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Land Use Change and Carbon Stocks in the Toari Watershed

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Abstract

Changes in land use are linked to climate change, resulting in the loss of carbon reserves due to decrease in vegetated land. Forests play crucial role in carbon storage. This research aims to determine carbon storage in the Toari Watershed, Southeast Sulawesi, in response to land use changes. The method uses GIS analysis to track changes in land use from 1991 to 2023, employing the SRTM Digital Elevation Model (DEM) for delineation. Carbon storage is calculated by multiplying the area of each land use by its respective carbon content value. The results of this research show that there have been significant land changes occurring from 1991 to 2023. Forest land is the land use with the most extensive changes, experiencing decrease in area of 7,181.20 hectares. This was also followed by increased mixed dryland farming use by 5,579.23 hectares, plantations by 1,994.28 hectares, residential land by 353.13 hectares, and open land by 640.85 hectares. From 1991 to 2023, land use changes had big impact on carbon stocks in the Toari Watershed. The largest decrease occurred in secondary dryland forests, leading to reduction of 741,530.7 tons C. Conversely, mixed agricultural land and plantations saw increases of 167,376.90 tons C and 125,639.60 tons C, respectively. Open land and residential areas also registered increases in carbon stocks. These findings highlight the influence of land use on carbon stock changes. The carbon stocks in the Toari Watershed decreased from 1,142,112.3 tons C in 1991 to 728,627.9 tons C in 2023 due to changes in land use.

Introduction

Climate change is a phenomenon that makes all living things that inhabit the earth indirectly have to adapt. This is because there is extreme weather resulting from the compilation of meteorological data which shows an increase in climate variability (Clarke et al., 2022). The impact of climate change is in the form of four phenomena: increasing air temperature, rising sea levels, increasing rainfall, and extreme events (Adamo et al., 2022; Ray Biswas & Rahman 2023). One of the factors that triggers climate change is an increase in the concentration of Green House Gases (GHG) (Bessou et al., 2011; Novita, 2021).

Land use changes are closely related to climate change which causes a loss of carbon stocks and a decrease in area and other categories in certain periods (Hanberry et al., 2024). The need for land use is increasing along with the increase in population. Population growth which continues to grow has encouraged land clearing for residential areas as well as for agricultural and industrial areas (Dong et al., 2019; Mendoza-Ponce et al., 2021; Mahtta et al., 2022). Apart from land clearing, population growth accompanied by economic development also spurred the conversion of rural land to urban areas, and this occurred quickly and beyond expectations (Tong & Qiu, 2020; Zhao & Yin, 2023). Rapid population growth and increasing demands for land by society often result in conflicts of interest over land use and incompatibility between land use and its intended use (Prasada & Masyhuri, 2019; Gidey et al., 2023). Conversion of

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forest land on a large scale into agricultural land and plantations can play a role in reducing carbon stocks (Anamulai et al., 2019; Mayer et al., 2020). High population growth causes increasingly limited land availability in an area, thereby underlying changes in land function, becoming uncontrolled, resulting in a decline in environmental quality, environmental degradation, or environmental damage as well as a reduction in natural resources (Asabere et al., 2020; Mahtta et al., 2022).

The Toari watershed is a river basin in Southeast Sulawesi with an area of 20,633.80 hectares, as a very potential natural resource. However, over the past three decades, forest resource extraction has been very rapid, resulting in a reduction in the area of forest land cover. Changes in the land cover area are related to land use by the community for settlements, plantations, and agriculture so carbon storage in the Toari watershed has decreased (Sulistyono et al., 2019; Parmar, 2022). Changing forest land into non-forest areas has an impact on global warming and microclimate changes. Changes in land use are closely related to climate change which causes loss of carbon reserves and increased CO2 emissions in the air (Novita, 2021; Feng et al., 2020). The high level of deforestation and low quality of land cover in the Toari watershed will allegedly affect the amount of carbon stocks and increase CO2 emissions in the air. Based on the description above, it is necessary to research to determine carbon stocks in each type of land use area in the Toari River Watershed (DAS). It is hoped that this research can be used as information and consideration in determining regulations in efforts to control land use as well as as a starting point in mitigation efforts and to achieve the commitment to reduce national CO2 emissions.

Methods

This research was conducted out in the Toari watershed, Southeast Sulawesi, with an area of 20,633.80 hectares, at coordinate points 4° 32' 14" - 4° 39' 24" South Latitude and 121° 29' 30" – 121° 42'12" East Longitude. Research time was implemented in February-June 2024.

