Journal of Infrastructure, Policy and Development 2024, 8(6), 3788.
https://doi.org/10.24294/jipd.v8i6.3788

Article

Evaluating the effects of changes in land use and assessing the value of ecosystem services in the Cisadane Watershed, Banten Province, Indonesia

Irmadi Nahib[1,*], Yudi Wahyudin[2], Widiatmaka[3], Wiwin Ambarwulan[1], Fahmi Amhar[4], Nawa Suwedi[1], Mulyanto Darmawan[4], Jaka Suryanta[1], Bono Pranoto[1], Fadhlullah Ramadhani[4], Nunung Puji Nugroho[5], Destika Cahyana[6], Vicca Karolinoerita[4]

[1] Research Center for Limnology and Water Resources, National Research and Innovation Agency of Indonesia (BRIN), Bogor 16911, Indonesia
[2] Faculty of Agriculture, Universitas Djuanda, Bogor 16720, Indonesia
[3] Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University Indonesia, Bogor 16680, Indonesia
[4] Research Center for Geoinformatics, National Research and Innovation Agency of Indonesia (BRIN), Kota Bandung 40135, Indonesia
[5] Research Center for Ecology and Ethnobiology, National Research and Innovation Agency, Bogor 16911, Indonesia
[6] Research Center for Food Crops, National Research and Innovation Agency, Bogor 16911, Indonesia
*** Corresponding author:** Irmadi Nahib, irma016@brin.go.id

CITATION

Nahib I, Wahyudin Y, Widiatmaka, et al. (2024). Evaluating the effects of changes in land use and assessing the value of ecosystem services in the Cisadane Watershed, Banten Province, Indonesia. Journal of Infrastructure, Policy and Development. 8(6): 3788. https://doi.org/10.24294/jipd.v8i6.3788

ARTICLE INFO

Received: 23 December 2023
Accepted: 18 February 2024
Available online: 10 July 2024

Abstract: Analyzing ecosystem service values (ESV) is crucial for achieving sustainable development. The main objective of this study was to assess the ecosystem services of the Cisadane watershed in Indonesia, with specific goals: (i) examining the spatiotemporal dynamics of ESV using multi-year land use and land cover (LULC) data from 2000 to 2021, (ii) exploring trade-offs and synergies among various ecosystem services, and (iii) investigating the sensitivity of ESV to changes in LULC. The results unveiled a significant decrease in forested areas (21.2%) and rice fields (10.2%), leading to a decline in ESV of $196.37 billion (33.17%) from 2010 to 2021. Throughout the period from 2000 to 2021, interactions between ESV were mainly synergistic. Projected from the baseline year (2021), the decline in ESV is expected to persist, ranging from $24.78 billion to $124.28 million by 2030 and from $45.78 billion to $124.28 million by 2050. The total estimated ecosystem values exhibited an inelastic response in terms of ecosystem value coefficients. The study also emphasizes an inelastic response in total estimated ESV coefficient concerning ecosystem value coefficients. These findings underscore the urgent need for targeted conservation efforts and sustainable land management practices to mitigate the further decline in ecosystem services and safeguard the long-term well-being of the Cisadane watershed and its inhabitants.

Keywords: ecosystem services value; trade-off/synergy; elasticity; sensitivity of ESV; land use/land cover change

1. Introduction

Ecosystem services (ES) encompass both tangible and intangible benefits that humans derive from the functioning of ecosystems. These benefits play a vital role in sustaining human livelihoods, well-being, and overall welfare. The immediate impacts on human welfare stem from direct benefits, which include provisioning, regulating, and cultural services. In contrast, there are secondary benefits known as supporting services that have enduring effects by maintaining the production of additional services within ecosystems. The ecosystem's benefits can be evaluated by quantifying their economic worth, known as ecosystem service values (ESV) (Costanza et al., 2014).

The evaluation of changes ESV due to modifications in land use and land cover (LULC) is of paramount significance in fostering awareness and guiding the formulation of policies and choices related to the allocation of finite resources in the face of competing needs. This strategy seeks to protect the ecosystems that deliver the most indispensable services (Solomon et al., 2019).

Recent research indicates that activities such as agricultural conversion, urban expansion, and deforestation have led to substantial reductions in ESV values. These declines can be attributed to the loss of critical services such as carbon sequestration, biodiversity decline, deterioration in water quality, and land degradation (Polasky et al., 2011).

LULC changes have emerged as a significant subject in assessing environmental transformations and formulating sustainable development strategies (Roy and Inamdar, 2019). The Cisadane region in Indonesia holds a critical position as a watershed, yet it has experienced substantial alterations in LULC. Urbanization and industrial growth in Jakarta have significantly influenced the patterns of LULC within this area, transforming it into a buffer zone catering to the city's needs. Researchers have consistently directed their efforts toward understanding the changes in LULC occurring across various segments of this region. For instance, (Hernina et al., 2018) delved into the consequences of urban expansion and projected a 50% reduction in the urban area of Cisadane by the year 2021.

The Cisadane watershed is one of 15 critical watersheds that receive priority treatment from the Indonesian government (MOFERI, 2018). This watershed is a water source for residents, industry, and agriculture in three provinces (DKI Jakarta, Banten, and West Java). Changes in land cover due to human activities have dominated this watershed, which has resulted in reducing the water holding capacity and function of water catchment areas. Apart from that, damage to the Cisadane watershed also triggers floods, droughts, and landslides. So, it is necessary to know the condition of ecosystem services, their changes, and future predictions.

The Cisadane watershed is very interesting for analyzing the dynamics of its ecosystem services due to several factors; first, the high level of human activity in this watershed, which is characterized by changes in other land cover to residential and industrial (Ambarwulan et al., 2023). This condition has an impact on floods, landslides, and drought. The second factor is the impact of climate change which results in changes in rainfall patterns, an increase in the frequency of extreme weather events, and an increase in temperatures. Such is the complexity and dynamics of the Cisadane watershed, whose area is not very large, but all pillars of ecosystem services can be found.

Cisadane watershed is characterized by very dynamic topographic and social-economic activities, which can be divided into three sub-watersheds. The first sub-watershed is characterized by flat topography flat areas with slopes ranging from 0 to 8%. This region is very dynamic because of the high population growth, industrial development, and economic center in Indonesia. This region is generally part of the DKI Jakarta Province, Indonesia's capital city. The second sub-watershed, or middle watershed, is characterized by wavy and hilly topography. This area is still dominated by settlements and industry, although it is less dense than the lower sub-watershed. Agriculture and forestry dominate the upper part of the Cisadane watershed, which is dominated by hilly and mountainous topography (around 40%). Generally, this area is a conservation area, with the main socio-economic activities of agriculture, plantations, and a little forestry. Population density is lower than in the other two sub-watersheds.

Information about the dynamics of ESV in response to changes in LULC is urgently needed by decision-makers as a basis for sustainable environmental management. However, management based on ecosystem services is still very limited, especially in Indonesia. Benefit transfer methods (BTM) prove effective for medium-scale planning when faced with cost constraints, allowing for a less detailed assessment of the ESV on a global scale.

For this reason, the main objective of this study was to analyze the ecosystem services of the Cisadane watershed, Indonesia, with the specific objectives of (i) analyzing the spatiotemporal dynamics of ESV in multi-year LULC (2000–2021), (ii) investigating the trade-offs and synergies between different ecosystem services, and (iii) exploring the sensitivity of ESV to changes in LULC.

2. Materials and methods

2.1. Study area

The study was carried out along the Cisadane River, which has developed into the primary river within the Cisadane Watershed, as depicted in **Figure 1**.

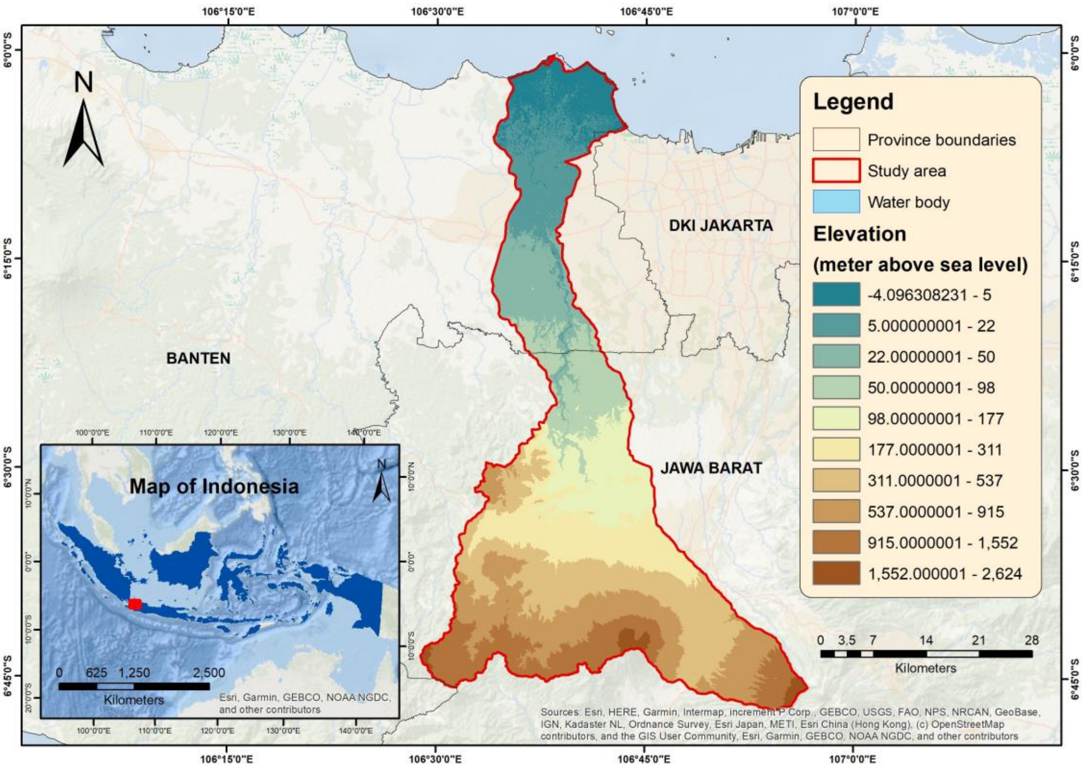


Figure 1. Study area, Cisadane watershed, Banten Province, Indonesia.

