International Journal of Sustainable Development and Planning
Vol. 20, No. 3, March, 2025, pp. 1199-1205
Journal homepage: http://iieta.org/journals/ijsdp

Mapping Potential Carbon Stocks and CO_2 Emissions Due to Land Cover Change in the Wanggu Watershed

La Ode Alwi[1*], La Gandri[2], Lies Indriyani[2], Agusrinal[2], Vivi Fitriani[3], Musram Abadi[4], Ridha Nabila Yamin[5]

[1] Department of Agribusiness, Halu Oleo University, Kendari 93232, Indonesia
[2] Department of Environment Science, Halu Oleo University, Kendari 93232, Indonesia
[3] Department of Soil Science, Jember University, Jember 68121, Indonesia
[4] Department of Animal Science, Halu Oleo University, Kendari 93232, Indonesia
[5] Department of Environment Science Student, Halu Oleo University, Kendari 93232, Indonesia

Corresponding Author Email: alwiode76@gmail.com

https://doi.org/10.18280/ijsdp.200325

Received: 20 October 2024
Revised: 6 February 2025
Accepted: 7 March 2025
Available online: 31 March 2025

Keywords:
land use, stock carbon, emission CO_2, Wanggu Watershed

ABSTRACT

Rapid land use change in the Wanggu Watershed also impacts the condition of carbon stocks and emissions. Geographic information systems have been widely used to estimate carbon uptake and storage for various types of land use, but research on carbon emissions and stocks as a result of land use change is still limited land use change is still limited, particularly including in the Wanggu Watershed. This study aims to determine the amount of carbon emissions and stocks as an impact of land use change in the Wanggu Watershed. The method used is the technique of overlaying time series data of land use and then an analysis of emissions and carbon stocks based on carbon stock coefficients based on land use. The results showed that land cover changes in the Wanggu Watershed have significantly impacted carbon stocks and CO_2 emissions. In 2022, the total carbon stock was recorded at 2,041,789 tonnes C, while emissions reached 5,015,794 tonnes CO_2, originating from nine land cover types, including dryland forests, secondary mangrove forests, plantations, agricultural lands, settlements, open land, and paddy fields. Between 1990 and 2022, these changes have substantially altered carbon dynamics, with forest degradation contributing 798,352 tonnes CO_2, a significantly larger share than deforestation, which accounted for 107,159 tonnes CO_2.

1. INTRODUCTION

Watersheds, as biodiversity-rich landscapes and important natural environments [1], face serious challenges related to land cover change, particularly through deforestation and forest degradation. These changes not only threaten ecosystem sustainability but also have profound impacts on potential carbon stocks and emissions. The negative impacts of land use change influence local ecological systems and environments that will affect terrestrial carbon stocks [2-4]. Continued deforestation and changes in land use represent significant developments, with potentially major consequences for global climate change.

The complexity of the problem of land use change in watersheds has caused simultaneous climate change impacts [5], especially in urban watersheds such as watersheds. Wanggu in Kendari City, Southeast Sulawesi Province. As the heart of the biodiversity-rich ecosystem closest to the capital, an in-depth understanding of changes in the Wanggu Watershed is crucial for climate change mitigation efforts. Changes in land use patterns in the Wanggu Watershed have resulted in a reduction in the area of forests and shrubs every year, while there is an increase in the area of mixed gardens, agricultural land (moor/rice fields), and settlements every year [2]. The results of a previous study [6] in 2023 on indicators of land carrying capacity in the Wanggu Watershed revealed that this watershed has poor land performance in its management. Land indicator parameters that contribute to suboptimal management include high critical land area, low vegetated land cover, especially in forest areas, and high erosion index values. These conditions not only threaten environmental sustainability but also the environment. These not only threaten environmental sustainability, but also increase the potential for greenhouse gas emissions and contribute to regional climate change.

In addition to impacts on environmental sustainability, the poor condition of land management in the Wanggu Watershed also has significant implications related to the research objectives that focus on the potential for carbon stocks and CO_2 emissions. The extent of critical land and low vegetated land cover, especially in forest areas, can affect the potential for carbon sequestration by the ecosystem. Conversely, high erosion index values can increase the potential for CO_2 emissions into the atmosphere. Therefore, an in-depth understanding of these land conditions is crucial in designing management strategies that support environmental sustainability and optimize ecosystems' capacity to store carbon and reduce greenhouse gas emissions.

