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Research Article

Quantifying Greenhouse Gas Emissions of Water Buffalo by Age Category in Central Aurora, Philippines

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ABSTRACT

The rise in global greenhouse gases, particularly methane from agricultural water buffalo, poses a significant climate threat. This study aimed to quantify methane and nitrous oxide emissions from these buffalo in Central Aurora, Philippines, where such data is currently unquantified. The objective was to provide local and national policymakers with specific emission data to develop targeted mitigation policies, reducing the environmental impact of buffalo farming while sustaining its benefits. The data were collected from farms and government offices, supplemented by expert discussions. IPCC Tier 1 emission factors with uncertainty value of 60%, specific to Southeast Asia and buffalo age categories, were used with population data to calculate annual methane and nitrous oxide emissions, expressed as CO_2 equivalents also referring to all different warming gases in the atmosphere.

Yearling buffalo were the highest individual methane emitters, emphasizing the need for targeted management during this stage to reduce overall emissions. Adult buffaloes contributed most to nitrous oxide emissions, highlighting the importance of age-specific emission factors for accurate inventories. Overall, water buffalo farming significantly contributed to greenhouse gases, necessitating age-aware and manure management strategies for mitigation.

The highest CO_2 emissions was mainly due to methane released during their growth. Adult buffalo, though individually less polluting, contributed substantially to overall emissions because of their numbers. For precise evaluations, it was crucial to consider age-specific emission factors. This highlighted the importance of targeting yearlings with mitigation strategies (like changes in diet) and implementing wider management practices for adult herds, especially in

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agricultural planning for areas like Aurora, Central Luzon. While future studies may employ Tier 2 methods or examine genetic and dietary modifications to further refine emission estimates.

Keywords: *Carbon dioxide emission, Greenhouse Gases, GHG inventory, Manure management, Methane emission, Nitrous oxide emission, Tier 1 IPCC method, Water buffalo*

Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2021) identifies rising atmospheric greenhouse gas (GHG) levels as a critical threat to the global environment and human societies. Among these, methane (CH_4) stands out due to its significantly higher global warming potential compared to carbon dioxide (CO_2) over a 20-year period (Myhre et al., 2013). While fossil fuel combustion remains the primary source of anthropogenic GHG emissions, agriculture plays a substantial role, contributing significantly to global CH_4 and nitrous oxide (N_2O) emissions (FAO, 2022). A major source of agricultural CH_4 is enteric fermentation in ruminant animals like cows, sheep, and buffalo (Hristov et al., 2013).

Water buffaloes (*Bubalus bubalis*) are key to agricultural economies in many regions, including the Philippines, despite being recognized as significant CH_4 emitters (Goopy et al., 2019). These animals are vital for food security and livelihoods, particularly in rural communities, by providing draught power, milk, and meat (Borghese et al., 2018). In Central Aurora, Philippines, water buffalo are deeply integrated into the agricultural landscape particularly in milk production, underpinning local economies and cultural practices. However, their contribution to regional GHG emissions remains largely unquantified.

Accurately understanding the magnitude of CH_4 emissions from water buffalo in specific locations is necessary for developing effective mitigation strategies and promoting sustainable agricultural practices. Recent studies, such as Lohakare (2023), emphasized that managing feral water buffalo populations can substantially reduce overall GHG outputs, further emphasizing the urgent need for a precise inventory of these emissions. Methane released during digestion is a potent greenhouse gas that significantly contributes to global warming (Macleod et al., 2018).

Thus, this research focused on a greenhouse gas (GHG) inventory, specifically quantifying methane (CH_4) and nitrous oxide (N_2O) emissions from water buffalo in Central Aurora. Water buffaloes are vital to the fresh milk production in Aurora province, supplying both local consumption and exports to nearby regions. The study aimed to provide quantified emissions data to inform policymakers at local and national levels, particularly those developing climate change mitigation strategies. By accurately estimating the carbon footprint of the area, this research may guide the design of precise plans to lower the environmental impact of buffalo farming, ensuring the continued societal benefits these animals provide. Furthermore, this study may contribute to the broader understanding of livestock-related GHG emissions and support policies aimed at achieving national and global environmental objectives.