Based on the information provided in **Figure 1**, the Cisadane watershed is geographically located within Banten Province, Java Island, Indonesia, situated explicitly between the coordinates of 106°20′50″–106°28′20″ E longitude and 6°0′59″–6°47′02″ S latitude. Administratively, it falls within the jurisdiction of West Java and Banten Province. The watershed encompasses the Cisadane River, which originates from Mount Gede at an elevation of 2958 meters above sea level and flows for a distance of 126 km until it reaches the Java Sea. The total area covered by the Cisadane watershed is 151,126 hectares. Its topography varies, with the upper region characterized by mountainous terrain and steep slopes surpassing 40%. The middle portion is characterized by undulating land, while the lower segment primarily consists of flat areas with slopes ranging from 0 to 8%. The region experiences an average annual rainfall of 2000 to 5000 mm, and the temperature fluctuates between 17.3 ℃ and 34 ℃ (Ambarwulan et al., 2023).

To calculate the economic value of ecosystem services, we utilize the land cover area information derived from Ambarwulan' research, as presented in **Table 1**.

Table 1. Area changes of LULC in the Cisadane watershed from 2010 to 2050 (ha, %) (Ambarwulan et al., 2023).

Year	**BUL (ha)**	**DF (ha)**	**PF (ha)**	**FRT (ha)**	**PLT (ha)**	**PO (ha)**	**WB (ha)**	**Total (ha)**
2010	33,622.28	12,153.69	27,904.59	6189.21	67,568.13	2879.10	1809.00	152,126.00
2015	46,630.07	33,631.11	19,167.57	6088.05	42,073.83	2723.94	1811.43	152,126.00
2021	53,811.71	40,024.53	12,481.74	5795.01	35,534.34	2648.52	1830.15	152,126.00
2030*	61,148.54	38,772.24	6404.30	6174.94	35,461.78	2424.98	1739.22	152,126.00
2050*	75,722.20	48,974.60	1578.60	6189.20	15,567.80	2281.30	1812.30	152,126.00
2030**	60,922.61	39,286.46	6464.82	5347.66	35,687.66	2544.18	1872.61	152,126.00
2050**	70,625.15	34,166.88	1532.43	6189.21	35,518.68	2281.32	1812.33	152,126.00
Year	**BUL (%)**	**DF (%)**	**PF (%)**	**FRT (%)**	**PLT (%)**	**PO (%)**	**WB (%)**	**Total (%)**
2010	22.10	7.99	18.34	4.07	44.42	1.89	1.19	100.00
2015	30.65	-	12.60	4.00	27.66	1.79	1.19	100.00
2021	35.37	26.31	8.20	3.81	23.36	1.74	1.20	100.00
2030*	40.20	25.49	4.21	4.06	23.31	1.59	1.14	100.00
2050*	49.78	32.19	1.04	4.07	10.23	1.50	1.19	100.00
2030**	40.05	25.82	4.25	3.52	23.46	1.67	1.23	100.00
2050**	46.43	22.46	1.01	4.07	23.35	1.50	1.19	100.00
Year	**BUL (%)**	**DF (%)**	**PF (%)**	**FRT (%)**	**PLT (%)**	**PO (%)**	**WB (%)**	**Total (%)**
2010–2021	60.05	229.32	−55.27	−6.37	−47.41	−8.01	1.17	-
2021–2030*	13.63	−3.13	−48.69	6.56	−0.20	−8.44	−4.97	-
2021–2050*	40.72	22.36	−87.35	6.80	−56.19	−13.87	−0.98	-
2021–2030**	13.21	−1.84	−48.21	−7.72	0.43	−3.94	2.32	-
2021–2050**	31.24	−14.64	−87.72	6.80	−0.04	−13.86	−0.97	-

BUL: Built-up DF = Dryland farming; PF = Pady Filed; FRT = Forest; PLT = Plantation; PO: Pond; WB = Water body; * BAU; ** FPA.

The results of this evaluation are considered acceptable, given that any Kappa score surpassing 80% in the context of LULC serves as a reliable marker of precision (Zheng et al., 2016). Ambarwulan et al. (2023) comprehensively elucidate the methodology adopted to analyze land cover data.

2.2. Ecosystem service value

We utilize LULC area data for 2010–2050 provided by Ambarwulan et al. (2023), as input data in calculations to determine the value of ecosystem services. Next, we use the ESV value as attribute data on the LULC map, to create an ESV map. We did not carry out our own calculations for the ESV value. We calculated the ESV value of the study area using the benefit transfer method approach presented **Figure 2**.

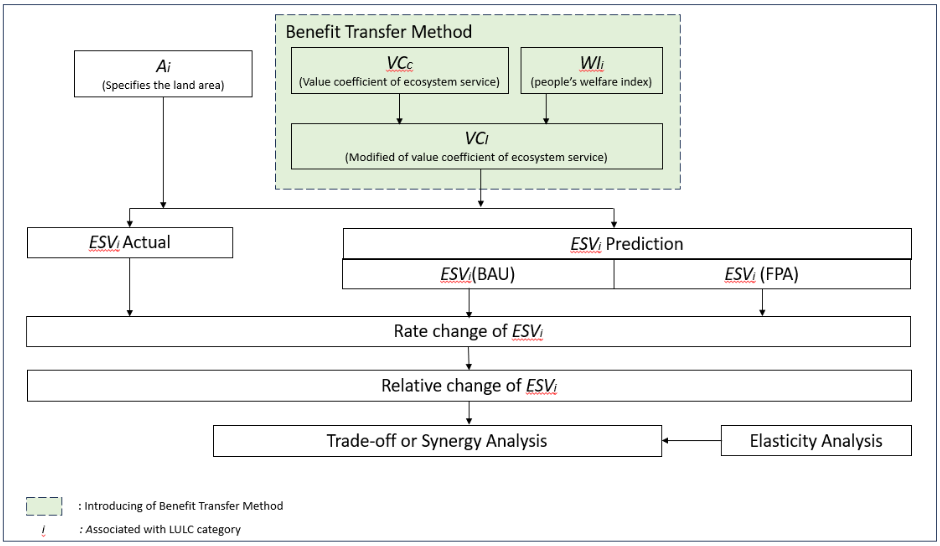


Figure 2. Steps of calculating ESV using the benefit transfer methods approach.

We refer to Costanza et al. (1998) biome equivalents for land use categories, and corresponding ecosystem values as coefficient values. Meanwhile, we use the average ESV value for West Java Province, Indonesia as a reference. So as a reference the average ESV value of West Java Province is used, to estimate the average ESV of Tangerang Regency (as the study area)

Benefit transfer methods (BTM) prove effective for medium-scale planning when faced with cost constraints, allowing for a less detailed assessment of the ESV on a global scale. This approach relies on utilizing existing secondary data as a benchmark, selecting areas with comparable conditions.

The ESV value of an area is adjusted to the specific characteristics of the study area using the community welfare index. The VC value in 2021 in this study is calculated using Equation (1).

$$VC_{Ii} = VC_{Ci} \times WI_i \quad (1)$$

where, VC_I denotes value coefficient of ESV in West Java; VC_c denotes value coefficient of ESV in reference (Costanza, 1997); *WI* denotes people's welfare index (calculated by the minimum wage of Tangerang Regency/the minimum wage of West Java Province).

The calculation results obtained by annual value coefficients for various ecosystem service functions, each of which is related to a particular land cover type

(USD ha-1 year-1) are presented in **Table 2**.

Table 2. Coefficients of ESV functions, each corresponding to specific land cover types. (USD ha-1 yr-1) (Costanza, 1997 (modified)).

Ecosystem service/sub type	BUL	DF	PF	FRT	PLT	PO	WB
Provisioning (PROV)							
Food production	0.00	574.85	46.53	699.99	1130.41	26.37	7.57
Raw material	0.00	79.74	40.84	423.74	106.57	23.15	0.00
Regulating (REGG)							
Gas regulation	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Climate regulation	0.00	37.09	263.25	355.85	200	149.21	0.00
Water regulation	0.00	0.00	455.72	447.15	194.65	258.3	665.32
Supporting (SUPP)							
Soil-formation and retention	0.00	9.27	327.35	250.5	310.95	185.54	0.00
Waste-treatment	0.00	0.00	228.46	280.93	193.19	129.49	65.52
Biodiversity	0.00	55.63	265.37	2568.18	533.33	150.41	0.00
Culture (CULT)							
Recreation. Cultural and Tourism	0.00	7.42	318.49	2317.68	39.9	180.52	154.59
Total (US)	0.00	764	1946.00	7344.00	2709.00	1103.00	893.00
Total (%)	0.00	5.18%	13.19%	49.76%	18.35%	7.47%	6.05%

BUL: Built-up; DF = Dryland farming; PF = Pady filed; FRT = Forest; PLT = Plantation; PO: Pond; WB = Water body.

