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Research Article

Estimated changes in carbon stock due to changes in land use around Yogyakarta International Airport

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Abstract

Land use plays an important role in maintaining carbon stock balance, ecosystem sustainability, and the environment. Massive land use changes in forest areas, peatlands, mangroves, and greenways result in an increase in CO_2 release. This research aimed to analyze the impact of land use changes on the value of carbon stock study around Yogyakarta International Airport. The data used were Pleiades images in 2014, 2018 and 2022. Image analysis was carried out visually to produce detailed and accurate land use classification. Meanwhile, multitemporal map overlays were carried out to find out land use changes. Changes in carbon stock were obtained from the land use formula multiplied by the value of the Greenhouse Gas Constant (GGC). The results showed that the construction of an airport and its supporting infrastructure triggered land use changes that had implications for the decreasing carbon stock. The decrease in the area of vegetation cover in fields, community plantations, and mixed plantations from 2014 to 2022, amounting to -640.99 ha, increased carbon emissions. The results of the analysis showed that there had been changes in carbon stock. In 2014, the value was 150,286.57 t C/ha; in 2018, it decreased to 136,631.56 t C/ha; and in 2022, it reduced to 133,554.36 t C/ha. Massive economic activity and infrastructure development trigger reduced vegetation cover, resulting in increased carbon and increased carbon being released into the atmosphere. The problem of land conversion that affects changes in carbon stock and impacts on climate change requires mitigation, among which is by proper land use management and sustainable spatial planning.

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Introduction

Land use and land cover have an important role in maintaining carbon stock balance, biodiversity sustainability, and ecosystem balance (Molina-Bacca et al., 2023; Tu et al., 2023; Qian et al., 2023; Xu et al., 2023). Rong et al. (2023) stated that the type of land use has a correlation with differences in carbon stock; for example, land utilized as mangrove forests, peatlands, and forest areas is able to bind the highest carbon compared to other uses (Shiraishi et al., 2023). With massive changes in land use, there are also changes in terrestrial carbon stored in vegetation and carbon stocks in the soil (Shao et al., 2023; Tsegaye et al., 2023). Various studies explain that changes in land use which cause reduced vegetation cover and decreased forest areas not only cause carbon emissions but also cause land degradation (Peri et al., 2024). Various anthropogenic activities often change vegetation/forest into open land or cultivated land which has implications for increasing erosion and changing the organic carbon content in the soil (Karamesouti et al., 2015; Hosseini et al., 2024). Ignoring this condition certainly threatens the sustainability of people's lives and triggers various disasters (Peri et al., 2024).

Industrial development, accelerated economic growth, population growth, increased anthropogenic activity, and urban sprawl in various countries are the causes of massive land use change (Gençay and Durkaya, 2023; Luo et al., 2023; Lyu et al., 2023; Murdiyarso et al., 2023; Swamy et al., 2023). Increased land conversion oriented to economic aspects, on the one hand, can encourage rapid national economic growth and improve welfare, but on the other hand, the impact of land conversion further exacerbates environmental damage, increases temperature, causes various disasters, and threatens human life (Ling et al., 2023; Lyu et al., 2023; Winkler et al., 2023). In addition, the increase in forest and peatland fires and wood needs in various countries are also the cause of increased CO_2 release, which contributes to the adverse effects of climate change/global warming (Susilo et al., 2018; Utami and Salim, 2021; Utami et al., 2022; Krisnawati et al., 2023; Muthuri et al., 2023; Shiraishi et al., 2023; Sweeney et al., 2023).

The rate of deforestation that occurs is very massive in various countries, especially in Indonesia, becoming one of the main problems in the environmental sector (Gençay and Durkaya, 2023; Müller et al., 2023; Range-Pinagé et al., 2023). The existence of forests/mangroves/peatlands that play a role in absorbing CO_2 and storing carbon (above the surface in the form of vegetation cover, soil carbon in the form of organic materials, underground biomass/plant roots, and dead organic carbon) continues to degrade. Infrastructure development, industry, mining and economic activities are the main causes of increasing pressure on forest/vegetation conversion.

The increasing impact of climate change caused by decreasing vegetation/deforestation is a serious concern internationally. As an effort to reduce the impact of climate change, several countries signed the Paris Agreement as a legally binding agreement. Indonesia, as a country that has a big contribution to this issue, has subsequently established regulations/various laws and policies of a strategic nature, including the establishment of institutions responsible for protecting mangroves/peat as well as various moratoriums to reduce carbon emissions. Apart from that, sustainable land management strategies, including through silvofishery systems, agroforestry, and ecotourism, are implemented so that economic and environmental aspects can be sustainable (Susilo et al., 2018; Utami and Salim, 2021; Utami et al., 2022; Muthuri et al., 2023). Even though various schemes have been implemented, the increase in carbon emissions continues to occur (Mujiyo et al., 2021).

One effort to mitigate the impact of global warming that needs to be done is through monitoring land use to maintain the balance of carbon stocks. This monitoring can be carried out by utilizing satellite imagery/aerial photography so that changes in land use cover in an area can be identified (Tsegaye et al., 2023). Monitoring is an important part of knowing lost carbon stocks (Gabriele et al., 2023). Wang et al. (2023) maintained the balance of carbon stocks and mitigates adverse impacts that will occur due to development and land conversion (Mutiibwa et al., 2014; Gençay and Durkaya, 2023).

