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To cite this article: I Kesaulya *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1207** 012030

IOP Conf. Series: Earth and Environmental Science 1207 (2023) 012030 doi:10.1088/1755-1315/1207/1/012030

Global Warming Potential of Carbon dioxide and Methane Emission from Mangrove Sediment in Waiheru Coastal, Ambon Bay.

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ABSTRACT: Mangroves can store carbon. However, it also produces carbon emissions by degrading organic matter in mangrove sediments. This research was conducted in a mangrove ecosystem at Waiheru, in the inner Ambon bay, to determine CO_2 and CH_4 emissions and their potential for global warming (GWP) from mangrove sediments. Gas is taken through a syringe mounted on the hood. Gas concentration analysis used the gas chromatography method, while the average gas concentration in each sediment was tested using ANOVA Single Factor. The results showed that the average concentration of CO_2 gas was significantly different for each sediment (P-value <0.05), while the average concentration of CH_4 gas was not significantly different (P-value >0.05). The largest CO_2 gas emission in mangrove sediments in Waiheru Village was found in sandy mud sediments with an emission value of 136.99 $mg.m^{-2}.h^{-1}$, and the lowest was in sand sediments, namely 13.01 $mg.m^{-2}.h^{-1}$. Meanwhile, the largest emission of CH_4 gas was in silty sand sediments, namely 0.32 $mg.m^{-2}.h^{-1}$, and the lowest was in sandy mud sediments, namely 0.15 $mg.m^{-2}.h^{-1}$. Fluctuations in carbon gas emissions in each sediment are inversely proportional, which indicates that the formation of CH_4 gas is obtained through ethanol reduction, which utilizes CO_2 gas concentrations. The total GWP in the mangrove sediments of Waiheru Village is 231.58 $mg.m^{-2}.h^{-1}$. The GWP contributed by the type of sandy silt sediment was 140.72 CO_2-eq $mg.m^{-2}.h^{-1}$, muddy sand was 70.95 $mg.m^{-2}.h^{-1}$, and sand sediment was 19.91 CO_2-eq $mg.m^{-2}. h^{-1}$.

1. Introduction

Increased emissions of greenhouse gases can trigger global warming to cause climate change. Climate change can impact various aspects of human life, such as agriculture (foodsecurity), health, and fisheries [1, 2]. Various studies have found that climate change impacts rising sea surface temperatures, sea level rise, rainfall, wind speed, lower seawater pH, seawater deoxygenation and heat waves [3]. These changes can decrease the benefits and ecological services of coastal marine, and freshwater ecosystems [4]. Meanwhile, it is reported [5], [6], and [7] that coastal and marine ecological damage due to climate change causes a decrease in fishery production and loss opeople's livelihoods.

Besides carbon dioxide (CO_2) and methane (CH_4) gases, another contributor to triggering climate change is nitrous oxide (N_2O). N_2O has the potential to affect the climate more than 298 times compared to CO_2 [7], and microorganism activities in the soil form N_2O through nitrification and denitrification processes in aerobic and anaerobic conditions [8]. N_2O increases significantly with increasing organic material concentration entering the aquatic environment [9].

Greenhouse gases that have the largest atmospheric concentration and are the main contributors to global warming are CO_2 and CH_4 [9]. These gases are produced by human activities, such as motorized vehicles, industrial, and burning fossil fuels, which causes accumulation of greenhouse gases [8, 9, 10]. Apart from human activities, the accumulation of carbon gas in the atmosphere can also occur naturally through the decomposition of litter produced by plant vegetation, including mangrove ecosystems [11,13]. Mangrove ecosystems can store up to 295 Mg $C.ha^{-1}$ of carbon in tree stands [13]. Meanwhile, [14] stated that the total carbon storage in mangrove ecosystems, namely tree stands and substrates, reaches 1000 Mg $C.ha^{-1}$ and is four times greater than other ecosystems.

Besides storing and absorbing carbon, mangrove ecosystems also produce carbon gas emissions through the degradation of litter [15]. Mangrove litter can come from fallen leaves or mangroves tha die naturally [16]. Besides that, mangrove litter can also come from logging activities and the conversion into ponds, settlements, and wharves [17, 18]. Mangrove litter mixes with organic waste produced by anthropogenic activities and decomposes in mangrove sediments [12]. Moreover, [11] reported that the substrate or sediment in the mangrove ecosystem consists of a substrate of sand, muddy sand, sandy silt, and silt. Each type of substrate can be occupied by one or two dominant species, which are the distinguishing features of other substrates [17].