Methods

This research set out how to generate a water buffalo greenhouse gas (GHG) inventory for Central Aurora, Philippines. It emphasized the measurement of greenhouse gas emissions.

Study Area and Population

The study was conducted in Central Aurora, Philippines. Specific municipalities like Maria Aurora and San Luis with significant water buffalo populations were selected based on data from the Provincial Veterinary Office. The target population was the water buffalo within the Central Aurora. All buffalo categories based on age were included in the study such as the calf, yearling, and adult.

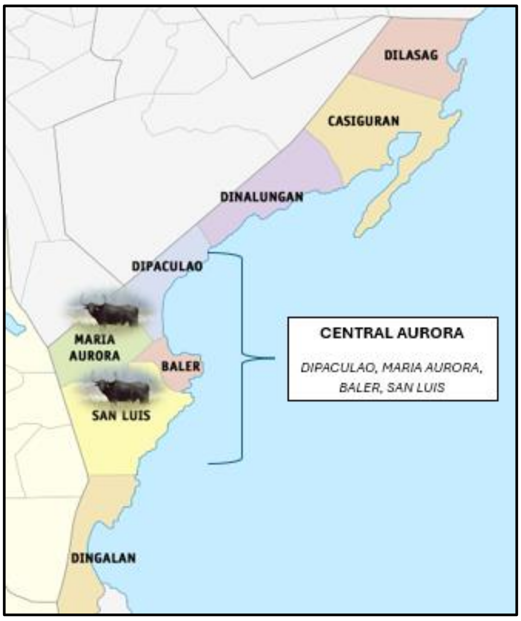

Figure 1. Map of the Municipalities with Water Buffalo.

Data Collection

Buffalo farms in Central Aurora were observed to confirm data results and obtain more insights into management techniques. The study was put into context by supplemental primary data and information from the Provincial Veterinary Office, PAG-ASA, PSA, and other related government offices. However, to support the findings of the observation and inventory, focus group discussions with experts from the Provincial Veterinary Office, PAG-ASA, and DOST staff were held.

To quantify greenhouse gas emissions, the study employed emission factors that represent the rate of GHG release per farm animal over time. The data were collected covering the year 2024. Specifically for water buffalo in Southeast Asia, the Tier 1 emission factor from the IPCC (2006) guidelines was primarily used. This approach was chosen due to data and resource constraints, as Tier 1 offers simplicity and feasibility. It relies on straightforward calculations using readily available default factors and aggregated animal population data, making it a practical choice for initial assessments where vigorous local data collection systems are not yet established.

For calculating CH_4 and N_2O emissions, the emission factors provided by the IPCC based on animal categories and regions were used. It required activity data (number of buffalo) and selection of the appropriate emission factor based on the predominant solid storage manure management system in a warm climate. This refers to a method of handling and storing animal waste where the manure is kept in a solid, stackable form rather than as a liquid slurry. The warm climate significantly influences how this system functions and its environmental implications.

Greenhouse Gas Emission Estimation

Methane (CH_4) Emissions were calculated using the following equation (IPCC, 2006)

CH_4 Emissions = $\sum$ (Animal Population x Emission Factor x Activity Data)

Where the emission factor is specific to the animal category (e.g., calf, yearling, and adult) with uncertainty value of 60%.

Nitrous Oxide (N_2O) Emissions from manure management were estimated using equations and emission factors from the IPCC guidelines.

Total GHG Emissions were expressed in CO_2 equivalents using the global warming potentials (GWPs) for CH_4 (25) and N_2O (298) (IPCC, 2013).

Data Analysis

The data were processed using Tier 1 emission factor with uncertainty value of 60%. A Tier 1 emission factor is a default value provided by the Intergovernmental Panel on Climate Change (IPCC) used to estimate greenhouse gas emissions from a particular source category. It represents the simplest and least data-intensive method for calculating emissions. The individual emission was calculated based on age categories of water buffalo. The annual greenhouse gas emissions from water buffalo were determined following the IPCC guidelines. Computed methane and nitrous oxide emissions were combined to get the total carbon dioxide emission per year.

Results and Discussion

This section discusses the greenhouse gas emissions from water buffalo according to their age categories. Greenhouse gases included both methane and nitrous oxide.

