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Original article

Accounting for the ecosystem services of different land uses: a case study of the ecological zones in the Mekong Delta Region, Vietnam

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ABSTRACT

This study analyzed the physical changes of ecosystems and measured the value of ecosystem services (ESV) in a subregion of Vietnam. The results showed that cropland accounted for the majority of the natural area with 85%, while urban land area increased by 5% from 1990 to 2020. Water and aquaculture accounted for a significant proportion, while the remaining land groups, such as grassland, barren land, and forest, accounted for insignificant proportions. Can Tho, serving as the socio-economic center of the region, showed the most obvious contrast between the growth of urban land and the decline of cropland when both had a change of 8%. Meanwhile, An Giang showed growth in both types of land use in the period 1990–2005, but this locality had a decrease in crop land in the period 2005–2020. Land use change impacted on ESV during the study period. This value decreased from 1990 to 2005 by 43.36 million US$/year, then increased by 462.37 million US$/year from 2005 to 2020. However, the rate of change in ESV by locality showed different values. Hau Giang is the province that shows the strongest growth by 8%, followed by Vinh Long and An Giang bothwith growth rates of over 7.6%. Dong Thap was the only province that witnessed a decrease in ESV after 30 years. The research aimed to support policymakers to have more background information as a basis for building strategies to ensure sustainable development to combat climate change and environmental change in the study sub-region in particular and inVietnam in general.

KEY WORDS: urbanization; sustainable development; land use change; environmental change; Vietnam

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1. Introduction

Land is a distinctive environmental resource that defines the area in which economic activities and environmental processes take place and functions as a repository for both environmental and economic assets. The importance of land places demands on land management and sustainable land use (Nziguheba et al., 2021; Zhang et al., 2023). For land-related policies to be effective, it is necessary to monitor land use changes using repeatable methods. In other words, reports on land use changes are important for the development and implementation of policies such as regional planning (Ahmad et al., 2022; Cabernard et al., 2024). Another issue that needs to be addressed is that land use changes have negative impacts such as accelerating climate change (Mendoza-Ponce et al., 2021; Barati et al., 2023), promoting soil erosion (Aneseyee et al., 2020; Guder & Kabeta, 2025), and decreasing biodiversity (Watt, 2020; Semenchuk et al., 2022). Accounting for land helps in monitoring the impact of land use change because it describes how land resources change over time and systematically helps in understanding the impacts of such changes

(Huang et al., 2024). Therefore, it can be said that land accounting is the spatial foundation for land conservation and management policies (Malek & Verburg, 2020). It can determine how land is distributed and what the land use trends are. In addition, urbanization is taking place rapidly in the world, especially in developing countries. Land accounting aims to determine which types of land are being converted into urban land and supports many aspects of sustainable development goals (Kalfas et al., 2023).

There is usually a core set of tables in land accounts that show how land use and land cover interact from an ecological standpoint, and then there is another set of tables that give issue-specific data that is useful for policymaking and tracking (Harris, 2003). Finding the connection between land cover and land use stocks is the focus of the first table (Harris, 2003). However, this setup appears to be available only for a specific land use classification. The second table, on the other hand, is related to the standard national accounts (Wentland et al., 2020). It requires extensive data on land use by sector and household, rather than by ownership. This creates difficulties in identifying major land uses and requires multiple data sources to establish linkages with industries. The third table gives a foundation for understanding the change causes by describing aggregated data flows between distinct land stocks across time (Ivits et al., 2024). Based on the foregoing description, in this study, we focus on developing physical land accounts.

Land accounts, especially land cover, are fundamental to ecosystems, or in other words, land cover is a key variable in the delineation of ecosystem types (Verde et al., 2020). Many studies have addressed the concepts and applications of natural capital and ecosystem accounting, especially ecosystem accounting methodologies (Russell et al., 2020; Gorman et al., 2024; Tran & Tuan, 2025). Studies have shown the urgency of the need to study this issue given the increasing pressures from the consequences of climate change (Liu et al., 2024), biodiversity loss (Mengist et al., 2022), and socio-economic trends (Ma et al., 2022). However, most studies offer a metric or indicator that measures some aspect of ecosystems in order to draw conclusions about how healthy such ecosystems are (Maes et al., 2020). As an alternative approach, some recent studies have applied monetary ecosystem accounting to a variety of ecosystem types in a spatially explicit manner (Remme et al., 2015; Schenau et al., 2022; Scheufele & Pascoe, 2023). Such accounting also quantifies and aggregates ecosystem services using monetary units as a measure of value and is easily comparable (Brander et al., 2024). Therefore, this study also determines the ecosystem services values (ESV) using monetary methods.

Vietnam is located in the Indo-Burmese biodiversity hotspot. The world's 30 regions with irreplaceable biodiversity include this country, which has high biodiversity and diverse natural ecosystems. However, Vietnam is also in the process of industrialization and urbanization. Land use conversion such as reclaiming agricultural land for construction (Tuan & Hegedűs, 2022) and unsustainable exploitation activities have contributed to disturbing natural landscapes and changing the natural conditions of ecosystems (Tuan, 2024). In fact, environmental degradation and pollution are increasing, while biodiversity is declining (Nguyen & Jones, 2022). Alongside this destruction, the exploitation and use of resources have not been as effective as expected, increasing the risk of ecological imbalance and not being able to ensure energy and food security (Nguyen et al., 2023). This affects the stability and sustainable development of the country. Therefore, analyzing the physical changes of ecosystems as well as measuring ESV in Vietnam is necessary. This approach promotes Vietnam's sustainable development goals, and this study can help policy-makers have a better basis for development and building strategies to ensure sustainable development. Therefore, this study establishes physical accounts for land and ecosystem service values by employing monetary methods in a representative ecological subregion of the Mekong Delta region in Vietnam.