Research on the global warming potential of carbon gas emissions from mangrove sediment in Indonesia is minimal, especially in the mangrove ecosystem around the inner Ambon bay mangrove. The mangrove ecosystem can be found in several locations along the inner Ambon bay's coastal area, such as Passo, Negeri Lama, Nania, Poka, and Waiheru. Mangrove species in Waiheru coastal area consist of six species, *Bruguiera cylindrica*, *Rhizophora apiculata*, *Sonneratia alba*, *Ceriops tagal*, *Avecenia alba*, and *Osbornia octodonta* [18, 19]. These mangrove species can produce debris, mix it with organic waste from anthropogenic activities, and decompose in mangrove sediments. The results of the decomposition of organic matter that occurs in mangrove sediments produce carbon emissions which have the potential for global warming. Therefore, this study aimed to analyze the potential for global warming from carbon emissions from the mangrove ecosystem in Waiheru coastal area in Inner Ambon Bay.

2. Materials and Methods

2.1. Description of research sites

This research was conducted in July 2022 in the mangrove ecosystem, the coastal area of Waiheru village, inner Ambon Bay, Ambon (Fig. 1). In 2012, the density of mangroves in Waiheru coastal area was 420 stands/ha for the tree category, and 2240 stands/ha for the saplings or saplings category [19].

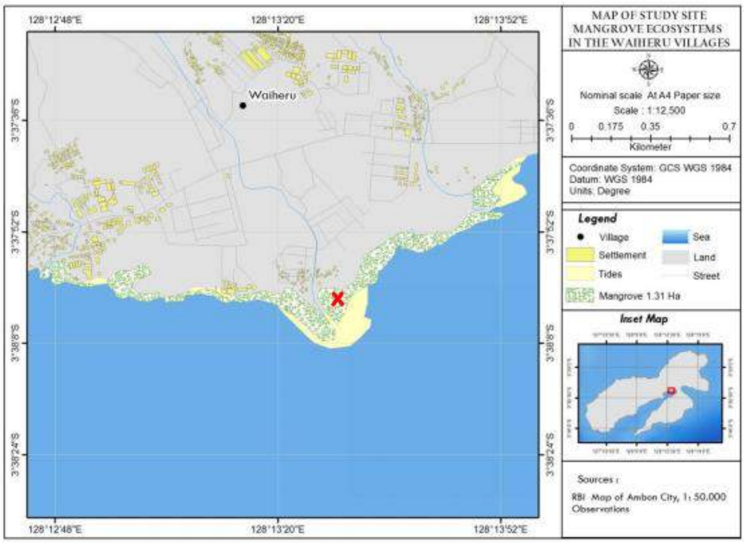

Figure 1. Map of the research site (x)

In general, the condition of the mangrove ecosystem in Waiheru coastal zone is influenced by the input of runoff from the adjacent, which impacts the fluctuation of the water salinity. The habitat of the mangrove ecosystem around the inner Ambon bay has a salinity ranging from 30 to 34.3 ppm [20]. However, during the rainy season, with the rainfall ranging from 292 – 330 mm/day, the salinity drops between 29 and 32 ppm. The dominant mangrove species in the study area are *B. cylindrica*, *R. apiculata*, *S. alba*, *C. tagal*, *A. alba*, and *Osbornia octodonta* [18, 19], and silt and silty sand are the dominant type of sediments [11, 12, 16, 17].

2.2. Gas collection

The gas carbon (CO_2 and CH_4) was collected by placing a chamber (17L) under the mangrove canopy on different substrates, such as muddy sand, sandy mud, and sand substrate. Gas was collected from the chamber using a syringe and put into the 10 mL bottles (Figure 2). The time interval of gas collection in each type of substrate was 30 seconds (0s, 30s, 60s, 90s, and 120s). The same method was repeated twice in each type of substrate. All samples were kept in the box for further analysis in the laboratory.

Figure 2. Gas trapped using a chamber

2.3. Samples Analysis

2.3.1. Carbon gas concentration

The concentration of CO_2 and CH_4 gas was analyzed using the gas chromatography method. In the analysis of CO_2 gas concentration, 2 ml of gas flowed through a thermal conductivity detector (TCD) for 5 minutes, which is done or three replication. Meanwhile, for CH_4 gas analysis, 3 ml of gas flowed through the flame ionization detector (FID) for 2 minutes with three replication (Fig. 3). The measurement of carbon gas concentrations was carried out at the Laboratory of the Agricultural Environmental Research Institute, Pati Regency – Central Java.