Methane Emissions from Water Buffalo

The data in Table 1 shows the estimated yearly methane output of water buffalo of different ages. Yearling buffalo (1.5 to 3 years old) released the most methane, at approximately 16.96 cubic meters, which translates to 218.78 kilograms per year. Calves produced 8.21 cubic meters (88.32 kg/year), while adult buffalo emitted the least, at 2.48 cubic meters (81.87 kg/year). Overall, the combined methane production across all age groups of water buffalo was about 388.97 kg annually.

Table 1. Annual methane emissions of water buffalo based on age categories.

Categories	No. of buffalo	CH_4 emission per head	Total CH_4 emission
Calf	15	8.21 m^3 CH_4/calf/year	88.32 kg CH_4/year
Yearling	18	16.96 m^3 CH_4/yearling/year	218.78 kg CH_4/year
Adult	46	2.48 m^3 CH_4/adult/year	81.87 kg CH_4/year
Total	**79**		**388.97** kg CH_4/year

The most significant finding is that methane production in water buffalo is strongly linked to their age. The yearling buffalo (1.5 to 3 years old) produces substantially more methane annually compared to both younger calves and older adult buffalo. Furthermore, the data clearly indicates that the period between 1.5 and 3 years of age is when water buffalo have the highest rate of methane emission, both in terms of volume (cubic meters) and mass (kilograms) per year. Calves produce a moderate amount of methane, while adult buffalo have the lowest individual yearly methane output among the three age categories studied.

Understanding that yearling buffalo are the highest emitters allows for the development of targeted strategies to reduce methane emissions from this specific age group. According to the provincial and municipal agriculture office, this could involve dietary adjustments, the use of methane inhibitors, or specific management practices focused on buffalo in this growth phase. Additionally, the provincial veterinary office emphasized that these greenhouse gas inventories may contribute particularly to agricultural sectors where water buffaloes are significant.

Methane production in water buffalo is strongly linked to their age (Ali et al., 2020). Yearlings are in a rapid growth phase, requiring a higher intake of feed to support their increasing body mass and development. This increased feed intake provides more substrate for fermentation by the microorganisms in the rumen, leading to greater methane production as a byproduct of this process (U.S. EPA, 2021). Likewise, as buffalo transition from milk to a predominantly forage-based diet, the rumen undergoes structural and functional changes to digest this more complex feed. The fermentation of fibrous plant material in the rumen produces more hydrogen, which is a key component in methane formation by methanogens (Dietary, environmental and microbiological aspects of methane production in ruminants, 2021).

Nitrous Oxide Emission from Water Buffalo

Table 2 details the yearly nitrous oxide (N_2O) emissions from water buffalo of different ages. Adult buffalo had the highest individual emissions at 0.28 kg N_2O per year, followed by yearlings at 0.08 kg N_2O per year, and calves at 0.047 kg N_2O per year. When considering the total emissions across all animals in each age group, adult buffalo contributed 13.0 kg N_2O per year, yearlings produced 2.26 kg N_2O per year, and calves released 0.705 kg N_2O per year. Additionally, the study found that the solid storage manure management system in a warm climate released approximately 15.965 kg of nitrous oxide annually.

Table 2. Annual nitrous oxide (N_2O) emissions of water buffalo based on age categories.

Categories	No. of buffalo	N_2O emission per head	Total N_2O emission
Calf	15	0.047 kg N_2O/calf/year	0.705 kg N_2O/year
Yearling	18	0.08 kg N_2O/yearling/year	2.26 kg N_2O / year
Adult	46	0.28 kg N_2O/Adult/year	13.0 kg N_2O/year
Total	**79**		**15.965** kg N_2O/year

The data denoted that N_2O emissions are not uniform across the lifespan of water buffalo. Adult animals were significantly higher than individual emitters compared to younger ones. This suggests that greenhouse gas inventories for agricultural systems involving water buffalo may consider age-specific emission factors for more accurate estimations. Likewise, the total emissions data emphasized the significant contribution of adult buffalo to the overall N_2O budget from these animals. Given the aggregate N_2O contribution of adult buffalo (13.0 kg/year), strategies such as improved manure storage and composting may be more effective at this life stage.