The types and sources of data needed are the Indonesian Earth Map from the Geospatial Information Agency (https://tanahairindonesia.go.id/), the Toari watershed boundaries obtained by delineation from the SRTM Digital Elevation Model (DEM), land cover spatial data and land use obtained from Landsat 5, 7 & 8 satellite imagery (http://earthexplorer.usgs.gov/), and land use maps for 1991 and 2023 from the Ministry of Environment and Forestry (KLHK) to assist image interpretation. The image correction and cutting process uses Erdas Imagine 2014 software, while map interpretation and analysis uses GIS on a computer with 8 GB RAM. Calculating surface carbon stocks using the ICLEI calculator approach (Rahman et.al., 2023), namely multiplying the carbon stock constant of each land cover (ton C. ha-1) by its area (ha) (Table 1).

Table 1. Constant Values of Carbon Stocks for Land Cover Types

Land Use/Land Cover	Code	Carbon Stock Constant (Ton C. ha-1)
Primary dryland forest	Hp / 2001	195.4
Secondary dry land forest	Hs / 2002	169.7
Primary swamp forest	Hrp / 2005	196
Secondary swamp forest	Hrs / 20051	155
Primary mangrove forest	Hmp / 2004	170
Secondary mangrove forest	Hms / 20041	120
Plantation forest	Ht / 2006	64
Plantation	Pk / 2010	63
Shrubs	B / 2007	30

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Swamp thickets	Br / 20071	30
Savanna/grassland	S / 3000	4.5
Dryland farming	Pt / 20091	10
Mixed dry land farming	Pc / 20092	30
Paddy field	Sw / 20093	2
Ponds	Tm / 20094	0
Built-up land	Pm / 2012	5
Transmigration Settlements	Tr / 20122	10
Open field	T /2014	2.5
Mining Land	Tb / 20141	0
Body of water	A / 5001	0
Swamp	Rw / 50011	0
Cloud	Aw / 2500	0
Airport/Port	Bdr/Plb / 20121	0

This section describes the various data processing and analysis steps carried out in deriving the findings of this study. To begin with, the satellite images were preprocessed to geometric and radiometric corrections using the Erdas Imagine 2014 software; this helped in matching the images for spatial as well as temporal features making comparison to be easy. Subsequently, the land use in the specified watersheds was categorized into zones including; primary and secondary forests, plantations, mixed dryland farming and built-up region. Such a classification was done with the help of spectra in the satellite images and was supplemented by ground-truthing data. In order to calculate carbon stocks, the study used the ICLEI carbon calculator method of using the area of the individual land use type and the carbon stock constant per hectare of ton C ha^-1. These constants were obtained from regional researches so as to provide an accurate account of the carbon storage capacity for every land cover type.

A temporal change detection analysis was then carried out to determine the effects of LU changes on carbon stocks. This analysis entailed the comparison of land use of the year 1991 and 2023, with the amount of change of various types of land cover being calculated alongside the corresponding change in carbon stocks. Other instruments of spatial analysis of the change in land use were also used within GIS framework. This analysis gave an overview of the location specific changes in carbon stock because of LU conversions within the watershed.

The study well utilized the sophisticated GIS software featuring tools for DEM analysis and carbon stock computations. Other computational needs specified were a computer with a RAM of 8 GB since the study involved the analysis of large amounts of data which called for computation. The issues of ethics formed the part of the overall activities as well. All activities performed in the study complied with ethical procedures appropriate for environmental studies including reporting the use of governmental as well as satellite data. In an endeavour to prevent the outcomes of this research to have a negative impact on local communities, safety and data privacy/Security was considered and upheld throughout the course of this study.

Results and Discussion

Based on the results of image interpretation carried out for 1991 and 2023, the area obtained based on data related to land cover types on a national scale resulted in seven types of land use in the Toari watershed in 1991 and eight types of land use in 2023.

Seven types of land use exist in the Toari watershed area with a total area of 20,633.57 hectares. From the land area, it can be seen that secondary dry land forest land use still dominates, namely 9,548.63 hectares or 46.28% of the Toari watershed area. The dominant use of forest land is due to population pressure on forests which is still limited (Hazarika & Bhattacharjee, 2021; Herrmann et al., 2020). Potential forest resources in the Toari watershed are still widely available to meet the economic needs of local communities (Ssentongo et al., 2024; Halewood et al., 2021). They were followed by the use of dry land agriculture land covering an area of 6,181.53 hectares or 29.29% of the Toari Watershed area, mixed dry land agriculture area of 2,952.46 hectares or 14.31% of the watershed area, and shrubs covering an area of 1,727.20 hectares or 8.37% of the watershed area. Even though forests were still dominant at the time, the community's tendency to carry out dry land agricultural activities in the form of cultivation systems and food crop farming had also been widely carried out in line with population growth (Tong & Qiu, 2020). Other land uses that are small in area are open land, settlements, and water bodies.

The land use in the Toari watershed had undergone significant transformations, with the most notable shift being the dominance of mixed dry land farming, which covered 41.35% of the area. This transition towards a sustainable agricultural system, integrating agroforestry, demonstrates efforts to balance agricultural productivity with environmental sustainability (Singh & Singh, 2023). This shift is supported by research from Ssentongo et al. (2024) and Tui et al. (2022), who emphasize the benefits of agroforestry in enhancing ecosystem resilience and reducing environmental degradation.