2. Overview of research on ecosystem service value accounting

The impetus for ecosystem services accounting comes from the emerging need to integrate information about environmental sustainability and human well-being (Lai et al., 2018). This implies a need to better understand what services ecosystems provide in terms of both marketable goods and services. It also reveals which ecosystem attributes are critical to sustaining these value streams for society (Costanza, 2020). Assessing monetary ESV is a crucial part of regulating the connections between natural and human systems (Sobhani et al., 2025). At the macro level, ecosystem valuation can contribute to the development of indicators of human well-being and sustainability (Dawson & Martin, 2015; Hori & Makino, 2018), while at the micro level, it reveals information about both the structure and functioning of ecosystems and the diverse roles ecosystems play in supporting human well-being (Meli et al., 2023). Accounting for ecosystem assets is particularly useful in contexts where institutional arrangements do not work well to reflect the social costs of environmental degradation (Ogilvy et al., 2018). Therefore, tracking how ecosystem transformation affects human well-being in both the short and long term is an important accounting activity (Jiang et al., 2024).

Diverse perspectives exist about the definition and scope of ecosystem service accounting. Costanza et al. (2014) posited that ecosystem services serve as the primary conduit via which natural capital enhances human well-being, asserting that ecological assets are synonymous with natural capital. ESV is seen as the supplementary value of ecosystem assets or inputs obtained from natural capital (Salles &Figuieres, 2020). Researchers have employed words such as natural assets (Leach et al., 2019) and ecological products (Wu et al., 2024) to denote the benefits that ecosystems confer upon humanity. These concepts share the application of economic principles to elucidate the role of natural ecosystems in human society (Rode et al., 2016). The UN System of Environmental-Economic Accounting Ecosystem Accounting (SEEA-EA) approach asserts that ecosystem accounting should exclusively focus on ecological activities that enhance human development (Edens et al., 2022). Ecosystem functions denote an inherent characteristic of ecosystem assets and produce various streams of information and services among ecosystems (Oliver et al., 2015). Services that directly impact and benefit humans are classified as ecosystem services, whilst others are categorized as supporting services (Mengist et al., 2020).

Despite its important contributions, the ecosystem services valuation approach has also encountered some academic criticism. Some scholars warn that converting natural services into monetary units may lead to the commodification of nature (Hejnowicz & Rudd, 2017; Martin-Ortega et al., 2019). This reduces the intangible moral and cultural values of the natural environment (Ascioti&Moraci, 2024). In addition, the use of ESVs as a policy decision-making tool in contexts with weak institutions or lack of legal protection may lead to the risk of misuse (Spash, 2008). Emphasizing economic values may lead to the neglect of intrinsic and social values (Guan et al., 2024). Studies also highlight the often contradictory, context-dependent, and challenging nature of synthesizing ecosystem values into a single index. Therefore, although ESV valuation plays a useful role in resource governance, it needs to be used with caution, incorporating social, ethical, and legal factors to ensure comprehensiveness and sustainability in policymaking.

Some scholars have also mentioned that ecosystem asset accounting is different from ecosystem service accounting. According to Luo et al. (2024), because ecosystem services are interdependent, supporting services should not be included in ecosystem asset accounting. The ultimate service may include the combined impact of numerous intermediary services because some services mediate between others (Hein et al., 2016). However, some researchers argue that ESV can be considered as the income from investing ecosystem assets in the form of natural capital (Sun et al., 2024). The term “ecosystem services” refers to the means by which human beingscan reap the advantages of ecosystem assets (Smallet al., 2017). Therefore, based on the clear classification of ecosystem services by the United Nations, together with the combination of technical methods of ESV accounting, we identify ecosystem accounting as being divided into three final services. These include provisioning services, regulation and maintenance, and cultural services.

Several countries around the world are also experimenting with ecosystem services accounts. In order to determine how shifting agricultural boundaries affect hydrological and soil-related ecosystem services, Brazil is conducting pilot ecosystem accounts in the Rio Grande Basin (IBGE, 2021). Natural capital accounting will have a road map built for it based on policy mapping and evaluation of data sources. The Chinese provinces of Guangxi and Guizhou are hosting pilot projects to help establish regional ecological compensation criteria as part of the country's efforts to construct an ecological civilization (NBS China, 2021). India is exploring the possibility of creating a water quality index, testing land accounts, and conducting pilot projects for some ecosystems' extent and condition accounts (MoSPI, 2021). The Mexican government has created detailed ecological profiles that include data on who owns what and whether or not it is a protected area (INEGI, 2021). Ecological service accounting is gaining popularity worldwide, and South Africa is doing its part by creating several national accounts, such as those for species, protected areas, metropolitan areas, and ecological scope (SANBI, 2021).

3. Research locations and methods

3.1. Study areas

In addition to being one of the country's most important food-producing and exporting regions, the Mekong Delta is also a prime location for the cultivation of tropical fruits. Half of the country's rice, and 95% of its rice exports, 65% of its aquaculture output, 60% of its fish exports, and approximately 70% of its fruits come from this region (Minh, 2024). For national and regional economic growth, investment collaboration, and trade with neighbouring and global nations, this is a crucial piece of land. Geographically, the Mekong Delta consists of three subregions. The western highlands encompass the provinces upstream of the Mekong River, Can Tho, Dong Thap, An Giang, the western portion of Long An, Tien Giang, Vinh Long, Hau Giang, and Kien Giang to the east. When the Mekong River rises during the rainy season, this region becomes inundated. Provinces Ca Mau, Ben Tre, Tra Vinh, Bac Lieu, and Tien Giang as well as portions of Long An, Vinh Long, Hau Giang, and Kien Giang all lie in the lowlands of the eastern coastline region. Even in the dry season, this region is susceptible to saltwater intrusion.

