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ORIGINAL PAPER

Country-specific emission information in relation to paddy residue burnt in Sri Lanka

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Abstract
Paddy residue is generated as a post-harvest by-product and farmers dispose of such residue in different ways, including in-situ open burning. Burning paddy residue results in a large loss of plant-essential nutrients in addition to polluting the environment and harming human health. In emission inventorying, particularly in the Intergovernmental Panel on Climate Change—greenhouse gas inventory process, estimating emissions due to burning paddy residue is essential. The present study aimed at providing country-specific information in relation to the in-situ open burning of paddy residue in Sri Lanka. Farmer surveys were conducted in selected five administrative divisions (districts) under wet, dry, intermediate and semi-arid climatic zones of Sri Lanka. For the calculations and analyses, the two cultivation seasons, *Yala* and *Maha* of the 2015/2016 cultivation year were considered. Fractions of paddy residue burnt, area burnt and emissions due to paddy residue burning were calculated. The highest percentage of burnt paddy residue (13.51%) was recorded from Anuradhapura District and the lowest percentage of burnt paddy residue (1.42%) was found in Kurunegala District. The highest percentage of area burnt was 13.47% in Anuradhapura District during the *Maha* season and 8.20% of the area was burnt during the *Yala* in Kurueagala District. Carbon monoxide (CO) was the highest emission due to paddy residue burning followed by methane (CH_4). The study's major findings could be incorporated into future national GHG inventories as country-specific information to be used with IPCC Tier 2 approach, to calculate the emissions from in-situ open burning of paddy residue.

Keywords Paddy residue · Residue burning · Non-carbon dioxide · Greenhouse gas

Introduction

Burning crop residues is a widespread practice (Lin and Begho 2022) which could lead to world's poor air quality. It could be a substantial source of trace gases and aerosols which could alter the atmosphere's chemistry and have a direct or indirect impact on the earth's radiative balance, altering its temperature and accelerating global climate change. Moreover, emissions from burning agricultural residue have detrimental effects on the environment and human health, causing significant problems such as haze formation, decline in soil flora and fauna, and depletion of plant nutrients (El-Sobky 2017; Lohan et al. 2018; Venkatramanan et al. 2021).

Since the pre-industrial era, worldwide anthropogenic greenhouse gas (GHG) and precursors of GHG emissions have continued to rise (Santos et al. 2022). Especially, increased greenhouse gases (GHGs) appear to be the dominant cause of the observed warming trend since mid of twentieth century (IPCC 2014a, 2014b). According to IPCC, (2014b), agriculture, forestry and other land-use (AFOLU) sector emit 24% of the total GHG emissions (counted in CO_2-equivalents). Agriculture is a source for three primary GHGs: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and it could act as a sink for atmospheric CO_2 (Johnson et al. 2007; Gambhir et al. 2017). Emissions of carbon monoxide (CO) and oxides of nitrogen (NOx) are also reported in GHG inventories under the crop residue burning (IPCC 2006), even though precursors to GHGs are not included in global warming potential-weighted greenhouse gas emission totals. Formation of Ozone (O_3) in the troposphere which is regarded as one of the potent GHGs

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is facilitated in the presence of CO, $NO_{(x)}$ and sunlight (Lu et al. 2019).

Sri Lanka is an island surrounded by the Indian Ocean, located within a latitude range of 5°55′ and 9°51′ N and a longitude range of 79°41′ and 81°53′ E (Arasaratnam and Peris 2023). It has traditionally been divided into three climatic zones: wet zone (annual rainfall > 2500 mm; no significant dry season; Rajendram 2021), dry zone (annual rainfall < 1750 mm; distinct dry season from May to September; Rajendram 2021) and intermediate zone (annual rainfall between 1750 mm and 2500 mm, a short and insignificant dry season; Nisansala et al. 2020). Two rainy seasons make up the major growing seasons of Sri Lanka, namely *Yala* and *Maha* cultivation seasons. First inter-monsoon rains (March–April) and south-west monsoon rains (May–September) coincide with the *Yala* season while the second inter-monsoon rains (October–November) and north-east monsoon rains (December–February) coincide with the commencement of *Maha* cultivation season (Zubair 2002; Silva et al. 2007; Sonnadara 2015). Rice is the major primary food source in Sri Lanka and the total land used for paddy (*Oryza sativa*) cultivation is estimated to be about 1,116,933 ha (i.e. 34% of the total cultivated area) (Department of Agriculture 2022).