The utilization of Geographic Information System (GIS) technology is key to monitoring and analyzing aboveground carbon emission data series, especially in the context of the Wanggu Watershed. GIS enables accurate spatial data integration and detailed mapping of carbon emission sources [7, 8]. Using GIS, we can precisely identify the location and trends of changes in carbon emissions, providing a solid basis for evidence-based decision-making. In addition, GIS enables effective data visualization, facilitating a better understanding of the spatial patterns of carbon emissions and their potential influence on the carbon balance in the Wanggu Watershed. Thus, utilizing GIS technology not only improves monitoring accuracy but also supports sustainability planning and more effective land management.

2. LITERATURE REVIEW

In the book Soil Carbon Pools and World Life Zones, previous studies [9, 10] found that soil has an important role in storing carbon and changes in land use can disrupt the carbon balance in the soil, which causes large amounts of carbon to be emitted into the atmosphere. In a review of the book Srchelesinge [11] in 1997, discussing the interaction between the biogeochemistry of soil, vegetation and the atmosphere in the global carbon cycle, this book explains that the carbon available in the soil is influenced by human activities which cause changes in land use such as urbanization and intensive agriculture which can cause an increase in the concentration of carbon dioxide in the atmosphere which can influence global warming [11]. A study conducted in 2000 [12] found that the process of burning and decomposing biomass as well as converting tropical forests to shifting cultivation and secondary vegetation causes the release of carbon from the soil and emits large amounts of greenhouse gases which have the potential to increase the amount of CO_2 emissions in the atmosphere.

Research on carbon stock estimation and CO_2 emissions has been widely conducted in various ecosystems in Indonesia. Such as in research in the Forest ecosystem in West Kalimantan, by estimating carbon stocks and CO_2 emissions due to forest damage, this study found that CO_2 emissions of 163,702,815.53 tons occurred due to deforestation and forest degradation during 1990 to 2021, the highest CO_2 emissions were found in Batu Ampar District while the lowest emissions were found in Sungai Kakap District [13]. Another study conducted in 2021 [14] found that changes in land cover were the sector that contributed the most to emissions due to changes in the area of secondary dryland forests which caused fluctuations in carbon stocks which were also caused by an increase in open land and settlements. Likewise, research in Gambut District which estimated carbon dioxide absorption due to changes in land cover, found that changes in land cover from vegetation to non-vegetation had an effect on reducing carbon absorption, especially in protected forests [13]. Several studies that have been mentioned estimate carbon stocks and CO_2 emissions from changes in forest land cover due to deforestation and degradation but do not explicitly provide information on how to calculate changes in carbon absorption capacity through analysis of carbon stock changes due to deforestation and degradation, and do not explicitly explain how deforestation and degradation cause large differences in emissions produced. In addition, previous studies have focused on anthropogenic pressures and on administrative areas, there are still few that have conducted research on river basin areas as areas that have complex and unique land use dynamics. So that in this study conducted in the Wanggu Watershed, it will explicitly explain how changes in carbon stock values and land carbon coefficients due to deforestation and degradation, that can provide information on changes in carbon stocks and CO_2 emissions produced specifically due to deforestation and degradation of forest land. The study focuses on the Wanggu Watershed which is a conservation area that affects the surrounding area. This study will highlight the role of degradation and deforestation in influencing the ability of land vegetation to absorb carbon and the release of carbon into the atmosphere through CO_2 emissions.

3. METHODS

This research will be conducted from July to June 2023, located along the Wanggu Watershed in Kendari City, Southeast Sulawesi Province. The research location map is shown in Figure 1.