Monitoring changes in land use and monitoring carbon stocks are the basis for formulating land management policy strategies to reduce carbon emissions as well as efforts to reduce land degradation (Liu et al., 2023; Raqeeb et al., 2024). However, efforts to monitor changes in land use and their impact on changes in carbon stocks and land degradation are still limited. This condition also occurs in the study area where the national strategy project in the form of the construction of the Yogyakarta International Airport has changed most of the vegetation cover, which has the potential to store carbon stock reserves. It is feared that land conversion that continues to occur without monitoring changes in carbon stock reserves will have a massive effect on the release of carbon emissions, which will further worsen global warming.

This research attempted to provide a solution to the problem above, namely by monitoring land use changes using high-resolution satellite imagery to obtain more accurate carbon stock calculation results Monitoring changes in carbon stocks caused by infrastructure development and economic activities is important as a basis for formulating land management policies (Wu and Wang, 2023). It is hoped that this analysis will be able to become a basis for formulating decarbonization efforts as a form of environmental sustainability responsibility (Müller et al., 2023), as well as a basis for preparing spatial planning so that the availability of green open space/urban forests in urban areas and vegetation planting can be optimized (Lerbinger et al. al., 2023). This monitoring is an important part of efforts to realize the 13th Sustainable Development Goal, namely controlling climate change, the impact of which is increasingly triggering a global socio-economic crisis.

It is hoped that spatial planning and land use efforts based on the availability of carbon stock will be a solution in maintaining the balance of carbon stocks (Sovacool et al. 2023), as well as being a solution for land restoration so that land degradation can be reduced and mitigated

Materials and Methods

Study area

This study was conducted on 26 villages in Temon, Wates, and Panjatan Sub-districts, Kulon Progo Regency, Yogyakarta Province, which were indicated to be affected by Yogyakarta International Airport (YIA) development, its supporting infrastructure (roads), and the growth of new economic centers. Temon Sub-district, the location for the construction of the airport, was originally a rural area where land use was dominated by vegetation cover (community plantations, mixed plantations, fields). Meanwhile, Wates Sub-district as the center of government and the center of economic growth, has the characteristics of an urban area. Geographically, the location of the study is presented in Figure 1.

Data and analysis

The data in this study used Pleiades images of YIA in 2014 (before the construction), 2018 (during the construction), and 2022 (after the construction). The Pleiades imagery was chosen because it has a very high spatial resolution of 0.5 m; apart from having the advantage of very high spatial resolution, this image also has two bands, namely one panchromatic band and four multispectral bands with wavelengths (blue, green, red and near-infrared).