The reduction of secondary dry land forests to 11.47% of the area reflects substantial deforestation, which is likely driven by the expansion of agricultural and plantation activities. This decline in forest cover aligns with findings by López-Carr (2021) and Kumar et al. (2022), who discuss the pressures of agricultural expansion on forest ecosystems. The deforestation in the Toari watershed highlights the need for effective land management strategies to mitigate the negative impacts on biodiversity and carbon sequestration (Deb, 2022).

The emergence of plantations, which now cover 9.67% of the watershed area, underscores a significant shift towards commercial agricultural investments. This trend is particularly evident in the cultivation of crops such as oil palm, as highlighted by Anamulai et al. (2019). The establishment of plantations indicates a growing focus on monoculture practices, which can have both economic benefits and environmental drawbacks, including the loss of biodiversity and changes in land use patterns. Land use changes during the period from 1991 to 2023 can be seen in Table 2.

Table 2. Data on land use changes in the Toari Watershed in 1991 and 2023.

No.	**Type of land use**	**Land area (hectares)**		**Changes (hectares)**	**Percent (%)**
		1991	**2023**		
1.	Settlement	26.66	379.76	(+) 353.13	92.99
2.	Shrubs	1,727.20	1,728.37	(+) 1.17	0.07
3.	Secondary dryland forest	9,548.63	2367.43	(-)7,181.20	75.21
4.	Open field	193.38	834.23	(+)640.85	76.82
5.	Mixed dryland farming	2,952.46	8,531.69	(+)5,579.23	65.39
6.	Dryland farming	6,181.53	4,769.08	(-)1,412.45	22.85
7.	Waterbody	3.72	29.10	(+)25.38	87.22
8.	Plantation	-	1,994.28	(+)1,994.28	100.00

Based on Table 2, it shows that there have been large changes in land use during the period from 1991 to 2023. The biggest change is in secondary dry land forests, there has been a decrease of 7,181.20 hectares or 75.21 percent. Also, the use of dry land agriculture decreased by 1,412.45 hectares or 22.85 percent. Meanwhile, the use of mixed dryland agricultural land increased by 5,579.23 hectares or 65.39 percent, plantation use increased by 1,994.28 or 100 percent, open land increased by 640.85 hectares or 7.82 percent, residential areas increased by 353.13 hectares or 92.99 percent. The Toari watershed area is experiencing deforestation due to increased land clearing for mixed dry land agriculture and plantations (Ssentongo et al., 2024).

Additionally, the increase in settlements and open land areas points to ongoing land development and urbanization pressures. This urban expansion reflects the broader socio-economic changes occurring within the watershed, driven by population growth and economic development. To fully understand these dynamics, it would be beneficial to integrate a more detailed analysis of the socio-economic factors driving these land use changes. This could include examining population trends, economic incentives for agricultural expansion, and policy frameworks that influence land use decisions. By elaborating on these points, the analysis provides a comprehensive understanding of the land use changes in the Toari watershed, highlighting the complex interplay between agricultural practices, environmental sustainability, and socio-economic development.

The results of carbon stock analysis based on land use classes in the Toari Watershed in 1991 are presented in Table 3.

Table 3. Carbon stocks in the Toari Watershed, 1991

No	Type of land use	Land area (hectares)	Carbon content (C ton/ha)	Total stock carbon (ton C)
1.	Settlement	26.66	2.5	66.65
2.	Shrubs	1,727.20	30	5,181.6
3.	Secondary dryland forest	9,548.63	103.26	985,991.5
4.	Open field	193.38	2.5	483.45
5.	Mixed dryland farming	2,952.46	30	88,573.8
6.	Dryland farming	6,181.53	10	61,815.3
7.	Waterbody	3.72	0	0
Total		**20,633.80**	**-**	**1,142,112.30**

Based on Table 3, the carbon reserves for each type of land use in the Toari Watershed in 1991 show that secondary dry land forests had the highest carbon reserves of 985,991.50 tons C. Furthermore, the use of mixed dryland agricultural land was 88,573.80 tons C, then dry land agricultural land was 88,573.80 tons C. 61,815.30 tons C, open land amounted to 483.45 tons C, shrubs were 5,181.60 tons C, and settlements were 66.65 tons C. So the total carbon reserves in the Toari watershed in 1991 were 1,142,112.30 tons C. The carbon stock data in 2023 according to land use data in the Toari Watershed will be explained in Table 4.

