The Agriculture Greenhouse Gas Inventory and Mitigation Action in North Sulawesi, Indonesia

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Manuscript received May 24, 2024; revised June 19, 2024; accepted August 7, 2024; published December 17, 2024

***Abstract*—This study aimed to predict agricultural greenhouse gas (GHG) emissions, map the distribution, and formulate effective mitigation strategies in North Sulawesi, Indonesia. The primary and secondary data were obtained from farmer groups and the official office. These data were collected through interviews and surveys using questionnaires and processed with Tier-1 methods to obtain GHG emissions. Subsequently, ArcMap was used for mapping, and focus group discussion (FGD) was conducted to formulate mitigation strategies. The results showed that agricultural GHG emissions, estimated for 2022, amounted to 1,697.88 Gigagram CO_2-eq per year (Gg CO_2-eq/y). Compared to 2021, there was an increase in emissions by 2.81 % due to the rise in direct nitrous oxide (N_2O) emissions from soil processing and fertilizer. Several adaptation efforts to climate change were formulated to address this challenge, including regulating or adjusting rice planting patterns and periodically reducing the use of inorganic fertilizers. Mitigation strategies were also formulated to maximize the implementation of organic farming, intermittent irrigation systems on paddy fields, and the use of several low-GHG-emission rice varieties.**

***Keywords*—adaptation, atmospheric gas, climate change, GHG emissions, global warming**

I. Introduction

Climate change is among the pressing issues of the current century, significantly affecting ecological systems, public health, and the global macroeconomic landscapes. The concept focuses on long-term changes in temperature and meteorological patterns that have extensive implications for various aspects of human existence and the ecosystem [1]. Climate change refers to fluctuations in climate conditions in a location or their statistically observable variability over a long period, particularly decades or more [2]. The phenomenon has caused a significant change in weather patterns, as shown by occurrences during the rainy season with humidity levels, leading to soil drought and water crises in various places [3]. Additionally, there is an increase in the level of destruction caused by natural disasters such as floods, droughts, and intense storms [4]. This change is attributed to the effect of greenhouse gas (GHG), which can absorb and stop solar heat from escaping into space.

GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) trap solar energy entering the Earth's atmosphere. These gases are essential for controlling global temperatures and keeping the environment warm to support life [5]. However, the concentration has increased over time, leading to global warming and significant climate change due to various human activities [6]. In this context, a portion of the heat reflected from the surface is trapped in atmosphere, causing the Earth's temperature to increase. The increase in GHG concentrations is the primary cause of global warming, which leads to a significant rise in atmospheric concentrations. The phenomenon is the underlying cause behind the Earth's sustained warm temperatures [7].

Increased temperature can lead to changes in weather patterns, extreme weather events, and severe ecological impacts. Scientists have offered a variety of factual data indicating a rise in GHG concentrations in the atmosphere and the existence of serious risks related to climate change [8]. Recent discoveries also show that global warming will result in changes to wind waves and storm patterns, causing a significant effect on cyclone activity. According to the data from Antarctic ice cores, the atmospheric concentration of CO_2 was approximately 280 parts per million (ppm) more than 10,000 years before the Industrial Revolution and quickly rose to 400 ppm by 2013 [9]. Therefore, climate change and global warming are closely connected with human activity.

Human activities have produced a considerable amount of GHG to meet basic needs. However, there is a continuous increase in CO_2, CH_4, and N_2O concentrations, contributing 14% of global emissions [10]. The increase in CO_2 is due to human activities such as microbial decomposition processes, waste, burning crop residues, organic soil matter, and uncontrolled land conversion. Approximately 10% of CO_2 in the atmosphere passes through terrestrial soil annually due to large deposits of organic carbon [11]. This production is limited to anaerobic conditions caused by several factors, including carbon (C) content, temperature, and rainfall density [12]. Furthermore, from 270 ppb (parts per billion) in the pre-industrial era to 319 ppb in 2005, a significant increase has been observed in the concentration of N_2O in the atmosphere [13].

The effect of global warming is experienced in Indonesia, a rural country with vast agricultural land and diverse natural resources. This is because many individuals depend on agriculture for livelihoods, which affects community welfare and generates significant GHG emissions. The Indonesia agricultural sector's share of the 2020 GHG emissions came from enteric fermentation of animal digestion processes [14,

doi: 10.18178/ijesd.2024.15.6.1503

15], fertilizer use [5, 16], rice farming [17], land use [18], and animal waste management [19], accounting for 9% or 98,703 Gg CO_2-eq of the total [20].