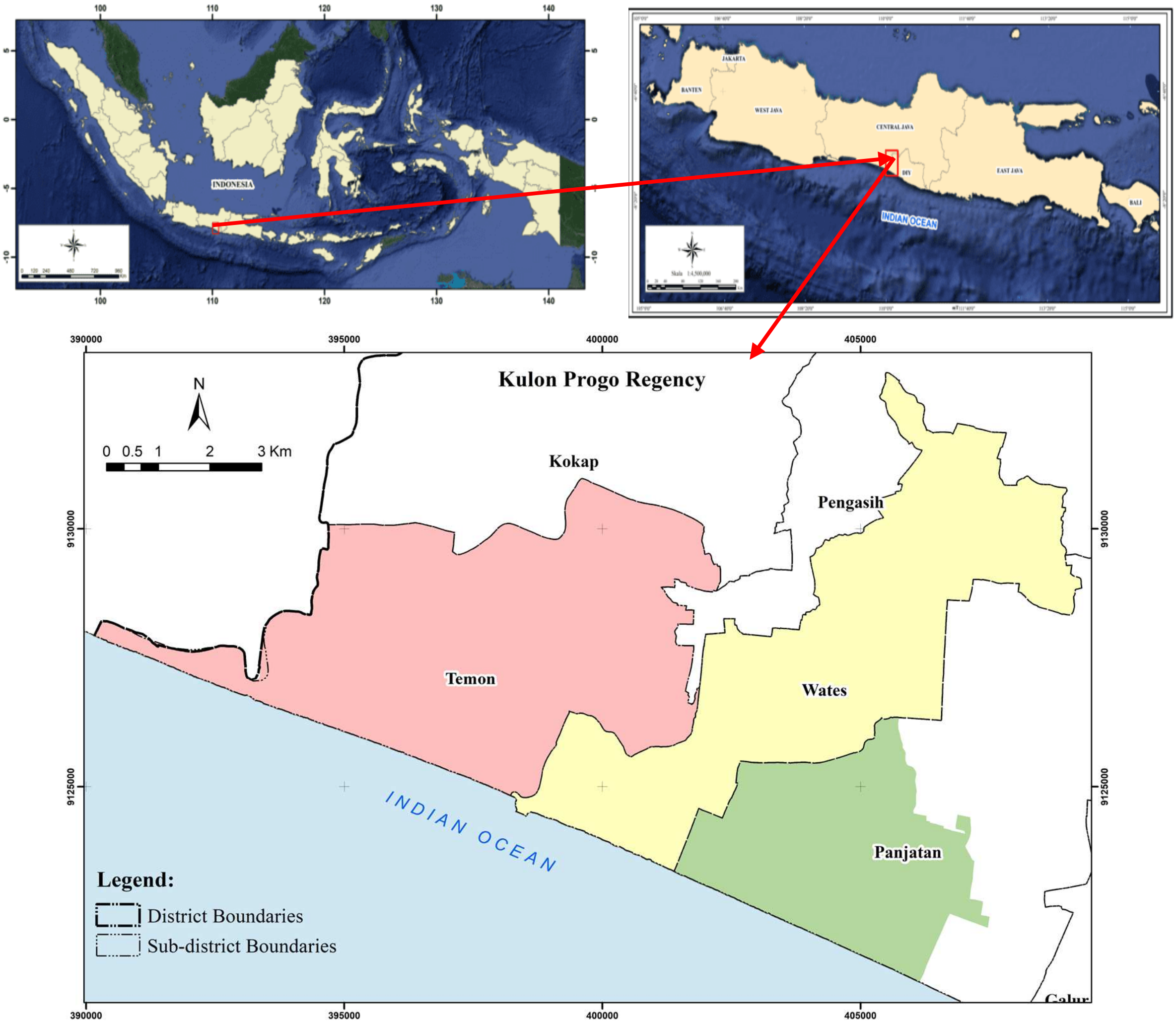


Figure 1. Study location map (based map source: BIG 2022).

Interpretation of Pleiades imagery was carried out not through random forest or maximum likelihood. Interpretation was carried out visually because the visual approach to Pleiades imagery can produce more accurate and detailed classification results (Rahman et al., 2022). The land use classifications in this study were divided into several groups: plantations/gardens, secondary mangrove forests, dryland, built-up land, rice fields, shrubs, open land, water bodies, airport/infrastructure, ponds/marine fishponds. To determine the level of accuracy of land use in this research, a sample test of land use in the field was carried out with a total of 441 samples. A land use accuracy test analysis was carried out using a confusion matrix analysis. Meanwhile, to determine land use changes, intersect analyses of multitemporal land use maps were carried out: 2014 with 2018 and 2018 with 2022. To determine land use changes, tabular analyses of changes per type of land use between T0 (initial years) and T1 (final years /observation) were carried out. Meanwhile, the changes in land use per year were determined by using the following equation.

LCC = $A1 - A0 T1 - T0$ ………………………….....1)

Notes:

LCC	=	Land cover change
$A1$	=	Area of final observation
$A0$	=	Area of initial observation
$T1$	=	Year of final observation
$T0$	=	Year of initial observation

Calculation of carbon stock per land use was carried out using the following equation.

$Carbon\ Stock$ (T_0 or T_1) = LUA * GHG Constant .2)

Notes:

LUA	=	Land use area
GHG	=	Greenhouse gas constant

Inventory of carbon stock per type of land use calculated in this study was carried out periodically, namely in 2014 (before land acquisition), 2018 (when the reconstruction began), and 2022 (when the airport was open for operation). Carbon stock was calculated using the following equation.

$$\Delta C = \frac{(Ct_2 - C\,t_1)}{(t_2 - t_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3)$$

Notes:

ΔC	=	Changes in carbon stock
$Ct2$	=	Carbon stock in year $t2$
$Ct1$	=	Carbon stock in year $t1$
$t2$	=	Year of final observation
$t1$	=	Year of initial observation

The stages and methods used in this study can be explained in the flowchart of Figure 2.

