BIODIVERSITAS
Volume 24, Number 4, April 2023
Pages: 1998-2005

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240408

Carbon sink and greenhouse gas emission of dryland vegetation cover in tourism villages in Flores Island, East Nusa Tenggara, Indonesia

FATMA LESTARI[1,2], INDRA NI TUA[3], ADONIS MUZANNI[4], DANESTA FEBIANTO NUGROHO[3], ANDRIO A. WIBOWO[2,5,♥], TRI WARTONO[3], BAIDURI WIDANARKO[1], ASEP SAEPULLAH[3], ROBIANA MODJO[1], MIFTACHUL FARIDA[3], DADAN ERWANDI[1], DESSY DWI ARYANI[3], ABDUL KADIR[1], ANINDHITA IRSALINA WIDIATMOKO[3], HENDRA[1], ZICO JUNI HERWANTO[3], MILA TEJAMAYA[1], RIZAL ALFIANSYAH HAMID[3], FATMAH[4], EZSA LARASHATI GUNAWAN[3], DINA LUSIANA SETYOWATI[6], M. FAIZIR HAFIDS[3], ROSSI YULIANI[2]

[1]Department of Occupational Health and Safety, Faculty of Public Health, Universitas Indonesia. C Building, 1st Floor Kampus UI Depok 16424, West Java, Indonesia
[2]Disaster Risk Reduction Center, Universitas Indonesia (DRRC UI). Integrated Laboratory and Research Centre Building, 2nd Floor Kampus UI Depok 16424, West Java, Indonesia
[3]Ministry of Tourism and Creative Economy of Indonesia. Jl. Medan Merdeka Barat No.17, Gambir, Jakarta Pusat 10110, Jakarta, Indonesia
[4]School of Environmental Science, Universitas Indonesia. Kampus UI Salemba, Jakarta Pusat 10430, Jakarta, Indonesia
[5]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia. Kampus Baru UI Depok 16424, West Java, Indonesia. Tel.: +62-21-7863436, 7863437, Fax.: +62-21-7270012, ♥email: awbio2021b@gmail.com
[6]Department of Occupational Health and Safety, Faculty of Public Health, Universitas Mulawarman. Jl. Kuaro, Gn. Kelua, Samarinda Ulu, Samarinda 75119, East Kalimantan, Indonesia

Manuscript received: 5 February 2023. Revision accepted: 4 April 2023.

Abstract. *Lestari F, Tua IN, Muzanni A, Nugroho DF, Wibowo AA, Wartono T, Widanarko B, Saepullah A, Modjo R, Farida M, Erwandi D, Aryani DD, Kadir A, Widiatmoko AI, Hendra, Herwanto ZJ, Tejamaya M, Hamid RA, Fatmah, Gunawan EL, Setyowati DL, Hafids MF, Yuliani R. 2023. Carbon sink and greenhouse gas emission of dryland vegetation cover in tourism villages in Flores Island, East Nusa Tenggara, Indonesia. Biodiversitas 24: 1998-2005.* Due to its natural features and scenery, the dryland ecosystem has recently become a tourist destination. One of the growing dryland ecosystems for village tourism is Flores Island, East Nusa Tenggara, Indonesia. Those tourism villages have the potential to promote carbon sequestration through the preservation of natural resources and, at the same time, can release Green-House Gases (GHG). Despite growing research on carbon stock, there is little information on the carbon budget of a dryland tourism village, which includes the values of carbon stock sequestered from the atmosphere and greenhouse gas emissions. This research aimed to measure the carbon stock and GHG emissions in three villages containing paddy fields, savanna, and forest covers. The measured gases, including CO_2, CH_4, and N_2O, were collected using the gas chamber method and analyzed using gas chromatography. The result shows that forest land covers have the highest carbon stock, with average values of 97.44 Mg ha^{-1} within the 57.34-117.5 Mg ha^{-1}. A low average carbon stock of 17.39 Mg ha^{-1} was observed in paddy fields. The GHG was in the order of $CO_2 > CH_4 > N_2O$. The paddy field has higher GHG than other land covers, with average CO_2, CH_4, and N_2O values of 292.45 ppm, 1.35 ppm, and 1.09 ppm. While CO_2, CH_4, and N_2O values for the forest were 281.05 ppm, 1.30 ppm, 1.05 ppm, 272.83 ppm, 1.26 ppm, and 1.02 ppm for savanna covers.

Keywords: Carbon, dryland, forest, greenhouse gas, paddy field

INTRODUCTION

Drylands, which include dry, semi-arid, and sub-humid biomes, cover 42% (Prăvălie 2016; Bastin et al. 2017; Wang et al. 2022) of the land surface and are important for a variety of ecological services. Dryland ecosystems dominated the interannual variability of the global carbon cycle (Poulter et al. 2014). As a result, carbon stocks in drylands soils and vegetation are often lower when expressed as carbon per unit area than in forested ecosystems. For example, carbon stocks in above-and below-ground plant biomass are often less than 100 Mg ha^{-1} C, particularly in wetter, drier sub-humid environments. Similarly, organic carbon stores in the top 30 cm of soil are normally less than 50 Mg ha^{-1} but can be significantly greater in high-latitude temperate dry lands and mesic grasslands (Bardgett et al. 2021). However, total carbon expressed as the sum of above and below-ground plant biomass and soil organic matter can significantly equal> 200 Mg ha^{-1} across a wide portion of the dry lands when combined (Gebregergis 2016).

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are reported as main Green-House gases (GHG). It is estimated that a global average of 2.28 ± 50% μmol CO_2 m^{-2} s^{-1} released from the global forestland with CH_4 is the second major greenhouse gas. While CO_2 is mostly related to anthropogenic activities, the main CH_4 sources were wetlands, ruminant animals, rice fields, biofuel, etc. The amount of CH_4 by industrial origin was smaller than that of biological origin. An annual average CH_4 flux is given by −1.38 ± 2.80 μmol CH_4 m^{-2} h^{-1}, with a range from −9.38 μmol CH_4 m^{-2} h^{-1} to 3.53 μmol CH_4

m^{-2} h^{-1}.·It was estimated that the mean N_2O-emission rate from tropical forest soils equals 1.23 ± 2.09 μmol N_2O m^{-2} h^{-1} was at least 2-3 times higher than those from temperate forest soils equaling 0.41 ± 0.15 μmol N_2O m^{-2} h^{-1}. In dryland ecosystems (Chevallier et al. 2016; Leley et al. 2022), the GHG usually comes from agricultural lands due to crop production, livestock production, indirect emission, and agroecosystem. The activities within the agricultural lands that contribute to GHG emissions comprise crop residues production, application of N-fertilizer, livestock enteric fermentation, manure storage, handling and application, soil cultivation, using of machinery, fueling, and transportation (Jantke et al. 2020).