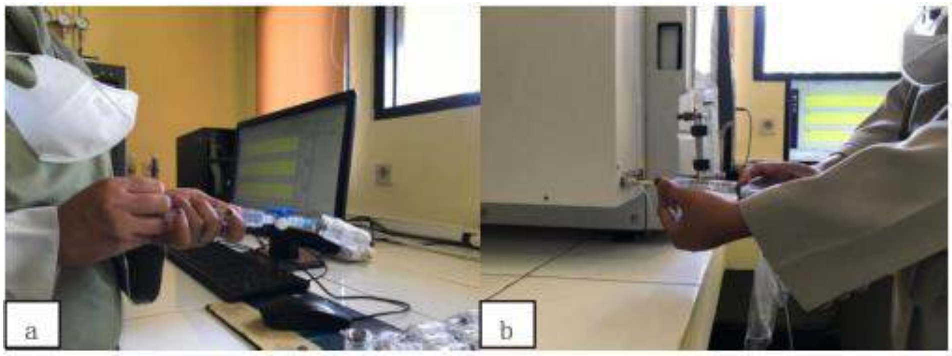

Figure 3. Measurement of carbon concentration using GC-MS; a.) 2-3ml carbon was taken from the bottle using injection b) the measurement of carbon using GC-MS.

2.3.2. Emission of carbon gases

The emission of carbon gases was calculated using the formula [14]:

$$F = \left| \frac{S * V * t * mW}{(RT * A)} \right|$$

Where: F=flux of CO_2 and CH_4 ($mg.m^{-2}.h^{-1}$), *S*=regression slope of carbon gas concentration every 30 seconds ($ppm.s^{-1}$), V=chamber volume (L), A=total area covered by chambers (m^2), R= constanta of ideal gas (0.082 $L.atm.K^{-1}.mol^{-1}$), T = temperature chamber or air temperature (K), t= Constanta of time transformation (1 hour/time interval of sampling time of gas), and mW = relative atomic mass of CO_2= 44 $g.mol^{-1}$ and CH_4 = 16 $g.mol^{-1}$

2.3.3. Global Warming Potential (GWP) of carbon

The GWP of greenhouse gasses is equivalent to the radiation of CO_2 concentration in the atmosphere [10]. GWP is equivalent to greenhouse gas radiation at 100 years [9]. The value of the GWP of carbon was analyzed using the formula [9]:

$$F_e = Fm \ x \ GWP$$

Where: F_e =value of flux CO_2-equivalent ($mg.m^{-2}.h^{-1}$), which is equal to a value of global warming potential, *Fm*=flux of CH_4 ($mg.m^{-2}.h^{-1}$), *GWP* =value of global warming potential of carbon which was converted from emission value per mol of CH_4, equivalent to 25 times CO_2-eq emission at 100 years.

2.4. Statistical Analysis

A single-factor ANOVA test was performed to test the difference in average carbon (CO_2 and CH_4) concentration from different types of mangrove sediment.

3. Result and Discussion

3.1. Carbon gas concentration

The concentration of CO_2 gas resulting from the activity of organic matter degradation in mangrove sediments shows different results between those found in sandy mud, muddy sand, and sand substrates. The average concentration of CO_2 gas was 593 ppm in sandy mud sediments, 609.33 ppm in muddy sand sediments, and 525.39 ppm in sand sediments (Fig. 4).

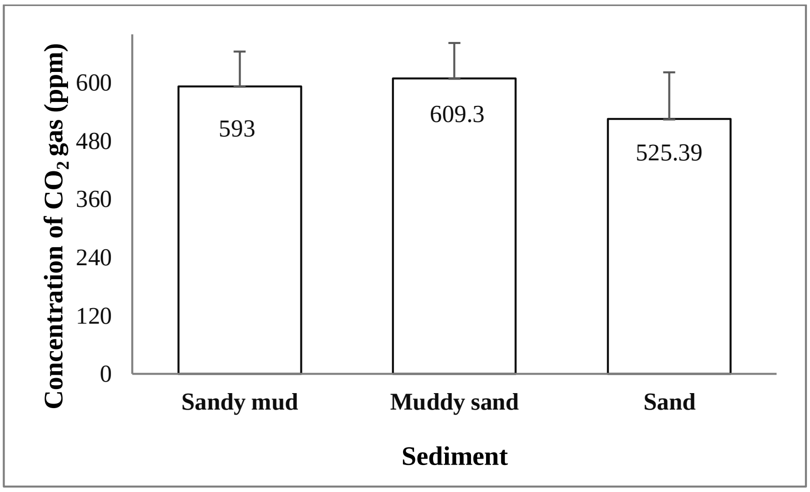

Figure 4. CO_2 concentrations from different types of mangrove sediment at the coastal zone of Waiheru.

Unlike CO_2 gas, the largest and smallest concentrations of CH_4 gas are found in muddy sand sediments and sand sediments, respectively. The value of CH_4 gas concentration in each sediment is 1.83 ppm for sandy mud sediment, 2.05 for muddy sand sediment, and 1.81 for sand sediment (Fig. 5).