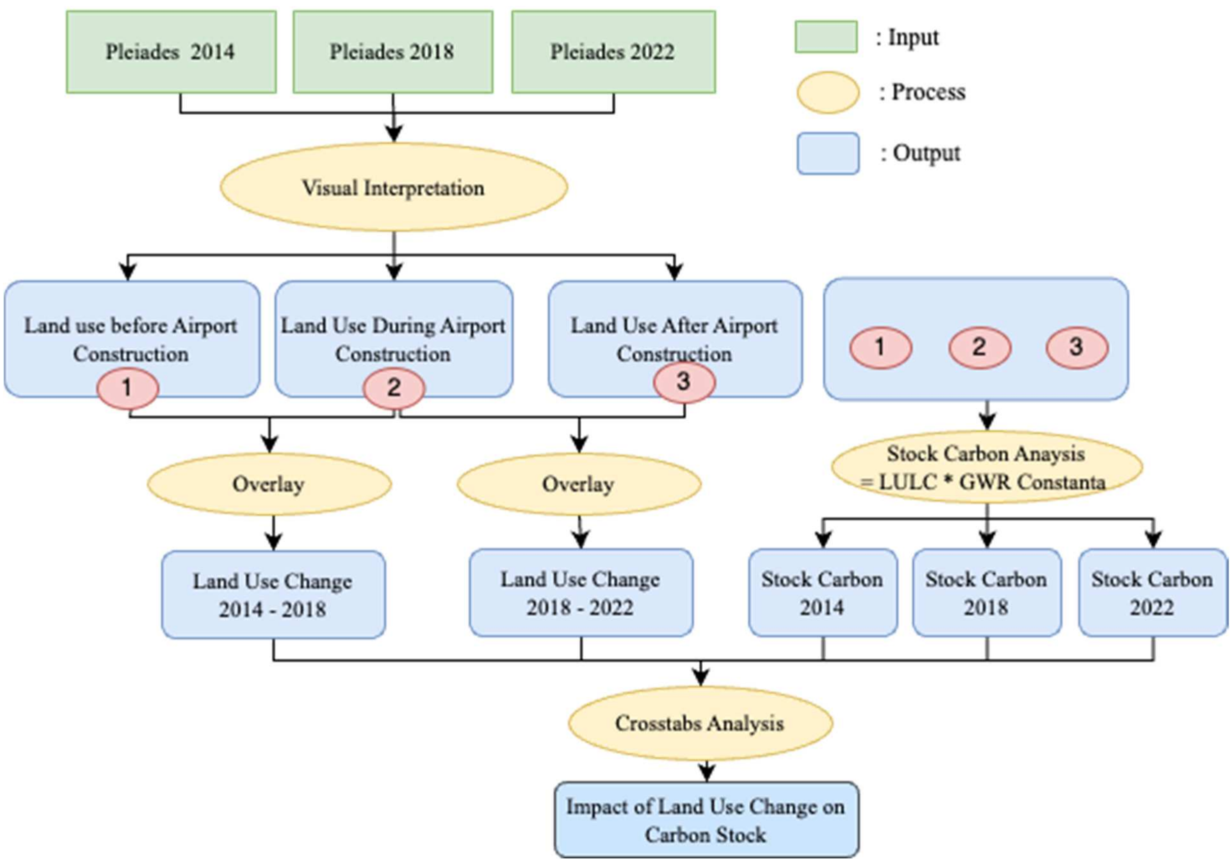


Figure 2. Flowchart analysis of the impact of land use change on carbon stock.

Results and Discussion

The results of the Pleiades image interpretation visually showed land use maps in 2014, 2018, and 2022. To determine the level of accuracy of the interpretation results, a total of 441 land use sample points were sampled in this study. From the results of the field study, there were 33 inappropriate samples and 408 appropriate samples. The results of the accuracy test calculation can be formulated as follows.

$$\text{Accuracy Value} = \frac{408}{441} \, x \, 100 \, \%$$

$$\text{Accuracy Value} = \; 92{,}52 \, \%$$

Based on the calculation above, the level of interpretation accuracy is 92.52%, which is classified as high, so it is suitable for analysis of land use changes and changes in carbon stock.

The impact of infrastructure development on land use change

The development of YIA and its supporting infrastructure, in addition to changing the land for the airport, resulted in massive land conversion around the airport. Land use conditions in the study area in 2014, 2018, and 2022 are presented in Figures 3, 4 and 5. Based on Figure 3, the condition of land use in the study area, especially in 2014, was mostly dominated by mixed plantations/fields with a total area of 1,956,62 ha and rice fields reaching 2,962.1 ha. Meanwhile, the built-up land in the form of settlements, public facilities, and trade and service areas was still limited, at only 1,654.66 ha. With the construction of YIA, settlements and various facilities such as hotels, offices, and trade and services increased significantly to reach 1,762.84 ha.

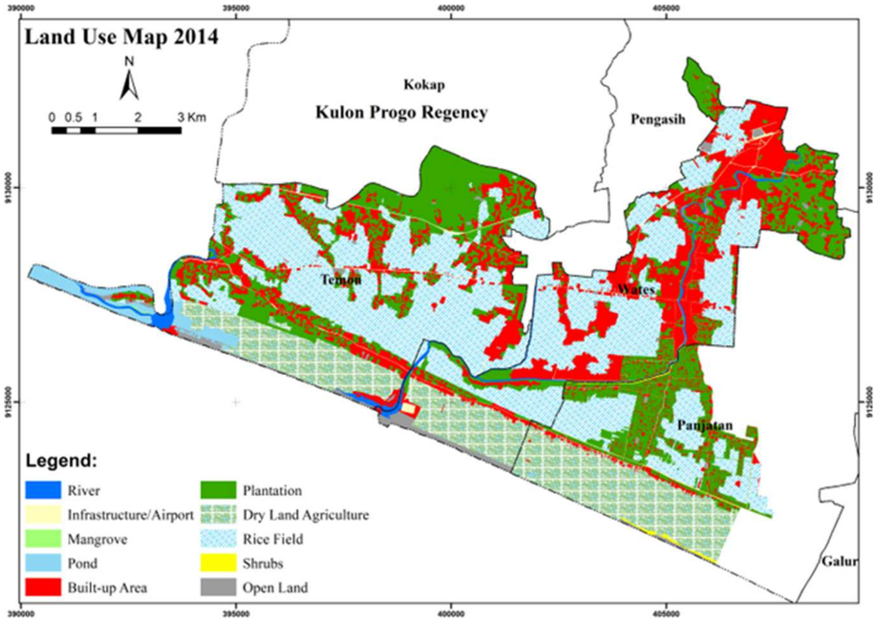


Figure 3. Land use map in 2014.

