ISSN: 2156-8359 Volume 16, Number 4, April 2025

Scientific Research Publishing

International Journal of Geosciences

ISSN: 2156-8359
9 772156 835003 04

https://www.scirp.org/journal/ijg

Journal Editorial Board

ISSN: 2156-8359 (Print)   ISSN: 2156-8367 (Online)
https://www.scirp.org/journal/ijg

International Journal of Geosciences, 2025, 16(4), 189-286
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

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Volume 16 Number 4 April 2025

International Journal of Geosciences (IJG)
Journal Information

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International Journal of Geosciences, 2025, 16(4), 240-263
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

The Effects of Land Use Change on the Ecosystem Services Value in Côte d'Ivoire (1990-2040): Simulation and Prediction

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How to cite this paper: Coulibaly, L.K., Liang, X., Guan, Q.F., Coulibaly, N. and Assoma, T.V. (2025) The Effects of Land Use Change on the Ecosystem Services Value in Côte d'Ivoire (1990-2040): Simulation and Prediction. *International Journal of Geosciences*, **16**, 240-263.
https://doi.org/10.4236/ijg.2025.164013

Received: March 15, 2025
Accepted: April 25, 2025
Published: April 28, 2025

Abstract

Ecosystem services values (ESV) are increasingly affected by land use land cover change (LULCC) in Côte d'Ivoire. However, there is a scarcity of studies to understand the current state of the ecological environment and the factors that influence the change of ESV in Côte d'Ivoire. This study aimed to quantify LULCC and the ESV change in Côte d'Ivoire from 1990 to 2040. The methodology used in this study is based on evaluating the change in land use and ESV from 1990 to 2020 and predicting the land cover in 2040 with a cellular automata (CA) based PLUS model. Our results demonstrated that vegetation cover is predicted to decrease by 0.370% per year from 2020 to 2040. Cultivated land is predicted to increase by 0.013% per year from 2020 to 2040. From 2020 to 2040, hotspots of ESV changes are predicted to mainly appear in the Tchologo and Hambol regions. Our results demonstrated that ecosystem management should be made to control cultivated land expansion and protect wetland, and forestland for more sustainable ecosystem services. Ecosystem management to mitigate vegetation loss is necessary to help decisions makers to manage land use, facilitate land use expansion and protect the ecosystem.

Keywords

Ecosystem Services Value, Value Coefficient, LULC Change, PLUS Model, Côte d'Ivoire

1. Introduction

There are an estimated 1.1 billion people in Africa, and the yearly population growth rate is 2.3% [1]. Population growth is expected to dramatically impact global climate and ecosystems if humans are not well prepared [2]. Thus, assessing ecosystem services (ES) is critical for Africa's long-term viability [1]. Ecosystems provide many essential services for human wellbeing [3]. However, due to increasing industrialization, consumption of energy, food, water, medical care, and waste, ecosystem services have globally experienced a decline over the past decades and are expected to continue to decline in the future [4] [5].

Research demonstrated that LULC changes may cause changes in ES [6] [7], Costanza *et al.* 2014). The relationship between ES and land-use changes highlights the importance of ES in shepherding land-use planning methods and managing ecosystems to support sustainable development. Unprecedented LULC changes brought on by anthropogenic activities harm biodiversity and ecosystems, impairing their capacity to offer ES in many regions of the world [7]. Since 1970, Côte d'Ivoire's forests have decreased by 80% and has lost 25% of its natural capital in the last 25 years [8]. Assessment of LULC changes is essential for understanding soil erosion control's ecosystem functions and evaluating ecosystem services [9]. As a framework for the scientific community, managers, and land planners to establish effective land management strategies, research on how LULC changes affect ecosystem service values is gaining momentum worldwide specifically in West Africa. Therefore, more and more researchers have focused on monitoring the influence of LULC landscape patterns on ecosystem services because of their importance [10].

Several LULCC simulation models, including FLUS model [11], the CLUE-S model [12], SLEUTH Model [13], the Multi-Agent System (MAS) model [14] and the PLUS model [15], were created and put to use to forecast future landscape dynamics related to socioeconomic and environmental driving forces in order to offer some recommendations for regional development and land coordination. In this study, we used the PLUS model to predict land cover. The advantage of adopting the PLUS model is that it can capture the spatial-temporal evolution of different land use patches using a unique analysis approach and a new seed growth mechanism [15]. According to previous research, PLUS can produce more accurate and realistic landscape patterns than other models [15].

Ecosystem valuation, commonly referred to ecosystem service value (ESV), is a technique for attributing a monetary value on an ecosystem and its essential goods and services [16]. ESV is one strategy that can aid in the provision of public goods and services and land-use planning [17]. Research on the relationship between LULCC and ESV and quantification of changes in ESV is of practical importance for land use planning and ecological protection [18]. Ecosystems studies are very important in Africa [19], in which cropland expansion was responsible for 60% of the increase in total ESV [20]. A major factor influencing the ESV is the substantial changes that expanding agriculture is causing in forests and savannahs [21].

To better assess the ESV, researchers have developed various methods for the valuation of the ecosystem [6] [17]. The benefits transfer method (BTM), is widely and most commonly used in estimation valuation studies in diverse locations. It is presummated that the chosen area possesses similar economic and ecological traits [22] [23]. The BTM has been extrapolated to the global economic value of the 17 ecosystem services that 16 major biomes supply [3]. Recently researchers used over 300 case studies worldwide to update the estimated ecosystem value and conclude that it could be applied at different levels to assess the variation in multiple ecosystem services [24]. In African region, several researchers valued the ecosystems [25] (Arowolo *et al.*, 2018; Tiando *et al.*, 2021; Kindu *et al.*, 2016; Msofe *et al.*, 2020).

Several studies have been conducted on LULC change impact in several small areas of Côte d'Ivoire [26]-[30]. Previous studies failed to demonstrate the impact of LULCC on ESV. Moreover, with only a few studies available at the national scale, there is a scarcity of research on LULC change impacts on ecosystems value at the national level that have been conducted at the resolution of 30 m in Africa. LULC degradation is currently a serious issue worldwide, particularly in developing countries [31]. Following the release Millennium Ecosystem Assessment (MEA), scientists and policymakers became interested in the concept of ecosystem services [4] [23] [24] [32]. Recently Côte d'Ivoire has committed to reducing emissions from deforestation and forest degradation (REDD+), which is an international framework to aid in the fight against climate change and restore the severely degraded land cover [33]. However, there has been no quantitative assessment of the impact of LULC change to reveal the effects of these changes on the ESV at a national scale attempted by researchers, especially in West Africa. Furthermore, estimating future LULC change and its impacts on the ecosystem in developing countries is of great value for decision-makers. The present research is vital for human and for the country's ecological monitoring and sustainable management. Because of improper land management in Côte d'Ivoire and the lack of preventive measures to protect the ecological environment, there is serious vegetation cover loss, soil erosion, and water pollution problem [9] [33]. This paper will help Côte d'Ivoire to achieve many universal Sustainable Development Goals (SDGs) including SDG 3 on "Good health and wellbeing", SDG 4 on "Life below water", SDG 6 on "Clean water and sanitation", SDG 13 on "Climate Action", and SDG 15 on "Life on land".

Thus, the present study aims to fill the gap of previous LULCC studies in Côte d'Ivoire by estimating the ecosystem economic value changes in response to the LULC change in Côte d'Ivoire between 1990 and 2040 using datasets on land cover at a 30 m resolution.

2. Materials and Methods

2.1. Study Area

The study area covers the entirety of Côte d'Ivoire, a country situated in the western part of Africa between 4˚16'13.50"N - 13˚53'31.24"N latitudes and 2˚W - 9˚W longitudes (**Figure 1**) and with a total area of approximately 322,463 km². It shares borders with five countries, including the northwest by Mali, the northeast by Burkina Faso, the east by Ghana, the Southwest by Liberia, West Northwest by Guinea, and the South by the Atlantic Ocean. Administratively, Côte d'Ivoire has 33 units divided into 2 Autonomous Districts and 31 administrative regions (**Figure 1**).