In relation to thesethree ecological subregions, the prime minister aimed the restructuring of agricultural output to adjust to changing environmental conditions in the Mekong Delta Regional Plan for the years 2021–2030. The provinces of An Giang, Dong Thap, Hau Giang, Vinh Long, and Can Tho City are part of the freshwater ecological region located upstream and centrally in the Delta (Fig. 1). No flooding, inundation, or salt intrusion has ever affected this freshwater natural zone. The Mekong Delta and the nation rely on this subregion for a variety of agricultural products, including rice, fruit, and freshwater aquaculture. To help the Mekong Delta control and absorb floods, this subregion plans to cultivate a diverse agricultural system. Beyond its agricultural significance, the freshwater ecological subregion also supports a mosaic of ecosystems, including wetlands, rivers and canals, rice paddies, fruit orchards, and freshwater aquaculture systems. These ecosystems provide a wide range of services, such as regulating floods, maintaining soil fertility, ensuring water balance, and conserving biodiversity, while sustaining local livelihoods. Nevertheless, they are increasingly exposed to pressures from climate change, saline intrusion, urbanization, and land-use conversion, which pose major challenges for long-term ecological resilience. Consequently, land accounting is critical for this area's sustainable growth.

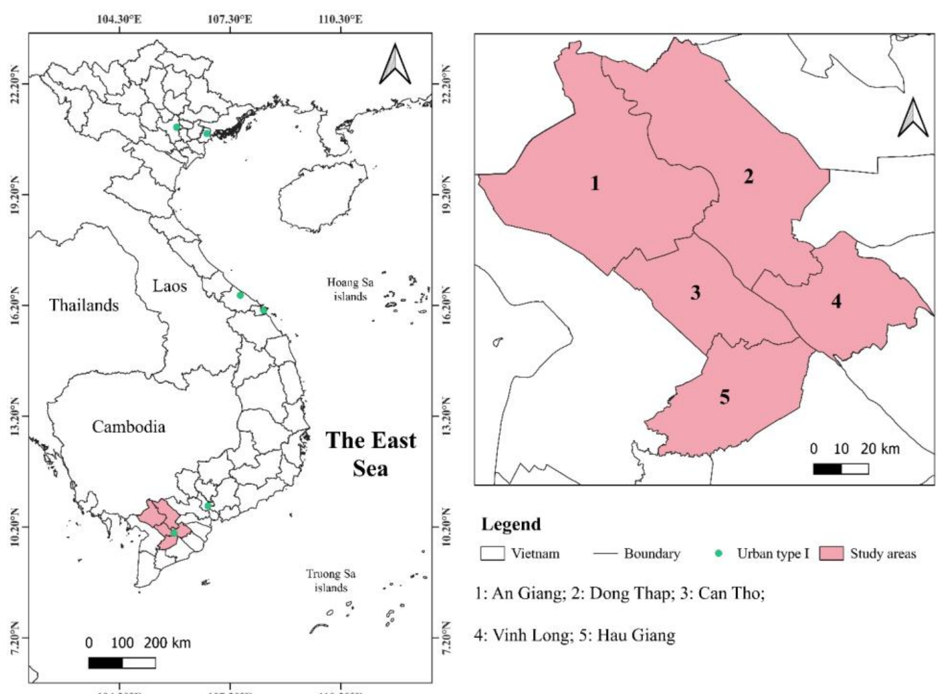

Fig. 1. Study areas (Source: authors' compilation, 2025)

3.2. Methodology

The Advanced Land Observing Satellite (Japan) has accrued a research dataset on land cover in Vietnam for each year from 1990 to 2020. This dataset has a high overall accuracy which ranges from 78% to 92%. The data for the three research years (1990, 2005, and 2020) have an accuracy of 78%, 80%, and 85%, respectively. The datasets have a spatial resolution of 30 m, and the land layers are divided into 2 levels, with level 1 being 10 land use classes while level 2 contains 18 classes. However, to suit the research purpose and research location, we combined data from land layers that are similar to each other to form a common layer. We also used research data from PHAM & LIN (2023) on how to measure ESV. In this study, the land use classes that were used were high- and low-developed areas, cropland, grassland, aquaculture, barren land, forest, and water.

To determine the physical accounts for the study area, we used QGIS 3.44 software to determine the changes of the number of pixels. These data were then processed using Excel 365 software to calculate the area of change for each land layer in each locality. Meanwhile, we determined the monetary accounts by calculating the ESV and applying formula (1).

$$ESV_k = \sum A_k \times VC_k \ (1)$$

where ESV_k is the ecosystem service value, A_k is the area, and VC_k is determined in Appendix 1.

The proportional change of ESV is determined through formula (2):

$$R = \frac{ESV_{t2} - ESV_{t1}}{ESV_{t1}} \times 100 \ (2)$$

In this, ESV_{t1} and ESV_{t2} are the ecosystem service values at times t1 and t2, respectively. R is the rate of change.

4. Results

4.1. Physical accounts

Figure 2 displays the findings of the geographical distribution of the study area's land type. The results show that the major land use types in the study area is cropland. Considering the whole area, cropland accounted for over 85%; especially in 2005, this land type accounted for over 90% of the land area of the study area (Appendix 2). The land use type showing the fastest growth is urban land, specifically the sparse development group. This land use type increased from 0.48% in 1990 to 1.93% in 2005 and reached 5.49% in 2020. This shows the rapid growth of this land type over the past 15 years. Due to natural conditions and geographical location, land groups such as water and aquaculture account for a significant proportion of land use types in this subregion. Meanwhile, the remaining land groups, such as grassland, barren land, and forest, account for an insignificant proportion.