The approach utilized in this research to estimate ESV was BTM (Costanza et al., 1998). Meanwhile, ESV values based on certain types of LULC have been developed by previous researchers using Equation (Gashaw et al., 2018; Kindu et al., 2016):

$$ESV_i = \sum_j A_i \times VC_{ij} \quad (2)$$

$$ESV_j = \sum_i A_i \times VC_{ij} \quad (3)$$

$$ESV_t = \sum_j \sum_i A_i \times VC_{ij} \quad (4)$$

where ESV_i, ESV_j, and ESV_t represent the ecosystem service value of LULC type i, LULC function j, and the total value of ecosystem services, respectively. A_i denotes the area (ha) of the land-use type i, VC_{ij} is the equivalent value coefficient (USD ha^{-1} $year^{-1}$) of a specific land-use type 'i' and ecosystem service 'i', respectively.

For evaluating the spatio-temporal changes of ESV during different periods, the value coefficient of each ecosystem service and land-use category was estimated using 2021 unit values (USD ha^{-1}) The changing dynamic of ESVs was estimated by calculating the difference between the estimated values in each reference year using the following Equation :

$$ESV_{cr} = \frac{ESV_{t2} - ESV_{t1}}{ESV_{t1}} \times 100 \quad (5)$$

ESV_{cr} denotes the rate of change of ecosystem service value (ESV) from the beginning to the end of the equation. ESV_{t1} and ESV_{t2} represent the total ESV at the start and end of the research period, respectively.

ESV predictions are made based on two scenarios, namely business as usual (BAU) and forest protected area (FPA) (Ambarwulan et al., 2023). BAU means no intervention; changes are based on regulations that occurred in 2010–2021. The BAU scenario assumes that past patterns of land-use transition are sustained and that land demand for 2021–2030 and 2021–2050 are calculated based on the transition probability of shifting the Markov chain model for 2010–2021. Meanwhile, FPA is used to support environmental functions, namely, the forest area in a river basin is at least 30%. Therefore, FPA was developed to assess the conservation function in Cisadane watershed regarding forest cover.

2.3. Ecosystem service trade-offs and synergies

This research delved into the interconnectedness of ecosystem services, exploring potential positive (synergistic) and negative (trade-off) relationships. Positive relationships indicate instances where two services are commonly provided together or rarely apart. In contrast, negative relationships denote situations where an increase in one service coincides with a decrease in another. To investigate these associations, the researchers employed the Pearson correlation coefficient. A positive correlation signifies a synergistic connection between two ecosystem services, whereas a negative correlation points to a trade-off relationship (Liu et al., 2019).

Referring to Wang et al. (2021), four ecosystem services raster datasets covering the period from 2010 to 2021 were employed in conjunction with the 'Create Random Points' tool within GIS software to create 750 randomly distributed points in the Cisadane watershed. Subsequently, an analysis of the synergy and trade-off dynamics among ecosystem services in various functional areas was carried out using spearman's correlation coefficient. A positive correlation ($r > 0$) with a significance level of $p < 0.05$ indicates a synergistic relationship, where both variables change in the same direction. Conversely, a negative correlation ($r < 0$) with $p < 0.05$ indicates a trade-off relationship, indicating that both variables change in opposite directions. In instances where the correlation is not statistically significant ($r = 0$, $p < 0.05$), the relationship is considered neutral. The strength of the association between variables is elucidated by the magnitude of the correlation coefficient.

The analysis in this paper are the relative changes in *ESs* i and j over the period $t_2 - t_1$ calculated using Equation (6) developed by Zhao and Li (2022):

$$\begin{aligned} \Delta ESV_{i_{it2-t1}} &= \left(ESV_{i,t2} - ESV_{i,t2}\right)/ESV_{i,t1} \\ \Delta ESV_{j_{it2-t1}} &= \left(ESV_{j,t2} - ESV_{j,t2}\right)/ESV_{j,t1} \end{aligned} \quad (6)$$

where $ESV_{i.t2}$ and $ESV_{i.t1}$ represent the value of ESV_i at time points t_2 and t_1. respectively. Meanwhile, the trade-offs and synergies among four categories of ecosystem and ESV_j ($TSD_{I\text{–}J}$) over the periods of t_2 and t_1 was calculated with equation: (Zhao and Li, 2022):

$$\mathrm{TSD}_{I-J} = \sqrt{\left(\Delta ESV_{i,t2-t1}\right)^2 + (\Delta ESV_{j,t2-t1})^2/2} \quad (\Delta ESV_{i,t2-t1} \times \Delta ESV_{j,t2-t1} = 0)$$
$$\mathrm{TSD}_{I-J} = \sqrt{\left(\Delta ESV_{i,t2-t1}\right)^2 + (\Delta ESV_{j,t2-t1})^2/2} \quad (\Delta ESV_{i,t2-t1} \times \Delta ESV_{j,t2-t1} > 0) \tag{7}$$
$$\mathrm{TSD}_{I-J} = -\sqrt{\left(\Delta ESV_{i,t2-t1}\right)^2 + (\frac{\Delta ESV_{j,t2-t1})^2}{2}} \quad (\Delta ESV_{i,t2-t1} \times \Delta ESV_{j,t2-t1} < 0)$$

where $\Delta ESV_{i,t2-t1}$ and $\Delta ESV_{j,t2-t1}$ are the relative changes in *ESV i* and *j* over the period $t_2 - t_1$ respectively.

As shown in Equation (6), if $\Delta ESV_{i,t2-t1} \times \Delta ESV_{j,t2-t1} = 0$, then $TSD_{i-j} = 0$ implying that no trade-off/synergy relationship exists between *ESVi* and *ESVj*.

If $\Delta ESV_{i,t2-t1} \times \Delta ESV_{j,t2-t1} > 0$, a synergy relationship exists between ESV_i and ESV_j. and the level of synergy can be measured by $\sqrt{\left(\Delta ESV_{i,t2-t1}\right)^2 + (\Delta ESV_{j,t2-t1})^2/2}$.

If $\Delta ES_{i.t2-t1}\Delta ES_{j.t2-t1} < 0$, a trade-off relationship exists between the two *ESs*. And the level of the trade-off can be measured by $-\sqrt{\left(\Delta ESV_{i,t2-t1}\right)^2 + (\Delta ESV_{j,t2-t1})^2/2}$.

2.4. Elasticity for the response of ESV to LULC change

The elasticity can be defined as sensitivity due to changes in one variable to another. The cross elasticity of demand is an economic concept that measures the responsiveness in the quantity demanded of one good when the price for another good. In some instances, the chosen biomes used as proxies for the seven LULC categories do not precisely align with Costanza et al.'s (1997) ESV model, leading to uncertainties in ESV estimation. Consequently, a sensitivity analysis was conducted to gauge the fluctuations in ESV resulting from a 50% adjustment to the ESV coefficients for each LULC type, as outlined by (Kindu et al., 2016). The conventional economic concept of elasticity was employed to calculate the coefficient of sensitivity (CS) using Equation (8) (Pan et al., 2021).

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})\ /VC_{ik}} \tag{8}$$

where *ESV* is the computed aggregate value of ecosystem services, *VC* is the value coefficient, and '*i*', '*j*', and '*k*' indicate the initial, modified, and LULC categories, respectively. A *CS* number of ≤ 1 indicates that the modified *ESV* coefficient is reliable, whereas a *CS* value of ≥ 1 indicates that the adjusted *ESV* coefficient is unreliable.

3. Results

3.1. Dynamics of ecosystem service values

The results of the analysis, expressed as ESV, are shown in **Table 3** and **Figure 3**. **Table 3** displays the changes in ESV associated with each land cover category from

2010 to 2050. The cumulative ESV for the entire study region were approximately $591.94 million in 2010, $395.57 million in 2021, $375.45 million in 2030, and $271.29 million in 2050 under the BAU. These values demonstrate the variation in ESV across the designated timeframe, highlighting the effects of evolving LULC patterns. Meanwhile, by FPA in 2030 ($365.55 million) and 2050 ($349.79 million), respectively.

Table 3. ESV of the Cisadane Watershed from 2010 to 2050 (millions of US dollars, %).