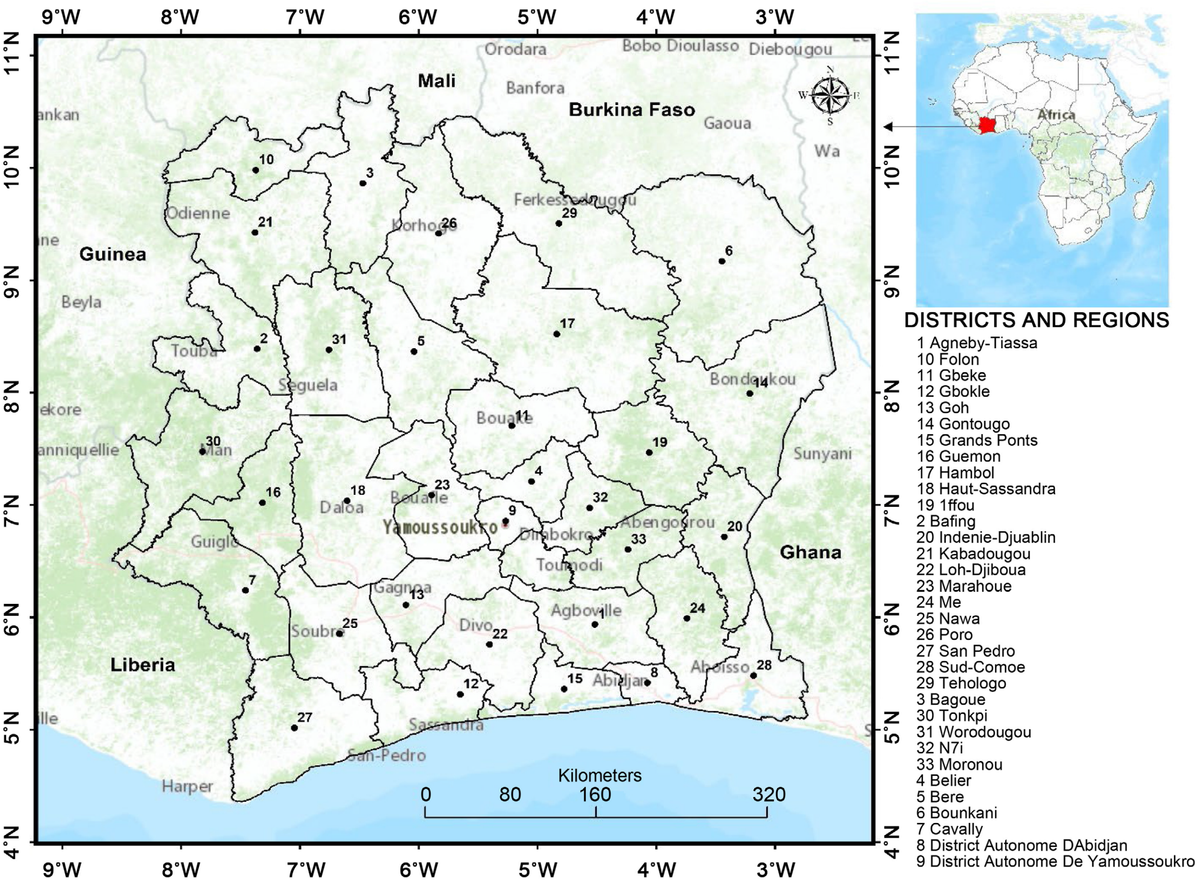

Figure 1. Location of the study area.

2.2. Methods

We proposed a method to evaluate the change in ESV based on the simulation of the future LULC and the benefice transfer method (**Figure 2**). The PLUS model selects available driving forces, including socioeconomic, environmental, and climatic data in Côte d'Ivoire, and uses cellular automata to simulate the actual and future change in LULC. We selected this method because of its accuracy and reliability in many other areas [34].

2.2.1. Projection Model to 2040

The future LULC change from 2020 to 2040 was predicted by combining a Geographic Information System (GIS) with a Markov chain in the (PLUS) model

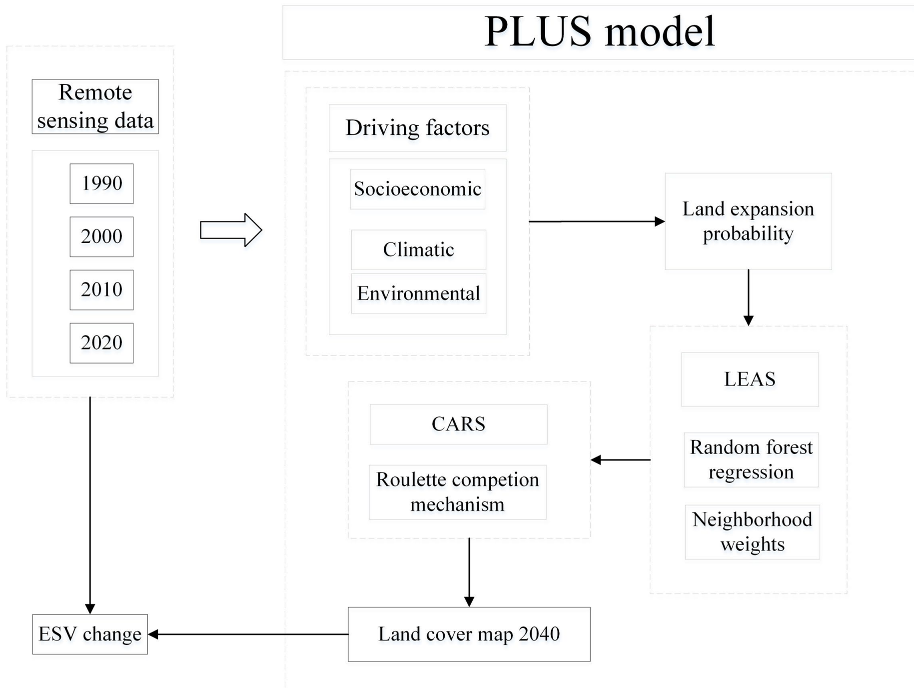

Figure 2. Framework of this study.

which is a reliable method for simulating LULC spatial-temporal change patterns [15]. Other land simulation models do not account for all land change processes [15]. The PLUS model can predict the dynamics of cities expansion and determine the factors that influence them. We selected ten driving factors for the PLUS model, including precipitation, temperature, DEM, proximity to primary road, proximity to secondary road, proximity to tertiary road, proximity to railway, distance to open water, population, and soil. The following parameters were configured as follows: the number of regression trees is 20, the sampling rate is 0.1, and the mTry is 10. The model documentation was used to determine the aforementioned parameter settings. The RFC performance and simulation precision were evaluated and calibrated throughout the years from 1990 to 2020. The simulation findings were verified using the figure of merit (FOM). The PLUS model can present the process of land use change dynamically, including the land cover spatial change, value change, and change curve of the different land use type.

2.2.2. LULC Change Analysis

Various LULC data exist, but they are only available for certain years [35] [36]. The present study used the Global Land Cover (GLC_FCS30) dataset provided by China academy of sciences (https://data.casearth.cn), with a fine classification system to determine land cover classes [37]-[39]. GLC_FCS30 had advantages in spatial details and achieved higher accuracy than the CCI_LC and MCD12Q1 products [39]. GLC FCS30 land cover data covers the period 1990 to 2020 with 30 m spatial resolution, and can be used to valuation the ecosystem and project vegetation changes over future years.