Various countries have agreed to mitigate the causes of global warming through the Kyoto Protocol and meetings under CoP/MoP (Conference of the Parties acting as the Meeting of the Parties) [21]. Indonesia has also committed to reducing GHG emissions by 26% independently or 41% with foreign assistance. This has been reinforced through Presidential Regulation No. 61/2011 on the National Action Plan for GHG Emission Reduction. Based on these commitments, the target for reducing emissions from the sector is 8 million t CO_2-eq (26%) or 41 million t CO_2-eq. Due to presidential regulations, there has been an increased need for more in-depth studies and assessments of GHG emissions and mitigation strategies.

Although numerous studies have been conducted, there are limitations in reporting regional sectoral GHG emissions, specifically regarding causative factors. In North Sulawesi Province, Indonesia, there is limited information from studies related to GHG inventory and mitigation in the agricultural sector [15]. Meanwhile, the existence of Presidential Regulation No. 61/2011 has required every province to provide a Regional Action Plan Document for GHG Reduction in each region. North Sulawesi province is no exception. This shows the need for urgent reports as input for regional governments to prepare the document. A study on GHG inventory is crucial to filling the knowledge gap and serves as the basis for decision-making in formulating Regional Action Plans to reduce GHG emissions. Therefore, this study aimed to estimate GHG emissions from agricultural land, map the distribution based on location source and then develop adaptation and mitigation strategies to reduce the impact of climate change in North Sulawesi Province.

II. Materials and Methods

A. Study Design

This study used a mixed-method design, incorporating both analytical and descriptive analysis. The distribution of GHG emissions was mapped using a spatial analysis method based on the Geographical Information System (GIS). This combined analytical and spatial method provides more comprehensive insights into emissions mitigation strategies in the agricultural sector.

Respondents included in this study consisted of farmer groups engaged in agricultural activities across 15 regencies and cities in North Sulawesi. Primary data collection was carried out using interview methods and questionnaire instruments. Respondents were considered members of farmer groups based on criteria such as the size of the managed land. 3–5 respondents were interviewed as coordinators of farmer groups by asking about types of agricultural land (wetland/dryland), fertilizers, and planting and harvesting frequencies. The questionnaire determined the farmers' perceptions, including their responses and reactions to the adaptation and mitigation strategies. The action trial was conducted on a demplot (demonstration plot) of rice plants (60×60 m) by 15 respondents in different locations who were willing to carry out the trial. The types of mitigation and adaptation action treatments included adjusting the time and planting patterns applicable in North Sulawesi, replacing urea fertilizer with organic fertilizer, and using low-emission rice varieties (Mekkonga). From start to harvest, planting rice takes 135 days. Subsequently, respondents filled out the Likert scale questionnaire regarding their experiences during GHG mitigation and adaptation action trials.

Secondary data comprised agricultural activities, such as data on harvested land and fertilization obtained from the Agency of Indonesia Statistics and Agriculture Office. Meanwhile, emission factor data were obtained from the Intergovernmental Panel on Climate Change (IPCC) 2006 documents and the Ministry of Environment and Forest of Indonesia (MEFRI).

The Tier-1 method from IPCC was used to estimate agricultural GHG emissions and continued mapping GHG distribution based on the location of each district/city in North Sulawesi using a GIS application. Meanwhile, GHG mitigation/adaptation action strategies were formulated using community participation methods through focus group discussion and field experiments. The technique is used through active engagement of farmers in action trial activities to select and determine suitable GHG mitigation strategies. This method was considered to have more potential to succeed compared to providing existing standard programs that were not suitable and appropriate. The novelty of this study is the active engagement of farmers as a new way of formulating mitigation strategies, which has not been used in previous reports [11, 14, 16, 22–27].

B. Data Analysis Method

Data processing to obtain estimates of GHG emissions was carried out using the Tier method from IPCC 2006 and 2019 Refinement to 2006 [28]. Subsequently, emissions were mapped by determining the distribution through spatial analysis. This analysis included determining the scale, attribute accuracy, data timeliness, and structure to evaluate the extent of distribution. ArcMap was selected as the GIS-based application capable of processing, selecting, and showing location data, complete with attribute projections and coordinates. Therefore, a map showing the distribution of GHG emissions for the agricultural sector over the whole study region was produced. The participation of respondents through Focus Group Discussion (FGD) and interviews generated qualitative data for formulating adaptation and mitigation strategies.