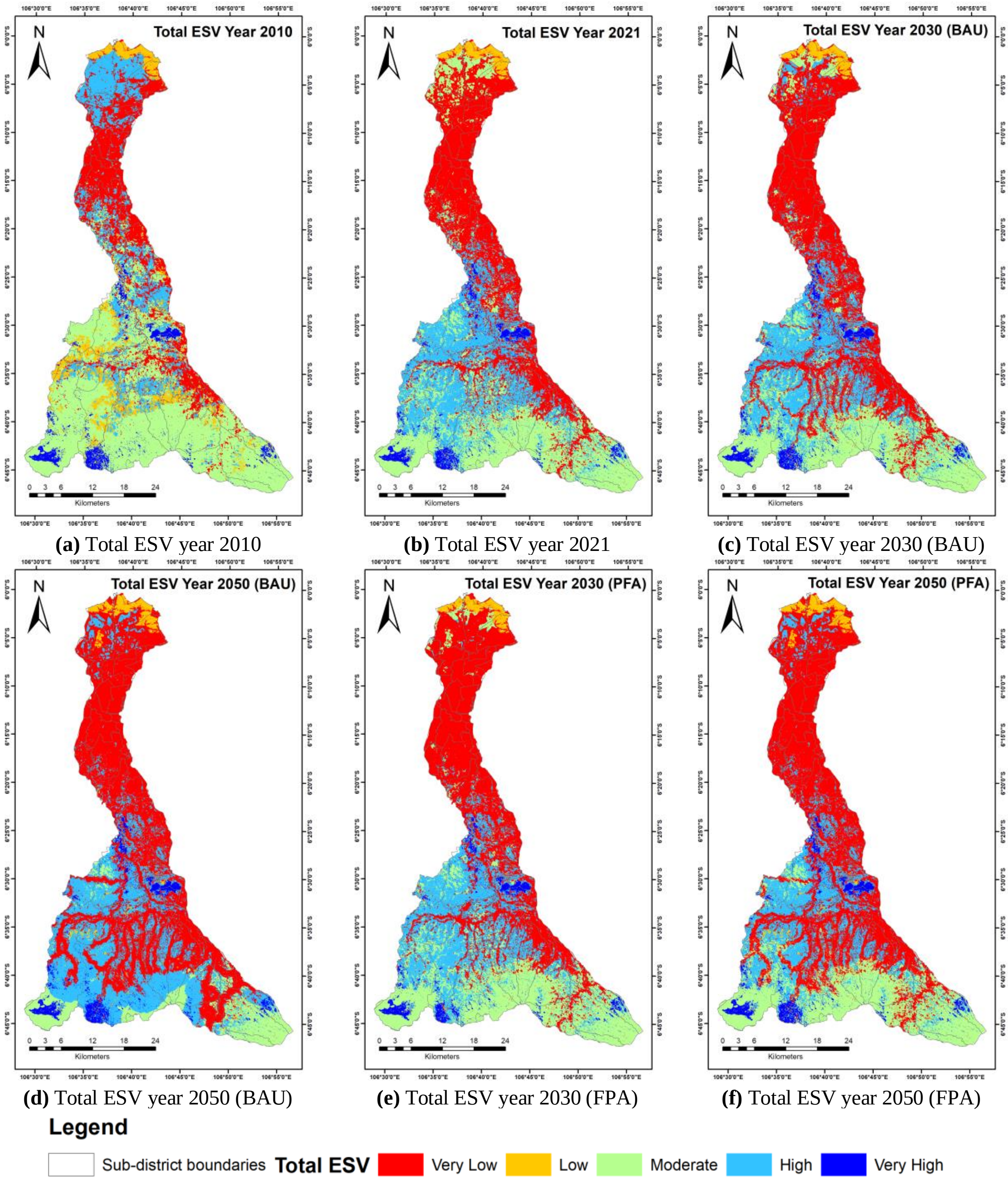
Type of LULC	2010		2021		2030*		2050*		2030**		2050**	
	US (10^6)	%	US (10^6)	%	US (10^6)	%	US (10^6)	%	US (10^6)	%	US (10^6)	%
DF	9.47	1.6	35.64	9.01	48.26	12.85	57.76	21.29	33.45	9.15	29.38	8.4
PF	55.29	9.34	28.48	7.2	17.43	4.64	4.75	1.75	14.07	3.85	3.36	0.96
FRT	505.22	85.35	306.41	77.46	280.33	74.66	176.5	65.06	294.16	80.47	293.54	83.92
PLT	17.05	2.88	19.7	4.98	23.31	6.21	25.88	9.54	18.9	5.17	18.85	5.39
PO	3.26	0.55	3.44	0.87	3.88	1.03	3.88	1.43	3.14	0.86	2.83	0.81
WB	1.66	0.28	1.9	0.48	2.25	0.6	2.52	0.93	1.83	0.5	1.82	0.52
Total	591.95	100	395.57	100	375.46	100	271.29	100	365.55	100	349.78	100

* BAU ** FPA; BUL: Built-up; DF = Dryland farming; PF = Pady Filed; FRT = Forest; PLT = Plantation; PO: Pond; WB = Water body.

FRT, PF, PLT, and DF contributed the most to ESV in 2010, accounting for around 85.35%, 9.34%, 2.88%, and 1.60% of total ESV, respectively. By 2021, however, there is a decline: forests and paddy fields have lost 32.048 hectares (21.2%) and 15.434 hectares (10.2%), respectively, resulting in a fall in ESV of roughly $196.37 million (33.17%). FRT, DF, PF, PLT are the leading contributors to ESV by 2021, accounting for approximately 77.46%, 9.01%, 7.21%, and 4.98% of total ESV, respectively.

In contrast, under FPA scenario in 2030 and 2050, the ESV is projected to amount to $365.55 million and $349.79 million, respectively. Upon closer examination, it becomes evident that the contributions from various land cover categories such as FRT, PLT, DF, PF, PLT constitute a significant portion of the total ecosystem service values, ranging from about 80.47% to 83.93%, 5.17% to 5.39%, and 0.96% to −3.95% for these respective categories in the specified years. This delineates the influence of these land cover types on the overall ecosystem service values.

Figure 3 provides an overview of the region's spatial distribution of ecosystem service values. In 2010, the northern portion of the Cisadane watershed displayed moderate ESV levels, while the central and southern regions exhibited a prevalence of high ESV categories. Moving to 2021, the northern sector saw a reduction in moderate ESV classification, whereas the middle and southern parts witnessed a continued increase in ESV spanning from moderate to high classes. The ESV conditions in 2030 (under the BAU) closely resembled those in 2021. Conversely, by 2050 (under the FPA), a greater expanse of regions displayed medium to high ESV categories compared to the state in 2030.



(a) Total ESV year 2010 **(b)** Total ESV year 2021 **(c)** Total ESV year 2030 (BAU)

(d) Total ESV year 2050 (BAU) **(e)** Total ESV year 2030 (FPA) **(f)** Total ESV year 2050 (FPA)

Figure 3. The spatial distribution of ESV per unit area evolved over the period from 2010 to 2050.

The impacts of changes in land cover area are translated into corresponding changes in ecosystem value, as illustrated in **Table 4** and **Figure 3**. These outcomes are derived from computations involving the actual situation land cover area for 2010–2021 and projections for 2030–2050.

Referring to **Table 4**, the examination of changes in the valuation of ecosystem services reveals a notable decline of 33.17% over the study duration (2010–2021). This reduction was primarily attributed to the decrease in forest area by 32,048 ha (21.2%) and paddy fields by 15,434 ha (10.2%). Meanwhile, if the initial year used is 2021, it is estimated that in 2030 the ESV will decrease by 5.09%–7.59 % (both the

BAU and FPA). In 2050, there will be a significant change, namely a loss of 31.42% ESV(BAU) and 11.57% (FPA).

Table 4. Dynamics of ESV of Cisadane watershed from 2010 to 2050 by LULC (%).

Type of LULC	Actual situation	BAU		FPA	
	2010–2021	**2021–2030**	**2021–2050**	**2021–2030**	**2021–2050**
DF	276.31	35.40	62.05	−6.15	−17.56
PF	−48.49	−38.80	−83.33	−50.59	−88.21
FRT	−39.35	−8.51	−42.40	−4.00	−4.20
PLT	15.55	18.32	31.38	−4.06	−4.29
PO	5.71	12.68	12.73	−8.65	−17.67
WB	14.56	18.59	32.88	−3.74	−4.20
Total	−33.17	−5.09	−31.42	−7.59	−11.57

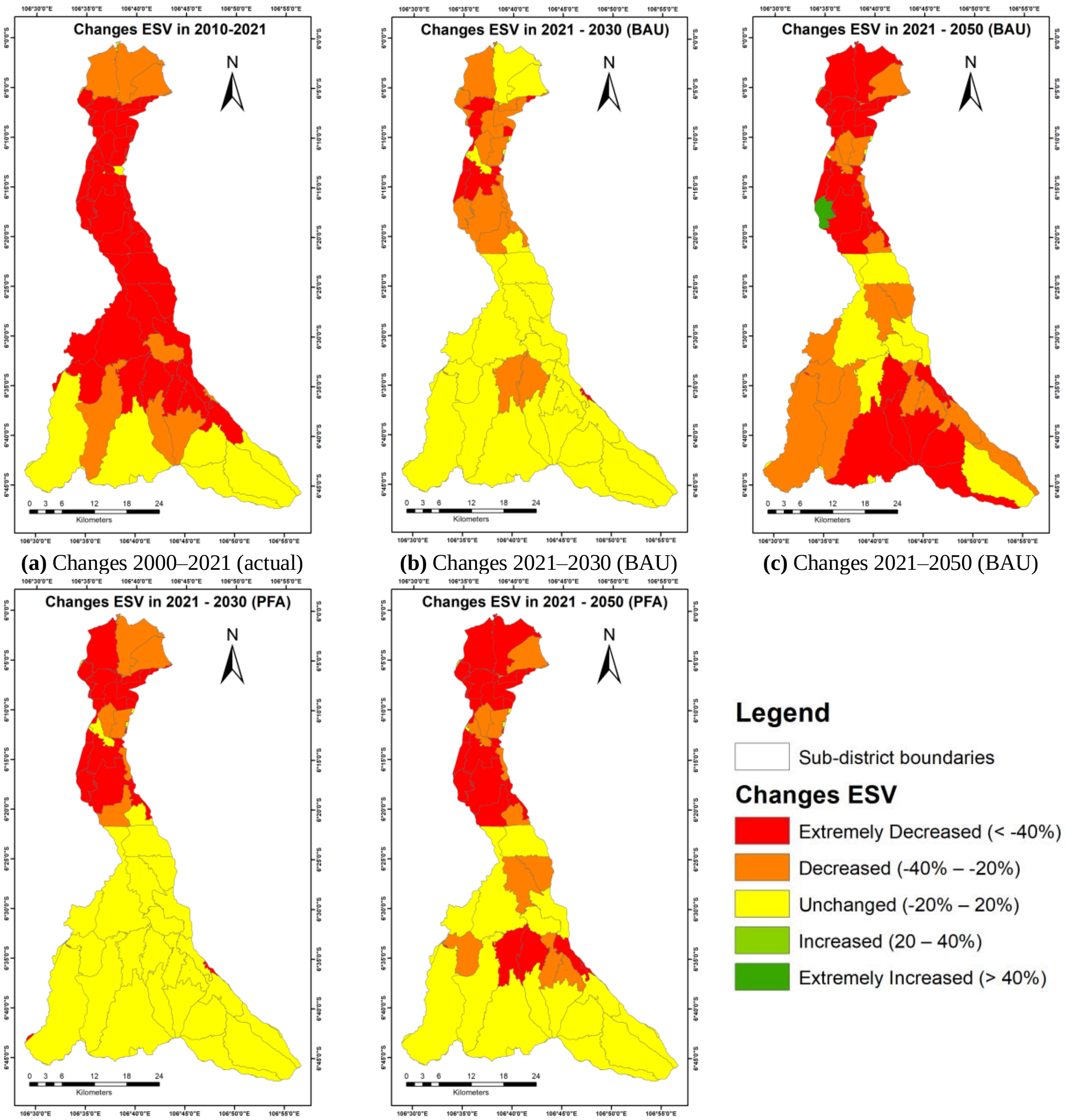
In 2050 under the BAU, the decrease in the area of paddy field, forest and pond respectively caused a decrease in ESV by 83.33%, 42.40% and 12.73%. Meanwhile, the contribution to the increase in ESV from dry land farming was only 62.05%. With engineering efforts to maintain forest-protected areas, the decrease in ESV is only around 11.57%, or an ESV of around 19.84% can be maintained.