The demand for rice would rise by 1.1% per year and in order to fulfil this need, rice output must increase by 2.9% annually (Senanayake and Premaratne 2016). With the increase in rice production, a concomitant increase in the production of paddy residue can be expected (Shafie 2015; York and Garden 2016). Paddy residue can be utilized as industrial fuel (Harun et al. 2022), personal cooking fuel (Sfez et al. 2017), animal fodder (Roy and Kaur 2016; Harun et al. 2022), animal bedding (Harun et al. 2022) and compost (Kaur et al. 2019), and thatching for rural dwellings (Roy and Kaur 2016). However, it may be quite difficult to dispose of such large amounts of paddy residue. Therefore, Asian farmers frequently set their paddy fields alight as they see it as the fastest and cost-effective method to remove massive amounts of crop leftovers or residues and get the field ready for the following crop season well in advance (Kanokkanjana and Garivait 2016). Even the second national communication of Sri Lanka which was submitted to United Nations Framework Convention on Climate Change (UNFCCC) reported that paddy residue burning during the year 2000 emitted 22,320 t of CO, 1060 t of CH_4, 50 t of N_2O and 1710 t of NO_x. As country-specific emission factors are developed by taking into account country-specific data, those are important in ensuring the accuracy of national GHG inventorying, especially when following Tier 2 and Tier 3 approaches of 2006—IPCC guidelines for GHG inventorying. In GHG inventorying procedure, the IPCC divides the inventory methodology based on the emissions factors and activity data as Tier 1, Tier 2 and Tier 3. The most fundamental approach or Tier 1 considers using country-level default emission factors given in IPCC guidelines, in contrast to Tiers 2 and 3 approaches, which are more advanced requiring more country-specific information. This study aimed at providing country-specific information in relation to the practice of crop residue burning in paddy fields, to be considered in the future GHG inventories in the country, for better accuracy. Data collection for the analyses was carried out from May to September in 2017.

Materials and methods

Study areas

Five administrative divisions (or districts) in Sri Lanka (Fig. 1) were sampling areas for the present study. Gampaha and Kalutara districts fall in the wet zone completely. Anuradhapura District belongs to the dry zone of the country. Kurunegala District is split between the dry

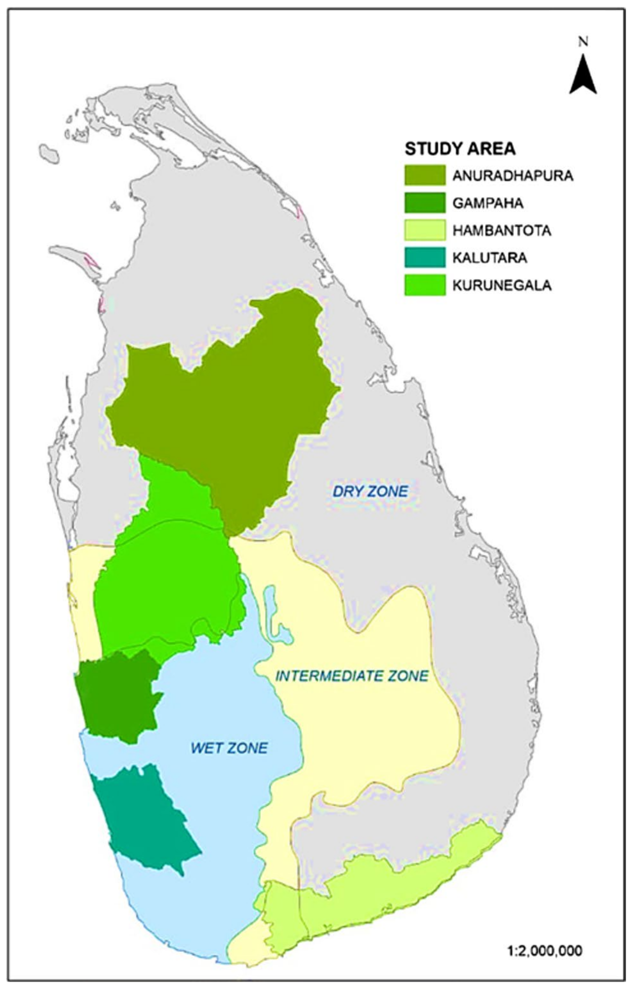

Fig. 1 Study locations (i.e. districts) representing different climatic zones of Sri Lanka

and intermediate zones. Hambantota District has a dry semi-arid climate with hot, dry weather and bright sunlight. The selection of the study districts was based on the discussions held with the agricultural extension officers, to cover a representative sample of locations where crop residue burning is practiced. The districts which have a large amount of paddy fields in each were considered for both dry zone and wet zone. Out of the three major districts (Kurunegala, Matale and Badulla) of the intermediate zone, Kurueagala District has larger area under paddy cultivation and hence it was chosen as the study district in the intermediate zone. Tables 1 and 2 further detail the background statistics of paddy cultivation at each study district relevant to 2015/2016 cultivation year.