A recent study shows the relationship between the Normalized Difference Vegetation Index (NDVI) and GHG (Shi et al. 2020). In an environment, GHG is caused by the land use changes of a land cover, and NDVI is an index to inform the particular land use changes. In terrestrial ecosystems, NDVI has been used to assess the quality of vegetated areas, including tourism villages. For example, Singgalen and Manongga (2022a,b) have used the NDVI method to assess the suitability of mangrove forests in North Maluku Province for village tourism purposes. The results confirm the NDVI ranges of 0.02-0.23. While in Chattogram, Bangladesh, Rafa et al. (2021) used NDVI to assess the suitability of forest covers in a botanical garden.

Indonesia is unquestionably one of the countries in the world with enormous tourism potential. Therefore, a tourism village (*Kementerian Koperasi dan UKM Republik Indonesia* 2017) in the context of village tourism is an asset based on rural potential with all its uniqueness and attractiveness that can be empowered and developed as a product of tourism to attract tourist visits to the location of the village (Sudibya 2018). Currently, according to the database provided by the Ministry of Tourism and Creative Economy of Indonesia, as available at https://jadesta.kemenparekraf.go.id/peta in Indonesia, there are approximately 3,619 tourist villages across Indonesia.

In Indonesia, dryland ecosystems are characterized by savanna, high temperature, and less precipitation in East Nusa Tenggara Province (Buditama et al. 2021; Sutomo and van Etten 2021). Generally, despite the growing numbers and potential of village tourism in East Nusa Tenggara, there is still a scarcity of data on the carbon stock and GHG emissions in some villages designated as tourist destinations. At the same time, this information is very important and required for managing village tourism immediately. Therefore, this study assesses the carbon stock, NDVI, and GHG emissions of East Nusa Tenggara tourism villages. This study will contribute to the environmental dimension by providing insight into sustainable tourism that can support the livelihood of the community for the long term and, at the same time, can mitigate GHG emissions.

MATERIALS AND METHODS

Study area

The study was conducted in three tourism villages in Flores Island, East Nusa Tenggara, and parts of Lesser Sunda Island Province, Indonesia (Figure 1, Table 1). The first village was West Detusoko, located in Ende District from south latitude of 8.715° S to 8.750° S and east longitude of 121.746° E and 121.799° E. The village, sizing 4.77 km² is located within the Kelimutu National Park landscape with elevations of 800 m above sea level (https://jadesta.kemenparekraf.go.id/desa/detosoko_barat). Mount Kelimutu is 1,690 m above sea level (masl). Furthermore, a combination of forest covers, savanna covers, paddy fields, and plantation covers across the village's hilly areas characterizes the landscape. Most forest covers were parts of Kelimutu National Park on the east side of this village. The air temperature was 21.6°C for July-August and an average of 25.5-31°C with precipitation rates of 1,651-3,363 mm $year^{-1}$.

The second village was Wae Rebo, located in Manggarai District from south latitude of 8.744° S to 8.799° S and east longitude of 120.272° E and 120.302° E. The village, sizing 1.02 km², is surrounded by forest and savanna at elevations of 1,200 masl. Furthermore, the last village was Liang Ndara, located in West Manggarai District from south latitude of 8.572° S to 8.630° S and east longitude of 119.918° E and 119.965° E. The village, sizing 22.45 km², is surrounded by forest and paddy fields at elevations of 725 masl.

Land cover surveys

The land cover and vegetation surveys of the designated land in West Detusoko, Wae Rebo, and Liang Ndara Villages were conducted following Fiqa et al. (2019). Vegetation analysis was carried out in the designated land covers by making sampling plots to record: the vegetation presence, Diameter at Breast Height (DBH or at 1.37 m above the ground), carbon stock, and GHG. The data collections with 10 m x 10 m plots for trees within forest covers, 5 m x 5 m plots for seedlings, saplings, and shrubs within savanna covers, and 1 m x 1 m plots for ground covers and grasses within paddy field covers (Pinto et al. 2021). In each land cover of each village, three replicated transects were placed (Table 1), and the surveys were implemented from August 2022 to October 2022. Furthermore, for each transect length at 100 m, ten nested plots were placed along the transects, with five plots on the right and another five on the left. Each nested plot has different sizes depending on the land cover types (Figure 2).

Procedures

Land cover NDVI analysis

Normalized Difference Vegetation Index (NDVI) measurement (Ibharim et al. 2015; Alatorre et al. 2016; Rhyma et al. 2020) of land covers in West Detusoko, Wae Rebo, and Liang Ndara Villages were following Philiani et al. (2016), Kawamuna et al. (2017), and Sukojo and Arindi (2019). The land covers in those villages was categorized as forests, savannas, and paddy fields. NDVI is described as a simple graphical indicator that can analyze remote sensing measurements, often from a space satellite platform, assessing whether the target being observed contains live green vegetation. The NDVI was measured by analyzing the wavelength of satellite images retrieved from Landsat 8 containing vegetation images and, in this study, forest, savanna, and paddy field covers. This measurement is possible since the cell structure of the vegetation leaves strongly reflects near-infrared light wavelengths ranging from 0.7 to 1.1 µm (Suwanto et al. 2021). The calculation of NDVI for each pixel of land cover was as follows:

$$\text{NDVI} = \frac{\text{near invisible red wavelength} - \text{red wavelength}}{\text{near invisible red wavelength} + \text{red wavelength}}$$

The NDVI was denoted as 0 (no vegetation) to 1 (high vegetation density). The land covers are then categorized and classified using NDVI following Suwanto et al. (2021). Finally, the NDVI was analyzed and developed using QGIS and included the following steps: acquiring satellite images in particular near-invisible red wavelength and red wavelength bands, calculating NDVI values using band values, and visualizing the NDVI into the graphs.