If we consider each type of land used in each locality separately, Can Tho shows that it has experienced the largest growth in urban land area with over 8% expansion in urban land area from 1990 to 2020. This is also the locality that experienced the largest decrease in cropland area - nearly 8% over the same time period. Ranked second in the expansion of urban land area was An Giang with over 5%. However, in contrast to Can Tho, the cropland area in An Giang grew by about 2% in the first 15 years of the research period, then decreased to 86.86% in 2020. The locality showing the least urban expansion was Hau Giang, with only 3.78% after 30 years. The localities in the study area showed that the vacant land area accounted for a very small proportion showing that the utilization of land resources in this area was large.

4.2. Monetary accounts

Table 1 shows the ESV of each land use type in each locality from 1990 to 2020. The results show that ESV in the entire study area decreased from 1990 to 2005, but this decrease was insignificant at only 43.36 million US$/year. Meanwhile, the following 15 years witnessed a strong growth in this value with 462.37 million US$/year, reaching 9,497.74 million US$/year. Of which, Dong Thap and An Giang were the two localities with the largest contribution to ESV with over 2,500 million US$/year. However, the trend of this value shift in the two localities shows differences. While An Giang witnessed a gradual growth over each research period, Dong Thap showed a decline from 1990 to 2005, followed by a return to growth at 2,965.3 million US$/year in 2020. However, this growth was still lower than ESV in Dong Thap in 1990.

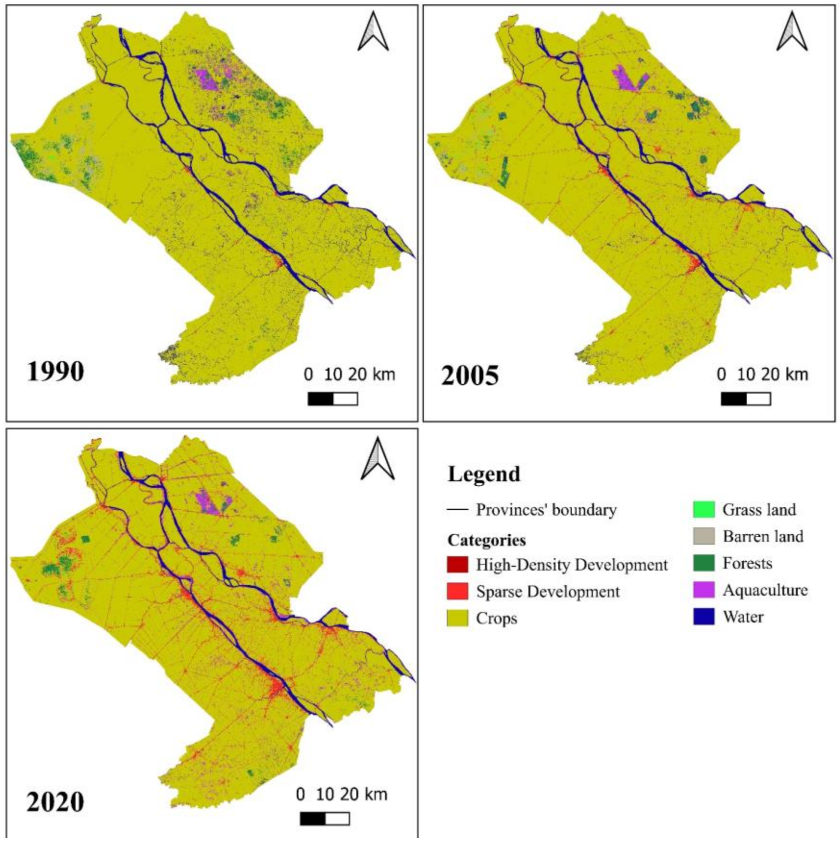

Fig. 2. Spatial distribution of land use types (Source: authors' compilation, 2025)

Table 1. Ecosystem service value of different land use in study areas (Source: authors' calculations, 2025)

Million US$/year		High-density	Sparse development	Crops	Grass	Barren	Aqua-culture	Forests	Water	Total
1990	An Giang	0.3	12.37	2201.12	3.6	0	39.85	86.78	199.44	2543.47
	Can Tho	0.24	8.85	935.73	0.41	0	22.45	4.01	134.51	1106.2
	Dong Thap	0.13	8.34	1991.73	1.93	0	497.7	102.49	386.62	2988.94
	Hau Giang	0.04	1.77	1074.23	0.17	0	36.28	15.08	97.29	1224.85
	Vinh Long	0.1	4.16	961.3	0.03	0	16.79	4.24	228.64	1215.26
	Total	0.81	35.5	7164.11	6.14	0	613.08	212.59	1046.5	9078.73
2005	An Giang	0.62	48.27	2262.75	8.07	0	96.2	30.31	188.25	2634.47
	Can Tho	0.65	32.68	925.47	0.16	0	44.25	0.79	92.93	1096.93
	Dong Thap	0.38	34.06	2090	0.3	0	433.01	46.48	276.41	2880.63
	Hau Giang	0.1	9.19	1088.97	0.01	0	56.91	8.51	51.55	1215.24
	Vinh Long	0.24	17.89	966.73	0.05	0	48.57	1.12	173.5	1208.1
	Total	2	142.08	7333.93	8.59	0	678.95	87.2	782.64	9035.37
2020	An Giang	1.49	131.74	2162.98	6.01	0	254.88	41.83	144.52	2743.44
	Can Tho	1.59	79.78	858.45	0.52	0	148.57	0.38	65.81	1155.1
	Dong Thap	1.35	106.13	2017.69	1.76	0	601.54	28.35	208.49	2965.3
	Hau Giang	0.37	39.98	1026.17	0.2	0	229.71	13.69	15.15	1325.27
	Vinh Long	0.5	47.4	908.15	0.76	0	210.96	7	133.85	1308.62
	Total	5.3	405.03	6973.44	9.26	0	1445.65	91.25	567.82	9497.74