Default global or regional emission and uptake parameters were used for the Tier-1 method calculation of GHG emissions. The basic equation included multiplying human activity information over a specific period (activity data, AD). The emission factors (EF) per unit activity are GHG Emissions = AD×EF, where AD represents activity data, information regarding implementing an activity releasing or absorbing gas influenced by human activities. The estimation of GHG emissions for each agricultural sector is obtained using Eqs. (1–4) with input data, such as harvested area, land type, and amount of fertilizer used. The emission units adopted are Gigagram CO_2-eq per year (Gg CO_2-eq/y) after conversion to CO_2-equivalents using the global warming potential (GWP) values in CO_2-eq units, which are CO_2=1; CH_4= 25 and N_2O= 298 [28]. N_2O has the highest global warming potential value, 298 times CO_2. Meanwhile, the emission factor (EF) shows emissions released or absorbed from a specific activity.

Based on the basic equation, derivative equations can be obtained based on activities in the agricultural sector, as follows:

1. CH_4 emissions resulting from rice field management can be estimated using Eq. 1 below [29]

$$CH_{4\,Rice} = \sum Ef.T.A.10^{-6} \tag{1}$$

where: $CH_{4\ Rice}$ = methane gas emitted from cultivated rice fields (gg/y); Ef = methane gas emission factor = 1.61; A = Ricefields area (hectare); T = planting period = 2 periods/y = 270 d/y. A sample of the calculation using Eq. 1.

2. CO_2 emissions resulting from the use of fertilizer on cropland can be estimated using Eq. 2 [30]

$$CO_{2\,Rice} = M_{Fertilizer}.EF_{Fertilizer} \tag{2}$$

where: $CO_{2\ Rice}$ = carbon dioxide emitted from rice fields that use fertilizer (t/y); $EF_{fertilizer}$ = fertilizer emission factor = 0.20; $M_{fertilizer}$ = fertilizer used quantity (t/y).

3. Direct N_2O emissions resulting from the use of fertilizer on soil can be estimated using Eq. 1 [3] below [30]

$$N_2O_{Dir} - N = \left[\left(F_{SN} + F_{on}\right).Ef_1\right] + \left[\left(F_{SN} + F_{on}\right).Ef_{1FR}\right] \tag{3}$$

where N_2O_{Dir} = Nitrous oxide gas is emitted directly due to soil processing (kg/y); F_{SN} = N fertilizer used quantity (kg/y). F_{on} = compost used quantity (kg/y); Ef_1 = Nitrous oxide emission factor from non-irrigated ricefields = 0.010; Ef_{1FR} = Nitrous oxide emission factor from irrigated ricefields = 0.003.

4. Indirect N_2O emissions from fertilizer use in soil management can be estimated using Eq. 4 below [30]

$$N_2O- = \left[\left(F_{SN} + Frac_{Gasf}\right) + \left(\left(F_{ON}Id + F_{PRP}\right)Frac_{Gasm}\right)\right]EF_4 \tag{4}$$

where: N_2O- = Nitrous oxide gas is emitted indirectly due to soil processing (kg/y); F_{SN} = N fertilizer used quantity (kg/y); F_{ON} = compost used quantity (kg/y); F_{PRP} = urine/faces (N) quantity produced by animals grazing on pastures (kg/y). $Frac_{Gasf}$ = synthetic N fertilizer fraction (kg N steam/kg N used) = 0,011; $Frac_{Gasm}$ = organic fertilizer fraction N (F_{ON}) and livestock manure deposited by livestock (F_{PRP}) (kg N steam/kg N deposited); EF_4 = N_2O emission factor from N deposits on water surface and soil = 0.01.

An example of GHG emissions calculation is presented in Table 1.

C. Study Location

This study was conducted in North Sulawesi Province, Indonesia, located at the northern tip of the Island, bordering the Philippines to the north (Fig. 1). The capital is Manado. The total population in the province is 2.575.933 individuals, with an area of 15.069 km^2, and the administrative division consists of 11 regencies and four cities. North Sulawesi has significant potential in agriculture and livestock farming. Most agricultural activities are dominated by food crops such as rice, corn, cassava, and coconut. Rice is the primary commodity in food crop production, using local rice varieties. The harvested rice area covers 58 thousand hectares, with production reaching 243 thousand tons in 2022. Furthermore, there is potential in plantation crops and horticulture, with coconut production reaching 266 thousand tons and bird-eye chili 175 thousand tons. The economy was predominantly driven by the agricultural sector, contributing US$ 2.2 billion or 20.9% of the total GDRP [31].