Carbon stock calculation

The carbon stock for each land cover within each designated sampling plot was calculated using a non-destructive approach based on allometric methods (Lukina et al. 2020) and tree diameter measurement at the Diameter at Breast Height (DBH). The measurement of DBH to estimate the carbon stocks were applied for trees in forest covers and shrubs in savanna covers (Victor et al. 2019). In this method, allometric models were established using independent variables of DBH. The allometric models for Above-Ground Biomass (AGB) estimation of each species were following Kangkuso et al. (2018) and Kusmana et al. (2018). The carbon stock was obtained from the above biomass and DBH-based allometric equation as follows:

Allometric model for AGB (Maulana et al. 2016.):

$$\text{Log(AGB)} = -0.267 + 2.23\ \text{Log(DBH)} + 0.649\ \text{Log(WD)}$$

DBH : Diameter at Breast Height
(WD) : Wood Density

Equation 1 is then used to estimate the carbon stock using the following equation (Khaple et al. 2021):

Carbon stock = AGB x 0.47; the unit for carbon stock is C ton/ha

Since the vegetation in paddy fields is dominated by *Oryza sativa* L., carbon measurement is not based on DBH measurement. In the field, *O. sativa* plants were uprooted and taken to the laboratory to remove the soil and dirt. Then, the roots of the rice plants were cut off and placed in paper bags. Samples were oven-dried at 105°C for 0.5 hours and 70°C until constant weight. Afterward, the dry weight of stems, leaves, and panicles of *O. sativa* was weighed and recorded. Rice AGB (kg m^{-2}) was calculated as the product of dry weight per plant (kg $plant^{-1}$) and plant density (plant m^{-2}) (Wang et al. 2022).

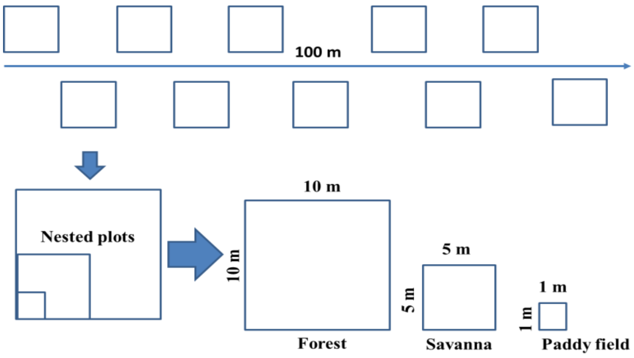

Figure 2. Survey layouts of West Detusoko, Wae Rebo, and Liang Ndara Villages across land cover types in Flores Island, Indonesia

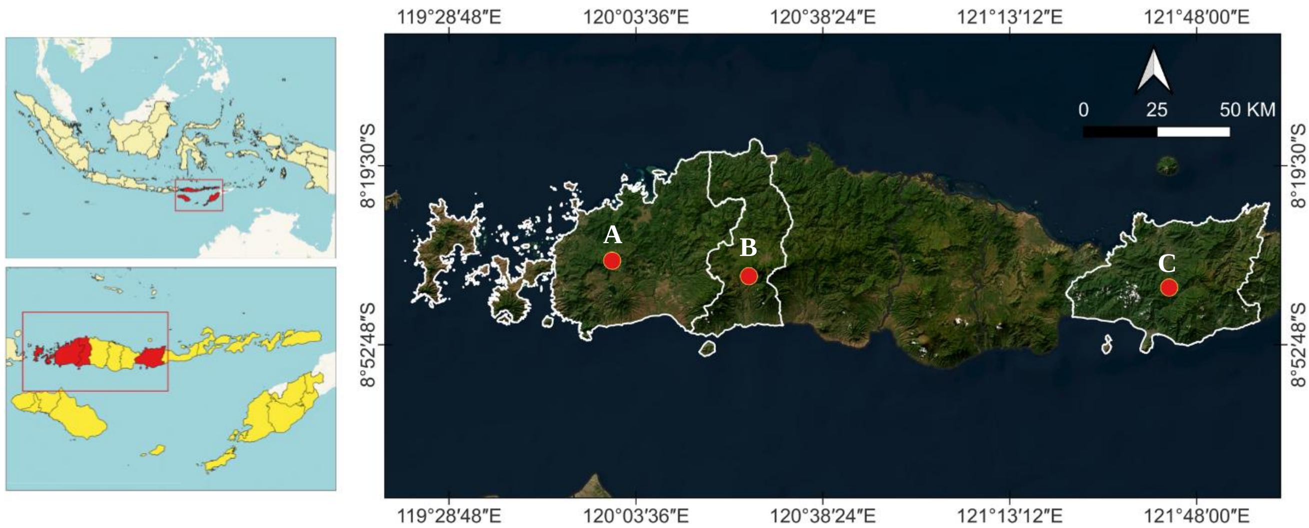

Figure 1. Liang Ndara (A), Wae Rebo (B), and West Detusoko (C) Villages are located across land cover types in Flores Island, Indonesia

Green-House Gas (GHG) calculation

Measured GHGs include CO_2, N_2O, and CH_4, and the measurements were implemented directly within each designated sampling plot in each land cover. The method used following Heinemeyer and McNamara (2011), Oertel et al. (2012), and Šimek et al. (2014) using gas chambers. In this method, an anti-corrosive stainless steel box sizing 50 cm x 50 cm x 100 cm was placed onto the soil surface so that the section of its base was open to the ground. The advantages of stainless steel box were not permeable to gases and were not releasing zinc and iron ions that could affect microbial activity and measurement. The chambers were inserted into the soil with a depth of 20 cm to prevent leakages. The gas within the chambers was then collected using a syringe sizing 60 mL equipped with a needle of 0.45 mm × 13 mm and 12 mL pre-evacuated exetainers.

From the chambers, the collected gas was taken using a syringe. The collected gas samples were then inserted into 12 mL storage exetainer vials to be transported into the laboratory for further gas volume readings. In the laboratory, Gas Chromatography (GC) (Zaman et al. 2021) was used to analyze CO_2, N_2O, CH_4, and measurement units in ppm.