In contrast to the large contributions of An Giang and Dong Thap to the region's ecosystem services value, Can Tho showed the lowest contribution, while Hau Giang and Vinh Long had slightly higher contributions compared to Can Tho. However, the rate of change in ecosystem services value by locality showed different levels (Fig. 3). In the period 1990–2005, An Giang was the only province showing growth, while the remaining four localities witnessed a decline, especially Dong Thap, which witnessed the largest decline of 3.62%. The period 2005–2020 showed positive growth in all localities, of which Hau Giang and Vinh Long were the two localities with the largest contributions with a growth rate of over 6%. In addition, considering the rate of change in ecosystem services value over the research time period, Hau Giang was the province that showed the strongest growth with over 8%, followed by Vinh Long and An Giang with growth rates of over 7.6%. Dong Thap is the only province that witnessed a decrease in ecosystem services value after 30 years. Among land-use ecosystems, crops are the land accounting type that contributes the most to the total ecosystem services value, followed by aquaculture and water. However, the ecosystem services value of water decreased by nearly 85%, while the value of crops decreased by a very small amount of only 3% from 1990–2020. Instead, ESV of aquaculture increased sharply with over 135%.

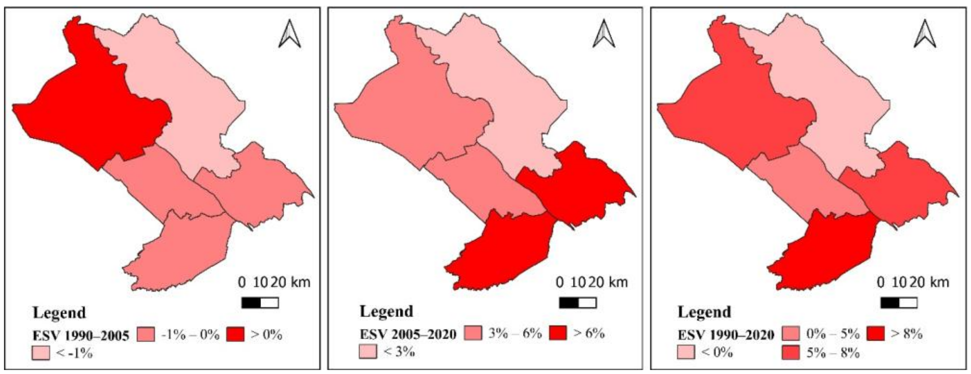

Fig. 3. Rate of change in ecosystem service value by locality (Source: authors' calculations, 2025)

Table 2. The value of final ecosystem services accounting (Source: authors' calculations, 2025)

Categories		An Giang	Can Tho	Dong Thap	Hau Giang	Vinh Long	Total
1990 (million USD/year)	Provisioning services	1640.04	693.33	1552.72	791.25	725.50	5402.84
	Regulation and Maintenance	805.40	363.86	1235.09	391.27	429.15	3224.77
	Cultural services	98.67	49.29	201.75	42.65	60.89	453.25
2005 (million USD/year)	Provisioning services	1669.69	679.85	1582.06	793.82	721.99	5447.41
	Regulation and Maintenance	836.28	351.49	1112.42	378.03	418.32	3096.54
	Cultural services	129.16	65.86	186.80	43.71	68.07	493.60
2020 (million USD/year)	Provisioning services	1604.72	634.68	1525.72	756.43	686.99	5208.54
	Regulation and Maintenance	918.84	402.08	1178.59	476.78	508.34	3484.63
	Cultural services	220.54	118.60	261.64	92.37	113.56	806.71
1990–2005 (%)	Provisioning services	1.81	-1.94	1.89	0.32	-0.48	0.82
	Regulation and Maintenance	3.83	-3.40	-9.93	-3.38	-2.52	-3.98
	Cultural services	30.90	33.62	-7.41	2.49	11.79	8.90
2005–2020 (%)	Provisioning services	-3.89	-6.64	-3.56	-4.71	-4.85	-4.39
	Regulation and Maintenance	9.87	14.39	5.95	26.12	21.52	12.53
	Cultural services	70.75	80.08	40.06	111.32	66.83	63.43
1990–2020 (%)	Provisioning services	-2.15	-8.46	-1.74	-4.40	-5.31	-3.60
	Regulation and Maintenance	14.08	10.50	-4.57	21.85	18.45	8.06
	Cultural services	123.51	140.62	29.69	116.58	86.50	77.98

Table 2 describes the value of the final services of ecosystem accounting, while Appendices 3–5 detail the value contributions of these services. The results show that provisioning services have the highest contribution to the total ESV in each locality, followed by regulation and maintenance with values nearly a half lower than provisioning services. Cultural services do not show a significant contribution to this value. However, this value shows large growth over each period in each locality except Dong Thap. Specifically, in the period 1990–2005, Dong Thap is the only province showing a decrease in the value of cultural services. In the period 2005–2020, Dong Thap shows positive growth but only reaches over 40%, the lowest growth rate in the study area. Although provisioning services contribute a large part of the total ecosystem services value, this value has shown a decline over time, especially in Can Tho with a decrease of nearly 8.5% after 30 years. The decline was mainly due to food and genetic resources.