The amount of nitrogen in the excreta is a primary driver of N_2O emissions. Adult animals might excrete different amounts and forms of nitrogen compared to younger animals due to variations in diet, feed conversion efficiency, and physiological state (Albano et al., 2020). While younger animals like calves typically consume less feed and have different metabolic efficiencies compared to older animals (Assessment of Methane and Nitrous Oxide Emissions from Livestock in India, 2020). This could lead to lower overall nitrogen excretion in their urine and feces, which is the primary substrate for N_2O production in soils.

Greenhouse Gas Emissions from Water Buffalo

Table 3 summarizes the total greenhouse gas emissions from water buffalo, considering both methane and nitrous oxide. The findings indicated that yearlings had the highest carbon dioxide equivalent (CO_2e) emissions at 6723.74 kg per year. Calves followed with 2659.785 kg CO_2e per year, and adult buffalo produced 5737.36 kg CO_2e per year. Overall, the combined greenhouse gas emissions from all water buffalo across the different age groups amounted to 15120.885 kg CO_2e per year.

The most striking finding was that yearling water buffalo individually produced the highest amount of greenhouse gases (expressed as carbon dioxide equivalent). The results implied that, on a per-animal basis, buffalo in their yearling stage had a greater impact on greenhouse gas emissions compared to both younger calves and older adults. While individual adult buffalo emitted less than yearlings, their total contribution to greenhouse gas emissions (implied to be based on a larger population size in the study) was still substantial at 5737.36 kg CO_2e per year. The Department of Science and Technology (DOST) Aurora reiterated in the interview that while methane is the primary greenhouse gas of concern from manure, the decomposition process also releases some Carbon Dioxide. The management practices employed can influence the amount and form of carbon released.

Table 3. Annual Greenhouse Gas Emissions (GHG) from water buffalo.

Categories	CH_4 emission	N_2O emission	CO_2 emission
Calf	88.32 kg CH_4/year	0.705 kg N_2O/year	2659.785 kg CO_2e/year
Yearling	218.78 kg CH_4/year	2.26 kg N_2O / year	6723.74 kg CO_2e/year
Adult	81.87 kg CH_4/year	13.0 kg N_2O/year	5737.36 kg CO_2e/year
Total	**388.97** kg CH_4/year	**15.965** kg N_2O/year	**15120.885 kg CO_2e/year**

Thus, the greenhouse gas emissions from water buffalo across different age categories revealed that yearlings exhibited the highest individual carbon dioxide equivalent (CO_2e) emissions, likely due to their rapid growth phase and proportionally higher feed intake leading to increased rumen fermentation and subsequent methane production. While adult buffaloes had lower individual emissions than yearlings, their total contribution remained substantial, likely influenced by population size. Calves, with their lower feed intake and less active rumen fermentation, demonstrated the lowest greenhouse gas emissions. These findings underscored the age-dependent nature of greenhouse gas emissions in water buffalo and highlighted yearlings as a key stage to target for potential mitigation strategies aimed at reducing the overall environmental impact of buffalo farming.

Yearlings are in a phase of rapid growth and have a higher feed intake relative to their body size compared to adults (Shibata & Terada, 2010). This increased consumption of plant material leads to more fermentation in the rumen and consequently, higher methane production (U.S. EPA, 2021). Calves, while also growing, have a lower overall intake due to their smaller size. While rapid growth in yearlings might suggest a higher overall metabolic rate and thus potentially more carbon dioxide production from cellular respiration, the fermentation process in the rumen is the primary source of methane and a significant source of carbon dioxide in ruminants (JMB, 2022). Since this process is less active in young calves, their overall emission of these gases would be lower.

The study denoted the significant contribution of yearling water buffalo to methane emissions, surpassing that of calves and adult buffalo, which carried substantial implications for climate change due to methane's high global warming potential. This finding underscored the critical need to focus on management practices during the yearling stage, such as optimizing feed composition and feeding schedules, as potential avenues for significantly mitigating methane output from buffalo farming. Ultimately, recognizing these age-specific emission patterns is crucial for developing targeted and effective strategies to reduce the overall greenhouse gas footprint of water buffalo farming systems within the broader agricultural sector.