RESULTS AND DISCUSSION

NDVI and carbon stock in West Detusoko, Wae Rebo, and Liang Ndara Villages

Each village has different land cover types. For example, West Detusoko was a village with paddy fields, savanna, and forest land covers. Paddy field was absent in Wae Rebo, while savanna was absent in Liang Ndara villages. NDVI values in West Detusoko, Wae Rebo, and Liang Ndara Villages are available in Figure 3. The land covers in Wae Rebo include forest and savanna, and paddy fields in Liang Ndara Villages have the highest NDVI values among other villages. Figure 4 depicts the carbon stocks in three villages. For carbon stock, Liang Ndara village has the highest carbon stock, with values ranging from 57.34 Mg ha^{-1} to 117.5 Mg ha^{-1}. The second village was Wae Rebo, with carbon stock values of 67.21Mg ha^{-1}. West Detusoko has the lowest carbon stock, ranging from 43.24 Mg ha^{-1} to 70.03 Mg ha^{-1}.

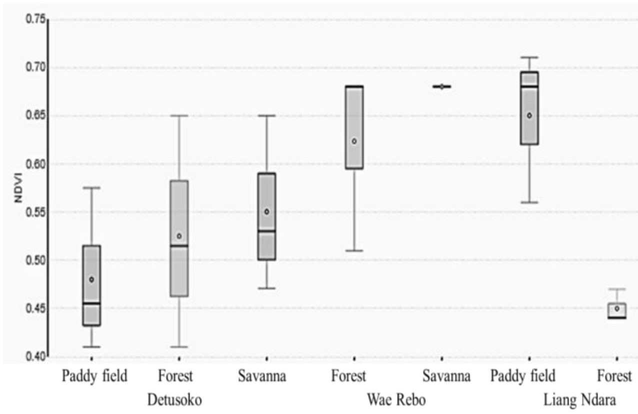

Figure 3. Boxplots of NDVI in each land cover (paddy field, savanna, forest) in West Detusoko, Wae Rebo, and Liang Ndara Villages in Flores Island, Indonesia

Table 1. Geocoordinate of sampling plots in various land covers in East Nusa Tenggara tourism villages in Flores Island, Indonesia

Tourism villages	Land cover types	Geocoordinates (south latitude, east longitude)	Size in km^2	Elevations above sea levels in m
West Detusoko	Paddy field	-8.719701, 121.7510	4.77	800
		-8.726379, 121.759346		
		-8.732094, 121.761035		
	Forest	-8.736530, 121.776775		
		-8.733126, 121.768592		
		-8.744339, 121.791445		
	Savanna	-8.746794, 121.793251		
		-8.732623, 121.771102		
		-8.734224, 121.788178		
Wae Rebo	Forest	-8.769010, 120.282228	1.02	1,200
		-8.772294, 120.284776		
		-8.767830, 120.284304		
	Savanna	-8.768576, 120.281206		
		-8.771762, 120.284372		
		-8.769655, 120.283316		
Liang Ndara	Paddy field	-8.608576, 119.960795	22.45	725
		-8.602729, 119.923849		
		-8.583796, 119.939205		
	Forest	-8.626646, 119.952451		
		-8.601165, 119.942703		
		-8.613482, 119.931584		

GHG in West Detusoko, Wae Rebo, and Liang Ndara Villages

Paddy field land covers were only available in West Detusoko and Liang Ndara villages. CO_2 always outperformed CH_4 and N_2O in all villages. GHG emissions from paddy fields always exceeded those from other land cover types in West Detusoko (Figure 5), in the order paddy field > forest > savanna. While CO_2 > CH_4 > N_2O was the order for GHG with average values of 292.45 ppm > 1.35 ppm > 1.09 ppm for paddy field land covers, The lowest GHG was observed in the savanna, with average values for CO_2, CH_4, and N_2O of 272.83 ppm > 1.26 ppm > 1.02 ppm. Furthermore, in Wae Rebo Village (Figure 6), paddy field cover was absent, with only forest and savanna. In this location, forest GHG exceeded savanna GHG. The forest's CO2, CH4, and N2O average values were 207.76 ppm > 0.96 ppm > 0.77 ppm. While in the savanna, the order for CO_2, CH_4, and N_2O average values was 174.27 ppm > 0.80 ppm > 0.65 ppm. Paddy fields were present in Liang Ndara Villages, and paddy field GHG average values were exceeded by forest cover GHG (Figure 7).

Discussion

Paddy fields always have carbon stock values lower than forest land covers in comparison among land cover types. Compared to Liang Ndara, West Detusoko and Wae Rebo villages were located at an elevation higher than Liang Ndara. A consequence of inhabiting high altitudes is facing the scarcity of water resources since water is accumulated in the lower downstream areas. Water will become more scarce, especially in dryland and within a climate change era. As ecosystems are limited by water, drylands are more vulnerable to climate change (Hanan et al. 2021; Sutomo et al. 2023).

This study's dryland carbon stock values were comparable to a previous result (Fu et al. 2021). Kurniawan and Yuniati (2015) have previously measured the carbon stock in East Nusa Tenggara and recorded a carbon stock value of 52.68 Mg ha^{-1}. Numerous factors influence carbon stock values in dryland ecosystems, with water availability (Koch and Missimer 2016) being the most prominent (Del Campo et al. 2019). Among the various factors are temperature, precipitation, and atmospheric CO_2 concentration. In drylands, precipitation (Ukkola et al. 2021) was the dominant factor affecting carbon stocks (Zhu et al. 2019). Besides that, the vegetation composition is also contributing to the carbon stock values. In this study, forests were characterized by the presence of woody plants absent in either paddy fields or savanna. According to Abdullah et al. (2022), the presence of woody plants in dryland ecosystems will increase plant density and carbon stocks. At the global level (Table 2), the GHG values obtained here are comparable and follow common patterns that CO_2 has always exceeded CH_4 and NO_2. However, CO_2 emissions obtained here are still below the permissible limit of 400 ppm.