5. Discussion

5.1. Discussion of changes to physical accounts of ecosystem service values

The rate of change in physical accounts recorded in the study area from 1990 to 2020 shows changes and is consistent with the trend of development in the region in particular and Vietnam in general. The urban land area grew strongly from 0.51% in 1990 to 5.71% in 2020, reflecting the rapid development of this type of land use. This result supports some other research results on urban expansion in Vietnam, mainly concentrated in the Mekong Delta (ZHOU ET AL., 2022). However, the increase mainly occurred in Can Tho and partly in An Giang provinces. This shows uneven development among localities. The significant increase in urban land area also emphasizes the need for sustainable urban planning to minimize its negative consequences on the environment. In contrast, the water surface decreased from 5.73% to 3.11% after 30 years. This decrease could have been caused by natural or anthropogenic factors such as climate change, local activities, and interventions from the upper Mekong River. Currently, the water source of the Mekong Delta depends heavily on the upper Mekong River, whichaccounts for 94% of the total water volume. Therefore, upstream exploitation activities have been reducing the water source flowing into Vietnam (PHAM ET AL., 2023). In addition, the impact of human activities in excessive sand mining in this area has changed the tidal regime of the river (PARK, 2024). This result seems to be warning of an environmental consequence related to the erosion of riverbanks and coasts that has taken place in this area.

The area of cropland did not show much fluctuation in the study area with this land area only decreasing by about 2.5% over 30 years. The area of this type of land use even increased by about 2% from 1990 to 2005. This shows that the urbanization process is taking place rapidly in this area. However, the stabilization of agricultural land, especially that given over to growing rice, to ensure national food security is being successfully ensured. Thanks to its advantageous location, Delta area receives annual deposits of alluvium, particularly the narrow strip of alluvium that runs along the rivers Tien and Hau. This creates ideal conditions for the provision of water needed for rice cultivation (TUAN, 2022). Hence, this region continues to boast about being Vietnam’s premier rice granary, even though it exports less than 10% of the country's rice (GSO, 2021). In addition, aquaculture is a key strength of the region, contributing 69.5% of Vietnam’s total aquaculture production. This has led to an increase in the area of aquaculture land from 1.64% in 1990 to 3.86% in 2020. It is predicted that the area of aquaculture land will continue to increase as this region is identified as a key economic zone for aquaculture.

5.2. Discussion of the changing monetary accounts of ecosystem services values

The change in monetary accounts shows changes in ecosystems and the services they provide. Overall, ESVs in the study area has increased over the past 30 years, although there was a slight decline in the first 15 years of the study. The study has shown different results from some other studies where land use conversion has had a negative impact on ecosystems. Our study results also show that, although there are many contributions to ESVs, the provisioning services function has shown a large decrease in the study area over the study period. Among them, the most significant losses are food, water, and genetic resources. This decline has come from the decrease in cropland and water. Cropland provides important ecosystem services related to food production (LIN ET AL., 2024), so these declines not only have negative impacts on the natural environment but also have negative impacts on livelihoods and short-term food security in the area (Viana et al., 2022). The results of this study show similarities with some studies by Rui et al. (2022) and Phuong et al. (2024). In addition, the characteristics of the ecosystem in the study area are wetland ecosystems, so water resources are considered as the life blood of the area, helping the ecosystem to develop. Therefore, these findings emphasize the need for sustainable land use planning to protect and maintain ecosystem services.

In addition, the study also showed the largest decline in water regulation services, reaching $105.9 million/year. Water regulation is considered one of the main regulatory ecosystem services in ecosystem accounting (Nedkov et al., 2022). These water regulation services are closely related to other regulatory ecosystem services such as erosion control (Kristanto et al., 2022). Therefore, the decline in water area has negative impacts on water regulation services and indicates negative environmental impacts on the study area. This finding is consistent with some research results that suggest that salinity and freshwater scarcity cause losses to local people in the study area (Tran & Cook, 2023; Tran et al., 2025). Several other studies have also suggested that changes in the ecosystems raise questions about the sustainability of the region's future economic development and threaten the country's water security (Rogozhina, 2022; Nghia et al., 2024).

Despite the low contribution to the total ESV, the values of cultural ecosystem services in the area showed a significant increase. These service values bring intangible benefits to people and directly affect the quality of life (Romanazzi et al., 2023). This value also shows the connection between humans and nature. The research results showed that the value of cultural ecosystem services increased by nearly 80% after 30 years. The most significant growth occurred in the individual service recreation sector, with an annual growth of 694.19 million dollars. This result results from the development of ecotourism in this area. This is a land rich in tourism potential, which can exploit many types, such as garden ecotourism, river landscapes, and nature conservation. These research results show similarities with Loc et al. (2018) and Berg et al. (2023).

Therefore, land use planning that integrates ESVs is necessary because land use changes can affect ecosystem services and lead to negative impacts on the environment and economy. Land use planning based on the ecosystem services approach is an important tool to establish long-term and sustainable frameworks for land use. This action aims at an overall balance in economic and social development, environmental protection, and improvement of urban and rural land space (Hoang, 2020). The ecosystem services approach not only focuses on natural characteristics but also addresses issues of overall balance between conservation and development. Accordingly, land use planning must be based on the natural capital accounting system of land resources and be recorded in terms of land resource valuation in terms of ecosystem services (Pham & Tuan, 2024). Therefore, ecosystem-based land use planning creates an overall balance to adapt to constantly changing political, economic, social, and environmental conditions.

5.3. Research limitations

Although this study provides a spatial–temporal accounting framework for ecosystem services value and land use changes in a typical ecological subregion of the Mekong Delta, there are some limitations that need to be acknowledged. First, the study mostly relies on numbers to measure ecosystem services value without looking into the discussions or criticisms from academics about how we measure natural values, this particularly concerns commercialization, legal issues, and ignores the inherent value of ecosystems. The lack of full integration of these criticisms may affect the theory's comprehensiveness. Second, while the study found differences in ESV values over time and space, it did not connect these findings to specific policy choices, current payment systems for ecosystem services (like Payment for Forest Environmental Services), or local development plans. Such limitations may undermine the practical applicability of the results in decision-making contexts. The study also did not look at how ready institutions or stakeholders are to create and use ESV-based financial tools or policies, like possibly expanding PFES to areas beyond forests. This is a necessary additional research direction to enhance policy implementation. These limitations suggest that future research should focuson bringing together ecological accounting, theoretical criticism, and policy analysis to better integrate ESV into land governance and sustainable development at both regional and national levels.