Next, we analyze the ESV by district administrative unit. Referring to Nahib et al. (2023) the amount of ESV change (%), was classified as shown in the **Figure 4** and **Table 5**.

Table 5. Dynamics of ecosystem service value of Cisadane watershed from 2010 to 2050 (%) by different district.

Class of ecosystem service value	Actual situation		BAU				FPA			
	2010–2021		**2021–2030**		**2021–2050**		**2021–2030**		**2021–2050**	
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**	***N***	**%**
Extremely decreased ≤ 40%)	45	52.94	12	14.12	0	0	25	29.41	0	0
Decreased (−40%–−20%).	12	14.12	21	24.71	20	23.53	9	10.59	19	22.35
Unchanged (−20%–20%)	28	32.94	52	61.18	63	74.12	50	58.82	65	76.47
Increased (20%–40%).	0	0	0	0	0	0	0	0	0	0
Extremely increased (> 40%).	0	0	0	0	2	2.35	1	1.18	1	1.18

N = number of sub-districts, *P* = percentage.



(a) Changes 2000–2021 (actual) **(b)** Changes 2021–2030 (BAU) **(c)** Changes 2021–2050 (BAU)

(d) Changes 2021-2030 (FPA) **(e)** Changes 2021-2050 (FPA) **(f)** Legend

Figure 4. Map of ESV base on scale district.

Figure 4a illustrates that a significant portion of the region, encompassing 45 districts (53%), underwent a marked extremely decreased, which extended from the north to the south. Conversely, in the southern area, changes were observed in the unchanged class for 28 districts (33%), while the remaining 12 districts (14%) were classified as decreased (D). Shifting attention to **Figure 4b**, it showcases the projected scenario for 2030 under BAU. Compared to the conditions in 2021, most regions, specifically 12 districts (61%), fall within the unchanged (UC) category.

Figure 4c presents the average magnitude of changes over a decade, focusing on the BAU in 2050. The relative pattern will remain consistent with the changing conditions in 2030. Specifically, the area exhibiting no changes is expected to increase from 52 districts (61.18%) to 63 districts (74.12%). Furthermore, there is one area where an increase in ESV was identified.

Figure 4d,e show the predicted impact of changes in ESV with the FPA. **Figure**

4d shows that in the middle to southern part (58%), unchanged is included, while in the northern part, there are 25 districts (30%) experiencing ED and 9 districts (11%) belonging to the decreased class. **Figure 4e** shows that with the success of the FPA, the ESV value will increase by 19.84% compared to the BAU. The spatial distribution of ESV changes in 2050 predictions (FPA) is relatively the same as in 2050 conditions predictions (BAU). Most of the area, namely 65 sub-districts (76%), is included in unchanged, and 19 districts (22%) were classified as class decreased.

3.2. Trade-offs and synergies affecting ESV

The results of the analysis concerning the interactions involving trade-offs and synergies among each ecosystem service within the period spanning from 2000 to 2020 are visually represented in **Figure 5** and further elaborated in **Table 6**. These visual depictions and tabulated data provide insights into the dynamic relationships among different ecosystem services, elucidating instances of both trade-offs and synergies that transpired during the specified time interval.

Table 6. Trade off and synergy of each ecosystem service during the 2000–2020.

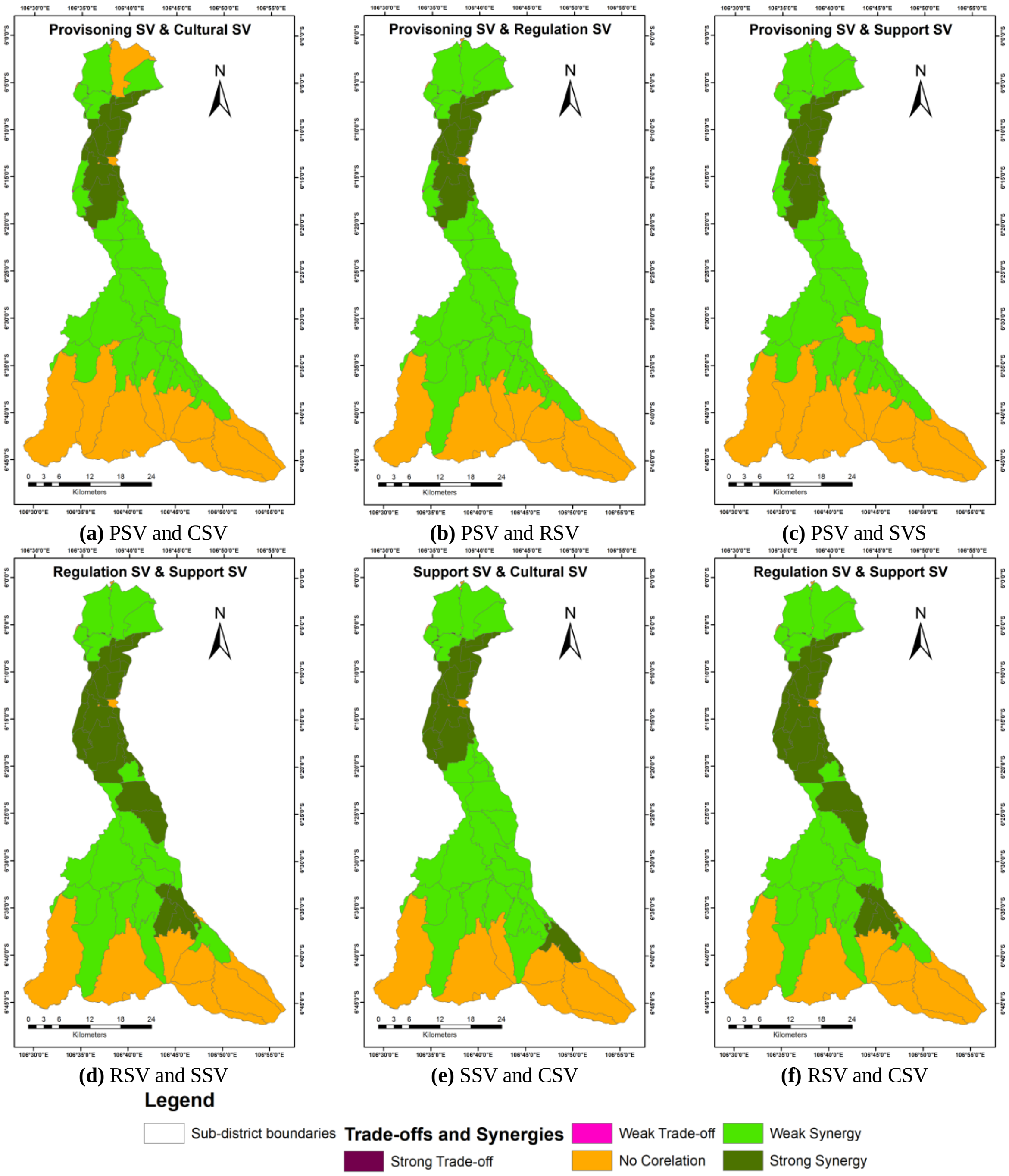
Relationship ecosystem service	Prov_Cult		Prov_Regg		Prov_Supp		Regu_Supp		Supp-Cult		Regg_Cult	
	N	***P***	***N***	***P***	***N***	***P***	***N***	***P***	***N***	***P***	***N***	***P***
Strong Synergy	20	23.53	20	23.53	20	23.53	29	34.12	24	28.24	27	31.76
Weaks Synergy	28	32.94	31	36.47	28	32.94	26	30.59	30	35.29	28	32.94
No Correlation	34	40.00	31	36.47	34	40.00	30	35.29	31	36.47	30	35.29
Weaks trade off	2	2.35	2	2.35	2	2.35	0	0	0	0	0	0
Strong trade off	1	1.18	1	1.18	1	1.18	0	0	0	0	0	0

N = number of sub-districts; *P* = percentage; Prov = Provisioning, Cult = Culture; Regg = Regulating; Supp = Supporting.

The outcomes of these trade-offs and synergies for each pair of ecosystem service categories were visually presented in **Figure 4** and further elaborated in **Table 6**. These visualizations and data tables provide valuable insights into the intricate relationships and interactions occurring among various ecosystem services.

Figure 5 visually portrays the intricate relationships among provisioning, regulatory, support, and cultural services. The study’s outcomes indicate that interactions between ESV predominantly exhibit synergistic tendencies during the timeframe spanning from 2000 to 2021. Notably, areas characterized by synergistic service provision and value (including cultural, regulatory, and support aspects) encompass approximately 50% of the total area, while trade-offs cover only around 5.00%. These spatial patterns demonstrate a relatively uniform distribution, with the prevailing trend extending from the central to the northern regions. Conversely, the southern area appears to lack significant correlations in this context.