Table 4. Carbon stocks in the Toari Watershed, 2023

No	Type of land use	Land area (hectares)	Carbon content (C ton/ha)	Total stock carbon (ton C)
1.	Settlement	379.76	2.50	949.40
2.	Shrubs	1,728.37	30	51,851.10
3.	Secondary dryland forest	2,367.43	103.26	244,460.80
4.	Open field	834.23	2.50	2,085.50
5.	Mixed dryland farming	8,531.69	30	255,950.70
6.	Dryland farming	4,769.08	10	47,690.80
7.	Waterbody	29.10	0	0

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8.	Plantation	1,994,28	63	125,639.60
Total		**20,633.80**	**-**	**728,627.94**

Based on Table 4, the carbon stock for each type of land use in the Toari Watershed in 2023 shows that mixed dry land farming has the highest carbon stock of 255,950.70 tons C. Furthermore, the secondary dry land forest was 244,460.80 tons C, the plantation was 125,639.60 tons C, Shrubs was 51,851.10 tonnes C, dry land farming was 47,690.80 tonnes C, the open land was 2,085.50 tonnes C, and settlements were 949.40 tonnes C. So the total carbon reserves in the Toari Watershed in 2023 will be 728,627.94 tons C. Table 5 will describe the increase or decrease in carbon stocks in various land uses in the Toari watershed.

Table 5. Changes of Stock Carbon in the Toari Watershed in 1991 and 2023.

No.	Type of land use	Changes stock carbon (ton C)
1.	Settlement	(+) 882.75
2.	Shrubs	(+) 35.10
3.	Secondary dryland forest	(-) 741,530.70
4.	Open field	(+) 1,602.05
5.	Mixed dryland farming	(+) 167,376.90
6.	Dryland farming	(-) 14,124.50
7.	Waterbody	-
8.	Plantation	(+) 125,639.60
Changes of stock carbon in 1991 and 2023		**(-) 413,484.36 (36%)**

Based on Table 5, it can be observed that there has been an overall decrease in carbon stocks in the Toari Watershed from 1991 to 2023, amounting to 413,484.40 tons C. The most significant decrease occurred in the use of secondary dry land forests, with carbon stocks decreasing by 741,530.7 tons C. On the other hand, the use of mixed dryland agricultural land and plantations saw increases of 167,376.90 tons C and 125,639.60 tons C, respectively. Additionally, open land and residential areas also experienced increases, with each area seeing gains of 1,602.05 tons C and 882.75 tons C. It's important to note that changes in forest cover will impact carbon uptake and have implications for global warming temperatures (Dong et al., 2019).

Table 6. Carbon Stocks

Land Use	1991	2023	Carbon Stock Change	Cumulative Impact
Settlement	0.01	0.13	1324.46	882.75
Shrubs	0.45	7.12	900.68	47552.25
Secondary dryland forest	86.33	33.55	-75.21	-693978.45
Open field	0.04	0.29	331.38	-692376.40
Mixed dryland farming	7.76	35.13	188.97	-524999.50
Dryland farming	5.41	6.55	-22.85	-539124.00
Waterbody	0.00	0.00	nan	-539124.00
Plantation	0.00	17.24	inf	-413484.40

From the map titled: Percentage Contribution, one is able to identify the number of impressions made by every land use type to the ultimate carbon pool in the two successive years of 1991 and 2023. For example, on average secondary dryland forests provided the most to the carbon stock in both the years but the rate in which it declined was much higher, from 86%. In 1991 it was 33%, in 1997 it was 33. three per cent in the US. 55% in 2023. The Relative Change in

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Carbon Stocks column weighs the change in carbon stocks for the respective LU type between 1991-2023 by the initial stock. It is relevant to mark that the carbon stock in settlements has been rising by 1307% and secondary dryland forests decreasing by 75%. Live Carbon Stock is the aggregate of the carbon stock changes and, therefore, another comprehensive measure that simply points out the net changes in carbon stock as a result of land use changes. The average of these represents a decline of overall carbon storage capacity with a adverse effect from the loss of secondary dry land forests.