Study participants

With the support of officers in Agrarian Development District Offices and Local Agrarian Development Centers, farmers who actively engaged in paddy cultivation and the farmers who were in the farmer societies during the study period within the boundaries of the selected study areas were approached. The average size of paddy fields within each district during the two main cultivation seasons (*Yala* and *Maha*) are indicated in Table 2.

Table 1 Paddy statistics of selected study districts in 2015/2016 cultivation year (Department of Census and Statistics, 2023)

Study district	Climatic zone	Paddy sown extent (ha)		Paddy harvested extent (ha)	
		Yala	*Maha*	*Yala*	*Maha*
Anuradhapura	Dry	38,701	96,254	38,223	95,865
Hambanthota	Dry	22,444	29,301	22,042	27,128
Kurunegala	Intermediate	50,190	80,778	49,356	80,625
Kaluthara	Wet	2799	11,736	2786	11,722
Gampaha	Wet	1903	9989	1875	9983

Data collection

Farmer surveys in study areas were conducted during the period between May 2017 and September 2017. A self-administered structured questionnaire (Data Collection Questionnaire–Quantification of Disposed Paddy Residue under currently practising paddy residue disposal methods (DCQ–QDPR)) was used to collect data on demographic details of the respondent, paddy cultivated seasons and extent in 2015/2016 cultivation year, rice varieties grown in each cultivation season, and paddy residue disposal methods followed in 2015/2016 cultivation year including the fractions disposed of by each method. The native language: *Sinhala*, was used as the communication media of the farmer survey.

District-level average paddy yield data and data on net extent harvested for the cultivation year of 2015/2016 were collected from Agriculture and Environment Statistics Division in the Department of Census and Statistics, Sri Lanka. The harvest indices of rice varieties were obtained through unpublished raw data used by Illangakoon et al. 2016.

Data to determine the paddy residue burnt, area burnt and the most popular paddy variety among farmers in both *Yala* and *Maha* seasons in selected 5 districts were obtained through DCQ–QDPR. The default value of combustion factor (0.8) for the post-harvest-agricultural residue field burning and GHG emission factors given by IPCC (2006) were used in GHG emission calculation for on-site burning of paddy residue.

Analyses of survey data

The survey data was analysed for both *Yala* and *Maha* cultivation seasons separately for all the study districts following the procedure mentioned below. All the calculations were done using Excel 2013.

The rice variety which was cultivated by many of the farmers in the sample (the highest percentage of farmers) was selected as the most popular rice variety among paddy farmer communities in each district relevant to the cultivation season. Harvest Index (HI) of the most popular rice

Table 2 Percentage of farmers under different agricultural methods in paddy cultivation

The study area (district)	% Of farmers under rainfed agriculture	% Of farmers under fully irrigated agriculture	% Of farmers under partially irrigated agriculture	Average size of a paddy field (ha)	
				Yala	*Maha*
Anuradhapura	2.70	21.62	75.68	0.61 *(11)	1.23 *(33)
Kurunegala	56	26	18	0.47 *(27)	0.51 *(29)
Gampaha	80.65	19.35	0	0.64 *(16)	0.54 *(29)
Kalutara	99.96	0.04	0	0.53 *(23)	0.56 *(23)
Hambantota	0	54.90	45.10	0.89 *(47)	0.89 *(48)

* denotes the number of farmers actively engaged in paddy cultivation during each cultivation season of the cultivation year of 2015/2016

Table 3 Fractions of paddy residue burnt and area burnt in *Yala* and *Maha* seasons

The study area (district)	Final sample size	Percentage (%) of post-harvest paddy residue burnt during the cultivation season	Percentage (%) of area burnt	
			Yala	*Maha*
Anuradhapura	37	13.51	0.00	13.47
Kurueagala	50	1.42	8.20	3.97
Gampaha	31	3.23	0.00	5.13
Kalutara	24	7.29	3.31	3.91
Hambantota	51	1.87	4.85	3.29

Table 4 Estimated amounts of in-situ open burnt paddy residue in *Yala* and *Maha* seasons of 2015/2016 cultivation year

The study area (district)	The most popular rice variety		Estimated amounts of paddy residue burnt on the post-harvest paddy fields in t	
	Yala	*Maha*	*Yala*	*Maha*
Anuradhapura	Bg 300–75.00%	Bg 358–57.14%	0.00	6842.27
Kurunegala	Bg 300–46.15%	Bg 352–54.00%	211.49	211.64
Gampaha	Bg 358–31.25%	Bg 358–34.50%	0.00	55.58
Kalutara	Bw 272-6B–29.16%	Bw 272-6B–16.70%	25.27	142.84
Hambantota	At 362–74.47%	At 362–70.21%	102.42	88.16