6. Conclusions

This study analyzed the physical changes of ecosystems as well as measure of ESV in Vietnam. The results show that the main land use type in the area is crops. This type of land accounts for over 85% of the natural area of the study area. However, this type of land use has tended to decrease in the last 15 years. Instead, the urban land area tends to grow steadily with over 5% growth after 30 years. Due to natural conditions and geographical location, land groups such as openwater and aquaculture account for a large proportion of land use types in this subregion. Meanwhile, the remaining land groups, such as grassland, barren land, and forest, account for an insignificant proportion. For each locality, Can Tho province shows the most obvious contrast between the growth of urban land and the decline of cropland when both had a change of 8%. Meanwhile, An Giang showed growth in both types of land use in the period 1990–2005, but this locality had a decrease in crop land in the period 2005–2020. The locality showing the least urban expansion was Hau Giang with only 3.78% after 30 years. Along with that, the localities in the study area showed that the vacant land area accounted for a very small proportion. This shows that the utilization of land resources in this area is large.

Land use change has changed ESV in the entire study area. This value decreased from 1990 to 2005 with 43.36 million US$/year, then increased by 462.37 million US$/year from 2005 to 2020. Dong Thap and An Giang were the two localities which showed the largest contribution to ESV with over 2,500 million US$/year. In contrast to the large contribution of An Giang and Dong Thap to ESV in the area, Can Tho showed the lowest contribution, while Hau Giang and Vinh Long had a slightly higher contribution compared to Can Tho. However, the rate of change in ESV by locality shows different levels. Hau Giang is the province that showed the strongest growth with over 8%, followed by Vinh Long and An Giang with growth rates of over 7.6%. Dong Thap is the only province that witnessed a decrease in the value of its ecosystem services after 30 years.

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Appendix 1. Value coefficient of ESV (Source: Pham& Lin, 2023)

Physical account	High-density	Sparse development	Crops	Grass	Barren	Aquaculture	Forests	Water
VC ($/ha/year)	2091	6273	6904	5166	0	31844	6672	15515

Appendix 2. Land use statistics by land type (Source: authors' calculations, 2025)

Categories			High-density	Sparse development	Crops	Grass	Barren	Aquaculture	Forests	Water	Total
1990	An Giang	ha	145.17	1972.26	318818.52	696.51	11950.65	1251.54	13006.44	12854.88	360695.97
		%	0.04	0.55	88.39	0.19	3.31	0.35	3.61	3.56	100.00
	Can Tho	ha	113.13	1411.47	135534.33	79.74	51.03	704.97	601.11	8669.70	147165.48
		%	0.08	0.96	92.10	0.05	0.03	0.48	0.41	5.89	100.00
	Dong Thap	ha	64.53	1329.39	288489.06	373.59	816.66	15629.22	15361.29	24919.29	346983.03
		%	0.02	0.38	83.14	0.11	0.24	4.50	4.43	7.18	100.00
	Hau Giang	ha	18.54	282.51	155595.06	32.94	43.74	1139.40	2259.54	6270.39	165642.12
		%	0.01	0.17	93.93	0.02	0.03	0.69	1.36	3.79	100.00
	Vinh Long	ha	46.17	663.93	139238.28	5.13	56.07	527.40	635.22	14736.78	155908.98
		%	0.03	0.43	89.31	0.00	0.04	0.34	0.41	9.45	100.00
	Total	ha	387.54	5659.56	1037675.25	1187.91	12918.15	19252.53	31863.60	67451.04	1176395.58
		%	0.03	0.48	88.21	0.10	1.10	1.64	2.71	5.73	100.00
2005	An Giang	ha	296.91	7694.28	327745.17	1562.58	3699.90	3020.94	4542.84	12133.35	360695.97
		%	0.08	2.13	90.86	0.43	1.03	0.84	1.26	3.36	100.00
	Can Tho	ha	311.22	5209.11	134048.88	31.59	67.86	1389.60	117.72	5989.50	147165.48
		%	0.21	3.54	91.09	0.02	0.05	0.94	0.08	4.07	100.00
	Dong Thap	ha	183.24	5429.25	302722.38	57.15	211.23	13597.92	6966.00	17815.86	346983.03
		%	0.05	1.56	87.24	0.02	0.06	3.92	2.01	5.13	100.00
	Hau Giang	ha	50.13	1465.29	157730.31	0.99	10.44	1787.22	1275.21	3322.53	165642.12
		%	0.03	0.88	95.22	0.00	0.01	1.08	0.77	2.01	100.00
	Vinh Long	ha	112.68	2851.65	140025.24	9.72	33.93	1525.32	167.49	11182.95	155908.98
		%	0.07	1.83	89.81	0.01	0.02	0.98	0.11	7.17	100.00
	Total	ha	954.18	22649.58	1062271.98	1662.03	4023.36	21321.00	13069.26	50444.19	1176395.58
		%	0.08	1.93	90.30	0.14	0.34	1.81	1.11	4.29	100.00
2020	An Giang	ha	710.55	21001.23	313293.69	1164.06	937.89	8003.88	6270.12	9314.55	360695.97
		%	0.20	5.82	86.86	0.32	0.26	2.22	1.74	2.58	100.00
	Can Tho	ha	762.66	12717.72	124341.12	101.43	278.73	4665.51	56.88	4241.43	147165.48
		%	0.52	8.64	84.49	0.07	0.19	3.17	0.04	2.88	100.00
	Dong Thap	ha	643.50	16919.10	292249.26	339.93	254.07	18890.19	4248.90	13438.08	346983.03
		%	0.19	4.88	84.23	0.10	0.07	5.44	1.22	3.87	100.00
	Hau Giang	ha	178.83	6372.81	148633.56	38.79	176.04	7213.50	2051.82	976.77	165642.12
		%	0.11	3.85	89.73	0.02	0.11	4.35	1.24	0.59	100.00
	Vinh Long	ha	237.60	7556.76	131539.59	147.42	126.99	6624.72	1048.50	8627.40	155908.98
		%	0.15	4.85	84.37	0.09	0.08	4.25	0.67	5.53	100.00
	Total	ha	2533.14	64567.62	1010057.22	1791.63	1773.72	45397.80	13676.22	36598.23	1176395.58
		%	0.22	5.49	85.86	0.15	0.15	3.86	1.16	3.11	100.00