The significant disparity in nitrous oxide emissions between adult and younger buffalo underlined the necessity for age-disaggregated emission factors in greenhouse gas inventories to accurately reflect the agricultural sector's contribution to climate change. This refined approach would not only provide a more precise understanding of the overall N_2O budget but also highlight the potential for targeted mitigation strategies focused on adult buffalo populations to achieve the most substantial reductions in emissions from water buffalo farming, ultimately leading to more effective climate change mitigation efforts within the agricultural sector.

Water buffalo farming showed a notable role in greenhouse gas emissions, with young buffaloes around one year old producing the most emissions per animal, while the larger number of adult buffaloes led to a considerable overall contribution. Additionally, the decomposition of manure released carbon dioxide, as observed by DOST Aurora, further increasing the climate impact. Understanding how emissions vary with age and how manure was handled is therefore essential for developing targeted approaches to reduce the environmental impact of this farming sector.

Comparison of Carbon Dioxide Emissions from Water Buffalo by Age Categories

Figure 2 comprehensively illustrates the total carbon dioxide equivalent (CO_2e) emissions per year from water buffalo, segmented by three distinct age categories: Calf, Yearling, and Adult. As estimated, Calves demonstrated the lowest emissions, estimated at approximately 2659.785 Kg CO_2e/year. The result was aligned with their lower metabolic rates and reduced feed intake, leading to less enteric methane production, which is a primary contributor to livestock CO_2e emissions.

Yearlings exhibited a notable increase, reaching approximately 6723.74 Kg CO_2e/year. This substantial rise was consistent with their rapid growth phase, as their digestive systems matured and feed consumption significantly increased to support their accelerated development.

Interestingly, adult water buffalo showed a slight reduction in emissions compared to yearlings, at approximately 5737.36 Kg CO_2e/year. While still considerably higher than calves, this suggested that peak emissions may occur during the intensive growth period of the yearling phase, potentially stabilizing or slightly decreasing as animals attain full maturity and their energy requirements shift towards maintenance rather than rapid growth. Variations in diet or activity levels of adult buffalo relative to yearlings could also contribute to this observed reduction (Shibata & Terada, 2010).

The data clearly indicates a significant increase in CO_2e emissions from water buffalo as they age, generally peaking around the yearling stage before a slight reduction in adulthood. This trend aligns perfectly with the physiological development of ruminants. As water buffaloes mature, their rumen becomes more developed, allowing for more efficient digestion of fibrous feeds. This enhanced digestive process, driven by microbial fermentation in the rumen, directly leads to increased methane production as a byproduct.

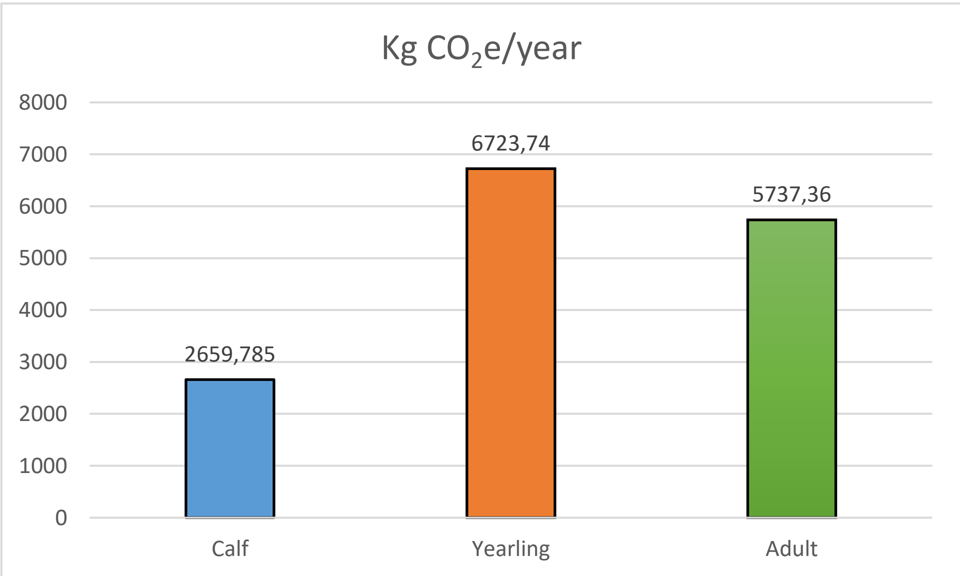

Figure 2. Total Carbon Dioxide Emissions from Water Buffalo by Age Categories.