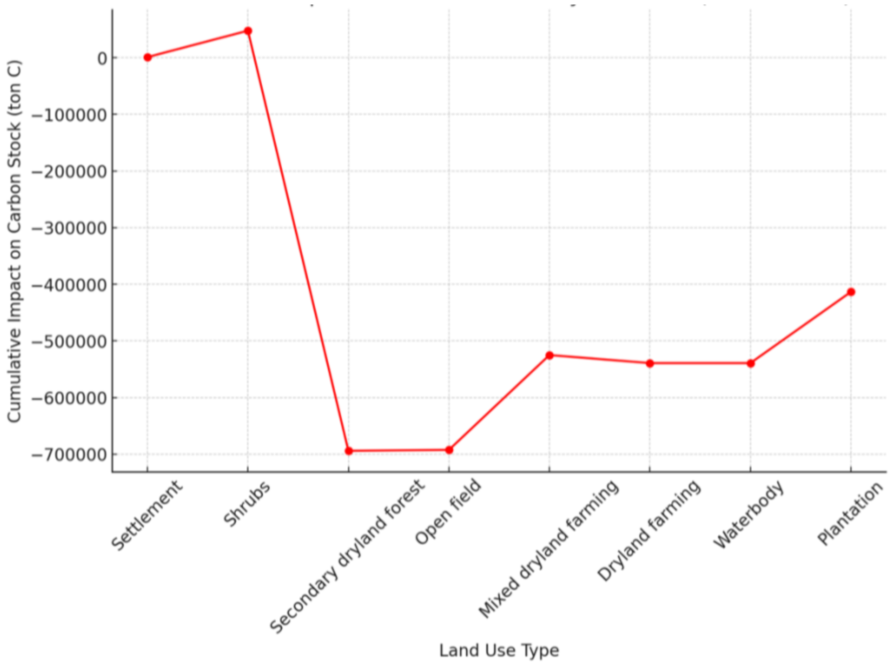

Figure 1. Cumulative impact on carbon stock by land use (1991-2023)

The figure 2 presents the changing effects of different LUTS on carbon stock in the Toari watershed over 1991-2023. Each type of land useavails or detracts to the carbon stock changes in that it provides an overall summation of the changes in the entire watershed area.

Secondary dryland forests declined the most, and have shown the overall change in carbon stocks depicted in the figures above. This land use type, which contained a considerable quantity of carbon in 1991, was furthermore reduced hence a total reduction in carbon stock of around 741530. 7 tons of carbon. This points to the importance of secondary dryland forests as carbon sinks and on the disastrous effect of their degradation. On the other hand, mixed dryland farming presents a positive gross effect whereby it contributes about 167,376. States that it eliminated more than 9 tons of carbon during the period of research. This implicates that the expansion of this particular type of land use has assisted in reducing some of the carbon losses, this because of the integration of agroforestry activities that improves sequestration of carbon.

The other two land use categories that had positive carbon stock changes includes the shrubland & plantation with the shrubland adding 46,669. Carbon: 5 tons carbon/Plantations: 125,639. 6 tons. All of these positive contributions signal that these land uses have either been preserved or increased to a degree that kept, or enhanced, carbon stocking or storage. Settlements and open fields have exhibited an augmentation in carbon stocks, still, their total improvements are not significant compared to other LU types. Settlements added approximately 882. 75 tons of carbon, while open fields contributed about 1, 602. To ridge or to slope, there is clear evidence that curtailing meadows would reduce carbonlessness. 05 tons.

However, when all the land use types that can affect carbon stocks are pooled together the overall net effect is reduction of stocks mainly due to large scale conversion of secondary dryland forests. The figure stresses the significance of the forests preservation as well as the necessity of rational use of land resources as a result of which one would be able to meet the demands for agriculture expansion without detriment of the natural resources.

From the cumulative impact assessment of the Toari water shed, the results have shown that there is a major change in carbon stocks through land use change and this study has pinpointed the fact that there is a disturbing degree of declining rate of secondary dry land forest. These forests have provided the traditional Carbon offset and their loss of in excess of 740,000 tons of Carbon through deforestation, supports the Global trend of forest depletion. Recent investigations stress this problem, as deforestation, in addition to the emissions of the carbon accumulated in the trees, additionally decreases the future carbon uptake capacity of the forest (Ameray et al., 2021; Smith et al., 2020). Such dual impacts require much greater attention towards reforestation and works for protecting the forest that is expected to ascend in areas such as Southeast Sulawesi where economic forces exert pressure for changes in land use in highly unsustainable manner.

Assuming the influence of mixed dryland farming on carbon stocks in this light, a rather different story of sustainable utilization of the land is told. This conclusion is similar to the current studies that show that an AF is an efficient method of sequestering carbon, and also economically successful for local inhabitants (Octavia et al., 2022; Gouhari et al., 2021). The long-term practice of trees, crops and/or livestock also known as agroforestry has been proven to enhance the health of the soil, increase the number of species within an ecosystem and increase the amounts of carbon dioxide absorbed from the atmosphere in contrast to elemental farming practices. However, the issues of scaling up these practices remain a huge question especially in the areas of land tenure and market infrastructure. Various research work indicates that broad based strategies alone are insufficient; what is needed is policy interventions that make land rights secure, provide financial rewards for the adoption and maintenance of more sustainable practices and effective support for farmer education (Kansanga et al., 2021; Kansanga et al., 2021).

However, the small net gains indicated for shrubland and plantations although positive, have implications regarding the future applicability of these ecosystems as carbon stocks. There are negative externalities or costs incurred by the environment when providing support to plantation agriculture especially monoculture systems such as oil palm. The outcomes of such systems usually include loss of biological diversity, degradation of soils and water resources, thus offsetting the benefits of carbon sequestration (Piñeiro et al., 2020; Shin et al., 2022). Besides, the actualization of sustainable plantation outcomes in emerging economies may require considerations for the coastline’s global environmental impacts that recent research shows may be better addressed by productive, mixed-species plantation systems (Dagar et al., 2020). Such approaches could reduce some of the undesirable impacts linking to monocultures while increasing the carbon sink capacity of plantation systems. Overall, these findings can be discussed in relationship to large scale land management synergies which address the challenges of land degradation and food security, by finding a balance between agricultural production and preservation of the environment. New literature progressively calls for multi-habitat management strategies, where protected forests, agroforestry, and sustainable agriculture are integrated in a spatial network to maximize carbon density and species richness (Jiao et al., 2019; Zina et al., 2022). In the case of Toari watershed, it would include enhanced protection of forests and increased practice of agriculture to increase soil carbon stocks efficiently.