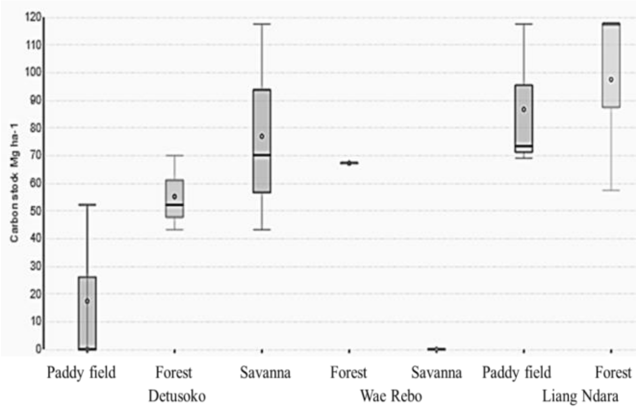

Figure 4. Boxplots of carbon stocks in Mg ha^{-1} in each land cover (paddy field, savanna, forest) in West Detusoko, Wae Rebo, and Liang Ndara Villages in Flores Island, Indonesia

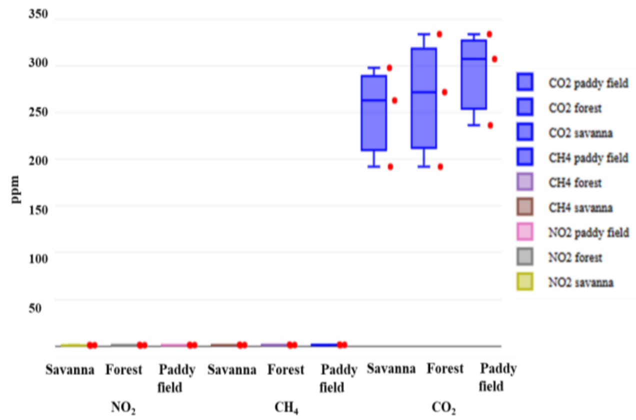

Figure 5. Boxplots of GHG in ppm in each land cover **(**paddy field, savanna, forest) in West Detusoko Village in Flores Island, Indonesia

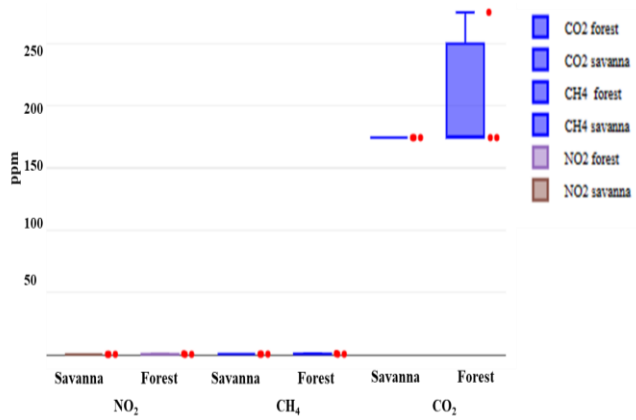

Figure 6. Boxplots of GHG in ppm in each land cover **(**savanna, forest) in Wae Rebo Village in Flores Island, Indonesia

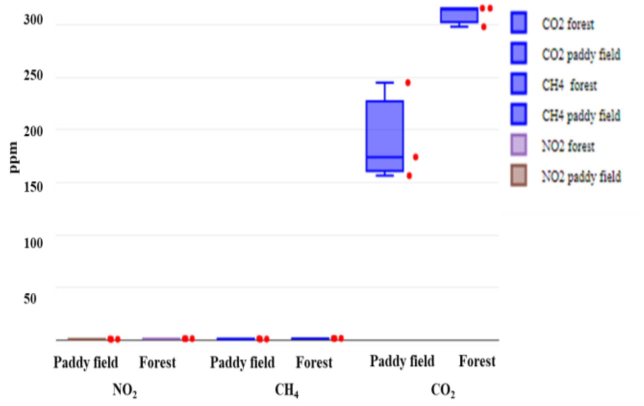

Figure 7. Boxplots of GHG in ppm in each land cover (paddy field, forest) in Liang Ndara Village in Flores Island, Indonesia

Table 2. Comparisons of global GHG with the previous study

Locations	GHG	Value (ppm).	Land cover	Sources
Hefei, China	CO_2	425-435	Paddy field	Li et al. (2023)
	CH_4	1.86-1.98		
	N_2O	0.33-0.34		
Mazandaran, Iran	CO_2	746.5-1753.3	Forest	Vatani et al. (2019)
	CH_4	1.01-1.82		
	N_2O	0.21-0.34		
East Nusa Tenggara, Indonesia	CO_2	156.55-333.81	Paddy field	This study
	CH_4	0.72-1.54		
	N_2O	0.58-1.25		
	CO_2	174.27-333.81	Forest	
	CH_4	0.80-1.54		
	N_2O	0.65-1.25		
	CO_2	174.27-297.77	Savanna	
	CH_4	0.80-1.37		
	N_2O	0.65-1.11		

Note: Limit for CO_2, N_2O, and CH_4 is 400 ppm

In this study, agriculture practices in the form of paddy fields were identified as contributing to GHG. The East Nusa Tenggara region has a long history of dry agriculture development and practices (Mulyani and Sarwani 2013; Supari et al. 2018). Agricultural practices have occupied an area equal to 3.3 million ha, or 71.7% of the province's total area. In village tourism, paddy fields have become one of the main tourist attractions instead of fulfilling their daily livelihood. Tourists are drawn to specific tourist villages to enjoy the unique scenery of paddy fields. Akliyah et al. (2022) have confirmed that paddy fields are very strategic in supporting community and tourism activities in particular rural areas compared to the villages in this study. The increasing paddy-field tourism trend is inextricable and could be linked to a movement in tourist attention toward agritourism. Paddy field tourism is thought to play a favorable role. It can improve farmers' quality of life, give educational opportunities for tourists, and preserve the community's original culture (Lestari 2022). Despite the importance and direct benefits of paddy field features in the context of village tourism, the existence of this agricultural practice may pose a challenge within the context of GHG emissions. The establishment of agricultural practices, especially in particular dry lands, will require extensive irrigation practices, leading to high demands for water consumption and availability (Yu et al. 2018; Tirtalistyani et al. 2022). Then the increases in water demand and consumption, mainly to irrigate dryland paddy fields, will have consequences for increased GHG emissions. Rice cultivation stimulates GHG emissions from the soil into the atmosphere due to crop management practices such as irrigation water management (Islam et al. 2020). Water management in the form of flooding irrigation is responsible for significantly increasing methane (CH_4) emissions (Aguilera et al. 2019). However, it contributes little to N_2O emissions (Shang et al. 2011; Wang et al. 2011; Yao et al. 2012).