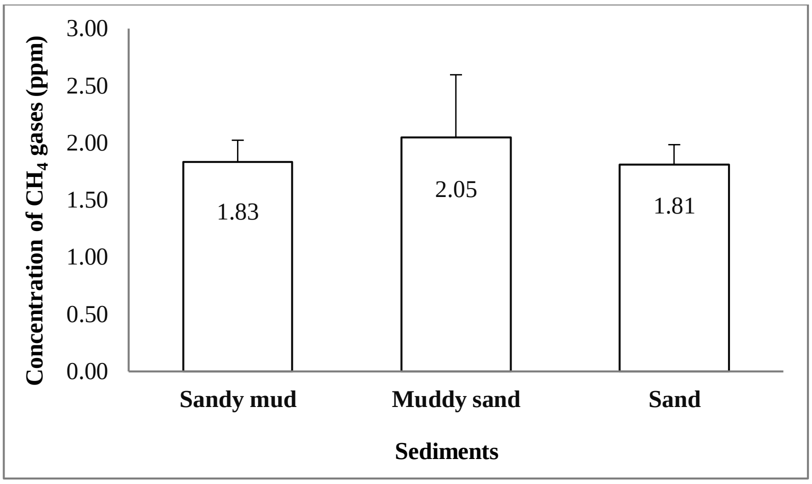

Figure 5. CH_4 concentrations from different types of mangrove sediment at the coastal zone of Waiheru.

Differences in concentrations of CO_2 and CH_4 gases in mangrove sediments indicate differences in organic matter content in each mangrove sediment [9, 13]. High organic matter content requires a longer decomposition process, so oxygen availability will not support the decomposition process. As a result, the decomposition process runs anaerobically and triggers increased CO_2 concentrations from the reduction of acetic, propionic, and lactic acids present in mangrove debris [11]. The formation of CH_4 gas occurs through a methanogenic process due to the accumulation of organic matter that is not proportional to the availability of oxygen in mangrove sediments.

The results of the variance test analysis (ANOVA single factor) showed that the average CO_2 gas concentration in the three sediments was significantly different from the F-value (4.02) > the critical F (3.35) (Table 1). It shows that the mean concentration of CO_2 gas resulting from the degradation of organic matter in each sediment is different. Significant differences in average CO_2 gas concentrations were also seen in the variance test between sandy mud and sand (F-value > F critical = 4.5819 > 4.4139) and between muddy sand and sand (F-value > F critical = 4.8379 > 4.4139). Meanwhile, the average concentration of CO_2 gas between sandy mud and muddy sand did not differ significantly or the same (F-value < F critical = 0.2564 < 4.4139) (Table 1).

In contrast to CO_2 gas, the average CH_4 gas concentration was not significantly different between all sediments where $P\text{-}_{\text{values}} < 0.05$ (Table 1). It shows that the process of forming CH_4 gas in all types of sediments takes place through the ethanol reduction process, not solely through the methanogenic process [22].

Table 1. Analysis of variance of CO_2 and CH_4 gas concentrations in several types of mangrove sediments in the coastal of Waiheru, inner Ambon Bay - Ambon

Gases	Sediment	*F-value*	*F-critical*	*P-values*
CO_2	Sandy mud: Muddy Sand: Sand	4.0213[a]	3.3541	>0.05
(n=10 - 30)	Sandy mud: Muddy Sand	0.2564[b]	4.4139	<0.05
	Sandy mud: Sand	4.5819[a]	4.4139	>0.05
	Muddy sand: Sand	4.8379[a]	4.4139	>0.05
CH_4	Sandy mud: Muddy sand: Sand	1.4409[a]	3.3541	<0.05
(n=10 - 30)	Sandy mud: Muddy sand	1.4019[a]	4.4139	<0.05
	Sandy mud: Sand	0.0851[a]	4.4139	<0.05
	Muddy sand: Sand	1.7579[a]	4.4139	<0.05

Remarks: a is significantly different, and b is not significantly different at the 0.05 significant values

3.2. CO_2 emission

Although the largest average concentration of CO_2 gas is found in muddy sand sediments, the most significant CO_2 emission is found in sandy mud sediments with an emission value of 136.99 $mg.m^{-2}.h^{-1}$. The lowest CO_2 emission was found in sand sediments, which was 13.01 $mg.m^{-2}.h^{-1}$ (Fig. 6). This difference is caused by fluctuations in CO_2 gas concentrations at each gas sampling interval of 30 seconds. This study's results align with reports [9] and [13], which state that CO_2 gas emissions in mud or sandy mud sediment types are more significant than in muddy sand and sand sediment types. This emission value is higher than the average total CO_2 gas emission found in the West Muna mangrove ecosystem, which ranges from 16.44 – 38.28 $mg.m^{-2}.h^{-1}$ [13], and lower when compared to CO_2 emissions. in the Tallo River - Makassar mangrove ecosystem, with CO_2 gas emission values ranging from 194.33 $mg.m^{-2}.h^{-1}$ [10].