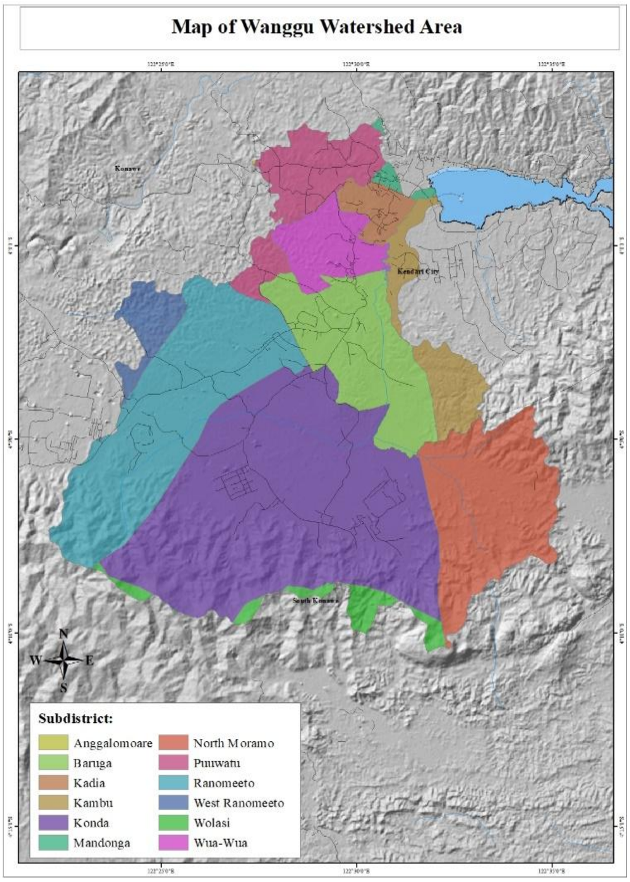

Figure 1. Wanggu Watershed area, Southeast Sulawesi Province

3.1 Total carbon stock

To estimate carbon stocks, the ICLEI approach formula is used based on the carbon stock coefficient, after knowing the land use area than multiplying by the carbon stock coefficient of each land use that is referred to in Table 1. The ICLEI Formula is followed by Eq. (1) [15].

$$TCS = annual\ activity\ data \times CSC \quad (1)$$

where, *TCS* is Total Carbon Stock per year (Ton), *CSC* is land Cover Carbon Stock Coefficient (Ton/Ha), and *annual activity data* is land cover area (Ha).

Table 1. Carbon stock coefficient values by type of land use

No.	Land Cover Class	Carbon Stock Coefficient (Ton C/Ha)
1	Primary dryland forest	195.4
2	Secondary dryland forest	169.7
3	Primary Swamp Forest	196
4	Secondary Swamp Forest / felling scars	155
5	Primary mangrove forest	170
6	Secondary mangrove forest / felling scars	120
7	Forest Plantation	64
8	Plantation/ Garden	63
9	Shrubs	30
10	Swamp Shrubs	30
11	Savanna / Grassland	4.5
12	Dryland farming	10
13	mixed bush/ mixed garden	30
14	Paddy field	2
15	Pond	0
16	Built-up land	5
17	Transmigration	10
18	Open Land	2.5
19	Mining	0
20	Water Body	0
21	Swamp	0
22	Clouds	0
23	Airport / Port	0

Source: [15]

3.2 CO_2 emission

The ability to emit or absorb greenhouse gases from land category units is converted in tons of CO_2/Ha/year, for land-based sectors including forestry, activity data is the area of each absorption-emission category [16]. Emission factors are obtained using reference (default) data on carbon stocks from all land covers. Estimation of potential CO_2 emission values is based on the method recommended by the IPCC, where the estimation of carbon emissions is the product of carbon stock by 3.67 or 44/12 to obtain an equivalent value for Carbon Dioxide Equivalent (CO_2-eq). Estimation of Potential CO_2 Emission Values based on Eq. (2) [16].

$$CO_2Emission = \left(CSC \times \frac{44}{12}\right) \times activity\ data \quad (2)$$

where, $CO_2\ Emission\ in\ Ton\ \ of\ \ CO_2$, $CSC \times \frac{44}{12}$ is the emission factor that obtained from changes in the carbon stock coefficient value multiplied by the Carbon equivalent value for CO_2, *activity data* is area of land cover change.

Emission factors and activity data are based on changes in land cover due to deforestation and land degradation from 1990 to 2020. Emission factors for deforestation are based on changes in the carbon stock coefficient value of primary forest to secondary forest, while emission factors for land degradation are based on changes in the value of forest carbon stock coefficient to non-forest. Activity data is the area of land cover change experiencing deforestation or degradation [15].