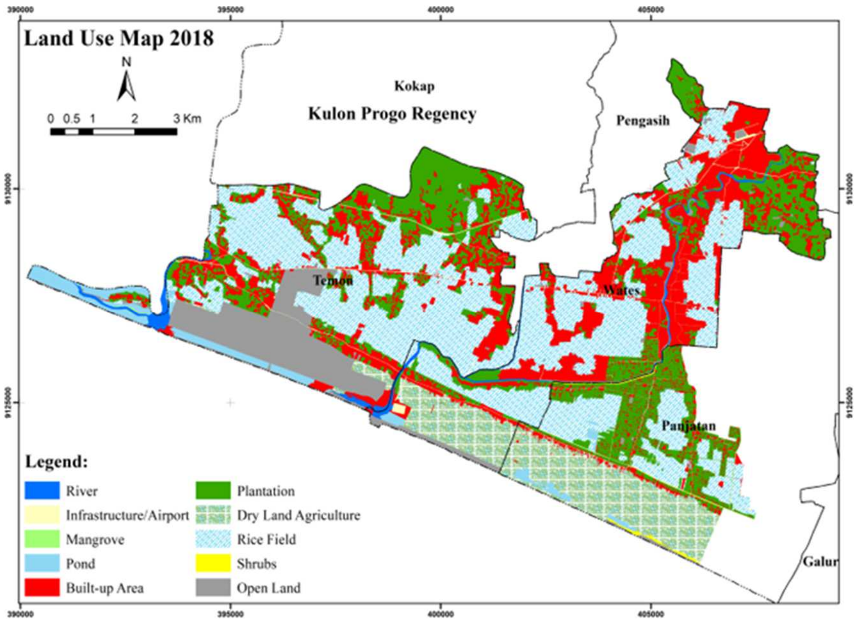


Figure 4. Land use map in 2018.

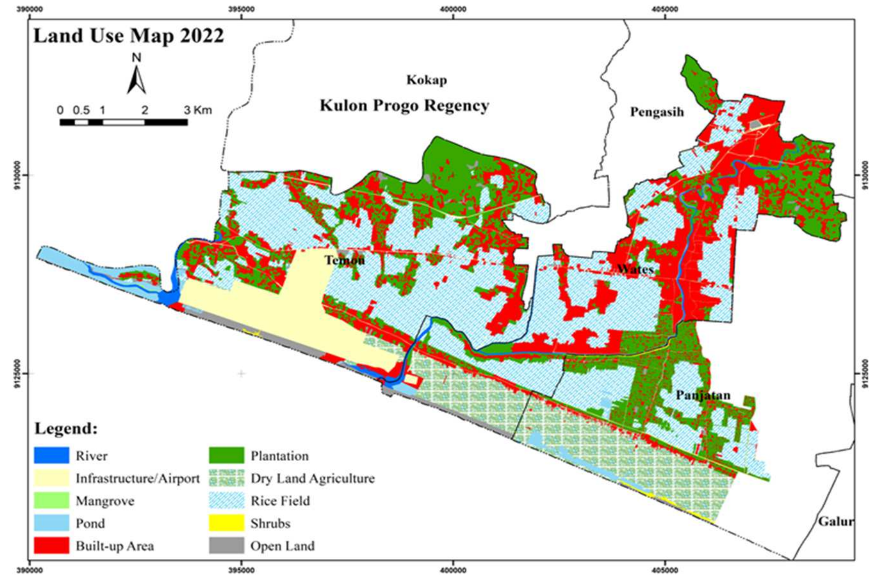


Figure 5. Land use map in 2022.

The growth of built-up land, especially the trade and service area, was located adjacent to the airport and along the arterial road that connects Yogyakarta City with the airport. Data on the area of land use at the study locations in 2014, 2018, and 2022 presented in Figure 6 show that plantation areas (mixed plantations, community plantations, and fields) are the land use types with the most changes. In eight years, from 2014 to 2022, there has been a decrease in plantation area of 203.45 ha. Meanwhile, built-up land consisting of settlements, offices, trade and service areas, industries, and public facilities increased by 151.24 ha. The details of the area of multitemporal land use change in the study area are presented in Tables 1 and 2.

The results of the pivot analysis show that from 2014 to 2018, massive changes in land use were caused by the construction of YIA with plantations, dryland, and rice fields, as most objects turned into open land. In addition to land-switching functions for the construction of the airport, plantations, and rice fields also changed and switched to built-up land during that period. Land use changes in the 2018-2022 period also occurred quite massively, where some vegetated land, namely plantations, dryland, and rice fields, were converted for the development of built-up land (settlements, hotels, and trade and service facilities).

The impact of land use changes on carbon stock

The development of airport infrastructure in Kulon Progo Regency is one of the factors triggering massive changes in land use. The results of the analysis showed that most of the airport infrastructure development, along with built-up land has changed vegetation cover in the form of mixed plantations, fields, and community plantations. Aiming to determine the condition of carbon stocks in the study area, this study utilized land use data in 2014, 2018, and 2022. Based on the calculation analysis of each type of land use multiplied by the constant value, the value of carbon stocks in 2014, 2018, and 2022 can be presented as shown in Table 3.

The results of the analysis of the calculation of carbon stocks in 2014, 2018, and 2022 showed that the total value of carbon stock stored in land cover has decreased. This indicates that with changes in land use, carbon is released into the atmosphere, which can trigger an increase in temperature and adverse effects of climate change. The decrease in the area of vegetated land cover from 2014 to 2022, the increase in built-up land, and the construction of airport infrastructure resulted in drastic changes in carbon stock. Plantations consisting of community plantations/mixed plantations/fields with a carbon constant value of 63 experienced a very massive conversion into built-up land with a constant value of 4 and into an airport/infrastructure with a constant value of 0. This is what contributes to a massive decrease in carbon stock in the study area. The value of changes in carbon stock in each land use in the period from 2014 to 2018 can be presented in Table 4, while the crosstab data on changes in carbon stock in the period from 2018 to 2022 is presented in Table 5.