It is rather imperative to put tighter consequent on nonobservable punitive measures that could help avoid furthering destruction of the forests and comes with encouragements for practising sustainable use of the land for instance, through engaging in practices like agroforestry. This two-pronged approach is important for actualization of climate change mitigation objectives and at the same time considering the welfare of the people who depend on the resources for their source of income. Further research efforts should therefore build elaborate models that include interaction of use of land, carbon and other socio-economic factors in order to plan and implement policies that address the issue of climate change in a balanced way.

Conclusion

This study is likely to contribute a wealth of information to understanding the changes in the stocks of carbon in the Toari watershed and more importantly the importance of secondary dryland forests as the dominant carbon reservoirs. These kinds of losses point at the need for increased afforestation and reforestation since forest cover has reduced significantly. On the other hand, benefits of mixed dryland farming with practices of achievements of agroforestry practices are clear indication how sustainable land use contribute to reduction of Carbon Footprints for enhanced productivity and improved lives of small holder farmers. Nevertheless, relatively small increase from shrubland and plantation as well as the side effects that these systems impose on the environment, suggest that such systems cannot be relied on to manage increasing carbon levels. The outcomes stressing the importance of the Comprehensive concept of the land management that implies equal consideration of environmental, economic, and social aspects. It consists in encouraging agro-sylvo-pastoral production and extensive agriculture and applying strict prohibitive measures for forest decline. Increasing population pressure and quest for economic growth will exert greater pressure on land use hence the need for effective and efficient policies to address these pressures in ways that respects current climate change ambitions and the needs of people. Subsequent studies should provide more detailed theory that includes the Socio-economic factors that can be used in determination of efficient and fair allocation of the land. Thus, this study contributes to the knowledge on the geographical perspective of land use and carbon in Southeast Sulawesi and serves practical recommendations to forescale sustainable land management solutions to deal with the climate change consequence worldwide.

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References

Adamo, N., Al-Ansari, N., & Sissakian, V. (2021). Review of climate change impacts on human environment: past, present and future projections. *Engineering*, *13*(11), 605-630. https://doi.org/10.4236/eng.2021.1311044

Ameray, A., Bergeron, Y., Valeria, O., Montoro Girona, M., & Cavard, X. (2021). Forest carbon management: A review of silvicultural practices and management strategies across boreal, temperate and tropical forests. *Current Forestry Reports*, 1-22. https://doi.org/10.1007/s40725-021-00151-w

Anamulai, S., Sanusi, R., Zubaid, A., Lechner, A. M., Ashton-Butt, A., & Azhar, B. (2019). Land use conversion from peat swamp forest to oil palm agriculture greatly modifies microclimate and soil conditions. *PeerJ*, (10), 1-16. https://doi.org/10.7717/peerj.7656.

Asabere, S. B., Acheampong, R. A., Ashiagbor, G., Beckers, S. C., Keck, M., Erasmi, S., ... & Sauer, D. (2020). Urbanization, land use transformation and spatio-environmental impacts: Analyses of trends and implications in major metropolitan regions of Ghana. *Land use policy*, *96*, 104707. https://doi.org/10.1016/j.landusepol.2020.104707

Bessou, C., Ferchaud, F., Gabrielle, B., & Mary, B. (2011). Biofuels, greenhouse gases and climate change. *Sustainable Agriculture Volume 2*, 365-468. https://doi.org/10.1007/978-94-007-0394-0_20

Clarke, B., Otto, F., Stuart-Smith, R., & Harrington, L. (2022). Extreme weather impacts of climate change: an attribution perspective. *Environmental Research: Climate*, *1*(1), 012001. https://doi.org/10.1088/2752-5295/ac6e7d

Dagar, J. C., Gangaiah, B., & Gupta, S. R. (2020). Agroforestry to sustain island and coastal agriculture in the scenario of climate change: Indian perspective. *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges-Vol. 1*, 367-424. https://doi.org/10.1007/978-981-15-4136-0_13

Deb, D. (2022). The erosion of biodiversity and culture: Bankura district of West Bengal as an illustrative locale. *Ecology, Economy and Society-the INSEE Journal*, *5*(1), 139-176. https://doi.org/10.22004/ag.econ.343116