4. RESULT AND DISCUSSION

The land cover of the Wanggu Watershed in 2022 has 13 types of land cover from the lowest land cover to the highest land cover. The lowest land cover type is Secondary Mangrove Forest with an area of 23.72 ha or 0.07%, Airport 59.42 ha (0.18%), mining 27.01 ha (0.08%), Open Land 84.13 ha (0.25%), Water Body 96.76 ha (0.29%), Pond 99.87 ha (0.29%), Plantation 428.53 ha (1.26%), Rice Fields 3,138.99 ha (9.25%), Dry Land Agriculture Mixed 3,870.79 ha (11.40%), Built-up Land 4,622.99 ha (13.62%), Dryland Agriculture 5,623.04 ha (16.56%), Shrubs 6,930.86 ha (20.42%), and the highest land cover type is Secondary Dryland Forest with an area of 8,941.33 ha or 26.34%, so that the total land cover of the Wanggu Watershed in 2022 is 33,947.45 ha (100%) (Figure 2).

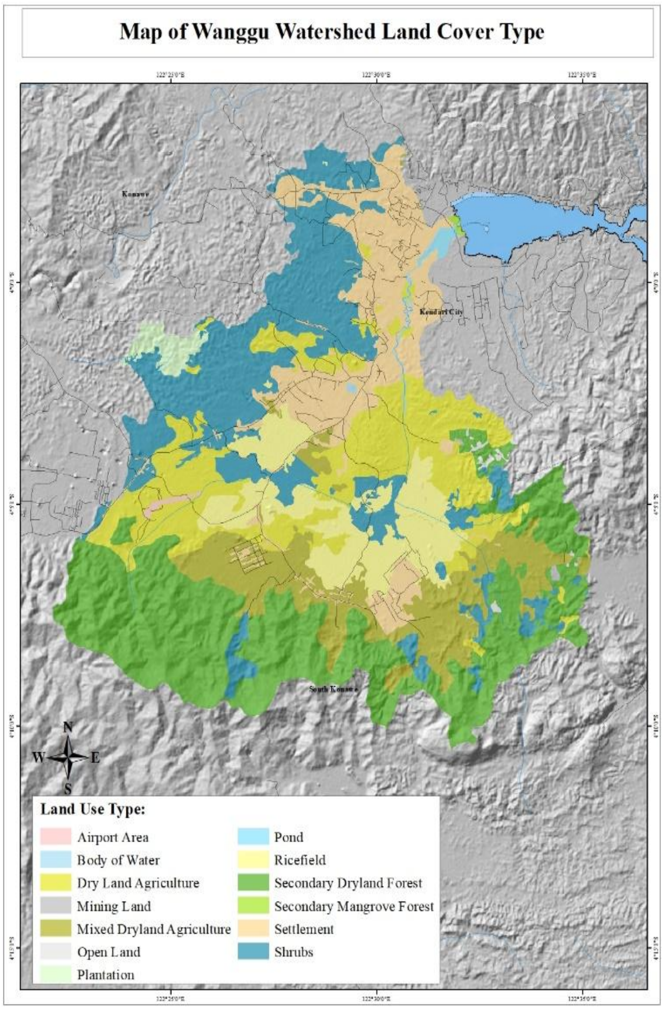

Figure 2. Land cover of Wanggu Watershed in 2022

4.1 Analysis of land cover, carbon stock and potential CO_2 emissions in the Wanggu Watershed in 2022

The development of trends of changes in carbon potential values can indicate that there are changes in land cover and a decline in forest quality in the Wanggu Watershed, Southeast Sulawesi. Estimation of changes in carbon stocks were carried out using spatial analysis of activity data and carbon stock/emission factor data for each class of land cover in the Wanggu Watershed. The analysis results are presented in Table 2.

Table 2. Land cover, carbon stock and potential CO_2 emissions in the Wanggu Watershed in 2022

Code	LC	Area	CSC	EF	TCS	PE
Bdr	Airport	59.8	0	0	0	0
Hp	Primary dryland forest	0	137.62	504.6	0	0
Hs	Secondary dryland forest	8,994	103.26	378.6	1,000,233	3,405,303
Hrs	Secondary Mangrove Forest	24	188.3	690.4	20,336	16,467
Pm	Settlement	4,649	4	14.7	109,263	68,185
Pt	Dryland farming	5,655	10	36.7	150,883	207,363
Pc	Dry Land Farming Mixed with Bushes	3,893	30	110	195,038	428,284
Sw	Paddy Field	3,157	2	7.3	6,300	23,153
B	Shrubs	6,970	30	110	402,084	766,716
Tm	Pond	100	0	0.0	0	0
A	Waterbody	97	0	0.0	0	0
Pk	Plantation	431	63	231	157,645	99,547
T	Bareland	85	2.5	9.2	8	776
Tb	Mining Land	27	0	0	0	0
	Total	34,143,3			2,041,789	5,015,794