The LULC data in 1990, 2000, 2010, and 2020 of Côte d'Ivoire were extracted and classified into 8 major land cover types that correspond to Costanza's biomes. This classification includes wetland, bare land, cropland, water bodies, forestland, shrubland, urban areas, and grassland (**Appendix**). Statistical analysis of the change within LULC class between two years was analysed to understand the change following two approaches: Dynamic Degree of Single Land Use (SLUDD) and Dynamic Degree of Integrated Land Use (LUDD) [4].

$$\text{SLUDD} = \frac{A_{\text{final}} - A_{\text{initial}}}{A_{\text{initial}}} \times \frac{1}{T} \times 100\% \quad (1)$$

$$\text{LUDD} = \frac{\sum_{k=1}^{n} \Delta\text{LUDD}_{k-i}}{\sum_{k=1}^{n} \text{LUDD}_{k}} \times \frac{1}{T} \times 100\% \quad (2)$$

where A_{initial} and A_{final} denotes the land use area of a single land use type at the start and end of the study period. T is the time span of the study. If SLUDD is greater than 0, the study area is experiencing land expansion. (otherwise, loss of land), ΔLUDD_k is the land use pattern "K" transformed to land cover pattern "i" during the study period, *i.e.* the changes of land cover of a particular pattern "K", ΔLUDD_k is the initial area of a land use category "K", and T denotes the range of the study period, n represent the number of land use.

2.2.3. Valuation of Ecosystem Services

The present study estimated ESV using the benefice transfer method (BTM) suggested by Costanza [3]. Some studies proposed the coefficient value according to Africa [25] [40]. In west Africa, researchers used the same coefficients (Tiando *et al.*, 2021). We selected local valuation coefficients of Africa and West Africa because they represent the most comprehensive valuation coefficients available [22]; Tiando *et al.*, 2021; [25] [40]. **Table 1** presents the differences between the local and the global value coefficient of the biomes. We analyzed the 8 LULC in Côte d'Ivoire (**Appendix**) and compared them to the 17 biomes previously established by researchers [24]. Then, we replaced them with the closest comparable biome. Cropland biomes were used as a proxy for cultivated and aquaculture land, tropical forests for forests, grasslands rangelands for grasslands, and shrublands. We mixed grassland and shrubland for the analysis because they have the same equivalent biome. This combination is called savannahs in **Table 2**.

Table 1. Global and local coefficient value.

LCLU Type Composition Equivalent Biome	Coefficient Value (USD/ha/Year)	
	Global value	local value
Cultivated land	5568	475.12
Forests	5381	1146.37
Savannah	4166	381.25
Waterbodies	12,512	8535
Wetland	140,174	2063.52

Table 2. Ecosystem services' value coefficients for seven LULC categories in. (US$/ha/yr).

Subtypes	Biomes				
	Cultivated land	forestland	savannah	Wetland	Water Body
Food production	187.56	32	117.45	185.68	41
Water supply		8		130.19	2117
Medical services				71.17	
Genetic resources		41		49.42	
Raw material		51.24		151	
Gas regulation	14	13.68	7	48.7	
Climate regulation		223		143.99	
Water treatment		136	87		431.5
Disturbance regulation	225.56	5			
Water regulation		6	3	536.02	5445
Biological control	24	13.68	23		
Erosion control		245	29	58.74	
waste treatment		136	87	23.84	431.5
Soil formation	10	10	1		
Nutrient cycling		184.4		74.06	
pollination	14	7.27	25		
Soil formation		10	1	31.43	
habitat/refugia		17.3		496.64	
Recreation		4.8	0.8	14.96	69
Cultural		2		47.68	
	475.12	1146.37	381.25	2063.52	8535

The ecosystem services values (ESV) were calculated using the equivalent value coefficient of each ecosystem according to the ESV model developed by Costanza, *et al.* [24].

$$\mathrm{ESV}_i = \sum j\, A_i \times \mathrm{VC}_{ij} \tag{3}$$

$$\mathrm{ESV}_j = \sum i\, A_i \times \mathrm{VC}_{ij} \tag{4}$$

$$\mathrm{ESV} = \sum j \sum f\, A_i \times \mathrm{VC}_{ij} \tag{5}$$

where ESV_i denote to the ecosystem service value of the LULC type *i*, A_i represents the area (ha) for the LULC type *i*, and VC_{ij} is the value coefficient (US$/ha/yr) [32]. ESV_j is the ecosystem service value of the service function *j*, and ESV is the total ecosystem value. We use the following formula to assess the changes in ESV:

$$\mathrm{ESV}_{\mathrm{ch}} = \frac{\mathrm{ESV}_{t2} - \mathrm{ESV}_{t1}}{\mathrm{ESV}_{t1}} \times 100\% \tag{6}$$

where ESV_{ch} denote to the change rate of ESV from the initial year t_1 to the final year t_2, ESV_{t1} and ESV_{t2} represent the estimated total ESV at the beginning and the end of the study period t_1 and t_2, respectively.

2.2.4. Coefficient of Sensitivity

The biomes that we have used as proxies for the 5 LULC categories do not correspond to Contanza's ESV model in some circumstance [3] (**Table 2**), leading to uncertainties in ESV assessment [22]. Therefore, we used sensitivity analysis to evaluate *ESV* changes in response to 50% adjustments of the ESV coefficients for each LULC type [32]. In the present study, the standard economic concept of elasticity was used to calculate the coefficient of sensitivity (CS) using the following formula [41]:

$$CS = \frac{\left(ESV_j - ESV_i\right)/ESV_i}{\left(VC_{jk} - VC_{ik}\right)/VC_{ik}} \tag{7}$$

where, ESV is the estimated total value of ecosystem services, VC is the value coefficient, and "*I*", "*j*" and "*K*" represent the initial, adjusted values, and LULC categories, respectively.

If CS > 1, then the estimated ESV is elastic with respect to that coefficient; if CS ≤ 1, the estimated ESV is inelastic. Thus, when CS < 1, even if the accuracy of VC values used as proxy biomes is low, the results of estimation of ESV are credible [18] [32] [41].

3. Results

3.1. LULC Change Analysis from 1990 to 2040

In the present study, we compare simulated data with real data from the study area to validate our simulation. The overall accuracy (OA = 0.87) and the Figure of Merit (FoM = 0.44) indicate that the PLUS model simulation was satisfactory.

In 1990, forests area represented the most dominant LULC class, covering about 85.573% of the total area following by the cultivated and savannah areas with proportions of 3.729% and 9.322%, respectively. The remaining LULC types (wetland, water bodies, Built-up land and bare land) make up only 1.376% of Côte d'Ivoire's total land area (**Table 3**). Results showed a continuous increase in cultivated and urban area by 11.551% and 2.413% respectively from 1990 to 2010 (**Table 3**). The spatial distribution of the major LULC types exhibited an increasing area of cultivated land, savannah and built-up area from 1990 to 2020 (**Figure 3**). When analysing the change every 10 years, forests decreased by 0.063% and 0.367% from 2000 to 2010, and from 2010 to 2020 respectively per year. Forests area are also predicted to decrease by 0.370% in 2040 (**Table 3**). Analysis of vegetation at the regional level indicated that, in 1990 most of the region of Côte d'Ivoire were dominated by forest with more than 69.5% of the total surface of each region and district except the region of Poro region covered by 51.158% of savannah. In 2000, Forests dominated the surface of all regions except the region of Bagoue and Poro covered by savannah at 68.82% and 65.71% of the total surface of each region. In 2010 forests were found to have the largest proportion of the area of each region except for Bagoue covered by savannah at 60.93%. The region of Bagoue, Poro, and Tchologo mostly covered by savannah at 61.95%, 68.87%, and 54.98% respectively was found to be the only regions where forests were not dominated in 2020. The prediction showed that forest will dominate most of the region in Côte d'Ivoire in 2040 except for four regions where savannah will cover the largest proportion of area including Bagoue 73.375%, Bere 59.288%, Poro 77.158%, and Tchologo 68.292%.

Table 3. Single land use dynamic degree in Côte d'Ivoire from 1990 to 2040.