Table 4 shows that from 2014 to 2018, the decrease in carbon stock was mostly due to changes in vegetation/plantations into open land intended for airport development and the expansion of fishpond cultivation in coastal areas. With the switch from plantation to open land and fishponds, the content of carbon stocks that can be tied to land use decreased, with open land having a constant value of 2.5 and fishponds having a constant value of 0. Meanwhile, from 2018 to 2022, the decrease in carbon stock was triggered by the conversion of open land into an airport with a constant value of 0 and an increase in built-up land with a constant value of 2.5. The conditions of dominant land use changes with periodic stock values are illustrated in Figure 7.

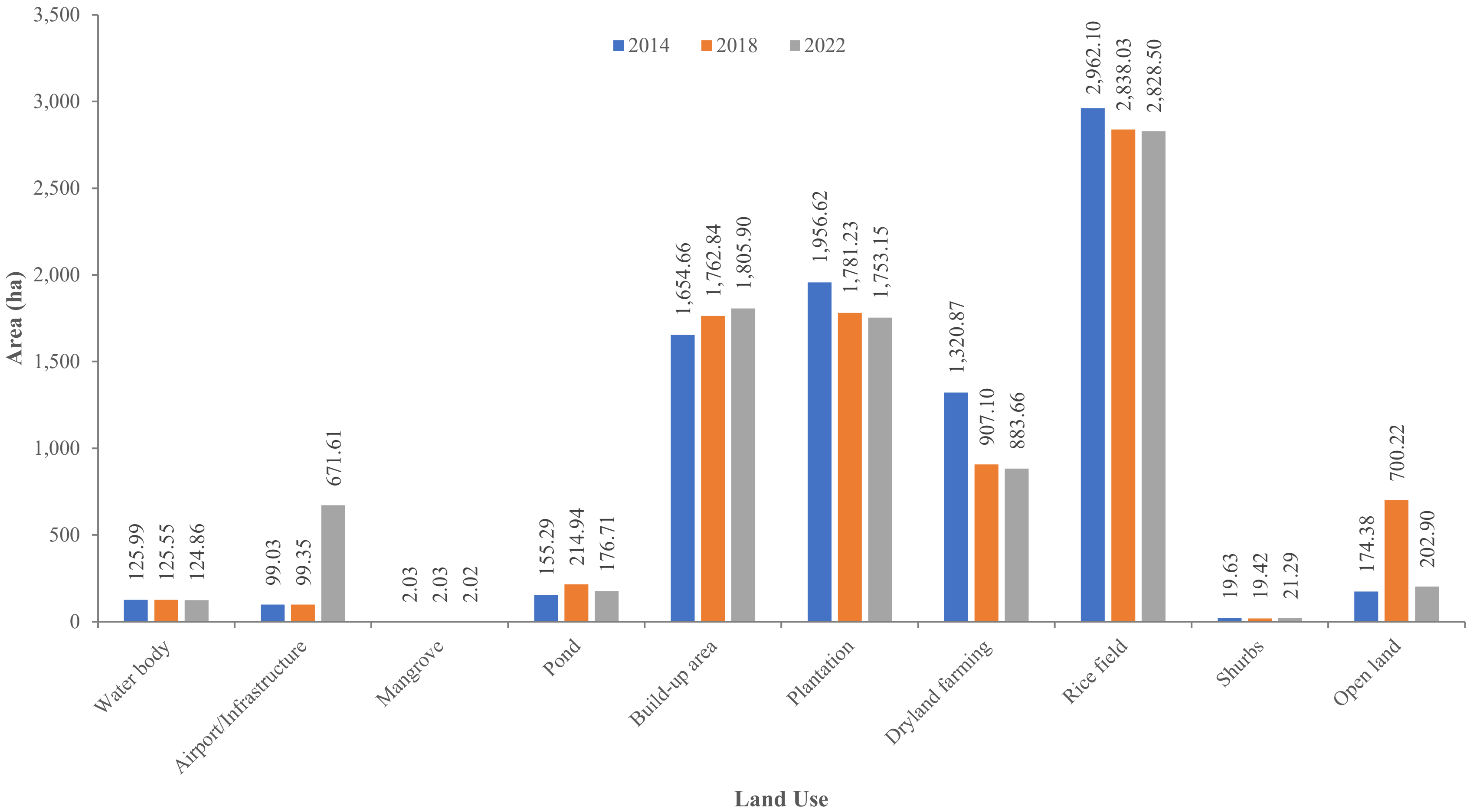


Figure 6. Land use areas in 2014, 2018, and 2022.

Table 1. Pivot matrix of land use change in 2014-2018.

Land Use 2014	**Land Use 2018 (ha)**									
	Water body	**Infrastructure**	**Mangrove**	**Pond**	**Built-up area**	**Plantation**	**Dry land agriculture**	**Rice field**	**Shrubs**	**Open land**
Water body	125.19			0.12	0.34					0.34
Infrastructure		98.99								
Mangrove			2.03							
Pond		0.01		113.41	0.11					41.77
Built-up area		0.21			1,634.35	0.05				19.70
Plantation		0.04		5.38	90.96	1,778.75	0.91	0.11		80.45
Dry land agriculture				64.44	10.92		905.66		0.01	339.84
Rice field		0.01		4.92	13.90	2.23		2,857.90		83.14
Shrubs	0.01						0.53		19.10	
Open land				26.67	12.12	0.16			0.31	134.98

Table 2. Pivot matrix of land use change in 2018-2022.