LC is land cover, CSC is carbon stock coefficient (Ton C/Ha), EF is emission factor (Ton CO_2/Ha), TCS is total carbon stock (Ton C), and PE is potential emission (Ton CO_2)

Source: Analysis results, 2023

Based on Table 2, it can be seen that there are 15 land covers in the Wanggu Watershed area in 2022, including, Airports, Secondary Dry Land Forests, Secondary Mangrove Forests, Settlements, Dry Land Agriculture, Dry Land Agriculture Mixed with Shrubs, Shrubs, Rice Fields, Ponds, Water Bodies, Open Land and Mining, with a total area of 34,143.3 ha. Based on the results of the analysis, it is known that the total value of carbon stocks stored in the Wanggu Watershed area in 2022 is 2,041,789 TonC/ha and the value of potential emissions that will occur when the Wanggu Watershed loses all its forests is 5,015,794 Ton CO_2.

4.2 Analysis of CO_2 emissions due to forest degradation in the Wanggu Watershed

The results of the analysis showed that from 1990 – 2022, the Wanggu Watershed experienced forest degradation of 6,337 ha spread over five sub-districts, namely Konda, Moramo, North Moramo, Wolasi and Ranomeeto sub-districts. Konda experienced forest degradation covering an area of 3,600 ha, being the highest area experiencing degradation, Ranomeeto which had the second highest area of degradation with a total area of 1,545 ha, Wolasi with forest degradation of 931 ha, North Moramo with 261 ha and the last one was Subdistrict Moramo with a degradation area of 0.18 ha. The extent of degradation is shown in Table 3.

The analysis results from Table 3 serve as a reference for calculating CO_2 emissions due to forest degradation Based on Table 4, analysis of CO_2 emissions due to forest degradation in the Wanggu River watershed shows that the total area of degraded area is 6,337.2 Ha, which causes total carbon dioxide (CO_2) emissions of 798,352 tonnes between 1990 and 2022. Konda, with a degraded area of 3,600 ha, contributed the largest emissions 453,554 tonnes of CO_2, followed by Ranomeeto with 194,600 tonnes of CO_2. Meanwhile, Moramo experienced a smaller decline in carbon stocks with emissions of only 23 tonnes of CO_2, indicating variations in emission factors between sub-districts, despite having relatively uniform emission factors across most of the region (125.99 tonnes of CO_2/ha) . This forest degradation contributes to the gradual release of carbon, which can contribute to climate change if there are no appropriate forest management and rehabilitation efforts. Mitigation efforts involving land restoration and carbon-based management need to be implemented to reduce the negative impacts of forest degradation, as suggested by previous research [16-18]. The change from primary forest to secondary forest causes CO_2 emissions due to reducing the forest's ability to carry out carbon sequestration. The distribution and value of CO_2 emissions from Wanggu Watershed Forest degradation for 1990 - 2022 can be seen in Table 4.

4.3 Analysis of CO_2 emissions due to deforestation

Based on the results of the analysis, deforestation that occurred in the Wanggu Watershed in 1990 - 2022 covered an area of 1,210 ha spread over six sub-districts, namely Konda, Baruga, Moramo, North Moramo, Poasia and Wolasi. The highest CO_2 emissions due to deforestation were in North Moramo District covering an area of 555 ha, while the lowest CO_2 emissions occurred in Wolasi at 40 ha. The distribution and value of CO_2 emissions from Wanggu Watershed due to deforestation for 1990 - 2022 can be seen in Table 5.

Deforestation that occurs in several sub-districts shows a significant impact on changes in carbon stocks and carbon dioxide (CO_2) emissions. North Moramo experienced the largest deforestation (555 ha) with a loss of carbon reserves reaching 493,615 tonnes C and the highest emissions of 49,748 tonnes CO_2, followed by Konda and Baruga. The relatively constant emission factor (EF) in some areas (110.1 tons CO_2/ha) indicates uniformity of initial vegetation type before deforestation, although some areas such as Ranomeeto have a lower EF (36.7 tons CO_2/ha), which could indicate variations in initial biomass. Overall, total carbon emissions from deforestation in this region reached 107,159 tons of CO_2, which contributes to increasing greenhouse gases and climate change.