Bg, Bw and At are varieties bred at Central Rice Breeding Centre, Batalagoda, Regional Rice Research & Development Centre, Bombuwala and Rice Research Station, Ambalantota of Sri Lanka, respectively

HI of each variety was between 0.4 and 0.5

variety and district-level seasonal average paddy yield in kilograms per hectare (kg ha^{-1}) were used to calculate the amount of seasonal aboveground total biomass, as given in Eq. (1).

$$\text{Seasonal Aboveground total biomass (kg ha}^{-1}\text{)} = \text{Seasonal paddy yield}\left(\text{kg ha}^{-1}\right)/\text{HI} \quad (1)$$

The amount of seasonal aboveground paddy residue which was available for combustion per unit area (kg ha^{-1}) was obtained by subtracting the average seasonal paddy yield from the seasonal aboveground total biomass. Percentage of amounts of paddy residue burnt and area bunt in each district were calculated using the data collected through farmer survey (i.e. fractions of paddy residue under different paddy residue disposal methods followed by the farmers have been attached as Annex 1). Considering each study district, it was multiplied by the amount of seasonal aboveground paddy residue to obtain the amount of paddy residue burnt (kg ha^{-1}).

The total area burnt (ha) due to paddy residue burning under each cultivation season was estimated by multiplying the net harvested area in each district and the relevant fraction of area burnt. Using the value of paddy residue burnt per ha and the total area burnt (ha), the amount of district-level paddy residue burnt in the 2015/2016 cultivation season was estimated. This was converted to tonnes (t) and directly used to represent (A (ha)$\times M_B$ (t ha^{-1})) in Eq. (2) (IPCC 2006) for estimating district-wise emissions due to in-situ open burning of paddy residue.

$$L_{fire} = A \times M_B \times C_F \times G_{ef} \times 10^{-3} \quad (2)$$

where $L_{\text{fire}=}$ Amount of emissions from paddy residue burning, Tonnes (t) of each GHG

Table 5 Estimated amounts of non-carbon dioxide GHGs and precursors of GHGs (tonnes (*t*)) due to in-situ open burning of paddy residue

District	CO		CH_4		N_2O		NO_x	
	Yala	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*
Anuradhapura	*0.00	503.59	*0.00	14.78	*0.00	0.38	*0.00	13.68
Kurunegala	15.57	15.58	0.46	0.46	0.01	0.01	0.42	0.42
Gampaha	*0.00	4.09	*0.00	0.12	*0.00	0.00	*0.00	0.11
Kalutara	1.86	10.51	0.05	0.31	0.00	0.01	0.05	0.29
Hambantota	7.54	6.49	0.22	0.19	0.01	0.00	0.20	0.18

*indicates that there was no paddy residue burning during *Yala* season in the respective districts

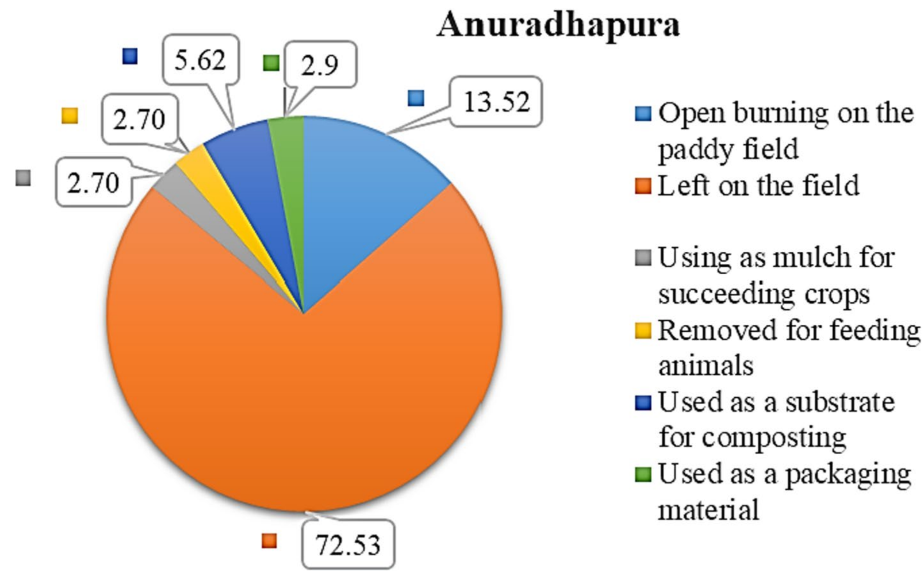

Fig. 2 Percentage of the amount of paddy residue disposed under different methods in Anuradhapura District

A = Area burnt in ha.