Aside from irrigation and water utilization, dryland paddy fields require fertilizers. Similar to the water, the use of fertilizer containing N was also responsible for the NO_2 emissions. Arunrat et al. (2018) have reported that nitrous oxide (N_2O) emissions are associated with nitrogen (N) fertilizer application and dryland conditions.

As can be seen and concluded from the results, tourism village that promotes forest covers as their main tourism features have the potential to store carbon stock. While tourism village that promotes paddy field covers as their main tourism features have the potential to emit GHG in the order of CO_2 > CH_4 > N_2O. Moreover, fertilizer and irrigation to support the paddy field should be monitored and regulated through crop management practices and nitrogen regulations (Mboyerwa et al. 2022).

ACKNOWLEDGEMENTS

We would like to express our gratitude to the students, academics, office of tourism, and tourism operators who helped in this research. This study is supported and funded by the Ministry of Education, Culture, Research, and Technology through the Kedaireka Scheme and the Ministry of Tourism and Creative Economy of Indonesia. The research uses a Ministry of Education, Culture-Higher Education No: 213/EI/KS.06.02/2022 grant, the Universitas Indonesia and the Ministry of Tourism and Creative Economy No: 306/PKS/WRITI-DISTP/U1/2022, and PKS-237/UNZ.INV/HKP.05/2022.

REFERENCES

Abdullah UH, Sufardi, Syafruddin, Arabia T. 2022. Soil organic carbon of grassland and bush forest on dryland in Aceh Besar District, Indonesia. Biodiversitas 23 (5): 2594-2600. DOI: 10.13057/biodiv/d230541.

Aguilera E, Vila-Traver J, Deemer BR, Infante-Amate J, Guzmán GI, de Molina MG. 2019. Methane emissions from artificial waterbodies dominate the carbon footprint of irrigation: A study of transitions in the food-energy-water-climate nexus (Spain, 1900-2014). Environ Sci Technol 53 (9): 5091-5101. DOI: 10.1021/acs.est.9b00177.

Akliyah LS, Hindersah H, Fikri MH. 2022. Analysis of the paddy fields to support community and tourism activities in Ciemas District, Indonesia [version 1; peer review: 1 approved with reservations]. F1000 Res 11: 523. DOI: 10.12688/f1000research.111281.1.

Alatorre LC, Sánchez-Carrillo S, Miramontes-Beltrán S, Medina RJ, Torres-Olave ME, Bravo LC, Wiebe LC, Granados A, Adams DK, Sánchez E, Uc M. 2016. Temporal changes of NDVI for qualitative environmental assessment of mangroves: Shrimp farming impact on the health decline of the arid mangroves in the Gulf of California (1990-2010). J Arid Environ 125: 98-109. DOI: 10.1016/j.jaridenv.2015.10.010.

Arunrat N, Sereenonchai S, Pumijumnong N. 2018. On-farm evaluation of the potential use of greenhouse gas mitigation techniques for rice cultivation: A case study in Thailand. Climate 6 (2): 36. DOI: 10.3390/cli6020036.

Bardgett RD, Bullock JM, Lavorel S et al. 2021. Combatting global grassland degradation. Nat Rev Earth Environ 2: 720-735. DOI: 10.1038/s43017-021-00207-2.

Bastin JF, Berrahmouni N, Grainger A et al. 2017. The extent of forest in dryland biomes. Science 356: 635-638. DOI: 10.1126/science.aam6527.

Buditama G, Saiya HG, Putri NP. 2021. Effects of climate change on dryland agriculture vegetation index in Nangapanda, East Nusa Tenggara. IOP Conf Ser: Earth Environ Sci 716: 012013. DOI: 10.1088/1755-1315/716/1/012013.

Chevallier T, Hamdi S, Tahar G, Brahim N, Cardinael R, Zohra B, Cournac L, Chenu C, Bernoux M. 2016. The Mediterranean Region Under Climate Change: A Scientific Update. IRD Éditions, Marseille.

Del Campo AD, González-Sanchis M, Ilstedt U, Bargués-Tobella A, Ferraz S. 2019. Dryland forests and agrosilvopastoral systems: Water at the core. Unasylva 70 (251): 27-35.

Fiqa AP, Fauziah, Lestari DA, Budiharta S. 2019. The importance of in-situ conservation area in mining concession in preserving diversity, threatened and potential floras in East Kalimantan, Indonesia. Biodiversitas 20 (1): 198-210. DOI: 10.13057/biodiv/d200123.

Fu C, Chen Z, Wang G, Yu X, Yu G. 2021. A comprehensive framework for evaluating the impact of land use change and management on soil organic carbon stocks in global drylands. Curr Opin Environ Sustain 48: 103-109. DOI: 10.1016/j.cosust.2020.12.005.

Gebregergis Z. 2016. A Review on: Management of carbon in dryland agriculture. J Environ Earth Sci 6 (2): 70-75.

Hanan NP, Milne E, Aynekulu E, Yu Q, Anchang J. 2021. A role for drylands in a carbon neutral world? Front Environ Sci 9: 786087. DOI: 10.3389/FENVS.2021.786087.

Heinemeyer A, McNamara NP. 2011. Comparing the closed static versus the closed dynamic chamber flux methodology: Implications for soil respiration studies. Plant Soil 346: 145-151. DOI: 10.1007/s11104-011-0804-0.

Ibharim NA, Mustapha MA, Lihan T, Mazlan AG. 2015. Mapping mangrove changes in the Matang Mangrove Forest using multi-temporal satellite imageries. Ocean Coast Manag 114: 64-76. DOI: 10.1016/j.ocecoaman.2015.06.005.

Islam SMM, Gaihre YK, Islam MR, Akter M, Al Mahmud A, Singh U, Sander BO. 2020. Effects of water management on greenhouse gas emissions from farmers' rice fields in Bangladesh. Sci Total Environ 734: 139382. DOI: 10.1016/j.scitotenv.2020.139382.

Jantke K, Hartmann MJ, Rasche L, Blanz B, Schneider UA. 2020. Agricultural greenhouse gas emissions: Knowledge and positions of German farmers. Land 9 (5): 130. DOI: 10.3390/land9050130.