Appendix 3. Value of individual ecosystem services in 1990 (Source: authors' calculations, 2025)

Million USD/year		1990					
		An Giang	Can Tho	Dong Thap	Hau Giang	Vinh Long	Total
Provisioning Services	Food	925.41	392.41	850.66	450.57	403.64	3022.69
	Material	88.95	37.40	90.53	43.32	38.29	298.50
	Water	188.10	87.07	207.42	91.89	102.40	676.88
	Genetic Resources	437.58	176.45	404.11	205.47	181.16	1404.77
Regulation and Maintenance	Gas Regulation	0.20	0.01	0.23	0.03	0.01	0.49
	Climate Regulation	198.08	72.31	196.70	86.02	73.52	626.63
	Disturbance	5.70	2.66	59.13	4.40	2.01	73.90
	Water Regulation	128.62	85.69	341.01	66.37	140.99	762.68
	Erosion Control	51.92	20.56	95.34	25.32	20.49	213.64
	Soil Formation	210.64	89.46	190.66	102.73	91.91	685.41
	Nutrient Cycling	2.71	1.50	33.26	2.43	1.12	41.02
	Waste Treatment	178.17	79.28	231.06	88.29	87.34	664.14
	Pollination	9.12	3.69	8.37	4.29	3.78	29.25
	Biological Control	14.75	6.40	30.44	7.75	6.34	65.68
	Habitat Refugia	5.48	2.30	48.89	3.63	1.64	61.94
Cultural Services	Recreation	95.41	47.53	163.04	39.83	59.59	405.39
	Cultural	3.26	1.76	38.71	2.83	1.31	47.86

Appendix 4. Value of individual ecosystem services in 2005 (Source: authors' calculations, 2025)

Million USD/year		2005					
		An Giang	Can Tho	Dong Thap	Hau Giang	Vinh Long	Total
Provisioning Services	Food	951.56	388.11	886.64	456.53	406.09	3088.94
	Material	91.74	37.40	92.15	44.23	39.12	304.65
	Water	191.68	80.71	197.29	86.65	95.35	651.67
	Genetic Resources	434.72	173.63	405.98	206.41	181.43	1402.16
Regulation and Maintenance	Gas Regulation	0.09	0.00	0.11	0.02	0.00	0.21
	Climate Regulation	187.21	74.03	184.95	86.02	75.22	607.44
	Disturbance	11.56	5.16	50.92	6.72	5.66	80.02
	Water Regulation	134.11	65.47	260.61	43.40	114.81	618.40
	Erosion Control	55.34	22.37	87.14	27.29	23.63	215.77
	Soil Formation	216.39	88.47	199.92	104.12	92.42	701.33
	Nutrient Cycling	6.43	2.95	28.91	3.80	3.24	45.34
	Waste Treatment	187.18	77.98	221.10	88.26	87.35	661.86
	Pollination	9.08	3.63	8.43	4.31	3.79	29.24
	Biological Control	17.11	7.13	28.50	8.59	7.54	68.87
	Habitat Refugia	11.77	4.28	41.83	5.50	4.67	68.05
Cultural Services	Recreation	121.37	62.42	153.19	39.30	64.30	440.57
	Cultural	7.79	3.44	33.61	4.42	3.77	53.03

Appendix 5. Value of individual ecosystem services in 2020 (Source: authors' calculations, 2025)

Million USD/year		2020					
		An Giang	Can Tho	Dong Thap	Hau Giang	Vinh Long	Total
Provisioning Services	Food	913.19	362.50	859.66	434.40	385.62	2955.36
	Material	91.29	36.95	92.58	45.46	40.32	306.60
	Water	180.94	73.75	185.06	79.73	88.10	607.58
	Genetic Resources	419.31	161.48	388.41	196.84	172.96	1339.00
Regulation and Maintenance	Gas Regulation	0.11	0.00	0.07	0.03	0.02	0.22
	Climate Regulation	198.67	77.44	185.86	90.85	80.26	633.08
	Disturbance	30.15	17.28	70.30	26.88	24.62	169.23
	Water Regulation	142.50	71.96	256.58	59.27	126.46	656.77
	Erosion Control	70.23	31.65	101.74	43.95	39.36	286.92
	Soil Formation	206.88	82.07	192.96	98.13	86.83	666.87
	Nutrient Cycling	17.03	9.91	40.14	15.33	14.08	96.48
	Waste Treatment	195.71	83.46	230.37	101.52	99.48	710.54
	Pollination	8.74	3.36	8.06	4.09	3.60	27.85
	Biological Control	22.39	10.59	34.27	14.61	13.20	95.06
	Habitat Refugia	26.43	14.36	58.24	22.12	20.44	141.59
Cultural Services	Recreation	200.51	107.06	214.90	74.54	97.17	694.19
	Cultural	20.02	11.54	46.74	17.83	16.40	112.53