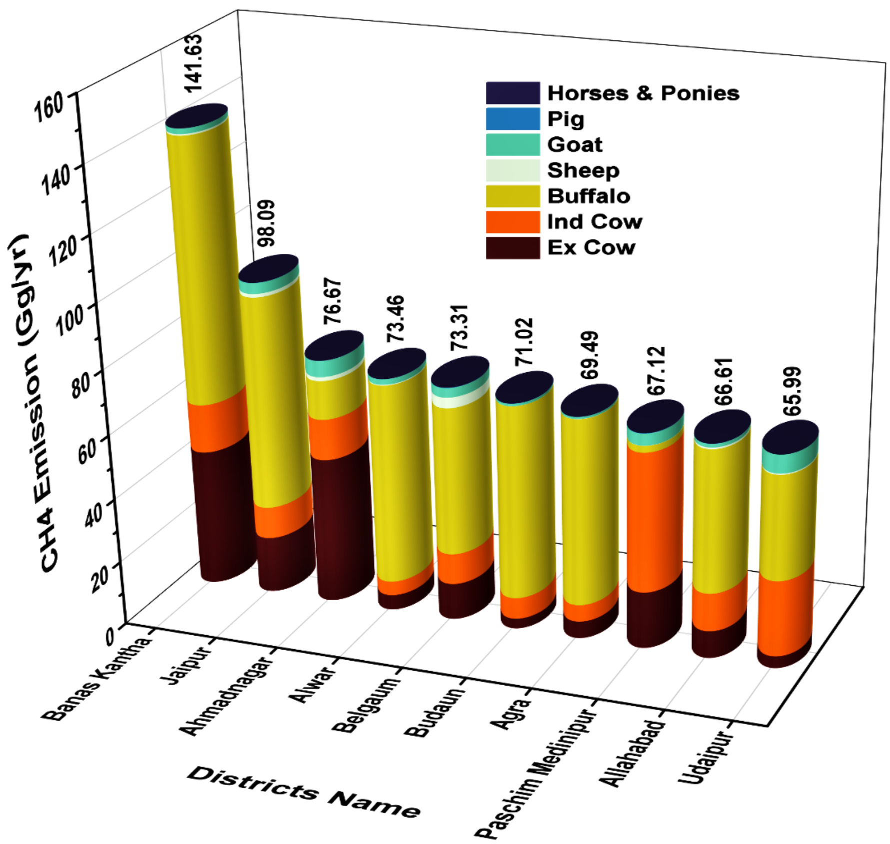

Figure 6: List of Ten districts showing the highest methane emission in India in 2019.

4. **Conclusion**:

The prime objective of developing a comprehensive gridded emission inventory of CH_4 emission from livestock in 2019 is accomplished through this study where the total methane emission generated from livestock is found to be 12.74 Tg yr^{-1}. A decreasing trend in livestock is recorded from 2007 and 2019, despite that the trend of CH_4 emission from 2007 to 2019 was observed to be stagnant due to changes in the composition of livestock in last two decades with no significant decrease in CH_4 emission from this sector Climate change point of view, CH_4 emission from world's largest ruminant do not show elevated level over last two decades is a good sign and do support India's claim in NDC.

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