Meanwhile, the relationship between culture and (supporters and regulations) and between regulations and supporters dominates synergy at around 70% and 30% does not correlate (fields with no relationship). Generally, regions have a synergistic relationship with a relatively balanced proportion of weak and strong synergies. Meanwhile, the central to northern regions are the synergy class, while the no correlation class dominates the southern region.



(a) PSV and CSV **(b)** PSV and RSV **(c)** PSV and SVS

(d) RSV and SSV **(e)** SSV and CSV **(f)** RSV and CSV

Figure 5. The study systematically examined the dynamics of trade-offs and synergies existing between distinct pairs of ecosystem service categories. These included trade-offs and synergies between **(a)** PSV and CSV; **(b)** PSV and RSV; **(c)** PSV and SVS; **(d)** RSV and SSV; **(e)** SSV and CSV; **(f)** RSV and CSV.

PSV = Provisioning services value, CSV = Culture services value, RSV = Regulating services value, SVS = Supporting services value.

Alterations in land use, such as conversion for agriculture or urbanization, and the impacts of climate change are influential factors that affect the values of ecosystem services (ESV). The resulting consequence is increased vulnerability, potentially leading to the loss of biodiversity and disturbance of ecosystem functions.

Understanding these dynamics is important for making informed decisions in land management. It enables the development of strategies that enhance positive interactions among ecosystem services while considering potential adverse effects on ecological well-being and biodiversity (Jiang et al., 2019).

At the regional scale, changes in regional land use and the relationship between land use change and ESV have also gained widespread attention. Climate and land use changes pose an increasing threat to ecosystem services related to freshwater, both in terms of supply and demand. A better understanding of the dynamics of these potential services, driven by interactions between the mentioned factors, could benefit water resource management, the environment, and human well-being (Pham et al., 2019).

Regarding the social economy, the transformations in the functions of ecosystem services are intricately linked to the complex interplay of various economic and social factors that influence the capacity of ecosystems to provide services (Ustaoglu and Williams, 2017).

3.3. Ecosystem sensitivity analysis

The computations carried out using Equaiton (8) resulted in the determination of the coefficient of sensitivity (CS), the values of which are elaborated upon in **Table 7**.

Table 7. The analysis involved examining the percentage change in the projected total ESV alongside the corresponding sensitivity coefficient.

Change of value coefficient	2010		2021		2030*		2050*		2030**		2050**	
	%	CS	%	SC	%	CS	%	CS	%	CS	%	CS
BUL VC ± 50%												
DF VC ± 50%	±1.56	0.03	±7.71	0.15	±7.89	0.16	±14.06	0.28	±8.20	0.16	±7.46	0.15
PF VC ± 50%	±9.15	0.18	±6.13	0.12	±3.32	0.07	±1.23	0.02	±3.44	0.07	±0.85	0.02
FRT VC ± 50%	±7.66	0.15	±38.73	0.37	±12.08	0.24	±17.06	0.34	±10.72	0.21	±11.99	0.26
PLT VC ± 50%	±30.83	0.62	±24.28	0.49	±25.59	0.51	±15.82	0.32	±26.42	0.53	±27.51	0.55
PO VC ± 50%	±0.53	0.01	±0.74	0.01	±0.71	0.01	±1.16	0.02	±0.77	0.02	±0.72	0.01
WB VC ± 50%	±0.27	0.00	±0.41	0.00	±0.41	0.00	±0.67	0.01	±0.46	0.00	±0.46	0.00

* BAU, ** FPA.

The data presented in **Table 7** revealed that all cases had sensitivity coefficients below one. Notable variations in calculated ecosystem service values within the study area were evident when modifying coefficients associated with specific land cover types by 50%. Initially, values for water bodies and ponds ranged from 0.00 to 0.02, but following the adjustment, the maximum sensitivity coefficient reached 0.62 for PLT. The effect of a 50% coefficient adjustment on estimated ESV was more pronounced in 2010 (±30.68%) compared to 2021 (±24.28%).

Nonetheless, adjusting the coefficient for DF by 50% had a negligible impact on the forecasted ESV in 2010 (approximately 1.56%). In contrast, in 2021, it resulted in a more substantial shift (about 7.71%). Similarly, altering the coefficient for PF by 50% induced a 9.15% change in the projected ESV for 2010 and a 6.13% modification for 2021. Likewise, a 50% coefficient adjustment for FRT led to a ±7.66% change in the estimated ESV in 2010 and a more pronounced ±38.73% alteration in 2021. These observations underscore the varying sensitivities of ESV to coefficient changes across different land cover types and years. Throughout the assessment period (2010–2021) and projection period (2030–2050), PLT exhibited the highest conservation status (CS) with values ranging from 0.51 to 0.55.

In summary, the study's findings reveal a hierarchy of ecological value coefficient sensitivities in the regional context, with the order being: PLT > FRT > PF > PO > WB. Notably, the sensitivity coefficient for the adjusted ESV coefficients is consistently below one. This signifies that the ESV for the examined area are reliable and demonstrate stability, implying a degree of robustness in the calculated values.

4. Discussion

4.1. Effects of land-use/land-cover change on ecosystem service values

The outcomes underscore a decrease in the comprehensive ESV from 2010 to 2021, primarily attributed to the diminishing extents of forest and paddy field areas. These findings concur with the conclusions drawn from Ambarwulan's investigation, which reveal that over the observed timeframe of 2010 to 2021, both forested and paddy field areas encountered reductions in size, amounting to 32,048 hectares (21.2%) for forests and 15,434 hectares (10.2%) for paddy fields (Ambarwulan et al., 2023).

Arifasihati and Kaswanto (2016) demonstrated that LUCC within the Cisadane watershed exhibited continuous fluctuations between 1978 and 2012. Notably, the dominant land cover category in 1978 was characterized by dry land areas, whereas the presence of water bodies experienced a consistent decrease from 1995 to 2012. As time progressed, the LUCC within the watershed followed diverse trajectories, eventually transitioning toward settlements and dry lands as the predominant features (Arifasihati and Kaswanto, 2016).

The decreasing trend observed in forest area and paddy fields within the Cisadane watershed is consistent with the patterns of LULC that are also prevalent in other watersheds in West Java, such as the Citarum watershed. Nahib et al.'s (2023) research conducted in 2023 sheds light on the transformations occurring in the Citarum watershed's land use and spatial land cover (LU/LC) from 2000 to 2018. The study unveils several notable trends, including a significant reduction in virgin forest area by 15,650 hectares (equivalent to a 35.87% decrease). A decline in plantation forest area by 18,710 hectares (a decrease of 13.87%). The rice field area decreased by 33,540 hectares (translating to a 6.57% reduction). A reduction in plantation area by 12,950 hectares (a decrease of 20.24%). A substantial decrease in shrub-covered area by 26,160 hectares (representing a reduction of 77.97%). The bare land area decreased by 2540 hectares (equivalent to a 24.56% decrease). These findings provide insights into the evolving dynamics of land use and land cover patterns within the Citarum watershed during the specified time frame. Additionally, the study highlights an increase in other categories of land use/land cover (Nahib et al., 2023).

To delve deeper into the matter, Rahmawaty's (2022) research emphasized that land cover alterations have yielded consequences detrimental to ecosystem functions and values. These repercussions encompass a decrease in biodiversity, heightened vulnerability to floods, augmented damage to mangrove ecosystems, and a reduction in rice production.

Land use transformation is a critical determinant with a significant impact on global environmental shifts change (Gomes et al., 2021). The collective influence of swift population expansion, urbanization, and climate change has a marked effect on the global ecosystem services, leading to a continuous degradation of these services. This degradation has extensive implications for ecosystem services, which are central to enhancing human well-being (Yee et al., 2021). As emphasized by Lambin and Geist (2006) in 2006, the trajectory of changes in LULC is undergoing rapid shifts due to accelerating processes like population growth, urban expansion, and intensified agricultural practices. These dynamics can potentially impact regional ecosystem services significantly (Nahuelhual et al., 2014), further highlighting the intricate relationship between human activities and the condition of ecosystems.

Consequently, a quantitative assessment of the impact of land use change on ecosystem service value holds paramount significance, as it offers a foundational framework for promoting sustainable development within the global ecological context (Lambin and Geist, 2006). Land use change is a multifaceted and dynamic process, and relying solely on comparisons between current and historical land use states is inadequate for comprehensively capturing the qualitative shifts in land use categories (Aksoy and Kaptan, 2022). This underscores the necessity for a more nuanced comprehension of land use changes, considering the intricate interplay of diverse factors shaping and propelling these transformations. Moreover, addressing the concurrent influence of multiple development objectives is imperative, which often remains overlooked.

Table 2 shows that the contributions from the forest and paddy fields amounted to $7344 (49.76%) and $1946 (13.19%), respectively, from the total ESV Cisadane watershed of $14,759. A reduction in forest area of 32,048 ha (21.2%) and paddy field of 15,434 ha (10.2%) will significantly decrease ESV.

Numerous preceding studies have unveiled the reduction or loss of ESV due to the decline in forest cover. For instance, research on ecosystem service value in Central Asia (Li et al., 2019), the Nanjing Metropolitan Area of China (Chen et al., 2023), the Yellow River Basin (Lou et al., 2022), Guizhou Province, China (Zhao et al., 2019), southwest coastal Bangladesh (Akber et al., 2018), Indonesia (Mohri et al., 2013), and Kalimantan (Sharma et al., 2019; Sumarga and Hein, 2014; Suwarno et al., 2016) have all yielded findings that underscore the connection between forest cover loss and the decrease in ecosystem services value.