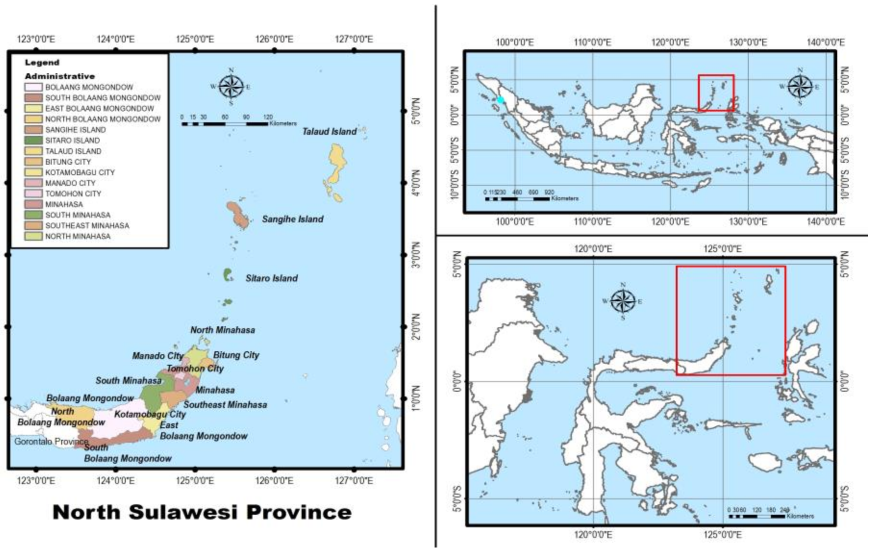

Fig. 1. North Sulawesi (Study area Map).

III. Result and Discussion

A. Plant Land Area and Fertilizer Usage

Land data were processed based on standard records from the Agriculture Office and North Sulawesi Statistics Agency, as shown in Table 2. During the estimation period of 2010-2022, agricultural land area decreased by an average of 2.16%/y, as shown in Table 2. The largest decrease occurred in wetland rice fields by 6.79%/y, which was contributed by a significant reduction of 22.19%/y from 2016 to 2019. This reduction was mainly due to the conversion of agricultural land into residential and office facilities as a direct result of the administrative expansion.

Table 1. Calculation sample of CH_4 from paddyland

Regencies/Cities	Emission Factor (Ef)	Planting Period (T)	Paddyland Area (A)	CO_2-eq	CH4 emission $= \sum Ef.T.A.10^{-6}$ (Gg CO_2-eq)
Bolaang Mongondow	1.61	270	32,863.26	23	328.5702
Minahasa	1.61	270	7,172.55	23	7119
South Minahasa	1.61	270	3,023.51	23	30.2294
North Minahasa	1.61	270	1,363.33	23	13.6307
North Bolaang Mongondow	1.61	270	5,173.42	23	51.7244
Southeast Minahasa	1.61	270	1,625.15	23	16.2484
South Bolaang Mongondow	1.61	270	1,980.94	23	19.8056
East Bolaang Mongondow	1.61	270	763.74	23	7.6359
Bitung City	1.61	270	59.20	23	0.5919
Tomohon City	1.61	270	561.07	23	5.6096
Kotamobagu City	1.61	270	3,743.80	23	37.4309
North Sulawesi					**583.1889**

Table 2. Land Area (hectare) in North Sulawesi

Year	Wetland	Dry Land	Horticulture	Farm	Total
2010	119,771.00	327,195.00	75,091.00	439,243.34	961,300.34
2011	122,108.00	330,460.00	72,686.00	440,112.70	965,366.70
2012	126,931.00	324,917.00	71,323.00	443,297.80	966,468.80
2013	127,413.00	316,489.00	74,071.20	444,261.77	962,234.97
2014	130,428.00	222,280.00	78,652.00	408,849.52	840,209.52
2015	137,438.00	346,154.00	82,823.00	408,263.56	974,678.56
2016	112,097.34	361,355.00	81,446.00	402,213.93	957,112.27
2017	98,726.87	365,904.00	78,321.00	387,298.69	930,250.56
2018	82,051.00	361,170.00	79,640.00	392,067.18	914,928.18
2019	62,020.39	386,538.40	78,282.00	383,138.44	909,979.23
2020	61,827.86	342,917.40	65,032.00	404,184.00	873,961.26
2021	59,514.72	333,279.00	62,962.00	400,725.00	856,480.72
2022	58,329.97	285,246.10	59,497.80	404,341.69	807,415.56

Fertilizer consumption for agricultural activities totals an average of 776,652.64 tons/y. These consisted of urea, NPK (Nitrogen, Phosphate, and Potassium), and manure fertilizers at 100,760.62 tons/y (12.97%), 149,536.08 tons/y (19.25%), and 525,851.15 tons/y (67.71%), respectively, as shown in Table 3.