	1990		2000		2010		2020		2040		SLUDD (%)		
LULC Types	(*10^4) ha	%	(*10^4) ha	%	(*10^4) ha	%	(*10^4) ha	%	(*10^4) ha	%	2000-2010	2010-2020	2020-2040
Cultivated land	120.241	3.729	393.338	12.198	398.012	12.343	433.867	13.455	435.025	13.491	0.119	0.901	0.013
Forests	2759.397	85.573	2297.795	71.258	2283.410	70.812	2199.637	68.214	2036.861	63.166	−0.063	−0.367	−0.370
Savannah	300.610	9.322	488.005	15.134	494.444	15.333	536.892	16.650	0697.014	21.615	0.132	0.858	1.491
Wetland	6.110	0.189	6.888	0.214	6.895	0.214	6.996	0.217	3.615	0.112	0.010	0.147	−2.417
Built-up land	10.601	0.329	12.512	0.388	15.716	0.487	20.431	0.634	23.086	0.716	2.561	3.000	0.650
Bare land	3841.135	0.012	3896.186	0.012	3896.186	0.012	3885.125	0.012	3741.437	0.012	0.000	−0.028	−0.185
Water bodies	27.288	0.846	25.702	0.797	25.765	0.799	26.420	0.819	0028.655	0.889	0.024	0.254	0.423
Total	32246300	100	32246300	100	32246300	100	32246300	100	32246300	100			

3.2. LULC Change in Côte d'Ivoire

Figure 3 exhibits the spatio-temporal features of land use change intensity diversity degree in the three study periods, 2000-2010, 2010-2020, 2020-2040. From 2000 to 2010 the highest intensity of the change was noticed in the region of Bagoue 0.461 followed by Poro 0.425, Bere 0.409 while the lowest was noticed in the region of Me 0.005 N'Zi 0.006, Iffou 0.009 (Figure 3(a)). From 2010 to 2020 the highest intensity was noticed in the region of Bere 1.270, followed by Tchologo 0.925, Poro 0.921. The lowest intensity of change during this period was found to be in Me 0.029, followed by Nawa 0.072, N'Zi 0.096 (Figure 3(b)). The region of Kabadougou with an intensity of 0.842 followed by the region of Worodougou 0.790, Bere 0.760 are predicted to have the highest diversity degree of change during the period 2020-2040 while the lowest degree was noticed in the region of Moronou 0.032, Iffou 0.033, Cavally 0.034 (Figure 3(c)).

3.3. Ecosystem Value Change in Côte d'Ivoire

Based on ecosystem services value coefficients in 1990, 2000, 2010, 2020, 2040 the total ESV in Côte d'Ivoire was estimated at 35903.005, 32521.622, 32438.440, 31911.705, 30807.121 million US$ respectively (Table 4). Forests contributed the highest of the total ESV about 88.1%, 81%, 80.7%, 79.02%, 75.79% respectively in

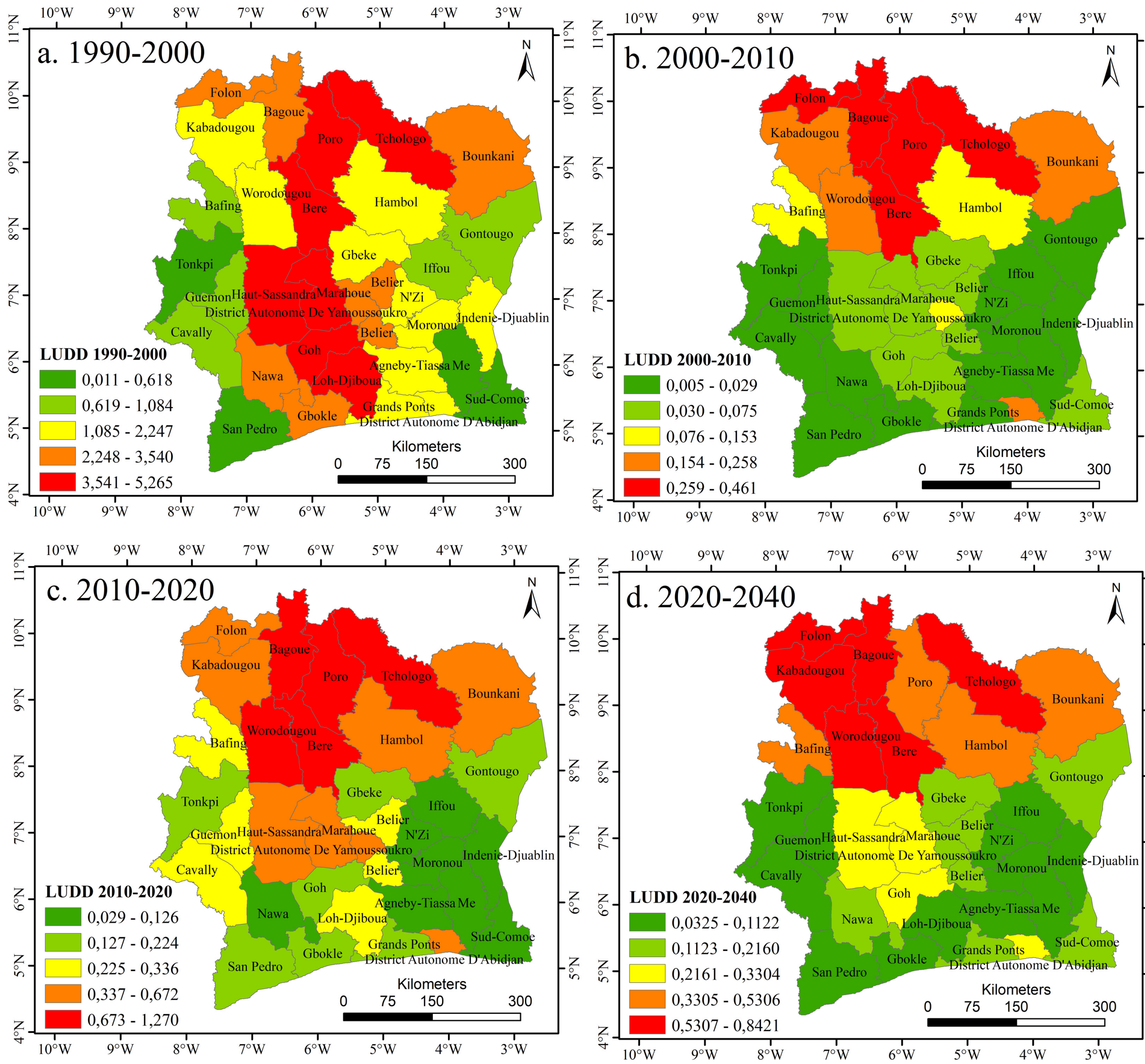

Figure 3. Land use dynamic degree at the county level in Côte d'Ivoire during the periods (a) 1990-2000, (b) 2000-2010 (c) 2010-2020, (d) 2020-2040.

1990, 2000, 2010, 2020, 2040 and covered the biggest proportion of the entire Country. The total ESV of the human-made capital ecosystems (*i.e.* cultivated) increased by 0.261% from 1.98 to 2.04 billion US$, 1.05% from 2.04 to 2.25 billion US$, 0.067% from 2.25 to 2.28 billion US$ per year, respectively during period 2000-2010, 2010-2020, and 2020-2040. In contrast, ESV in Côte d'Ivoire from the natural ecosystems (*i.e.* forests, savannahs, wetlands, and water bodies) decreased by −0.04% from 30.5 to 30.04 billion US$, by −0.24% from 30.04 to 29.7 billion US$, and by −0.19% from 29.7 to 28.5 billion US$ respectively during the period of 2000-2010, 2010-2020, and 2020-2040. Of the total ESV of these natural landscapes, only ESV from forests accounted for 122.25%, 129.69%, and 164.47% respectively, during the period 2000-2010, 2010-2020, and 2020-2040. Forest loss was responsible for the largest loss of the ESV from the natural ecosystem. ESV in Côte d'Ivoire from forests decreased every studied period by 0.626, 3.669, and 7.4% respectively during 2000-2010, 2010-2020, and 2020-2040 (Table 4). During the period 2000-2010 and 2010-2020 built-up land increased by 25.607% with 29.51 million US$ contribution of the total ESV change and 30.001% with 43.42 million US$ contribution of the total ESV change respectively and was responsible for the largest change in ESV in Côte d'Ivoire. The largest contribution of the ESV change from 2020 to 2040 in Côte d'Ivoire is predicted to be from the decreasing Wetland, accounting for the loss of 69.77 million US$.