Li’s study in Central Asia revealed noteworthy trends in land use alterations. Notably, there was a remarkable expansion in agricultural land (+22.10%) and urban areas (+322.40%), accompanied by a reduction in water bodies (−38.43%) and vacant land (−9.42%) from 1995 to 2035. These changes had profound implications for the values of ecosystem services. The increase in agricultural land contributed to a substantial rise of $93.45 billion in the value of agricultural land ecosystem services between 1995 and 2035. Conversely, the decrease in water bodies over the same period resulted in a significant loss of $64.38 billion in ESV. These transformations emphasize the significant influence of land use changes on assessing ESV.

Chen’s research, conducted in the Nanjing Metropolitan Area of China, revealed that the cumulative value of ecosystem services experienced a slight decline from 2000 to 2020, with an annual reduction rate of CNY 2.19 million. Notably, water bodies held the highest aggregated values of ecosystem services, followed by forest land, cultivated land, and grasslands. In contrast, construction land and unused land exhibited the lowest overall values of ecosystem services (Chen et al., 2023). This study provides insights into the varying contributions of different land cover types to the provision of ecosystem services within the Nanjing Metropolitan Area.

The current research evaluates and analyses the economic advantages linked to seven ES in Central Kalimantan. Additionally, the study delves into the distribution of these benefits among different beneficiary categories. The findings of this investigation reveal that oil palm production yields substantial economic gains for private entities. However, these gains are comparatively less pronounced for public entities and local indigenous households, particularly within Dayak communities (Suwarno et al., 2016). This implies that the monetary benefits derived from oil palm production might not be equitably distributed across diverse societal sectors, potentially resulting in varying impacts on different communities.

4.2. The synergies and trade-offs

According to **Figure 5**, the results show that the trade-offs and synergy among the ESV affected the spatial variation in ESV. Most of the ESV relationships in the study area show a synergistic relationship between ecosystem services (56.47%–64.7%), trade off (3%–4.53%), and there is no correlation (35.29%–40%) refer to **Table 8**. Synergy of ecosystem services is visible in the central part of the Cisadane watershed where the water utilization function has succeeded in providing benefits for social and economic interests. Maintenance of water infrastructure such as management of rivers, reservoirs and lakes is carried out well. One of the factors causing the results to have the same relative tendency is due to the lack of detailed spatial resolution, in which the function of the ecosystem is assumed (generalized) based on the closure class. The spatial distribution of ESV based on each ecosystem function does not change. In the future, it is hoped that with the advancement of high-resolution remote sensing data, the spatial distribution of each ecosystem function will be more thorough and detailed.

This condition aligns with Chen's research findings in the Nanjing Metropolitan Area of China that most areas: 73%–85% synergy. In contrast, the areas with a stride of between supply-cultural service value, (26.81%), supply-regulation service value (21.66%), supply-support service value 16.33% and regulation support service value 14.97% of the area where the ESV was declining. Spatial variations in the value of ecosystem services are also influenced by trade-offs and synergies between the value of supply, regulatory, supporting, and cultural services. (Chen et al., 2023).

This spatial distribution underscores the significant influence of trade-offs and synergies among supply, regulatory, supporting, and cultural services on the overall distribution of ecosystem service values. These observations highlight the complexity of interactions between different categories of ecosystem services and the consequential spatial disparities in their values. This complexity further underscores the importance of taking a holistic approach when assessing and managing ecosystem values. The interconnected nature of ecosystem services necessitates comprehensive evaluations considering the diverse interactions to ensure effective decision-making and sustainable management practices.

4.3. Ecosystem service sensitivity analysis

The method used in estimating the ESV, the benefit transfer method, is obtained by multiplying the area of a particular land use category with the appropriate value coefficient. The value generated using this method is global and highly dependent on the land cover area. The predictive ESV has several weaknesses, including low resolution, high deviation, and high level of uncertainty because it cannot be predicted, dynamic and nonlinear nature of biological systems (Gashaw et al., 2018).

While land use can often serve as a useful proxy for estimating ecosystem services, the same cannot be universally extended to using biomass as a proxy. The relationship between biomass and ecosystem services can vary significantly depending on specific ecological contexts, making it a less straightforward approximation than land use. The efficacy of biomass as a proxy variable is not consistently applicable across all contexts (Kreuter et al., 2001).

These results also indicate that the estimation of the ESV is strong, but coefficient values that are below or above this value can substantially affect the level of estimation of ESV values from time to time. In this study, the sensitivity of the revised value coefficient is below 1. This indicates that the ESV for the study area is stable and usable. The total estimated ESV are inelastic concerning the ecosystem value coefficients. This finding is in line with previous ESV studies in Central Asia (Li et al., 2019), in the Yellow River Basin and southwest coastal Bangladesh (Akber et al., 2018), and all of these studies found a CS value of less than 1.

The Characteristic as Inelastic watershed, the Cisadane watershed is less resilient or responsive to environmental changes and more vulnerable to disturbances such as flooding, landslide and limited capacity to adapt or recover from disruptions to their ecological balance. Factors contributing to the inelasticity of a Cisadane watershed could include extensive land degradation, loss of biodiversity, fragmentation of habitats, and impaired water quality.

The Cisadane watershed, located in West Java, Indonesia, is one of the most critical river basins in the region, known for its ecological significance and the challenges it faces due to pollution, urbanization, and industrialization. Sensitivity analysis results in the Cisadane watershed can provide valuable insights into the environmental dynamics, vulnerabilities, and potential mitigation strategies unique to this specific region when compared to other watersheds such as Citarum (Irmadi et al, 2023). The inelastic condition of the Cisadane watershed may experience chronic environmental problems without management efforts. These region-specific insights can inform environmental decision-making and sustainable management in the Cisadane watershed.

Akber research state that the ESV for all land use categories remain consistently below one throughout the year. This suggests that the overall ESV in the study area is not significantly affected by variations in the coefficient values, indicating a relatively inelastic relationship. Even when the coefficient values experience changes, the impact on the total ESV is minimal, with less than a 2% fluctuation observed for ±50% changes in the coefficient value. These findings underscore the robustness of the ESV, highlighting that coefficients perceived as too low (undervalued) or too high (overvalued) can exert a substantial influence on the ESV over time (Akber et al., 2018).

Findings from Muleta's (2021) research that the sensitivity coefficient indicates an inelastic value. Despite the limitations of this approach, it directly provides essential information regarding spatial and temporal changes in ESV, which holds significance for decision-making and the formulation of local-level processes.

To improve the accuracy of estimating ESV, especially within the context of the Cisadane watershed, we propose a strategy involving refining coefficient values by acquiring high-resolution imagery. This imagery should be subjected to efficient processing techniques, capturing essential parameters such as soil water content, vegetation carbon stock, and chlorophyll content. By incorporating such detailed and context-specific information, this approach aims to enhance the precision with which local ecosystem services within the watershed are portrayed. This strategy would enable a more nuanced understanding of the relationships between biomass and ecosystem services, accounting for the unique characteristics of the Cisadane watershed. It would provide a more accurate foundation for calculating value coefficients and ultimately improve the reliability of ecosystem service estimates, allowing for better-informed decision-making and sustainable management practices. However, it's important to note that implementing this strategy would require advanced technologies, expertise, and resources for data acquisition and processing.

Furthermore, improving ESV requires enhancing the accuracy, comprehensiveness, and reliability of the methods used. Some ways to achieve this include: (1) Implementing integrated assessment methods that consider various ecosystem services and their interactions, such as cost-benefit analysis, avoided cost, replacement cost, and benefit transfer. (2) Integrating biophysical indicators with economic metrics. This approach combines ecological data with economic valuation, providing a stronger foundation for decision-making. For economic valuation, market-based techniques like payments for ecosystem services (PES) can be applied. (3) Recognizing and valuing non-market values, such as cultural, aesthetic, and recreational values, which may not be covered through market-based approaches. Non-market valuation methods, such as contingent valuation or choice experiments, can be employed. (4) For this reason, we should involve all stakeholders, including decision-makers, academics, businesses, and local communities, in the assessment process to incorporate diverse perspectives for the identification and prioritization of relevant ecosystem services and accurate value determination.

5. Conclusion

The analysis of the evolving dynamics of land cover in the Cisadane watershed from 2010 to 2050 reveals a significant cumulative reduction in ecosystem services, amounting to $196.37 billion (33.17%) between 2010 and 2021. This decline can be primarily attributed to the diminished extents of forest and paddy field areas, which experienced reductions of 32,048 hectares (21.2%) and 15,434 hectares (10.2%), respectively.

Based on the initial year (2021), it is predicted that there will be a decline in the ecosystem value in 2030 of $24.78–$124.28 million (5.09%–7.59%) and in 2050 of $45.78–$124.28 million (11.57%–31.42%). Forest protection scenarios are able to minimize the decline in ecosystem value. Over the period 2000–2020, trade-offs and synergies between ESV were mostly synergies. The total estimated ESV demonstrated an inelastic response concerning the ecosystem value coefficients.

The novelty lies in generating specific empirical findings about changes, interactions, and spatial sensitivity of ecosystem services that have never been studied before in this critically important watershed. These region-specific insights can inform decision-making regarding the environment and sustainable management in the Cisadane watershed.

Limitations of the study

The current presentation of ESV maps, organized by administrative areas (districts), falls short in capturing the detailed heterogeneity of both physical ecosystem factors and socio-economic factors. It is anticipated that a future ESV mapping method based on a grid scale can be devised, allowing for the representation of regional differences at a finer scale than districts. This approach would enable the creation of more maps and the mapping of additional factors influencing ESV.