Table 3. Fertilizer consumption in North Sulawesi

Year	Fertilized land area (ha)	Urea (tons)	NPK (tons)	Manure (tons)
2010	522,057	104,411.40	156,617.10	522,057.00
2011	525,254	105,050.80	157,576.20	525,254.00
2012	523,171	104,634.20	156,951.30	523,171.00
2013	517,973	103,594.64	155,391.96	517,973.20
2014	431,360	86,272.00	129,408.00	431,360.00
2015	566,415	113,283.00	169,924.50	566,415.00
2016	554,898	110,979.67	166,469.50	554,898.34
2017	542,952	108,590.37	162,885.56	542,951.87
2018	522,861	104,572.20	156,858.30	522,861.00
2019	526,841	105,368.16	158,052.24	526,840.79
2020	469,777	93,955.45	140,933.18	469,777.26
2021	455,756	91,151.14	136,726.72	455,755.72
2022	403,074	78,025.04	96,174.43	676,749.75

The distribution percentage showed farmers preferred manure or compost over other inorganic fertilizers. Manure comes from organic waste, such as animal or plant residues, including naturally decomposing microbes.

B. Estimated Agricultural GHG Emissions

The total estimated GHG emissions for the agricultural sector in 2022 amounted to 1,697.88 Gg CO_2-eq/y (Fig. 2). This was based on the data from Tables 2 and 3 as input for Eqs. (1–4).

Table 4. Agricultural GHG emission (Gg CO_2-eq/y)

Year	CH_4 Paddyland	CO_2 Fertilizer	N_2O Direct	N_2O Indirect	Total
2010	1,349.35	76.57	676.16	228.99	2,331.06
2011	1,379.88	77.04	680.33	230.40	2,367.65
2012	1,447.61	76.73	677.75	229.51	2,431.60
2013	1,442.26	75.97	670.94	227.23	2,416.40
2014	1,481.32	63.27	558.95	189.31	2,292.85
2015	1,557.38	83.07	733.71	248.56	2,622.73
2016	1,312.24	81.39	718.88	243.51	2,356.01
2017	1,181.90	79.63	703.44	238.28	2,203.25
2018	998.82	76.69	677.31	229.46	1,982.28
2019	822.43	77.27	682.65	231.22	1,813.57
2020	807.99	68.90	608.77	206.22	1,691.88
2021	792.59	66.84	590.66	200.10	1,650.19
2022	775.32	57.22	691.86	173.48	1,697.88
Total	15,349.08	960.58	8,671.41	2,876.29	27,857.36

The contribution by emissions per gas type included CH_4, Direct N_2O, Indirect N_2O, and CO_2 emissions of 775.32 Gg CO_2-eq/y (45.66%), 691.86 Gg CO_2-eq/y (40.75%), 173.48 Gg CO_2-eq/y (10.22%), and 57.22 Gg/y (3.37%), respectively, as shown in Table 4. Compared to 2021, the total emissions increased by 2.81% due to high direct N_2O from soil processing and fertilizer. Fig. 2 shows a downward trend from 2016 to 2022 due to decreased harvested land area, specifically in food crop fields. The downward trend was mainly caused by conversion or changes in agricultural land's function to residential and office areas.

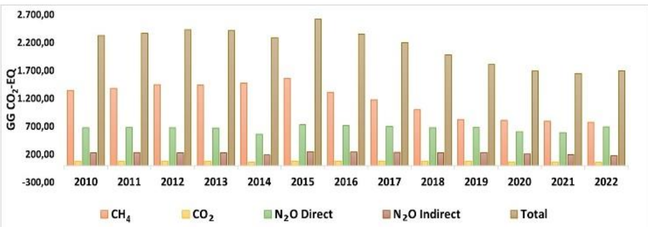

Fig. 2. Agricultural GHG Inventory (2010-2022).

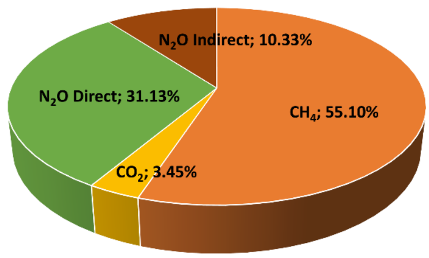

Fig. 3. Main gas sources of GHG emissions in North Sulawesi.