Table 4. Ecosystem service value for different land use in Côte d'Ivoire from 1990 to 2040.

		Cultivated land	Forests	Savannahs	Wetland	Water bodies	Total
1990	ESV ($\times 10^6$ USD)	571.287	31,632.897	1146.076	126.07	2329.039	35,903.005
	ESV (%)	1.59	88.11	3.19	0.35	6.49	100
2000	ESV ($\times 10^6$ USD)	1868.827	26,341.233	1860.520	142.136	2193.670	32,521.622
	ESV (%)	5.75	81.00	5.72	0.44	6.75	100
2010	ESV ($\times 10^6$ USD)	1891.033	026,176.324	1885.068	142.272	2199.000	32,438.440
	ESV (%)	5.83	80.70	5.81	0.44	6.78	100
2020	ESV ($\times 10^6$ USD)	2061.388E+6	25,215.974	2046.901	144.359	2254.917	31,911.705
	ESV (%)	6.46	79.02	6.41	0.45	7.07	100
2040	ESV ($\times 10^6$ USD)	2066.893	23,349.963	2657.366	74.587	2445.690	30,807.121
	ESV (%)	6.71	75.79	8.63	0.24	7.94	100
1990-2000	ESV change ($\times 10^6$ USD)	1297.541	−5291.664	714.444	16.064	−135.369	
	ESV (%)	227.13	−16.73	62.34	12.74	−5.81	
2000-2010	ESV change ($\times 10^6$ USD)	22.205	−164.909	24.548	0.135	5.330	
	ESV change (%)	1.19	−0.63	1.32	0.10	0.24	
2010-2020	ESV change ($\times 10^6$ USD)	170.355	−960.350	161.833	2.087	55.917	
	ESV change (%)	9.01	−3.67	8.58	1.47	2.54	
2020-2040	ESV change ($\times 10^6$ USD)	5.505	−1866.011	610.465	−69.772	190.773	
	ESV change (%)	0.27	−7.40	29.82	−48.33	8.46	

For the analysis of the ESV by region, we divided the total ESV of each region by the area of this region to obtain the weighted average ESV. Figure 4 exhibits the ESV per unit area at the region scale. Analysis of the weighted average ESV of the ESV for the administrative regions was highest in 2010 for Grands Ponts region 1833.49 US$, followed by Autonomous District of Abidjan 1677 US$, Sud-

Comoe 1642.75 US$, Gbeke 1168.30 US$, Belier 1166.59 US$. The same trend was noticed in 2020, the average ESV was highest for Grands Ponts region 1829.31 US$, followed by Autonomous District of Abidjan 1648.35 US$, Sud-Comoe 1635.54 US$, Gbeke 1188.75 US$, Belier 1175.63 US$. In 2040, Grands Ponts region is predicted to have the highest weighted average of the ESV 1970.45 US$, followed by Autonomous District of Abidjan 1827.75 US$, Sud-Comoe 1774.97 US$, Nawa 1238.87 US$, Belier 1203.70 US$. The ESV for these regions was mainly contributed in 2010 in Grands Ponts region by water bodies 50.04% followed by forest 44.93% and in the Autonomous District of Abidjanby forest 39.64% followed by water bodies 47.04%. Also, in 2020 in Grands Ponts region by water bodies 48.70% followed by forest 43.37% and in the Autonomous District of Abidjanby water bodies 46.77% followed by forest 37.59%. In 2040 in Grands Ponts region by water bodies 54.71% followed by forest 41.01% and in Autonomous District of Abidjanby water bodies 53.23% followed by forest 33.65%.

The weighted average of the ESV in 2010 was low in Poro region 620.20 US$, Bagoue region 658.74 US$ with main contributions from forest 52.80% and 60.14% respectively in each region. The weighted average of the ESV in 2020 was also low in Poro region 588.78 US$, Bagoue region 645.32 US$ with main contributions from forest 46.24% and 57.03% respectively. In 2040, ESV is predicted to be low in Poro region 530.24 US$, Bagoue region 566.86 US$ with main contributions from savannahs 70.596% and 66.542% respectively.

From 2000 to 2010, ESV decreased in 30 of the 33 regions of Côte d'Ivoire and the highest decreased was notice in Me (−0.012%), Cavally (−0.022%) Iffou (−0.024%), N'Zi (−0.024%), Moronou (−0.026%), Guemon (−0.028%). In the same period, ESV increase only in, Gbeke (0.278), Nawa (0.051), Gontougo (0.051) (**Figure 5(b)**). From 2010 to 2020 ESV also decreased in all regions except Gbeke (1.75), Belier (0.78). The highest decreased was noticed in Nawa (−0.06%), Me (−0.16%), Grands Ponts(−0.23%), Sud-Comoe (−0.44%) (**Figure 5(c)**). ESV is predicted to decrease in 17 regions of the country during the period 2020 to 2040 including, Bere (−20.79%), Tchologo (−18.33%), Worodougou (−16.74%), Kabadougou (−14.91%), Poro (−14.51%), Bagoue (−13.95%), Folon (−13.58%), Bounkani (−10.60%), Bafing (−7.43%), Hambol (−6.91%), Gontougo (−2.27%), Tonkpi (−1.22%), Iffou (−0.70%), Moronou (−0.40%), Cavally (−0.36%), Indenie-Djuablin (−0.14), N'Zi (−0.03) (**Figure 5(d)**).

3.4. Changes in Values of Ecosystem Service Functions in Côte d'Ivoire

We further analysed the Changes in individual values of ecosystem service functions (ESV_j) by comparing the contributions of each ecosystem function to the overall ESV in Côte d'Ivoire (**Table 5**). In 2010 the most important contribution ESV_j of the total in 2010 in Côte d'Ivoire were erosion control 17.7%, followed by climate regulation 16.17%, Nutrient cycling 13%, waste treatment 11.25%, and water treatment 11.24%. The same trend was noticed in 2020 with the largest contribution of the total ESV in 2020 by erosion control 17.39%, followed by