Land Use 2018	**Land Use 2022 (ha)**									
	Water body	**Infrastructure**	**Mangrove**	**Pond**	**Built-up area**	**Plantation**	**Dry land agriculture**	**Rice field**	**Shrubs**	**Open land**
Water body	124.86				0.70					
Infrastructure		99.25								
Mangrove			2.03							
Pond				161.67	0.35				1.59	51.34
Built-up area		0.60			1,760.94	1.29				13.28
Plantation		0.02			16.99	1,750.68		0.26		
Dry land agriculture				15.04	7.50	0.91	883.65			
Rice field		21.36			7.31	0.09		2827.45		1.81
Shrubs									19.42	
Open land		550.38			12.11	0.19		0.79	0.28	136.48

Table 3. Land uses and carbon stocks in 2014, 2018, and 2022.

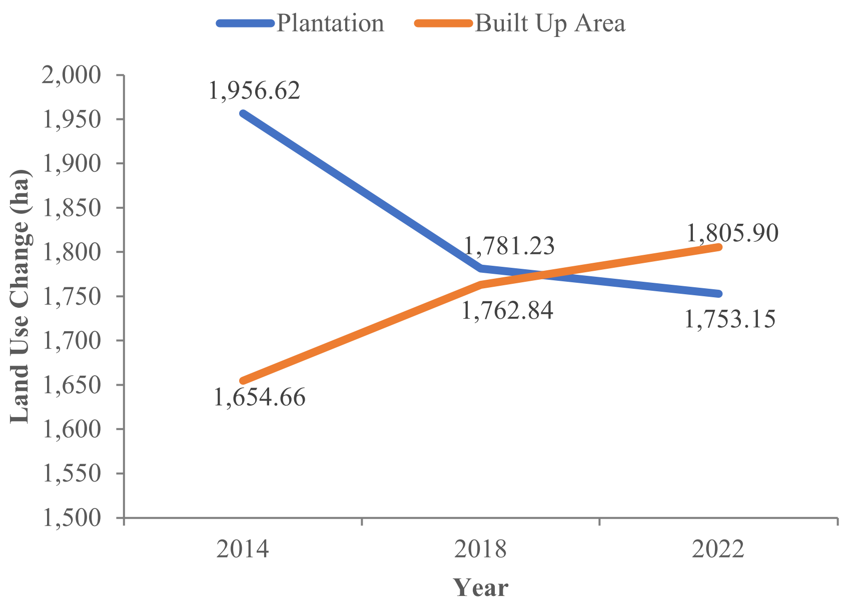
Land Use	**Carbon Constanta (t C/ha)**	**Land use 2014 (ha)**	**Carbon Stock 2014 (t C/ha)**	**Land use 2018 (ha)**	**Carbon Stock 2018 (t C/ha)**	**Land use 2022 (ha)**	**Carbon Stock 2022 (t C/ha)**
Water body	0	125.99	0	125.55	0	124.86	0
Infrastructure/airport	0	99.03	0	99.25	0	671.61	0
Mangrove	120	2.03	243.6	2.03	243.6	2.03	243.48
Pond	0	155.29	0	214.94	0	176.71	0
Bulit-up area	4	1,654.66	6,618.64	1,762.84	7,051.36	1,805.90	7,223.61
Plantation	63	1,956.62	12,3267.06	1,781.23	112,217.49	1,753.15	110,448.70
Dryland farming	10	1,320.87	1,3208.7	907.1	9071	883.66	8,836.56
Rice field	2	2,962.10	5,924.2	2,858.03	5,716.06	2,828.50	5,656.99
Shrubs	30	19.63	588.9	19.42	582.6	21.29	638.73
Open land	2.5	174.38	435.95	700.22	1,750.55	202.90	507.25
Total Carbon Stock			150,287.05		136,632.66		133,555.33

Table 4. Carbon stock value based on the land use change in 2014-2018.