Beyond digestive processes, manure management plays a crucial role in overall methane emissions. The anaerobic decomposition of livestock manure in environments like lagoons, pits, or deep stacks is a significant contributor. The amount of methane generated from manure depends on several key factors: moisture content, temperature, and the duration of storage (Chadwick, D., et al., 2020).

The findings carried significant implications for assessing and mitigating the environmental footprint of water buffalo farming in Central Aurora Province, Philippines. The strategies aimed at reducing greenhouse gas emissions from water buffaloes included optimizing diets across different age categories to specifically reduce enteric methane production, possibly through feed additives or the provision of highly digestible forages, improving the efficiency of weight gain to reduce the time animals spend in high-emission stages (like the yearling phase) before reaching target market weight or reproductive maturity, and implementing effective manure management practices, particularly for adult and yearling buffalo, as manure decomposition is another significant contributor to GHG emissions.

Total Greenhouse Gas Emissions of Water Buffalo (Methane, Nitrous Oxide, and Carbon Dioxide)

Figure 3 provides a very specific representation of greenhouse gas (GHG) emissions from water buffalo.

While carbon dioxide (CO_2) showed the highest mass (15,120.885 kg), it is important to understand its context. CO_2 from biological sources like animal respiration is typically considered part of the natural carbon cycle. However, the remarkably high CO_2 mass in this figure strongly denoted the inclusion of significant non-biological CO_2 sources. These could originate from fossil fuel use (e.g., farm operations, feed transport), or even land-use change such as deforestation for pasture.

Nitrous Oxide (N_2O), at 15.965 kg, had the smallest mass but is the most potent of the three. Its GWP over 100 years is about 265-298 times that of CO_2. Therefore, 15.965 kg of nitrous oxide is roughly equivalent to 4,200 to 4,750 kg of CO_2 in warming potential. N_2O emissions from water buffalo typically arise from manure management and nitrogen cycling in soils related to feed production.

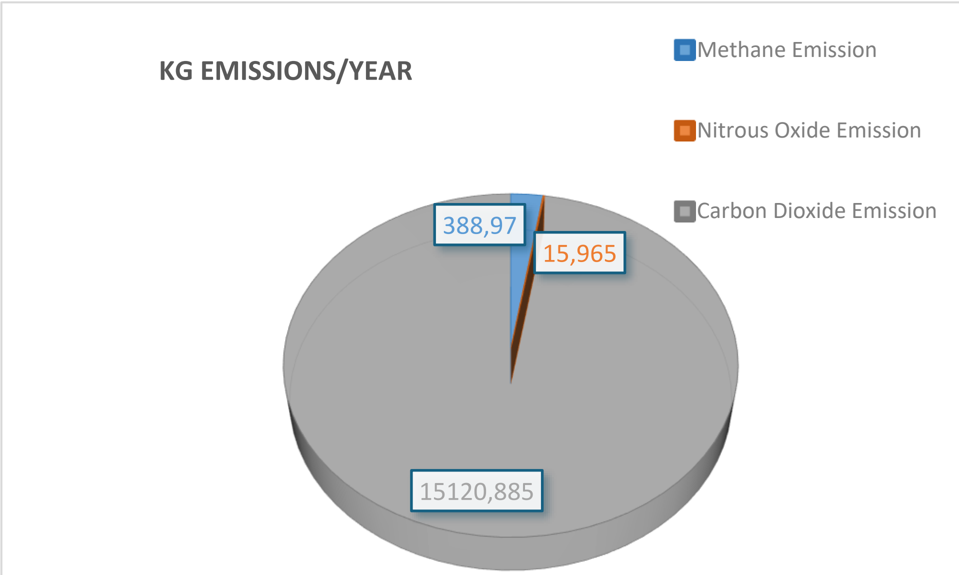

Figure 3. Total Greenhouse Gas Emissions of Water Buffalo (Methane, Nitrous Oxide, and Carbon Dioxide).