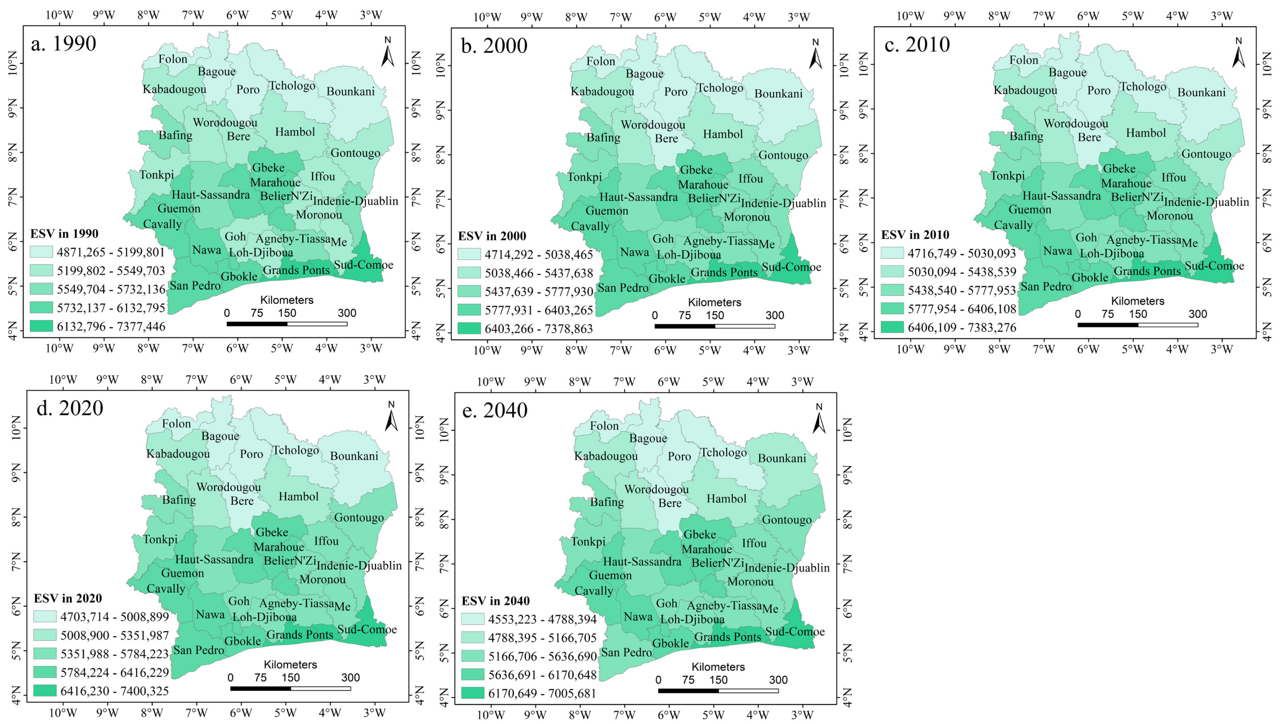

Figure 4. Spatial distribution of ecosystem services value by regions in Côte d'Ivoire. (a) 1990; (b) 2000; (c) 2010; (d) 2020; (e) 2040.

Table 5. Ecosystem service value for different land use in Côte d'Ivoire from 1990 to 2040.

		Cultivated land	Forests	Savannahs	Wetland	Water bodies	Total
1990	ESV ($\times 10^6$ USD)	571.287	31,632.897	1146.076	126.07	2329.039	35,903.005
	ESV (%)	1.59	88.11	3.19	0.35	6.49	100
2000	ESV ($\times 10^6$ USD)	1868.827	26,341.233	1860.520	142.136	2193.670	32,521.622
	ESV (%)	5.75	81.00	5.72	0.44	6.75	100
2010	ESV ($\times 10^6$ USD)	1891.033	026176.324	1885.068	142.272	2199.000	32,438.440
	ESV (%)	5.83	80.70	5.81	0.44	6.78	100
2020	ESV ($\times 10^6$ USD)	2061.388E+6	25215.974	2046.901	144.359	2254.917	31,911.705
	ESV (%)	6.46	79.02	6.41	0.45	7.07	100
2040	ESV ($\times 10^6$ USD)	2066.893	23,349.963	2657.366	74.587	2445.690	30,807.121
	ESV (%)	6.71	75.79	8.63	0.24	7.94	100
1990-2000	ESV change ($\times 10^6$ USD)	1297.541	−5291.664	714.444	16.064	−135.369	
	ESV (%)	227.13	−16.73	62.34	12.74	−5.81	
2000-2010	ESV change ($\times 10^6$ USD)	22.205	−164.909	24.548	0.135	5.330	
	ESV change (%)	1.19	−0.63	1.32	0.10	0.24	
2010-2020	ESV change ($\times 10^6$ USD)	170.355	−960.350	161.833	2.087	55.917	
	ESV change (%)	9.01	−3.67	8.58	1.47	2.54	
2020-2040	ESV change ($\times 10^6$ USD)	5.505	−1866.011	610.465	−69.772	190.773	
	ESV change (%)	0.27	−7.40	29.82	−48.33	8.46	

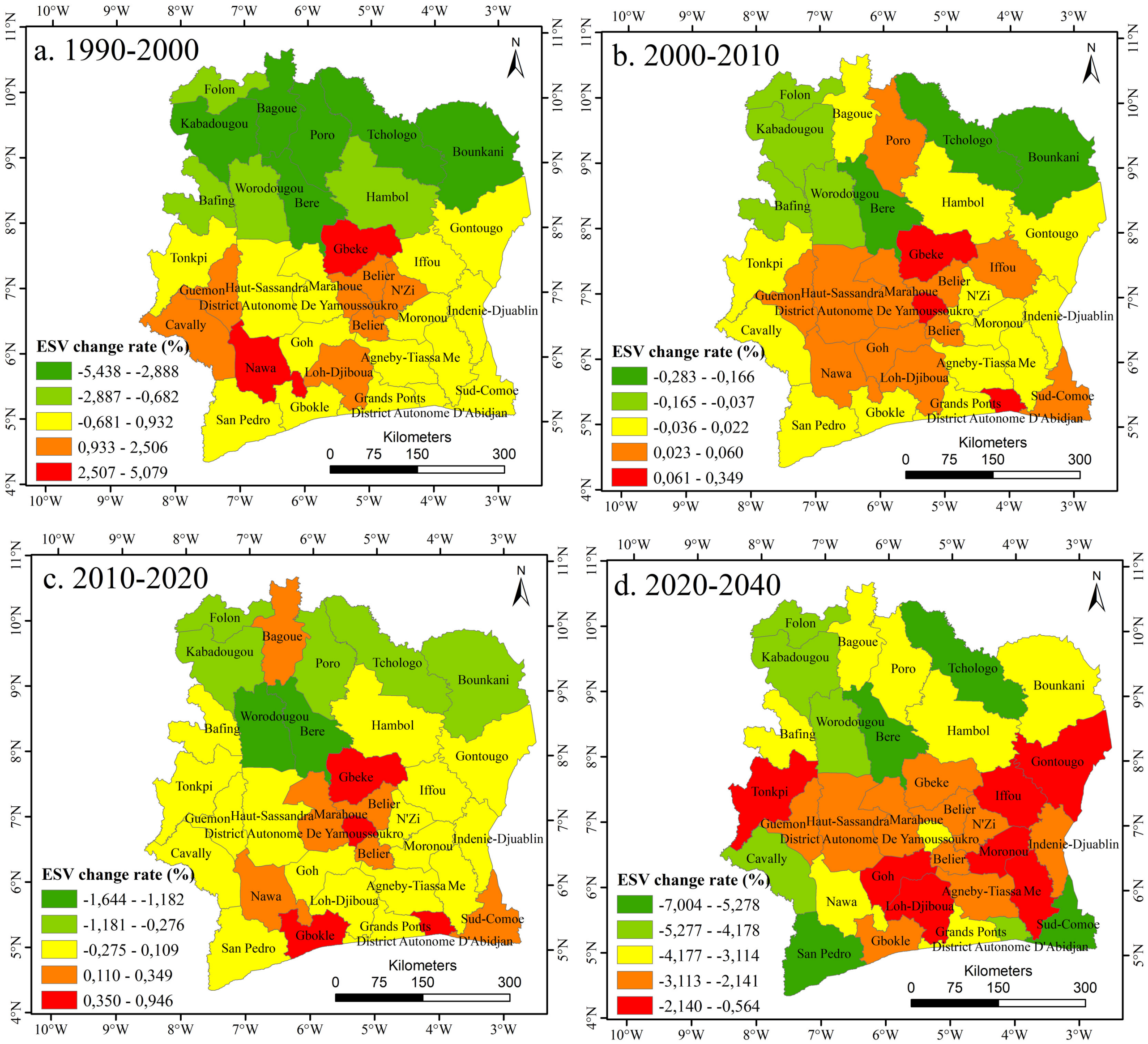

Figure 5. Changes in ESVs at the county level in Côte d'Ivoire in the periods (a) 1990-2000, (b) 2000-2010, (c) 2010-2020, (d) 2020-2040.

climate regulation 15.98%, Nutrient cycling 12.73%, waste treatment 11.20%, and water treatment 11.195%. In 2040 the most important contribution ESV_j of the total in 2040 is predicted to be erosion control 16.86%, followed by climate regulation 15.44%, Nutrient cycling 12.2%, waste treatment 11.364%, and water treatment 11.361%.