High carbon emissions, reaching 5,015,794 tons of CO_2, from changes in land cover in the Wanggu Watershed contributed significantly to increasing local temperatures and changes in rainfall patterns. Specifically, emissions due to forest degradation reached 798,352 tonnes of CO_2, while deforestation contributed 107,159 tonnes of CO_2. The loss of forests as carbon sinks reduce the ecosystem's ability to balance CO_2 levels in the atmosphere, accelerates the effects of greenhouse gases, and worsens global warming. As a result, the rainy season becomes more extreme with a higher risk of flooding due to increased surface runoff, while the dry season lasts longer with the potential for increasingly severe droughts. The impact of these large emissions not only threatens water availability in the Wanggu Watershed, but also reduces agricultural productivity due to changes in groundwater patterns and increasing temperatures, which ultimately disrupts the balance of the ecosystem and worsens the vulnerability of the environment and the lives of surrounding communities to climate change.

This study found that forest degradation contributes more to carbon release/CO_2 emissions than deforestation, with total emissions of 798,352 tonnes of CO_2 for Degradation and 107,159 tonnes of CO_2 for Deforestation. These findings are in line with previous research, such as that conducted by Qin et al. [19] which found that forest degradation contributed 73% (three times greater) than forest deforestation (27%) to carbon loss from surface biomass and resulting CO_2 emissions. This indicates that forest degradation is a trigger for carbon loss and must be a major concern. Another study shows that the Amazon region has released more carbon than it has absorbed because of deforestation and degradation, losing 90.5 Tg of carbon per year. Forest degradation and other natural phenomena contribute 82.1% of carbon emissions, while forest deforestation is around 17.9% of surface carbon [20].

Some of the main factors causing CO_2 emissions have been identified in previous research. The results of previous studies state that economic growth and urbanization are the main contributors to CO_2 emissions in the environment [2, 21, 22]. Previous studies show that tropical deforestation contributes around 10-15% of total global carbon emissions, so mitigation efforts such as reforestation and sustainable land management are very important [18]. Change in land use have caused a significant release of CO_2 to the atmosphere [23]. Therefore, stricter conservation policies are needed to reduce the loss of carbon stocks and control CO_2 emissions from the land use sector and land cover change [24]. Green open space development is one of the solutions to reduce CO gas emissions in the environment. This effort requires contributions and synergy from various stakeholders such as researchers, communities, and local governments [25, 26]. In order for the benefits of watersheds to be obtained, it is necessary for management to be properly planned and implemented including in the research.

Table 3. Distribution and area of Wanggu Watershed forest degradation 1990 – 2022

No.	Sub-District	Land Cover		Area
		1990	2022	(ha)
1.	Konda	Hp	Hs	3,600
2.	Wolasi	Hp	Hs	931
3.	Moramo	Hp	Hs	0.18
4.	North Moramo	Hp	Hs	261
5.	Ranomeeto	Hp	Hs	1,545
	Total forests degradation area			6,337

Source: Analysis results, 2023

Table 4. Distribution and value of CO_2 emissions from forest degradation in the Wanggu Watershed 1990 – 2022

No.	Sub-District	CSC		DA	ΔCSC	EF	ET
		1990	2022				
1.	Konda	137.62	103.26	3,600	34.36	125.99	453,554
2.	Wolasi			931			117,324
3.	Moramo			0.18			23
4.	North Moramo			261			32,851
5.	Ranomeeto			1,545			194,600
	Total			6,337.2			798,352

DA is degradation area (Ha), ΔCSC is change of CSC (Ton C/Ha), EF is emission factor (Ton CO_2/Ha), ET is emission total (Ton CO_2/Ha)
Source: Analysis results, 2023

Table 5. CO_2 emissions from deforestation in the Wanggu Watershed 1990 – 2022

No.	Sub-District	LC		DFA	ΔCSC	EF	ET
		1990	2022				
1	Baruga	Forest	Non-Forest	119	30	110.1	6,859
2	Konda			350	30	110.1	3,8503
3	North Moramo			555	134.5	493.615	49,748
4	Ranomeeto			80	10	36.7	2,939
5	Wolasi			40	30	110.1	4,355
6	Poasia			66	32.5	119.275	4,755
	Total			1,210			107,159

DFA is deforestration area (Ha), ΔCSC is change of CSC (Ton C/Ha), EF is emission factor (Ton CO_2/Ha), ET is emission total (Ton CO_2/Ha)
Source: Analysis results, 2023

5. CONCLUSIONS

Based on the results of the study, it can be concluded that the amount of carbon stock based on land use of the Wanggu Watershed in 2022 amounted to 2,041,789 tonnes C and the amount of emissions of 5,015,794 tonnes CO_2 originating from nine types of land cover, namely dryland forests, secondary mangrove forests, plantations, dryland agricultural shrubs mixed with shrubs, dryland agriculture, settlements, open land, and paddy field.