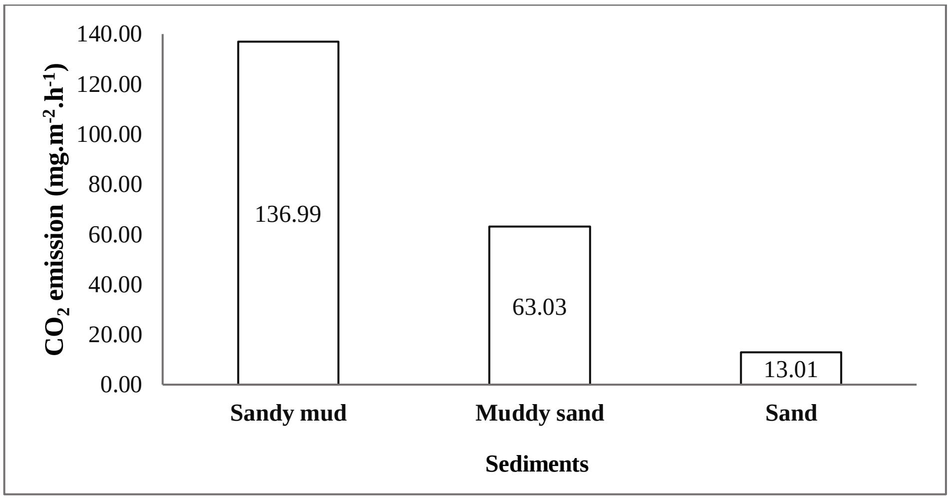

Figure 6. CO_2 emission at the different types of mangrove sediment in the study area

Differences in sediments show differences in total soil carbon, bulk density, and salinity [24]. *B. cylindrica* species live on muddy substrates, so that mangrove litter degradation can occur faster than in sandy sediment types [24, 25]. In addition, the value of CO_2 emissions is generally influenced by the frequency and duration of rain during the observation. The influence of the frequency and duration of the rain causes the decomposition process of organic matter to be faster, thus triggering an increase in CO_2 emissions.

CO_2 emissions in mangrove ecosystems are generally influenced by two factors, namely internal and external. Internal factors such as temperature and salinity affect the rate of acidogenic reactions in the litter decomposition process and the formation of CO2 gas [13, 22]. External factors are the input of organic and fresh waste, which increases the amount of organic matter that must be decomposed, thereby increasing the production of CO_2 gas [13, 25, 27, 28].

Seasons also spatially and temporally influence CO_2 gas emissions in mangrove ecosystems. The length of sunlight in summer causes an increase in water temperature which triggers the rate of microorganism activity in the reaction to form CO_2 gas [21, 29]. The same goes for the duration and frequency of heavy rains. The degradation process of organic matter and mangrove debris becomes faster during the rainy season because it can reduce the water salinity between 25 and 28 ppm in the mangrove ecosystem to an optimal value for the process of litter degradation [13].

3.3. Gas CH_4 emission

Muddy sand sediments contributed the most significant CH_4 emission (0.32 $mg.m^{-2}.h^{-1}$), while the lowest CH_4 gas emission was in sandy mud sediments, 0.15 $mg.m^{-2}.h^{-1}$ (Fig. 7) . The value of CH_4 gas emissions is higher than gas emissions in mangrove sediments in North India reported by [29], with CH_4 gas emission values of 0.0003 – 0.0004 mg.m^{-2}.h^{-1}. However, it is much lower than the average emission in mangrove sediments in the Tallo - Makassar River, which is 6.68 mg.m^{-2}.h^{-1} [12]. The difference in fluctuations in CO_2 and CH_4 gas emissions in each sediment (Fig. 8) shows that decomposing glucose to form CO_2, a further reaction occurs, namely the formation of CH_4 gas by utilizing CO_2 gas [10,11].