M_B = Mass of paddy residue available for combustion on the field in t $ha.^{-1}$

C_F = Combustion factor (default values according to IPCC 2006).

G_{ef} = Emission factor, grams per kilogram (g kg^{-1}) dry matter burnt (default values according to IPCC 2006).

Results and discussion

As indicated in Table 3, 13.51% of paddy residue was burnt in the district of Anuradhapura which was the highest among all districts' fractions of paddy residue burnt. Moreover, 13.47% of the extent of post harvested paddy fields in Anuradhapura was burnt to dispose of paddy residue and it was the largest area among extents of paddy residue burnt in *Maha* season. It was observed that there is no residue burning in Anuradhapura and Gampaha districts during the *Yala* season. The percentage of 8.20% of paddy land extent was subjected to burning in Kurunegala District in *Yala* as the highest fraction of burnt area out of all the study districts.

Table 4 indicates the district-wise most popular rice variety along with the percentage of farmers cultivating the same rice variety. Bg rice varieties which are bred at Central Rice Breeding Centre, Batalagoda, Sri Lanka, were very popular in both cultivation seasons in three districts: Anuradhapura, Kurunegala, Gampaha. Further, estimated amount of paddy residue burnt on paddy fields in the 2015/2016 cultivation year in each district has been shown in Table 3. As indicated in Table 5, the highest emission from paddy residue burning was CO, followed by CH_4 in all the districts for both cultivation seasons.

Country-specific data on in-situ open burning of paddy residue were investigated under the present study considering five administrative divisions (i.e. districts) representing major climatic zones of in Sri Lanka. This study fills the data gap of country-specific information for calculating emissions due to in-situ open burning of paddy residue, which are required in the Tier 2 and Tier 3 approaches of IPCC guidelines for GHG inventorying.

Paddy residue burning in the recent past has been reported by Nanayakkara et al. (2018) and it was further confirmed through the findings of the present research. Ariyawansha et al. (2014) mentioned that 50% of paddy residue is burnt in Sri Lanka per year. In the present study, the total percentage of paddy residue bunt was 5.46% even if the selected study districts have paddy cultivation abundantly. Therefore, it can be an indicator of lowered country-wise percentage of paddy residue burnt per year. The study also allowed policymakers and researchers to determine the fractions of burning of paddy residue in the different climatic zones, considering the representative major districts of cultivation. On average the fraction of the paddy residue burnt within the wet zone was 5.26%, and that of dry zone was 7.69%. The fraction burnt in the intermediate zone was 1.42%.

Regardless of the amount of paddy residue produced in different cultivation seasons in Sri Lanka, the same fraction of paddy residue was burnt by farmers who practised it as a residue disposal method in both *Yala* and *Maha* seasons. Not all the farmers in the study samples were equally engaged in paddy cultivation in both cultivation seasons. According to the analysis of survey data, farmers cultivated paddy in *Maha* season more frequently, compared to the *Yala* season in Anuradhapura (dry zone) and Kurunegala (intermediate zone) districts (70.27% and 56.86% of farmers cultivated

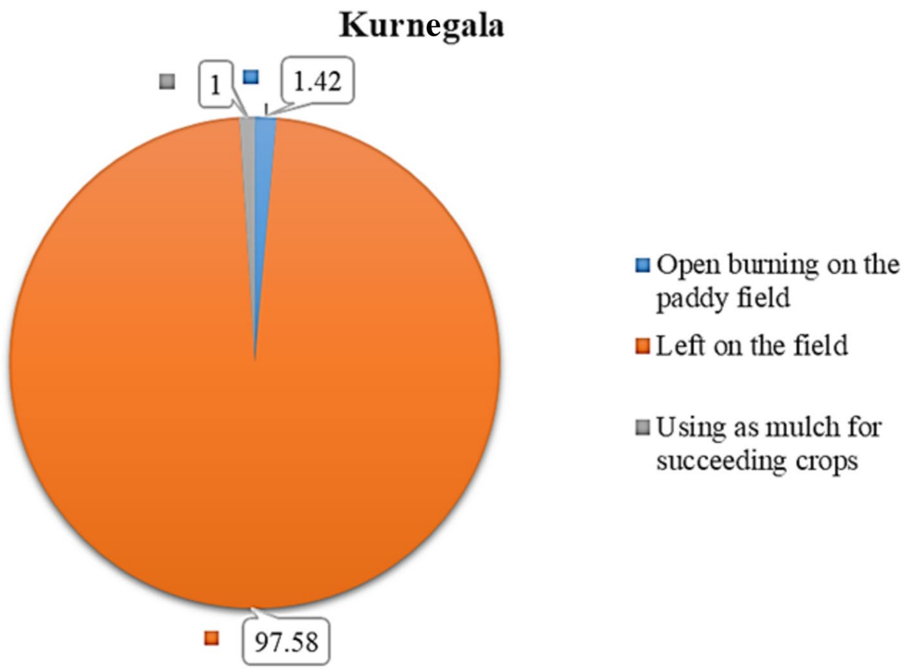

Fig. 3 Percentage of the amount of paddy residue disposed under different methods in Kurunagala District