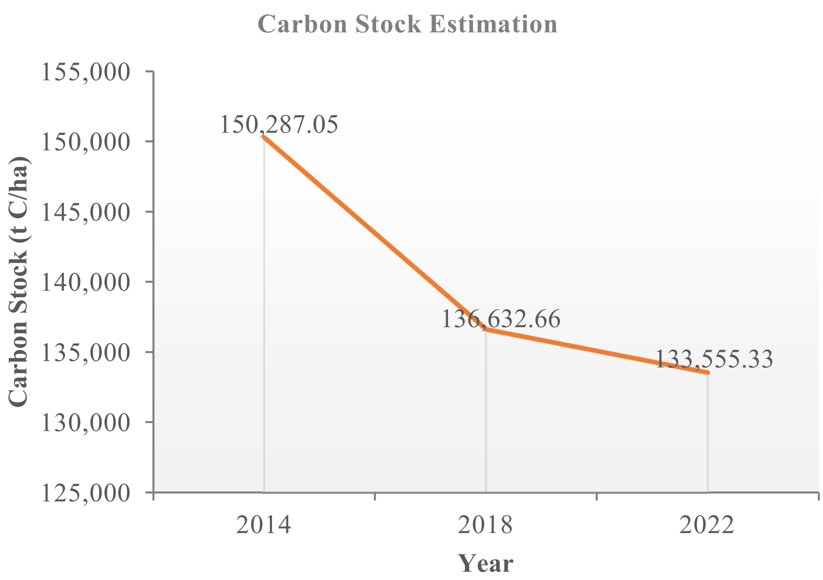
Land Use Carbon Stock 2014	**Land Use Carbon Stock 2018 (t C/ha)**										
	Water body	**Built-up area**	**Shrubs**	**Plantation**	**Open land**	**Dry land agriculture**	**Infrastructure**	**Rice field**	**Pond**	**Mangrove**	**Total**
Water body		1.36	0.05	2.09	0.85						4.34
Built-up area				3.08							3.08
Shrubs				0.01		-10.50					-10.50
Plantation		-5,362.16	-0.07			-48.35			-339.23		-5,749.81
Open land		18.38	8.65	9.86					-66.67		-29.78
Dry land agriculture											
Infrastructure											
Rice field		26.65		135.89	41.57				-9.84		194.27
Pond											
Mangrove											
Total		-5,315.77	8.63	150.93	42.42	-58.85			-415.74		

Table 5. Carbon stock value based on the land use change in 2018-2022.

Land Use Carbon Stock 2018	**Land Use Carbon Stock 2022 (t C/ha)**										
	Water body	**Built-up area**	**Shrubs**	**Plantation**	**Open land**	**Dry land agriculture**	**Infrastructure**	**Rice field**	**Pond**	**Mangrove**	**Total**
Water body		2.79									2.79
Built-up area				76.09			-2.34	-15.62			73.75
Shrubs				0.04	-0.01			-0.39			0.03
Plantation		-1,005.23			-803.35						-1,824.20
Open land	-0.01	25.84		11.27			-1,372.85				-1,339.15
Dry land agriculture		-44.99							-150.37		-195.36
Infrastructure											0
Rice field	-0.01	14.63		5.65	0.90		-42.57				-21.40
Pond			49.03		128.34						177.36
Mangrove											0
Total	-0.02	-1,006.97	49.03	93.03	-674.11		-1420.77	-16.01	-150.37		



(a)



(b)

Figure 7. (a) Dominant land use changes, (b) Carbon stock changes 2014-2018.

Based on Figure 7, in the period of 2014-2018, the decrease in carbon stock occurred very drastically, reaching 13,654.39 t C/ha, which was influenced by the high need for land to build YIA. Meanwhile, after the construction of the airport, from 2018 to 2022, a decrease in the carbon stock of 3,077.33 t C/ha occurred due to the increase in various airport support facilities as well as settlements/built-up land. The decrease in carbon stock in the study area is likely to continue, considering that airport development is still at an early stage and the government keeps encouraging the continuation of the supporting infrastructure development process. In addition, the attractiveness of the airport also triggers various investors to build hospitality, trade, and service facilities as well as industries, and it will trigger the rate of land conversion.

Multitemporal land use change monitoring, as what was carried out in this study, is an important part of formulating mitigation that can be done to reduce changes in the value of carbon stock. Monitoring land use change to regulate environmental sustainability and control the impact of disasters/climate change can be done using geographic information systems and remote sensing image data (Fan et al., 2023; Gabriele et al., 2023; Stagakis et al., 2023). One of the mechanisms for controlling environmental damage and climate change can be carried out intensively and effectively through regulatory policies on the use and utilization of land (Molina-Bacca et al., 2023; Winkler et al., 2023). Regulations and restrictions on land use types and the direction of regional/urban development are very important to developing the airport area as an aerotropolis (Luo et al., 2023). In addition, political and economic interventions that emphasize environmental sustainability, renewable energy use, and decarbonization efforts are necessary to be applied in development (Soboka and Yimer, 2022; Hayes et al., 2023; Sovacool et al., 2023).

Socio-economic activities that continue to develop around the construction of YIA airport are inevitable. In this case, mitigation of changes in carbon stock, including maintaining the balance of carbon stock, needs to be formulated. The role of forests on the north side of the airport development and mangroves on the west side of the airport that can store carbon stock certainly needs to be optimized. Both land uses are expected to be able to provide a balance in the availability of carbon stocks so that the impact of climate change can be mitigated from the beginning (Bouillon et al., 2008; Nugroho et al., 2022; Murdiyarso et al., 2023).

Conclusion

The development of YIA infrastructure and its supporting facilities has implications for the increasing conversion of land functions from plantation areas (mixed plantations, community plantations) as well as dryland into airport areas and built-up land. The very massive land conversion has decreased carbon stock stored in land, resulting in an increase in carbon emissions released into the atmosphere. Within eight years, the decrease in carbon stock in the study area reached 16,731.72 t C/ha. This decrease is very massive because the plantations, which were initially able to store carbon stocks of up to 63 t C/ha turned into an infrastructure/airport with a constant value of 0/ha. Land use changes that trigger changes in carbon stock in the study area are feared to occur continuously. In this case, carbon politic-economic policy interventions and land use regulation policies need to be formulated. In addition, the optimization of reforestation of forest areas and the restoration of mangrove areas around the airport needs to be done to maintain the carbon stock balance to minimize the impact of climate change.

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