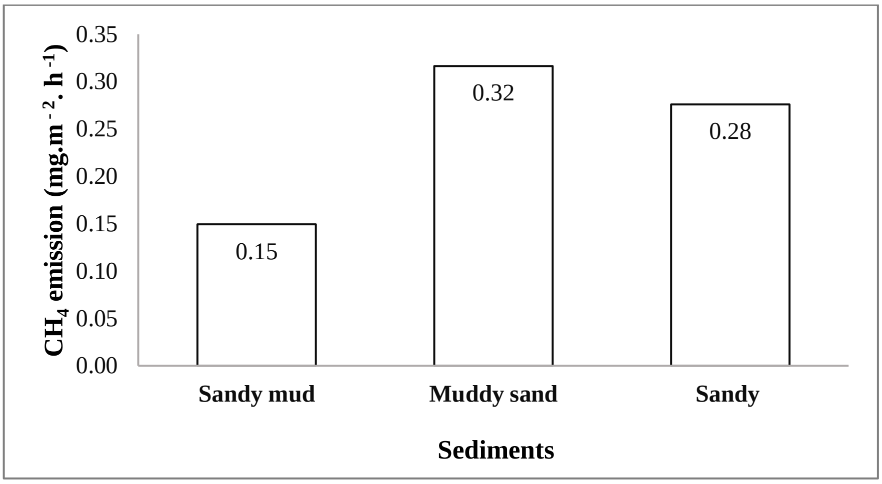

Figure 7. CH_4 gas emissions on several types of mangrove sediments in the coastal of Waiheru.

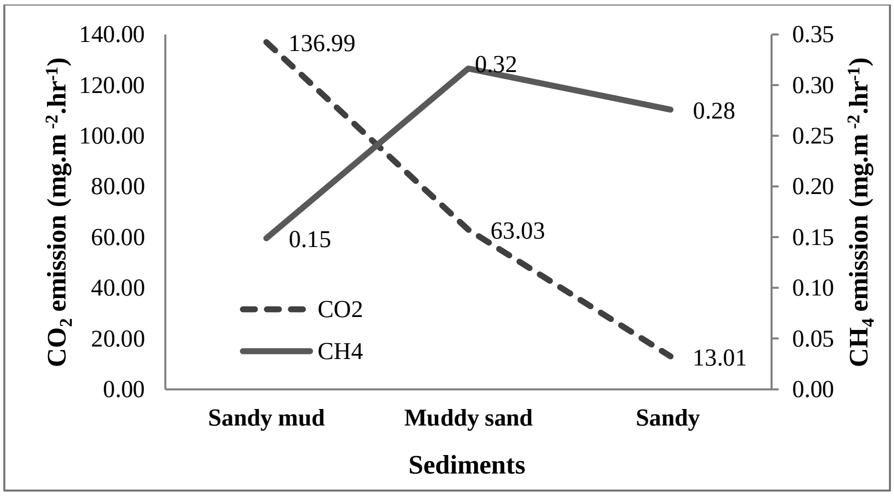

Figure 8. Comparison of fluctuations in CO_2 and CH_4 gas emissions in different types of mangrove sediments in the coastal of Waiheru.

CH_4 gas has not been optimally produced in methanogenic processes. Most of the CH_4 gas formation resulted from the reduction of CO_2. However, the input of organic matter from human activities can trigger a reduction in oxygen for aerobic waste decomposition so that a methanogenic anaerobic reaction will occur to form more significant CH_4 gas [10].

Internal and external factors generally influence CH_4 emissions in mangrove ecosystems. Internal factors such as temperature and salinity affect the rate of acidogenic reactions and methanogenic in the litter and organic matter decomposition, and CH_4 gas formation [30, 31]. External factors are the input of organic and fresh waste, which increases the amount of organic matter that must be decomposed, thereby increasing the production of CH_4 gas [25, 27]. Increased nutrients and organic matter in mangrove ecosystem areas can be influenced by anthropogenic activities [29]. Organic matter accumulated in mangrove sediments can increase the amount of total organic carbon, which is a significant factor in the formation of methane gas in mangrove ecosystem areas [30].

3.4 Global Warming Potential

Carbon gas is the main contributor that can trigger climate change [8]. Several factors, such as fossil burning, fuel use, forest conversion, and the degradation of organic waste, trigger the increase in carbon gas in the atmosphere. The carbon gas concentration also increases due to natural processes such as litter degradation in mangrove sediments [30].

The GWP in the mangrove sediments of the Waiheru coastal area is 231.58 mg.m^{-2}.h^{-1}. The highest contributed by the sandy mud sediment type (140.72 CO_2-eq mg.m^{-2}.h^{-1}). and sand sediments contributed the lowest (19.91 CO_2-eq mg.m^{-2}.h^{-1}) (Table 2).

Table 2. The GWP of carbon produced from different types of mangrove sediment in Waiheru coastal area

Sediments	**Carbon emission (mg.m^{-2}.hr^{-1})**		**GWP (mg.m^{-2}.h^{-1})**
	CO_2	CH_4	CO_2-eq
Muddy sand	136.99	0.15	140.72
Sandy mud	63.03	0.32	70.95
Sand	13.01	0.28	19.91
Total	213.04	0.74	231.58

The total GWP value is lower than the GWP value of mangroves in Honda Bay - Philippines, namely 8606.88 mg.m^{-2}.h^{-1} [31] and mangrove ecosystems in Twin Bays - Central Belize with GWP values ranging from 332.63 - 1203, 84 CO_2-eq mg.m^{-2}.h^{-1} [28], and the GWP of the mangroves of the Tallo – Makassar river is 346.71 mg.m^{-2}.h^{-1} [10]. The GWP value of the mangrove sediments of Waiheru coastal area is greater than the GWP in the coastal mangrove ecosystem of the Northeast Bay of Bengal - India, with CO_2-eq values ranging from 0.03 to 2.06 mg.m^{-2}.h^{-1} [33].