Kangkuso A, Sharma S, Jamili, Septiana A, Sahidin I, Rianse U, Rahim S, Nadaoka K. 2018. Trends in allometric models and aboveground biomass of Rhizophoraceae mangrove family at the coral triangle ecoregion, Southeast Sulawesi, Indonesia. J Sustain For 37 (7): 691-711. DOI: 10.1080/10549811.2018.1453843.

Kawamuna A, Suprayogi A, Wijaya AP. 2017. Analisis kesehatan hutan mangrove berdasarkan metode klasifikasi NDVI pada Citra Sentinel-2 (Studi kasus: Teluk Pangpang Kabupaten Banyuwangi). Jurnal Geodesi UNDIP 6 (1): 277-284. [Indonesian]

Kementerian Koperasi dan UKM Republik Indonesia. 2017. Buku Panduan Pengembangan Desa Wisata Hijau. Asisten Deputi Urusan Ketenagalistrikan dan Aneka Usaha Kementerian Koperasi dan UKM Republik Indonesia, Indonesia. [Indonesian]

Khaple AK, Devagiri GM, Veerabhadraswamy N, Babu S, Mishra SB. 2021. Chapter 6-Vegetation biomass and carbon stock assessment using geospatial approach. Forest Resources Resilience and Conflicts. Elsevier. DOI: 10.1016/B978-0-12-822931-6.00006-X.

Koch M, Missimer TM. 2016. Water resources assessment and management in drylands. Water 8 (6): 239. DOI: 10.3390/w8060239.

Kurniawan H, Yuniati D. 2015. Carbon sink potency in three types of savanna in Nusa Tenggara Timur. Jurnal Penelitian Kehutanan Wallacea 4 (1): 51-62. DOI: 10.18330/jwallacea.2015.vol4iss1pp51-62. [Indonesian]

Kusmana C, Hidayat T, Tiryana T, Rusdiana O, Istomo. 2018. Allometric models for above-and below-ground biomass of Sonneratia spp. Glob Ecol Conserv 15: e00417. DOI: 10.1016/j.gecco.2018.e00417.

Leley NC, Langat DK, Kisiwa AK, Maina GM, Muga MO. 2022. Total carbon stock and potential carbon sequestration economic value of Mukogodo Forest-landscape ecosystem in Drylands of Northern Kenya. Open J For 12 (1): 19-40. DOI: 10.4236/ojf.2022.121002.

Lestari ND. 2022. The sustainability of paddy field tourism: Problems and control instruments. Marcapada: Jurnal Kebijakan Pertanahan 1 (2): 139-154. DOI: 10.31292/mj.v1i2.11.

Li J, Xue Z, Li Y, Bo G, Shen F, Gao X, Zhang J, Tan T. 2023. Real-time measurement of atmospheric CO_2, CH_4 and N_2O above rice fields based on Laser Heterodyne Radiometers (LHR). Agronomy 13 (2): 373. DOI: 10.3390/agronomy13020373.

Lukina N, Kuznetsova A, Tikhonova E, Smirnov V, Danilova M, Gornov A, Bakhmet O, Kryshen A, Tebenkova D, Shashkov M, Knyazeva S. 2020. Linking forest vegetation and soil carbon stock in Northwestern Russia. Forests 11 (9): 979. DOI:10.3390/f11090979.

Maulana SI, Wibisono Y, Utomo S. 2016. Development of local allometric equation to estimate total aboveground biomass in Papua tropical forest. Indones J For Res 3 (2): 107-118. DOI: 10.20886/ijfr.2016.3.2.107-118.

Mboyerwa PA, Kibret K, Mtakwa P, Aschalew A. 2022. Greenhouse gas emissions in irrigated paddy rice as influenced by crop management practices and nitrogen fertilization rates in eastern Tanzania. Front Sustain Food Syst 6: 868479. DOI: 10.3389/fsufs.2022.868479.

Mulyani A, Sarwani M. 2013. Karakteristik dan potensi lahan sub optimal untuk pengembangan pertanian di Indonesia. Jurnal Sumberdaya Lahan 7: 47-55. DOI: 10.2017/jsdl.v7n1.2013.%p. [Indonesian]

Oertel C, Herklotz K, Matschullat J, Zimmermann F. 2012. Nitric oxide emissions from soils: A case study with temperate soils from Saxony, Germany. Environ Earth Sci 66: 2343-2351. DOI: 10.1007/s12665-011-1456-3.

Philiani I, Saputra L, Harvianto L, Muzaki AA. 2016. Pemetaan vegetasi hutan mangrove menggunakan metode Normalized Difference Vegetation Index (NDVI) di Desa Arakan, Minahasa Selatan, Sulawesi Utara. Surya Octagon Interdisc J Sci Technol 1 (2): 211-222. [Indonesian]

Pinto LOR, de Souza CR, Terra MdeCNS, de Mello JM, Calegario N, Júnior FWA. 2021. Optimal plot size for carbon-diversity sampling in tropical vegetation. For Ecol Manag 482: 118778. DOI: 10.1016/j.foreco.2020.118778.

Poulter B, Frank D, Ciais P, Myneni RB, Andela N, Bi J, Broquet G, Canadell JG, Chevallier F, Liu YY, Running SW, Sitch S, van der Werf GR. 2014. Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle. Nature 509: 600-603. DOI: 10.1038/nature13376.

Prăvălie R. 2016. Drylands extent and environmental issues. A global approach. Earth Sci Rev 161: 259-278. DOI: 10.1016/j.earscirev.2016.08.003.

Rafa N, Nuzhat S, Uddin SMN, Gupta M, Rakshit R. 2021. Ecotourism as a forest conservation tool: An NDVI analysis of the Sitakunda Botanical Garden and Ecopark in Chattogram, Bangladesh. Sustainability 13 (21): 12190. DOI: 10.3390/su132112190.

Rhyma PP, Norizah K, Hamdan O, Faridah-Hanum I, Zulfa AW. 2020. Integration of normalised different vegetation index and soil-adjusted vegetation index for mangrove vegetation delineation. Remote Sens Appl: Soc Environ 17: 100280. DOI: 10.1016/j.rsase.2019.100280.