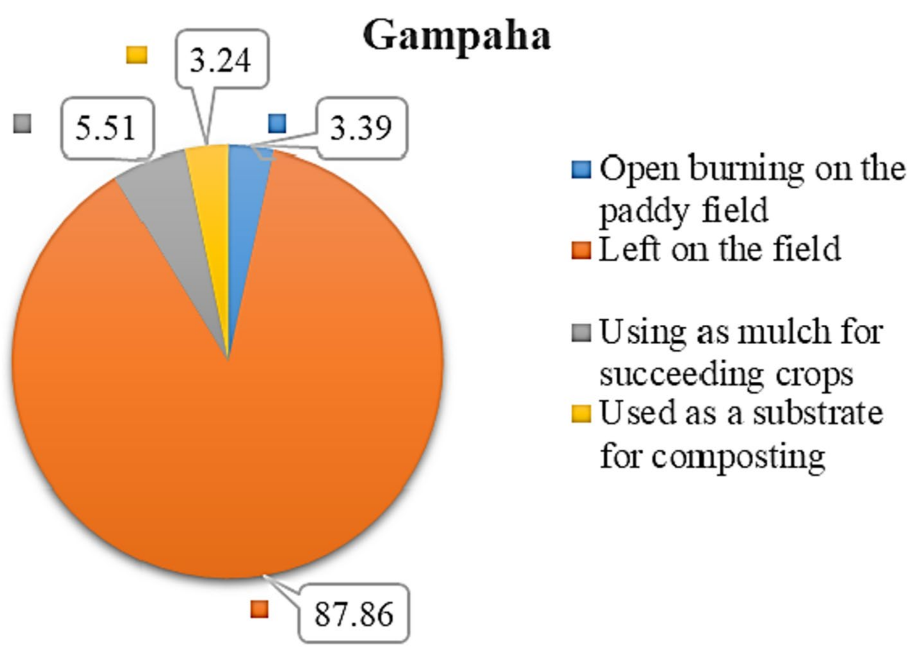

Fig. 4 Percentage of the amount of paddy residue disposed under different methods in Gampaha District

paddy in 2015/2016 cultivation year, respectively). Therefore, higher amounts of paddy residue production could be expected during *Maha* season in both districts which could increase the amount of residue burnt as well. In the wet zone, paddy fields are generally abandoned during the *Yala* season due to crop losses caused by high rains. This explains the lowered paddy residue burning during *Yala* season in Gampaha District.

As found in the third national communication of Sri Lanka the highest amount of emissions due to paddy residue burning was CO followed by CH_4 which similar to the results obtained in the present study. The government's advertising efforts and outreach/extension activities on using paddy straw as mulch in paddy soils might have encouraged the reduction in the practice of burning and therefore reduced emissions due to the open burning of paddy residue can be expected.

There may be uncertainty connected with any human inaccuracies because the fractions of paddy residue burned were estimated values based on data provided by the farmers. Moreover, due to the cost considerations and exploratory

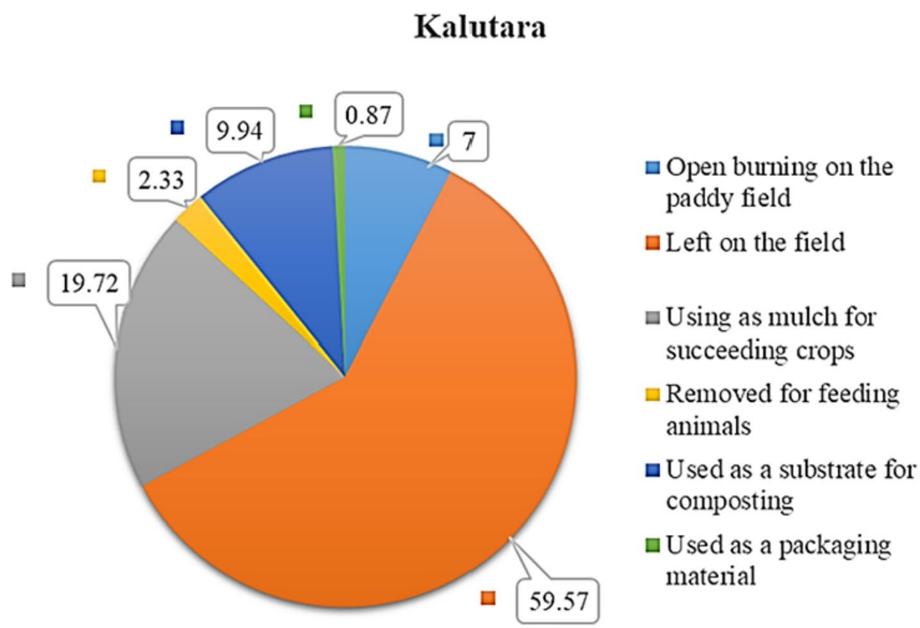

Fig. 5 Percentage of the amount of paddy residue disposed under different methods in Kalutara District