The cumulative GHG emissions during the estimation period of 2010-2022 amounted to 27,857.36 Gg CO_2-eq. The primary sources were 15,349.08 Gg CO_2-eq, 8,671.41 Gg CO_2-eq, 2,876.29 Gg CO_2-eq, and 960.58 Gg for CH_4 Paddyland, Direct N_2O, Indirect N_2O and CO_2 emissions, respectively. The contribution of each gas is shown in Fig. 3.

CH_4 is mainly generated from anaerobic fermentation processes in soil, where organic fertilizers or decomposed matter can provide methanogen substrates. Under anaerobic conditions, these bacteria produce CH_4 by-products of organic matter decomposition. In wetland rice fields, excessive N fertilizer application can increase CH_4 production. N fertilizer stimulates rice plant growth, and the decomposing plant residues in rice mud create ideal conditions for CH_4 production. Furthermore, nitrate and ammonium fertilizers provide excess N to soil. This is because nitrification and denitrification processes lead to N_2O as a byproduct [32]. A greater chance of increased N_2O emissions can occur when more N fertilizer is administered. However, the correct dosage can reduce the risk of excessive N_2O emissions.

GHG emissions burden is estimated based on types, resulting in a map depicting the distribution for each district, as shown in Fig. 4. Red shows the highest spread, orange and yellow represent moderate, while green denotes low. The highest emissions are found in Bolaang Mongondow Regency, amounting to 583.33 Gg CO_2-eq/y (38.78%), followed by South Minahasa, Minahasa, and North Bolaang Mongondow Regencies with 201.47 Gg CO_2-eq/y (13.39%), 170.38 Gg CO_2-eq/y (11.33%), and 101.65 Gg CO_2-eq/y (13.39%), respectively.

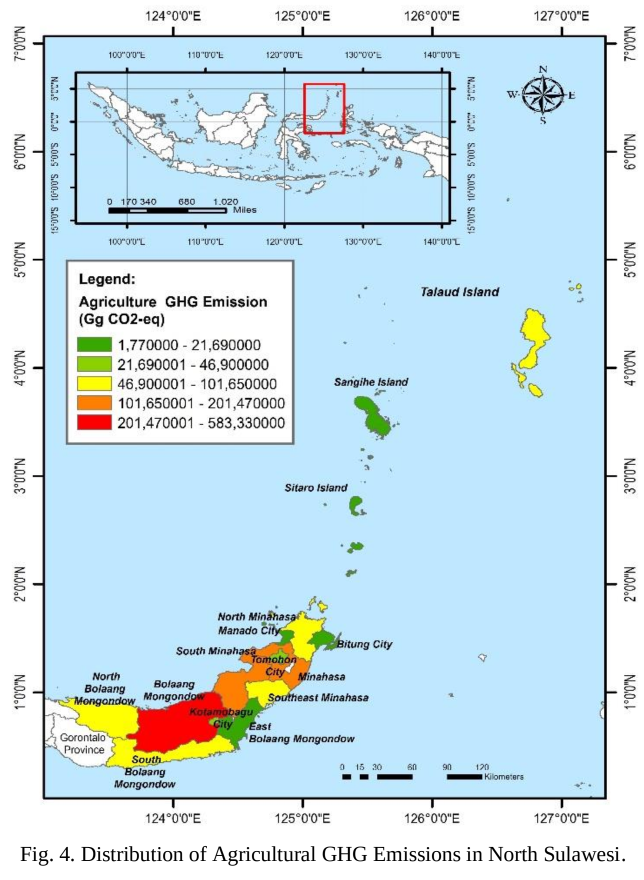

Fig. 4. Distribution of Agricultural GHG Emissions in North Sulawesi.

These emissions are generated from agricultural activities since the three regencies are the main rice production centers and the largest producers of horticultural crops such as tomatoes, onions, and chili peppers (Minahasa Regency). Therefore, farmers in these regencies use considerable fertilizer, as shown in Table 2.