Shang Q, Yang X, Gao C, Wu P, Liu J, Xu Y, Shen Q, Zou J, Guo S. 2011. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: A 3-year field measurement in long-term fertilizer experiments. Glob Change Biol 17 (6): 2196-2210. DOI: 10.1111/j.1365-2486.2010.02374.x.

Shi Y, Lou Y, Zhang Z, Ma L, Ojara MA. 2020. Estimation of methane emissions based on crop yield and remote sensing data in a paddy field. Greenh Gases: Sci Technol 10 (1): 196-207. DOI: 10.1002/ghg.1946.

Šimek M, Hynšt J, Šimek P. 2014. Emissions of CH_4, CO_2, and N_2O from soil at a cattle overwintering area as affected by available C and N. Appl Soil Ecol 75 (5): 52-62. DOI: 10.1016/j.apsoil.2013.10.010.

Singgalen YA, Manongga D. 2022a. Mangrove-based ecotourism sustainability analysis using NDVI and AHP Approach. Indones J Comput Cybern Syst 16 (2): 125-136. DOI: 10.22146/ijccs.68986.

Singgalen YA, Manongga D. 2022b. Monitoring of mangrove ecotourism area using NDVI, NDWI, and CMRI in Dodola Island, Morotai Island

Regency, Indonesia. J Ilmu Teknol Kelaut Tropis 14 (1): 95-108. DOI: 10.29244/jitkt.v14i1.37605.

Sudibya B. 2018. Wisata desa dan desa wisata. Jurnal Bali Membangun Bali: Jurnal Bappeda Litbang 1 (1): 21-25. DOI: 10.51172/jbmb.v1i1.8.

Sukojo BM, Arindi YN. 2019. Analisa perubahan kerapatan mangrove berdasarkan nilai Normalized Difference Vegetation Index menggunakan Citra Landsat 8 (Studi kasus: Pesisir Utara Surabaya). Geoid 14 (2): 1-5. DOI: 10.12962/j24423998.v14i2.3874. [Indonesian]

Supari, Tangang F, Salimun E, Aldrian E, Sopaheluwakan A, Juneng L. 2018. ENSO modulation of seasonal rainfall and extremes in Indonesia. Clim Dyn 51: 2559-2580. DOI: 10.1007/s00382-017-4028-8.

Sutomo, Kurniawan H, Pujiono E, Yuniati D, Saputra MH, Januar HI, Kuswandi R, Hadiyan Y, Hadi EEW, Hidayah I, Humaida N, Sukmawati JG. 2023. Karbon Hijau Savana Nusa Tenggara Timur. Media Sains Indonesia. Bandung, Indonesia. [Indonesian]

Sutomo, van Etten E. 2021. Savanna plant communities in the wetter parts of the Indonesian archipelago. Folia Geobot 56: 193-204. DOI: 10.1007/s12224-021-09401-y.

Suwanto A, Takarina ND, Koestoer RH, Frimawaty E. 2021. Diversity, biomass, covers, and NDVI of restored mangrove forests in Karawang and Subang Coasts, West Java, Indonesia. Biodiversitas 22 (9): 4115-4122. DOI: 10.13057/biodiv/d220960.

Tirtalistyani R, Murtiningrum, Kanwar RS. 2022. Indonesia rice irrigation system: Time for innovation. Sustainability 14 (19): 12477. DOI: 10.3390/su141912477.

Ukkola AM, De Kauwe MG, Roderick ML, Burrell A, Lehmann P, Pitman AJ. 2021. Annual precipitation explains variability in dryland vegetation greenness globally but not locally. Glob Change Biol 27 (18): 4367-4380. DOI: 10.1111/gcb.15729.

Vatani L, Hosseini SM, Sarjaz MR, Alavi SJ. 2019. The effect of tree species on greenhouse gas emissions from forest plantation soils. J Agric Meteorol 7 (1): 36-46.

Victor AD, Valery NN, Louis Z. 2019. Carbon storage and emission factor of savanna ecosystems in Soudano-Sahelian Zone of Cameroon. J Bot Res 2 (1): 60-70. DOI: 10.36959/771/562.

Wang H, Liu Y, Wang Y, Yao Y, Wang C. 2022. Land cover change in global drylands: A review. Sci Total Environ 863: 160943. DOI: 10.1016/j.scitotenv.2022.160943.

Wang W, Dalal RC, Reeves SH, Butterbach-Bahl K, Kiese R. 2011. Greenhouse gas fluxes from an Australian subtropical cropland under long-term contrasting management regimes. Glob Change Biol 17 (10): 3089-3101. DOI: 10.1111/j.1365-2486.2011.02458.x.

Wang Z, Ma Y, Chen P, Yang Y, Fu H, Yang F, Raza MA, Guo C, Shu C, Sun Y, Yang Z, Chen Z, Ma J. 2022. Estimation of rice aboveground biomass by combining canopy spectral reflectance and unmanned aerial vehicle-based red green blue imagery data. Front Plant Sci 13: 903643. DOI: 10.3389/fpls.2022.903643.

Yao Z, Zheng X, Dong H, Wang R, Mei B, Zhu J. 2012. A 3-year record of N_2O and CH_4 emissions from a sandy loam paddy during rice seasons as affected by different nitrogen application rates. Agric Ecosyst Environ 152: 1-9. DOI: 10.1016/j.agee.2012.02.004.

Yu D, Ramsey RD, Zhao XM, Fu YQ, Sun CK. 2018. Feasible conversion degree of dryland to paddy field in Jinxian County, Jiangxi province, China. Geocarto Intl 34 (9): 1042-1053. DOI: 10.1080/10106049.2018.1452988.

Zaman M, Kleineidam K, Bakken L et al. 2021. Methodology for measuring greenhouse gas emissions from agricultural soils using non-isotopic techniques. In: Zaman M, Heng L, Müller C (eds). Measuring Emission of Agricultural Greenhouse Gases and Developing Mitigation Options using Nuclear and Related Techniques. Springer, Cham, Swiss. DOI: 10.1007/978-3-030-55396-8_2.

Zhu S, Li C, Shao H, Ju W, Lv N. 2019. The response of carbon stocks of drylands in central asia to changes of CO_2 and climate during past 35 years. Sci Total Environ 687: 330-340. DOI: 10.1016/j.scitotenv.2019.06.089.