4. Conclusion

The average CO_2 gas concentration was significantly different for each sediment (P-value < 0.05), while the average CH_4 gas concentration was not significantly different (P-value > 0.05). The largest CO_2 gas emission in mangrove sediments in Waiheru coastal area was found in sandy mud sediments with an emission value of 136.99 mg.m^{-2}.h^{-1}, and the lowest was in sand sediments, namely 13.01 mg.m^{-2}.h^{-1}. Meanwhile, the largest emission of CH_4 gas was in muddy sand sediments, namely 0.32 mg.m^{-2}.h^{-1}, and the lowest was in sandy mud sediments, namely 0.15 mg.m^{-2}.h^{-1}. Fluctuations in carbon gas emissions in each sediment are inversely proportional, which indicates that the formation of CH_4 gas is obtained through ethanol reduction, which utilizes CO_2 gas concentrations. The total GWP in the mangrove sediments of Waiheru Village is 231.58 mg.m^{-2}.h^{-1}. The GWP contributed by the type of sandy silt sediment was 140.72 CO_2-eq mg.m-2.h-1, muddy sand was 70.95 mg.m^{-2}.h^{-1}, and sand sediment was 19.91 CO_2-eq mg.m^{-2}.h^{-1}.

Acknowledgement

The authors would like to thank the students of Marine Science Study Programs, who helped us in the field with data collection. This research was funded by PNBP 2022 of Pattimura University to IK, R, and SH.

Reference

[1] Badjeck M C, Allison E H, Halls A S, Dulvy N K 2010. Impacts of climate variability and change on fishery-based livelihoods. Mar Pol. **34**: 375 – 83.

[2] Shawket N, Elmadhi Y, Kharrim K E, Belghyti D 2019. Impacts of climate change on fish performance. *J Entomol Zoo Stud*; **7**: 343 – 49.

[3] Cintra AKA, Setyobudiandi I, Fahrudin A. 2017. Analisis kerentanan perikanan tangkap akibat perubahan iklim pada skala propinsi. *Marine Fisheries.* 8(2): 223-233.

[4] Finney B.P, Gregory-Eaves I., Sweetman J, Dougas M.S.V, Smol J.P. 2000. Impacts of climatic change and fishing on Pacific salmon abundance over the past 300 years. Science, 290, 795-799.

[5] Ohwayo R.O, Natugonza V., Musinguz, L., Olokotum M., Naigaga S. 2016. Implications of climate variability and change for African lake ecosystems, fisheries productivity, and livelihoods. *J Great Lakes Res*; **42**: 498 – 510

[6] Asch R G, Cheung W W L, Reygondeau G. 2017. Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. *Mar Pol*; http://dx.doi.org/10.1016/j.marpol.2017.08.015.

[7] Lang M., Cai Z.C., Chang S.X. 2011. Effects of land use type and incubation temperature on greenhouse gas emissions from Chinese and Canadian Soils. *J Soil Sed*; **11**: 15-24.

[8] IPCC Climate Change. 2001. *The Intergovernmental panel on climate change on a scientific basis*. (Cambridge UK: Cambridge University Press)

[9] Oertel C., Matschullat J., Zurba, K., Zimmermann, F., Erasmi, S. 2016. Greenhouse gas emissions from soils - a review. *Chemie der Erde*; **76**: 327-52.

[10] Rahman, Yulianda F, Rusmana I, Wardiatno Y. 2018. Fluks gas rumah kaca CO_2, CH_4, and N_2O dari sedimen mangrove di Sungai Tallo, Makassar. *J Trop Biol*; **18**: 149 – 58.

[11] Rahman., Yulianda F., Rusmana I., Wardiatno Y., Bengen D.G.B. 2020e. Metode dan Analisis Studi Ekosistem Mangrove. IPB Press. 124p.

[12] Rahman, Effendi H, Rusmana I. 2017. Estimasi stok dan serapan karbon mangrove di Sungai Tallo, Makassar. *J of Forests Science.* **11**: 19 – 28.

[13] Alongi D.M., 2014 Carbon cycling and storage in mangrove forests. Ann. Rev. of Mar. Sci. 195 – 219. https://doi.org/10.1146/annurev-marine-010213-135020.

[14] Rahman, Wardiatno Y, Yulianda F, Rusmana I 2020d Seasonal fluxes of CO_2, CH_4 and N_2O greenhouse gases in various mangrove species on the coast of West Muna Regency, Southeast Sulawesi, Indonesia. *Plant Archives.* **20**(2): 4301 – 4311.