Dong, N., Liu, Z., Luo, M., Fang, C., & Lin, H. (2019). The Effects of Anthropogenic Land Use Changes on Climate in China Driven by Global Socioeconomic and Emission Scenarios. *Earth's Future*, *7*(7), 784–804. https://doi.org/10.1029/2018EF000932

Feng, Y., Chen, S., Tong, X., Lei, Z., Gao, C., & Wang, J. (2020). Modeling changes in China's 2000–2030 carbon stock caused by land use change. *Journal of Cleaner Production*, *252*, 119659. https://doi.org/10.1016/j.jclepro.2019.119659

Gidey, E., Gitet, S., Mhangara, P., Dikinya, O., Hishe, S., Girma, A., Gebremeskel, G., Lottering, R., Zenebe, A., Birhane, E. (2023). Impact of urban and peri-urban growth on arable land (1976–2029) in a medium sized city of Shire Indaselassie, North Western Tigray, Ethiopia. *SN Applied Sciences*, *5*(4), 1-13. https://doi.org/10.1007/s42452-023-05322-x

Gouhari, S., Forrest, A., & Roberts, M. (2021). Cost-effectiveness analysis of forest ecosystem services in mountain areas in Afghanistan. *Land Use Policy*, *108*, 105670. https://doi.org/10.1016/j.landusepol.2021.105670

Halewood, M., Bedmar Villanueva, A., Rasolojaona, J., Andriamahazo, M., Rakotoniaina, N., Bossou, B., ... & Nnadozie, K. (2021). Enhancing farmers' agency in the global crop commons through use of biocultural community protocols. *Agriculture and Human Values*, *38*, 579-594. https://doi.org/10.1007/s10460-020-10164-z

Hanberry, B. B., Abrams, M. D., & Nowacki, G. J. (2024). Potential Interactions between Climate Change and Land Use for Forest Issues in the Eastern United States. *Land. Multidisciplinary Digital Publishing Institute (MDPI)*, *13* (3), 1-20. https://doi.org/10.3390/land13030398.

Hazarika, B., & Bhattacharjee, N. (2021). Population Pressure and Its Impact on Forest Resources in North East India. *Journal of Positive School Psychology*, *2022*(4), 4245–4255.

Herrmann, S. M., Brandt, M., Rasmussen, K., & Fensholt, R. (2020). Accelerating land cover change in West Africa over four decades as population pressure increased. *Communications Earth & Environment*, *1*(1), 1-10. https://doi.org/10.1038/s43247-020-00053-y

Jiao, Y., Ding, Y., Zha, Z., & Okuro, T. (2019). Crises of biodiversity and ecosystem services in Satoyama landscape of Japan: A review on the role of management. *Sustainability*, *11*(2), 454. https://doi.org/10.3390/su11020454

Kansanga, M. M., Kerr, R. B., Lupafya, E., Dakishoni, L., & Luginaah, I. (2021). Does participatory farmer-to-farmer training improve the adoption of sustainable land management practices?. *Land Use Policy*, *108*, 105477. https://doi.org/10.1016/j.landusepol.2021.105477

Kansanga, M. M., Luginaah, I., Kerr, R. B., Dakishoni, L., & Lupafya, E. (2021). Determinants of smallholder farmers' adoption of short-term and long-term sustainable land management practices. *Renewable agriculture and food systems*, *36*(3), 265-277. https://doi.org/10.1017/S1742170520000289

Kumar, R., Kumar, A., Saikia, P. (2022). Deforestation and Forests Degradation Impacts on the Environment. In: Singh, V.P., Yadav, S., Yadav, K.K., Yadava, R.N. (eds) Environmental Degradation: Challenges and Strategies for Mitigation. *Water Science and Technology Library*, *104*, 19-49. https://doi.org/10.1007/978-3-030-95542-7_2

López-Carr, D. (2021). A review of small farmer land use and deforestation in tropical forest frontiers: Implications for conservation and sustainable livelihoods. *Land*, *10*(11), 1-23. https://doi.org/10.3390/land10111113

Mahtta, R., Fragkias, M., Güneralp, B., Mahendra, A., Reba, M., Wentz, E. A., & Seto, K. C. (2022). Urban land expansion: the role of population and economic growth for 300+ cities. *Npj Urban Sustainability*, *2*(1), 5. https://doi.org/10.1038/s42949-022-00048-y

Mayer, M., Prescott, C. E., Abaker, W. E. A., Augusto, L., Cécillon, L., Ferreira, G. W. D., … Vesterdal, L. (2020). Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. *Forest Ecology and Management*. *Elsevier B.V.*, *466* (4), 1-25. https://doi.org/10.1016/j.foreco.2020.118127

Mendoza-Ponce, A., Corona-Núñez, R. O., Nava, L. F., Estrada, F., Calderón-Bustamante, O., Martínez-Meyer, E., … Pardo-Villegas, P. D. (2021). Impacts of land management and climate change in a developing and socioenvironmental challenging transboundary region. *Journal of Environmental Management*, *300* (5), 1-10. https://doi.org/10.1016/j.jenvman.2021.113748.