Land cover changes affect carbon stocks and CO_2 emissions in the Wanggu Watershed (1990–2022). Forest degradation contributes more to carbon release/CO_2 emissions than deforestation, with total emissions of 798,352 tonnes of CO_2 for Degradation and 107,159 tonnes of CO_2 for Deforestation respectively. Konda sub-district is the largest contributor to emissions due to degradation, while North Moramo is the largest contributor to emissions due to deforestation.

High carbon emissions from land cover changes in the Wanggu Watershed contribute to increased local temperatures and changes in rainfall patterns. Reducing forests as a carbon sink accelerates the effect of greenhouse gases, which can lead to more extreme rainy seasons with the risk of flooding and longer dry seasons that increase the potential for drought. These changes not only impact water availability in the Wanggu Watershed but also disrupt agricultural productivity and ecosystem balance, exacerbating the vulnerability of the environment and society to climate change.

REFERENCES

[1] Abadi, M., Nafiu, L.O., Rezky, M., Syaf, H., Yunus, L., Sudia, L.B., Gandri, L. (2024). Socio-economic carrying capacity of the Poleang watershed area Indonesia. International Journal of Sustainable Development and Planning, 19(7): 2799-2804. https://doi.org/10.18280/ijsdp.190737

[2] Alwi, L.O., Dharmawan, A.H., Fauzi, A., Hutagaol, M.P. (2016). Mineral fund and regional sustainable development: Case study of Bombana Regency, Southeast Sulawesi Province. Australian Journal of Basic and Applied Sciences, 10(6): 127-134.

[3] Long, L.H., Liu, Y.Q., Hou, X.G., Li, T.T., Li, Y.R. (2014). Effects of land use transitions due to rapid urbanization on ecosystem services: Implications for urban planning in the new developing area of China. Habitat International, 44: 536-544. http://doi.org/10.1016/j.habitatint.2014.10.011

[4] Tao, Y., Li, F., Wang, R., Zhao, D. (2015). Effects of land use and cover change on terrestrial carbon stocks in urbanized areas: A study from Changzhou, China. Journal of Cleaner Production, 103: 651-657. https://doi.org/10.1016/j.jclepro.2014.07.055

[5] Achmad, A., Ramli, I., Sugiarto, S., Irzaidi, I., Izzaty, A. (2024). Assessing and forecasting carbon stock variations in response to land use and land cover changes in Central Aceh, Indonesia. International Journal of Design & Nature and Ecodynamics, 19(2): 465-475. https://doi.org/10.18280/ijdne.190212

[6] Sabilu, K., Ketjulan, R., Hisein, W.S.A., Muskita, W.H. (2023). Assistance in implementing a strategic area-based regional development model in Muna Regency, Southeast Sulawesi. Meambo Devotion Journal, 2(2): 120-131. https://doi.org/10.56742/jpm.v2i2.72

[7] Saing, Z., Djainal, H., Deni, S. (2021). Land use balance determination using satellite imagery and geographic information system: Case study in South Sulawesi Province, Indonesia. Geodesy and Geodynamics, 12(2): 133-147. https://doi.org/10.1016/j.geog.2020.11.006

[8] Gafaruddin, A., Sudarmo, H. (2024). Mapping agricultural land potential based on the geographic information system (GIS) in Muna Regency, Southeast Sulawesi Province. International Journal of Environmental Engineering and Development, 2: 223-233. https://doi.org/10.37394/232033.2024.2.20

[9] Post, W.M., Emanuel, W.R., Zinke, P.J., Stangenberger, A.G. (1982). Soil carbon pools and world life zones. Nature, 298: 156-159. https://doi.org/10.1038/298156a0

[10] Baker, A.J., McGrath, S.P., Reeves, R.D., Smith, J.A.C. (2020). Metal hyperaccumulator plants: A review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In Phytoremediation of Contaminated Soil and Water, pp. 85-107. https://www.researchgate.net/publication/284669331.