Applying fertilizers on agricultural land releases CO_2 produced during production, contributing to increased GHG effects. Meanwhile, the levels of CH_4 and CO_2 emissions are positively and significantly correlated with fertilization and water availability [22]. Applying N fertilizer increases soil microbial activity, accelerating organic matter breakdown, thereby releasing CH_4 and CO_2. When the urease enzyme and water are present, urea ($CO(NH_2)_2$) changes into ammonium NH^+, OH^-, and HCO^- [33]. Results from interviews with farmers showed that the timing and dosage of fertilizers exceeded recommended levels. Furthermore, farmers applied fertilizers in excessive amounts to increase harvest [34]. The results showed that because urea was applied heavily and frequently, land-managed N_2O emissions reached 8,671.41 Gg CO_2-eq/y or contributed 31.13% to overall agricultural emissions. CH_4 emissions amounted to 15,349.08 Gg CO_2-eq/y or 55.10% of total farm emissions. The minimal incorporation of crop residue into soil led to lower emissions. The dry and horticultural land used for rainfed rice cultivation and upland variety experiencing drought periods during planting led to higher CH_4 emissions. Intermittent water availability limited the anaerobic conditions required for CH_4 production, while the use of low CH_4 rice varieties also reduced the level of emissions. Therefore, the development of several varieties successfully reduced emissions from rice plants. These varieties were continuously developed, although their availability varied over time, as Inpari 13 and Mekongga varieties emitted low levels of CH_4 gas.

C. Adaptation and Mitigation Potential

The adaptation and mitigation strategies are derived from analysis, discussions, and interviews with farmers representing existing groups. This study included farmers in formulating mitigation strategies. The possibility of implementing some adaptation and mitigation strategies was discussed and offered to farmers for application. However, not all measures were feasible to execute. This was due to incompatibility with regional conditions, lack of evidence that certain practices are advantageous, and lack of technological know-how. Moreover, adaptation efforts are adjustments to the time and planting patterns in North Sulawesi. Planting types and methods are selected by paying attention to weather conditions during the growing season. When planting is carried out considering weather and land conditions, there is a tendency to obtain quality results with lower GHG emission levels. Implementing organic farming is another method to mitigate GHG emissions, as it limits the use of synthetic fertilizers, pesticides, herbicides, and fungicides. This can also potentially lower the flow of hazardous chemicals and nitrates released into the atmosphere. Additionally, using soil-improvement materials such as biochar and selecting rice varieties have the potential to minimize CH_4 emissions, such as the Mekkonga variety. The Mekkonga rice varieties are a collection of rice cultivars renowned for producing little GHG emissions while in cultivation. These varieties were developed through breeding and genetic improvement initiatives in the Mekong Delta region by crossbreeding and selection to deliver a high yield quickly. Previous studies showed that Mekkonga had 25%–35% fewer CH_4 emissions during the growing season. This is due to improved root structure, plant design, and modified soil microbial populations of the variety [35–37].

In this study, respondents provided approximately identical responses, with over 95% showing that GHG mitigation reduced rice production and farmers' income. Responses to Questions 3 through 7 reflected various strategies. Table 5 shows the average response to Questions 1, 2, and 7, indicating high acceptance of GHG adaptation and mitigation strategies.

Table 5. Farmer perceptions of implementing GHG adaptation/mitigation

Questionable variables	SD	D	N	A	SA
1. GHG mitigation reduces rice production	0	0	2.1	46.8	51.1
2. GHG mitigation reduces farmer income	0	0	0	46.9	53.1
3. Adjustment of planting time	0	0	0	46.9	53.1
4. Adjusting planting patterns	0	0	0	61.7	38.3
5. Reduce the use of pesticides	0	26.8	0	57.5	15.7
6. Use low-emission rice varieties	0	21.3	0	56.8	21.9
7. Replacing urea fertilizer with organic fertilizer	0	44.6	4.3	21.3	29.8

SD=Strongly Disagree, D=disagree, N=Neutral, A=Agree, SA=Strongly agree. Kruskal Wallis Test: Chi-Square 37.527, df: 6, Sign. 0,000

This is evidenced in Questions 1 and 2, despite the awareness of the potential decrease in income and production. The phenomenon is clarified in Question 7 regarding the replacement of urea with organic fertilizer. Based on the results, 44.6% of respondents disagreed, while 50% strongly agreed to replace urea with organic fertilizer despite the potential risk of crop failure.

The t-test statistic was used to examine the difference between rice production and farmers' income before and after the GHG mitigation program, as shown in Table 6. Based on the results, the variables rice production and farmer income showed a significant decrease (p-value < 0.01). The average rice production and farmers' income decreased by 28.2% and 39.2% from 9,421 to 6,764 kg and 14.21 million to 8.65 million IDR (Indonesia Rupiah).