The data clearly illustrates carbon dioxide (CO_2) as the primary emission by mass within the water buffalo production system. However, understanding the true climate impact requires converting all greenhouse gas (GHG) emissions into carbon dioxide equivalents (CO_2e). This conversion is essential because, despite their smaller mass contributions, gases like methane (CH4) and nitrous oxide (N_2O) possess significantly higher Global Warming Potentials (GWPs). This means that even small quantities of these gases can have a disproportionately large impact on global warming compared to CO_2.

Beyond mitigating emissions from farmed animals, there is a promising opportunity to address those from feral ruminants. Incentivizing the management of these populations through the generation of carbon credits could offer a triple benefit: it would simultaneously avoid additional GHG emissions, create a new income stream for landowners, and provide significant ecological advantages (Davies, H.F., et al. 2023). This approach emphasizes a potential pathway for both climate action and sustainable land management.

Despite its significantly smaller mass, Methane (CH_4) stands out as a far more potent greenhouse gas (GHG) than carbon dioxide (CO_2). A mere 388.97 kg of methane, when released into the atmosphere, has a warming impact roughly equivalent to 10,900 to 13,200 kg of CO_2 over a 100-year period. This staggering difference is attributed to methane's Global Warming Potential (GWP), which is approximately 28 to 34 times greater than that of CO_2 over the same timeframe. Consequently, even with its lower atmospheric concentration compared to CO_2, methane has been, and continues to be, a very significant contributor to global warming. A major portion of these potent emissions originates from anthropogenic sources, primarily the agricultural sector. Specifically, enteric fermentation (the digestive process in ruminant animals like cattle, buffalo, sheep, and goats) is the largest single source of agricultural methane emissions globally. Within the rumen, specialized microbes break down plant fibers, producing methane as a metabolic byproduct (Hristov, A.N., et al., 2013). Another substantial source within agriculture is the decomposition of animal manure under anaerobic conditions. The high GWP of methane, coupled with its substantial emissions from these agricultural activities, underscores its critical role in climate change. Understanding and mitigating these methane sources are therefore paramount in addressing the global warming challenge.

Conclusions

Yearling buffalo exhibit the highest individual carbon dioxide equivalent (CO_2e) emissions, primarily driven by their elevated methane production during this rapid growth phase. While adult buffalo have lower per-animal emissions compared to yearlings, their total contribution remains significant, likely due to a larger population size within the studied group. Calves, with their lower feed intake and less developed rumen function, demonstrate the lowest greenhouse gas output across all categories.

These emphasize the importance of considering age-specific emission factors when assessing the environmental impact of water buffalo farming. The identification of yearling buffalo as the highest individual emitters presents a targeted opportunity for developing mitigation strategies, such as dietary adjustments or methane inhibitors, specifically aimed at this life stage. Moreover, the substantial total emissions from adult buffalo highlight the need for broader management practices that can reduce the overall carbon footprint of this agricultural sector, as also emphasized by the insights from the provincial and municipal agriculture and veterinary offices, and the DOST Aurora regarding manure management.

The discovery that young adult water buffalo (yearlings) produce the most greenhouse gases per animal, mainly methane, offers a key opportunity to combat climate change through focused efforts such as altering their diets or using emission-reducing additives. This detailed information about emissions at different ages is also essential for generating reliable reports on agricultural greenhouse gas contributions, directing resources and policies effectively, improving general knowledge of livestock emissions over their lives, supporting more environmentally friendly farming methods, and is especially pertinent for Central Aurora, Philippines, where it can shape local agricultural planning.

Further studies may gather more localized and detailed data within Central Aurora Province. This may include precise information on feed composition, animal productivity (such as growth rates and milk yield), breed-specific characteristics, and specific manure management practices. Collecting this granular data may pave the way for developing more accurate Tier 2 or even Tier 3 emission factors, significantly refining the understanding of Central Aurora’s greenhouse gas inventory. Furthermore, while the current study categorized emissions by age, a longitudinal study tracking individual water buffalo from calf to adulthood is essential. This may provide more precise insights into the "peak emission" yearling phase and reveal how unique animal characteristics influence their lifetime emissions.

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