[15] Nugraha W.A. 2010 Produksi serasah (guguran daun) pada berbagai jenis mangrove di Bangkalan. *Jurnal Kelautan*. **3**(1): 66 - 69.

[16] Ilman M.P, Dargusch P, Dart P, Onrizal. 2016. A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. *Land Use Pol*; **54**: 448 – 59.

[17] Rahman, Wardiatno Y, Yulianda F, Rusmana I. 2020a. Socio-ecological system of carbon-based mangrove ecosystem on the coast of West Muna Regency, Southeast Sulawesi, Indonesia. *AACL Bioflux*. **13**(2): 518-528.

[18] Suyadi. 2009. Kondisi hutan mangrove di Teluk Ambon: prospek dan tantangan. *Berita Biologi*. **5**(9): 481 – 490.

[19] Suyadi. 2012. Satu dekade kondisi hutan mangrove di Teluk Ambon. *Jurnal Biologi Indonesia.* **8**(1): 197 – 203.

[20] Gemilang W.A, Rahmawan G.A., Wisha, U.J. Kualitas perairan Teluk Ambon Dalam berdasarkan parameter fisika dan kimia pada musim peralihan I. *EnviroScienteae.* **13**(1): 79 – 90.

[21] Chen G.C, Tam N.F.Y, YeY. 2012. Spatial and seasonal variations of atmospheric N_2O and CO_2 fluxes from a subtropical mangrove swamp and their relationships with soil characteristics. *Soil Biol Biochem*. **48**: 175 – 81.

[22] Alongi D.M, Sasekumar A, Chong V.C, Pfitzner J, Trott L.A, Tirendi F, Dixon P, Brunskill G.J. 2004. Sediment accumulation and organic material flux in a managed mangrove ecosystem: estimates of land-ocean-atmosphere exchange in peninsular Malaysia. *Mar Geol*; **208**: 383 – 402.

[23] Alongi D.M, Pfitzner J, Trott L.A, Tirendi F, Klumpp D.W. 2005. Rapid sedimentation and microbial mineralization in the Jiulongjiang estuary mangrove forest, China. *Estuar Coast Shelf Sci.* 63: 605 – 18
[24] Abril G, Borges A.V. 2005. Carbon dioxide and methane emissions from estuaries. In Greenhouse gas emissions – fluxes and process. (187 – 207) Springer, Berlin, Heidelberg.
[25] Kim Y. 2015. Effect of thaw depth on fluxes of CO_2 dan CH_4 in manipulated Arctic coastal tundra of Barrow, Alaska. *Sci Tot Environ*; **505**: 385 – 9.
[26] Kristensen E, Flindt M.R, Ulomi S, Borges A.V, Abril G, Bouillon S. 2008. Emission of CO_2 and CH_4 to the atmosphere by sediments and open waters in two Tanzanian mangrove forests. *Mar Ecol Prog Ser*; **370**: 53 – 67.
[27] Lovelock C.E, Ruess R.W, Feller I.C. 2011. CO_2 efflux from cleared mangrove peat. *PLoS ONE* 6 (6), e21279.
[28] Chen G.C, Tam N.F.Y, Ye Y. 2010. Summer fluxes of atmospheric greenhouse gases N_2O, CH_4 and CO_2 from mangrove soil in South China. *Sci Tot Environ*; **408**: 2761 – 7.
[29] Prayitno, H.B. 2016. Methane formation in mangrove sediment. *Oseana*. **41**(3): 44 – 53.
[30] Lin C.W, Kao YC, Chou M.C, Wu H.H, Ho C.W, Lin H.J. 2020. Methane emissions from subtropical and tropical mangrove ecosystems in Taiwan. *Forests.* **11** (470): doi:10.3390/f11040470
[31] Castillo J.A.A, Apan A.A, Maraseni T.N, Salmo S.G. 2017. Soil greenhouse gas fluxes in tropical mangrove forests and land use on deforested mangrove lands. *Catena*; **159**: 60 – 9.
[32] Rahman, Effendi H, Yulianda F, Rusmana I, Wardiatno Y. 2020b. Pengelolaan ekosistem mangrove untuk ruang terbuka hijau sebagai mitigasi gas rumah kaca di kawasan Sungai Tallo Kota Makassar. *J Nat Resources and Environ Manag.* **10**(2): 320 – 328.
[33] Biswas H, Mukhopadhyay S.K, Sen S, Jana T.K. 2007. Spatial and temporal pattern of methane dynamics in the tropical mangrove dominated estuary, NE coast of Bay of Bengal, India. *J Mar Syst*; **68**: 55 – 64.