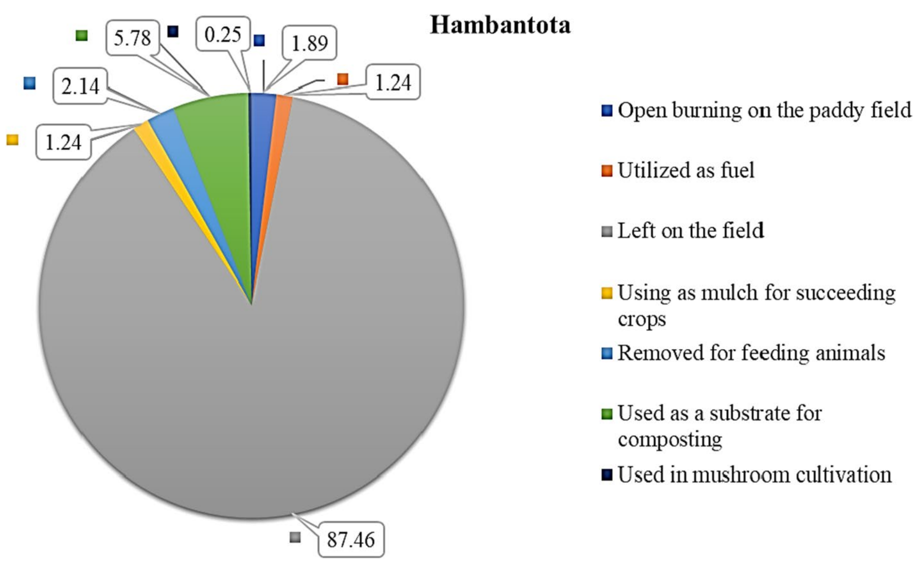

Fig. 6 Percentage of the amount of paddy residue disposed under different methods in Hambantota District. Note: as we were informed, Paddy straw was used as a fuel for brick manufacturing

nature of the study, researchers had to select the non-probability sampling technique in the research methodology. However, the estimated values in the present study provide reasonable, representative and disaggregated district-wise fractions of paddy residue burnt within the different climatic zones of Sri Lanka, which can be considered in the future national GHG inventories. Annexed data will also be needed for GHG inventory preparation purposes and for researchers who carry out their investigations in crop residue management.

Conclusion

Burning paddy residue generates emissions, as well as issues with pollution, health risks and loss of nutrients. The present study estimated the emissions of non-CO_2 GHGs and precursors of GHGs from in-situ open burning of paddy residue which is still happening in Sri Lanka during the major cultivation seasons, *Yala* and *Maha*. The major findings of the study could be utilized in the emission calculations from in-situ open burning of paddy residue in future national GHG inventories targeting better accuracy. Knowing the extent and frequency of burning helps in future awareness programs for farmers, as such practices need to be discouraged considering the climatic and environmental concerns. Annexed information can be used to introduce alternative paddy residue ex-situ and in-situ disposal methods and awareness creation on crop residue management among farmers. Overall, the present study provides significant country-specific information/findings in relation to the fate of paddy residue in Sri Lanka.

Appendix

The percentage of the amount of paddy residue disposed under various paddy residue disposal methods in each study district during the 2015/2016 cultivation year.

See Figs. 2, 3, 4, 5 and 6

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Ariyawansha T, Senevirathne S, Basnayake B (2014) Paving the way for the future we want potential of converting paddy straw to biochar and electricity in Sri Lanka paving the way for the future we want

De SCS, Weatherhead EK, Knox JW, Rodriguez-diaz JA (2007) Predicting the impacts of climate change—a case study of paddy irrigation water requirements in Sri Lanka. Agric Water Manag 93:19–29. https://doi.org/10.1016/j.agwat.2007.06.003

Department of Agriculture. (2022). Rice-the staple food-general information. [Online] Available at: https://doa.gov.lk/rrdi_rice_introduction-2/ [Accessed 7 Mar. 2023]

Department of Census and Statistics. (2023). Agriculture. [Online] Available at: http://www.statistics.gov.lk/Agriculture/StaticalInformation/new [Accessed Mar. 1AD]