Novita, A. A. (2021). Environmental Governance and Climate Change Adaptation in Indonesia. *Jurnal Ilmiah Administrasi Publik*, *7*(1), 46–55. https://doi.org/10.21776/ub.jiap.2021.007.01.6.

Octavia, D., Suharti, S., Murniati, Dharmawan, I. W. S., Nugroho, H. Y. S. H., Supriyanto, B., ... & Ekawati, S. (2022). Mainstreaming smart agroforestry for social forestry implementation to support sustainable development goals in Indonesia: A review. *Sustainability*, *14*(15), 9313. https://doi.org/10.3390/su14159313

Parmar, S. (2022). *Assessment of Ecosystem Services and Agroecotourism in existing Agroforestry Systems of Kanatal-Dhanolti region of Garhwal Himalaya, India* (Doctoral dissertation, College of Forestry, Ranichauri).

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A. M., Kinengyere, A., ... & Torero, M. (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nature Sustainability*, *3*(10), 809-820. https://doi.org/10.1038/s41893-020-00617-y

Prasada, I. Y., & Masyhuri. (2019). The Conversion of Agricultural Land in Urban Areas (Case Study of Pekalongan City, Central Java). *Agraris*, *5*(2), 112–118. https://doi.org/10.18196/agr.5280

Rahman, F.A., Mubarokah, N., Yuhardi, E., Adiputra, A., Supriyadi, S., dan Suryawati, S. (2023). Perubahan Tutupan Lahan dan Stok Karbon Permukaan di Daerah Aliran Sungai (DAS) Blega. *Jurnal Sumberdaya Alam Dan Lingkungan*, *10*(2), 69–78. https://doi.org/10.21776/ub.jsal.2023.010.02.3

Ray Biswas, R., & Rahman, A. (2023). Adaptation to climate change: A study on regional climate change adaptation policy and practice framework. *Journal of Environmental Management*, *336* (7), 1-17.

Shin, Y. J., Midgley, G. F., Archer, E. R., Arneth, A., Barnes, D. K., Chan, L., ... & Smith, P. (2022). Actions to halt biodiversity loss generally benefit the climate. *Global change biology*, *28*(9), 2846-2874. https://doi.org/10.1111/gcb.16109

Singh, S., & Singh, G. (2023). Agroforestry for sustainable development: Assessing frameworks to drive agricultural sector growth. *Environment, Development and Sustainability*, 1-37. https://doi.org/10.1007/s10668-023-03551-z

Smith, C. C., Espírito-Santo, F. D., Healey, J. R., Young, P. J., Lennox, G. D., Ferreira, J., & Barlow, J. (2020). Secondary forests offset less than 10% of deforestation-mediated carbon emissions in the Brazilian Amazon. *Global Change Biology*, *26*(12), 7006-7020. https://doi.org/10.1111/gcb.15352

Ssentongo, B., Egeru, A., & Barasa, B. (2024). Refugee settlement induces accelerated land use/cover change in Northern Uganda. *Annals of GIS*, *30*(1), 137–149. https://doi.org/10.1080/19475683.2024.2304696.

Sulistyono, N., Bastian Samuel P. Ginting, Pindi Patana, & Susilowati, A. (2019). Land Cover Change and Deforestation Characteristics in The Management Section of National Park (MNSP) VI Besitang, Gunung Leuser National Park. *Journal of Sylva Indonesiana*, *2*(2), 91–100. https://doi.org/10.32734/jsi.v2i2.1120.

Tong, Q., & Qiu, F. (2020). Population growth and land development: Investigating the bi-directional interactions. *Ecological Economics*, *169*, 106505. https://doi.org/10.1016/j.ecolecon.2019.106505.

Tui, S. H. K., Descheemaeker, K., Valdivia, R. O., Masikati, P., Sisito, G., Moyo, E. N., Crespo, O., Ruane, A. C., & Rosenzweig, C. (2021). Climate change impacts and adaptation for dryland farming systems in Zimbabwe: a stakeholder-driven integrated multi-model assessment. *Climatic Change*, *168*(10), 1–21. https://doi.org/10.1007/s10584-022-03433-9.

Zhao, S., & Yin, M. (2023). Change of urban and rural construction land and driving factors of arable land occupation. *PLoS One*, *18*(5), e0286248. https://doi.org/10.1371/journal.pone.0286248

Zina, V., Duarte, G., Fonseca, A., Conde, S., Ferreira, M. T., Franco, J. C., & Fernandes, M. R. (2022). Land use system, invasive species and shrub diversity of the riparian ecological infrastructure determine the specific and functional richness of ant communities in Mediterranean river valleys. *Ecological Indicators*, *145*, 109613. https://doi.org/10.1016/j.ecolind.2022.109613