Analysis of the ESV_j change during the period 2000-2010 showed a decreased of 13 ESV function including climate regulation −0.06%, gas regulation −0.21%, soil formation −0.33%, erosion control −0.58%, genetic resources −0.62%, nutrient cycling −0.63% (**Table 6**). During 2010-2020 we observed the same trend of decline in 13 ESV function. Prediction of ecosystem functions change showed the same trend with a decline of disturbance regulation (−0.51%) and medical services

(−48.33%) during the period 2020-2040 added to the continuous decline of the 13 functions observed during the past 10 years (*i.e*. 2010-2020) while a continuous increase was predicted in other functions including pollination 7.99%, food production 6.11%, water regulation 6.09%, water supply 4.02%, biological control 2.81%.

Table 6. Estimated values for different ecosystem functions in from 1990 to 2040.

Ecosystem services	subtypes	1990 ($\times 10^6$ USD)	2000 ($\times 10^6$ USD)	2010 ($\times 10^6$ USD)	2020 ($\times 10^6$ USD)	2040 ($\times 10^6$ USD)	Change 2000-2010 (%)	Change 2010-2020 (%)	change 2020-2040 (%)
provisioning services	Food production	1484.129	2069.529	2081.292	2172.046	2304.832	0.57	4.36	6.11
	Water supply	806.395	736.904	737.083	744.383	774.277	0.02	0.99	4.02
	Medical services	4.348	4.902	4.907	4.979	2.572	0.10	1.47	−48.33
	Genetic resources	1134.372	945.5	939.605	905.308	836.899	−0.62	−3.65	−7.56
	Raw material	1423.140	1187.791	1180.430	1137.657	1049.146	−0.62	−3.62	−7.78
regulating services	Gas regulation	418.337	406.921	406.061	402.641	390.097	−0.21	−0.84	−3.12
	Climate regulation	6258.189	5247.234	5244.159	5100.160	4756.333	−0.06	−2.75	−6.74
	Water treatment	4132.059	3660.470	3646.777	3572.603	3500.179	−0.37	−2.03	−2.03
	Disturbance regulation	409.184	1002.103	1011.926	1088.612	1083.086	0.98	7.58	−0.51
	Water regulation	1694.864	1590.908	1594.186	1627.402	1726.446	0.21	2.08	6.09
	Biological control	475.484	520.981	521.615	528.523	543.362	0.12	1.32	2.81
	Erosion control	6851.288	5775.165	5741.793	5548.918	5194.567	−0.58	−3.36	−6.39
	waste treatment	4133.515	3662.112	3648.421	3574.270	3501.040	−0.37	−2.03	−2.05
supporting services	Soil formation	290.970	273.993	273.087	268.719	254.159	−0.33	−1.60	−5.42
	Nutrient cycling	5092.852	4242.235	4215.714	4061.311	3758.648	−0.63	−3.66	−7.45
	pollination	292.594	344.118	345.337	354.878	383.237	0.35	2.76	7.99
	Soil formation	280.866	236.824	235.452	227.531	211.792	−0.58	−3.36	−6.92
	habitat/refugia	507.718	431.727	429.271	415.281	370.328	−0.57	−3.26	−10.82
Recreation and cultural services	Recreation	154.599	132.963	132.368	129.154	000123.658E+6	−0.45	−2.43	−4.26
	Cultural	58.101	49.240	48.956	47.328	42.461	−0.58	−3.32	−10.28

3.5. Analysis of the Coefficient of Sensitivity

During the study period (1990-2040), CS for forest land was the highest due to the service value coefficient and large forestland area (Table 7). CS for forest decreased by 8%, 0.28%, 2.52%, 3.41% respectively during period 1990-2000, 2000-2010, 2010-2020, and 2020-2040. Meanwhile, CS for Cultivated land increased by 261.44%, 1.54%, 10.31%, 4.58% during period 1990-2000, 2000-2010, 2010-2020, and 2020-2040 respectively. In the present study, all CS were less than "1", indicating that the estimated ecosystem values are inelastic with respect to the ecosystem value coefficients, therefore the results of estimation of ESV are credible.

Table 7. Change in coefficient of sensitivity CS from 1990 to 2040.

	1990	2000	2010	2020	2040
Cultivated land VC ± 50%	0.016	0.058	0.059	0.065	0.068
forestland VC ± 50%	0.883	0.810	0.813	0.811	0.763
Savannahs VC ± 50%	0.032	0.057	0.058	0.064	0.087
wetland VC ± 50%	0.004	0.004	0.004	0.005	0.002
Water bodies VC ± 50%	0.065	0.067	0.068	0.071	0.08

4. Discussion

The study of the dynamic change of LULCC and their impacts on the ESV change, identified the trend of vegetation loss and the relationship between LULCC and ESV.

4.1. Comparison with ESV Changes Found in Other Studies

The results of this study show that the total ESV in Côte d'Ivoire was 180.38, 179.573, 179.556, and 179.348 billion US$ in 1990, 2000, 2010, and 2020 respectively (Table 4). The prediction shows that ESV will be 173.039 billion US$ by 2040. From 2000 to 2010, ESV in Côte d'Ivoire decreased by 0.01%. In contrast, ESV increased by 0.23% in some other areas during the same period (2000-2010) and using the local coefficient value of previous research [22].

When comparing the ESV change in Côte d'Ivoire from 2000 to 2010, with the results of the global ESV change that decreased by 28.82% because of land use change, during the period of 1997-2011 based on Costanza, 1997 coefficient unit value, we notice that ESV change ESV in Côte d'Ivoire was relatively low. However, even if ESV change is relatively low in Côte d'Ivoire, it should be noticed that ESV decreased every 10 years as long as forests are lost. This is mainly due to the conversion of forests into savannahs that have a lower coefficient and area compared to forests.

When comparing to west African countries ESV in Côte d'Ivoire decrease as long as forest decrease (Tiando *et al*., 2021).

4.2. Vegetation Cover Change Impact on Ecosystem Value

LULC is widely changing rapidly due to the acceleration of anthropogenic effects including expansion of agricultural land, population growth, mining, and expansion of urban land, and this change could affect regional ESV [23] [32].

In Côte d'Ivoire, Forests contributed the most to the ecosystem value followed by savannahs and cultivated land. The accelerated development of cultivated land, drought, the use of wood for business, and the development of traditional mining sites significantly degrade forests and impact the change of ecosystem value. Similarly, previous research demonstrated that the Me region is confronted with forest degradation like other regions of the country [30], and the expansion of cocoa plantations lead to massive deforestation in Côte d'Ivoire [42]. Our results demonstrated that the loss of vegetation cover contributes to the change in ESV. Although deforestation was prominent from 1990 to 2000, meaning that 21.63% of the total forests were converted to other land use resulting in a contribution of 16.728% decrease of the total ESV during 1990-2000, it should be noticed that the conversion rate, during the period 2000-2010 and 2010-2020, was relatively low, compare the period of 1990 to 2000, corresponding to a decrease of 6.59% of the total forest in 2000 converted to other land use resulted in 0.626% decrease of the total ESV, and 4.39% of the total forest in 2010 converted to other land use resulted in 3.669% decrease of the total ESV respectively. This trend is maybe due to the diversification of the economy after the year 2000 because from 1990 to 2000 the economy was based on agriculture. However, deforestation and agricultural and built-up expansion will increase year to year, according to the prediction over 2040.

LULCC has a profound relationship with climate change and land degradation. Global climate change and forests loss are not the only cause of the change in ESV but also the lack of preparation of the country will results in a loss of 7.8% of the total forest in 2020 during the period 2020-2040 and this will contribute to decrease by 7.4% of the ESV during the same period. Côte d'Ivoire should implement intense conservation planning to protect forests and the ecosystem. Research showed that Côte d'Ivoire is highly vulnerable to climate change and land degradation that impact ESV [9] [43]. The remarkable decline of forests must not be ignored as long as human well-being depends on ecosystem services. Similarly, research demonstrated that forestland mostly contributes to ecosystem services but cultivated areas and urbanization significantly change ecosystem services [4] [23].