El-Sobky EEA (2017) Effect of burned rice straw, phosphorus and nitrogen fertilization on wheat (*Triticum aestivum* L.). Ann Agric Sci 62:113–120. https://doi.org/10.1016/j.aoas.2017.05.007

Gambhir A, Napp T, Hawkes A et al (2017) The contribution of non-CO_2 greenhouse gas mitigation to achieving long-term temperature goals. Energies (basel). https://doi.org/10.3390/en10050602

Harun SN, Hanafiah MM, Noor NM (2022) Rice straw utilisation for bioenergy production: a brief overview. Energies 15(15):5542

IPCC (2014a) Summary for policymakers

IPCC (2006) Volume 1 chapter 4: methodological choice and identification of key categories. pp 1–30

IPCC (2014b) Climate change 2014: impacts, adaptation, and vulnerability. Summaries, frequently asked questions, and cross-chapter boxes

Johnson JMF, Franzluebbers AJ, Weyers SL, Reicosky DC (2007) Agricultural opportunities to mitigate greenhouse gas emissions. Environ Pollut 150(1):107–124. https://doi.org/10.1016/j.envpol.2007.06.030

Kanokkanjana K, Garivait S (2013) Alternative rice straw management practices to reduce field open burning in Thailand. Int J Environ Sci Develop 4(2):119. https://doi.org/10.7763/IJESD.2013.V4.318

Kaur K, Kaur P, Sharma S (2019) Management of crop residue through various techniques. J Pharmacogn Phytochem 8(1S):618–620

Lin M, Begho T (2022) Crop residue burning in South Asia: a review of the scale, effect, and solutions with a focus on reducing reactive nitrogen losses. J Environ Manage 314:115104. https://doi.org/10.1016/J.JENVMAN.2022.115104

Lohan SK, Jat HS, Yadav AK et al (2018) Burning issues of paddy residue management in north-west states of India. Renew Sustain Energy Rev 81:693–706. https://doi.org/10.1016/j.rser.2017.08.057

Lu X, Zhang L, Shen L (2019) Meteorology and climate influences on tropospheric ozone: a review of natural sources, chemistry, and transport patterns. Curr Pollut Rep 5:238–260

Nanayakkara M, Pabasara W, Samarasekara A et al (2018) Extraction and characterisation of cellulose materials from Sri Lankan agricultural waste. p 47

Nisansala WDS, Abeysingha NS, Islam A, Bandara AMKR (2020) Recent rainfall trend over Sri Lanka (1987–2017). Int J Climatol 40:3417–3435. https://doi.org/10.1002/joc.6405

Rajendram K (2021) Rainfall variability and drought in the dry and wet zones of Sri Lanka. World Sci News 160:172–189

Roy P, Kaur M (2016) Economic analysis of selected paddy straw management techniques in Punjab and West Bengal. Indian J Econ Dev 12:467. https://doi.org/10.5958/2322-0430.2016.00107.4

Santos FD, Ferreira PL, Pedersen JST (2022) The climate change challenge: a review of the barriers and solutions to deliver a Paris solution. Climate 10(5):75

Senanayake SMP, Premaratne SP (2016) An analysis of the paddy/rice value chains in Sri Lanka. Asia Pac J Rural Develop 26:105–126. https://doi.org/10.1177/1018529120160104

Sfez S, De Meester S, Dewulf J (2017) Co-digestion of rice straw and cow dung to supply cooking fuel and fertilizers in rural India: Impact on human health, resource flows and climate change. Sci Total Environ 609:1600–1615. https://doi.org/10.1016/J.SCITOTENV.2017.07.150

Shafie SM (2015) Paddy residue based power generation in Malaysia: environmental assessment using LCA approach. ARPN J Eng Appl Sci 10:6643–6648

Sonnadara DUJ (2015) The onset, retreat and the length of growing season in the north-eastern region of Sri Lanka. Int J Climatol 35:3633–3639. https://doi.org/10.1002/joc.4237

Venkatramanan V, Shah S, Rai AK, Prasad R (2021) Nexus between crop residue burning, bioeconomy and sustainable development goals over North-Western India. Front Energy Res 8:1–14. https://doi.org/10.3389/fenrg.2020.614212

York N, Garden B (2016) The problem of rice straw waste: a possible feed through fermentation Author (s): YW Han, AW Anderson, Published by: Springer on behalf of New York botanical garden press stable URL : http://www.jstor.org/stable/4253523 The Problem of Rice. 28: 338–344

Zubair L (2002) El Niño-Southern oscillation influences on rice production in Sri Lanka. Int J Climatol 22:249–260. https://doi.org/10.1002/joc.714