Table 6. Statistical test of average rice production and farmer income

Variable	Means	Std. Error	Mean	P-value
Rice production (kg)			3.206	0.002
Before mitigation	9,421	11.405		
After mitigation	6,764	5.685		
Income (IDR)			3.242	0.002
Before mitigation	14,217,021.28	1,704,119.917		
After mitigation	8,645,454.55	1.252,681.720		

Respondents showed readiness but required more time to accept GHG mitigation as an effort to reduce emissions entirely. Some adaptation and mitigation strategies in the demplot did not cause instant improvements. For example, they applied organic fertilizers to replace urea, which required time for the soil to recover after being continuously inundated with urea fertilizer for a long time. In this context, rice production had decreased, leading to a reduction in income.

IV. Conclusion

In conclusion, this study showed the agricultural sector in North Sulawesi contributed to GHG emissions, primarily in the form of CH_4 and N_2O gasses. In 2022, this sector emitted 1,697.88 Gg CO_2-eq/y of GHG from the contributions of CH_4, Direct N_2O, Indirect N_2O, and CO_2 emissions of 775.32 Gg CO_2-eq/y (45.66%), 691.86 Gg CO_2-eq/y (40.75%), 173.48 Gg CO_2-eq/y (10.22%), and 57.22 Gg/year (3.37%), respectively. Compared to 2021, the total emissions increased by 2.81%, attributed to the rising direct N_2O emissions from soil management and fertilizer use.

The cumulative emissions during the estimation period of 2010-2022 amounted to 27,857.36 Gg CO_2-eq. CH_4, Direct N_2O, Indirect N_2O, and CO_2 emissions contributed 15,349.08 Gg CO_2-eq, 8,671.41 Gg CO_2-eq, 2,876.29 Gg CO_2-eq, and 960.58 Gg, respectively. In terms of GHG emission distribution, the highest was found in Bolaang Mongondow Regency at 583.33 Gg CO_2-eq/y (38.78%), followed by South Minahasa, Minahasa, and North Bolaang Mongondow Regencies at 201.47 Gg CO_2-eq/y (13.39%), 170.38 Gg CO_2-eq/y (11.33%), and 101.65 Gg CO_2-eq/y (13.39%), respectively. These emissions were from agricultural activities, as three regencies were major rice production centers and the largest producers of horticultural crops, such as tomatoes, onions, and chili peppers. Therefore, farmers used a considerable amount of fertilizers.

Based on the trial of several mitigation programs, 50% of farmers replaced urea with organic fertilizer despite the potential risk of crop failure. The trial results showed a significant decrease (p-value <0.01) in the variables. The average rice production and farmers' income decreased by 28.2% and 39.2%, from 9,421 to 6,764 kg and 14.21 million to 8.65 million IDR, respectively.

Lower rice harvests could negatively impact farmers' livelihoods and food availability. Increased reliance on imports also had adverse effects on the economy and environment. Similarly, the significant reduction in agricultural income could impact the economic welfare and quality of life. To address this challenge, agricultural GHG inventory should be estimated accurately to create practical mitigation strategies. Comprehending the fundamental factors, such as modifications of farm techniques, crop supervision, or ecological aspects, would be crucial for thoroughly examining the broader investigation. This study significantly impacted agricultural GHG inventory and the need to develop appropriate mitigation strategies.

Numerous initiatives were required to build collaboration at the national and international levels for the effective execution of all currently available adaptation and mitigation strategies. In this context, farmers have devised many solutions for adaptation and mitigation with local stakeholders and the government.

This study had several limitations based on emissions from rice fields and other food crops, including horticulture. The results did not discuss the economic feasibility of mitigation strategies. Therefore, further investigations should carried out to facilitate additional analyses, including collaboration with other agencies.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Daniel S. I. Sondakh: Conceptualization, Methodology, Formal analysis, Writing-original draft, Writing-review & editing. Franky R. Tulungen: Conceptualization, Formal analysis, Supervision. Stanss L. H. V. J. Lapian: Validation, Investigation, Supervision. Joni K. Kampilong: Formal analysis, Data curation. Fadly S. J. Rumondor: Resources, Project administration. Yolla S. Kawuwung: Data Curation, Visualization. All authors had approved the final version.

Funding

The research was funded under the PFR-Bima Program 2024, No. 0667/E5/AL.04/2024.

Acknowledgment

We thank the Directorate General of Research, Technology, and Community Service (DRTPM), the Republic of Indonesia's Minister of Education, Culture, Research, and Technology for funding this research, the farmers and experts who responded to interviews and discussions, and the anonymous reviewers for their valuable comments and suggestions.

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