4.3. Management of the Ecosystem Area and Policy Implications

Côte d'Ivoire has committed to the REDD + International Mechanism in 2011 to contribute to the global struggle against climate change and restore its strongly degraded forest cover [26]. National spatial development of land could help to mitigate forest degradation. Thus REDD + mechanism is a new opportunity to find sustainable solutions for the safeguarding of the latest natural forests and reconstruct the forest cover. Côte d'Ivoire is certainly in a development process. Managing the complex combination of climate change, social development, deforestation, and food security could be challenging. With the current development, the expansion of built up land and cultivated land is bound to happen. However reducing deforestation by increasing the productivity of cultivated land, agroforestry, and planning the development of land use with high ESV potential in the built-up area could in a certain way mitigate the ecosystem services value change in Cote d'Ivoire. More to guarantee a coordinated development of economic, ecological, and social benefits during the emergence of the country, and urbanization, delineation, and promotion of the concept of the "three zones and three lines" should be encouraged [44].

Empirical research has demonstrated evidence of the close link between the degradation of LULC and the negative contribution of this degradation to the value of the ecosystem. Therefore, decisions makers should consider the implementation of sustainable land use management to limit the degradation of the ecosystem. Evaluation and mapping of the ecosystem value provide guidance to the delineation at the national scale of ecological conservation priority zone and sustainable development of the country. The spatiotemporal evaluation of ESV explicitly provides a decision-making tool to govern change in ecosystem services that previous research demonstrated [4]. Based on the advantages of remote sensing and GIS, and the evaluation presented Ecosystem services valuation, a natural capital project should be integrated into the national planning process.

Efforts in the different regions by selected priorities could help to reach national objectives. The present study showed that Gbeke region, Autonomous District of Yamoussoukro, Autonomous District of Abidjan, Cavally, Nawa had the relatively highest elasticity of ESV to LULC. This high elasticity can be attributed to deforestation. The prediction showed that the region of San Pedro, Sud Comoe, and Cavally will have high elasticity in 2040. The environmental policy for this region should focus on agroforestry, encouraging the return of abandoned cultivated land to forestry, preventing the conversion of forest to cultivated land and traditional mining site, and promoting and strong protection of national parks and forests area in cities such as Banco forests, Thai parc. The planning of the development of cities by integrating planting trees could be considered. The national strategy should be strengthened. Indeed, Ecosystems provide vital tangible and non-tangible services, and the assessment of ecosystem services provides a simple way to learn about the benefits that humans obtain from a given ecosystem [3] [44]. However, considering ecosystem in land use planning and ecological conservation is challenging and not well understood in developing countries, especially in Côte d'Ivoire. Thus, research on LULC change impacts on ecosystem services could help decisions makers to manage land use, guide land use expansion, and ecosystem protection. Integration of ESV assessment in the national development planning should be considered in future land use decision-making and ecological protection policies. Similarly, regarding the importance of ecosystems, studies have discussed the incorporation of ecosystem services into ecological conservation decisions [45].

5. Limitations and Validity of the Study and Future Directions

The confidence of the analysis results is influenced by the land use land cover data, the benefit transfer method, and system errors in the spatial analysis provided by the geographic information system (GIS). Therefore, it is better to modify the coefficient value according to the local conditions [22]. Indeed, modifications should be made according to expert opinion surveys or based on a spatial statistical model and other dependencies. However, determining the coefficient value for a large area like Côte d'Ivoire could be very expensive. Due to the lack of study in west Africa we used local coefficients proposed by previous research [22] [25] [40]. Some researchers used the same coefficient similarly [46]. We also analysed the CS and results indicating that the results of estimation of ESV are credible. However, in further studies, we suggest the use of coefficient value adjusted by collecting and processing satellite and radar imagery to access the vegetation carbon stock, and soil moisture content to accurately reflect Côte d'Ivoire ecosystem services. We used this BTM and the coefficient of Costanza 2014 because of the quick assessment and low cost of collecting primary data. Further research could focus on the improvement of this method at the local scale by calibration of the coefficient value. The potential errors of the BTM method should be assessed if decision-makers would like to use these results to implement national conservation planning.

Remote sensing and GIS provide global land cover and important data sources for the estimation of ESV. However, definition and classification may be different from one data to another. For example, ESA CCI overestimates cultivated land and the resolution is 300 m, while Globeland 30 does not represent well the study area from 2000 to 2020. Similarly, some research found that LULC data may be underestimated or overestimated [32]. Thus, we used the GLC data with the resolution of 30 m and reclassify this data. However, the limitations of the land cover data arise from satellites sensor, descriptions, and classification methods. Such uncertainties may be introduced in the analysis of spatial patterns when the biomes used as proxies match LULC types [22] [41]. Moreover, the projected map of change for 2040 should be considered with caution, as we assumed constant human development for this prediction. The parameters of the PLUS model and the driving factors were selected based user manual guide that can result in uncertainties at the locale scale. In the future intense field work is needed for calibration and to determine local parameters for land use change projection.

The present study was focused on the impact of LULC changes on ESV. Remarks of previous studies demonstrated that Côte d'Ivoire is impacted and is predicted to be more impacted by climate change [43], therefore the use of models like Integrated Valuation of Ecosystem Services and Tradeoffs (INVEST) could help to access the combining impact of LULC change and climate change on ESV in future research.

6. Conclusion

LULC has substantially changed during the study periods because of human activities. Considering that the country is developing and experiencing modernization following the global trend, Savannah and cultivated land are predicted to increase while forest area will decrease in 2040. Based on BTM the results of this study showed that the change in forests lead to the decrease of ESV from 1990 to 2020 and will contribute to decrease ESV in 2040. The lower CS than one indicated that our results are credible. The empirical results of the present study demonstrated that the decline of forests is an urgent problem to be solved because the degradation of the forest not only impacts the CO_2 emissions but also impacts the economic value of ecosystems. The development of intense conservation planning and expert evaluation to develop a framework that can help to determine net value of ecosystem services in the study area is needed.

Acknowledgements

This work was supported by China University of Geosciences and University of Bondoukou. Special acknowledgment should be expressed to the School of Geography and Information Engineering, China University of Geosciences (Wuhan), and China National Engineering Research Center of GIS.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. Land cover classification used.

	Land cover types	LCCS classification system	Fine classification system	Codes numbers
1	Cropland	Rain-fed cropland	Rain-fed cropland	10
			Herbaceous cover	11
			Tree or shrub cover (orchard)	12
		Irrigated cropland	Irrigated cropland	20
2	Forest	Evergreen broadleaved forest	Evergreen broadleaved forest	50
		Deciduous broadleaved forest	Deciduous broadleaved forest	60
			Closed deciduous broadleaved forest	61
			Open deciduous broadleaved forest	62
		Evergreen needle-leaved forest	Evergreen needle-leaved forest	70
			Closed evergreen needle-leaved forest	71
			Open evergreen needle-leaved forest	72
		Deciduous needle-leaved forest	Deciduous needle-leaved forest	80
			Closed deciduous needle-leaved forest	81
			Open deciduous needle-leaved forest	82
		Mixed-leaf forest	Mixed-leaf forest	90
3	Shrubland	Shrubland	Shrubland	120
			Evergreen shrubland	121
			Deciduous shrubland	122
4	Grassland	Grassland	Grassland	130
5	Wetlands	Wetlands	Wetlands	180
6	urban areas	Impervious surfaces	Impervious surfaces	190
7	Bare areas	Lichens and mosses	Lichens and mosses	140
		Sparse vegetation	Sparse vegetation	150
			Sparse shrubland	152
			Sparse herbaceous cover	153
		Bare areas	Bare areas	200
			Consolidated bare areas	201
			Unconsolidated bare areas	202
8	Water body	Water body	Water body	210

Note: adopted from the GLC_FCS30 land cover quick user guide.