Author contributions: Conceptualization, IN, WA, FA and BP; methodology, IN, YW, W and NS; software, NPN and FR; validation, DC and VK; formal analysis, DC and VK; investigation, BP, NS, MD and JS; resources, IN. WA and JS; data curation, IN, W, WA and YW; writing—original draft preparation, IN, W, WA and JS; writing—review and editing, IN, W, WA and YW; visualization, NPN and FR; supervision, IN and WA; project administration, BP and VK; funding acquisition, IN. All authors have read and agreed to the published version of the manuscript

Funding: In 2022, the National Research and Innovation Agency (BRIN) in Indonesia offered financial backing through the Priority Lake and Water Resources Management Program. The Research Organization of Earth Sciences and Maritime received the grant, identified by reference number B-22/III/PR.03/1/2022.

Acknowledgments: We wish to extend our gratitude to the Head of Research Center for Geospatial for providing access to the laboratory facilities. providing access to the laboratory facilities.

Conflict of interest: The authors declare no conflict of interest.

References

Akber, Md. A., Khan, Md. W. R., Islam, Md. A., et al. (2018). Impact of land use change on ecosystem services of southwest coastal Bangladesh. Journal of Land Use Science, 13(3), 238–250. https://doi.org/10.1080/1747423X.2018.1529832

Aksoy, H., & Kaptan, S. (2022). Simulation of future forest and land use/cover changes (2019–2039) using the cellular automata-Markov model. Geocarto International, 37(4), 1183–1202. https://doi.org/10.1080/10106049.2020.1778102

Ambarwulan, W., Yulianto, F., Widiatmaka, W., et al. (2023). Modelling land use/land cover projection using different scenarios in the Cisadane Watershed, Indonesia: Implication on deforestation and food security. The Egyptian Journal of Remote Sensing and Space Science, 26(2), 273–283. https://doi.org/10.1016/j.ejrs.2023.04.002

Arifasihati, Y. & Kaswanto. (2016). Analysis of Land Use and Cover Changes in Ciliwung and Cisadane Watershed in three Decades. Procedia Environmental Sciences, 33, 465–469. https://doi.org/10.1016/j.proenv.2016.03.098

Chen, S., Liu, X., Yang, L., & Zhu, Z. (2023). Variations in Ecosystem Service Value and Its Driving Factors in the Nanjing Metropolitan Area of China. Forests, 14(1), 113. https://doi.org/10.3390/f14010113

Costanza, R., de Groot, R., Farber, S., et al. (1998). The value of the world# s ecosystem services and natural capital. Ecological Economics, 25(1), 3–15.

Costanza, R., De Groot, R., Sutton, P., et al. (2014). Changes in the global value of ecosystem services. Global Environmental Change, 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Gashaw, T., Tulu, T., Argaw, M., et al. (2018). Estimating the impacts of land use/land cover changes on Ecosystem Service Values: The case of the Andassa watershed in the Upper Blue Nile basin of Ethiopia. Ecosystem Services, 31, 219–228. https://doi.org/10.1016/j.ecoser.2018.05.001

Gomes, E., Inácio, M., Bogdzevič, K., et al. (2021). Future land-use changes and its impacts on terrestrial ecosystem services: A review. Science of The Total Environment, 781, 146716. https://doi.org/10.1016/j.scitotenv.2021.146716

Hernina, R., Wicaksono, A., & Rokhmatuloh. (2018). Urban growth modeling of Ciliwung and Cisadane watersheds within Bogor municipality by using integrated Ca-Markov and frequency ratio. 020175. https://doi.org/10.1063/1.5064172

Jiang, Z., Sun, X., Liu, F., et al. (2019). Spatio-temporal variation of land use and ecosystem service values and their impact factors in an urbanized agricultural basin since the reform and opening of China. Environmental Monitoring and Assessment, 191(12), 739. https://doi.org/10.1007/s10661-019-7896-z

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2016). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. Science of the Total Environment, 547, 137–147. https://doi.org/10.1016/j.scitotenv.2015.12.127

Kreuter, U. P., Harris, H. G., Matlock, M. D., & Lacey, R. E. (2001). Change in ecosystem service values in the San Antonio area, Texas. Ecological Economics, 39(3), 333–346.

Lambin, E. F., & Geist, H. (editors). (2006). Land-use and land-cover change: Local processes and global impacts. Springer.

Li, J., Chen, H., Zhang, C., & Pan, T. (2019). Variations in ecosystem service value in response to land use/land cover changes in Central Asia from 1995–2035. PeerJ, 7, e7665. https://doi.org/10.7717/peerj.7665

Liu, H., Wu, J., & Liao, M. (2019). Ecosystem service trade-offs upstream and downstream of a dam: A case study of the Danjiangkou dam, China. Arabian Journal of Geosciences, 12(2), 17. https://doi.org/10.1007/s12517-018-4145-7

Lou, Y., Yang, D., Zhang, P., et al. (2022). Multi-Scenario Simulation of Land Use Changes with Ecosystem Service Value in the Yellow River Basin. Land, 11(7), 992. https://doi.org/10.3390/land11070992

Mohri, H., Lahoti, S., Saito, O., et al. (2013). Assessment of ecosystem services in home garden systems in Indonesia, Sri Lanka, and Vietnam. Ecosystem Services, 5, 124–136. https://doi.org/10.1016/j.ecoser.2013.07.006

Muleta, T. T., Kidane, M., & Bezie, A. (2021). The effect of land use/land cover change on ecosystem services values of Jibat forest landscape, Ethiopia. GeoJournal, 86(5), 2209–2225. https://doi.org/10.1007/s10708-020-10186-4

Ministry of Environment and Forestry Republic of Indonesia [MOEFRI]. (2018). Available online: http://perpustakaan.menlhk.go.id/pustaka/home/index.php?page=detail_news&newsid=665 (accessed on 26 March 2023).

Nahib, I., Ambarwulan, W., Sutrisno, D., et al. (2023). Spatial-temporal heterogeneity and driving factors of water yield services in Citarum river basin unit, West Java, Indonesia. Archives of Environmental Protection, 3–24.

Nahuelhual, L., Carmona, A., Aguayo, M., & Echeverria, C. (2014). Land use change and ecosystem services provision: A case study of recreation and ecotourism opportunities in southern Chile. Landscape Ecology, 29(2), 329–344. https://doi.org/10.1007/s10980-013-9958-x

Pan, N., Guan, Q., Wang, Q., et al. (2021). Spatial Differentiation and Driving Mechanisms in Ecosystem Service Value of Arid Region: A case study in the middle and lower reaches of Shule River Basin, NW China. Journal of Cleaner Production, 319, 128718. https://doi.org/10.1016/j.jclepro.2021.128718

Pham, H. V., Sperotto, A., Torresan, S., et al. (2019). Coupling scenarios of climate and land-use change with assessments of potential ecosystem services at the river basin scale. Ecosystem Services, 40, 101045. https://doi.org/10.1016/j.ecoser.2019.101045

Polasky, S., Nelson, E., Pennington, D., & Johnson, K. A. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. Environmental and Resource Economics, 48(2), 219–242. https://doi.org/10.1007/s10640-010-9407-0

Rahmawaty, R., Rauf, A., Harahap, M. M., & Kurniwan, H. (2022). Land cover change impact analysis: An integration of remote sensing, GIS and DPSIR framework to deal with degraded land in Lepan Watershed, North Sumatra, Indonesia.

Biodiversitas Journal of Biological Diversity, 23(6). https://doi.org/10.13057/biodiv/d230627
Roy, A., & Inamdar, A. (2019). Multi-temporal Land Use Land Cover (LULC) change analysis of a dry semi-arid river basin in western India following a robust multi-sensor satellite image calibration strategy. Heliyon, 5, e01478. https://doi.org/10.1016/j.heliyon.2019.e01478
Sharma, S. K., Baral, H., Laumonier, Y., et al. (2019). Ecosystem services under future oil palm expansion scenarios in West Kalimantan, Indonesia. Ecosystem Services, 39, 100978. https://doi.org/10.1016/j.ecoser.2019.100978
Solomon, N., Segnon, A. C., & Birhane, E. (2019). Ecosystem service values changes in response to land-use/land-cover dynamics in dry afromontane forest in northern Ethiopia. International Journal of Environmental Research and Public Health, 16(23), 4653. https://doi.org/10.3390/ijerph16234653
Sumarga, E., & Hein, L. (2014). Mapping ecosystem services for land use planning, the case of Central Kalimantan. Environmental Management, 54, 84–97. https://doi.org/10.1007/s00267-014-0282-2
Suwarno, A., Hein, L., & Sumarga, E. (2016). Who benefits from ecosystem services? A case study for Central Kalimantan, Indonesia. Environmental Management, 57, 331–344. https://doi.org/10.1007/s00267-015-0623-9
Ustaoglu, E., & Williams, B. (2017). Determinants of Urban Expansion and Agricultural Land Conversion in 25 EU Countries. Environmental Management, 60(4), 717–746. https://doi.org/10.1007/s00267-017-0908-2
Wang, L., Yu, E., Li, S., et al. (2021). Analysis of Ecosystem Service Trade-Offs and Synergies in Ulansuhai Basin. Sustainability, 13(17), 9839. https://doi.org/10.3390/su13179839
Yee, S. H., Paulukonis, E., Simmons, C., et al. (2021). Projecting effects of land use change on human well-being through changes in ecosystem services. Ecological Modelling, 440, 109358. https://doi.org/10.1016/j.ecolmodel.2020.109358
Zhao, J., & Li, C. (2022). Investigating ecosystem service trade-offs/synergies and their influencing factors in the Yangtze River Delta Region, China. Land, 11(1), 106. https://doi.org/10.3390/land11010106
Zhao, Q., Wen, Z., Chen, S., et al. (2019). Quantifying Land Use/Land Cover and Landscape Pattern Changes and Impacts on Ecosystem Services. International Journal of Environmental Research and Public Health, 17(1), 126. https://doi.org/10.3390/ijerph17010126