[11] Schlesinger, W.H. (1997). Biogeochemistry: An Analysis of Global Change. Academic Press.

[12] Fearnside, P.M. (2000). Global warming and tropical land-use change: Greenhouse gas emissions from biomass burning, decomposition and soils in forest conversion, shifting cultivation and secondary vegetation. Climatic Change, 46(1): 115-158. https://doi.org/10.1023/A:1005569915357

[13] Sugiarto, A., Utaya, S., Bachri, S., Shrestha, R.P. (2024). Estimation of carbon stocks and CO2 emissions resulting from the forest destruction in West Kalimantan, Indonesia. Environmental Challenges, 17: 101010. https://doi.org/10.1016/j.envc.2024.101010

[14] Fadhli, R., Sugianto, S., Syakur, S. (2021). Analysis of land cover change and carbon potential in Pocut Meurah Intan Grand Forest Park, Aceh Indonesia. Journal of Environmental Science, 19(2): 450-458. https://doi.org/10.14710/jil.19.2.450-458

[15] Tosiani, A. (2015). Carbon Absorption and Emission Activity Book. Publishing Agency of the Ministry of the Environment, Jakarta.

[16] Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Japan.

[17] Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., Houghton, R.A. (2017). Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science, 358(6360): 230-234. https://doi.org/10.1126/science.aam5962

[18] Harris, N.L., Gibbs, D.A., Baccini, A., Birdsey, R.A., de Bruin, S., Farina, M., Fatoyinbo, L., Hansen, M.C., Herold, M., Houghton, R.A., Potapov, P.V., Requena Suarez, D., Roman-Cuesta, R.M., Saatchi, S.S., Slay, C.M., Turubanova, S.A., Tyukavina, A. (2021). Global maps of twenty-first century forest carbon fluxes. Nature Climate Change, 11: 234-240. https://doi.org/10.1038/s41558-020-00976-6

[19] Qin, Y., Xiao, X., Wigneron, J.P., Ciais, P., et al. (2021). Carbon loss from forest degradation exceeds that from deforestation in the Brazilian Amazon. Nature Climate Change, 11(5): 442-448. https://doi.org/10.1038/s41558-021-01026-5

[20] Csillik, O., Keller, M., Longo, M., Ferraz, A., et al. (2024). A large net carbon loss attributed to anthropogenic and natural disturbances in the Amazon Arc of deforestation. Proceedings of the National Academy of Sciences, 121(33): e2310157121. https://doi.org/10.1073/pnas.2310157121

[21] Adebayo, T.S., Awosusi, A.A., Adeshola, I. (2020). Determinants of CO2 emissions in emerging markets: An empirical evidence from MINT economies. International Journal of Renewable Energy Development, 9(3): 411-

422. https://doi.org/10.14710/ijred.2020.31321

[22] Gandri, L., Hidayat, H., Tuwu, E.R., Irawati, I., Bana, S., Fitriani, V., Indriyani, L. (2022). Spatial analysis of urban heat island phenomenon using land surface temperature algorithm of Kendari City. Journal of Meteorology and Geophysics, 23(2): 109-118. https://doi.org/10.31172/jmg.v23i2.852

[23] Houghton, R.A., Hobbie, J.E., Melillo, J.M., Moore, B., Peterson, B.J., Shaver, G.R., Woodwell, G.M. (1983). Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO2 to the atmosphere. Ecological Monographs, 53(3): 235-262. https://doi.org/10.2307/1942531

[24] IPCC. (2019). IPCC Updates Methodology for Greenhouse Gas Inventories. https://www.ipcc.ch/2019/05/13/ipcc-2019-refinement/.

[25] Pratiwi, Y., Rejo, A., Fariani, A., Faizal, M. (2022). Modelling for estimation carbon stocks in land cover using a system dynamic approach (Case study: Prabumulih City, South Sumatera, Indonesia). Jurnal Manajemen Hutan Tropika, 28(3): 221-221. https://doi.org/10.7226/jtfm.28.3.221

[26] Slamet, A., Iswandi, R.M., Alwi, L.O. (2019). The role of ornamental plant business groups in the green open space (RTH) programme in Kendari City. Journal of Socio Agribusiness, 4(2): 63-70. http://doi.org/10.33772/jsa.v4i2.8933